High Resolution 3D Optical Scanning of Crossties to Assess Cross-Sectional Parameters and the Effects of Long-Term Abrasion and Wear

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Abstract

This report documents measurement of the 3D geometrical properties associated with prestressed concrete railroad ties that have been subject to long-term in-track loading. A commercially-available 3D laser-based optical scanning system was used to scan the surface of sampled in-service crossties to a spatial resolution of about 1-mm, resulting in a 3D solid body CAD model of each scanned tie. A high-speed algorithm was developed to process the detailed cross-section geometrical parameters to an axial resolution of 0.5 inches, achieving an overall processing time of only a few minutes. The agreement between the ideal CAD model cross-section parameters and the measured (scanned) parameters was found to be excellent. Measured crosstie cross-sectional parameters used in support of on-going FRA project work included cross-sectional area, area moment of inertia, neutral axis position, eccentricity, and shape factor.

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U.S. Department of Transportation
Federal Railroad Administration

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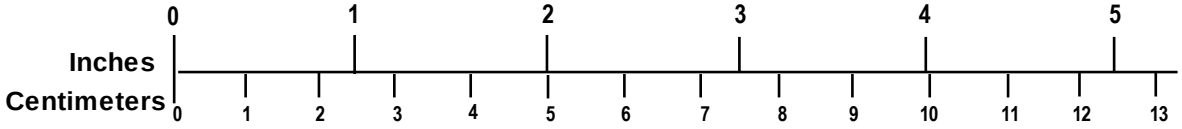
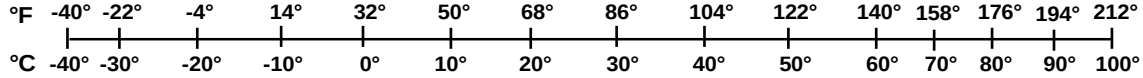
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH (APPROXIMATE)**
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE)	**AREA (APPROXIMATE)**
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)	1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)	1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT (APPROXIMATE)**
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = 0.45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME (APPROXIMATE)**
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
1 pint (pt) = 0.47 liter (l)	
1 quart (qt) = 0.96 liter (l)	
1 gallon (gal) = 3.8 liters (l)	
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)	1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)	**TEMPERATURE (EXACT)**
[(x-32)(5/9)] °F = y °C	[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

This report summarizes work that is part of a larger project funded by the FRA titled "Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials." The overall project has the following Major Research Tasks:

1) Measure Fracture Toughness of Concrete Mixtures used in Ties.
2) Test Prisms to Determine Effects of Cover on Cracking Propensity.
3) Conduct Precise Measurements of Wire Indent Geometry.
4) Identify KEY Wire Indent Parameters Responsible for Cracking.
5) Non-Destructive Testing of Ties with Long-Term In-Track Record.
6) 3D Scan Existing Crossties to Quantify Cross-Section Parameters.
7) Test Existing Crossties with Long-Term In-Track Service Record.
8) Propose System Qualification Test to Minimize Tie Splitting Potential.
9) Propose New Standard for Measuring KEY Indent Parameters.

The work presented herein specifically covers primarily task (6) "3D Scan Existing Crossties to Quantify Cross-Section Parameters," along with the visual inspection conducted in task (5) "Non-Destructive Testing of Ties with Long-Term In-Track Record." The report documents detailed quantitative and visual information associated with concrete railroad ties that have performed well in track for more than 25 years. Additionally, it includes analysis of ties that have failed in track or that show significant signs of distress and damage.

The ties subjected to testing were obtained from several sources, including AMTRAK, BNSF, CSX and TTCI. A total of 72 ties were evaluated, comprised of 6 ties of each type. A generic labeling of ties (A-1, A-2, A-3, A-4, A-5, A-6, B-1, B-2, B-3, B-4, B-5, B-6, …etc.) was used for identification purposes.

Systematic testing of the ties included visual and photographic inspection to identify key damage features associated with the prestressing reinforcement, including detection of any visible cracking, along with measurement and mapping of all observed cracks. In addition, measurements were taken of the longitudinal prestressing reinforcement locations and the concrete cover at each end of the ties. Alternate Non-Destructive Evaluation (NDE) methods were also conducted, including pulse-velocity testing, in an attempt to detect any existing internal damage; however, this technique revealed somewhat limited quantitative results.

Full 3-Dimensional scanning of each tie was conducted using commercially available laser-based scanning hardware. The 3-D scans resulted in a high-resolution point-cloud representation of the entire surface of each tie, to a spatial resolution of about $\pm$ 1mm. Although the scanning hardware was capable of providing measurements to a resolution significantly less than $\pm$ 0.1mm, the $\pm$ 1mm resolution was selected as a reasonable compromise between the ability to resolve surface features (including abrasion) and the memory storage requirements needed to store the 3D point-cloud file. Even at the $\pm$ 1mm resolution, the file size requirements were on the order of 4 GB. With a $\pm$ 0.1mm spatial resolution, the memory storage requirements would have increased by a factor of approximately 1000 (to about 4 TB per tie).

The detailed 3D tie surface data was used to quantitatively extract the exact cross-sectional information along the length of each sampled tie. In particular, software was developed to process the detailed 3D scanned tie surface and thereby determine all relevant internal cross-sectional properties

along the entire length of the tie. These properties included the cross-sectional area, centroid, and area moment of inertia as a function of axial position along the ties. Combined with visual end measurements of the wire positions and cross-sectional areas, and assuming that the wire positions remained the same along the entire length of the tie, the numerical "slicing" also yielded local wire centroid, eccentricity and shape factor information.

These properties, evaluated at the mid-point position, were also used in support of destructive evaluation of the ties by providing the cross-sectional parameters needed to determine the residual prestress force using a 4-point bending test[1]. This "numerical slicing" of the ties to obtain cross-sectional information was later supplemented by "physical slicing (saw cutting) of the ties to allow direct observation of the cross-sectional parameters, including wire locations. The direct observations of the tie cross-sectional parameters compared well with the numerically sliced properties determined from the 3D optical scanning.

Using the 3D surface point-cloud results, the overall volume of a tie was evaluated by numerically adding the digitized cross-sectional area multiplied by the thickness of each slice. As a means of estimating the capability of the 3D scanning to resolve apparent abrasion damage, artificial damage was induced in a sampled tie by gouging out a portion of the concrete near one end. Comparing the resulting tie volume of the undamaged sampled tie with a direct measurement of the volume of an "induced damaged region" provided an estimate of the damage volume, along with an estimate of the resolution of the apparent abrasion measurement. This revealed an approximate abrasion resolution of about $\pm$ 1.0 in^3. While this resolution was reasonable, there was no reliable way to directly establish the actual amount of in-track tie abrasion since no CAD model was available for direct comparison with the measured tie volume. However, relative amounts of abrasion/damage were assessed on the sampled ties. A large amount of the damage appeared to be due to transport of the ties, rather than track-induced damage.

In addition to supplementing the direct measurements of cross-sectional information needed for destructive testing, the 3D scanning system and processing software was used to provide measurements of tie geometry in a tie manufacturing plant in Pueblo, Colorado [27]. This was for the purpose of making transfer length measurements using our Non-Contact Automated Transfer Length measurement system. The procedure was similar to that previously conducted in a manufacturing plant (Rocla Concrete Tie Plant) in Sciotoville, OH [26]. However, the 3D scanning provided measurements of the necessary tie cross-sectional (shape factor) parameters prior to the actual in-plant transfer length measurements. In this case, no CAD drawing was available to obtain the necessary shape factor information. The result was statistical sampling of over 100 transfer length measurements, yielding a complete characterization of transfer length variation in the entire casting bed. To the best of our knowledge, this was the first time this had ever been attempted in an actual crosstie manufacturing plant and, in particular, while the ties were being manufactured.

[1] The 4-point bending test for extraction of residual prestressing force was later replaced by a more direct, brute-force tension test which proved successful in yielding an accurate assessment without the need of detailed cross-section information.

1. Introduction

The main focus of the research effort reported here was on the systematic evaluation of existing concrete ties to provide invaluable information about the combination of prestressing reinforcement and concrete mixtures that have worked successfully and also to identify those combinations that have resulted in pre-mature failures. Specifically, concrete railroad ties that have performed well in track for more than 25 years were identified and obtained for extensive study. Additionally, ties that have failed in track or that showed significant signs of distress were also included in the sampled ties. The overall investigation included both destructive and non-destructive methods.

As part of the non-destructive evaluation (NDE) testing associated with his effort, a three-dimensional (3D) Optical Scanning System was used to accurately scan for the purpose of quantifying the surface geometry and estimating the volume (for assessment of abrasion and wear) of a large sample of previously manufactured ties. A commercially-available 3D Laser-Based Optical Scanning System, with a maximum spatial resolution set to approximately 0.1mm, was used to perform the surface scanning operation. The scanning procedure ideally produced an accurate 3D CAD model of the tie geometry, which was then analyzed to determine the desired geometrical features at any given cross-section. With this detailed cross-section information, it was also possible to determine a measure of the tie volume, the variation of which provided some direct indication of the extent of abrasion and wear. This report documents the detailed 3D scanning of sampled ties and the extraction of cross-sectional parameters along the entire length of the tie using special-purpose processing algorithms. These extracted parameters were subsequently used in conjunction with both destructive and non-destructive testing.

1.1 Background

Research has been on-going for a number of years in an attempt to quantify the important geometrical and physical parameters associated with the manufacture of prestressed concrete railroad ties. A key measure of tie performance, and a parameter that is critical to maintaining continuous production quality in the modern manufacture of prestressed concrete railroad ties, is the so-called ***transfer length*** [1, 2, 3]. Pre-tensioned concrete railroad ties are commonly fabricated by casting concrete around already tensioned steel wires or strands. The stress transfers from the wires or strands to the concrete and is developed gradually from each end of the concrete tie, where the stress is zero, to locations well away from the ends where the stress reaches its full value. The transfer length is defined as the length required to fully develop the prestressing force.

Relatively recent research has been focused on quantifying the parameters that affect the transfer length in pretensioned concrete railroad ties, including properties of the concrete as well as the important geometrical features associated with the prestressing wires [5-22]. Of critical importance to the ability to conduct this research has been the development of robust and rapid non-contact optical methods to assess transfer length [5,7-10,12-13,15,17-18,20-24]. Furthermore, a new multi-camera version of this basic technology, designed as a prototype to a device that could be implemented in-plant in a production setting, has been successfully demonstrated in the harsh manufacturing plant environment [20-21]. It has also been used to investigate the effect of cross-section shape and prestressing wire eccentricity on the longitudinal surface strain profile of non-prismatic members [23] and the effect of thermal strain offset on the surface strain profiles of both prismatic and non-prismatic members [24].

The need for accurate determination of concrete railroad tie cross-sectional information in the current project was important for two key applications: (1) The accurate assessment of transfer length associated with "real-time" in-plant testing accomplished using an automated strain profiling system [7,11-12,17,20,26-27], and (2) The assessment of the bending characteristics of a tie subjected to multiple-point loading to failure in an attempt to extract the residual prestress force [28,29]. These two applications are briefly introduced below, and more detail will be provided later in this report.

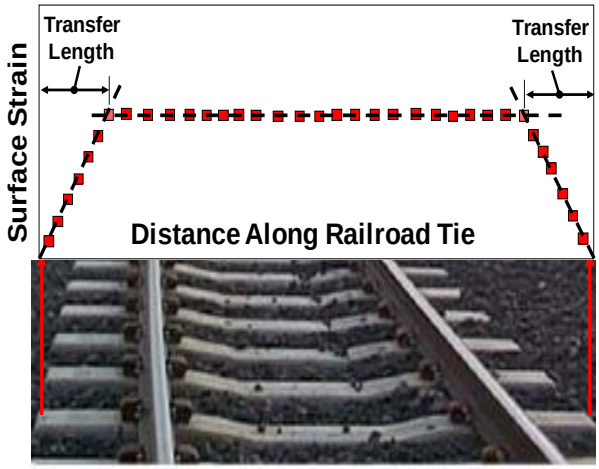


Figure 1: The Transfer Length

The transfer length application can be described in reference to Figure 1, which shows an idealized bi-linear railroad crosstie strain profile superimposed above a section of track. Pretensioned concrete railroad ties are fabricated by casting concrete around already tensioned steel wires or strands. After the casting process is complete and the concrete has hardened, a de-tensioning procedure is undertaken by cutting the reinforcing wires or strands at both ends of the concrete members to release the tension.

The stress transfers from the prestressing wires (or strands) to the concrete and is developed gradually from each end of the concrete tie, where the stress is zero, to locations well away from the ends where the stress reaches its full value. The length required to fully develop the prestressing force is defined as the transfer length, as depicted in the idealized bilinear strain profile shown in Figure 1. In order for the prestressed concrete ties to exhibit maximum load bearing capability over their expected service life, the prestressing force must be fully introduced into the railroad tie at a location well before the rail load is applied; in other words, the transfer length should be shorter than the distance from the rail seat to the end of tie, also depicted in Figure 1. In most cases, the rail seat is 21 in. from the end of the tie; however, in some specialty ties, such as those used in railway switches, the rail seat is 24 in. from the end of the tie [4].

A key parameter required for accurate assessment of transfer length is the so-called shape factor, R(x), which is a purely geometrical parameter that depends on the local geometrical characteristics of the tie cross-section. The shape factor, along with the underlying prestress force distribution, P(x), determines the shape of the longitudinal strain profile $S(x) = P(x)R(x)/E$ of the crosstie, where E is Young's modulus of elasticity. Because most ties have a shape factor that varies significantly along the length of the tie, the resulting strain profile is typically much more complex than the simple bilinear profile shown in Figure 1. Therefore, the cross-section parameters must either be measured in some manner, or in some cases they may be determined from an available CAD drawing for the tie. In

this report, the use of 3D scanning is described in detail as a method of assessing the required shape factor distribution if no CAD model is available.

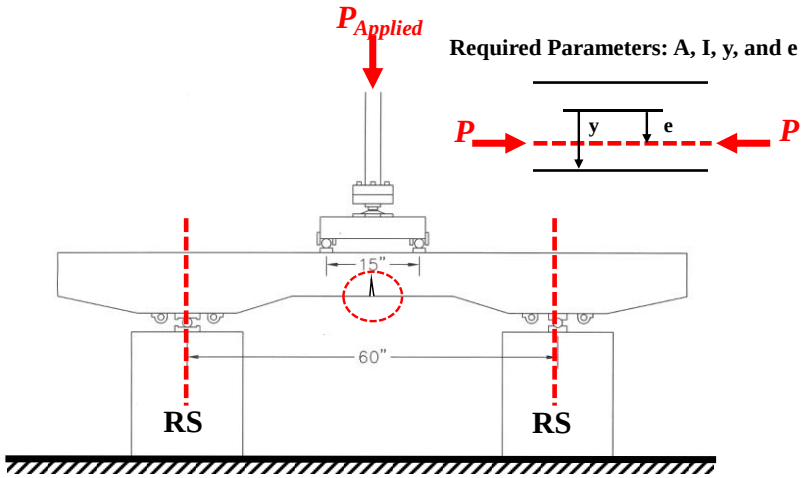


Figure 2: Crosstie Center Negative (C-) Loading Testing to Assess Residual Prestressing Force

The assessment of tie cross-sectional parameters was also undertaken in part to support planned systematic destructive testing methods [28,29]. After completion of the NDE techniques, systematic testing was conducted on sampled ties from each source and type. These tests included the determination of the remaining level of prestress force by load testing. This was initially done by supporting the ties near the end (rail seat positions, RS) and loading in the center on the bottom of the tie to a level that initiated flexural cracking, in the four-point bending configuration shown in Figure 2. This load was then to be used to estimate the internal prestress force (known as the residual prestress force) by making us of an equilibrium of forces at the crack location. To accurately evaluate the equilibrium force balance required detailed knowledge of the tie cross-sectional parameters near the center of the tie in the region where cracking was initiated. The required cross-sectional parameters were similar to those required for determination of the shape factor mentioned above. These parameters were also evaluated at the rail seat locations on each end of the ties.

1.2 Objectives

This report focusses primarily on the non-destructive testing phase of the project, and provides detailed information regarding the assessment of crosstie cross-sectional parameters using a non-contact 3D optical scanning process. The report also describes several of the applications of the measured parameters for both non-destructive and destructive testing.

The overall non-destructive testing phase of the project consisted of the following:

(1) Systematic documentation via photography. Photographs from several different orientations were taken of the sample tie surfaces, including views from all sides and views of each end showing the indented wire locations.

(2) Detailed visual inspection to note and document any obvious damage. This included spraying the ends of the ties with alcohol to detect any visible cracking, measurement and mapping of all cracks, and measurement of end-slippage of all longitudinal reinforcements.

(3) Measurement of the longitudinal prestressing reinforcement locations and concrete cover as observed from each end of the ties.

(4) Full 3-Dimensional scanning of each tie. From this it was possible to determine the cross-section parameters associated with each sampled tie along its entire length.

(5) Pulse-velocity testing to detect any existing internal damage. This method is not specifically addressed in the current report.

1.3 Organization of the Report

Chapter 2 presents background on transfer-length measurement and the motivation for the use of 3D optical scanning.

Chapter 3 describes the selection of in-service ties used in this report.

Chapter 4 describes the 3D optical scanning system and the pre-scanning tie preparation requirements.

Chapter 5 describes the overall optical scanning process, and the alignment issues and extraneous feature removal prior to conversion to a useful point cloud representation.

Chapter 6 describes the processing of the point cloud representation of the surface of the tie. The digital slicing of the point cloud for determination of the cross-section parameters is also described.

Chapter 7 presents the sample of ties that were processed using the 3D scanning system, and describes the algorithms used to extract all relevant cross-section parameters.

Chapter 8 presents an estimated assessment of the repeatability and uncertainty of the cross-section parameters.

Appendix A gives a summary table of the basic processed crosstie results.

Appendix B gives a complete compilation of the detailed tie reports for all sampled ties.

Appendix C briefly describes the basic application of the cross-section parameters to the destructive tie loading tests.

Appendix D discusses the applications that have been made using the 3D scanning procedure for in-plant transfer length measurement using the automated strain profiling system.

2. Assessment of 3D Crosstie Geometry

2.1 Key Cross-Sectional Parameters

The generic trapezoidal cross-section shape which is used to define the important geometrical parameters associated with an arbitrary crosstie cross-section is shown in Figure 3. These cross-sectional parameters are A(x), the area of the cross-section, e(x), the eccentricity of the wire grid centroid, y(x), the distance from the bottom of the concrete tie to the neutral axis of the cross-section, and I(x), the moment of inertia of the cross-section of the concrete tie at the location of x. Note that C is the location of the centroid of the cross-section. In order to achieve the accuracy and reliability required for use of transfer length as a quality control parameter it has been necessary to account for the generally non-prismatic nature of the typical railroad tie geometry.

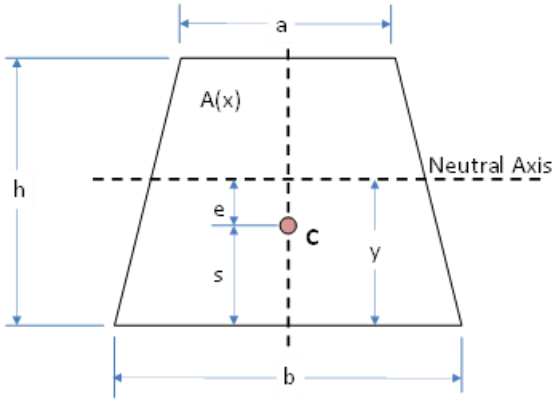
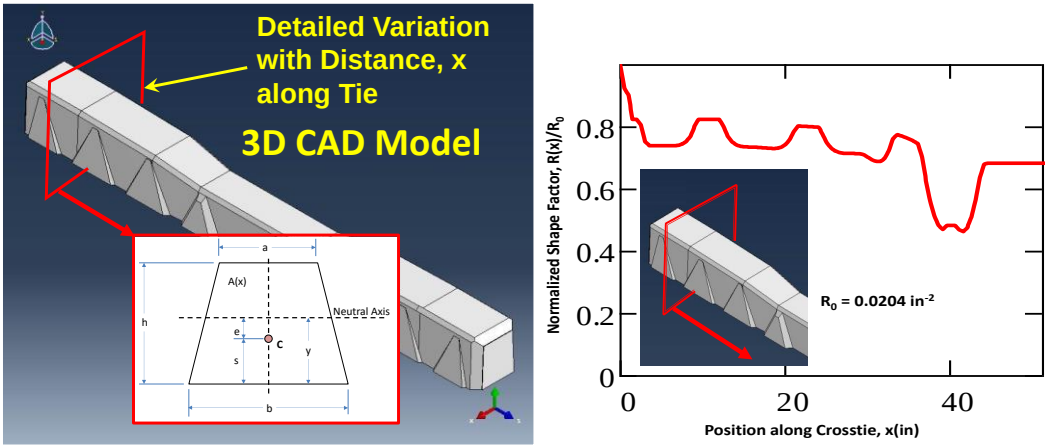


Figure 3: Trapezoidal shape defining crosstie cross sections

2.2 Crosstie Shape Factor Variation

Figure 4 shows the complex geometry of a typical USA (CXT) railroad concrete crosstie. Figure 4(a) shows a 3D (Abaqus®) model of the tie, and Figure 4(b) shows the corresponding normalized shape factor variation, which indicates the expected departures from prismatic behavior.



(a) 3D CAD Model of Crosstie (b) Normalized Shape Factor

Figure 4: Typical Geometry of Concrete Railroad Crosstie (CXT)

Figure 4 is an excellent example of a complex "scalloped" tie geometry, which results in a strain profile that departs significantly from the ideal bi-linear strain profile associated with prismatic members. A normalized shape factor, R(x)/R(0) for this tie is depicted in Figure 4(b). In reference to the trapezoidal shape shown in Figure 3, the shape factor, R(x) is defined by

$$R(x) = \frac{1}{A(x)} + \frac{e(x)y(x)}{I(x)} \tag{1}$$

As a result of the variation in this shape factor along the length of a tie, the strain profiles for railroad crossties can depart considerably from the ideal bilinear surface strain profile associated with a constant cross-section (prismatic) member such as is depicted in Figure 1. Further details regarding the variation of the other cross-sectional parameters will be presented below.

3. Selection of Crossties for Study

The overall goal of this research effort was to establish the material properties and fabrication requirements which minimize the long-term risk of splitting and structural failures of crossties. The non-contact optical part of this investigation provided detailed and fully three-dimensional (3D) optical scans of existing crossties, using commercially-available non-contact technology. These ties were selected from those that have been subjected to long-term in-track load.

3.1 In-Track Ties Sampled from TTCI Facility

Many of the ties for this study came from the crosstie graveyard located at the TTCI facility in Pueblo, Colorado. A small sample of such graveyard ties is shown in Figure 5. The ties sampled represent a range of long-term in-track performance, and include (1) those ties which have been in service and performed well for as long as 25 years, (2) those ties which have failed in track, and (3) those ties which have shown signs of distress in service.

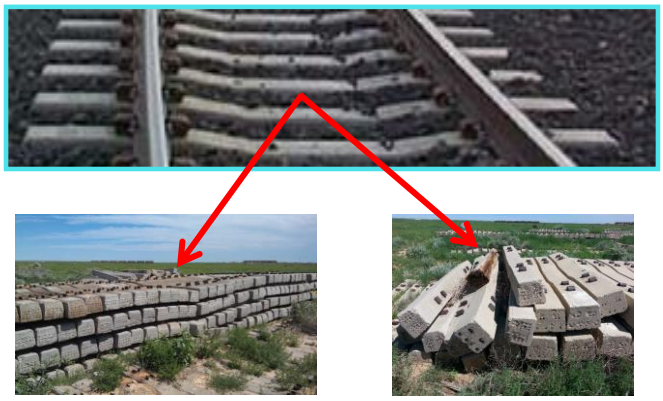


Figure 5: In-Service crossties at Pueblo Colorado facility

3.2 Ties with Known CAD Models Available

Some of the ties in this study had 3D CAD models already available. An example being the large sample of CXT ties shown in Figure 6, the performance of which was actually the subject of long-term in-track loading tests at the TTCI facility [22] associated with an earlier phase of the current project.

Figure 6: CXT crossties from in-track TTCI facility

The available 3D CAD model for the CXT tie was used to help assess the capability of the 3D optical

scanning system in obtaining cross-sectional parameters for this type of tie. The CAD model for the CXT tie geometry, along with an available CAD model for a ROCLA tie which was the subject of in-plant transfer length measurements [26], provided useful initial evaluations of the accuracy and general feature-capturing capability of the scanning procedure. A detailed qualitative and quantitative analysis was conducted which compared the known 3D CAD model geometry for each of these ties with the 3D geometry of the experimentally scanned ties. More will be said about this comparison in a later section of this report.

3.3 Description of Ties Subjected to 3D Scanning and Geometrical Analysis

This section provides a description of the general characteristics of the ties that were sampled for analysis using the 3D optical scanning procedure. These ties were also photographed from several different angles to show the general appearance of the tie surface wear or presence of cracking, along with a general qualitative assessment of the condition of the ties.

Table 1: Basic Characteristics of Sampled Ties

	Layout				
	# of Wires	Wire Type	Indentations	Dia. Wire	Pattern
A	4	Wire	Non-indented	0.415"	2-2
B	7	Strand	Non-indented	0.375"	3-4
C	6	Strand	Indented	0.375"	2-4
D	8	Strand	Indented	0.375"	4-4
E	18	Wire	Indented	5.30mm	4-4-4-6
F	26	Wire	Indented	4.86mm	10-6-10
G	8	Strand	Indented	0.385"	4-4
H	24	Wire	Indented	4.97mm	6-6-6-6
J	24	Wire	Indented	4.94mm	6-6-6-6
K	24	Wire	Indented	4.95mm	8-8-8
L	28	Wire	Indented	4.97mm	8-10-10
M	28	Wire	Indented	5.02mm	8-6-6-8

Table 1 shows a list of the sampled ties that were subjected to testing. A total of 72 ties were evaluated, and this list was comprised of 6 ties of each type. A generic group labeling of ties (A, B, C,…) was used for tabulation purposes. The 6 ties within each group were further designated with a number suffix (A-1, A-2, A-3, A-4, A-5, A-6, B-1, B-2, B-3, B-4, B-5, B-6, …etc.) so that each individual tie could be identified. The table shows the general physical characteristics of the tie types, including prestressing wire type (wire or multi-wire strand), number of wires used, whether the wires were indented or smooth, the diameter of the prestressing wires, and the general pattern of the wire distribution as observed from each end.

Table 2 shows additional information regarding the manufacturer, alternate tie ID (external label markings if available, and the length of the ties.

Table 2: General Tie Identification Information

ID	Quantity	Manufacturer	Alternate ID	Wire #	Length
A	6	Itisa	136 RE	4	8'3"
B	6	Unknown	N/A	7	8'6"
C	6	FLORIDA EAST COAST	N/A	6	9'0"
D	6	SAN-VEL	Sante Fe	8	8'6"
E	6	CXT GRAND ISLAND	CXT497S	18	8'6"
F	6	CONFORCE COSTAIN	CN 60A	26	8'3"
G	6	KOPPERS	CSX	8	8'6"
H	6	ROCLA	N/A	24	8'6"
J	6	ROCLA	N/A	24	8'3"
K	6	COSTAIN GENSTAR	CP RAIL	24	8'6"
L	6	CXT	BN100	28	8'3"
M	6	ROCLA	BN100	28	8'3"

The data shown in Table 1 and Table 2 was determined from the initial visual inspection of the ties, prior to 3D optical scanning.

4. Pre-Scan Preparation of Sampled Ties

Upon arrival at KSU, the sampled ties were initially stored in a United States Department of Agriculture (USDA) Facility just off-site from the main campus. Subsequently, a considerable amount of preparation was required prior to the actual 3D optical scanning operation.

4.1 Arrival, Sorting, Labeling, and Tie Surface Preparation

Two semi-trailer loads of ties were shipped to the USDA ARS Lab in Manhattan Kansas in July 2015 where the initial visual inspection and 3D scanning took place. Arrival of sampled ties, and their initial stacked storage in the interior of the Building 7 facility, is shown in Figure 7(a) and Figure 7(b). Prior to any photographic or optical scanning, the ties were washed and thoroughly dried at the facility. They were sorted according to tie type (A,B,C,…) identified in Table 1 and Table 2, and labeled with a permanent marker. The manufacturer was also identified, and identifying markings recorded for future reference.

(a) Arrival of Ties at USDA ARS Lab (b) Interior of USDA Building 7 Facility

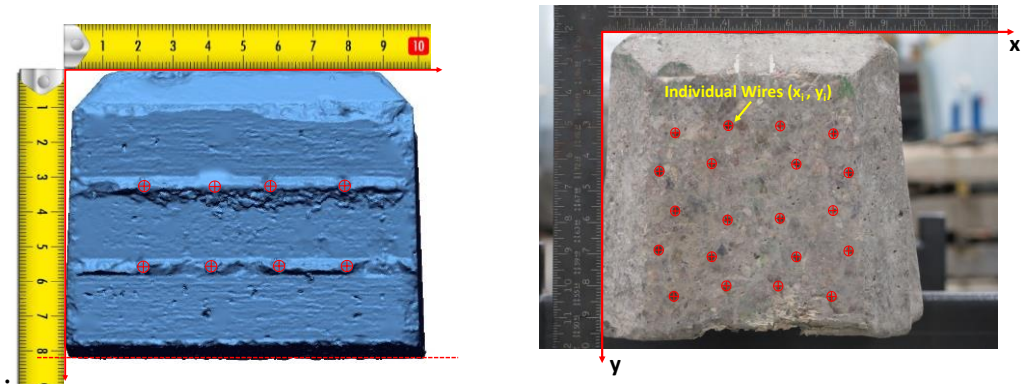
Figure 7: Tie Storage Initial Inspection in USDA Building 7 Facility

Initially, the 3D scanning and photographic records were made at the USDA Building 7 Facility. Later, the ties were moved to the Structures Laboratory in the KSU Department of Civil Engineering. The majority of the photographic recording and documentation, as well as the 3D optical scanning operation, took place in this on-campus facility.

4.2 Wire Centroid Measurement

In order to be able to fully evaluate the tie cross-section parameters defined in Figure 3, it was necessary to determine the centroid of the prestressing wires, and the eccentricity of the wire-concrete cross-section. This was particularly important in applications involving the measurement of transfer length, where the eccentricity is directly associated with the shape factor. This could be accomplished in at least a couple of ways, either from directly photographing the ends of the ties and digitally (visually) extracting the centroid of the wire configuration (see Figure 8(b)), or through the use of a 3D scanned rendering (see Figure 8(a)). End views showing the wire configurations for a CAD rendering of a CXT tie and an end view photograph of a ROCLA tie are shown in Figure 8(a) for the

ROCLA tie and in Figure 8(b) for the CXT tie. The locations of the prestressing wires have been highlighted in each of these end views.



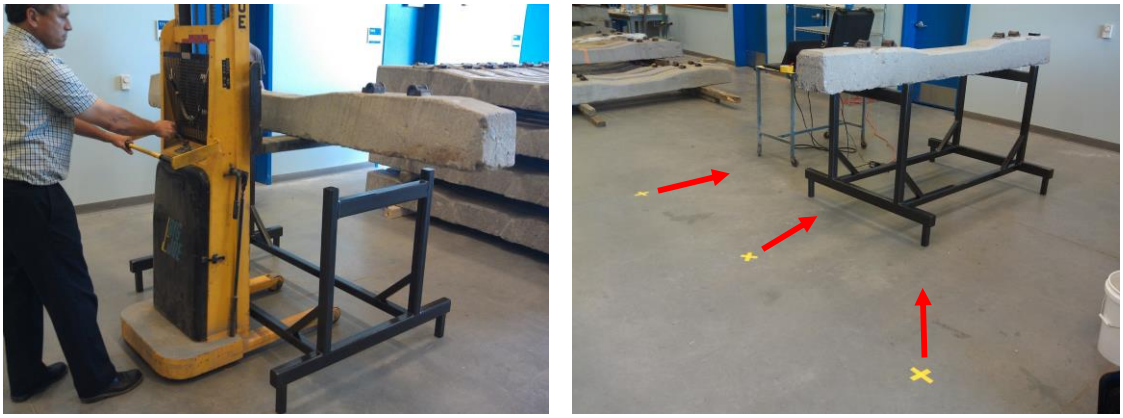
(a) End View 3D Scanned ROCLA Tie (b) Photograph of CXT Tie End View

Figure 8: Crosstie End Views Showing Wire Configuration

A chief difficulty associated with the accurate extraction of the crosstie cross-sectional parameters from a 3D scanned solid body model lies mainly in the need to accurately identify the location of the bottom surface of the tie. From the end views shown in Figure 8, it is clear that the process of locating the bottom of the tie could have a relatively large uncertainty, perhaps on the order of 0.1 to 0.2 inches. Since the bottom of the tie forms the reference from which the eccentricity is extracted, as shown in Figure 3, it is not surprising that the eccentricity (and related shape factor) should the largest uncertainty in comparison to all the other cross-sectional parameters.

4.3 Photographic Documentation Prior to 3D Scanning

Figure 9(a) shows the re-positioning of a tie onto a heavy duty steel frame that was constructed specifically to support ties during inspection and measurement. Photographic documentation and 3D scanning took place while the ties were mounted on the steel frame shown. This allowed easy visual access to the entire surface of the tie with minimal blockage due the steel frame supports. Prior to scanning, photographs of the sampled ties were staged to provide views from several different angles. Identification of key damage features, such as cracking, were also assessed visually, and were traced using a permanent marker.



(a) Positioning of Tie for Inspection (b) Marked Positions for Photography

Figure 9: Supported Tie and Marked Camera Positions for Photography

Figure 9(b) shows a typical tie mounted on the steel frame in the Building 7 facility, and the marked camera positions for recording different views of the tie. This procedure was later moved to the CE Department Structures Laboratory. Figure 10 shows several different views of a type D1 tie, which represents a tie that exhibited very little apparent damage. In particular, no observable cracking was apparent. A somewhat remarkable observation is seen in Figure 10(g) and Figure 10(h), where the original form troweling marks seem to be evident. It should be noted that the localized darkened regions on the sides of the tie, as shown in Figure 10(b) and Figure 10(c) are as a result of the NDE pulse velocity testing procedure.

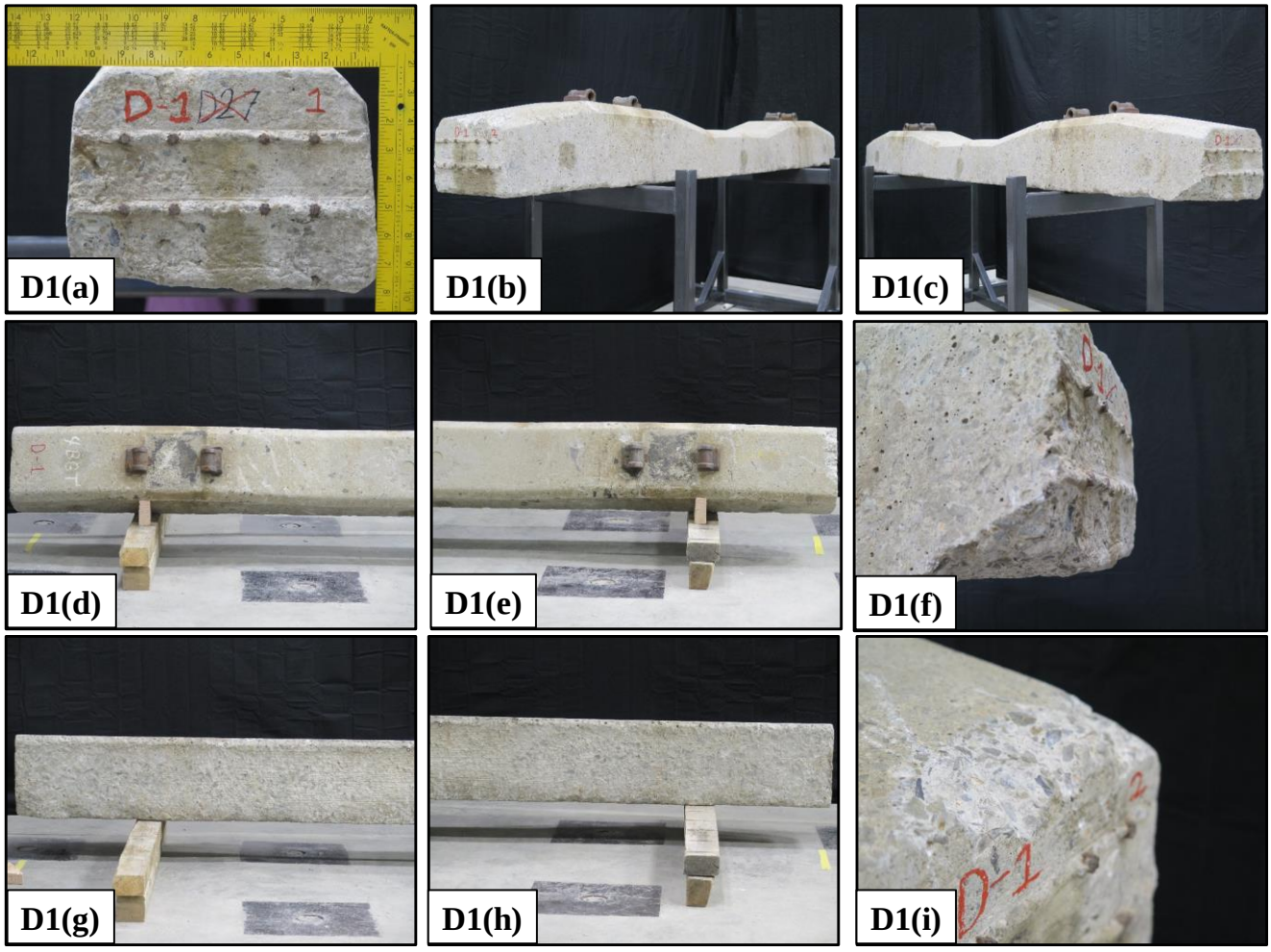


Figure 10: Photographic Views of Sampled Tie D1

Figure 10(f) and Figure 10(i) show apparent damage; however, this damage does not appear to be as a result of in-track loading. In particular, there does not appear to be any cracking evident. Hence, the damage may be more associated with transport of the ties from the TTCI facility.

Figure 11 shows similar alternate views for the G3 tie. This tie exhibited considerable crack damage starting from each end of the tie and progressing well over a third of the length of the tie from each end. Close up views of the damage are shown in Figure 11(f) and Figure 11(i).

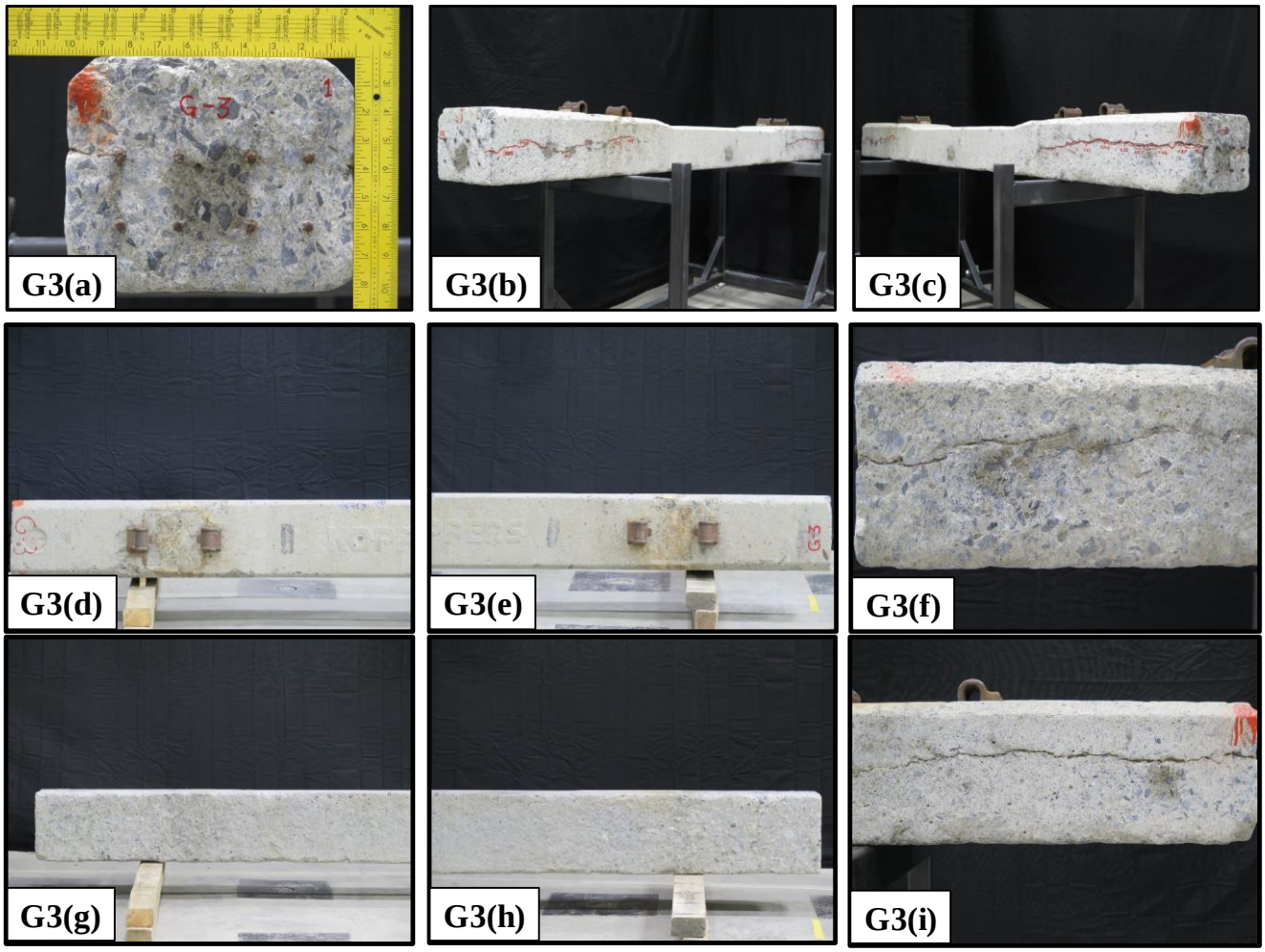


Figure 11: Photographic Views of Sampled Tie G3

Comparing the end view in Figure 11(a), the orthographic view shown in Figure 11(c), and the close up side view in Figure 11(c), it is clear that the cracking propagated from one of the wires closest to the surface of the tie. The interesting thing here is that the cover thickness is rather large (greater than 1.5 inches), yet the cracking still took place. This thickness is large in comparison to the range of cover thicknesses thought to be sufficient to prevent cracking in relation to proposed qualification test development [30,31,32]. This suggests that there may have been some long-term in-track loading effects that affected the tie's resistance to crack formation.

5. Optical Scanning of Crossties

This section gives a detailed description of the 3D optical scanning of the sampled crossties. The objective was to achieve a high-resolution 3D rendering of each tie, from which the important cross-section parameters shown in Figure 3 could be determined by appropriately "digitally slicing" the ties along their entire length.

5.1 Description of the 3D Scanning System

The 3D scanning system used for the current crosstie measurements was a commercially-available laser-based system[2], having a maximum measurement spatial resolution of about 0.05mm. It was a dual camera triangulation device with 7 intersecting laser light sheets capable of capturing continuously changing images of the crosstie surface contour. The depth of field was large (250mm), as was the scanning area (275mm x 250mm). The hand-held unit thus easily allowed manual scanning of an entire crosstie surface relative to a fixed xyz coordinate axis.

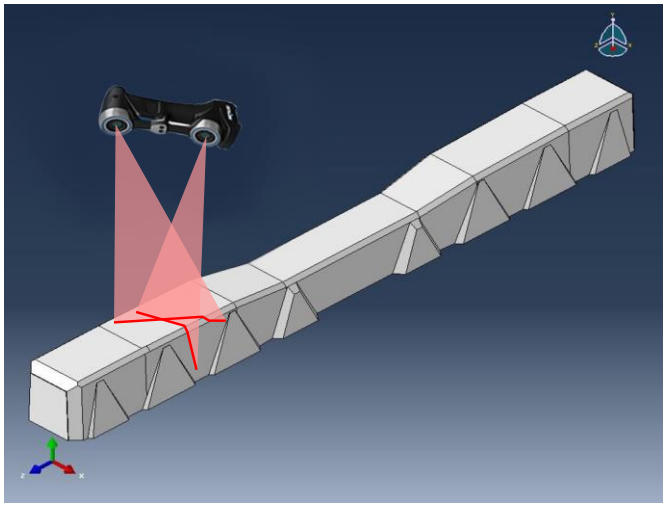
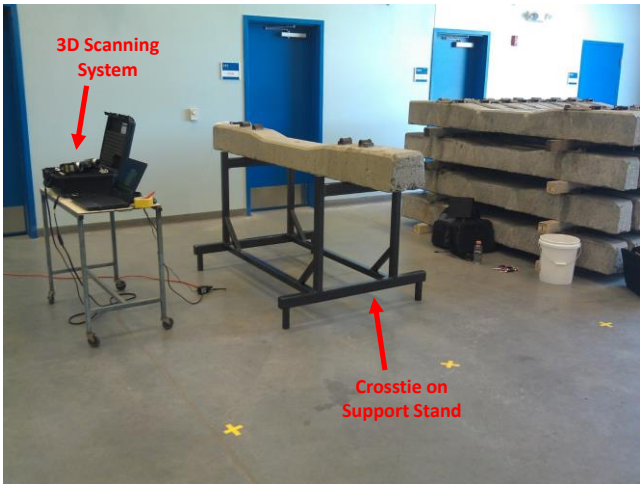


Figure 12: 3D Optical scanning of railroad crosstie

A schematic representation of the basic scanning system, in operation while scanning a CXT crosstie, is shown in Figure 12. The CXT tie has a relatively complex geometry which includes scallop structures on the sides of each tie. The figure depicts two intersecting light sheets for simplicity; however, there are actually 7 pairs of intersecting light sheets utilized in the actual hand-held unit.

Prior to scanning, each crosstie was mounted on the steel support frame and initial photographic documentation of the crosstie surface features was taken. A photograph of the support frame, together with the scanning system hardware is shown in Figure 13. To facilitate later cross-section analysis, calibrated photos of the tie ends were taken to establish the locations of all prestressing wires, as depicted in Figure 8(b). As mentioned earlier, this facilitated evaluation of the centroid of the wires, which was needed to determine the prestressing wire eccentricity and overall crosstie shape factor, for later multi-point bending analysis and for transfer length assessment.

[2] CREAFORM HandySCAN700™ laser-based 3D scanning unit

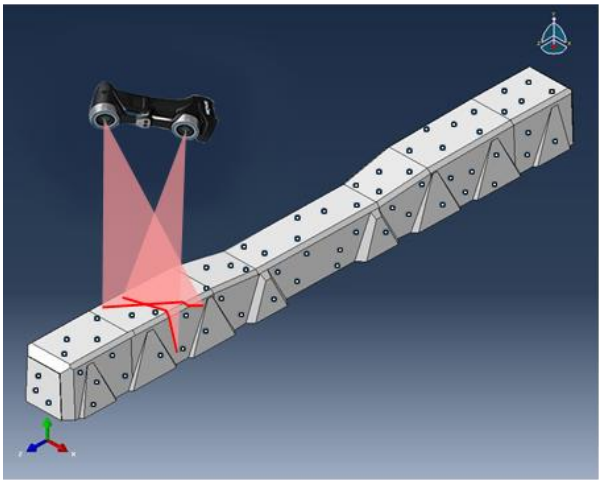


(a) Crosstie with Scanning System

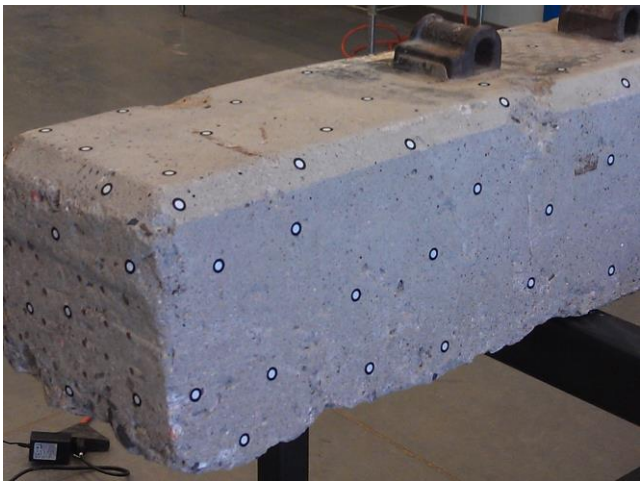
(b) Close up of 3D Scanning System Hardware

Figure 13: Crosstie on Support Frame with 3D Scanning Hardware

For accurate 3D scanning of a large object such as a railroad crosstie, it was necessary to attach self-adhesive retro-reflective points having a nominal spacing of about 4 inches over the entire surface of the tie. These points provided a distributed 3D reference frame to the scanning system, and were especially critical when attempting to scan around sharp corners to reach features on the underside of large objects such as the crossties. Figure 14(a) shows the distribution of these points schematically over the entire tie surface, and Figure 14(b) shows a photograph of these retro-reflective points mounted on the surface of one end of a crosstie. About 200 of these points were required for scanning of each of the crossties associated with the current study.



(a) Schematic of reference points



(b) Photograph of points on actual crosstie

Figure 14: Retro-reflective reference points for 3D scanning system

5.2 The Optical Scanning Process

Once the initial documentation was complete, the actual scanning could begin. Initially the discrete retro-reflective points were scanned completely over the entire tie surface, establishing a complete 3D

reference grid. Then the detailed surface structure of the tie was scanned in a procedure that closely resembles the "painting of an invisible man" as the surface features were revealed. This is depicted in the screen capture image shown in Figure 7. It took approximately 1-2 hours to complete the 3D scan of a single tie.

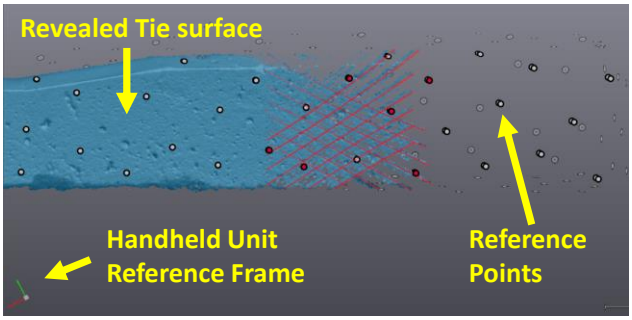


Figure 15: Revealing 3D tie surface structure

Even though the optical scanning system was capable of a spatial resolution better than 0.1mm, a resolution of 1mm was selected for the crosstie scanning associated with the current research. This resulted in computer storage requirements of 3 to 5 GB per tie scan, which was quite sufficient to resolve all relevant tie surface features. A resolution of 0.1mm would clearly have resulted in prohibitively large memory requirements, likely on the order of terabytes per crosstie scan.

5.3 Initial Post-processing of 3D Crosstie Scans

A flow chart showing the step-by-step procedure associated with the scanning and post-processing of cross-section data for a given crosstie, is shown in Figure 16. After the initial scanning procedure described above, additional third-party software was utilized to further process the 3D tie data.

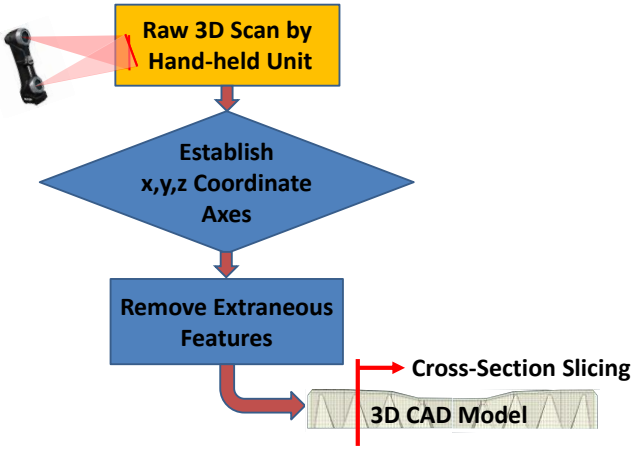
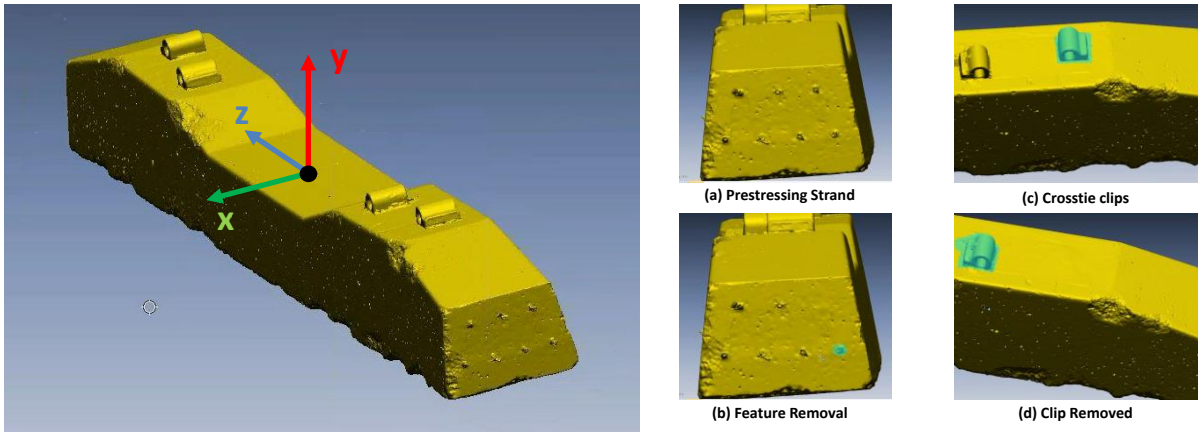


Figure 16: Flow chart of crosstie 3D scan processing

The 3D scans were exported from the proprietary commercial scanning system software as an *.STL file, and then imported into other commercial software (Geomagic™), where unnecessary external features (such as the rail seat clips and protruding pre-stressing wire) were removed. Illustrations which show this repairing and "de-featuring" of the scanned 3D crosstie are shown in Figure 17(b) for the tie shown in Figure 17(a). The tie model was subsequently aligned/oriented and converted to a "point cloud" representation using open-source 3D computer graphics software (Blender™), where the orientation of the scanned crosstie was adjusted along with its position in the global coordinate system.

Rather than the arbitrary coordinate system originally set up by the hand-held scanner unit (depicted in Figure 14(a)), the new and more useful x,y,z coordinate system was manually established in reference to the actual crosstie geometry, as suggested in Figure 17(a). At this point in the processing procedure, the crosstie is represented by a "point cloud" and is now ready for further digital processing to arrive at the cross-sectional geometrical parameters.



(a) Establishing x,y,z Coordinate System (b) Removal of Extraneous Features

Figure 17: Establishing x,y,z crosstie coordinate system and "De-Featuring"

Earlier initial processing was accomplished by converting the scanned model into a closed body solid. The solid body model was then digitally "sliced up" manually in AutoCAD™ to obtain the desired cross-sectional shape parameters. This old method was prohibitively time intensive; therefore, a special purpose processing algorithm was developed that could obtain the shape parameters directly from the aligned "point cloud" data. The earlier manual post-processing procedure was abandoned in favor of this special-purpose slicing software, which is capable of completely processing (slicing and extracting the tie cross-section parameters) in a few minutes rather than some 8-10 hours for the manual processing in AutoCAD™. More details regarding this improved processing procedure will be discussed in a subsequent section of this report.

6. Processing of Crosstie Point Cloud Representation

6.1 Slicing of Point Cloud

The special-purpose point cloud processing algorithm, an alternative to converting the scanned model into a closed solid body for manual evaluation of tie cross-section parameters, is described in this section. Figure 18 shows a schematic representation of the point cloud rendering of the scanned tie surface model, and the associated slicing procedure. For the current 1mm scanning resolution, point cloud slices of thickness $\Delta z = 0.50$ inches were formed from all of the measured points in the interval ($z - \Delta z/2 < z < z + \Delta z/2$) about a given z-position, as shown. This resulted in about 20,000 points around the perimeter of the slice at position z.

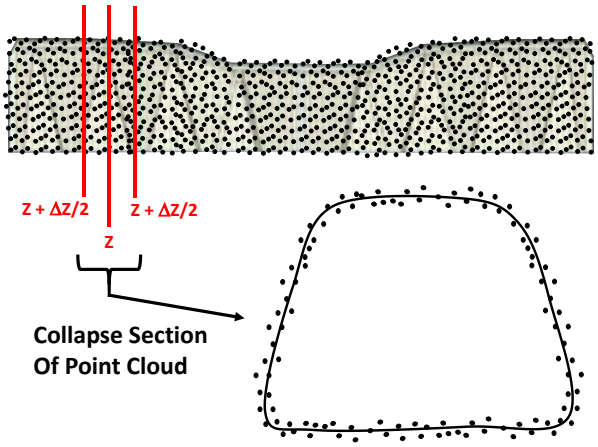


Figure 18: Collapsing a typical slice of the tie point cloud

These points were then collapsed into a single plane, and subsequently grouped into about 500 "clusters" containing nominally about 40 points each, spaced approximately uniformly around the perimeter, as suggested in Figure 9.

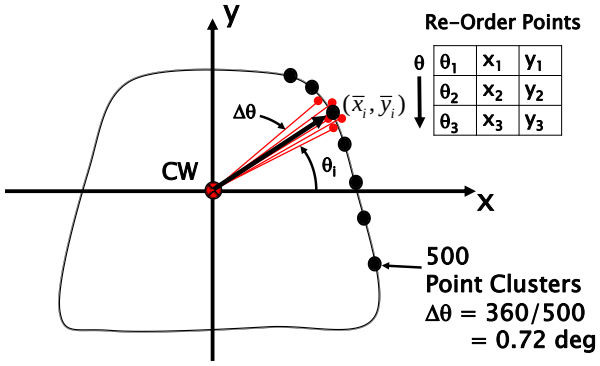


Figure 19: Formation of point clusters from slice data

The points were then re-ordered for processing with any desirable method in addition to the high-speed algorithm that was developed specifically for the purpose of extracting the desired cross-section parameters, including cross-sectional area, area centroid, area moment of inertia, eccentricity and shape factor. As shown in Figure 19, the angular resolution of the resulting point clusters is approximately $\Delta\theta = 0.72$ deg.

6.2 Voxelization and Processing of Tie Cross-Sectional Parameters

As suggested above, any appropriate discretized processing algorithm could be used to extract the desired tie cross-sectional parameters from the point cluster data. However, a particularly simple algorithm based on voxelization is described below. First a high resolution rectangular grid is superimposed so as to enclose the boundaries of the cross-section as defined by the point clusters, as shown in Figure 20. The enclosed region is subdivided into a grid of about 500 x 500 cells, resulting in a nominal cell dimension (grid resolution) of $\Delta x = \Delta y = 0.02$ inches.

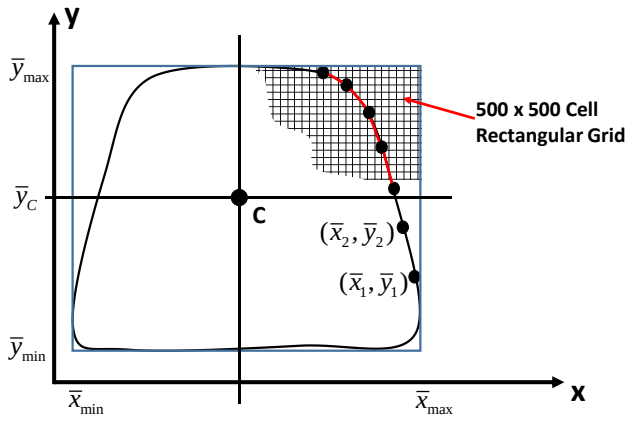


Figure 20: Superposition of High-Resolution Rectangular Grid

Figure 21 shows the voxelization process, in which the rectangular cells enclosed by the boundary defined by the surface cluster points are identified to represent interior cells. The identification of these interior cells (voxels) form the basis for the high-speed cross section processing algorithm used in the current study.

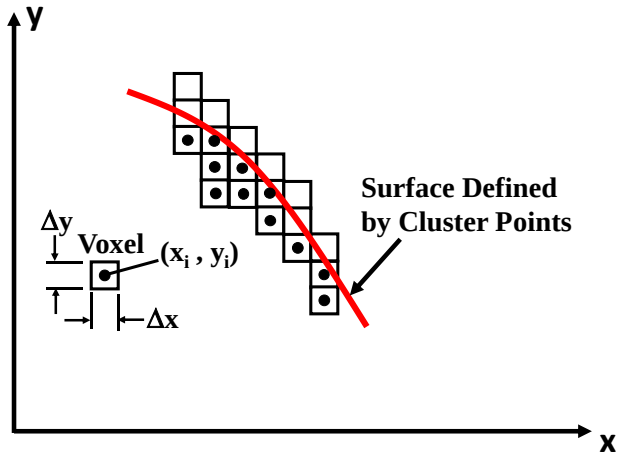


Figure 21: Voxelization of Enclosed Tie Cross-Section

6.2.1 Cross-Sectional Area

Using the results of the above voxilation process, a set of convenient and very fast algorithms was developed for the determination of all relevant tie cross-sectional parameters. The simplest of these is the cross-sectional area, A, which can be represented as follows:

$$A = \sum_{i=1}^{N} \Delta x \Delta y = \sum_{i=1}^{N} \Delta A \tag{2}$$

where $\Delta A = \Delta x \Delta y$ is the area of a single voxel within the tie surface boundary defined in Figure 21, and N is the total number of voxels in the enclosed area.

6.2.2 Centroid of the Cross-Section

The centroid, or "center of gravity" of the cross-section, can be represented using the previously defined voxels as follows:

$$y_c = \frac{1}{N} \sum_{i=1}^{N} y_i \tag{3}$$

where the y_i corresponds to the y-coordinate of a voxel in the interior of the cross-section.

6.2.3 Area Moment of Inertia

The area moment of inertia of the cross-section about the centroid is given by

$$I_c = \frac{1}{N} \sum_{i=1}^{N} (y_i - y_c)^2 \Delta x \Delta y \tag{4}$$

6.2.4 Eccentricity

The eccentricity requires first the determination of the centroid of the prestressing wire. If the centroid of the wire (or strand) is $s = y_{cw}$, then the eccentricity can be expressed as

$$e = y_c - y_{cw} = y_c - s \tag{5}$$

as depicted in the general trapezoidal cross-sectional shape shown in Figure 3.

6.2.5 Shape Factor

The shape factor can similarly be defined in terms of the above cross-sectional parameters as follows:

$$R = \left[\frac{1}{A} + \frac{ey}{I} \right] \tag{6}$$

7. Accuracy of 3D Tie Scanning Process

This section investigates the overall accuracy (repeatability and bias uncertainty) of the 3D tie scanning process, and the resulting assessment of tie cross-section geometrical parameters. Several different comparisons will be made against available 3D CAD model representations, as well as comparisons between the slow manual AutoCAD tie slicing algorithm and the high-speed special-purpose tie slicing algorithm, for processing tie cross-sectional parameters. The repeatability of the scanning process, as demonstrated by the ability to measure all tie cross-sectional parameters, will also be presented graphically.

7.1 3D Scans of CXT Tie using Manual AutoCAD Slicing Algorithm

7.1.1 3D Renderings Compared to Photographs of CXT Tie

The processing algorithm used in this first comparison was the manual AutoCAD processing procedure. Once the scanned model was exported in *.STL file format, it was subsequently imported into commercially-available third-party software for additional processing. At this point the crosstie was represented by a hollow interconnected surface mesh in 3D. This other software was then used to repair any inconsistencies in this "surface mesh" so that the model can be converted into a solid body model for later analysis. This software was also used to remove any unwanted features picked up during the scanning process, such as rail clips and protruding prestressing wires, both of which are shown in Figure 17. After repairing and removing unwanted features from the 3D surfacing, the scan file was exported in *.IGS format as a closed mesh model. This file was then imported into CAD software (such as Solidworks™) so that it could be converted into a solid body model and be exported as a *.sldprt solid part file. The final step in the manual processing flow chart involves importing the solid body part into other CAD software (AutoCAD™ was used), where it could be digitally sliced up to obtain the desired tie cross-sectional data. In addition to digitally slicing the tie, the solid body model representation will be compared directly to photographs of the scanned tie.

The ties used in the current demonstration were part of a long-term in-track loading study by the authors at TTCI [19]. The sampled tie was the subject of detailed cross-sectional analysis subsequent to the optical scanning. Photographs of each end of the CXT tie are shown in Figure 22.

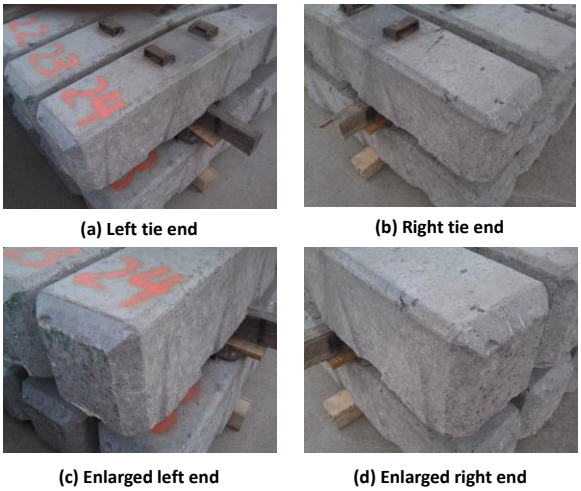
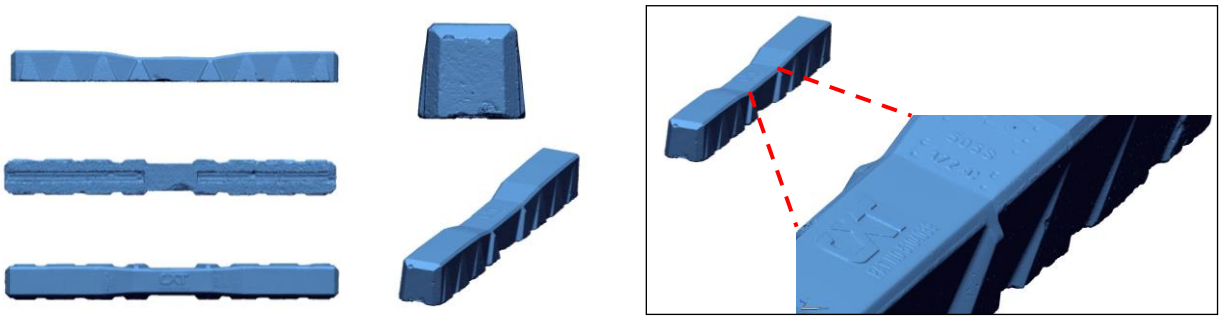


Figure 22: Photographs of CXT Tie

Figure 23(a) shows various selected views of the 3D CXT tie that was used in this initial testing of the 3D scanning process depicted in Figure 16. It is important to note the extreme level of surface detail that has been achieved, in spite of the apparently limited 1mm spatial resolution.



(a) Various Views of 3D Scanned CXT Tie (b) Detail Reveled in 3D Rendering

Figure 23: Detail Revealed in 3D Rendering of Scanned CXT Crosstie

Not only do the scanned images capture the basic geometrical features, but they also capture the small amount of abrasion (chipping) and wear apparent in the tie surface. Another example of the feature capturing capability is shown in Figure 23(b), which shows an enlarged pull-out of the scalloping on the side of the tie. These ties also are seen to contain channels on the bottom surface of the tie that were used to house and protect Whittemore points used for the long-term in-rack testing at the TTCI facility in Colorado [19]. These features could have been removed to eliminate errors in the cross-section parameter assessment; however, they are not likely to have a major effect on these extracted cross-section features. They do, however, provide additional evidence of the high-resolution feature-capturing capability that has been achieved with the 3D tie scanning.

7.1.2 Comparison of Ideal CAD Cross-Section Parameters and 3D Scan Results

For the CXT crosstie currently being analyzed, a 3D (Abaqus®) CAD model was available and was used for direct comparison of the theoretical geometrical tie parameters with the parameters measured using the 3D optical scanning process with manual slicing algorithm.

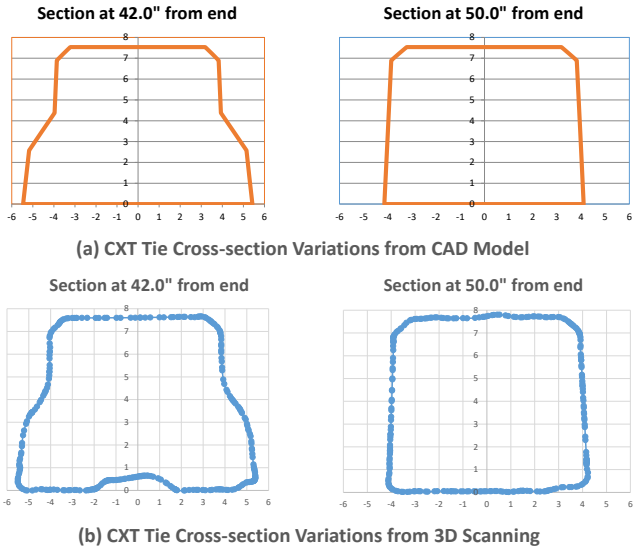
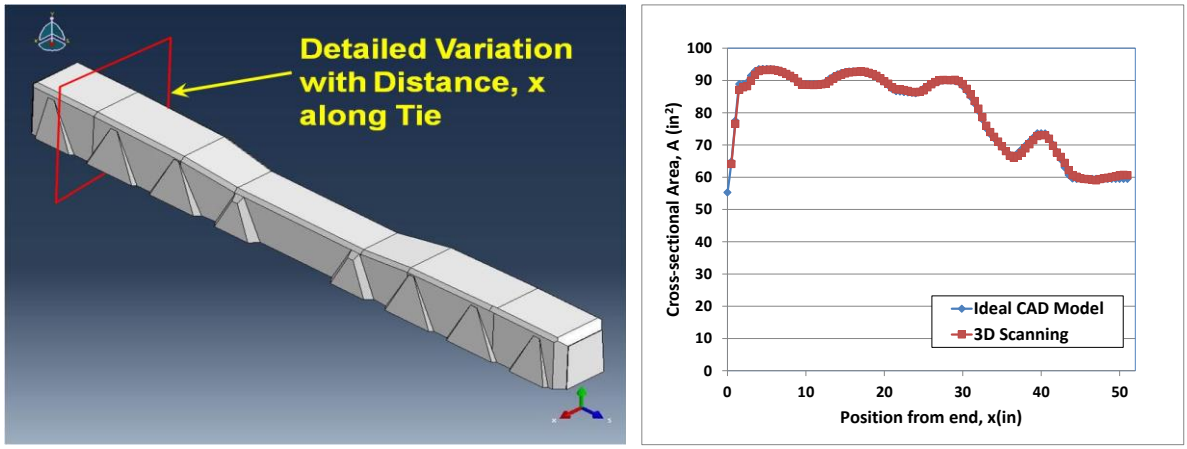


Figure 24: CXT crosstie cross-sections at selected positions

It is of interest to compare the variation of the shape factor obtained from the 3D scanning procedure with this theoretical result, along with a comparison of other cross-section parameters as well.

Figure 24 shows a comparison between the theoretical CAD model cross-section shape and the cross-section shape obtained from the 3D scanning procedure, for two different axial positions along the tie. The theoretical CAD model for these two sampled locations is given in Figure 24(a), and the corresponding measured cross-section shapes are given in Figure 24(b). There is excellent agreement between the ideal theoretical shapes and the measured shapes. Also evident in the measured cross-section shapes is the presence of rounding of sharp corners on the boundaries of the cross-section, apparently either due to slight damage in transport or due to in-track wear. The channel on the underside of the tie that was used for enclosing the Whittemore points is also evident in the measured cross-section at the 42.0 inch position. The scalloping on the side-walls at the 42.0 inch position, which is a characteristic of the CXT tie shape, has also been captured well by the 3D scanning.

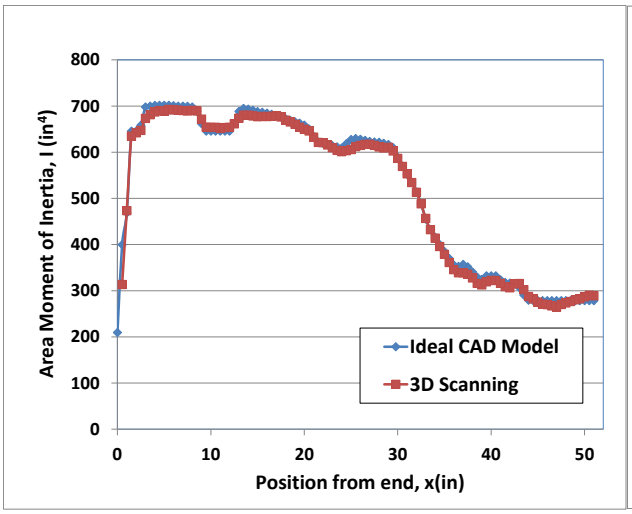
The overall trends in the cross-sectional area and the eccentricity are due to the basic non-prismatic shape of the CXT concrete tie, while the local variation ("bumps") in the shape factor shown in Figure 4(b) are caused by the scallops on both sides of the concrete tie. In particular, before the seat location of the tie, the cross-section centroid is above the wire's centroid, giving a positive eccentricity; whereas after the seat location, the cross-section centroid is below the wire's centroid, giving a negative eccentricity. This shift in prestressing eccentricity is intentionally designed to offset the bending that the concrete crosstie would experience during service [10]. It is the variation of these characteristic parameters, and the resulting variation in the shape factor, that cause the strain profile of the concrete tie to deviate from simple bilinear shape. For accurate assessment of transfer length, these variations must be properly taken into account.



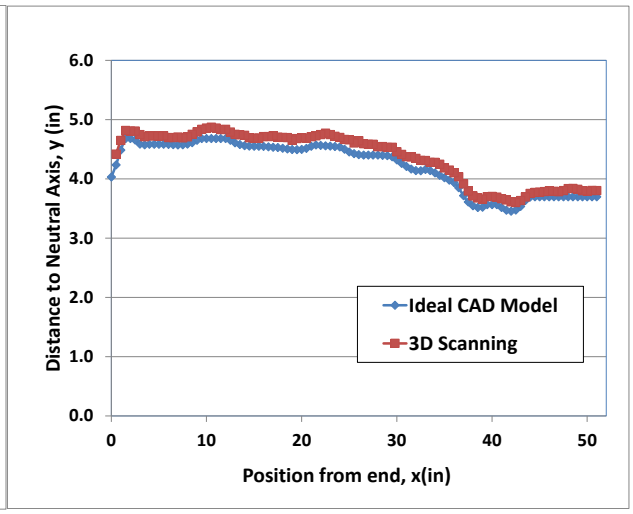
(a) 3D CAD Model of CXT Tie (b) Cross-Sectional Area Variation

Figure 25: Cross-sectional Area Variation along CXT Tie

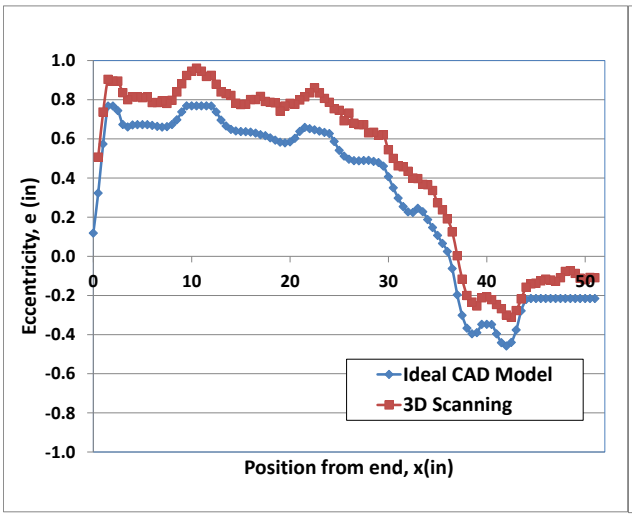
Further analysis of the 3D solid body model obtained from the 3D scanning procedure yields measurements of all of the geometrical characteristics that make up the shape factor in Equation(6). These measured characteristics are compared directly to the values obtained from the ideal CAD model for the CXT crosstie in Figure 25 through Figure 26. Figure 25(b) indicates that the 3D scanning has captured a very accurate representation of the tie cross-sectional area, with virtually negligible difference between the ideal CAD model and the measured values. Similar results are obtained for the area moment of inertia given in Figure 26(a). It is clear that the 3D scanning operation yields a very good representation of the tie geometry.



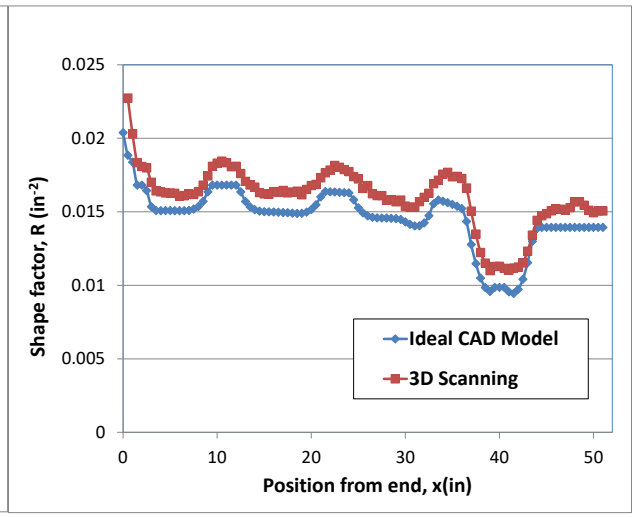
(a) Area Moment of Inertia



(b) Distance to Neutral Axis



(c) Eccentricity



(d) Shape Factor

Figure 26: Variation in Tie Cross-Section Parameters

The distance to the neutral axis from the bottom of the tie is shown in Figure 26(b). Here some differences are apparent, probably due to the difficulty in identifying a true bottom surface of the tie in the 3D scanned measurement. Comparing with the measured cross-sections shown in Figure 24, it is clear that the bottom surface does not provide a smooth flat reference from which to measure the position of the neutral axis. Figure 26(c) shows the variation in the eccentricity, and the differences here are clearly due to the differences already noted in the neutral axis position. However, the overall magnitude is very close and the variation indicates a simple bias shift due to the difficulty in identifying a clear zero reference for the neutral axis from the bottom surface of the tie. Similar good results are shown for the shape factor variation given in Figure 26(d) where again the differences between the ideal CAD model representation and the 3D scanning result appears to be largely a simple bias for the reasons described above.

From the above results, the observed deviations in the cross-sectional parameters, including the shape factor, from the ideal CAD model for the CXT tie geometry appear to be largely due to a small bias

error in determining the vertical position of the neutral axis relative to the bottom of the tie. It should be noted, however, that the normalized shape factor will be nearly identical to the theoretical result shown in Figure 4(b). Since the current generalized Zhao-Lee statistical transfer length algorithm makes direct use of the normalized shape factor, and does not require an absolute magnitude of the shape factor, there should be negligible effect on the resulting transfer length.

7.2 Processing of In-Plant 3D Scanned Tie using Special-Purpose High-Speed Cross-Section Slicing Algorithm

The main objective of this section is to present additional results obtained using the 3D scanning procedure to evaluate tie cross-section parameters. In this case, it was done so as to allow measurement of the expected variation of transfer length during a tie manufacturing process. This represented an attempt to characterize experimentally the in-plant manufacturing variations in transfer length that can occur in practice. To the best of the authors' knowledge, this is the first time extensive real-time measurements to this extent had been attempted in an actual tie manufacturing plant with the expressed purpose of statistically characterizing the variations in transfer length that take place over an entire casting bed. Furthermore, no CAD model of the tie geometry was available to allow determination of the required shape factor information for the tie. Since no 3D CAD model was available, a representative tie manufactured in the plant under study was scanned using the 3D optical scanning system [25,26,27].

Figure 27: In-plant crosstie with 3D reflective points for 3D scanning

The ties tested in the plant exhibited a relatively complex geometry, which included scalloping on the sides of each tie. An in-plant photograph of the tie that was scanned to extract the shape factor parameters is shown in Figure 3. This Figure also depicts the small self-adhesive retro-reflective points that were applied over the entire surface of the tie, with a nominal spacing of about 4 inches. These points provide a distributed 3D reference frame for the scanning system, and are especially critical when attempting to scan around sharp corners to reach features on the underside of large objects such as this crosstie.

The geometrical parameters depicted in Figure 1 were subsequently calculated at 0.5 in. intervals (slices) for the scanned tie, using the special-purpose high-speed processing algorithm discussed in Section 6. Figure 28 through Figure 32 shows the variation of tie cross-sectional parameters obtained for the scanned crosstie. These were process by "slicing" the generated CAD model of the tie every 0.5 inches along its length. Because each tie is very symmetrical, only half (51 inches) of the tie is shown in these Figures.

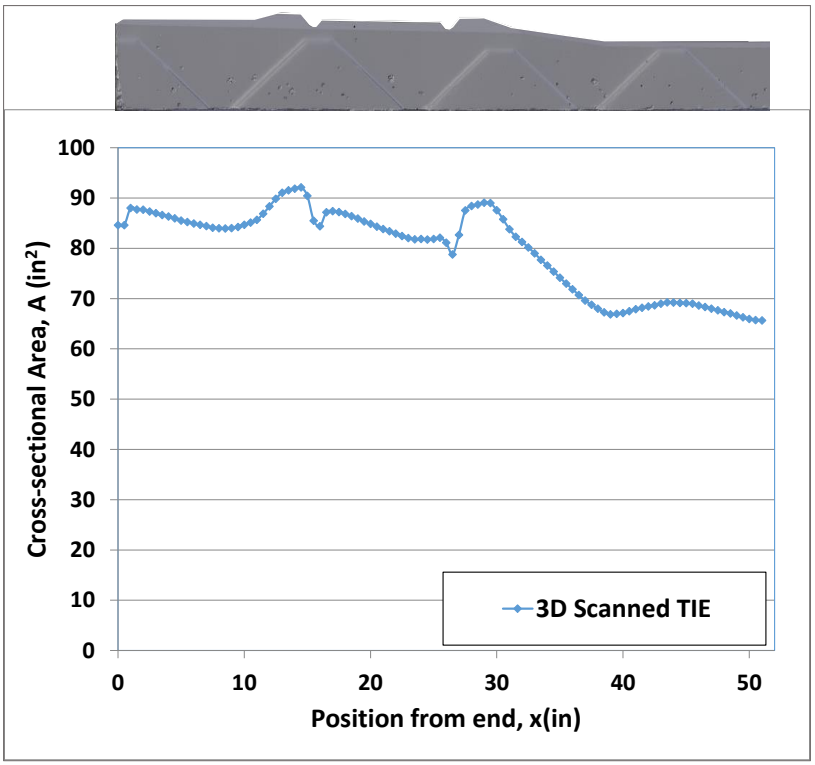


Figure 28: Variation of tie cross-sectional area

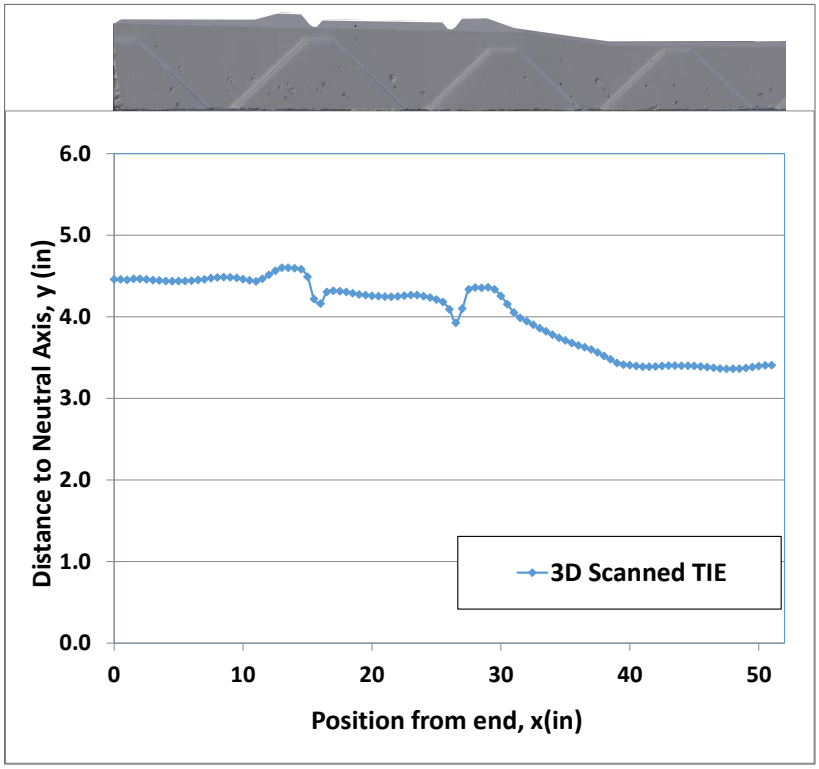


Figure 29: Variation of distance to neutral axis

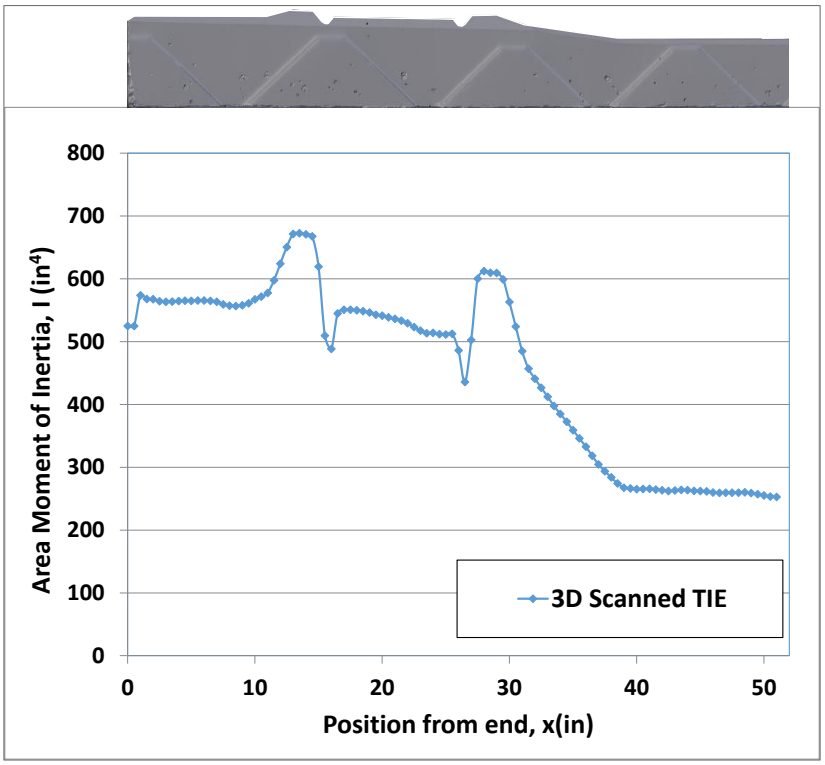


Figure 30: Variation of tie area moment of inertia

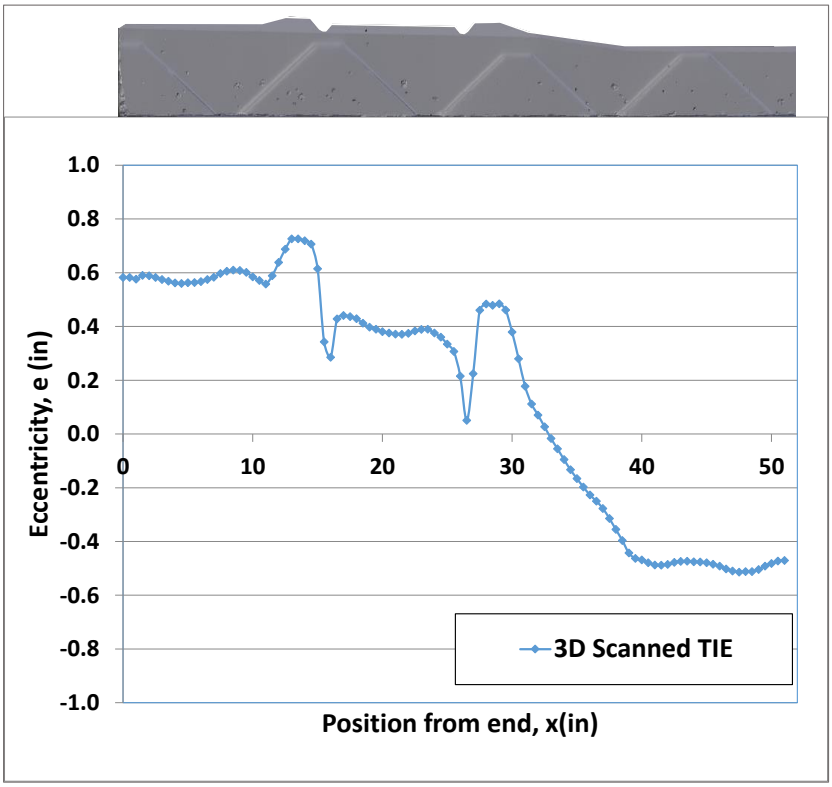


Figure 31: Variation of tie eccentricity

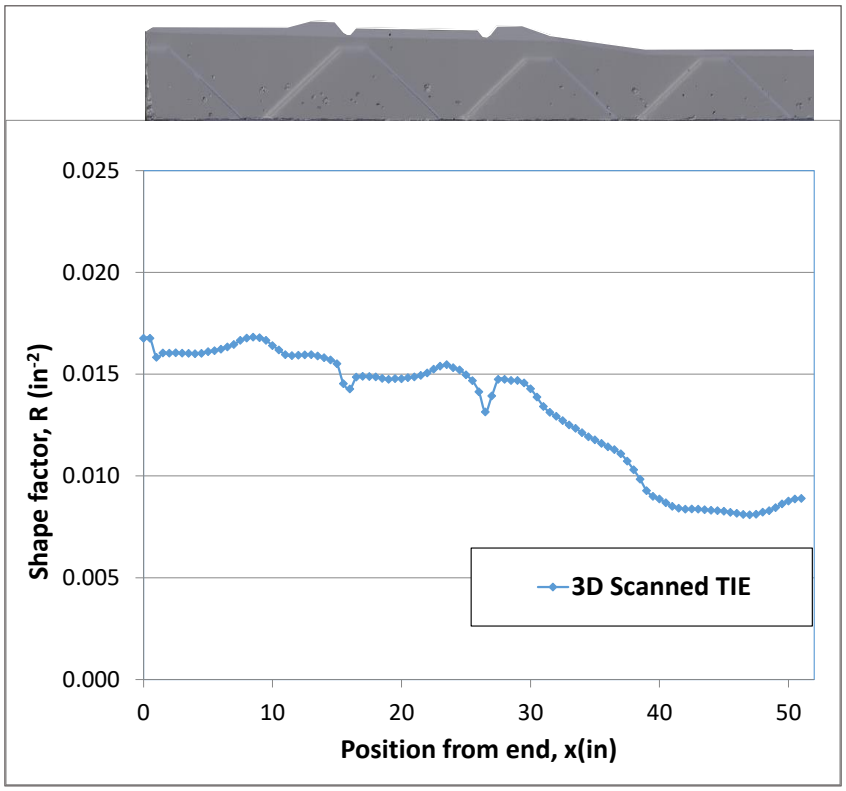


Figure 32: Variation of tie shape factor

To help in interpreting the variations in the cross-section shape parameters shown above, a profile view of the scanned tie is shown at the top of each diagram. Note the correspondence between the variations in tie geometry shown in the profile view and the characteristic changes in the shape parameters that take place, especially near the rail seat location.

7.3 Repeatability of 3D Scanning Process using Special-Purpose High-Speed Cross-Section Slicing Algorithm

This section presents an investigation of the repeatability of the overall 3D scanning and cross-section parameter determination using the special-purpose high-speed crosstie slicing algorithm. The repeat scanning results are presented for one of the CXT crossties from the stack, shown earlier in Figure 22, that had been part of a long-term in-track loading study by the authors at TTCI [19]. This tie was also the subject of preliminary cross-sectional analysis subsequent to earlier optical scanning [25]. For the current study, six repeat scans of the same sampled tie were conducted by the same operator to allow assessment of the likely variations (repeatability) in the determination of the cross-sectional parameters. Initial testing of the 3D scanning procedure [25] compared results to an available 3D CAD model for this tie. A sample of the comparison between the CAD model and a single 3D scanned rendering of the cross-sectional parameters was shown earlier in Figure 25 thru Figure 26, with excellent agreement [25]. It is important to note, however, that CAD models are not typically available for the crossties sampled from the "grave yard" facility at TTCI, or from other sources of long-term in-track ties. Hence, it is desired to develop a method for processing and statistically analyzing scanned tie information to the extent possible without the use of a CAD model. The 3D scanning process fulfills this requirement.

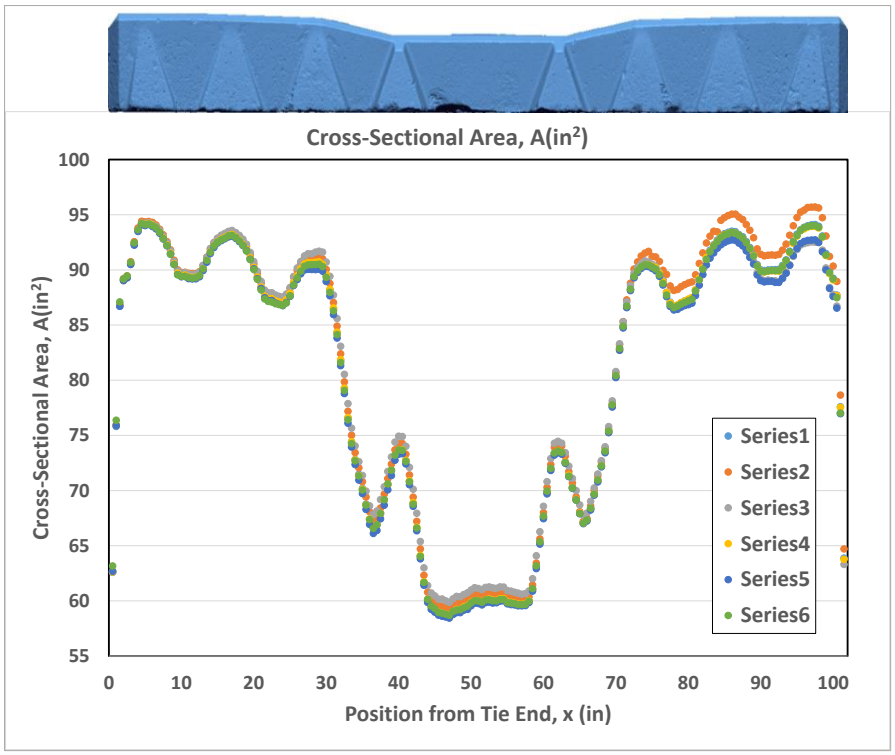


Figure 33: Variations in tie cross-sectional area

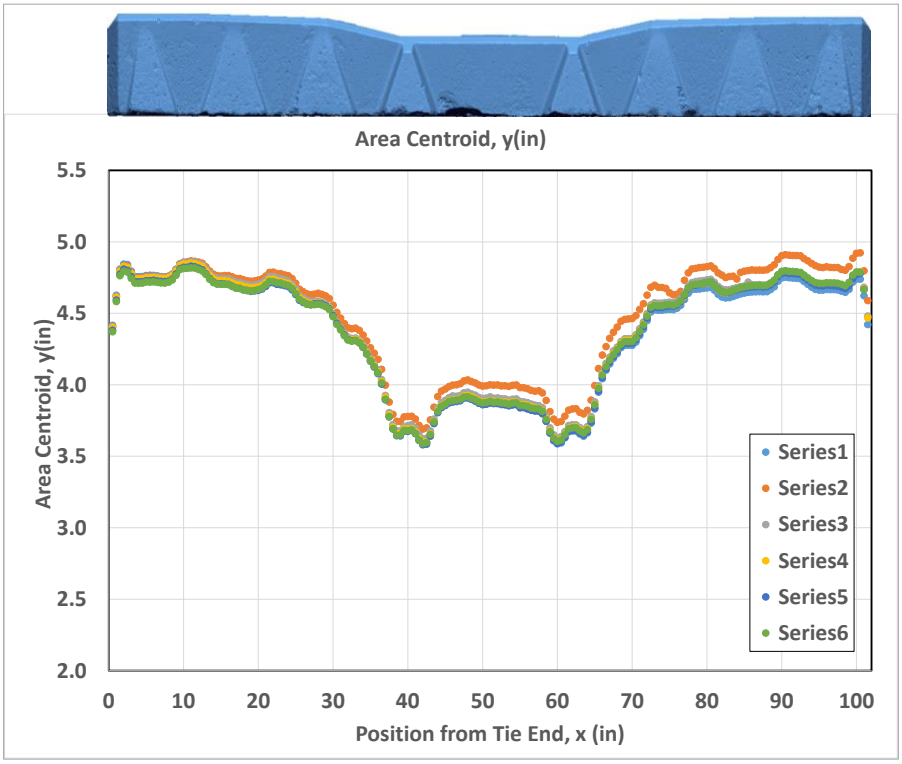


Figure 34: Variations in tie area centroid

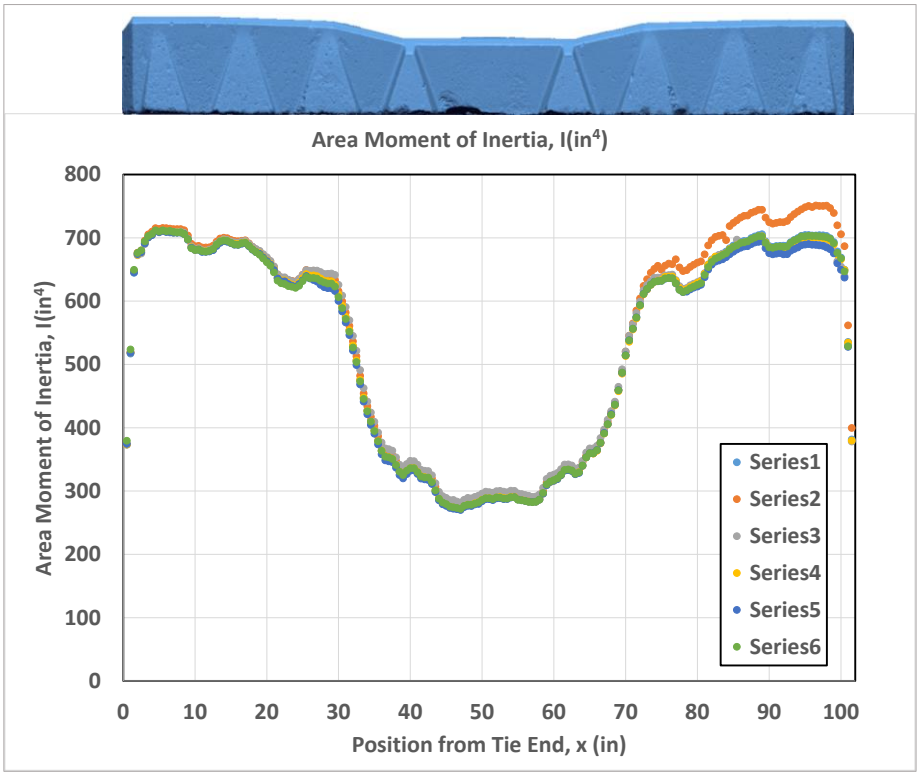


Figure 35: Variations in tie area moment of inertia

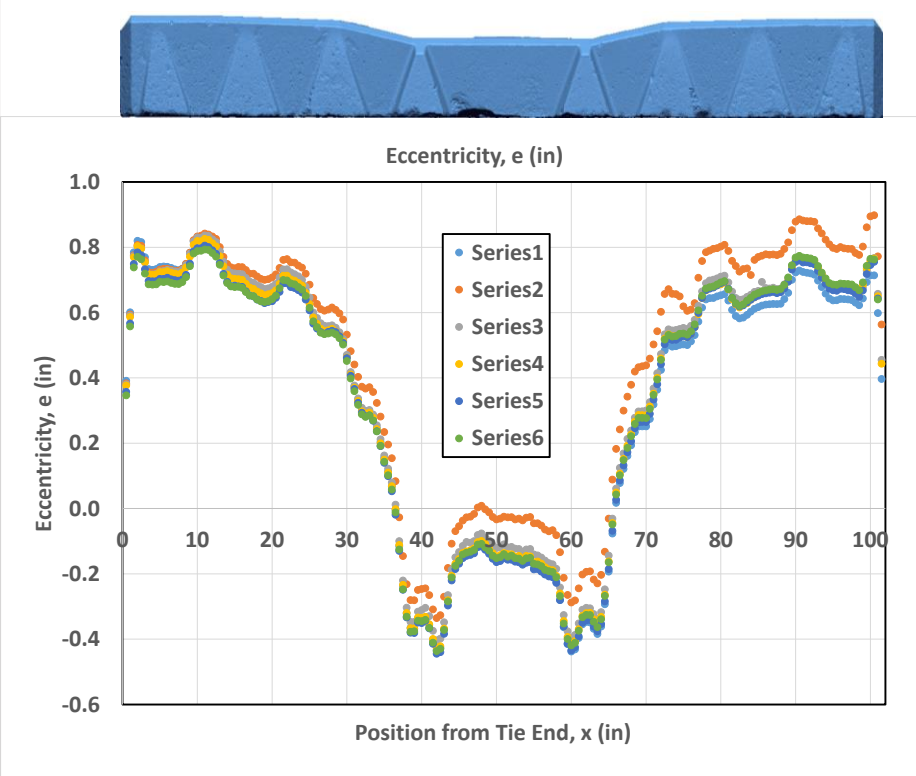


Figure 36: Variations in tie eccentricity

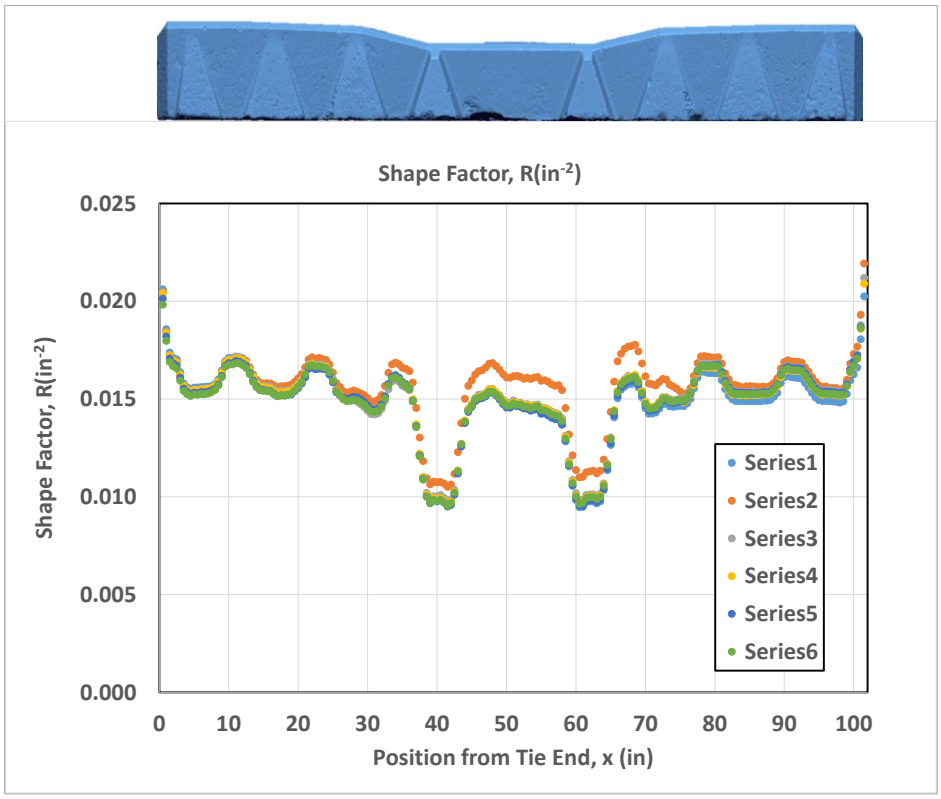


Figure 37: Variations in tie shape factor parameter

Figure 33 through Figure 37 show the variations in each of the cross-section geometrical parameters for the 6 independent scans. For comparison purposes, the profile view developed from a 3D scan of the CXT tie is shown at the top of each Figure.

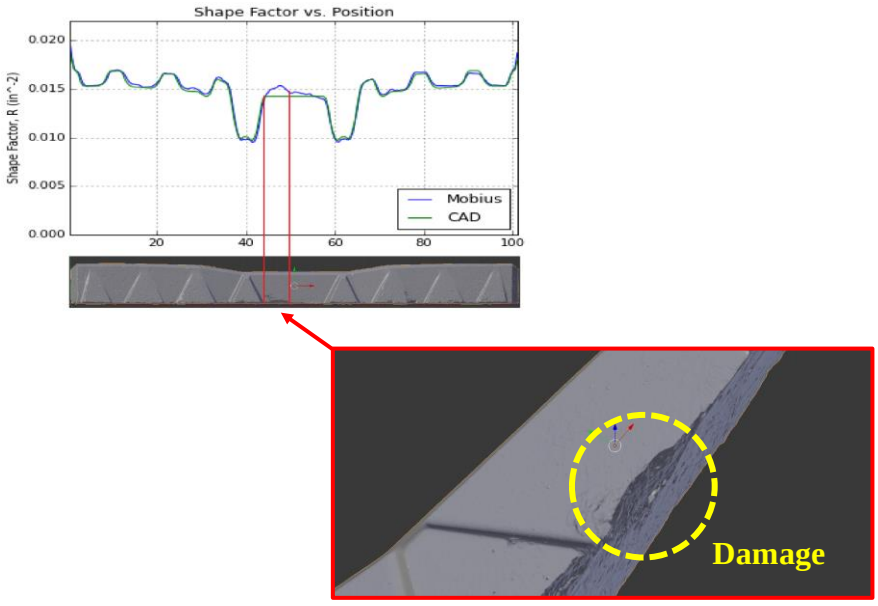


Figure 38: Correlation of Shape factor to Crosstie Damage

It is of particular interest to compare the detailed variations in geometrical parameters with the scalloping along the sides of the tie as shown in the profile. There is also a small amount of "spalling"

observed near the center of the tie on the bottom surface as shown in the profile view at the top of Figure 33. The slight dip in the cross-sectional area at around 46 inches from the left end of the tie, as shown in the Figure 33 plot, appears to be as a direct result of this small abrasion. This shows that a fine level of detail is capable of being captured by the 3D scanning. An alternate view showing the correlation between the damage and its effect damage on the shape factor is depicted in Figure 38.

In essentially all cases shown here, the deviations between scans appear to increasingly diverge from each other as one gets further from the left end of the tie (the starting point for the scan). There appears to be a more pronounced deviation in the Series 2 scan for essentially all of the tie cross-sectional parameters shown in Figure 33 through Figure 37. This "outlier" may be due human error associated with the tedious manual alignment of coordinate axes prior to cross-section processing. It may also be somewhat related to the inherent accuracy of the scanning system, which degrades as the scan progresses further from the point of origin along the tie. The source of the deviation is not known; however, the results still look very good overall in terms of repeatability. The largest and most pronounced deviations among the repeat scans occur in the eccentricity and shape factor. This is likely due to the difficulty in evaluating the area centroid and centroid of the prestressing wire relative to a consistent reference (the bottom surface of the tie). The bottom surface of the tie constitutes the reference for these parameters, as suggested in Figure 3, and there is considerable uncertainty as to the precise location of this bottom surface by as much as 0.1 inches or more. This is especially true if the bottom of the tie is significantly rough or exhibits a sinusoidal ripple characteristic of some designs.

7.4 Assessment of Tie Abrasion Losses

7.4.1 Assessment of Tie Volume from Scanning Results

The cross-sectional area variation, as shown in Figure 33, is particularly important from the standpoint of assessing long-term abrasion and wear of the ties that have been in extended service. Integration of the cross-sectional area over the length of the tie yields an estimate of the tie volume, as suggested in the schematic representation shown in Figure 39.

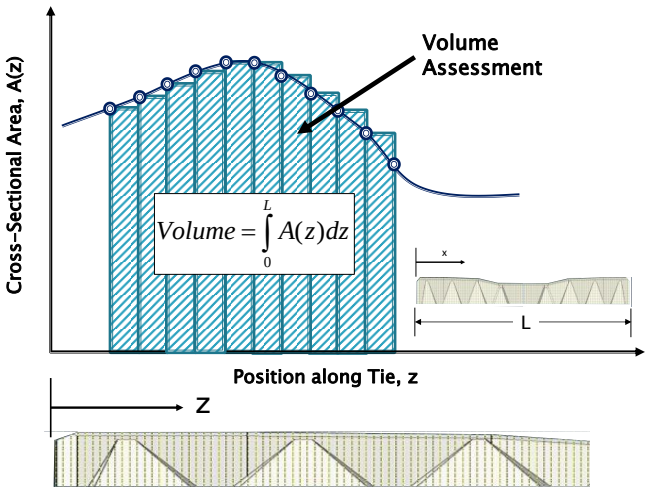


Figure 39: Estimate of Tie Volume from Cross-Sectional Area Integration

Deviations in this volume are one measure of the repeatability of the scanning process in capturing volumetric abrasion. Table 3 shows the resulting tie volume assessment for the 6 independent scans of

the same tie, where the tie volume was calculated using a simple trapezoidal integration algorithm over the length of the tie (less 0.50 inches from each end).

Table 3: Volume Assessment Statistics

Set#	V (in^3)
1	8187.9
2	8258.1
3	8225.3
4	8185.9
5	8147.4
6	8181.1

Volume Assessment Statistics	
V_{ave}	8197.6 in^3
σ_V	38.6 in^3
V_{min}	8147.4 in^3
V_{max}	8258.1 in^3
ΔVol (%)	$\pm$ 0.67%

Because the ends of the tie are not typically perfectly flat in the vertical direction, these regions were omitted from the volume assessment for simplicity. The tie volume is seen to be repeatable to within about $\pm$ 0.67%, which appears to be relatively good except that it represents a random uncertainty of about $\pm$ 55 in^3 for the tie volume. The largest of the volume deviations is clearly due largely to the Series 2 outlier shown in Figure 33, for the reasons suggested above. Eliminating this outlier reduces the volume scatter by about a factor of two. Clearly this approach yields somewhat of a worst-case scenario since the tie shape is compared grossly over the entire volume of the tie, amplifying any distortions due to lack of perfect alignment.

7.4.2 Assessment of Tie Volume Loss from Induced Abrasion

An alternate means of deducing the measurable resolution of volumetric abrasion and wear was also investigated in this study. This was accomplished by first subjecting the sampled tie to known (induced) abrasion with measurable volume, and then attempting to evaluate (measure) the local volume of the removed concrete.

Figure 40: Region of induced abrasion (undamaged tie)

Figure 40 shows the region of the scanned tie that was subjected to induced abrasion. It was in a region near one end of the tie, where from Figure 33 the observed scatter in the cross-sectional area

was small. The white plaster material was not associated with the current abrasion testing. The bottom surface of the tie originally contained a channel that acted as a protective housing for metal "points" associated with manual measurement of strain using a Whittemore gauge. All the ties in Figure 6 had similar channels on their bottom surface as they were previously subject to long-term testing under in-track loading conditions at the TTCI facility in Pueblo, Colorado. Figure 41 shows the extent of the damaged zone and the amount of material removed from the tie. This material was collected in the plastic sheet placed underneath the tie during the time it was subjected to damage. The volume of concrete removed by the induced abrasion was determined by weighing the volume and dividing by a nominal value for the specific weight of the concrete. The resulting volume estimate was 10.5 in^3, with a nominal uncertainty estimate of about $\pm$ 1 - 2% , based on likely loss of collected concrete material and a nominal range for the density of the concrete.

(a) Undamaged Tie

(b) Damaged Region

(c) Collected Abrasion

Weight of Concrete Collected,
W = 14.1 oz

Specific Weight of Concrete,
γ = 145 lbf/ft^3 = 1.34 oz/in^3

Damaged Volume = W/ γ = 10.5 in^3

Figure 41: Region of Induced Tie Damage

Figure 42 shows the result of an alternate method of assessing the volume of the removed concrete associated with the same damage imposed to the tie under test. In this case, modeling clay was used to fill the damaged region and the damaged area was formed by hand to conform to the shape of the region before damage. Figure 42(a) shows the sculpted region filled with clay prior to removal and Figure 42(b) and (c) show the clay removed from the concrete for measurement. The resulting estimated damaged volume was, remarkably, virtually identical to the 10.5 in^3 estimate based on direct weighing of collected concrete. However, due to uncertainty in the measured density of the clay, as well as to the degree to which the sculpting process truly represents the removed concrete volume, the measured clay volume is also likely to have a nominal uncertainty of about $\pm$1 – 2 %.

(a) Clay-Filled Damaged Area

(b) Clay Removed

(c) Isolated Clay Specimen

Weight of Clay Collected,
W = 10.4 oz

Specific Weight of Clay,
γ = 0.996 oz/in^3

Damaged Volume = W/ γ = 10.5 in^3

Figure 42: Abrasion Measurement using Clay Filling

Figure 43 shows a schematic of the assessment of abrasion volume for the tie with imposed abrasion, using the localized cross-sectional area results from the 6 repeat scans.

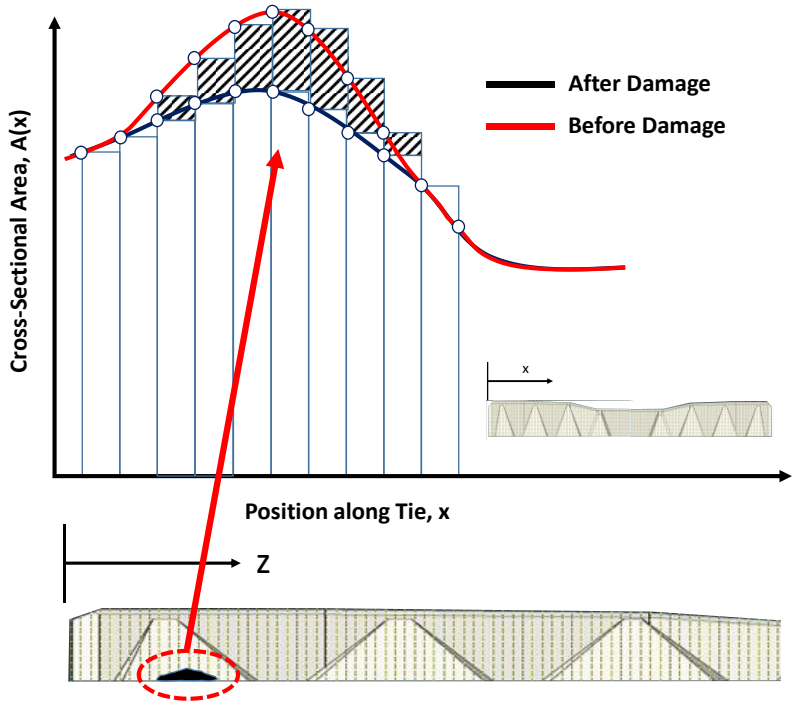


Figure 43: Damage Assessment from Localized 3D Scanning

The upper solid curve in Figure 43 represents the original (undamaged) variation of cross-sectional area in the region where damage took place, and the lower solid curve represents the reduced cross-

sectional area associated with the damage. To obtain the variation of cross-sectional area after damage, the tie was scanned again, and the variation of the cross-sectional area was once again extracted using the same special-purpose processing algorithm. The region of shaded rectangles represents the volume of concrete removed due to the imposed abrasion. A plot of the actual cross-sectional area difference resulting from the damage is shown in Figure 44. The area under the curve shown represents the volume of the induced damage. Using a simple rectangular integration method yields an estimate of the volume change as 11.5 in^3, where the 6-scan averaged cross-sectional area was used in the region of the damage to represent the area variation of the undamaged tie. It is clear that using the localized scan results gives a much better representation of the abrasion volume, and the associated volume resolution now appears to be on the order of about 1 in^3. More work is necessary to better optimize the procedure so as to best represent the abrasion of ties taken from long-term service. There may also be some merit in further investigating the clay molding procedure, provided that the regions of the damaged ties are obvious and well-defined for sculpting.

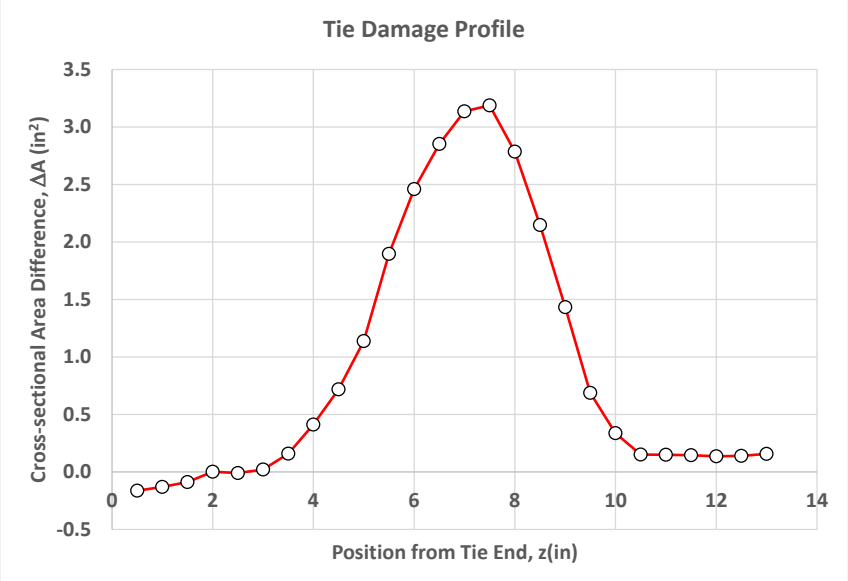


Figure 44: Measured Region of Tie Volume Abrasion

In summary, a commercially-available 3D Laser-Based Optical Scanning System was used to conduct a series of 6 repeat scans of the surface of a sampled in-service CXT crosstie to a spatial resolution of about 1mm over its entire surface. The high-speed processing algorithm discussed in Section 6 was then used to extract all of the relevant cross-sectional parameters for the tie at a spatial resolution of 0.50 inches along its entire length. These parameters included the cross-sectional area, the area centroid, the area moment of inertia, the eccentricity, and the shape factor.

Comparison of the repeat scans indicated generally good agreement for all cross-sectional parameters; however, some tendency was observed for deviations to progressively increase systematically over the length of the tie. The reason for this bias may be related to human error associated with difficulty in the alignment of the coordinate axes.

Testing of the volume resolution achievable by the scanning was also conducted by subjecting the scanned tie to induced volume abrasion. The damaged volume was experimentally measured using two methods, one based on direct collection of the removed concrete, and the other based on sculpting modeling clay to conform to the removed concrete abrasion region. Agreement between the two

methods of damage volume measurement was excellent. The damaged tie was then scanned and processed to allow direct comparison between before and after tie volume within the localized region of damage. The resolution of the assessed damage was greatly improved to a nominal 1 in^3. This level of volume resolution is difficult to achieve in general. Furthermore, it is difficult to identify actual tie damage in practice as distinguished from damage in transport. Cracking as a measure of damage is much easier to identify; however, the causes responsible for long-term cracking may depend on factors such as in-tack loading which are largely unknown.

7.5 Comparison between 3D Scanning and Center Saw Cut Tie Slice Geometry

The above scanning results have identified sources of uncertainty in the measured tie geometry related to several factors including the following:

(1) The inherent scanning resolution. However, the overall effect of this is very small since the selected 1mm spatial resolution is very small compared to any identifiable feature of interest on the surface of the ties.

(2) The alignment of the coordinate system for the ties. This is one of the more challenging aspects in the process of extracting the tie geometry from the external scanning of the surface features, because it is difficult to identify reference features in a three-dimensional coordinate system repeatably to within the $\pm$ 1mm spatial resolution of the scanning system.

(3) The measurement of the centroid of the prestressing wires or strands from either directly photographing the end views of the ties, or from measurements of the 3D rendering of the scanned ends of the ties. The errors associated with this measurement are primarily due to the difficulty in identifying the bottom surface of the tie. Even with relatively new ties this can be difficult to determine from an end view, but it is even more challenging with ties that have sustained even minor damage on the ends either due to transport or to in-track loading or splitting.

(4) Failure to accurately define the bottom surface of the tie also introduces error in the eccentricity of the tie, because this requires measurement of the centroid of the concrete relative to the same bottom surface reference that is used for determining the wire (or strand) centroid.

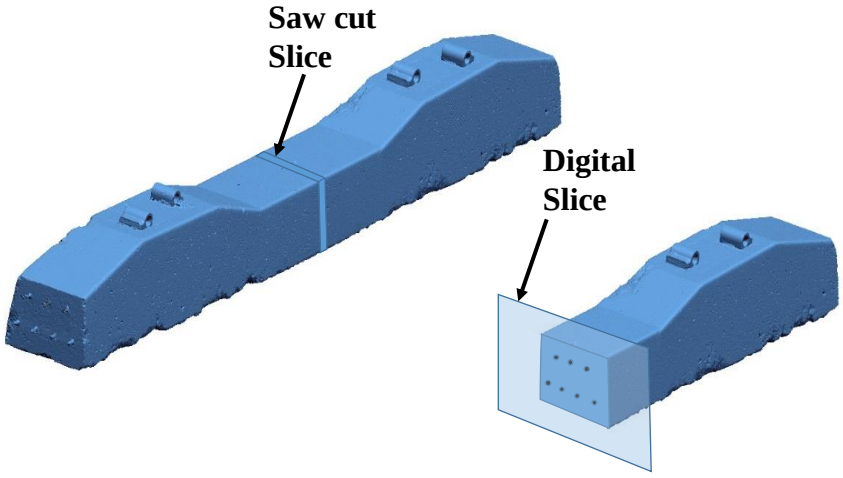


Figure 45: Mid-plane Saw Cutting vs. Digital Slicing of Tie Type B

In this section a comparison will be made between the measurements of tie cross-section parameters made using the 3D scanning procedure, and those determined from direct measurements of these parameters by means of saw cutting the tie. The saw cutting was done at the mid plane of the ties.

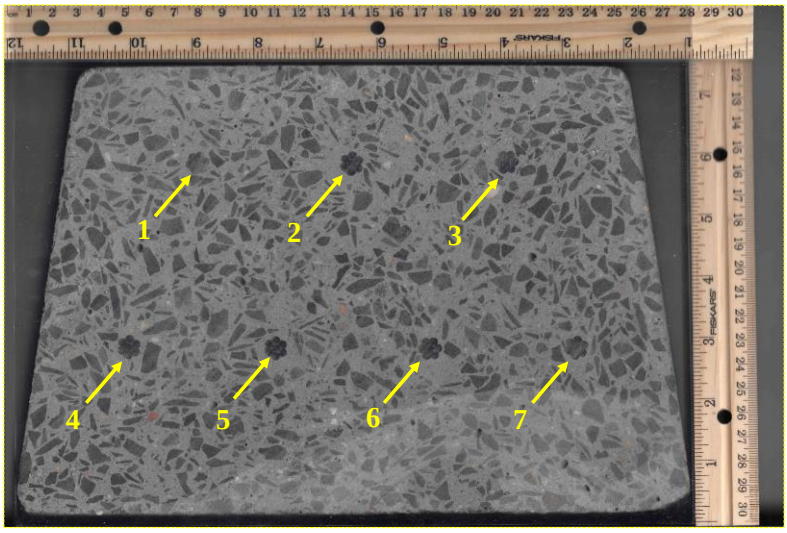


Figure 46: Saw Cut Slice of Type B Tie at Mid-Plane

This corresponds to the same location where cracking was initiated for the multi-point bending tests, as part of an effort to extract the residual prestress in the ties. A schematic drawing depicting the saw cutting, in comparison to the digital slicing of a tie, is shown in Figure 45. The isometric rendering shown here is for a type B tie, which has 7 prestressing strands. A photograph of the saw cut cross-section for this tie is shown in Figure 46, which also highlights the locations of the prestressing stands.

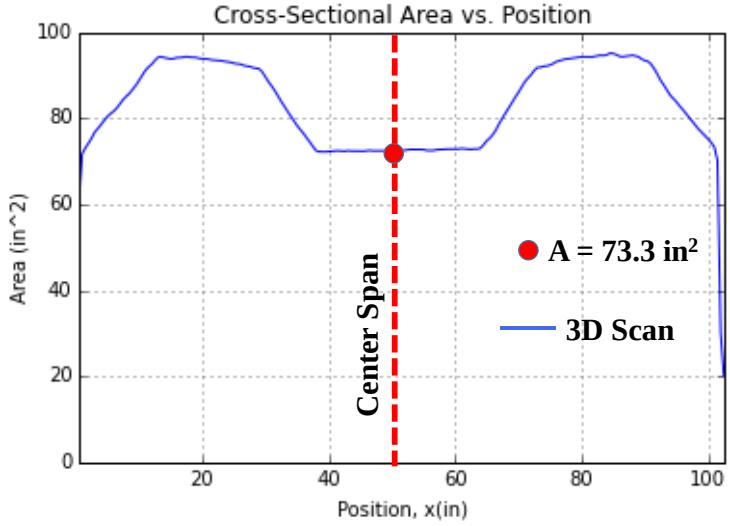


Figure 47: Cross-Sectional Area vs. Position along Type B Tie

It is important to note that extraction of cross-section parameters from the 3D scanning process is limited to what can be determined from the outer surface of the tie. Hence, determining cross-sectional parameters in the mid-plane is clearly an extrapolation of sorts, in comparison to what can be directly observed from the actual saw cut slicing of the tie. The saw cut slices of the ties at the mid-plane location provide a direct measurement capability for extracting the cross-section geometry,

along with the centroid of the prestressing wires and the corresponding eccentricity. Therefore, this provides a means of further assessing the accuracy of the 3D scanning process and its ability to determine cross-sectional parameters.

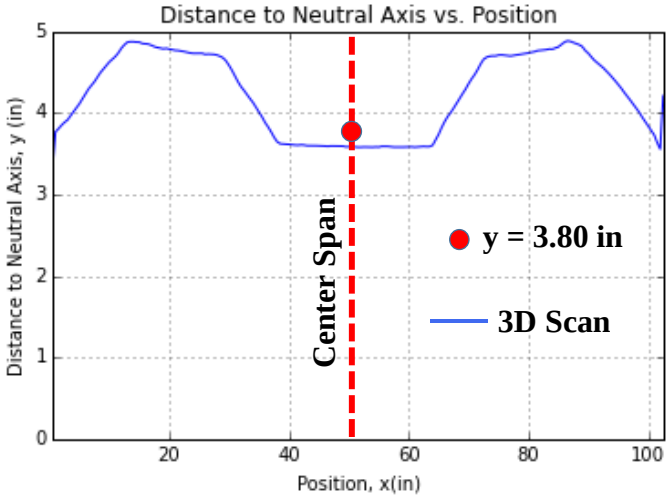


Figure 48: Neutral Axis Location vs. Position along Type B Tie

The 3D scanning and digital slicing process yields all of the cross-sectional parameters as a function of position over the entire length of the tie. Figure 47 shows the variation of cross-sectional area as a function of position along the tie. The mid-plane or center span location is identified in this Figure, along with the cross-sectional area obtained from direct analysis of the saw cut slice shown in Figure 46. The position of the red dot shows the cross-sectional area calculated from the saw cut slice image. The cross-sectional area obtained from the 3D scanning and digital slicing is seen to compare very well with the mid-plane area calculated directly from the saw cut slice image.

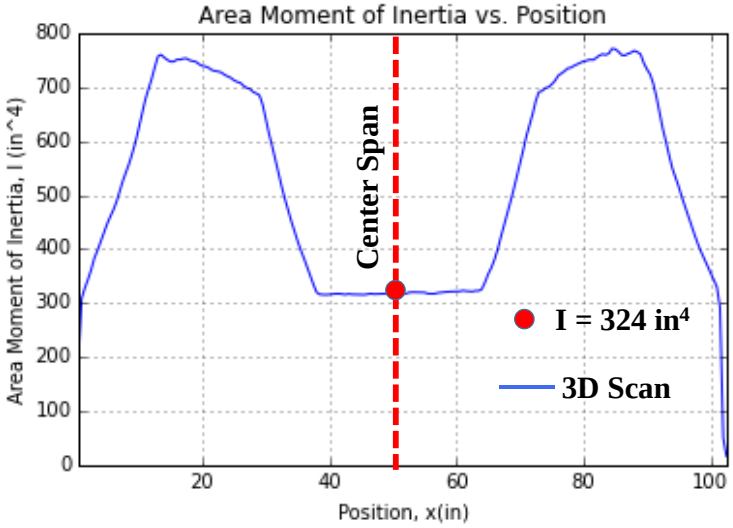


Figure 49: Area Moment of Inertia vs. Position along Type B Tie

Figure 48 and Figure 49 show the variation of the neutral axis location and the area moment of inertia as a function of position along the tie, respectively. Again, the results from the 3D scanning

measurements compare well to the results obtained from the direct measurements of the photograph shown in Figure 46.

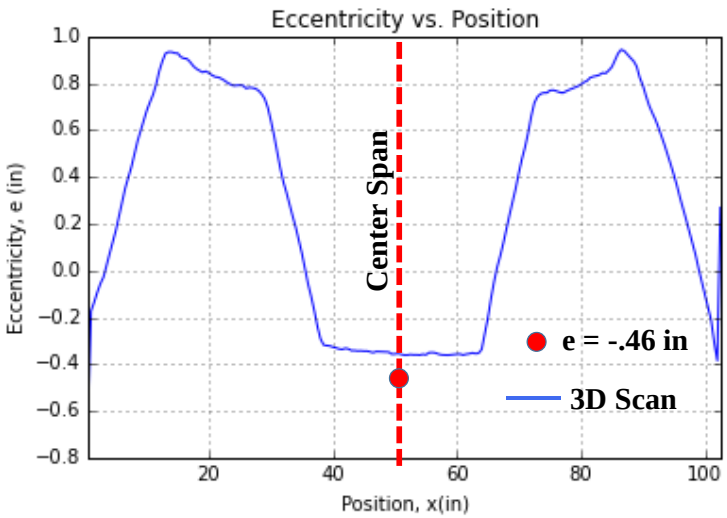


Figure 50: Eccentricity vs. Position along Type B Tie

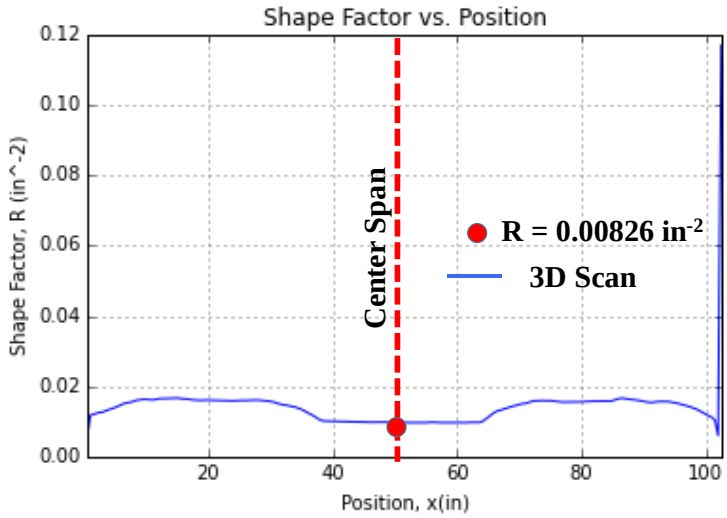


Figure 51: Shape Factor vs. Position along Type B Tie

Figure 50 and Figure 51 show the variation in eccentricity and shape factor, respectively. The agreement between the indirect 3D scanning results and the mid-plane direct saw cut slice measurements is also good. It should be noted that the shape factor is quite sensitive to the eccentricity parameter. Because of the issues mentioned above regarding the difficulty in identifying the bottom surface reference, relatively large uncertainty in the eccentricity up to on the order of $\pm$ 0.2 inches is quite possible. This, in turn, would be expected to significantly affect the associated shape factor. However, the normalization process that is used now in the evaluation of transfer length [27], where shape factor is particularly important, tends to reduce the effect of this error to a negligibly small level. The influence of this eccentricity error is more pronounced in relation to the extraction of residual prestress force, and in the evaluation of local moments [28,29].

8. Summary of Tie Scanning Results

The finalized results of the systematic scanning measurements of the sampled ties listed in Table 1 and Table 2 are presented in this section. Detailed reports summarizing all individual test results for each tie are also given in the Appendix.

8.1 Tabular Summary of Tie Cross-Section Parameter Scanning Results

The tie cross-section parameter results from the 3D scanning process are shown in Figure 52 for the digital slicing at the rail seat location. The basic cross-section nomenclature for the results is shown in the adjacent figure.

	Rail Seat Average				
	Area	y	I	e	R
Tie Type	(in^2)	(in)	(in^4)	(in)	(in^{-2})
A	93.3	4.5	628	0.97	0.0176
B	91.9	4.77	690	1.01	0.0179
C	79.2	4.05	382	0.64	0.0194
D	96.2	4.87	703	0.77	0.0158
E	79.5	4.33	474	0.88	0.0207
F	73.2	4.09	367	1.5	0.0305
G	79.4	4.09	401	0.6	0.0188
H	84	4.55	516	0.71	0.0182
J	73.2	4.25	390	1.06	0.0253
K	88.9	4.48	552	0.89	0.0185
L	74.3	4.12	379	0.91	0.0234
M	74.3	4.04	389	0.72	0.021

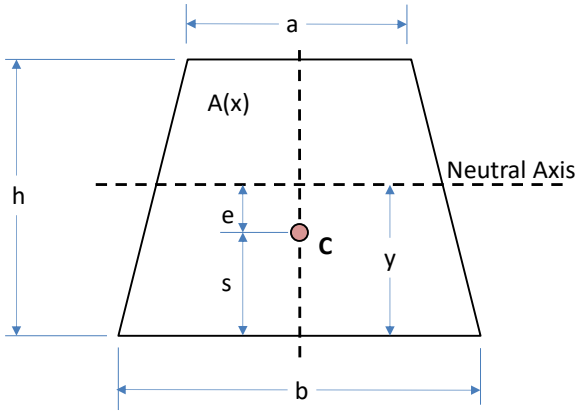


Figure 52: 3D Scanning Cross-Section Parameter Results at Rail Seat

Figure 53 shows the cross-section parameters developed from the 3D scanning for digital slicing at the center span location. The results shown in both Figure 52 and Figure 53 represent averages over all 6 of the sampled ties of each tie type.

	Center Span				
	Area	y	I	e	R
Tie Type	(in^2)	(in)	(in^4)	(in)	(in^{-2})
A	58.9	3.48	235	-0.05	0.0162
B	70.6	3.59	293	-0.17	0.0122
C	59.6	3.13	163	-0.28	0.0115
D	73	3.67	298	-0.43	0.0085
E	61.5	3.49	224	0.04	0.0169
F	52	2.99	126	0.4	0.0291
G	71.4	3.64	288	0.15	0.016
H	68.3	3.63	273	-0.21	0.0119
J	59.6	3.48	204	0.3	0.022
K	71	3.61	274	0.03	0.0144
L	57.4	3.35	169	0.14	0.0204
M	60.7	3.25	203	-0.07	0.0154

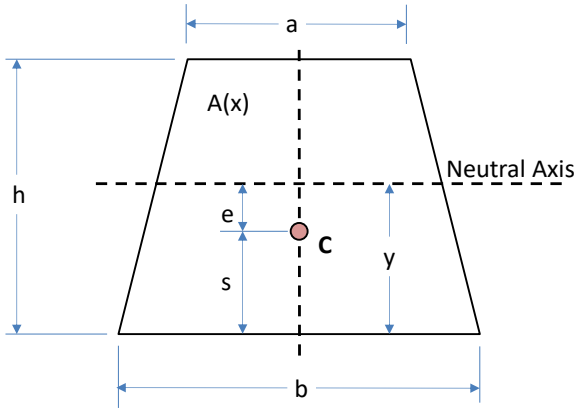


Figure 53: 3D Scanning Cross-Section Parameter Results at Center Span

For comparison purposes, Figure 54 shows these same cross-section parameters obtained from direct observation and processing of the saw cut images. It should be noted that the results shown in Figure 54 were developed from only a single sample of each tie type, whereas the corresponding center span

results shown in Figure 53 represent averages over the 6 ties of each tie type. It is clear from the results that the 3D scanning results for cross-sectional area, A, compare the most favorably with the direct saw cut parameters. This is likely due to the fact that the cross-sectional area does not require a reference for measurement. Hence, it is not affected by the uncertainty in the tie base location. Area moment of inertia, I, and centroid (or "center of gravity"), y, also are parameters for which the 3D scanning procedure yielded results that compared well with the direct saw cut slice analysis.

	Center Span				
	Area	y	I	e	R
Tie Type	(in^2)	(in)	(in^4)	(in)	(in^{-2})
A-1	58.5	3.67	238	-0.538	0.00878
B-1	73.3	3.54	317	-0.459	0.00852
C-1	61.2	2.91	163	-0.536	0.00676
D-1	73.1	3.51	300	-0.602	0.00663
E-1	59.2	3.22	210	-0.069	0.01583
F-1	52.6	2.70	131	-0.067	0.01762
G-1	71.3	3.51	279	-0.013	0.01385
H-1	69.9	3.60	298	-0.565	0.00749
J-1	62.6	3.21	207	-0.215	0.01264
K-1	72.5	3.44	297	-0.127	0.01233
L-1	60.5	3.11	189	-0.377	0.01033
M-1	59.4	3.00	182	-0.132	0.01465

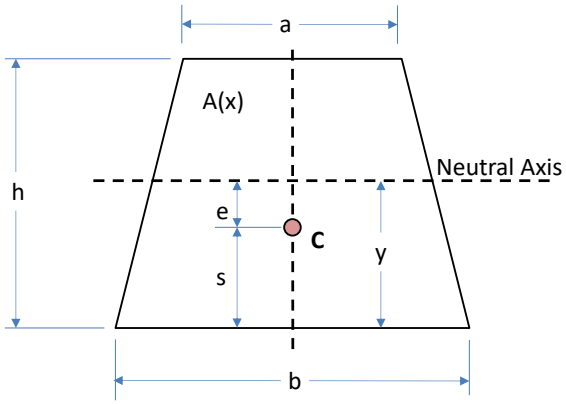
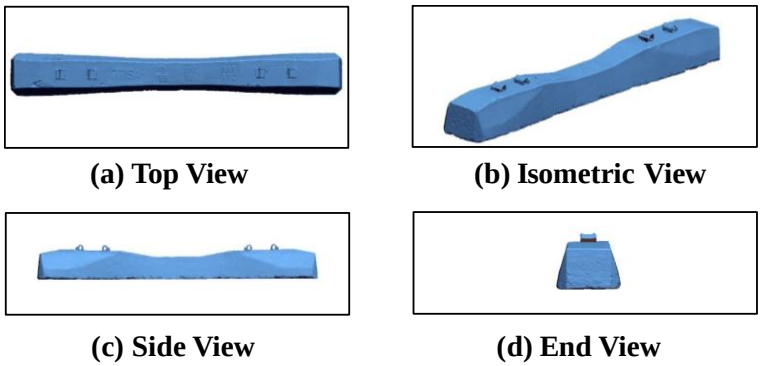


Figure 54: Saw Cut Cross-Section Parameter Results at Center Span

The eccentricity, e, and the shape factor, R, show the most significant differences between the 3D scanning results and the direct saw cut slice analysis. This is due to the difficulty in accurately determining the base of the tie, which is the reference for measurement of the centroid of the concrete and the centroid of the prestressing wires (or strands). Errors on the order of tenths of an inch are possible in the location of the base plane position, which translates into similar errors in the centroid locations. This error can be minimized if the baseline position can be obtained directly from the end view of the 3D scanned image; however, the prestressing wires do not always reveal themselves clearly in the 3D scanned end view images. Hence, it was generally necessary to determine the concrete and wire centroid separately, by using a photograph of the tie ends for wire centroid location.

8.2 Summary of 3D Renderings of Scanned Tie Results

Multiple views of the 3D scanned rendering of tie type A are shown in Figure 55.



(a) Top View **(b) Isometric View**

(c) Side View **(d) End View**

Figure 55: 3D Model Renderings of Scanned Tie Type A

Figure 55(a) shows a top view of the 3D rendering, and there is sufficient detail to clearly identify the labeling on the top surface of the tie. Figure 55(b) shows an isometric view, with detail of the underside edge of the tie and of the rail clips. These rail clips were removed digitally as part of the preparation for processing the point cloud representation of the tie to extract the cross-sectional parameters. Figure 55(c) shows a side view of the tie, and Figure 55(d) shows a view from one end of the tie. It is clear from each of these views that there was sufficient resolution in the measurements to provide a very detailed feature-capturing 3D rendering of the tie.

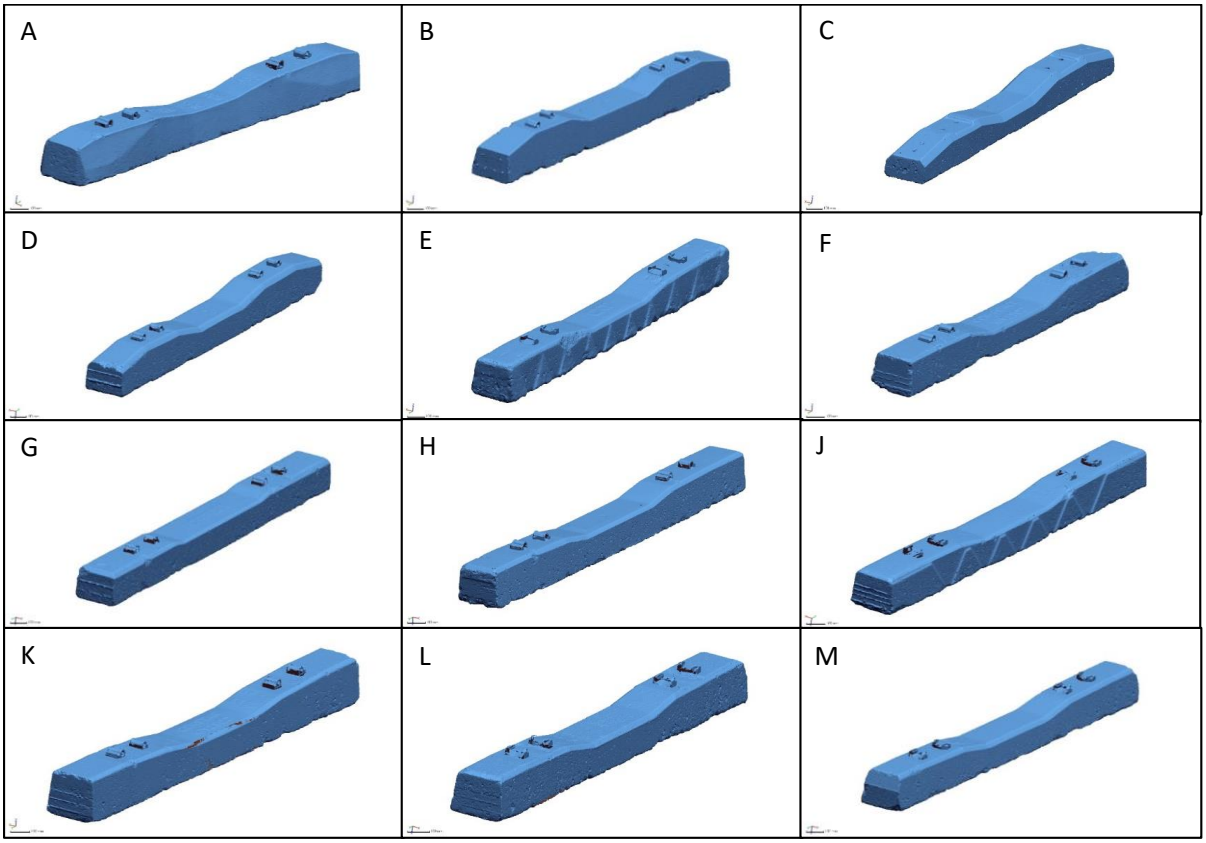


Figure 56: 3D Isometric View of all Scanned Tie Types

Figure 56 shows a 3D isometric view of all scanned tie types, including the type A shown separately in Figure 55. These renderings all show the high level of resolution that was achieved by the scanning process. Detailed capture of scalloping on the bottom surfaces of some of the ties is clearly evident, along with even the protruding prestressing wire or strand. Some apparent damage is also visible on the bottom surfaces; however, the mechanism for this damage is not clear. It may be more related to damage in transport rather than significant in-track damage or damage related to manufacturing prior to installation in track.

Figure 57 shows a 3D top view of all scanned tie types, including the type A shown separately in Figure 55. Again, the detail of the top surface features, including the rail clips and identification labeling is clearly revealed by the selected $\pm$1 mm scanning resolution. Figure 58 shows a 3D rendering of one side of all sampled ties. Note that tie types E and J have a distinct scalloping along the side walls, which is characteristic of the CXT tie design. Tie type A has the most unusual top view shape (planform shape), and is characterized by an “hour-glass” profile. All of the other tie types exhibit a more rectangular planform shape.

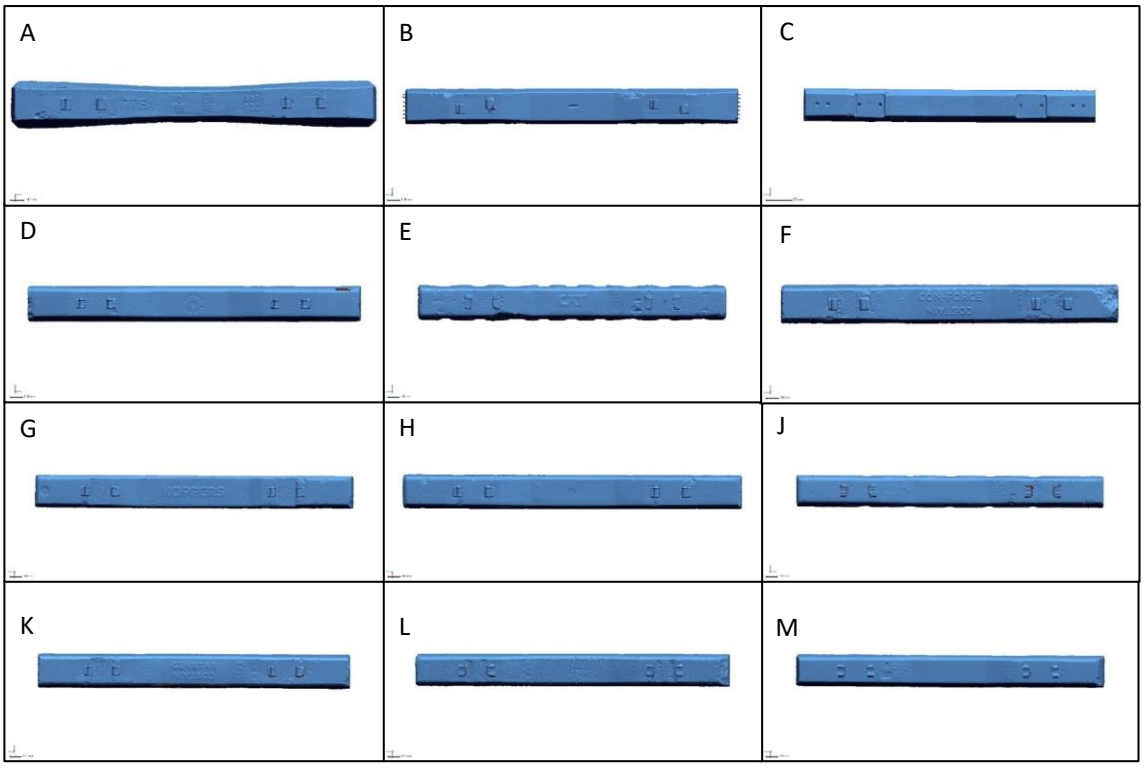


Figure 57: 3D Top View of all Scanned Tie Types

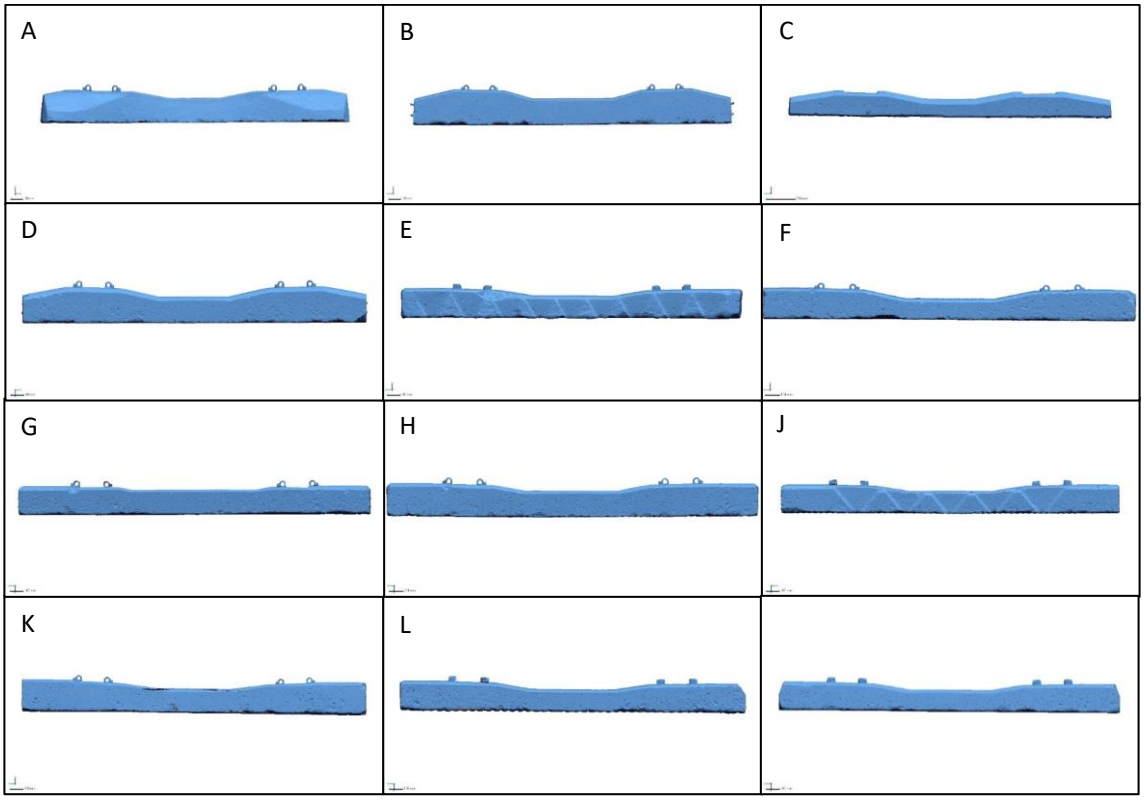


Figure 58: 3D Side View of all Scanned Tie Types

8.3 Summary of Photographic Results for Sampled Ties

A photographic record of sampled ties was taken to provide a visual record of the tie appearance, and to aid in the identification and documentation of any presence of cracks. Figure 59 and Figure 60 show photographs of isometric views of tie types A, B, C, D, E, G, F, H, J, K, L, and M.

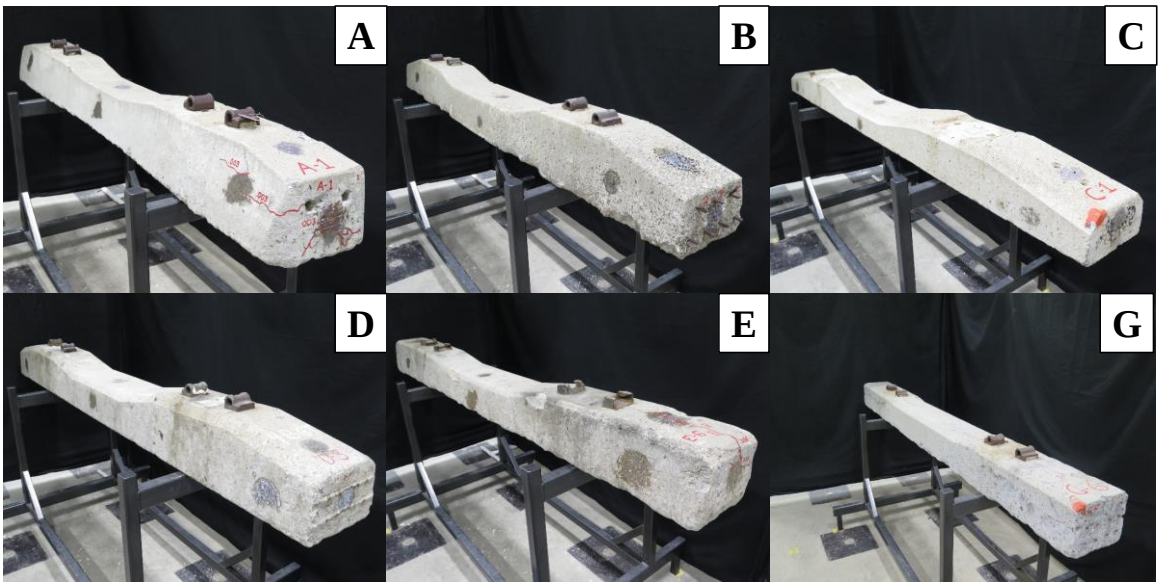


Figure 59: Photographs of Sampled Tie Types A, B, C, D, E, and G in Isometric View

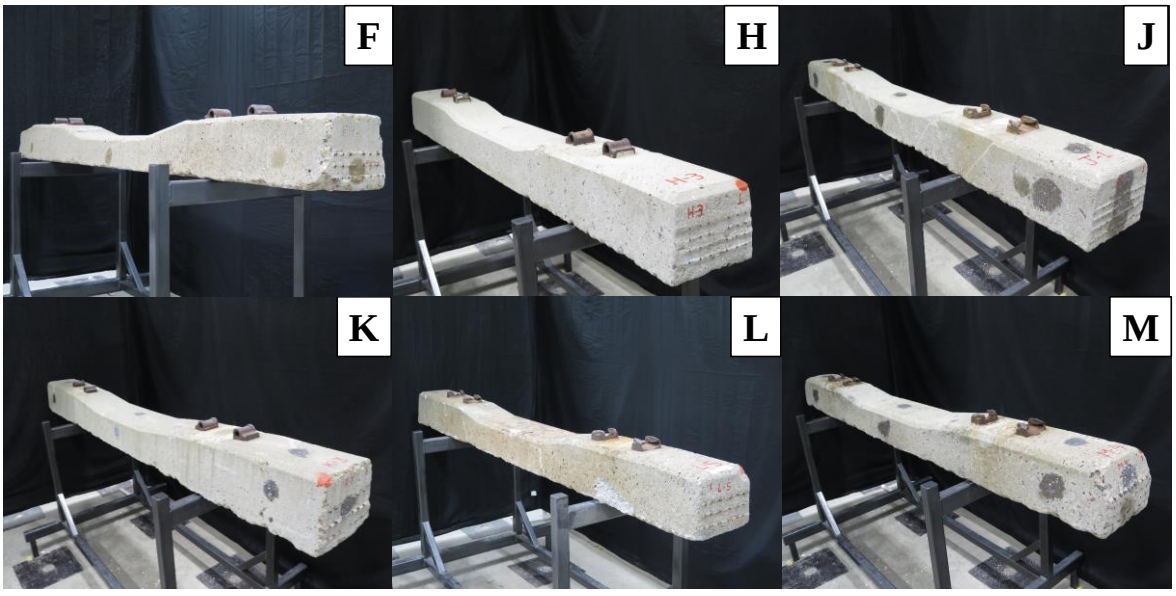


Figure 60: Photographs of Sampled Tie Types F, H, J, K, L, and M in Isometric View

Some significant cracking is evident on ties A and E, although the cause of the cracking is not clear. Tie type A is also a post-tensioned tie. The dark gray splotches on some of the photographs are residue from ultrasound testing.

9. Summary and Conclusions

9.1 Identification of KEY Tie Cross-section Parameters

This report summarizes work that was part of a larger project funded by the FRA titled "Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials." The work presented herein specifically covers the 3D Scanning of existing crossties to quantify their cross-section parameters, along with the visual inspection of these ties. The report documents detailed quantitative and visual information associated with sampled concrete railroad ties that have performed well in track for more than 25 years. Additionally, it includes analysis of ties that have failed in track or that showed significant signs of distress and damage.

Many of the ties for this study came from the crosstie graveyard located at the TTCI facility in Pueblo, Colorado. The ties sampled represented a range of long-term in-track performance, and included (1) those ties which have been in service and performed well for as long as 25 years, (2) those ties which failed in track, and (3) those ties which showed signs of distress in service. As with earlier analysis, the generic trapezoidal cross-section shape was used to define the important geometrical parameters associated with an arbitrary crosstie cross-section. These cross-sectional parameters are A, the area of the cross-section, e, the eccentricity of the wire grid centroid, y, the distance from the bottom of the concrete tie to the neutral axis of the cross-section, and I, the moment of inertia of the cross-section of the concrete tie at a given location along the tie. In addition, the shape factor, R, was also evaluated because of its importance to the accurate measurement of transfer length.

9.2 Selection of Ties for 3D Scanning in Current Study

Many of the ties for this study came from the crosstie graveyard located at the Transportation Technology Center, Inc. (TTCI) facility in Pueblo, Colorado. Rusty Croley of Rocla Concrete Tie and Steve Mattson of voestalpine Nortrak traveled to Pueblo, CO and spent a day with our research team selecting some of the ties that were included in this study. The ties in this study represented a range of long-term in-track performance, and included (1) those ties which have been in service and performed well for as long as 25 years, (2) those ties that failed in track, and (3) those ties that exhibited signs of distress in service. A large number of CXT 505S ties were among those that actually had been the subject of long-term in-track loading tests at the TTCI facility associated with a previous FRA-funded research project at Kansas State University. The CXT ties had a characteristic scalloping designed into the side walls. This tie was among the few that had a 3D CAD model available for comparison with the cross-section parameter results obtained from the 3D scanning system used in the current research. A detailed qualitative and quantitative analysis was conducted which compared the known 3D CAD model geometry for the CXT ties with the 3D geometry obtained experimentally by 3D optical scanning.

9.3 Pre-Processing and Documentation for Sampled Ties

The general characteristics, of the ties that were sampled for analysis using the 3D optical scanning procedure were first identified with respect to manufacturer (if known), sorted, labeled, and photographs were taken from several different angles to show the general appearance of the tie surface wear or presence of cracking, along with a general qualitative assessment of the condition of the ties. A total of 72 ties were evaluated, and this list was comprised of 6 ties of each type. A generic group labeling of ties (A, B, C,…) was used for tabulation purposes. The 6 ties within each group were further designated with a number suffix (A-1, A-2, A-3, A-4, A-5, A-6, B-1, B-2, B-3, B-4, B-5, B-6,

…etc.) so that each individual tie could be identified for study. The ties shipped from TTCI were initially delivered to the USDA ARS Lab in Manhattan Kansas in July 2015, where the initial visual inspection and 3D scanning took place. Initially, the 3D scanning and photographic records were made at the USDA Building 7 facility associated with this lab. Later, the ties were moved to the Structures Laboratory in the KSU Department of Civil Engineering. The majority of the photographic recording and documentation, as well as the 3D optical scanning operation, took place in this on-campus facility. In addition to the ties obtained from TTCI, ties with many years of service were also provided by CSX, AMTRAK, and BNSF Railways for evaluation in this study.

To fully evaluate the tie cross-section parameters, it was necessary to determine the centroid of the prestressing wires and the eccentricity of the wire-concrete cross-section. This was accomplished primarily by directly photographing the ends of the ties and digitally (visually) extracting the centroid of the wire configuration from these images. A chief difficulty associated with the accurate extraction of the crosstie cross-sectional parameters from the 3D scanned solid body model was associated with the need to accurately identify the location of the bottom surface of the tie. The process of locating the bottom edge of the tie resulted in a relatively large uncertainty, as much as on the order of 0.1 to 0.2 inches. As a result, the eccentricity (and related shape factor) exhibited the largest uncertainty in comparison to all the other cross-sectional parameters.

Photographic documentation and 3D scanning took place while the ties were mounted on a special-purpose steel supporting frame. Identification of key damage features, such as cracking, were also assessed visually, while the ties were supported on this frame, and were traced using a permanent marker. Apparent tie damage ranged from little to none, to significant abrasion and cracking. Some ties even appeared to show such a small amount of damage that the original manufacturer troweling marks seemed to be still intact. Some ties exhibited cracking even when the cover thickness was thought to be sufficient to prevent cracking—based on prism studies associated with qualification test development. This suggested that there may be some unknown long-term in-track loading that affected the tie's resistance to crack formation.

9.4 The 3D Optical Scanning System

The 3D scanning system used for the current crosstie measurements was a commercially-available laser-based system, having a maximum measurement spatial resolution of about $\pm$0.05 mm. It was a dual camera triangulation device with 7 intersecting laser light sheets capable of capturing continuously changing images of the crosstie surface contour. The depth of field was large (250mm), as was the scanning area (275mm x 250mm). The hand-held unit allowed manual scanning of an entire crosstie surface relative to a fixed xyz coordinate axis. Prior to scanning, each crosstie was mounted on the special-purpose steel support frame and initial photographic documentation of the crosstie surface features was taken. To facilitate later cross-section analysis, calibrated photos of the tie ends were taken to establish the locations of all prestressing wires. This enabled determination of the prestressing wire eccentricity and the crosstie shape factor, for later multi-point bending analysis and for transfer length assessment.

For accurate 3D scanning of the railroad crossties, it was necessary to attach self-adhesive retro-reflective points randomly spaced about 4 inches apart over the entire surface of the tie. These points provided a distributed 3D reference frame for the scanning system, which was especially critical in order to scan around sharp corners and reach features on the underside of the crossties. Initially the discrete retro-reflective points were scanned completely over the entire tie surface, establishing a complete 3D reference grid. Then the detailed surface structure of the tie was scanned in a procedure

that closely resembles the “painting of an invisible man” as the surface features were revealed to the observer. It took approximately 1-2 hours to complete the 3D scan of each tie, and resulted in computer storage requirements of 3 to 5 GB per tie scan.

The 3D scans were exported from the proprietary commercial scanning system software as an *.STL file, and then imported into other commercial software (Geomagic™), to remove unnecessary external features (such as the rail seat clips and protruding pre-stressing wire). The tie model was subsequently aligned/oriented and converted to a “point cloud” representation using open-source 3D computer graphics software (Blender™), where the orientation of the scanned crosstie was adjusted along with its position in the global coordinate system.

9.5 Processing of 3D Tie Scans

Initial processing was accomplished by converting the scanned 3D model into a closed solid body. The solid body model was then digitally “sliced up” manually in AutoCAD™ to obtain the desired cross-sectional shape parameters. This old method was prohibitively time intensive; therefore, a special purpose processing algorithm was developed that obtained the shape parameters directly from the aligned “point cloud” data. This reduced the manual cross-section parameter processing time of 8-10 hours in AutoCAD™ to only a few minutes. For the current 1mm scanning resolution, point cloud slices of thickness $\Delta z = 0.50$ inches were formed about a given z-position, resulting in about 20,000 points around the perimeter of a slice at some given position z. These points were then collapsed into a single plane, and subsequently grouped into about 500 “clusters” containing nominally about 40 points each, spaced approximately uniformly around the perimeter. The cluster points, with an angular resolution of about $\Delta\theta = 0.72$ deg could then be processed with any desirable method in addition to the high-speed algorithm that was developed specifically for the purpose of extracting the desired cross-section parameters, including cross-sectional area, area centroid, area moment of inertia, eccentricity and shape factor.

The high-speed algorithm used to extract the cross-section parameters was based on a voxelization (rectangular grid) procedure. The enclosed cross-section region was subdivided into a grid of about 500 x 500 cells, resulting in a nominal cell dimension (grid resolution) of $\Delta x = \Delta y = 0.02$ inches. A set of convenient and very fast algorithms was developed for the determination of all relevant tie cross-sectional parameters based on this volelization of the cross-section interior.

9.6 Accuracy of 3D Scanning Process

The overall accuracy (repeatability and bias uncertainty) of the 3D tie scanning process, and the resulting assessment of tie cross-section geometrical parameters was evaluated initially by comparing the high-speed special-purpose tie slicing algorithm results against available 3D CAD model representations. The repeatability of the scanning process, as demonstrated by the ability to measure all tie cross-sectional parameters, was compared graphically over the entire span of the ties.

Not only were the scanned images able to capture the basic geometrical features of the ties, but they also captured the small amount of abrasion (chipping) and wear apparent in the tie surface. The 3D scanning was shown to easily resolve the scalloping on the sides of the CXT tie, as well as channels in the bottom surface of the tie that were used to house and protect Whittemore points during the long-term in-rack testing of these ties at the TTCI facility in Colorado. The theoretical CAD model cross-section shape for the CXT tie and the cross-section shape obtained from the 3D scanning procedure, compared very well at selected axial positions along the tie. Further analysis of the 3D solid body

model obtained from the 3D scanning procedure yielded measurements of all of the cross-section geometrical characteristics. The 3D scanning was shown to capture a very accurate representation of the tie cross-sectional area, with virtually negligible difference between the ideal CAD model and the measured values, along the entire length of the tie. Similar results were obtained for the area moment of inertia, indicating that the 3D scanning operation yielded a very good representation of the tie geometry.

Somewhat larger errors were noted in the 3D scanning results in relation to the distance to the neutral axis. These differences are likely due to the difficulty in identifying a true bottom surface of the tie in the 3D scanned measurement. The bottom surface does not always provide a smooth flat reference from which to measure the position of the neutral axis, and this can lead to errors in all parameters that rely on this reference position (wire or strand eccentricity, shape factor).

The 3D scanning system was used to facilitate the measurement of transfer length during a tie manufacturing process. This represented an attempt to characterize experimentally the in-plant manufacturing variations in transfer length that can occur in practice. To the best of the authors' knowledge, this is the first time extensive real-time measurements to this extent had been attempted in an actual tie manufacturing plant with the expressed purpose of statistically characterizing the variations in transfer length that take place over an entire casting bed. Furthermore, since no 3D CAD model was available, a representative tie manufactured in the plant under study was scanned using the 3D optical scanning system. The results were used successfully to characterize the transfer length in an entire casting bed within the manufacturing plant. The 3D scanning was shown to bring out the characteristic changes in the shape parameters that take place along the length of the tie, especially near the rail seat location. The variation in the resulting shape factor was used in conjunction with the author's previously demonstrated automated strain profiling system for transfer length assessment. Without the availability and capability of the 3D scanning system, this in-plant operation would not have been possible.

An investigation of the repeatability of the overall 3D scanning and cross-section parameter determination was conducted using the special-purpose high-speed crosstie slicing algorithm. Six repeat scans of the same sampled CXT tie were conducted by the same operator to allow assessment of the likely variations (repeatability) in the determination of the cross-sectional parameters. Although a small amount of drift in the resulting scanning parameter results was noted, the general agreement among repeat scans was excellent. This drift may be somewhat related to the inherent accuracy of the scanning system, which degrades as the scan progresses further from the point of origin along the tie. It may also be largely related to the ability to align each scan independently. While the source of the deviation is not known, the results still look very good overall in terms of repeatability. The 3D scanning results were shown to resolve a high level of detail in these cross-sectional parameters along the entire length of the tie. The scanning process was even shown to detect a small amount of spalling that took place on one edge of the actual tie. This showed that a fine level of detail was capable of being captured by the 3D scanning system and high-speed cross-section processing algorithm.

In an effort to further resolve the ability of the 3D scanning to assess abrasion, integration of the cross-sectional area over the length of the tie was used to yield an estimate of the total tie volume. The tie volume was shown to be repeatable to within about $\pm$ 0.67%, which appears to be relatively good except that it represented a random uncertainty of about $\pm$ 55 in^3 for the tie volume. The largest of the volume deviations was clearly due an outlier in one of the repeated 3D scans. Elimination of this outlier reduced the volume scatter by about a factor of two.

An alternate means of deducing the measurable resolution of volumetric abrasion and wear was accomplished by first subjecting the sampled tie to known (induced) abrasion with measurable volume, and then measuring the local volume of the removed concrete. The volume of concrete removed by the induced abrasion was determined by weighing the volume and dividing by a nominal value for the specific weight of the concrete. The resulting volume estimate was 10.5 in^3, with a nominal uncertainty estimate of about $\pm$ 1 - 2% , based on likely loss of collected concrete material and a nominal range for the density of the concrete. Modeling clay was used to fill the damaged region and the damaged area was formed by hand to conform to the shape of the region before damage. Repeat scans of the tie in the region involving the induced damage were conducted before and after the damage. The difference between the scanned volume region before and after the induced damage provided a measure of the volume of the induced damage. The estimate of the volume change was 11.5 in^3, indicating that the localized scan results produced a very good representation of the abrasion volume, and the associated volume resolution was as a result on the order of about 1 in^3.

To further investigate the repeatability and bias of the 3D scanning, a comparison was made between the measurements of tie cross-section parameters made using the 3D scanning procedure, and those determined from direct measurements of these parameters by means of saw cutting the tie. The saw cutting was done at the mid plane of the tie. The 3D scanning and digital slicing process yielded all of the cross-sectional parameters as a function of position over the entire length of the tie. The cross-sectional area obtained from the 3D scanning and digital slicing were seen to compare very well with the mid-plane area calculated directly from the saw cut slice image. The same was true for the neutral axis position and the area moment of inertia. As expected the largest deviations between the 3D scanning evaluated at the center plane and the direct saw cut measurements were largely due to the difficulty in identifying the bottom surface reference, which could cause a relatively large uncertainty in the eccentricity up to on the order of + 0.2 inches. This, in turn, would be expected to significantly affect the associated shape factor.

9.7 3D Tie Scanning Results

The finalized results of the systematic scanning measurements of cross-section parameters for the sampled ties were compiled in table form for all 72 sampled ties. Detailed reports were also compiled which summarize all individual test results for each tie, and these individual tie reports are located in Appendix A and Appendix B. These same cross-section parameters obtained from direct observation and processing of the saw cut images were also compared with the 3D scanning results at the mid-plane location. The comparison at the mid-plane was shown to be quite good. As expected, the eccentricity, e, and the shape factor, R, show the most significant differences between the 3D scanning results and the direct saw cut slice analysis. This was likely due once again to the difficulty in accurately determining the base of the tie, which was the reference for measurement of the centroid of the concrete and the centroid of the prestressing wires (or strands).

Multiple views of the 3D scanned rendering of all tie types were compared and shown to reveal a high level of detail in the surface structure of the ties. Top views of the 3D renderings showed a sufficient detail to clearly identify the labeling on the top surface of the ties. Detailed capture of scalloping on the bottom surfaces of some of the ties was clearly evident, along with even the detail of the protruding prestressing wire or strand. Some apparent damage was also visible on the bottom surfaces; however, the mechanism for this damage was not clear. It may be more related to damage in transport rather than significant in-track damage or damage related to manufacturing prior to installation in track. To draw more significant conclusions would require much more in depth

analysis. In addition to the 3D renderings of the scanned ties, detailed photographic analysis was shown to also reveal clear depiction of surface cracking features. Some of the ties were also in remarkable condition for having been in track for as long as 25 years—some even with what appears to be the original troweling marks on the bottom surfaces of the ties.

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Appendix A.
Description of Processed Tie Report Results

This Appendix summarizes the contents of the tie reports for all testing of ties included in this report. Each tie summary report is comprised of five pages which contain the following:

1. Page 1: A summary of the quantitative 3D scan results for each tie.
2. Page 2: 3D scan renderings of the Top, Side, and Bottom views of each tie.
3. Page 3: 3D scan renderings of the End view, and Isometric view of each tie.
4. Page 4: Cross-sectional parameters, A, y, I, e, and R vs. position for each tie.
5. Page 5: Selected photographic documentation for each tie.

An abbreviated example is shown below for one of the ties of type A.

```
+--------------------------------------------------------------------+
|              Test Report                    07/01/2017     Ver1    |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : A1                                               |
|    Manufacturer : ITISA                                            |
|    Alternate ID : 136 RE                                           |
|    Tie Length   : 8'3"                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : N/A                                                   |
|      Right : 3.558 in                                              |
|      Avg.  : 3.558 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (NON-INDENTED)                                 |
|      Diameter: 0.415 in                                            |
|      Tendons : 4                                                   |
|      Pattern : 2-2                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                        Rail Seat Avg.     Center Span              |
|         A   [in^2]        92.13             58.64                 |
|         I   [in^4]       604.88            234.23                 |
|       Y_cog  [in]          4.38              3.36                 |
|       height [in]          9.15              7.05                 |
|         e    [in]          0.82             -0.17                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 61.2 [kips] (A-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                        End #1         End #2                       |
|        Left  [in]       N/A            3.31                       |
|        Right [in]       N/A            3.07                       |
|        Top   [in]       N/A            2.74                       |
|        Bottom[in]       N/A            1.83                       |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

Figure 61: Sample Page 1 of Tie Report for Tie A-1

Figure 61 shows a sample of the tie report for one of the six ties of type A. This page contains tie identification, quantitative data including the cross-section parameters determined from 3D scanning, and a qualitative assessment of observed abrasion and apparent cracking. Figure 62 shows the qualitative scale used for the assessment of apparent abrasion and cracking damage.

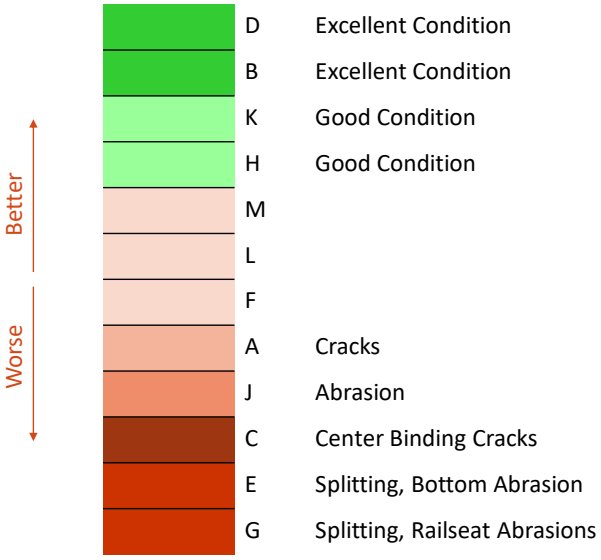


Figure 62: Observed Severity of Apparent Abrasion and Cracking

The sample of page 2 of the report for tie A-1 is shown in Figure 63. It consists of the 3D renderings of the top view, side view, and bottom view of the tie.

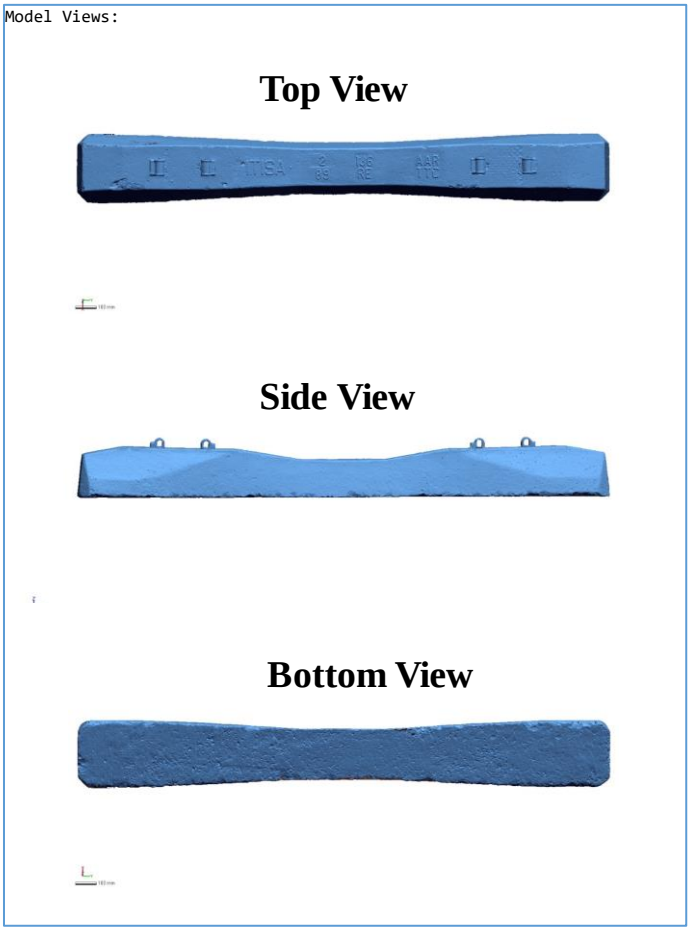


Figure 63: Sample Page 2 of Tie Report for Tie A-1

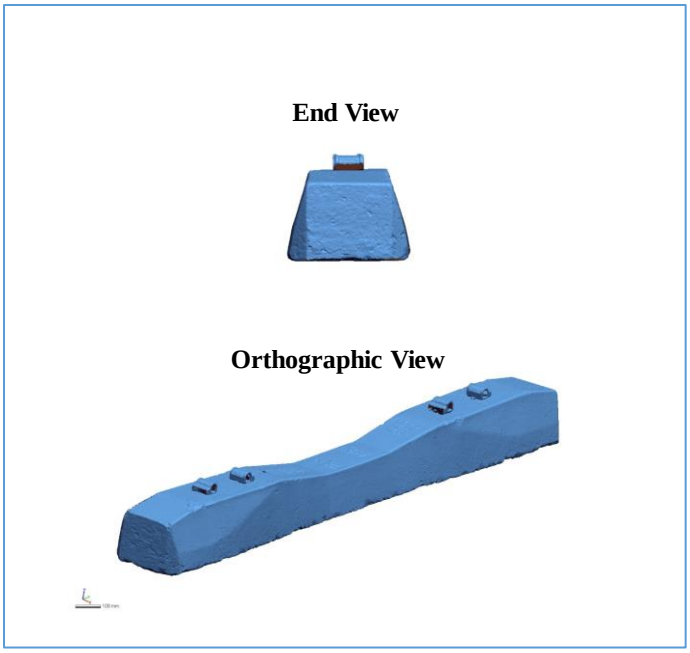


Figure 64: Sample Page 3 of Tie Report for Tie A-1

A sample of page 3 of the tie reports is shown in Figure 64. It shows the 3D renderings of the end view, and an orthographic (isometric) view of the tie.

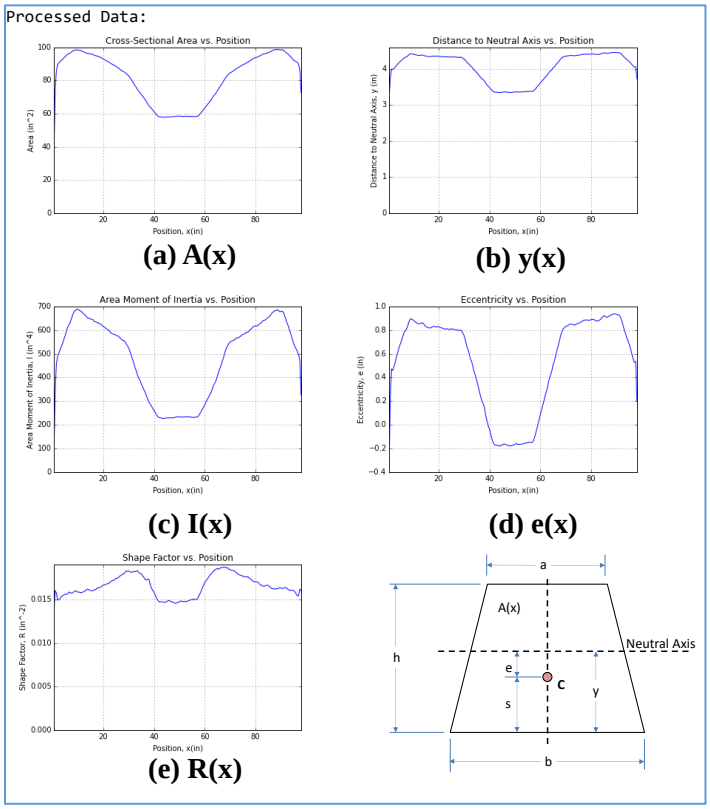


Figure 65: Sample Page 4 of Tie Report for Tie A-1

Figure 65 shows the characteristic tie cross sectional parameters, A, y, I, e, and R as a function of

position along the tie. Lastly, Figure 66 shows selected photographic views of the tie and some apparent damage.

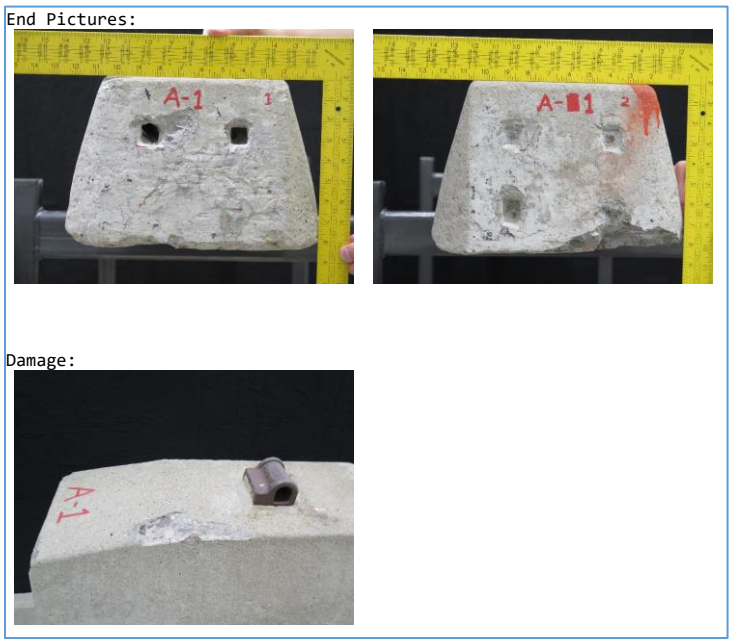


Figure 66: Sample Page 5 of Tie Report for Tie A-1

Appendix B.
Compilation of Reports for all Sampled Ties

This Appendix contains the individual summary reports for all sampled ties. Each tie report consists of the 5 pages, as described in Appendix A.

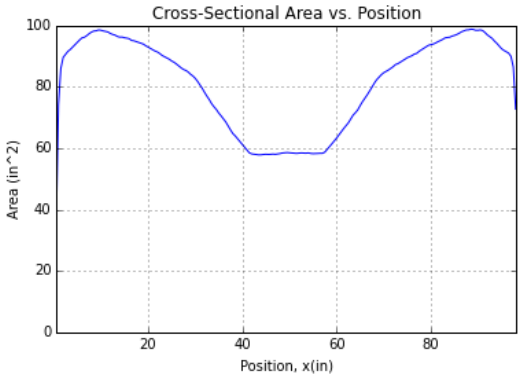
Report for Tie A-1

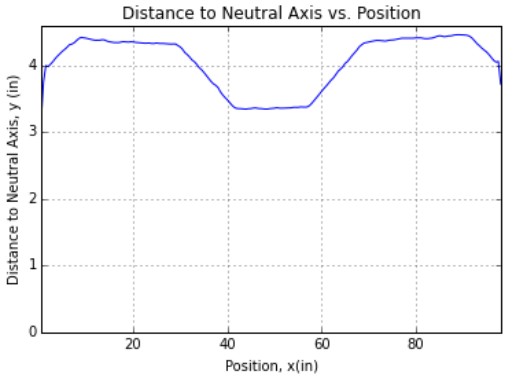
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : A1                                                  |
|    Manufacturer : ITISA                                               |
|    Alternate ID : 136 RE                                              |
|    Tie Length   : 8’3”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : N/A                                                      |
|      Right : 3.558 in                                                 |
|      Avg.  : 3.558 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (NON-INDENTED)                                    |
|      Diameter: 0.415 in                                               |
|      Tendons : 4                                                      |
|      Pattern : 2-2                                                    |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        92.13             58.64                    |
|         I   [in^4]       604.88            234.23                    |
|       Y_cog  [in]          4.38              3.36                    |
|       height [in]          9.15              7.05                    |
|         e    [in]          0.82             -0.17                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 61.2 [kips] (A-6)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]       N/A           3.31                           |
|        Right [in]       N/A           3.07                           |
|        Top   [in]       N/A           2.74                           |
|        Bottom[in]       N/A           1.83                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : Moderate                                     |
+-----------------------------------------------------------------------+
```

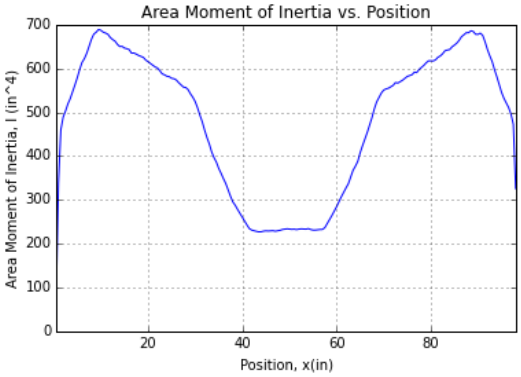
Model Views:

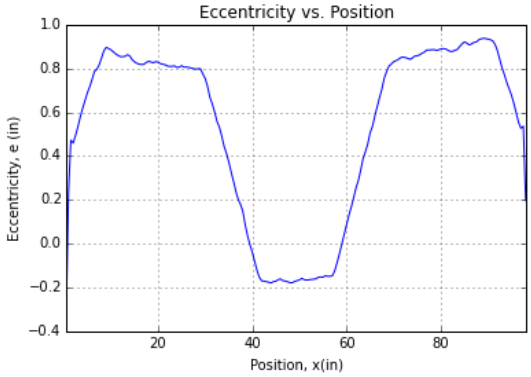
100 mm

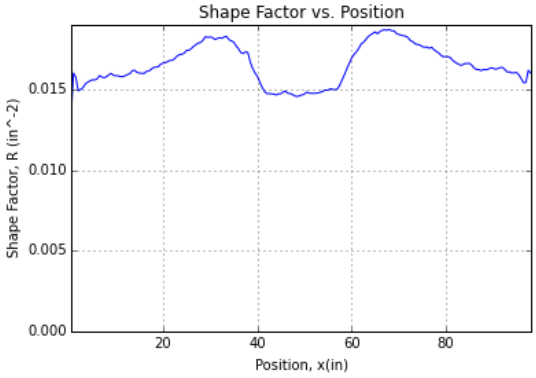
Processed Data:



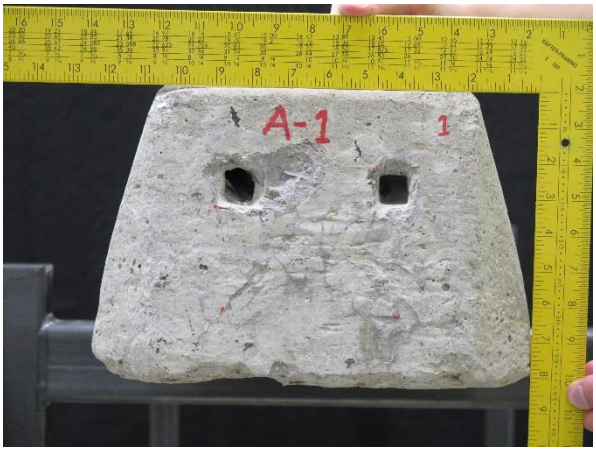


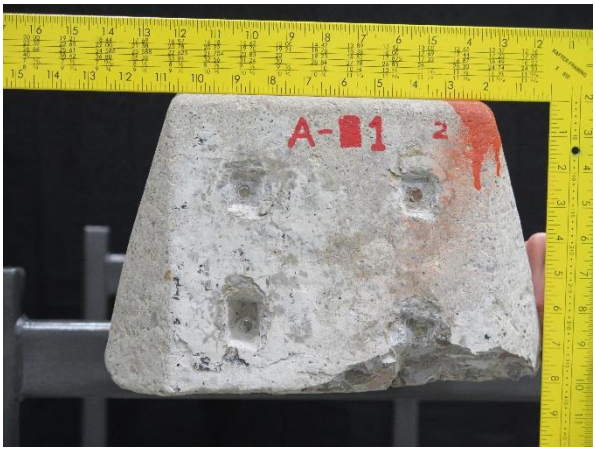






End Pictures:





Damage:

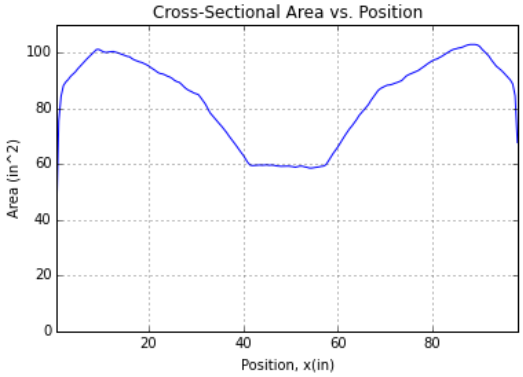
Report for Tie A-2

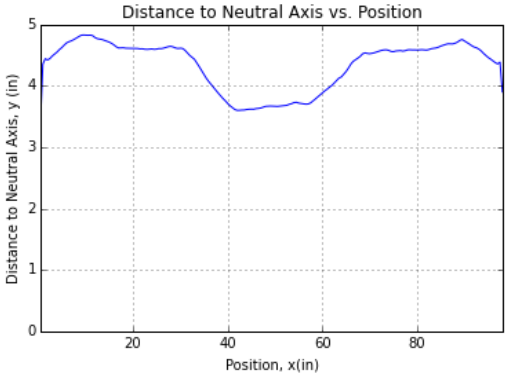
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : A2                                                  |
|    Manufacturer : ITISA                                               |
|    Alternate ID : 136 RE                                              |
|    Tie Length   : 8’3”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : N/A                                                      |
|      Right : 3.496 in                                                 |
|      Avg.  : 3.496 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (NON-INDENTED)                                    |
|      Diameter: 0.415 in                                               |
|      Tendons : 4                                                      |
|      Pattern : 2-2                                                    |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        94.35             59.28                    |
|         I   [in^4]       640.86            233.26                    |
|       Y_cog  [in]          4.60              3.67                    |
|       height [in]          9.49              7.40                    |
|         e    [in]          1.12              0.17                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 61.2 [kips] (A-6)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      N/A            3.33                           |
|        Right [in]      N/A            3.18                           |
|        Top   [in]      N/A            2.69                           |
|        Bottom[in]      N/A            1.57                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : Moderate                                     |
+-----------------------------------------------------------------------+
```

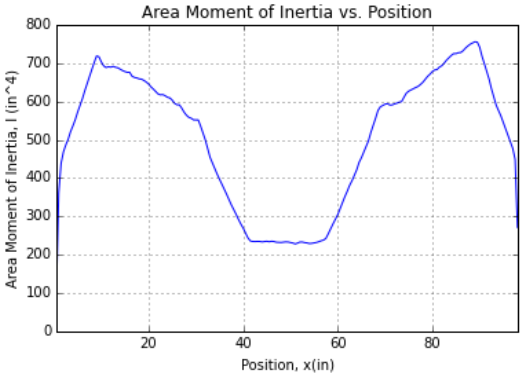
Model Views:

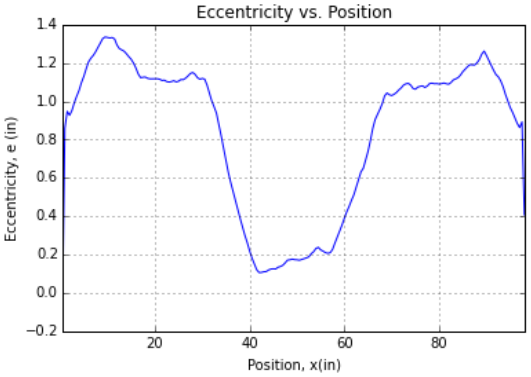
Z
Y
X
100 mm

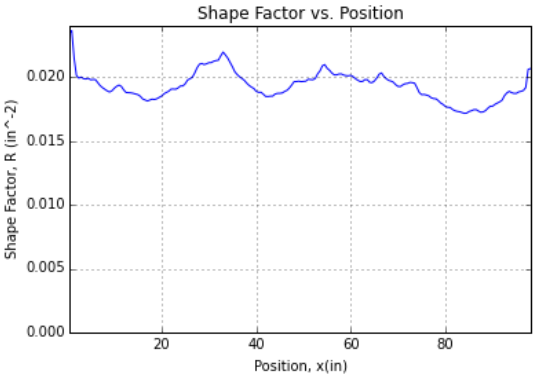
Processed Data:



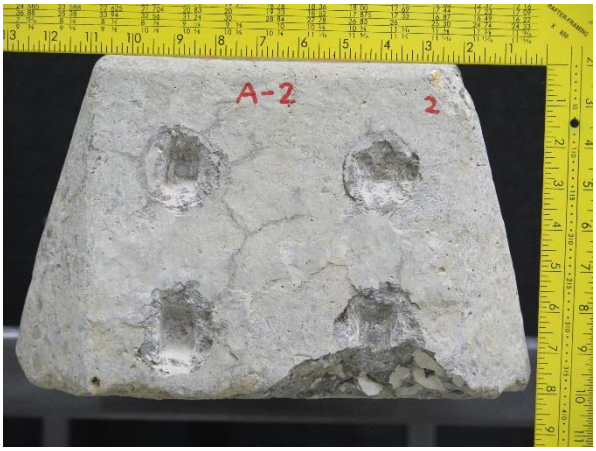








End Pictures:

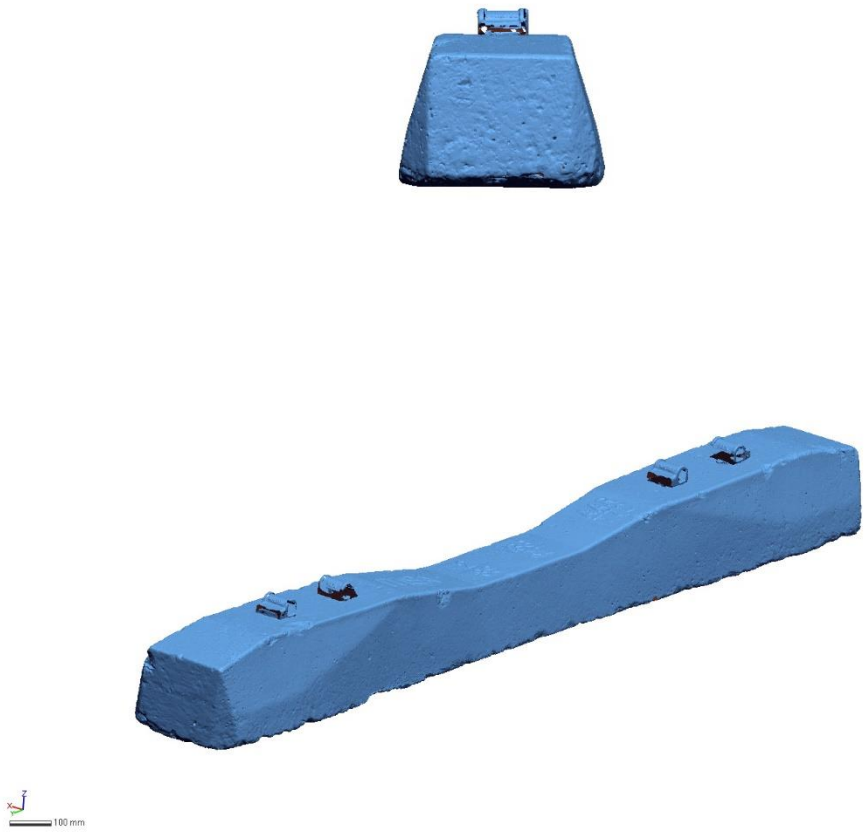


Damage:

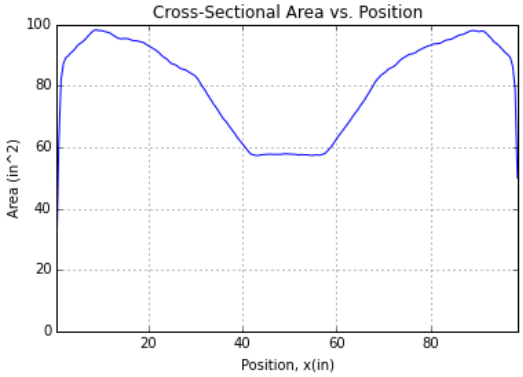
Report for Tie A-3

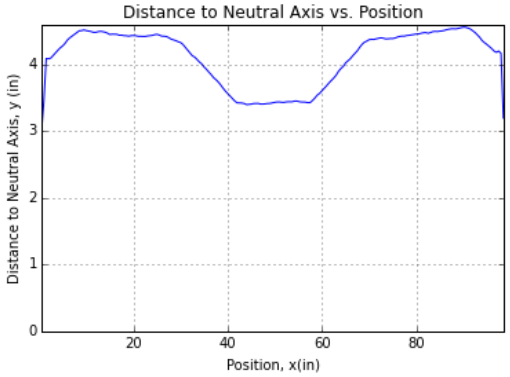
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : A3                                               |
|    Manufacturer : ITISA                                            |
|    Alternate ID : 136 RE                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : N/A                                                   |
|      Right : 3.791 in                                              |
|      Avg.  : 3.791 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (NON-INDENTED)                                 |
|      Diameter: 0.415 in                                            |
|      Tendons : 4                                                   |
|      Pattern : 2-2                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        92.13             57.87                  |
|         I   [in^4]       606.53            228.44                  |
|       Y_cog  [in]          4.43              3.43                  |
|       height [in]          9.23              7.40                  |
|         e    [in]          0.63             -0.36                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 61.2 [kips] (A-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      N/A            3.18                        |
|        Right [in]      N/A            3.19                        |
|        Top   [in]      N/A            2.56                        |
|        Bottom[in]      N/A            1.68                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

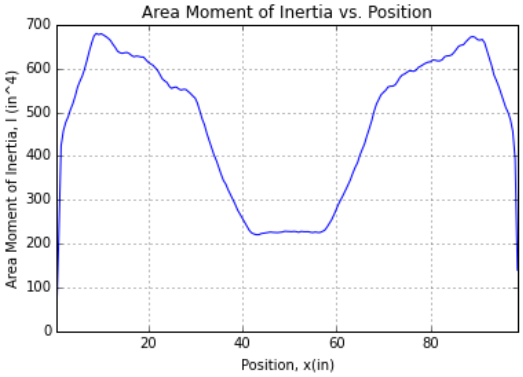
Model Views:

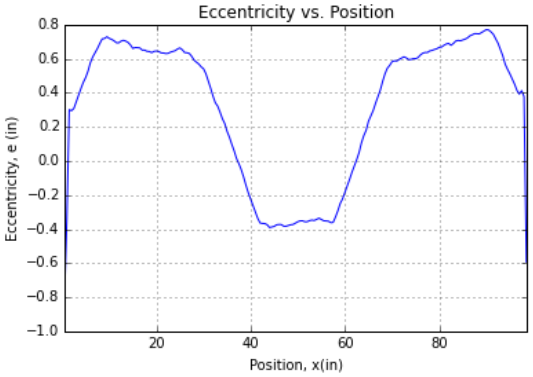

100 mm

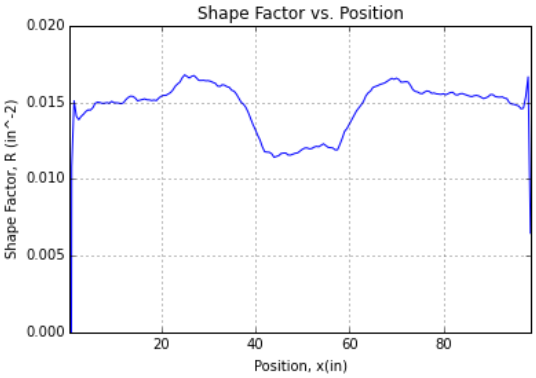
Processed Data:



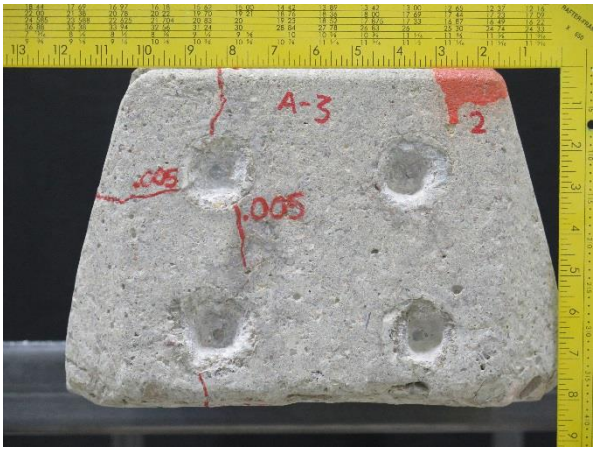








End Pictures:



Damage:

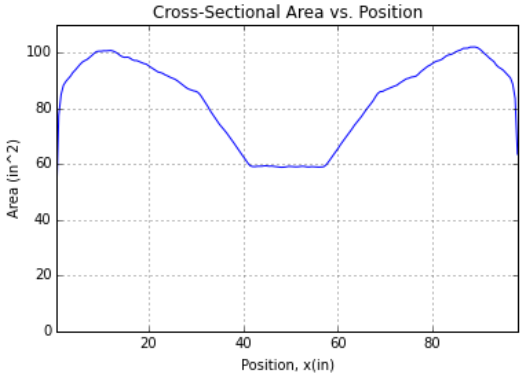
Report for Tie A-4

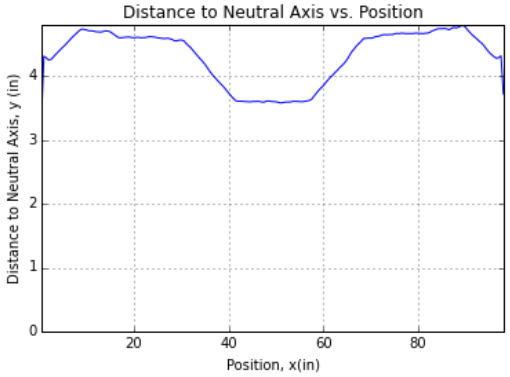
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : A4                                               |
|    Manufacturer : ITISA                                            |
|    Alternate ID : 136 RE                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : N/A                                                   |
|      Right : 3.375 in                                              |
|      Avg.  : 3.375 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (NON-INDENTED)                                 |
|      Diameter: 0.415 in                                            |
|      Tendons : 4                                                   |
|      Pattern : 2-2                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        93.91             59.16                 |
|         I   [in^4]       638.19            235.65                 |
|       Y_cog  [in]          4.63              3.60                 |
|       height [in]          9.53              7.28                 |
|         e    [in]          1.23              0.22                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 61.2 [kips] (A-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      N/A            N/A                          |
|        Right [in]      N/A            N/A                          |
|        Top   [in]      N/A            N/A                          |
|        Bottom[in]      N/A            N/A                          |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

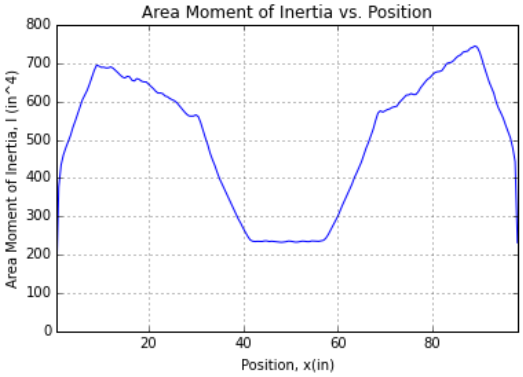
Model Views:

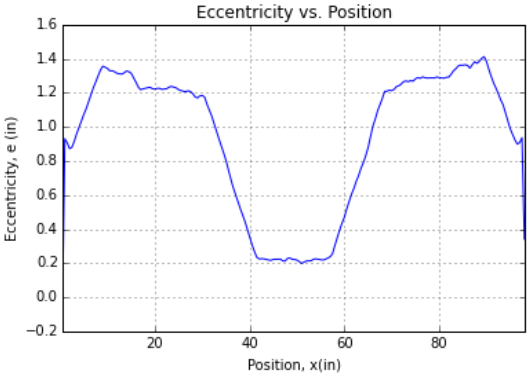
100 mm

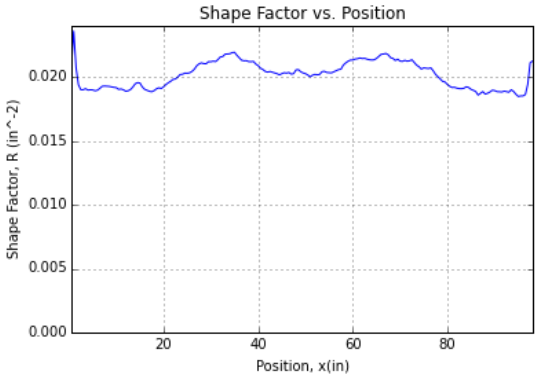
Processed Data:











End Pictures:

Damage:

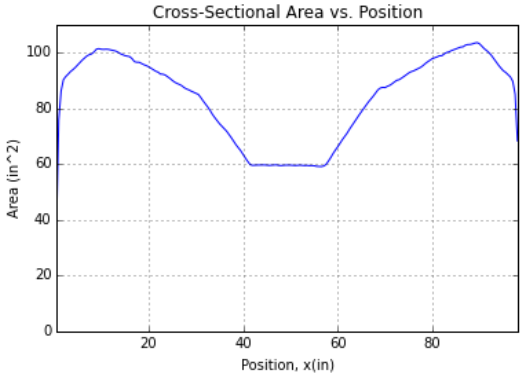
Report for Tie A-5

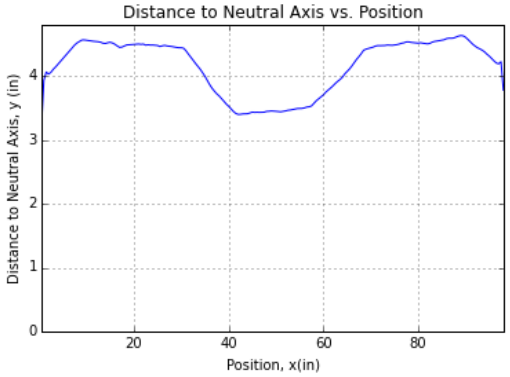
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : A5                                               |
|    Manufacturer : ITISA                                            |
|    Alternate ID : 136 RE                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : N/A                                                   |
|      Right : 3.460 in                                              |
|      Avg.  : 3.460 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (NON-INDENTED)                                 |
|      Diameter: 0.415 in                                            |
|      Tendons : 4                                                   |
|      Pattern : 2-2                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        94.56             56.63                  |
|         I   [in^4]       654.86            242.49                  |
|       Y_cog  [in]          4.51              3.45                  |
|       height [in]          9.43              7.20                  |
|         e    [in]          1.04             -0.01                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 61.2 [kips] (A-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      N/A            N/A                          |
|        Right [in]      N/A            N/A                          |
|        Top   [in]      N/A            N/A                          |
|        Bottom[in]      N/A            N/A                          |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

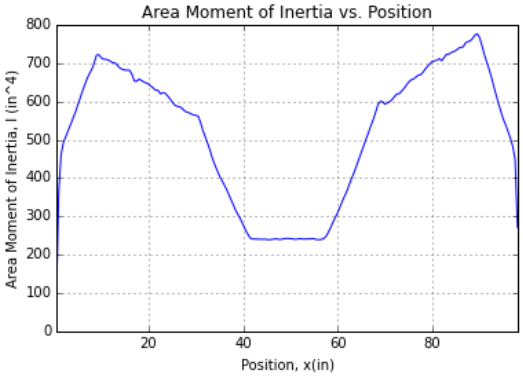
Model Views:

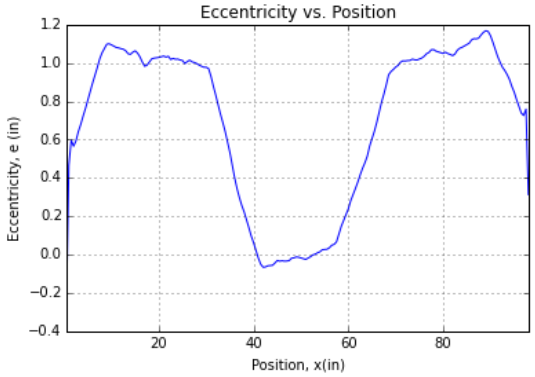
100 mm

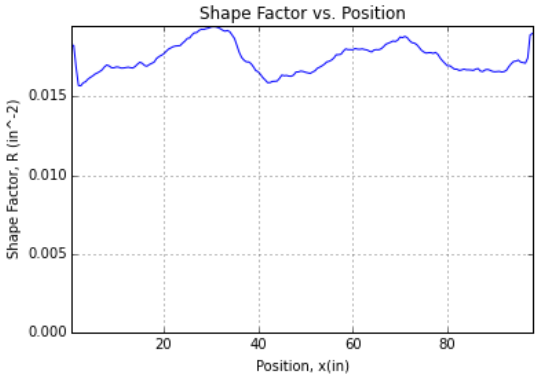
Processed Data:



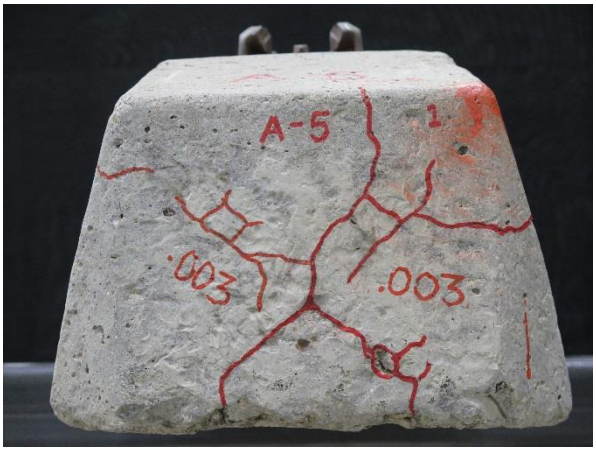








End Pictures:

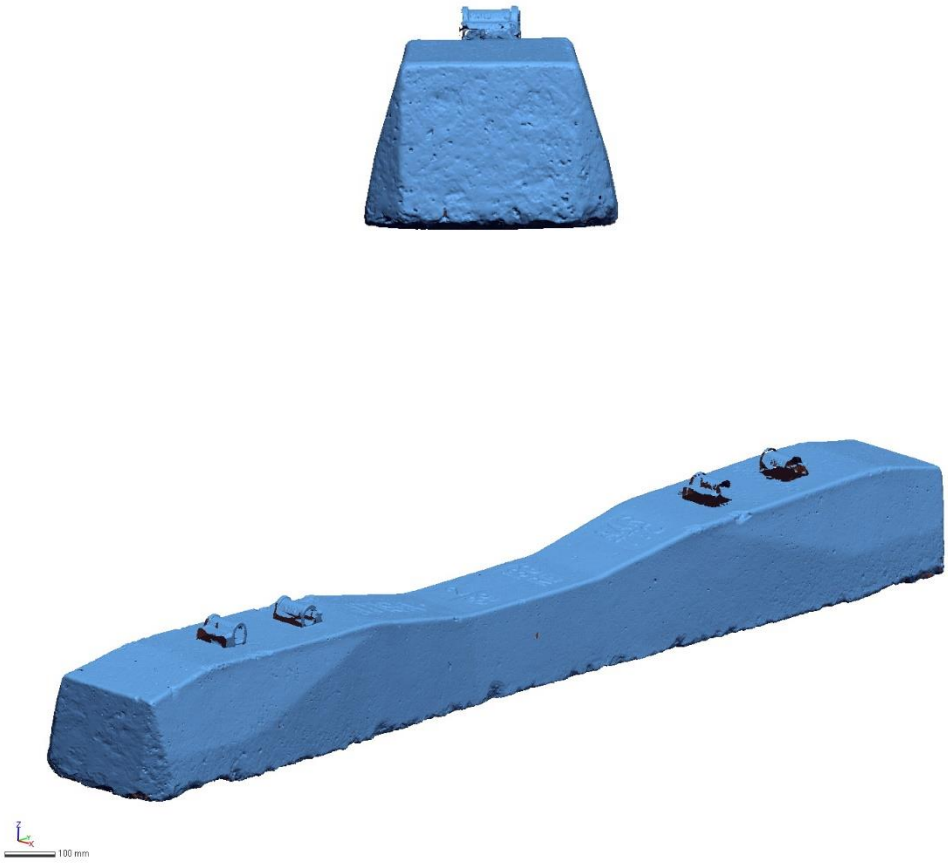


Damage:

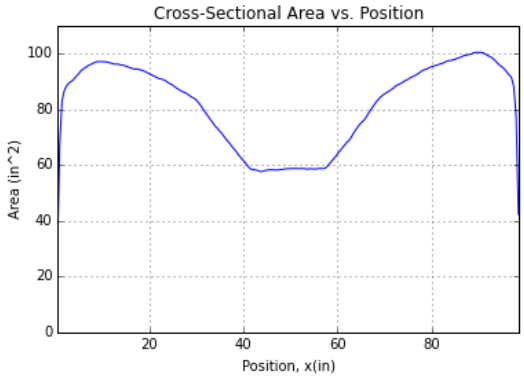
Report for Tie A-6

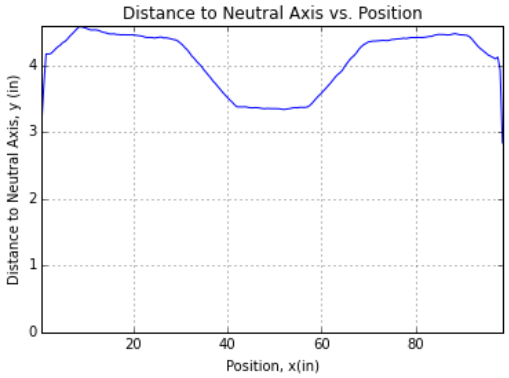
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : A6                                               |
|    Manufacturer : ITISA                                            |
|    Alternate ID : 136 RE                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : N/A                                                   |
|      Right : 3.535 in                                              |
|      Avg.  : 3.535 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (NON-INDENTED)                                 |
|      Diameter: 0.415 in                                            |
|      Tendons : 4                                                   |
|      Pattern : 2-2                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        92.91             58.72                 |
|         I   [in^4]       619.81            238.37                 |
|       Y_cog  [in]          4.43              3.36                 |
|       height [in]          9.25              7.09                 |
|         e    [in]          0.92             -0.18                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 61.2 [kips] (A-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      N/A            N/A                         |
|        Right [in]      N/A            N/A                         |
|        Top   [in]      N/A            N/A                         |
|        Bottom[in]      N/A            N/A                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Low                                       |
+--------------------------------------------------------------------+
```

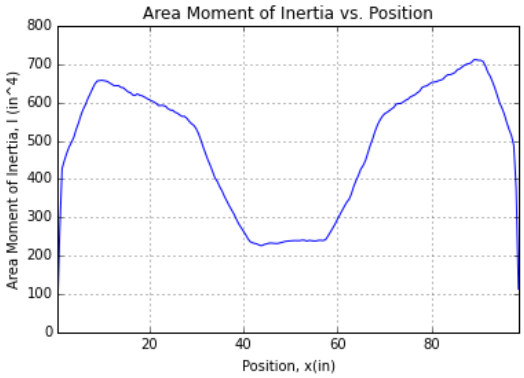
Model Views:

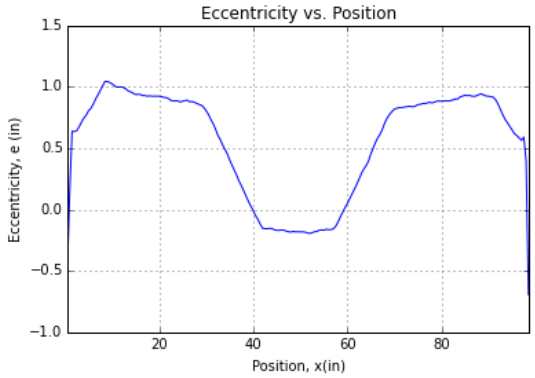

100 mm

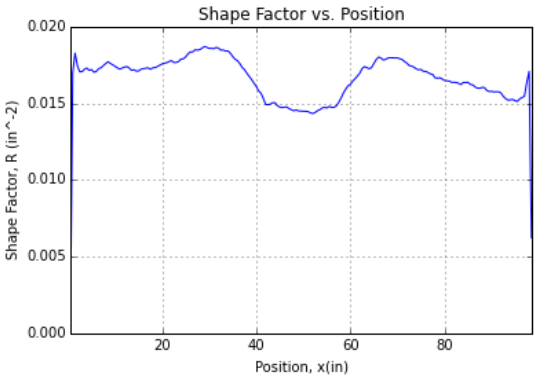
Processed Data:



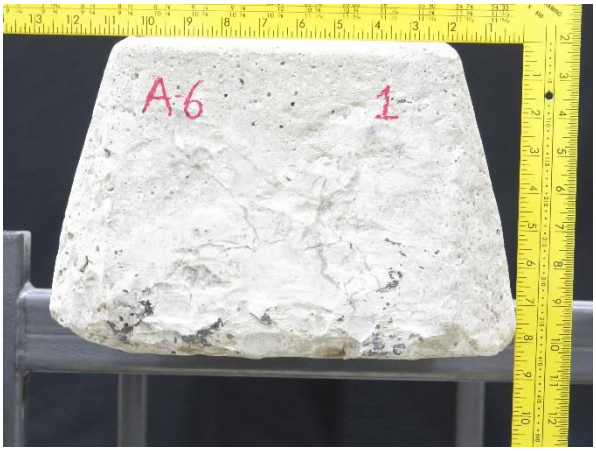


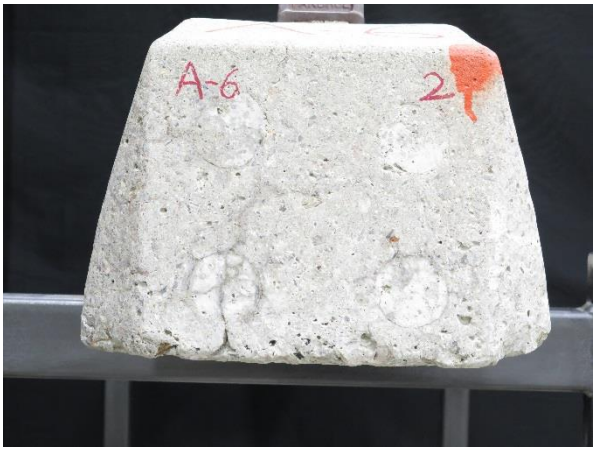






End Pictures:



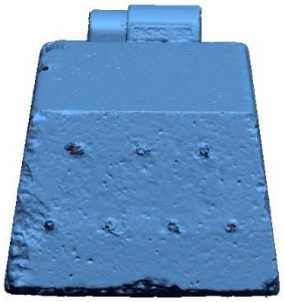


Damage:

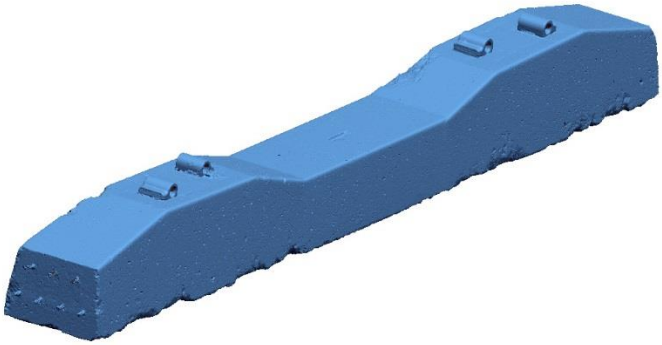
Report for Tie B-1

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : B1                                               |
|    Manufacturer : UNKNOWN                                          |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                       |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.968 in                                              |
|      Right : 3.918 in                                              |
|      Avg.  : 3.943 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (NON-INDENTED)                               |
|      Diameter: 0.375 in                                            |
|      Tendons : 7                                                   |
|      Pattern : 3-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        93.77             72.46                  |
|         I   [in^4]       734.21            315.99                  |
|       Y_cog  [in]          4.73              3.59                  |
|       height [in]          9.88              7.36                  |
|         e    [in]          0.80             -0.36                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 87.5 [kips] (B-7)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.75           1.83                         |
|        Right [in]      1.85           1.76                         |
|        Top   [in]      1.58           1.56                         |
|        Bottom[in]      2.60           2.46                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

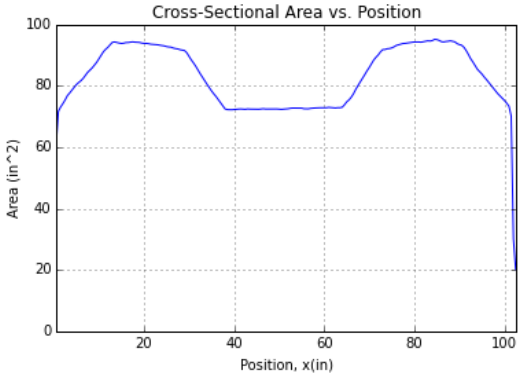


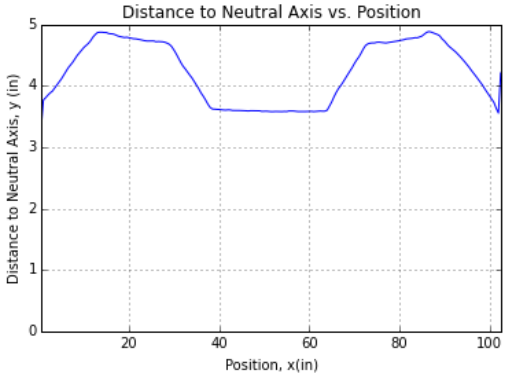
50 mm

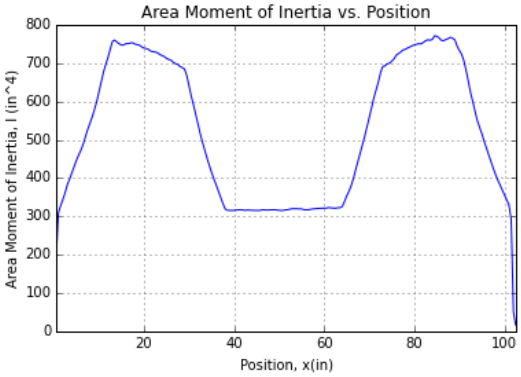


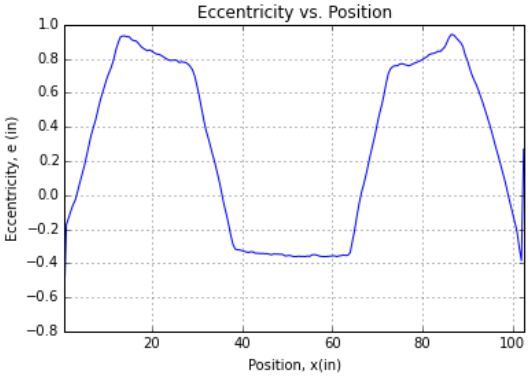
100 mm

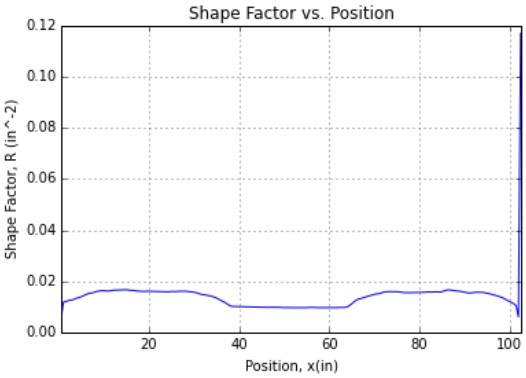
Processed Data:



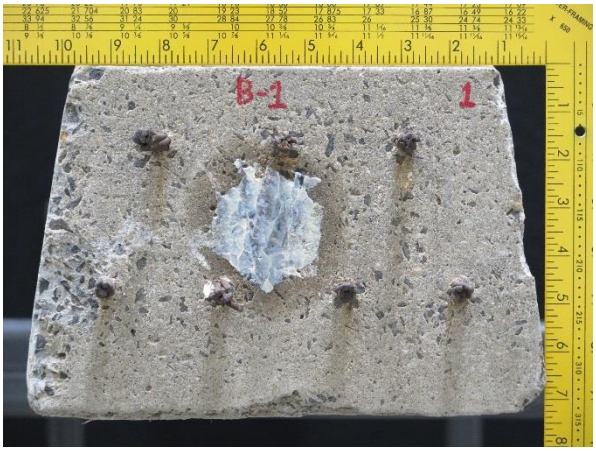


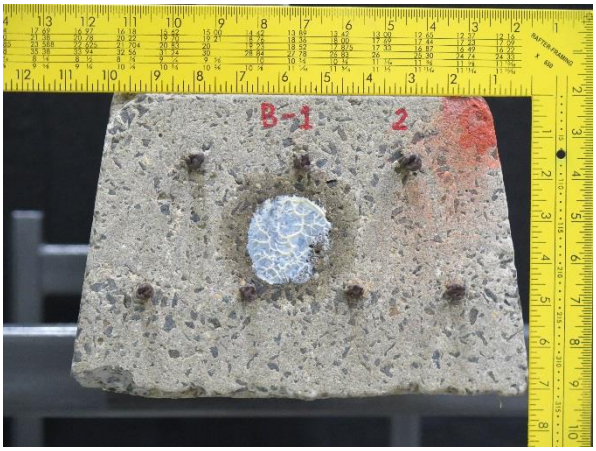






End Pictures:



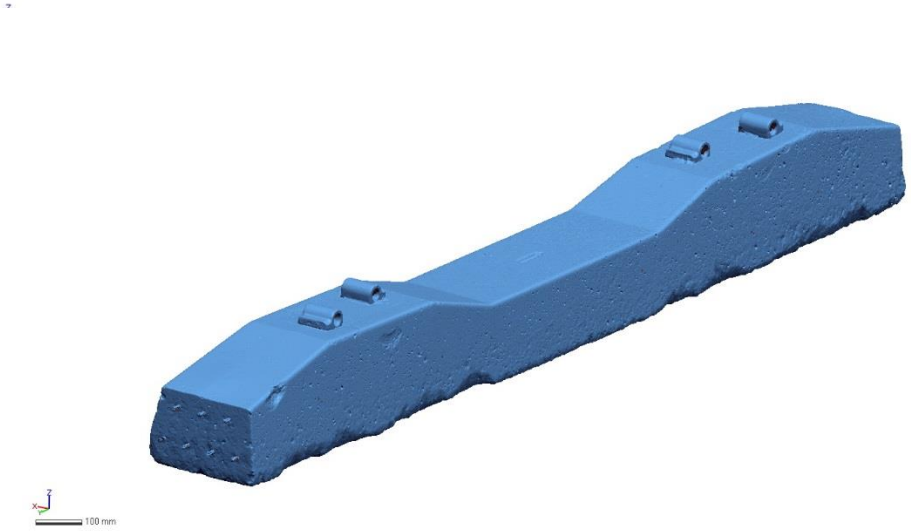


Damage:

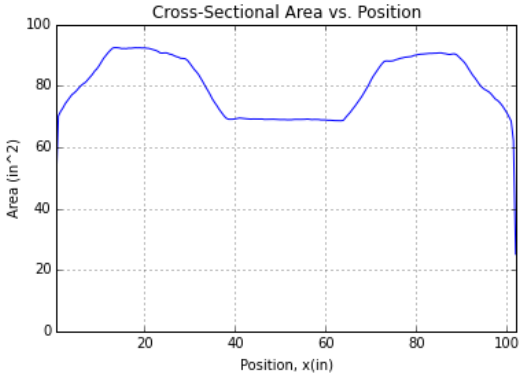
Report for Tie B-2

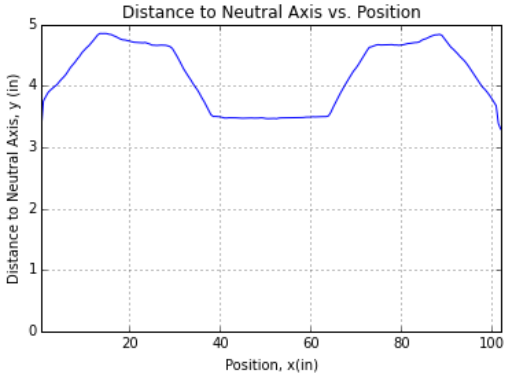
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : B2                                               |
|    Manufacturer : UNKNOWN                                          |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                       |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.778 in                                              |
|      Right : 3.749 in                                              |
|      Avg.  : 3.764 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (NON-INDENTED)                               |
|      Diameter: 0.375 in                                            |
|      Tendons : 7                                                   |
|      Pattern : 3-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        90.44             69.06                 |
|         I   [in^4]       659.12            275.17                 |
|       Y_cog  [in]          4.69              3.47                 |
|       height [in]          9.66              7.08                 |
|         e    [in]          0.94             -0.29                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 87.5 [kips] (B-7)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.77           1.78                        |
|        Right [in]      1.76           1.81                        |
|        Top   [in]      1.60           1.47                        |
|        Bottom[in]      2.39           2.28                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

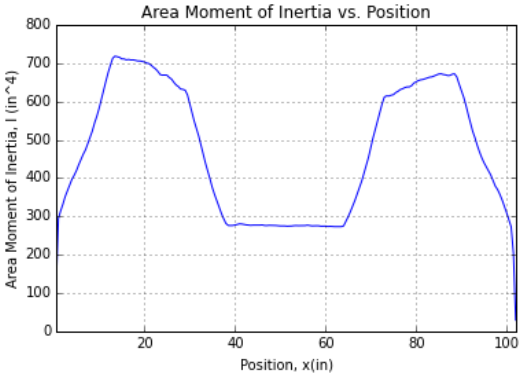
Model Views:

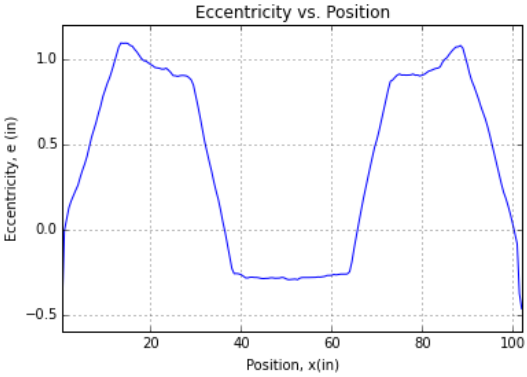

Z
X
100 mm

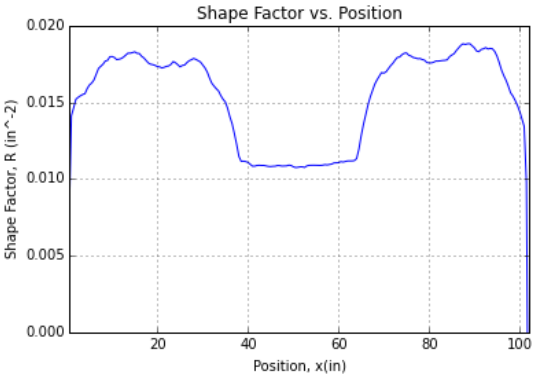
Processed Data:



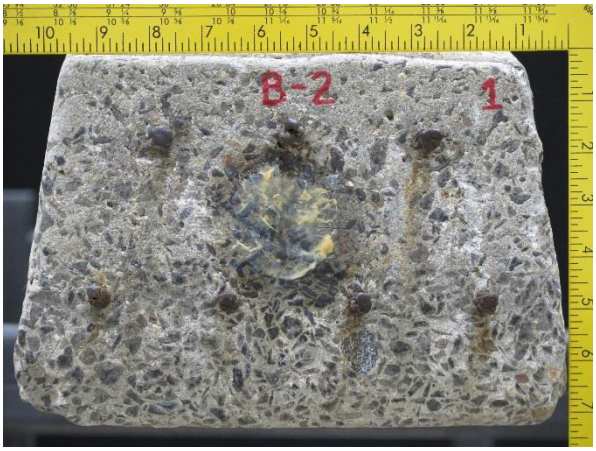


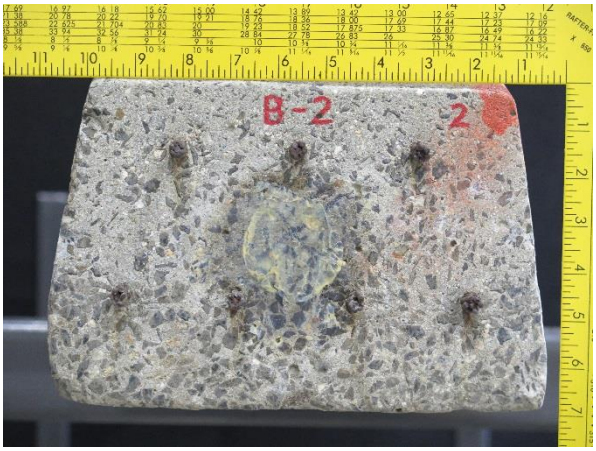






End Pictures:



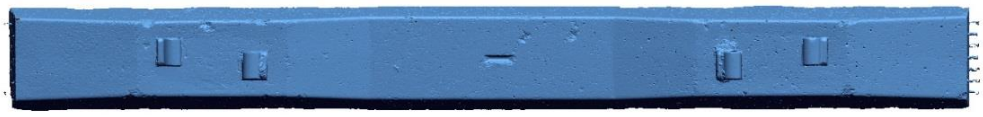


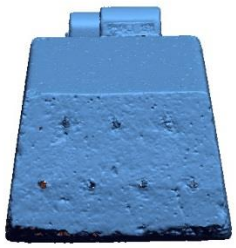
Damage:

Report for Tie B-3

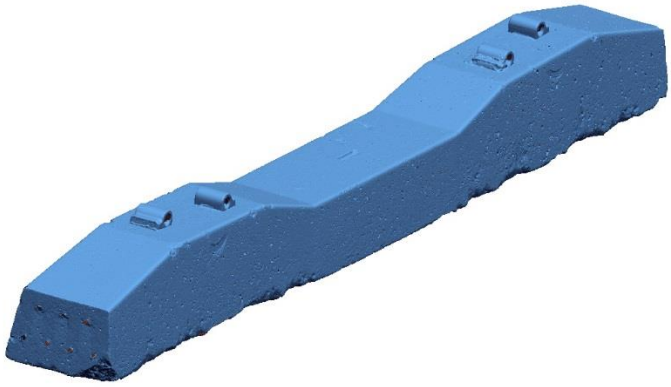
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : B3                                                  |
|    Manufacturer : UNKNOWN                                             |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                          |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.660 in                                                 |
|      Right : 3.680 in                                                 |
|      Avg.  : 3.670 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : STRAND (NON-INDENTED)                                  |
|      Diameter: 0.375 in                                               |
|      Tendons : 7                                                      |
|      Pattern : 3-4                                                    |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        92.79             71.62                    |
|         I   [in^4]       702.45            303.92                    |
|       Y_cog  [in]          4.87              3.70                    |
|       height [in]          9.92              7.32                    |
|         e    [in]          1.21              0.03                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 87.5 [kips] (B-7)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      1.82           1.79                           |
|        Right [in]      1.77           1.87                           |
|        Top   [in]      1.50           1.66                           |
|        Bottom[in]      2.41           2.43                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : Low                                          |
+-----------------------------------------------------------------------+
```

Model Views:



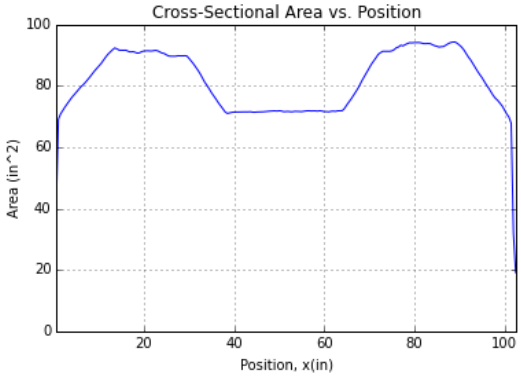


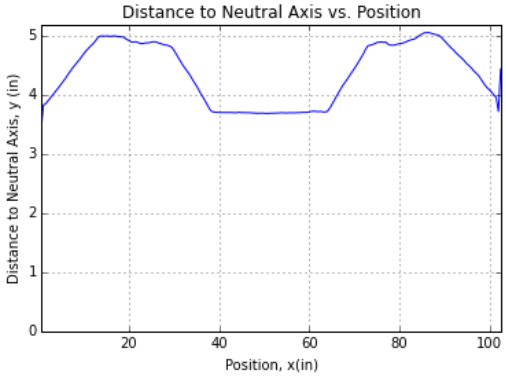
50 mm

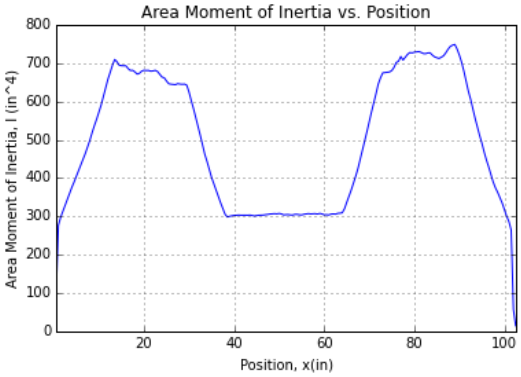


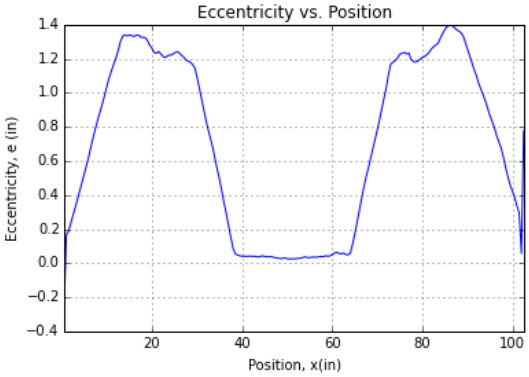
100 mm

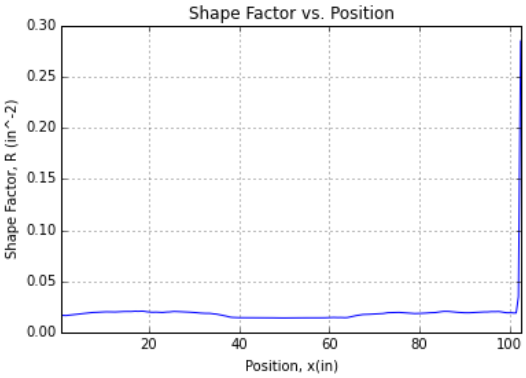
Processed Data:



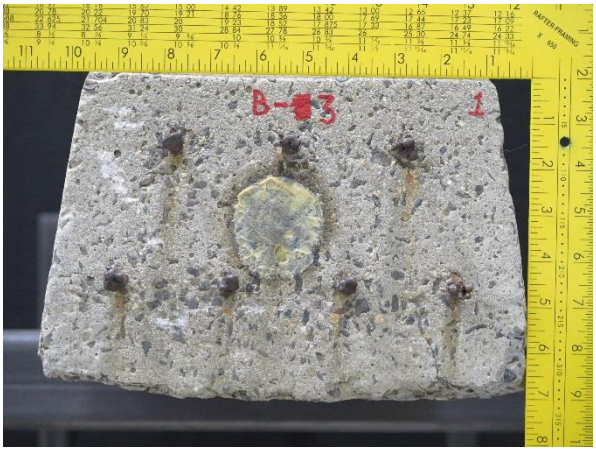


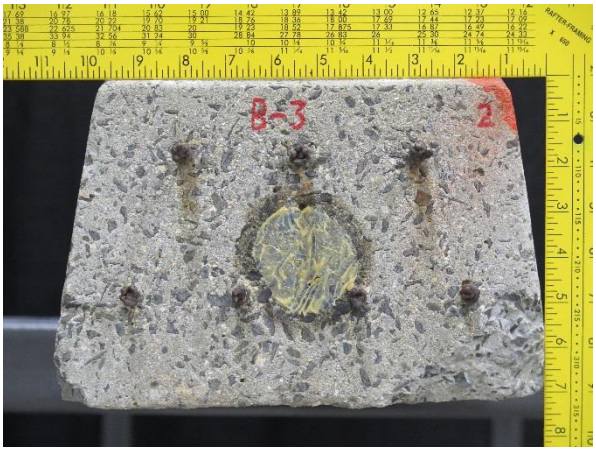






End Pictures:



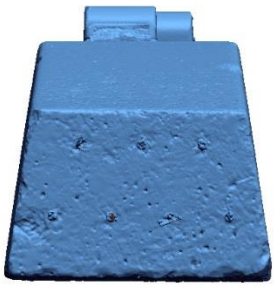


Damage:

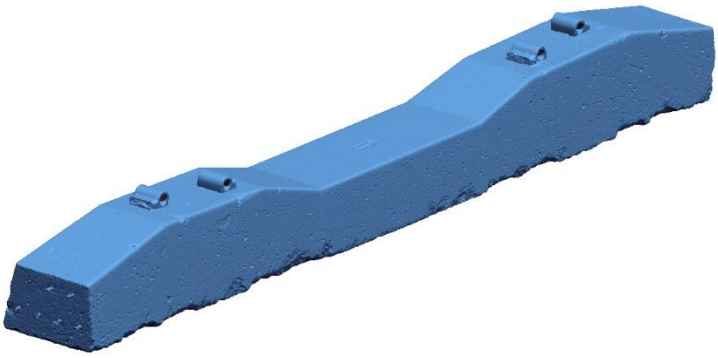
Report for Tie B-4

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : B4                                               |
|    Manufacturer : UNKNOWN                                          |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                       |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.921 in                                              |
|      Right : 3.780 in                                              |
|      Avg.  : 3.850 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (NON-INDENTED)                               |
|      Diameter: 0.375 in                                            |
|      Tendons : 7                                                   |
|      Pattern : 3-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        91.44             70.00                 |
|         I   [in^4]       677.59            284.39                 |
|       Y_cog  [in]          4.66              3.47                 |
|       height [in]          9.69              7.05                 |
|         e    [in]          0.80             -0.38                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 87.5 [kips] (B-7)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.80           1.91                        |
|        Right [in]      1.80           1.70                        |
|        Top   [in]      1.56           1.57                        |
|        Bottom[in]      2.54           2.44                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

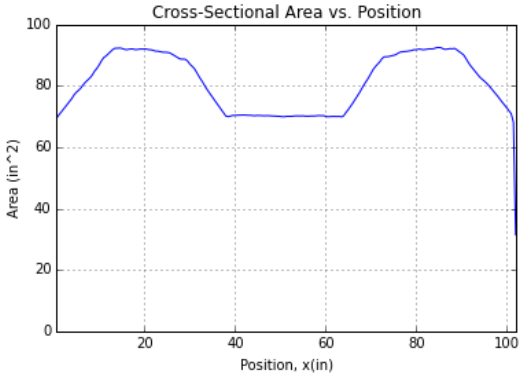


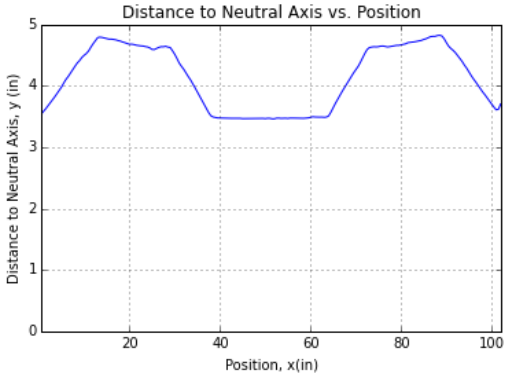
50 mm

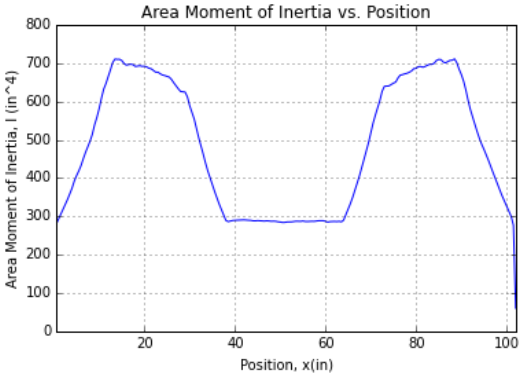


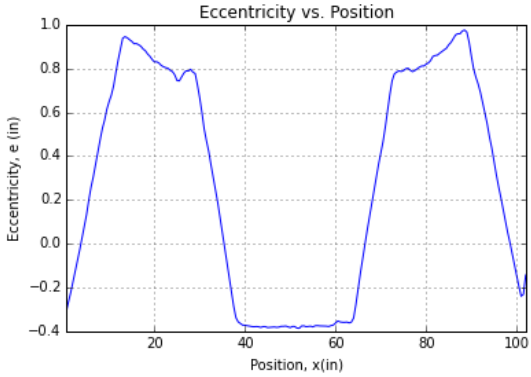
100 mm

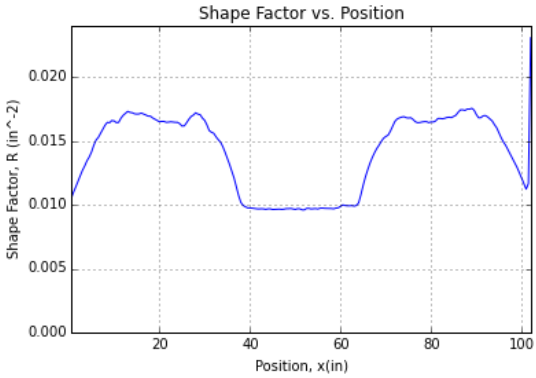
Processed Data:



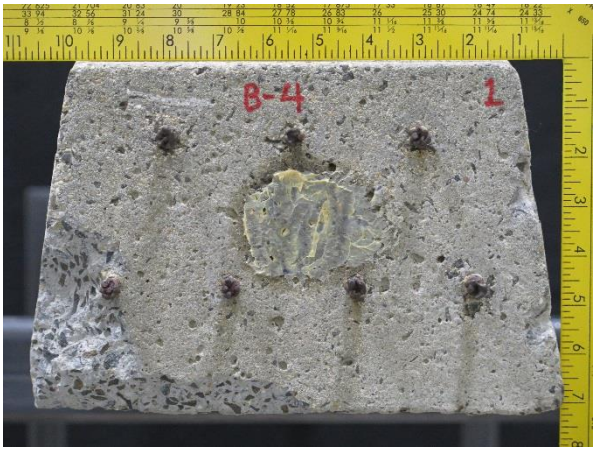


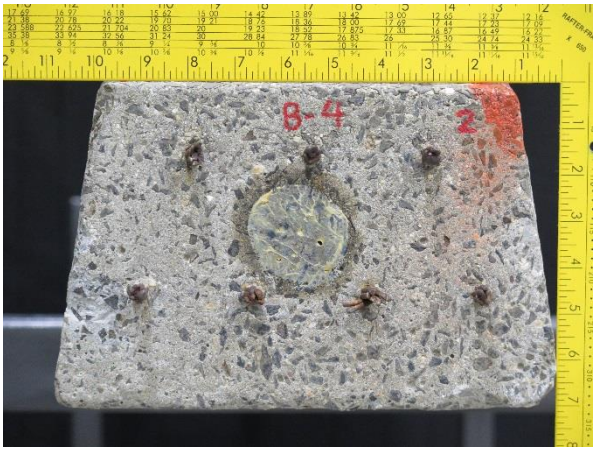






End Pictures:



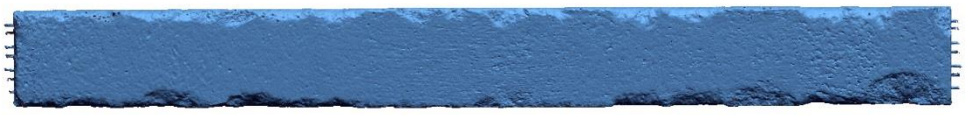


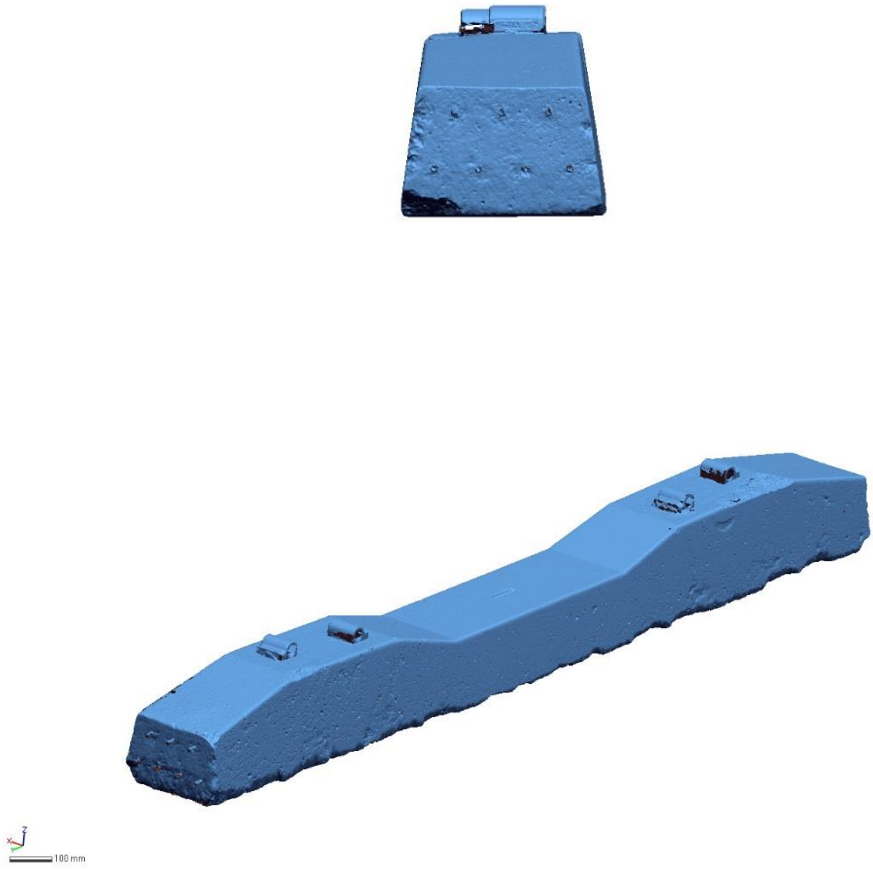
Damage:

Report for Tie B-5

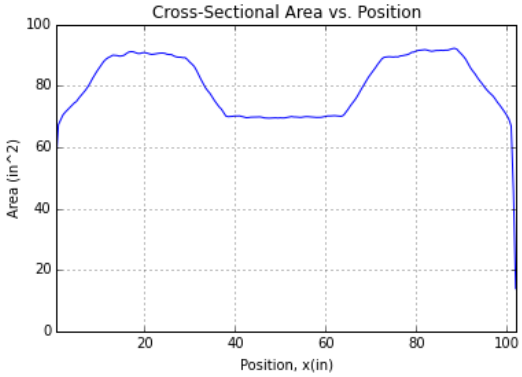
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : B5                                               |
|    Manufacturer : UNKNOWN                                          |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                       |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.602 in                                              |
|      Right : 3.581 in                                              |
|      Avg.  : 3.591 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (NON-INDENTED)                               |
|      Diameter: 0.375 in                                            |
|      Tendons : 7                                                   |
|      Pattern : 3-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        90.78             69.61                  |
|         I   [in^4]       666.09            281.81                  |
|       Y_cog  [in]          4.87              3.70                  |
|       height [in]          9.88              7.20                  |
|         e    [in]          1.28              0.11                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 87.5 [kips] (B-7)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.83           1.79                         |
|        Right [in]      1.78           1.82                         |
|        Top   [in]      1.45           1.59                         |
|        Bottom[in]      2.41           2.40                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

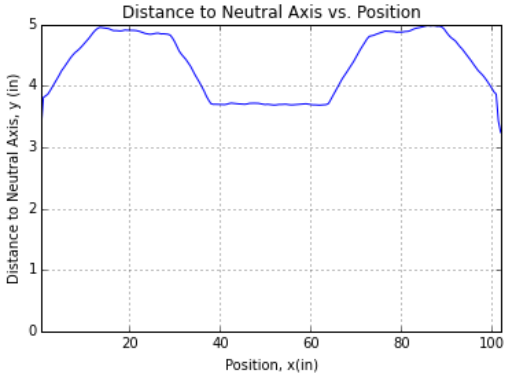
Model Views:

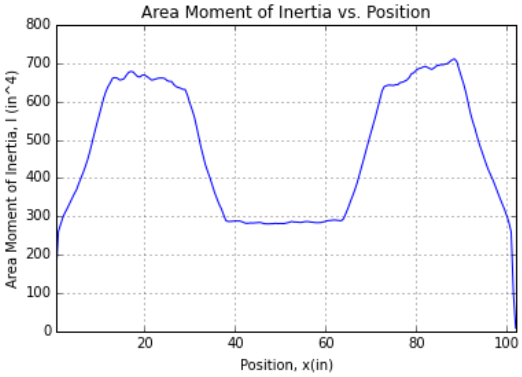


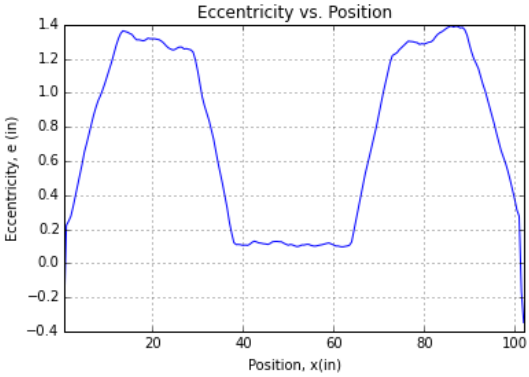

100 mm

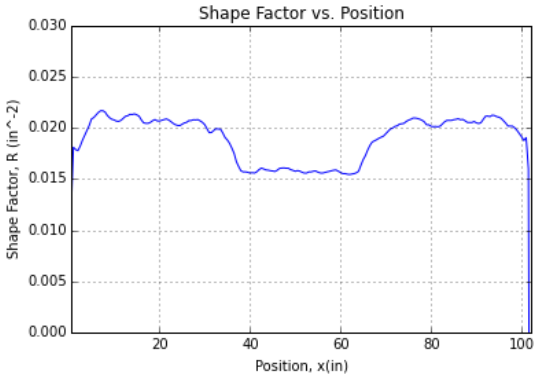
Processed Data:



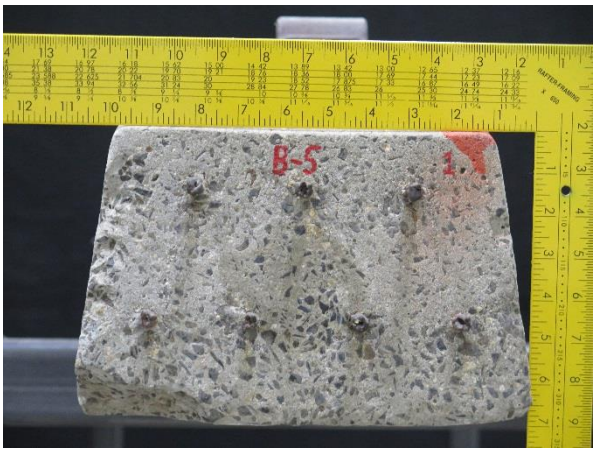








End Pictures:

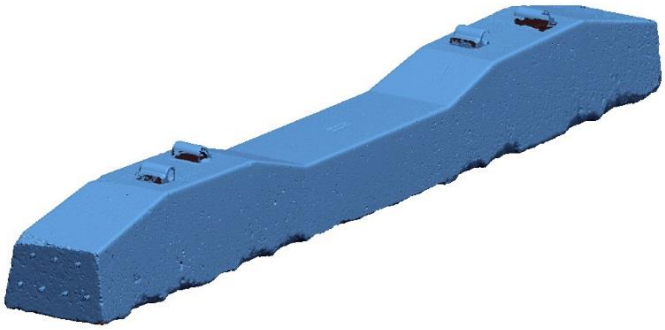


Damage:

Report for Tie B-6

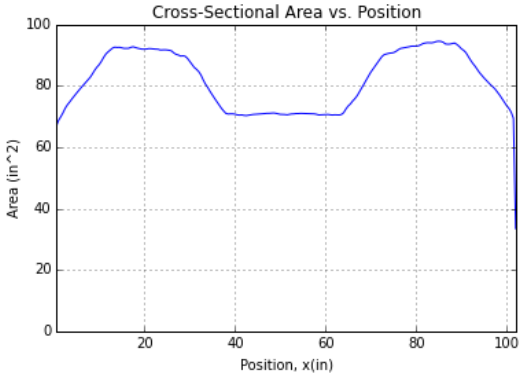
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : B6                                               |
|    Manufacturer : UNKNOWN                                          |
|    Alternate ID : N/A (ABETING MFG. SYSTEM?)                       |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.620 in                                              |
|      Right : 3.859 in                                              |
|      Avg.  : 3.739 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (NON-INDENTED)                               |
|      Diameter: 0.375 in                                            |
|      Tendons : 7                                                   |
|      Pattern : 3-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        92.47             70.71                 |
|         I   [in^4]       703.40            295.50                 |
|       Y_cog  [in]          4.78              3.63                 |
|       height [in]          9.86              7.09                 |
|         e    [in]          1.05             -0.11                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 87.5 [kips] (B-7)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.70           1.84                         |
|        Right [in]      1.72           1.71                         |
|        Top   [in]      1.48           1.49                         |
|        Bottom[in]      2.34           2.54                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

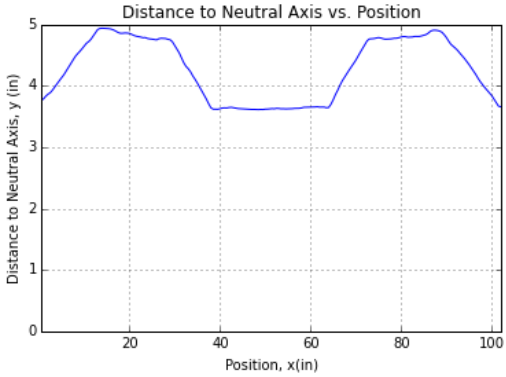
Model Views:

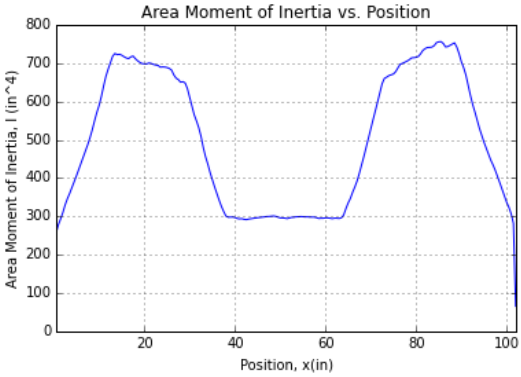


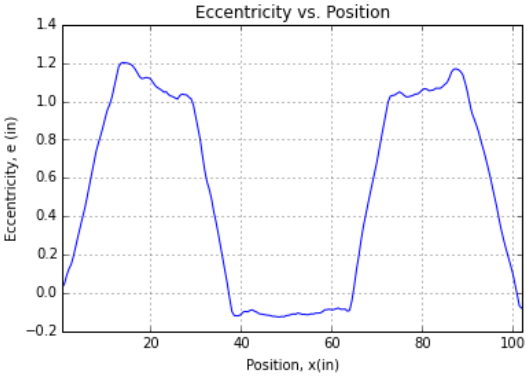
100 mm

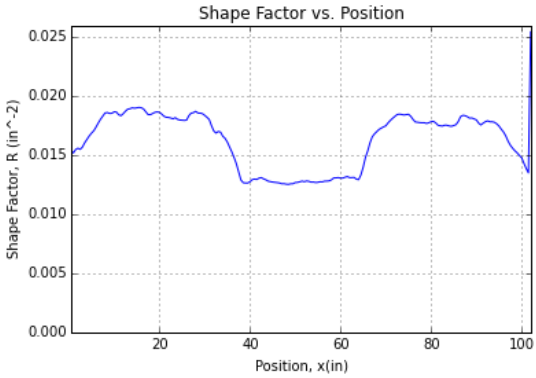
Processed Data:



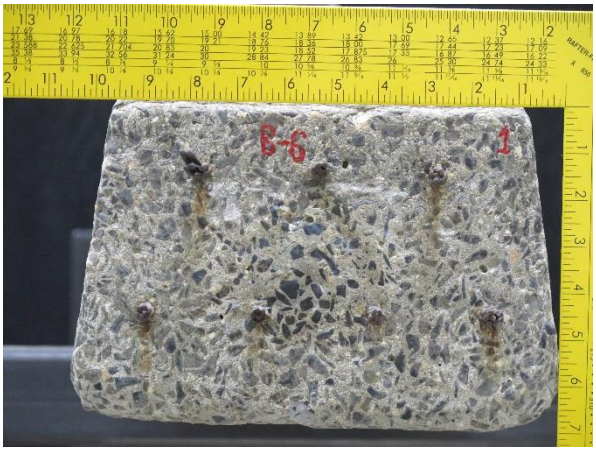


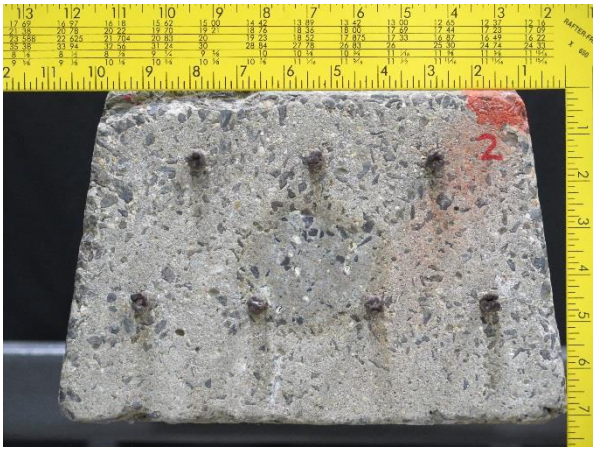






End Pictures:



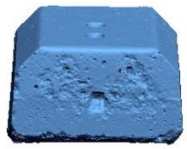


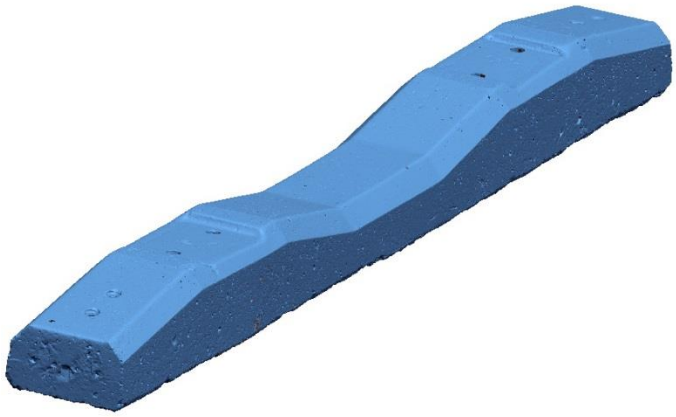
Damage:

Report for Tie C-1

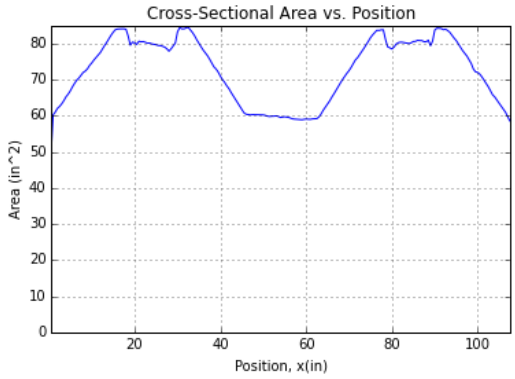
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C1                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.442 in                                              |
|      Right : 3.368 in                                              |
|      Avg.  : 3.405 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        79.93             59.56                 |
|         I   [in^4]       390.08            163.14                 |
|       Y_cog  [in]          3.95              2.97                 |
|       height [in]          7.96              6.06                 |
|         e    [in]          0.50             -0.47                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.70           2.77                        |
|        Right [in]      2.71           2.70                        |
|        Top   [in]      1.57           1.64                        |
|        Bottom[in]      2.86           2.91                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

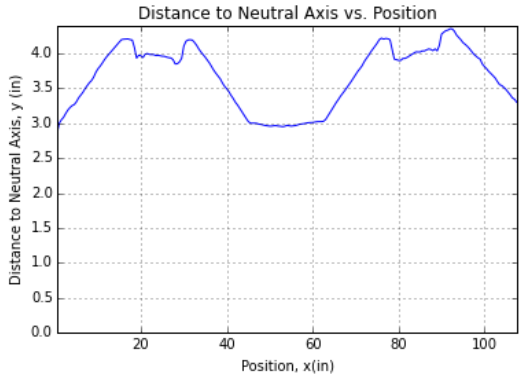
Model Views:

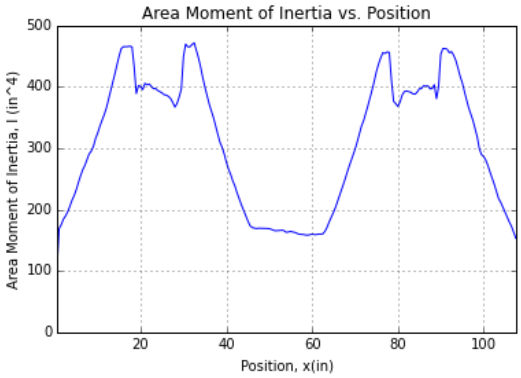


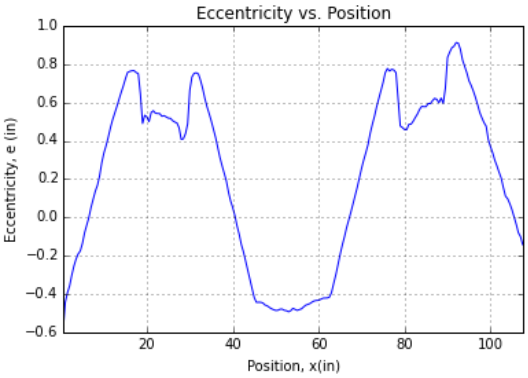


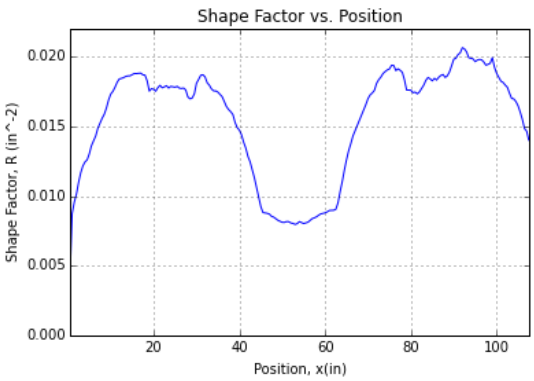
Processed Data:



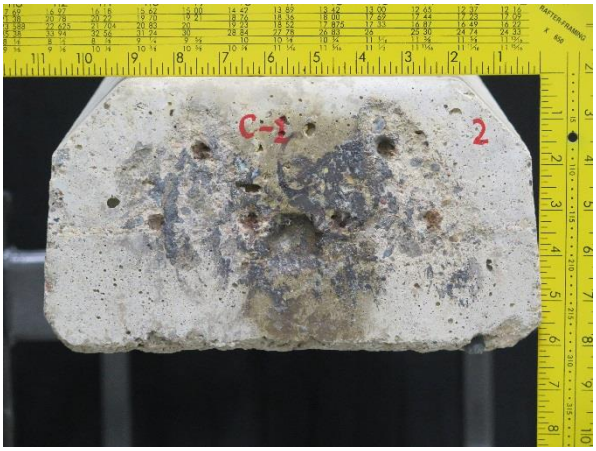








End Pictures:

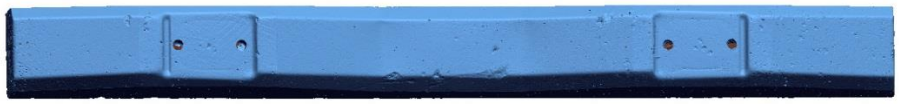


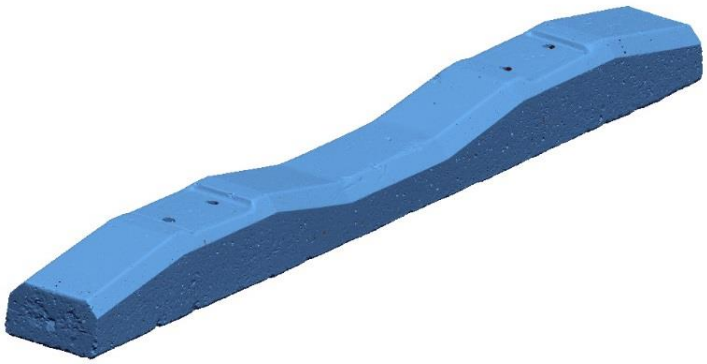
Damage:

Report for Tie C-2

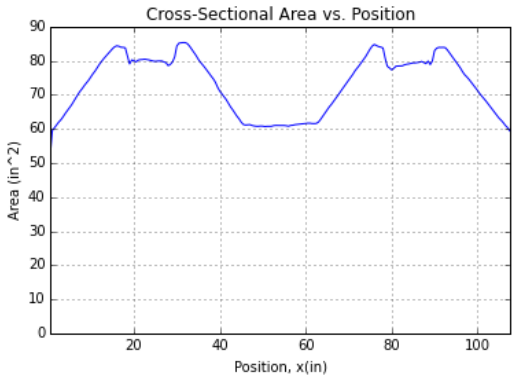
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C2                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.427 in                                              |
|      Right : 3.460 in                                              |
|      Avg.  : 3.443 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        79.19             61.00                 |
|         I   [in^4]       384.08            174.49                 |
|       Y_cog  [in]          4.00              3.07                 |
|       height [in]          7.99              6.26                 |
|         e    [in]          0.54             -0.33                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.74           2.78                        |
|        Right [in]      2.70           2.67                        |
|        Top   [in]      1.59           1.53                        |
|        Bottom[in]      2.81           2.95                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

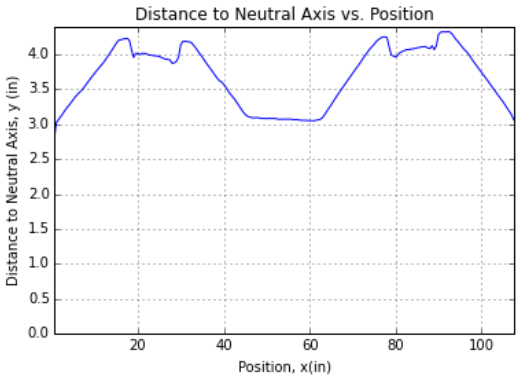
Model Views:

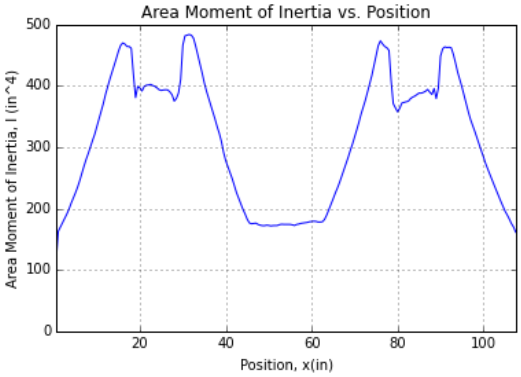


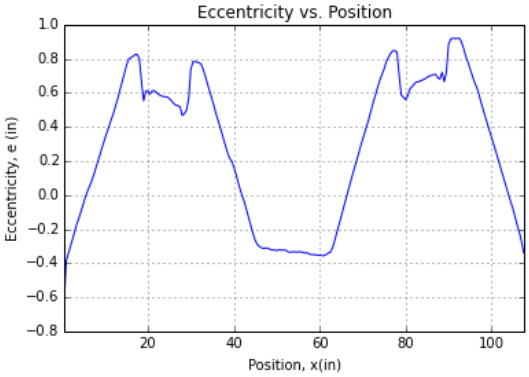


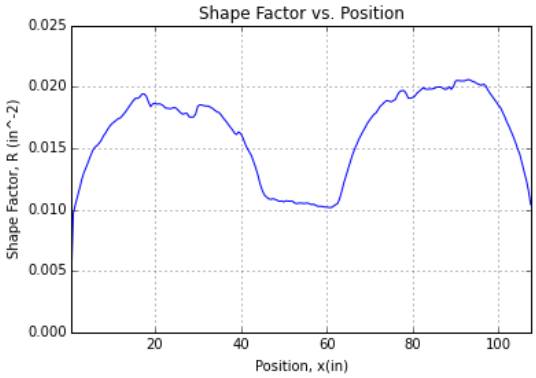
Processed Data:



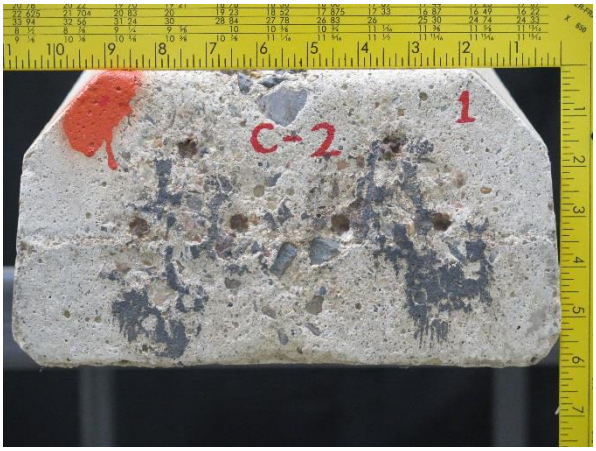








End Pictures:

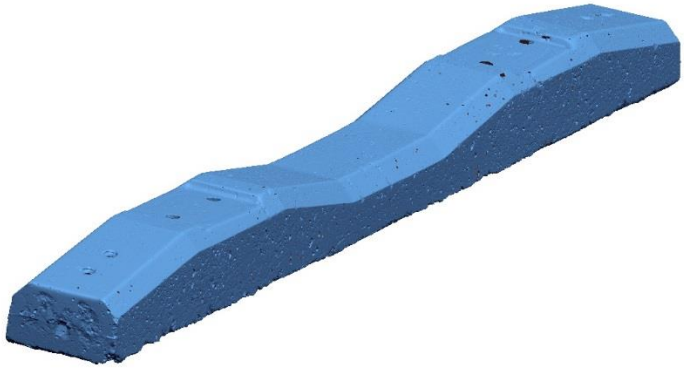


Damage:

Report for Tie C-3

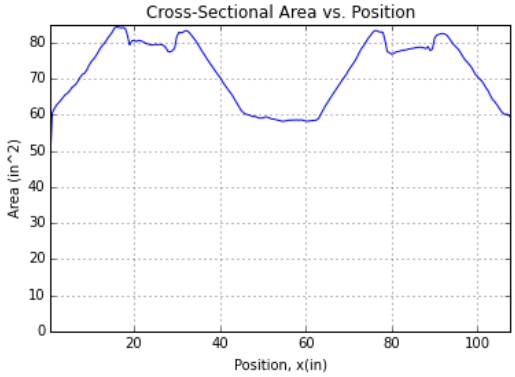
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C3                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.487 in                                              |
|      Right : 3.412 in                                              |
|      Avg.  : 3.450 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        78.61             57.41                  |
|         I   [in^4]       373.00            154.64                  |
|       Y_cog  [in]          3.99              3.04                  |
|       height [in]          7.97              6.10                  |
|         e    [in]          0.47             -0.40                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.69           2.78                         |
|        Right [in]      2.71           2.68                         |
|        Top   [in]      1.50           1.55                         |
|        Bottom[in]      2.85           2.98                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

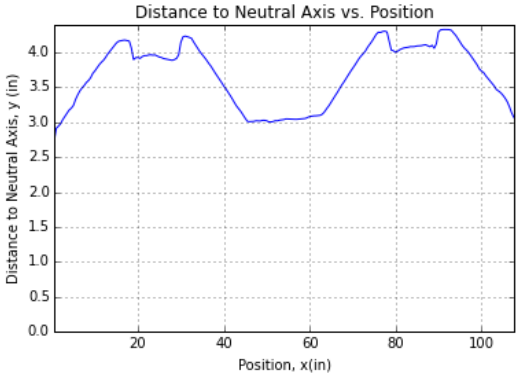
Model Views:

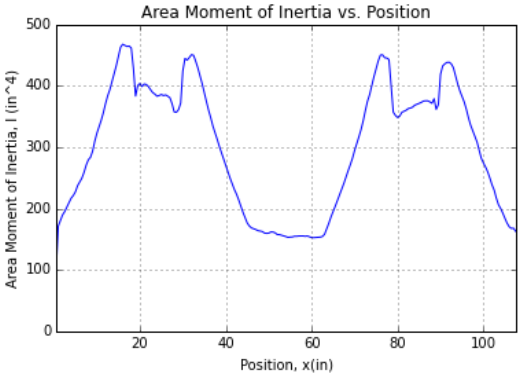


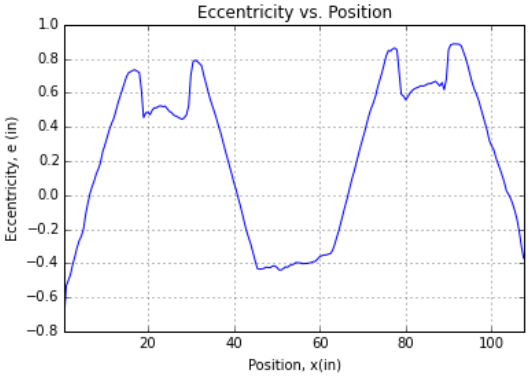
100 mm

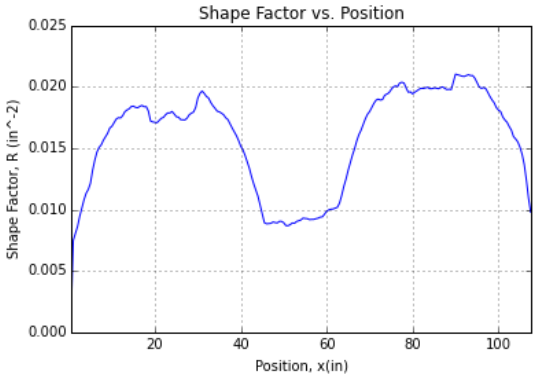
Processed Data:



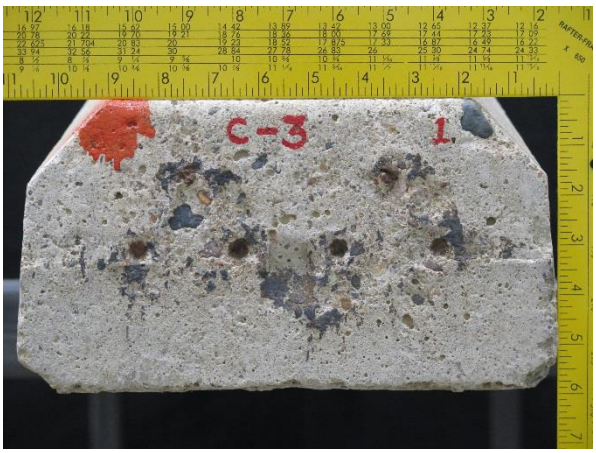








End Pictures:

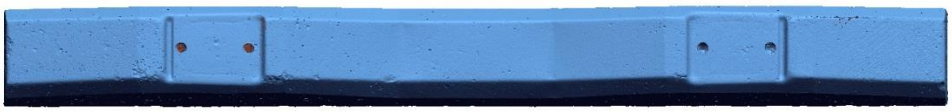


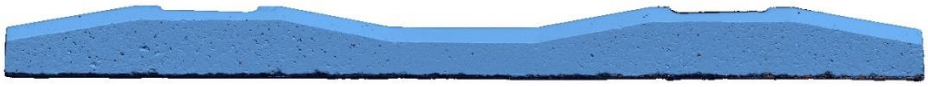
Damage:

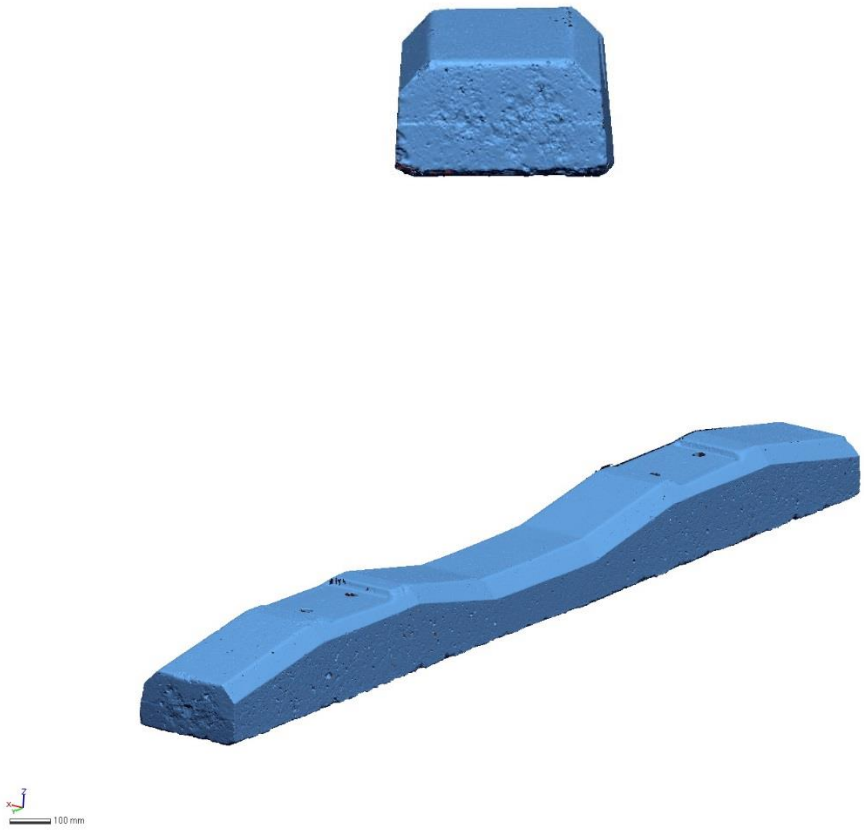
Report for Tie C-4

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C4                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.546 in                                              |
|      Right : 3.381 in                                              |
|      Avg.  : 3.463 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        80.07             60.29                  |
|         I   [in^4]       392.28            167.95                  |
|       Y_cog  [in]          4.06              3.09                  |
|       height [in]          8.09              6.22                  |
|         e    [in]          0.60             -0.37                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.75           2.84                         |
|        Right [in]      2.73           2.70                         |
|        Top   [in]      1.67           1.63                         |
|        Bottom[in]      3.00           2.86                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

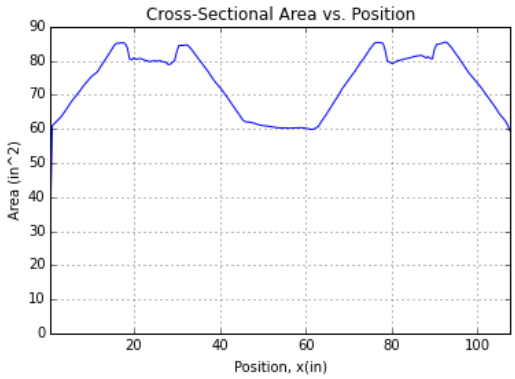
Model Views:

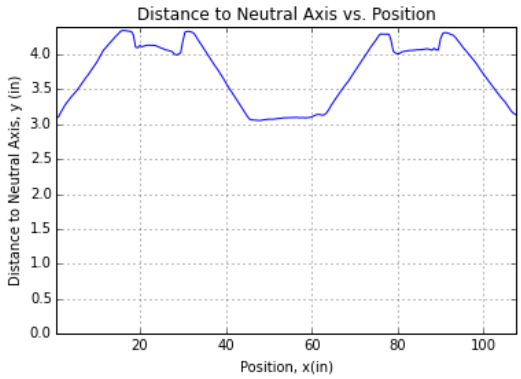


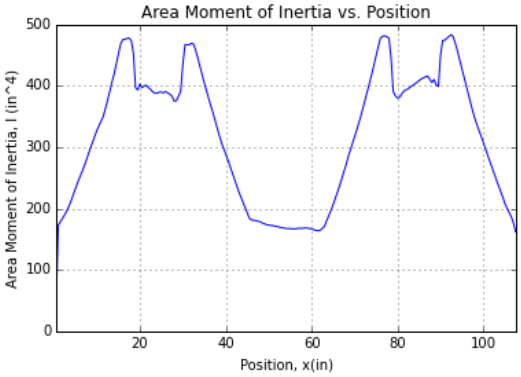


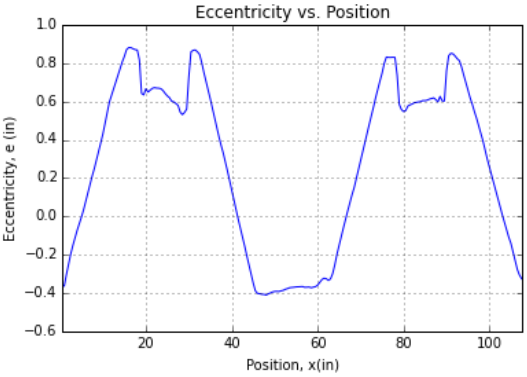

100 mm

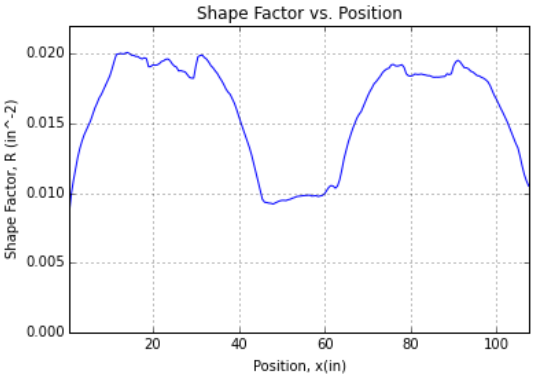
Processed Data:











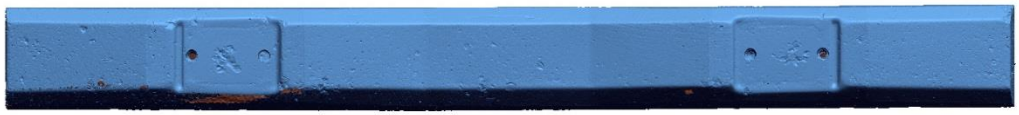
End Pictures:

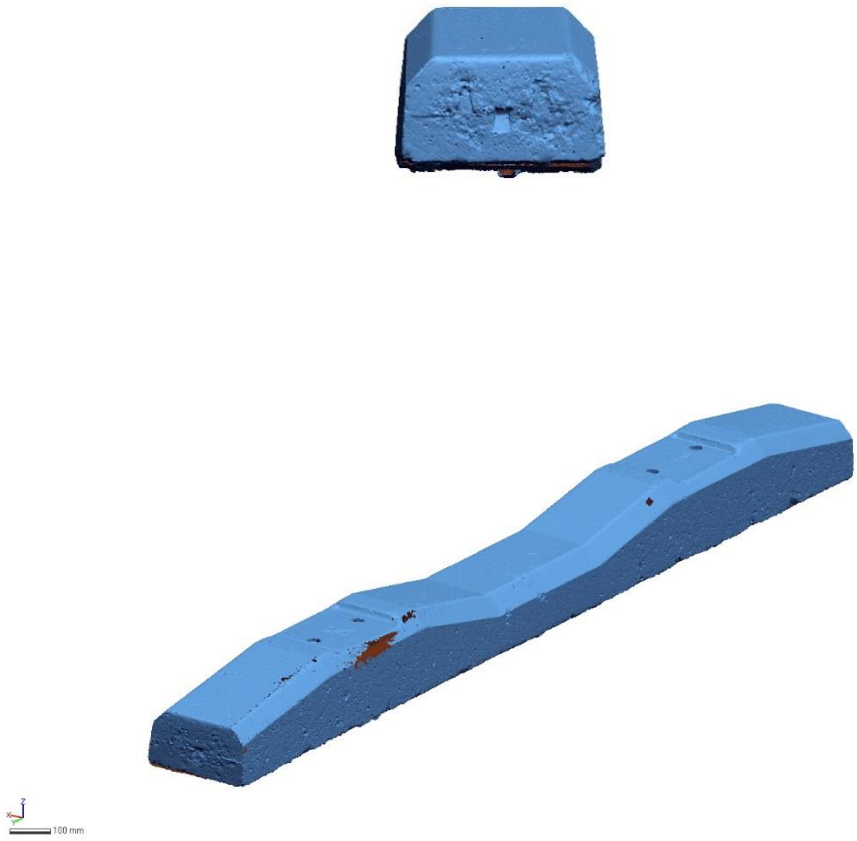
Damage:

Report for Tie C-5

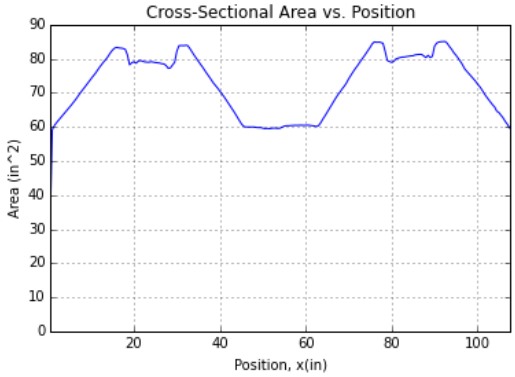
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C5                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.287 in                                              |
|      Right : 3.385 in                                              |
|      Avg.  : 3.336 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        79.52             59.61                  |
|         I   [in^4]       386.45            161.93                  |
|       Y_cog  [in]          4.15              3.36                  |
|       height [in]          8.19              6.57                  |
|         e    [in]          0.86              0.02                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.82           2.86                         |
|        Right [in]      2.64           2.64                         |
|        Top   [in]      1.73           1.63                         |
|        Bottom[in]      2.87           2.92                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

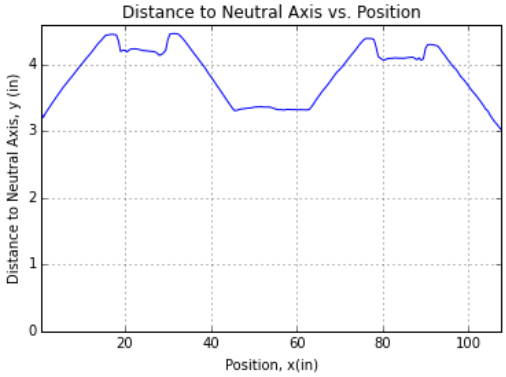
Model Views:

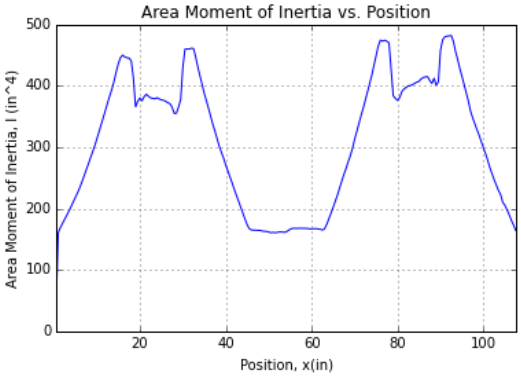


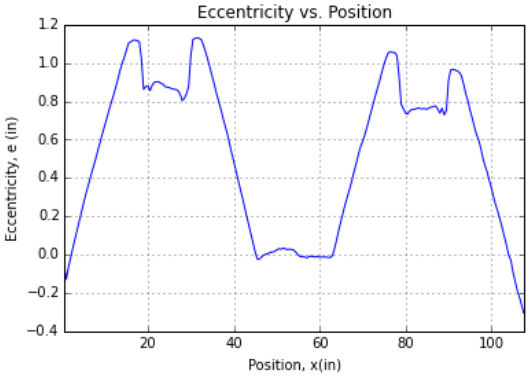

100 mm

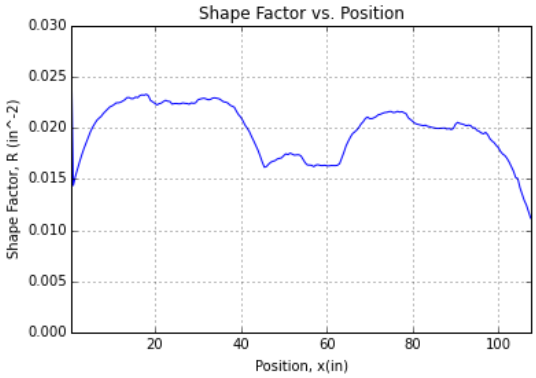
Processed Data:











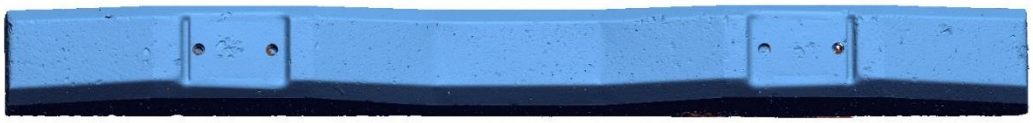
End Pictures:

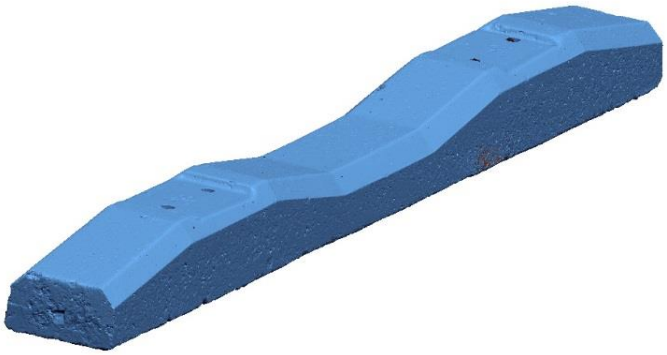
Damage:

Report for Tie C-6

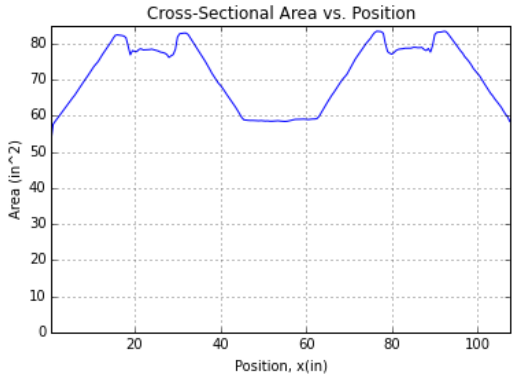
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : C6                                               |
|    Manufacturer : FLORIDA EAST COAST                               |
|    Alternate ID : N/A                                              |
|    Tie Length   : 9’0”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.246 in                                              |
|      Right : 3.480 in                                              |
|      Avg.  : 3.363 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 6                                                   |
|      Pattern : 2-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        78.10             58.56                 |
|         I   [in^4]       366.48            156.71                 |
|       Y_cog  [in]          4.13              3.23                 |
|       height [in]          7.93              6.14                 |
|         e    [in]          0.81             -0.13                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.70           2.67                        |
|        Right [in]      2.76           2.70                        |
|        Top   [in]      1.68           1.55                        |
|        Bottom[in]      2.77           5.66                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

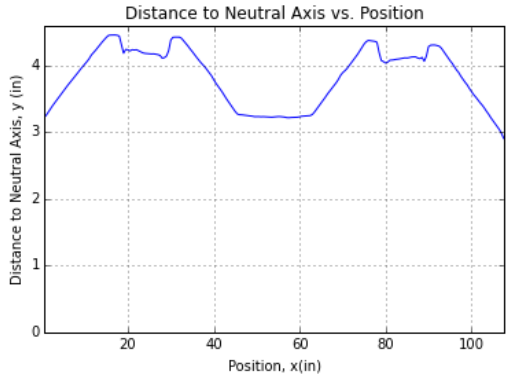
Model Views:

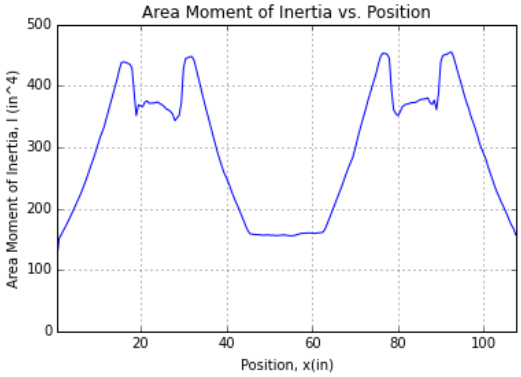


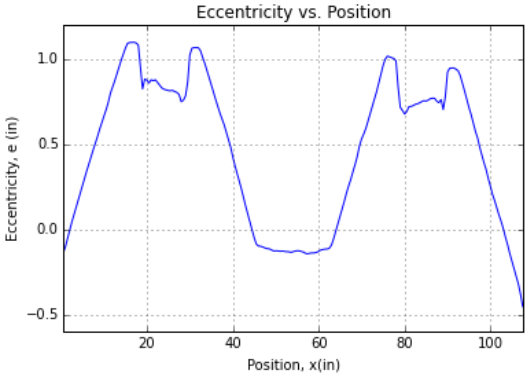


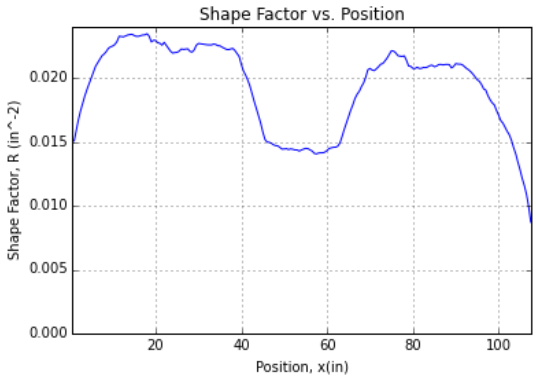
Processed Data:



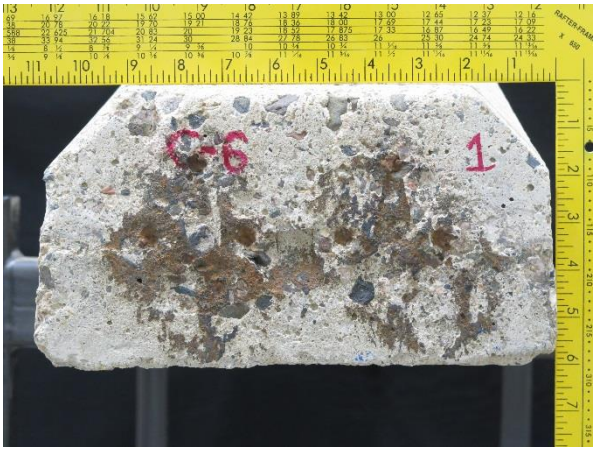








End Pictures:

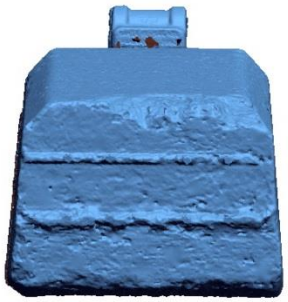


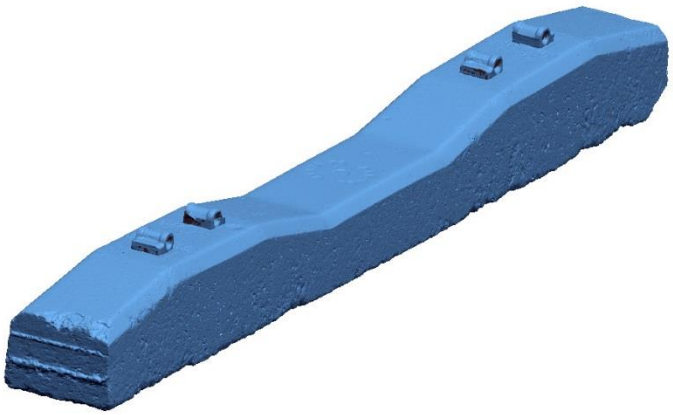
Damage:

Report for Tie D-1

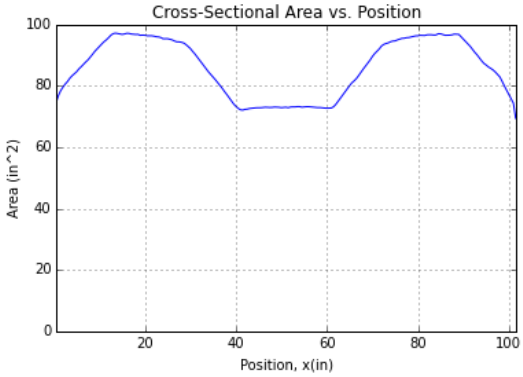
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : D1                                               |
|    Manufacturer : SAN-VEL                                          |
|    Alternate ID : SANTA FE                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.258 in                                              |
|      Right : 4.272 in                                              |
|      Avg.  : 4.265 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        96.03             73.09                 |
|         I   [in^4]       702.89            299.63                 |
|       Y_cog  [in]          4.72              3.53                 |
|       height [in]          9.69              7.20                 |
|         e    [in]          0.43             -0.73                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 90.8 [kips] (D-2)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.91           2.03                        |
|        Right [in]      2.00           1.95                        |
|        Top   [in]      2.52           2.68                        |
|        Bottom[in]      2.68           2.89                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

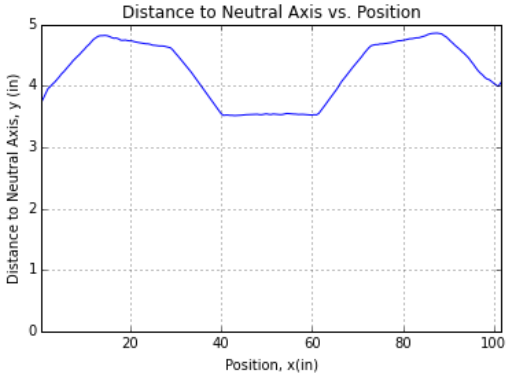
Model Views:

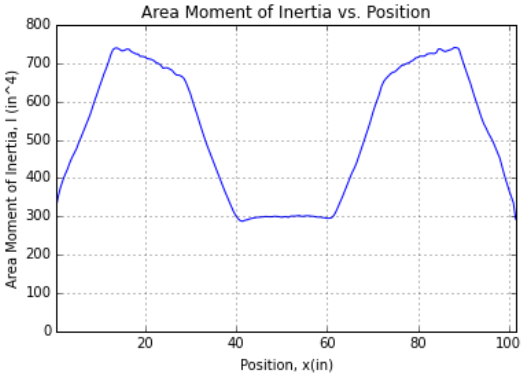


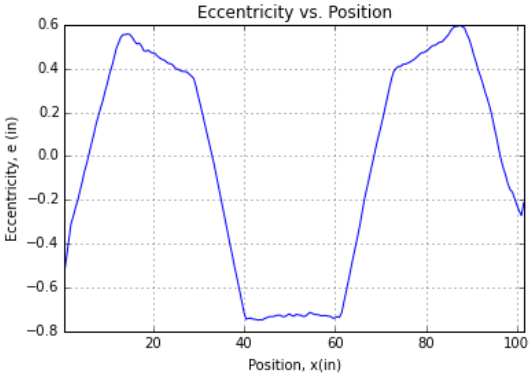


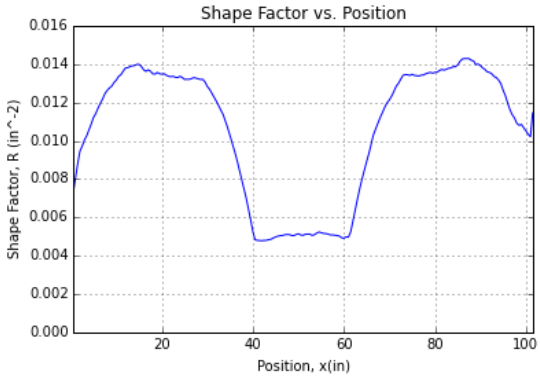
Processed Data:





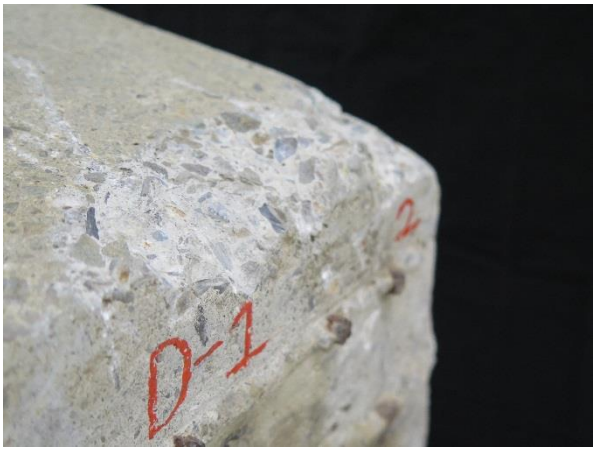






End Pictures:

Damage:

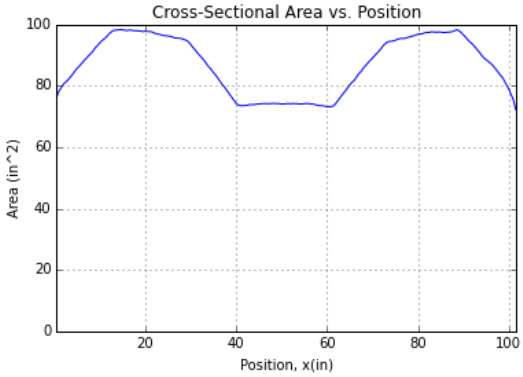


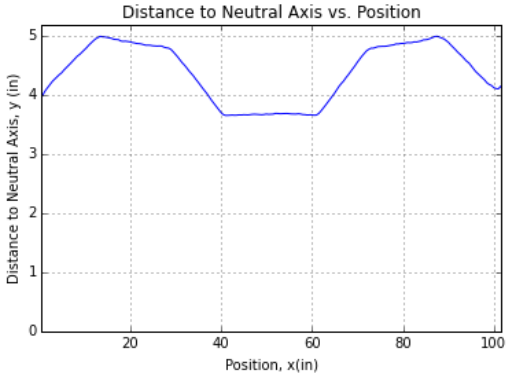
Report for Tie D-2

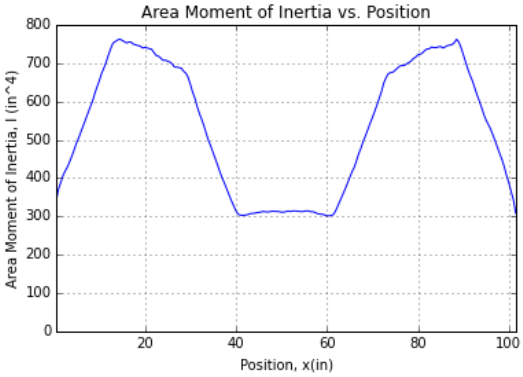
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : D2                                               |
|    Manufacturer : SAN-VEL                                          |
|    Alternate ID : SANTA FE                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.024 in                                              |
|      Right : 3.992 in                                              |
|      Avg.  : 4.008 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        96.63             74.18                 |
|         I   [in^4]       714.45            312.38                 |
|       Y_cog  [in]          4.87              3.68                 |
|       height [in]          9.85              7.42                 |
|         e    [in]          0.59             -0.58                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 90.8 [kips] (D-2)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.87           2.02                        |
|        Right [in]      2.07           1.94                        |
|        Top   [in]      2.46           2.44                        |
|        Bottom[in]      2.72           2.87                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

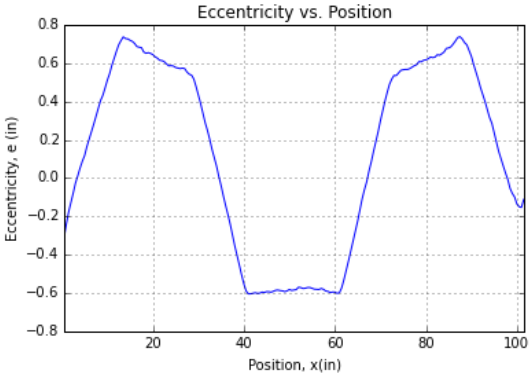
Model Views:

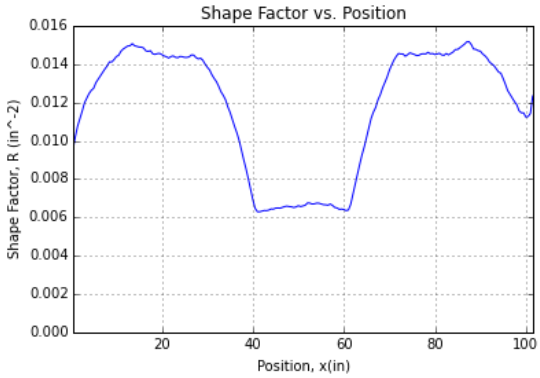
Processed Data:











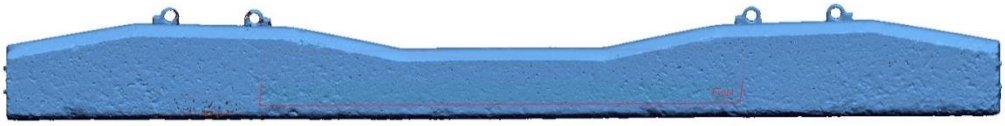
End Pictures:

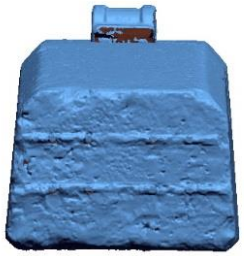
Damage:

Report for Tie D-3

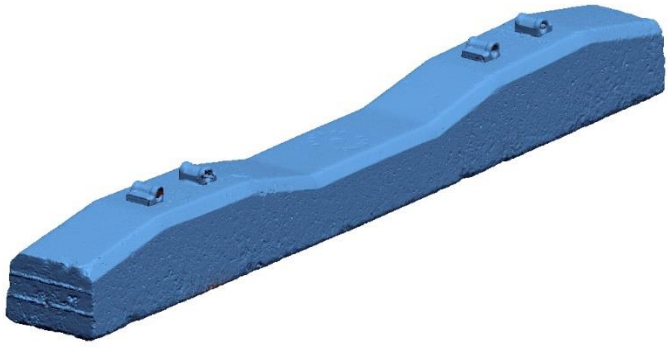
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : D3                                               |
|    Manufacturer : SAN-VEL                                          |
|    Alternate ID : SANTA FE                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.122 in                                              |
|      Right : 4.076 in                                              |
|      Avg.  : 4.099 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        96.30             73.20                  |
|         I   [in^4]       705.21            300.62                  |
|       Y_cog  [in]          4.90              3.70                  |
|       height [in]          9.88              7.28                  |
|         e    [in]          0.87             -0.31                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 90.8 [kips] (D-2)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.87           1.96                         |
|        Right [in]      1.92           1.84                         |
|        Top   [in]      2.41           2.37                         |
|        Bottom[in]      2.73           2.84                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:



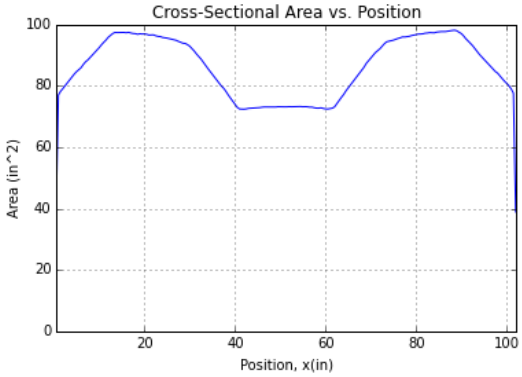


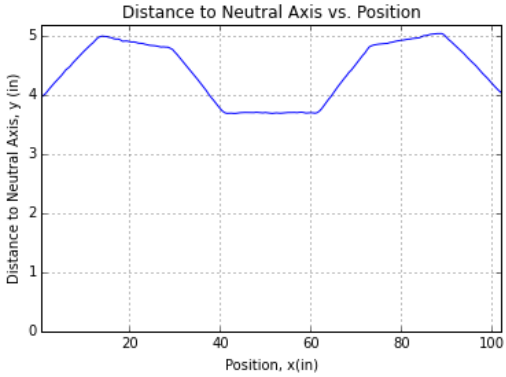
50 mm

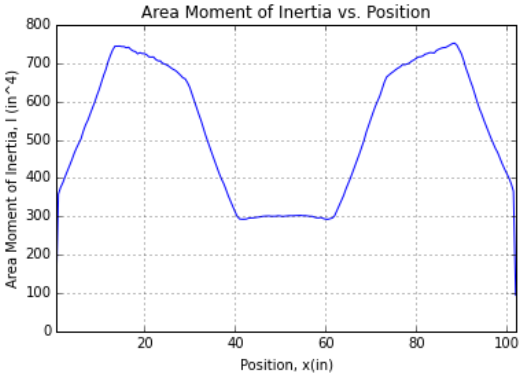


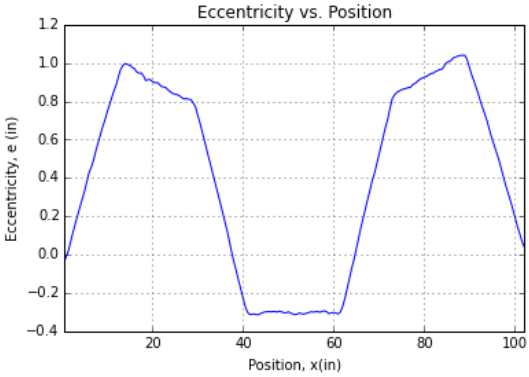
100 mm

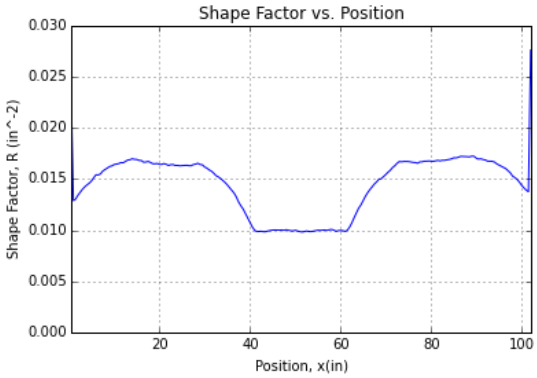
Processed Data:











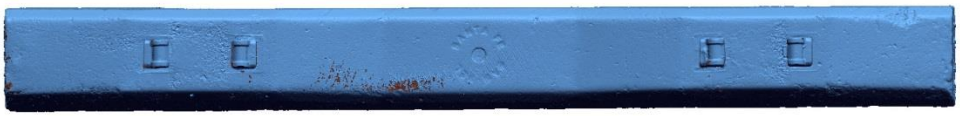
End Pictures:

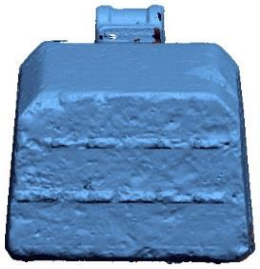
Damage:

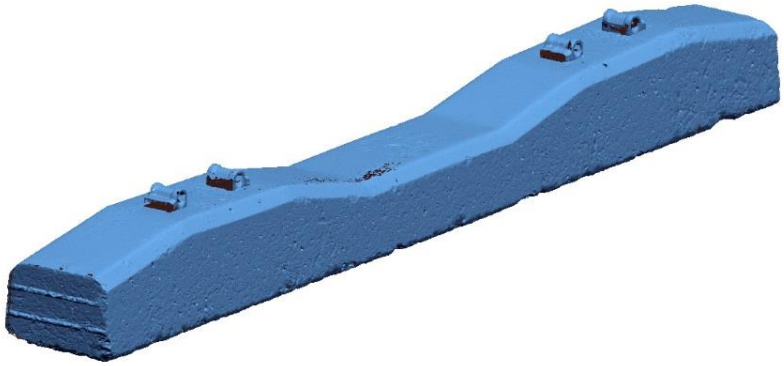
Report for Tie D-4

```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : D4                                                  |
|    Manufacturer : SAN-VEL                                             |
|    Alternate ID : SANTA FE                                            |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.929 in                                                 |
|      Right : 3.958 in                                                 |
|      Avg.  : 3.944 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : STRAND (INDENTED)                                      |
|      Diameter: 0.375 in                                               |
|      Tendons : 8                                                      |
|      Pattern : 4-4                                                    |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        95.89             72.91                    |
|         I   [in^4]       689.03            292.93                    |
|       Y_cog  [in]          4.91              3.71                    |
|       height [in]          9.84              7.32                    |
|         e    [in]          0.86             -0.39                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 91.7 [kips] (D-4)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      1.99           1.85                           |
|        Right [in]      1.84           2.03                           |
|        Top   [in]      2.45           2.47                           |
|        Bottom[in]      2.68           2.79                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : None                                         |
|      Cracking Severity : None                                         |
+-----------------------------------------------------------------------+
```

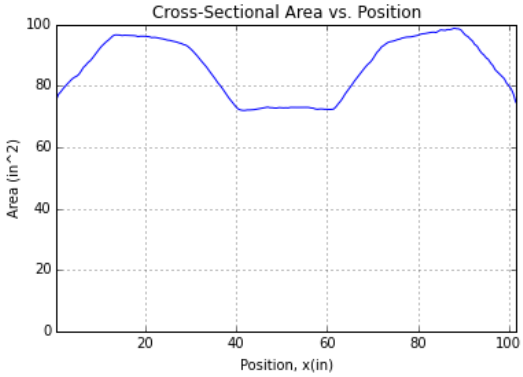
Model Views:

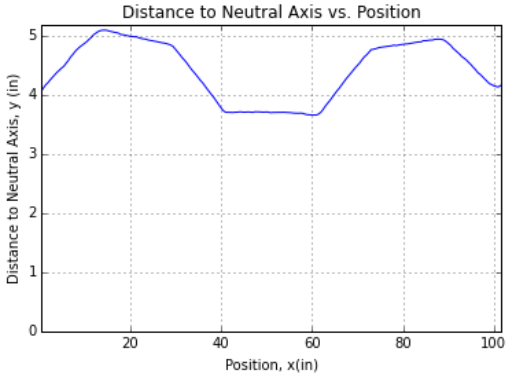


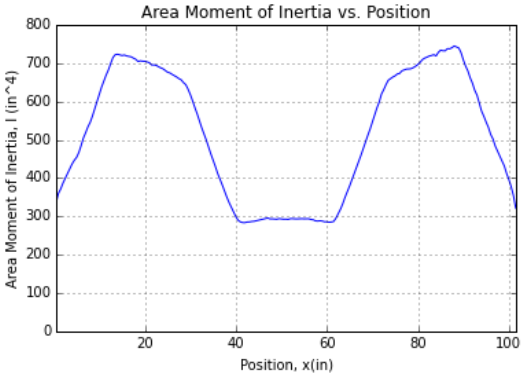


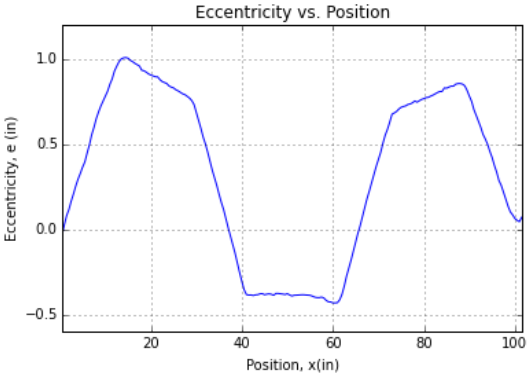


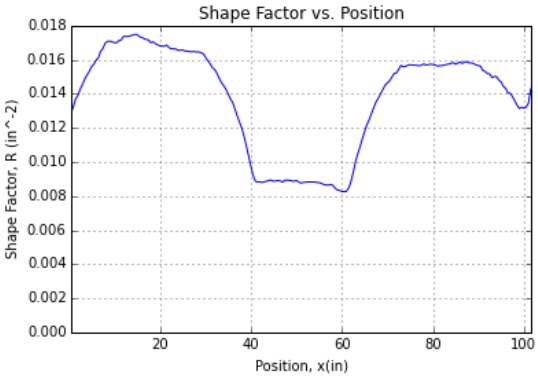
Processed Data:











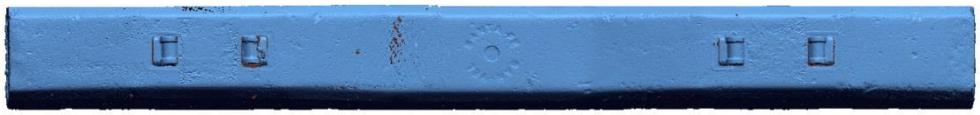
End Pictures:

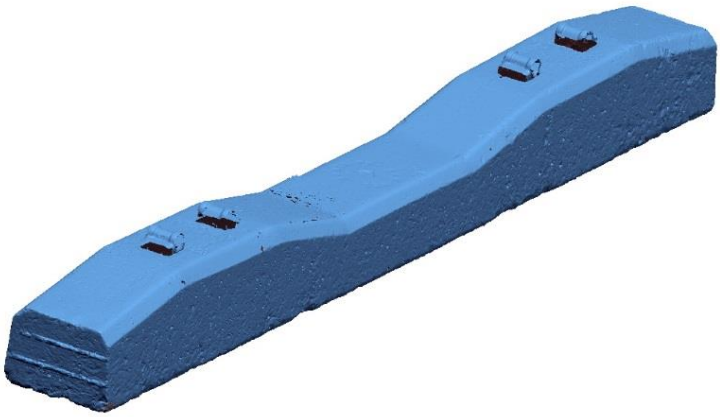
Damage:

Report for Tie D-5

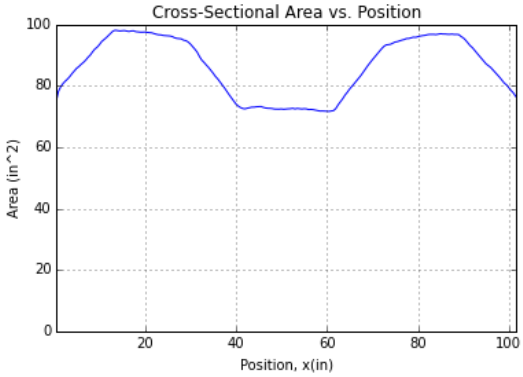
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : D5                                               |
|    Manufacturer : SAN-VEL                                          |
|    Alternate ID : SANTA FE                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.023 in                                              |
|      Right : 3.955 in                                              |
|      Avg.  : 3.989 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        96.30             72.51                 |
|         I   [in^4]       706.90            293.63                 |
|       Y_cog  [in]          4.94              3.72                 |
|       height [in]          9.96              7.40                 |
|         e    [in]          0.97             -0.27                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 90.8 [kips] (D-2)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.99           1.86                        |
|        Right [in]      1.89           2.00                        |
|        Top   [in]      2.48           2.39                        |
|        Bottom[in]      2.73           2.79                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

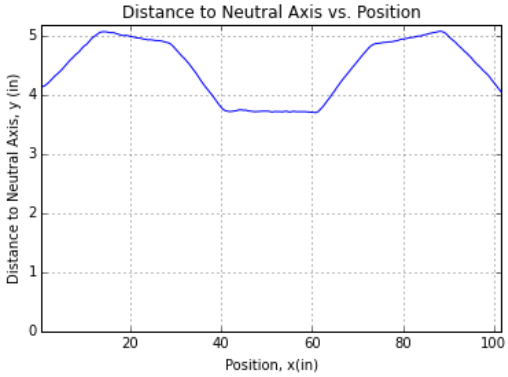
Model Views:

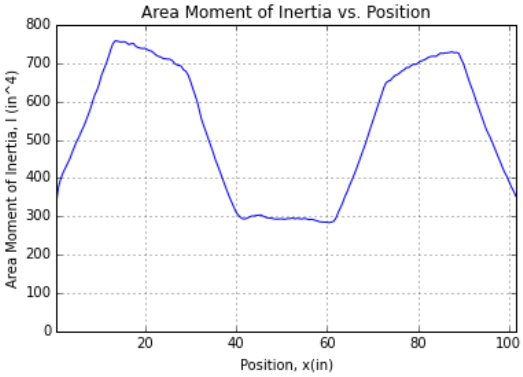


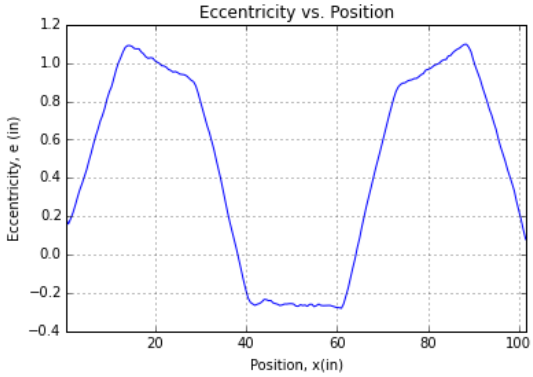


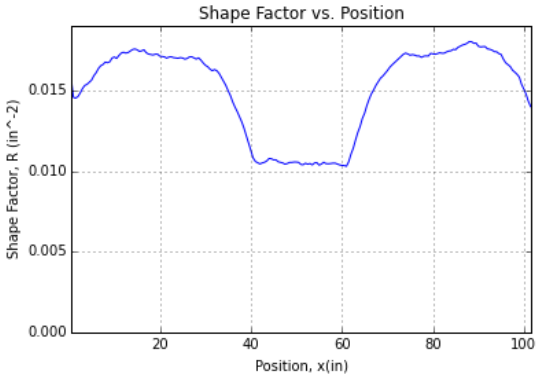
Processed Data:











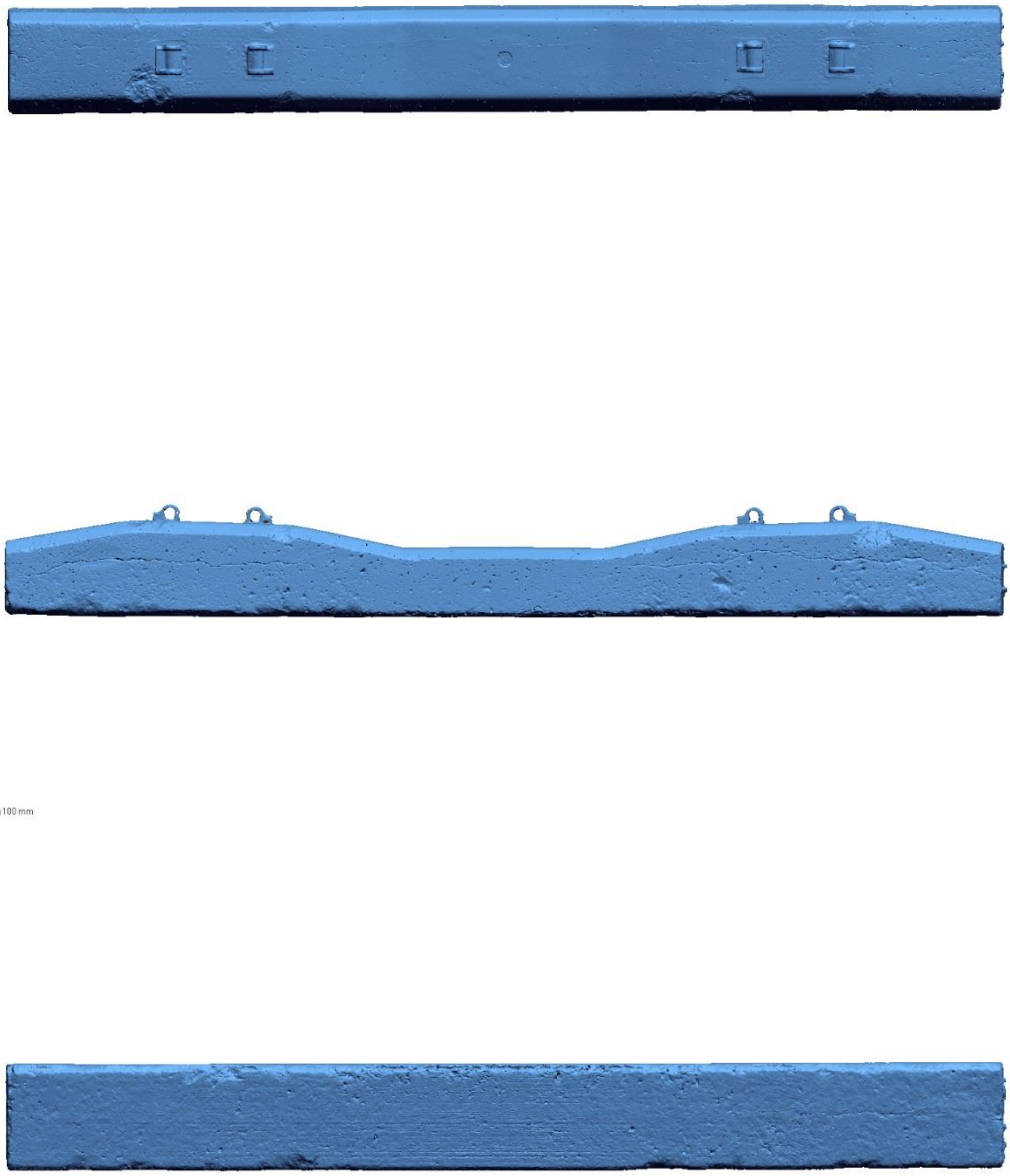
End Pictures:

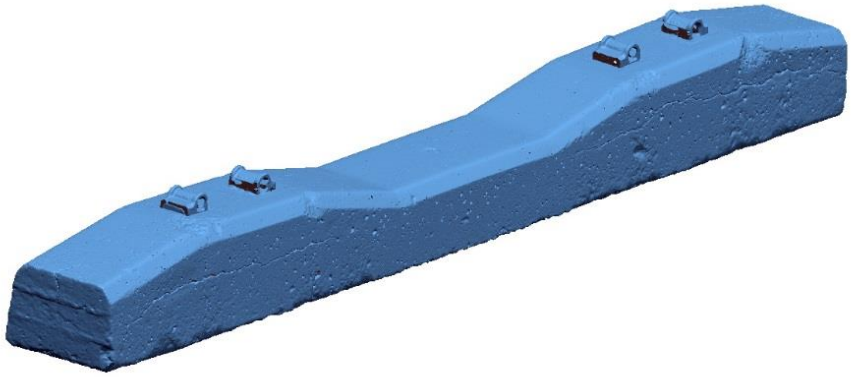
Damage:

Report for Tie D-6

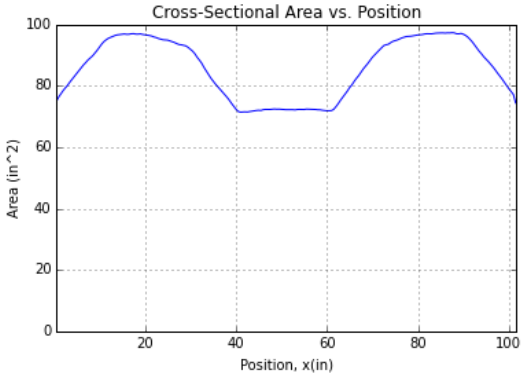
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : D6                                               |
|    Manufacturer : SAN-VEL                                          |
|    Alternate ID : SANTA FE                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.912 in                                              |
|      Right : 3.957 in                                              |
|      Avg.  : 3.934 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.375 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        95.91             72.28                  |
|         I   [in^4]       697.90            290.89                  |
|       Y_cog  [in]          4.87              3.66                  |
|       height [in]          9.84              7.24                  |
|         e    [in]          0.93             -0.27                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 90.8 [kips] (D-2)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.81           1.86                         |
|        Right [in]      1.87           1.93                         |
|        Top   [in]      2.48           2.42                         |
|        Bottom[in]      2.65           2.70                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : Severe                                    |
+--------------------------------------------------------------------+
```

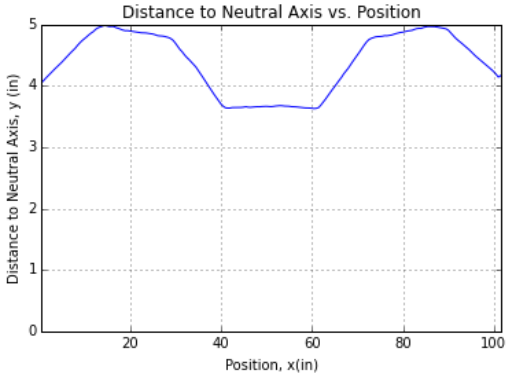
Model Views:

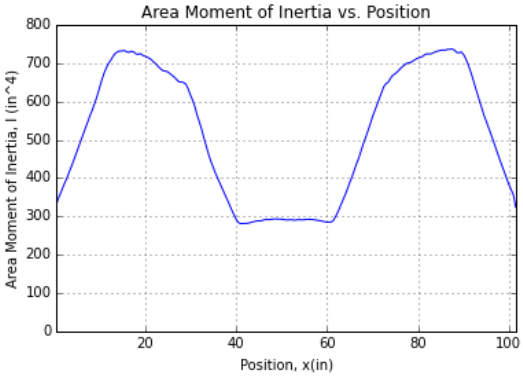


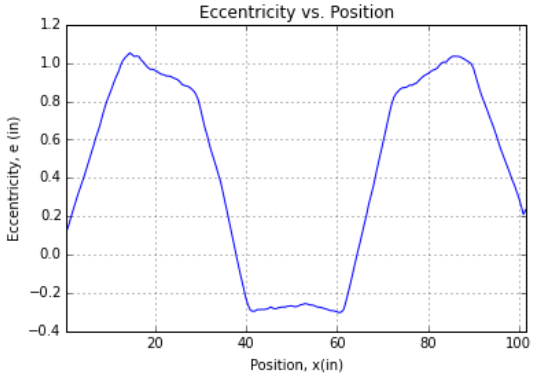


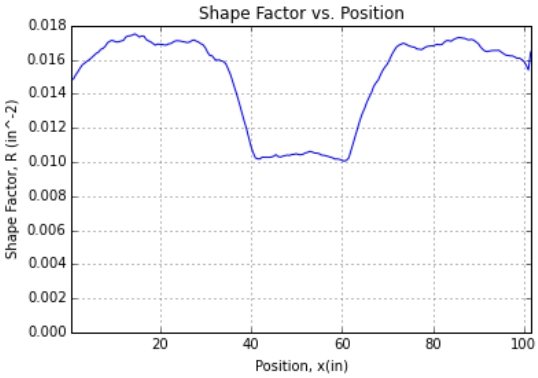
Processed Data:



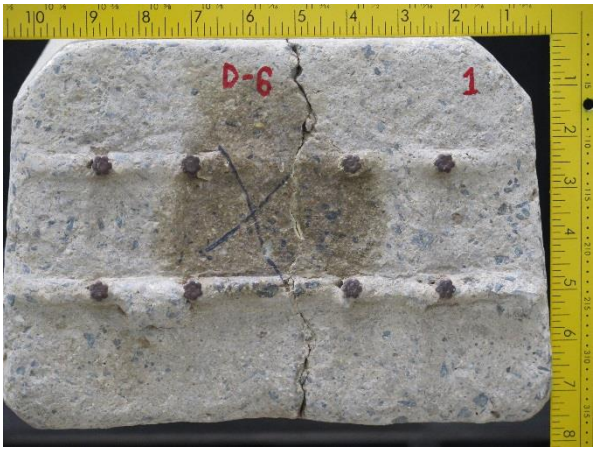


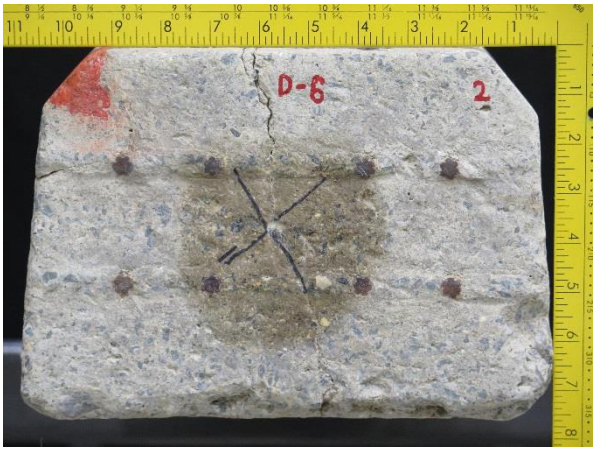






End Pictures:



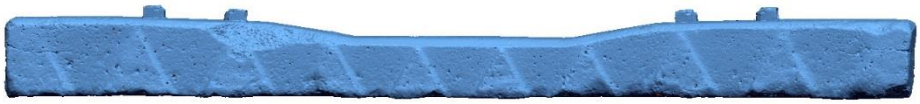


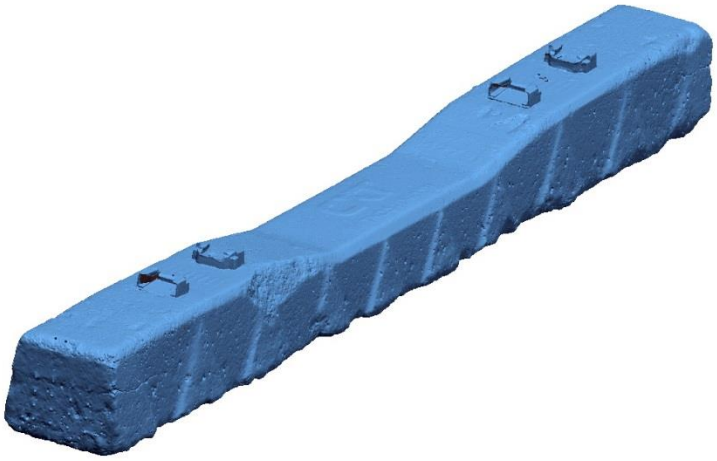
Damage:

Report for Tie E-1

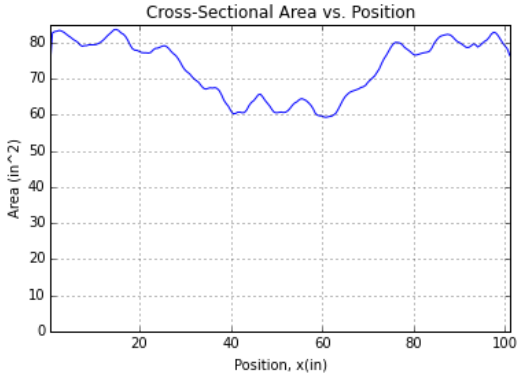
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : E1                                                  |
|    Manufacturer : CXT GRAND ISLAND                                    |
|    Alternate ID : CXT 4975                                            |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.477 in                                                 |
|      Right : 3.399 in                                                 |
|      Avg.  : 3.438 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 5.30 mm                                                |
|      Tendons : 18                                                     |
|      Pattern : 4-4-4-6                                                |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        77.85             60.77                   |
|         I   [in^4]       447.85            216.54                   |
|       Y_cog  [in]          4.27              3.45                   |
|       height [in]          8.66              6.85                   |
|         e    [in]          0.82              0.01                   |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = N/A                                               |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                         |
|        Left  [in]      2.43           2.30                          |
|        Right [in]      2.26           2.33                          |
|        Top   [in]      3.65           3.41                          |
|        Bottom[in]      1.67           1.55                          |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : Low                                          |
+-----------------------------------------------------------------------+
```

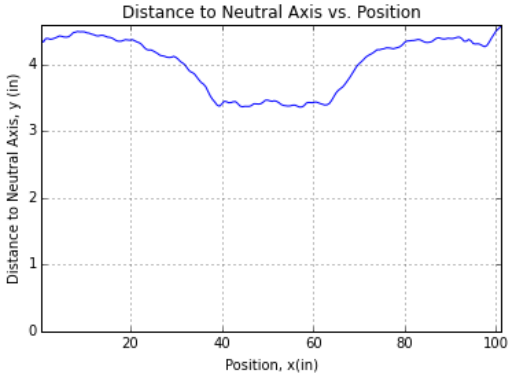
Model Views:

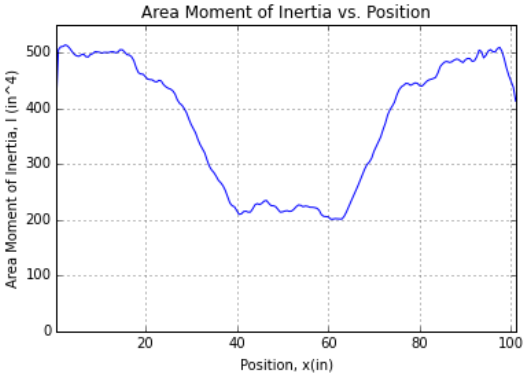


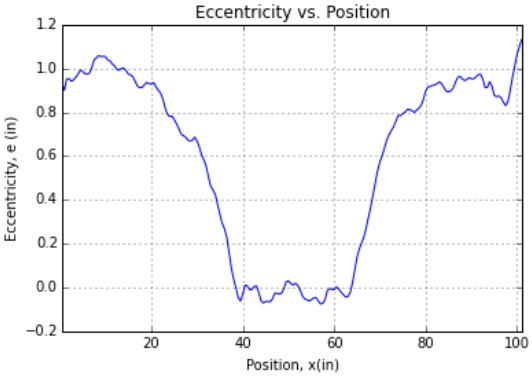


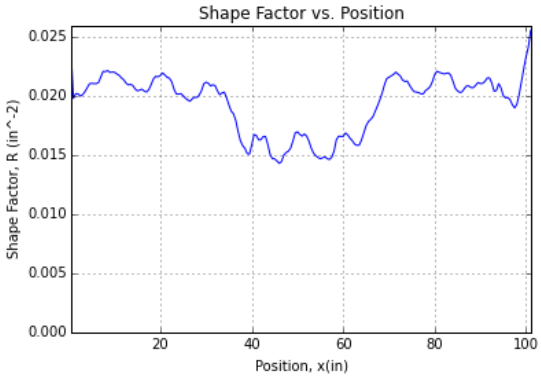
Processed Data:



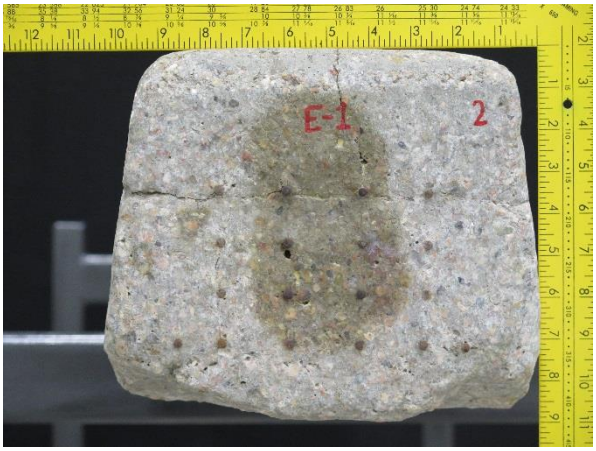








End Pictures:

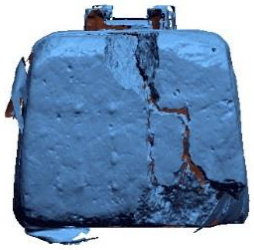


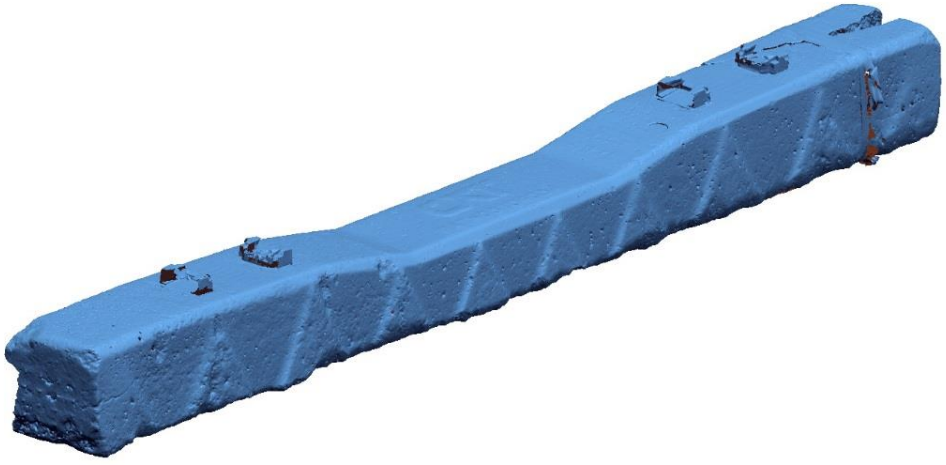
Damage:

Report for Tie E-2

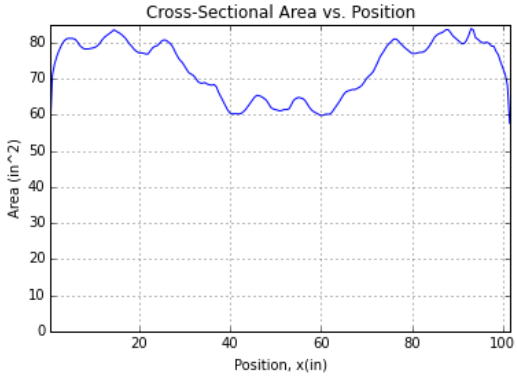
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : E2                                                  |
|    Manufacturer : CXT GRAND ISLAND                                    |
|    Alternate ID : CXT 4975                                            |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.585 in                                                 |
|      Right : 3.314 in                                                 |
|      Avg.  : 3.450 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 5.30 mm                                                |
|      Tendons : 18                                                     |
|      Pattern : 4-4-4-6                                                |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        78.27             61.10                    |
|         I   [in^4]       452.08            217.97                    |
|       Y_cog  [in]          4.20              3.39                    |
|       height [in]          8.58              6.89                    |
|         e    [in]          0.77             -0.06                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = N/A                                               |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      2.00           DAMAGED                         |
|        Right [in]      2.14           DAMAGED                         |
|        Top   [in]      3.38           DAMAGED                         |
|        Bottom[in]      1.74           DAMAGED                         |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : Severe                                       |
+-----------------------------------------------------------------------+
```

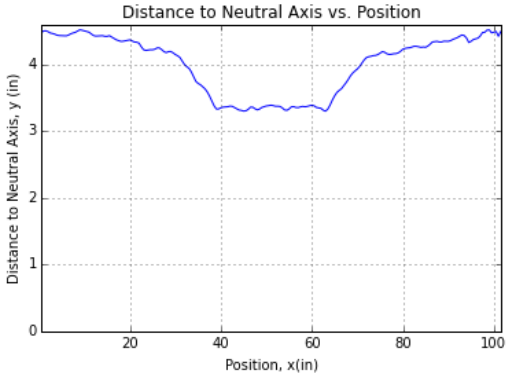
Model Views:

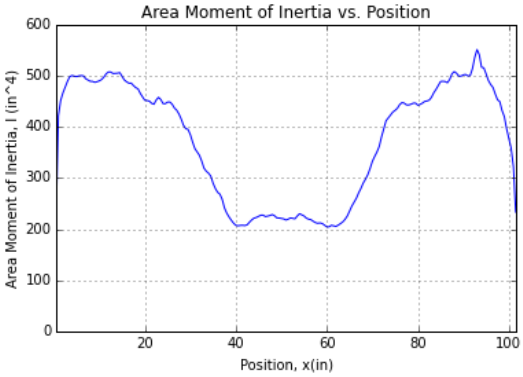


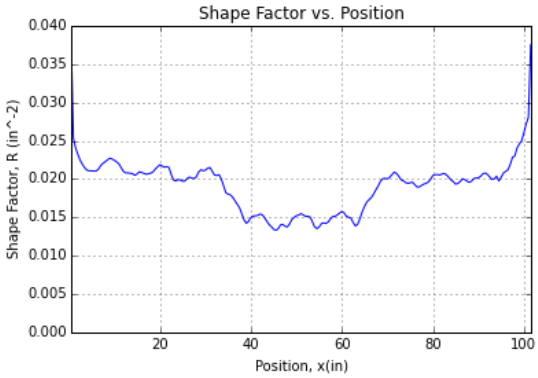


Processed Data:









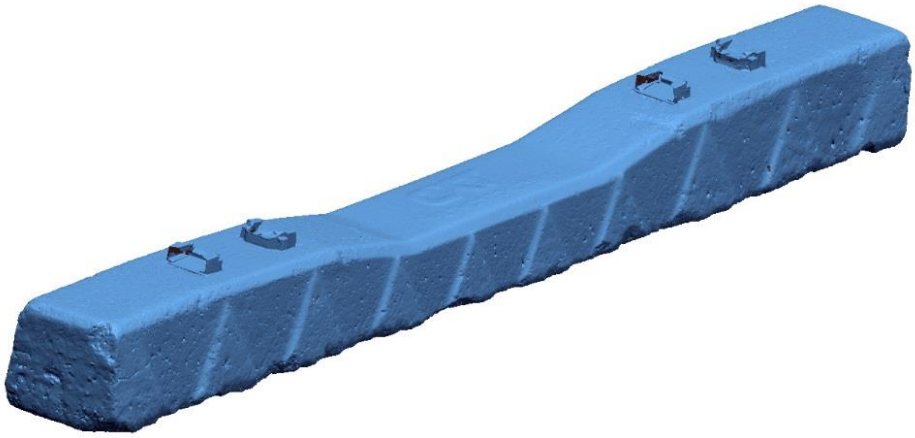
End Pictures:

Damage:

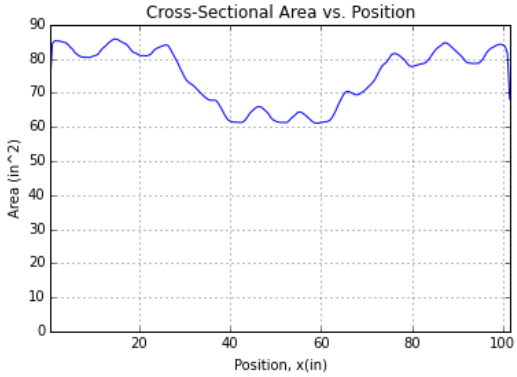
Report for Tie E-3

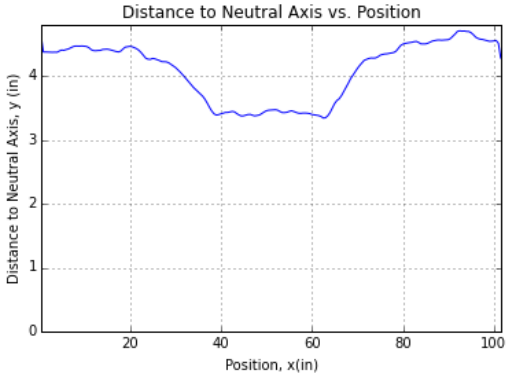
```
+-------------------------------------------------------------------+
|               Test Report                      07/01/2017   Ver1  |
+-------------------------------------------------------------------+
|  Identification                                                   |
|    ID Numbers   : E3                                              |
|    Manufacturer : CXT GRAND ISLAND                                |
|    Alternate ID : CXT 4975                                        |
|    Tie Length   : 8’6”                                            |
+-------------------------------------------------------------------+
|  Test Data                                                        |
|    Wire Centroid                                                  |
|      Left  : 3.490 in                                             |
|      Right : 3.539 in                                             |
|      Avg.  : 3.515 in                                             |
|                                                                   |
|    Wire Info                                                      |
|      Type    : WIRE (INDENTED)                                    |
|      Diameter: 5.30 mm                                            |
|      Tendons : 18                                                 |
|      Pattern : 4-4-4-6                                            |
|                                                                   |
|    Critical Points (Scan)                                         |
|                       Rail Seat Avg.     Center Span              |
|         A   [in^2]        80.20             61.31                |
|         I   [in^4]       484.74            221.36                |
|       Y_cog  [in]          4.37              3.46                |
|       height [in]          8.58              6.89                |
|         e    [in]          0.80             -0.05                |
|                                                                   |
|    Estimated Prestress Force                                      |
|      P_prestress  = N/A                                           |
|                                                                   |
|    Coverage Avg.                                                  |
|                       End #1         End #2                       |
|        Left  [in]      2.47           2.36                       |
|        Right [in]      2.01           2.30                       |
|        Top   [in]      3.31           3.34                       |
|        Bottom[in]      1.80           1.79                       |
|                                                                   |
|    Observations                                                   |
|      Abrasion Severity : Low                                      |
|      Cracking Severity : Low                                      |
+-------------------------------------------------------------------+
```

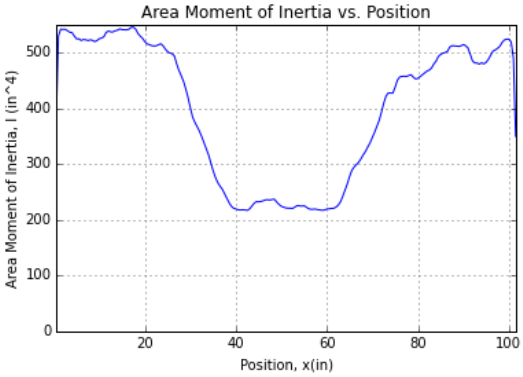
Model Views:

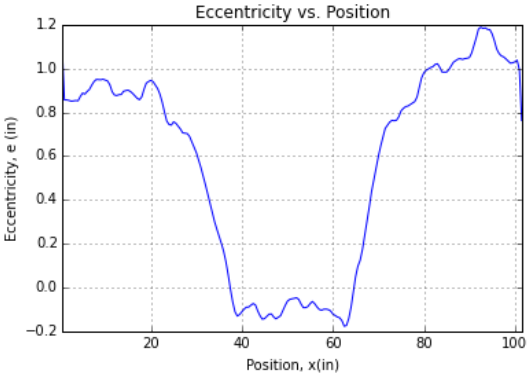


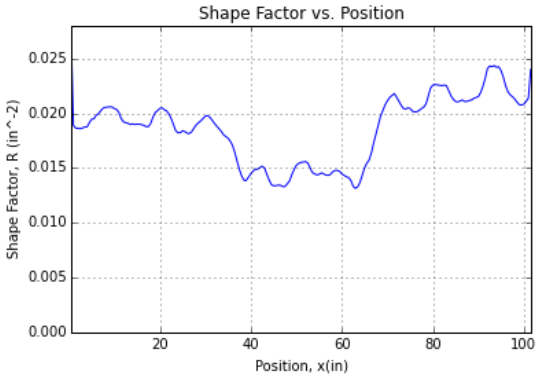
Processed Data:



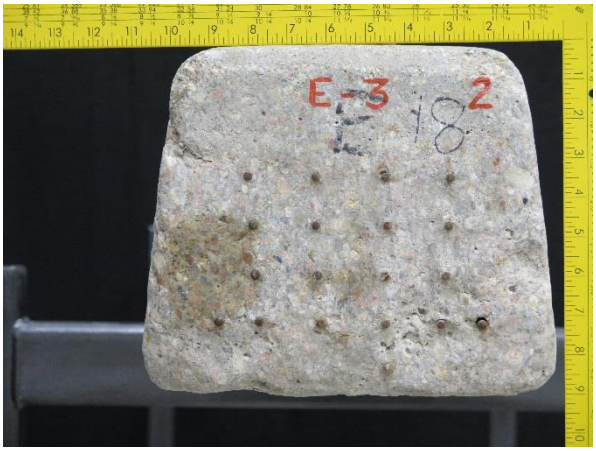








End Pictures:

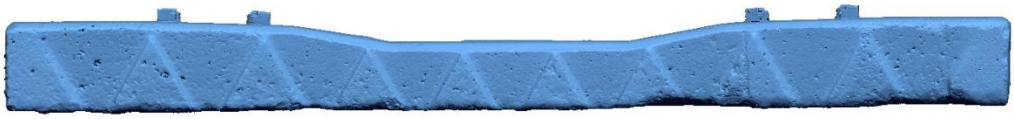


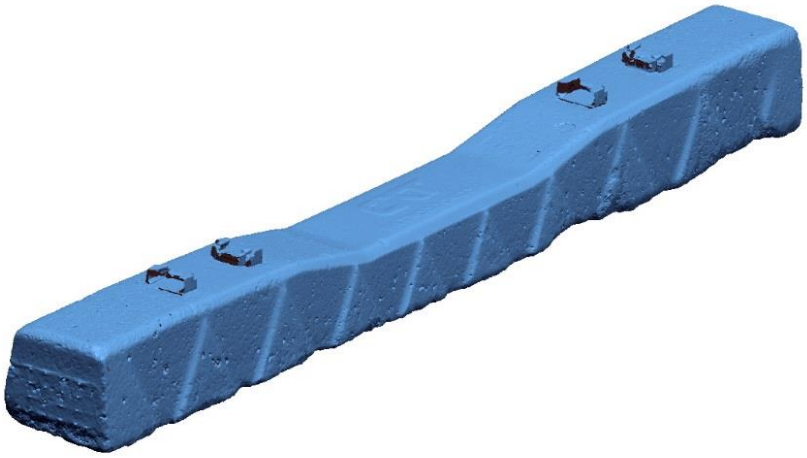
Damage:

Report for Tie E-4

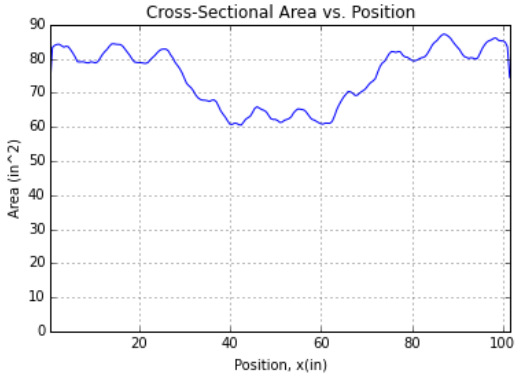
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : E4                                                  |
|    Manufacturer : CXT GRAND ISLAND                                    |
|    Alternate ID : CXT 4975                                            |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.664 in                                                 |
|      Right : 3.539 in                                                 |
|      Avg.  : 3.602 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 5.30 mm                                                |
|      Tendons : 18                                                     |
|      Pattern : 4-4-4-6                                                |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        80.37             61.29                    |
|         I   [in^4]       484.26            219.57                    |
|       Y_cog  [in]          4.40              3.55                    |
|       height [in]          8.94              7.05                    |
|         e    [in]          0.79             -0.05                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = N/A                                               |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      2.25           2.49                           |
|        Right [in]      2.36           2.10                           |
|        Top   [in]      3.48           3.41                           |
|        Bottom[in]      1.79           1.84                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Moderate                                     |
|      Cracking Severity : Low                                          |
+-----------------------------------------------------------------------+
```

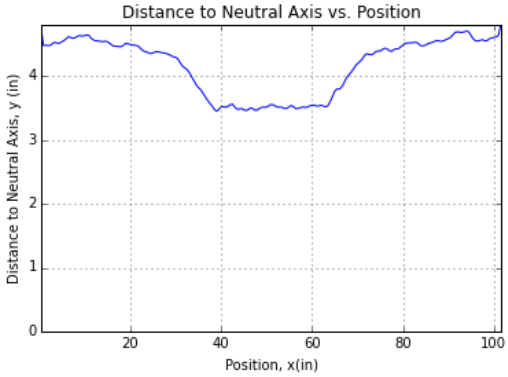
Model Views:

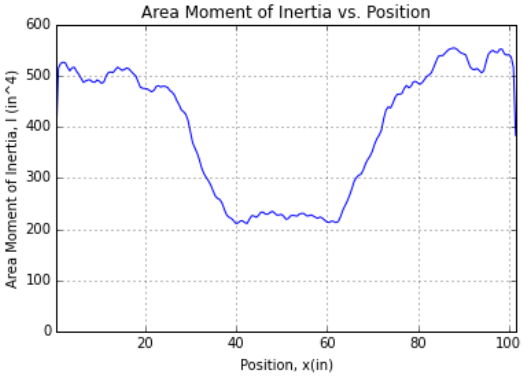


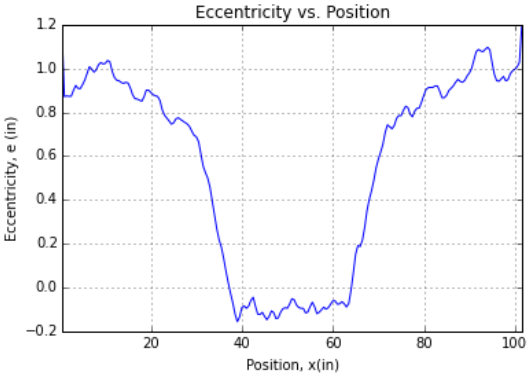


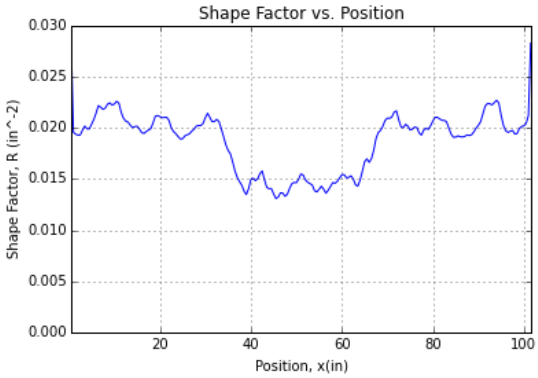
Processed Data:



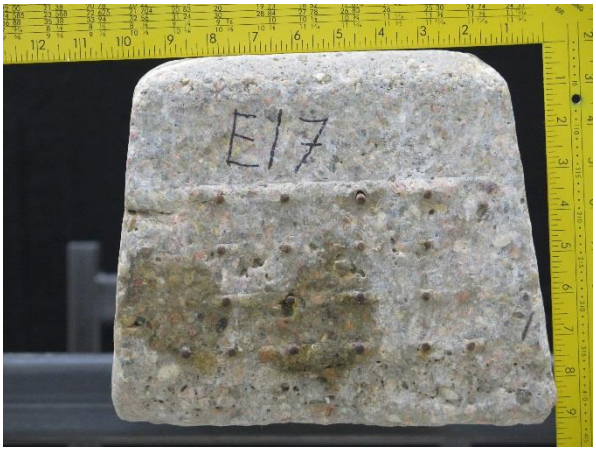








End Pictures:

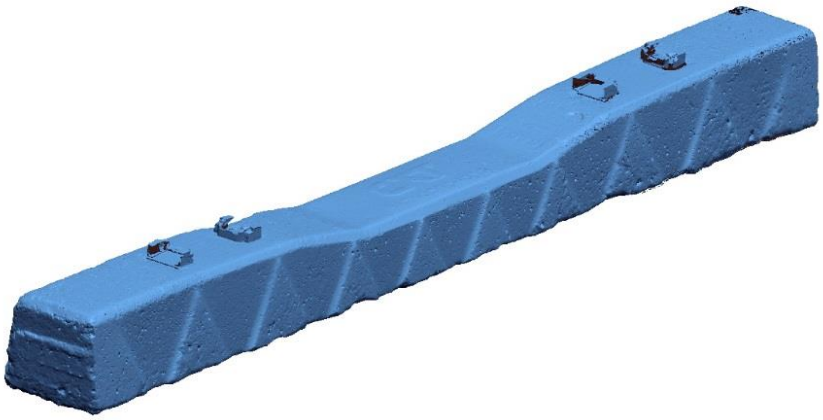


Damage:

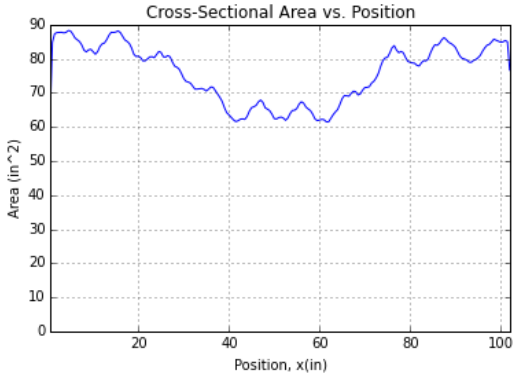
Report for Tie E-5

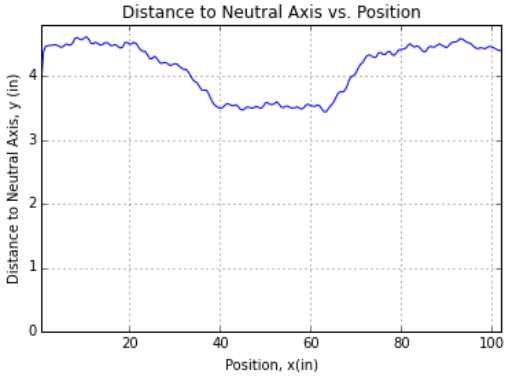
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : E5                                               |
|    Manufacturer : CXT GRAND ISLAND                                 |
|    Alternate ID : CXT 4975                                         |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.297 in                                              |
|      Right : 3.228 in                                              |
|      Avg.  : 3.292 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.30 mm                                             |
|      Tendons : 18                                                  |
|      Pattern : 4-4-4-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        80.47             62.73                  |
|         I   [in^4]       495.40            241.41                  |
|       Y_cog  [in]          4.37              3.55                  |
|       height [in]          8.94              7.28                  |
|         e    [in]          1.09              0.26                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.93           1.82                         |
|        Right [in]      1.74           1.86                         |
|        Top   [in]      3.81           3.78                         |
|        Bottom[in]      1.54           1.48                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : None                                      |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

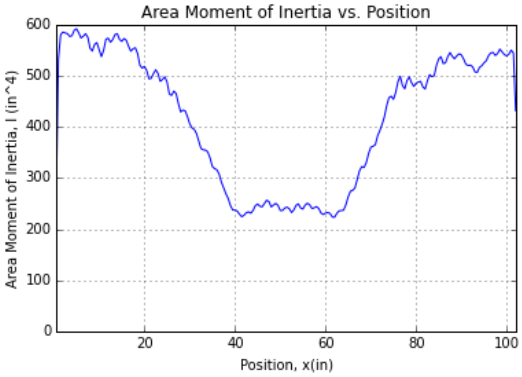
Model Views:

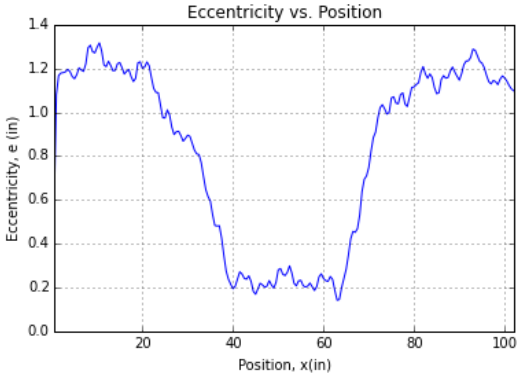


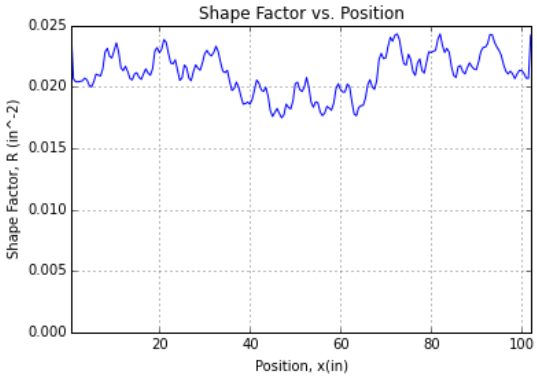
Processed Data:



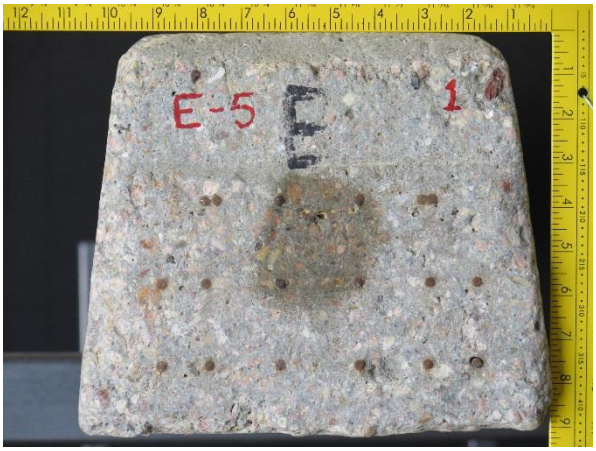








End Pictures:

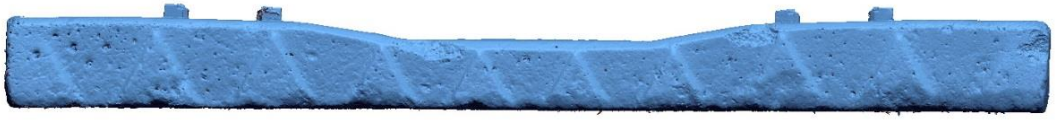


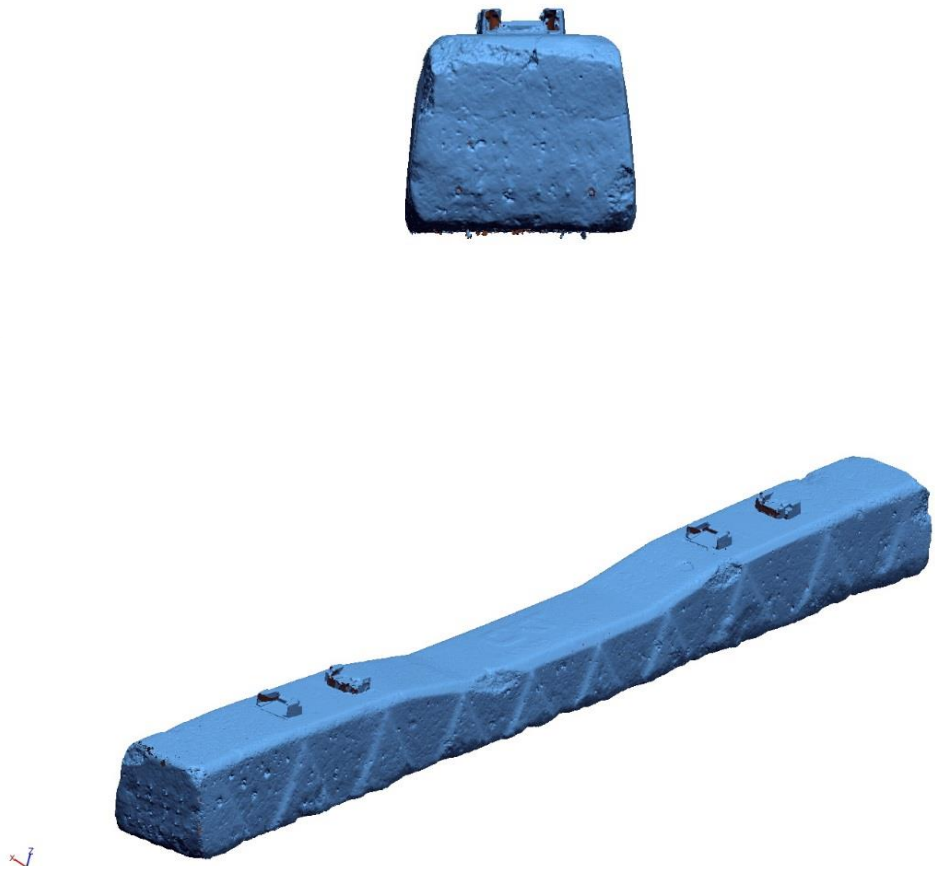
Damage:

Report for Tie E-6

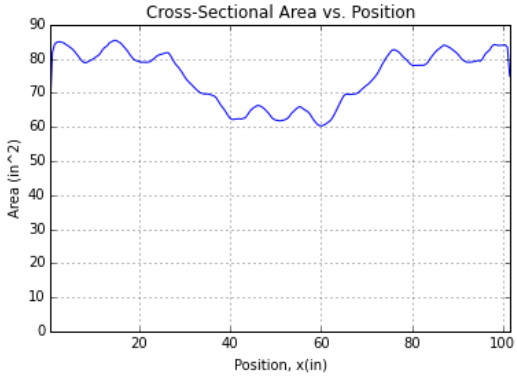
```
+-------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1 |
+-------------------------------------------------------------------+
|  Identification                                                   |
|    ID Numbers   : E6                                              |
|    Manufacturer : CXT GRAND ISLAND                                |
|    Alternate ID : CXT 4975                                        |
|    Tie Length   : 8’6”                                            |
+-------------------------------------------------------------------+
|  Test Data                                                        |
|    Wire Centroid                                                  |
|      Left  : 3.475 in                                             |
|      Right : 3.281 in                                             |
|      Avg.  : 3.378 in                                             |
|                                                                   |
|    Wire Info                                                      |
|      Type    : WIRE (INDENTED)                                    |
|      Diameter: 5.30 mm                                            |
|      Tendons : 18                                                 |
|      Pattern : 4-4-4-6                                            |
|                                                                   |
|    Critical Points (Scan)                                         |
|                       Rail Seat Avg.     Center Span              |
|         A   [in^2]        79.55             61.75                |
|         I   [in^4]       480.06            227.74                |
|       Y_cog  [in]          4.37              3.53                |
|       height [in]          8.88              7.09                |
|         e    [in]          1.01              0.15                |
|                                                                   |
|    Estimated Prestress Force                                      |
|      P_prestress  = N/A                                           |
|                                                                   |
|    Coverage Avg.                                                  |
|                       End #1         End #2                       |
|        Left  [in]      2.54           2.43                       |
|        Right [in]      2.30           2.40                       |
|        Top   [in]      3.40           3.60                       |
|        Bottom[in]      1.71           1.53                       |
|                                                                   |
|    Observations                                                   |
|      Abrasion Severity : Low                                      |
|      Cracking Severity : Moderate                                 |
+-------------------------------------------------------------------+
```

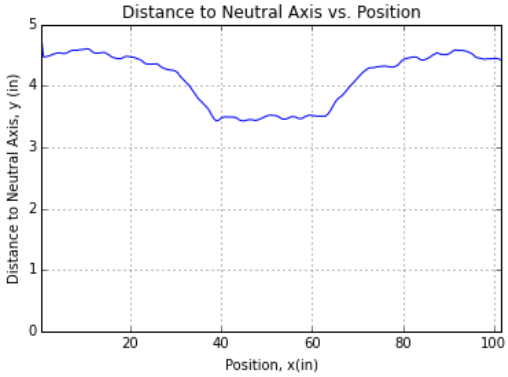
Model Views:

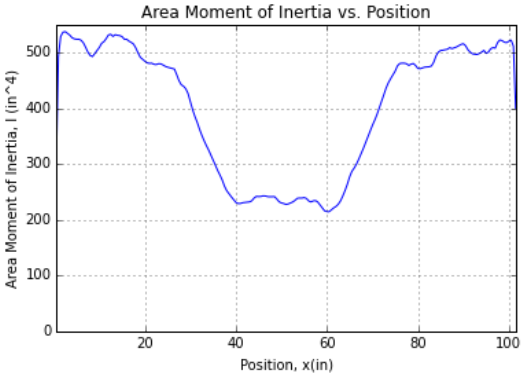


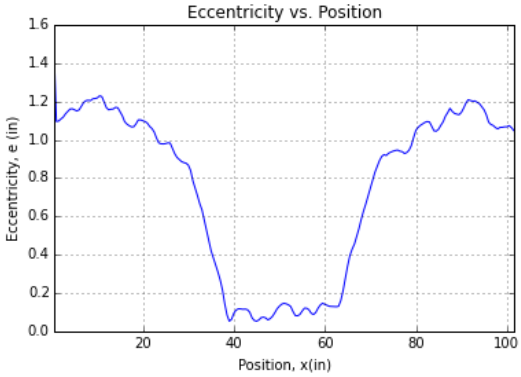


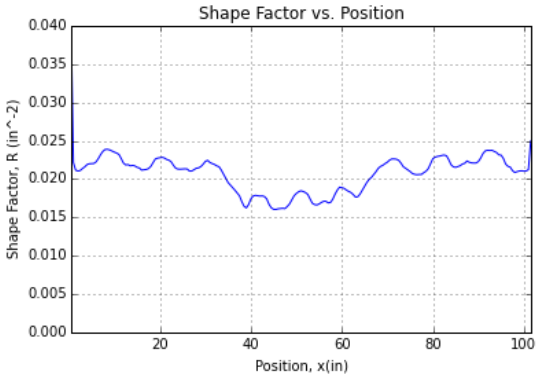
Processed Data:





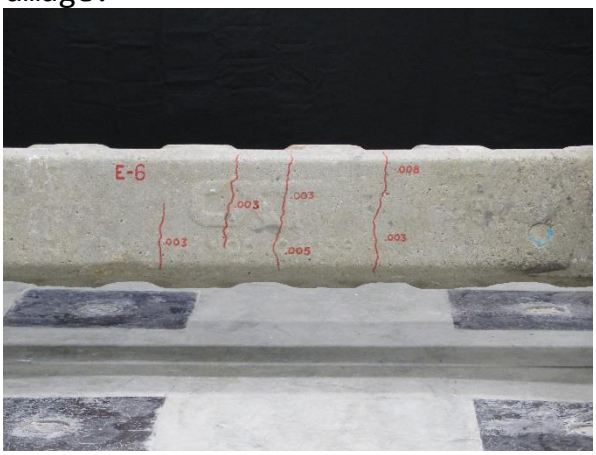






End Pictures:

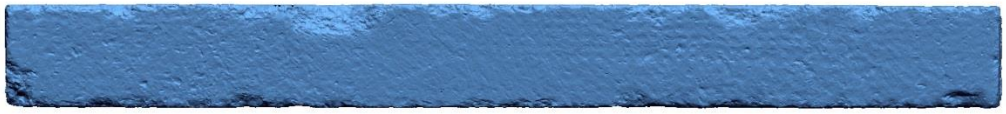
Damage:

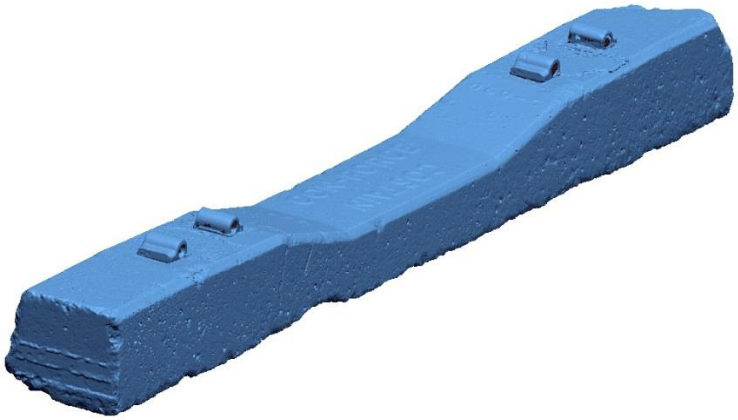


Report for Tie F-1

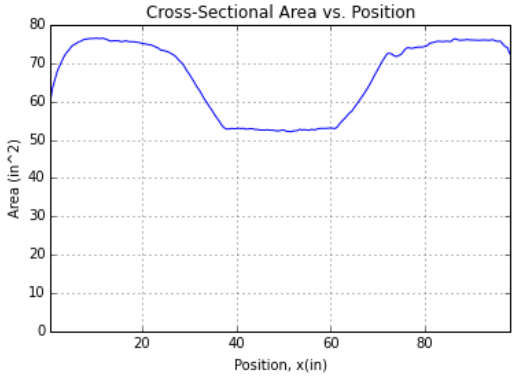
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : F1                                               |
|    Manufacturer : CONFORCE COSTAIN                                 |
|    Alternate ID : CN 60A                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 2.783 in                                              |
|      Right : 2.661 in                                              |
|      Avg.  : 2.722 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.86 mm                                             |
|      Tendons : 26                                                  |
|      Pattern : 10-6-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        74.45             52.43                 |
|         I   [in^4]       381.92            128.52                 |
|       Y_cog  [in]          3.94              2.83                 |
|       height [in]          8.27              5.67                 |
|         e    [in]          1.20              0.11                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 82.4 [kips] (F-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.43           1.32                         |
|        Right [in]      1.26           1.24                         |
|        Top   [in]      4.26           4.02                         |
|        Bottom[in]      1.38           1.45                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

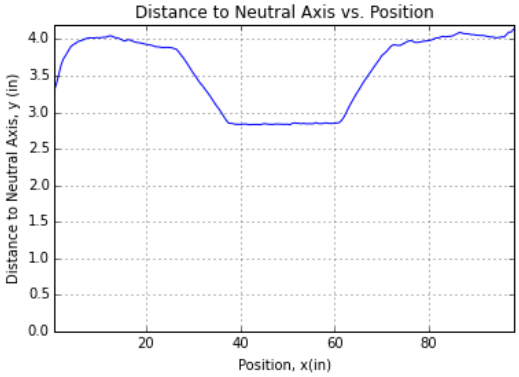
Model Views:

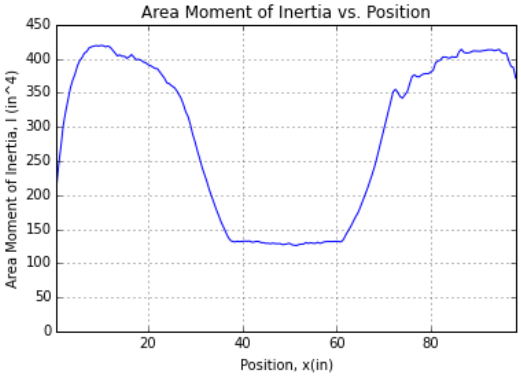


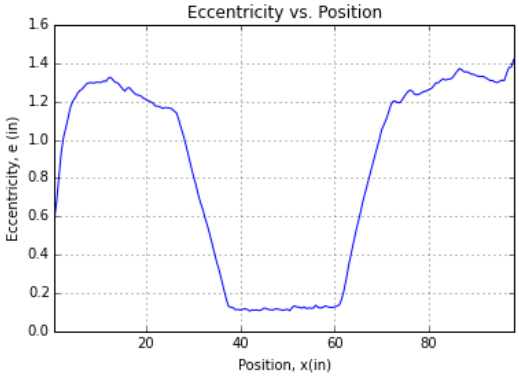


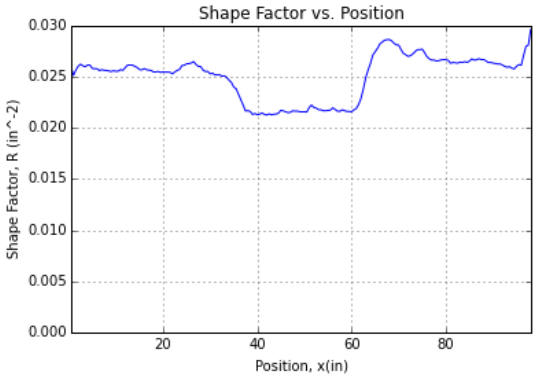
Processed Data:



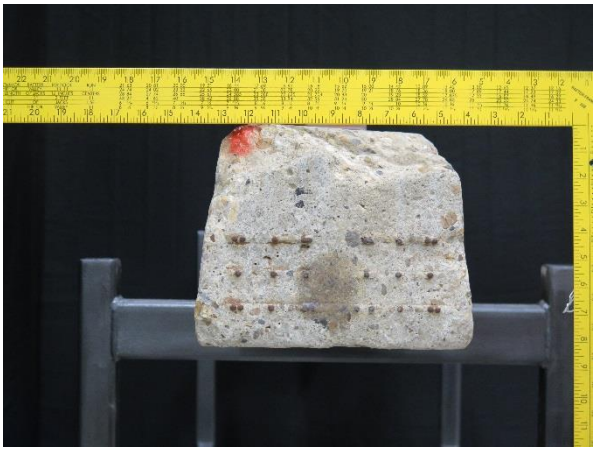








End Pictures:

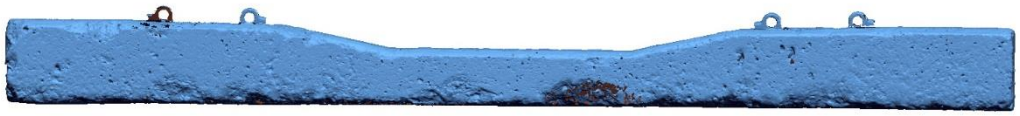


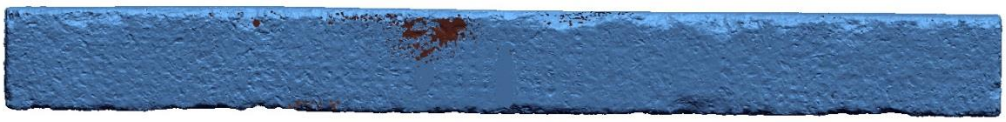
Damage:

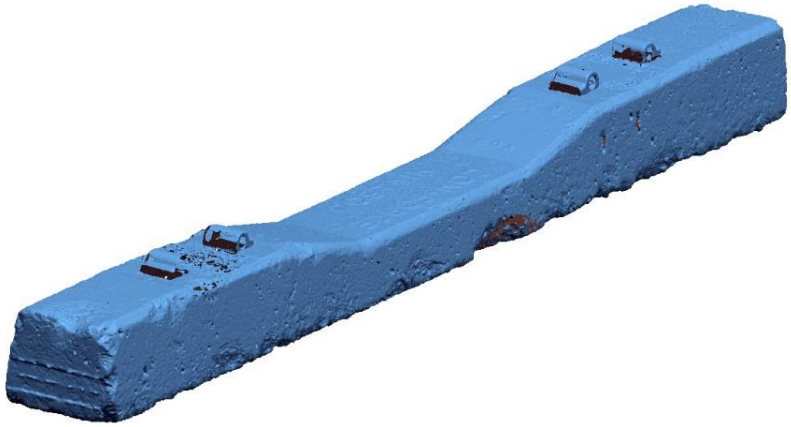
Report for Tie F-2

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : F2                                               |
|    Manufacturer : CONFORCE COSTAIN                                 |
|    Alternate ID : CN 60A                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 2.434 in                                              |
|      Right : 2.398 in                                              |
|      Avg.  : 2.416 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.86 mm                                             |
|      Tendons : 26                                                  |
|      Pattern : 10-6-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.83             52.85                  |
|         I   [in^4]       356.49            130.14                  |
|       Y_cog  [in]          4.00              2.88                  |
|       height [in]          8.09              5.75                  |
|         e    [in]          1.28              0.16                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 82.4 [kips] (F-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.23           1.27                         |
|        Right [in]      1.27           1.22                         |
|        Top   [in]      4.13           4.13                         |
|        Bottom[in]      1.32           1.33                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

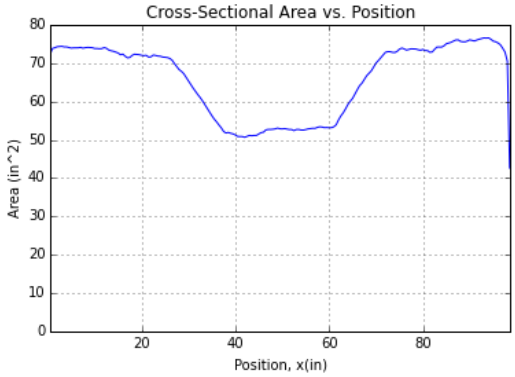
Model Views:

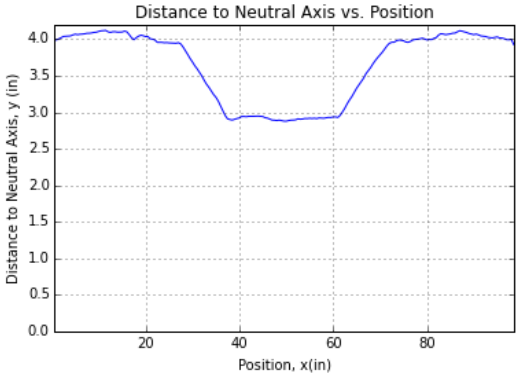


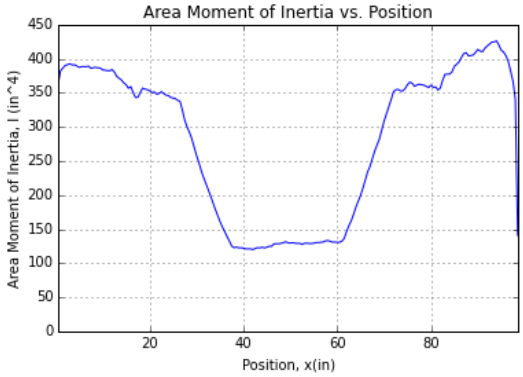


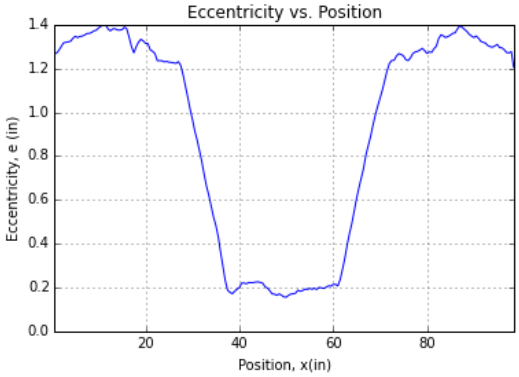


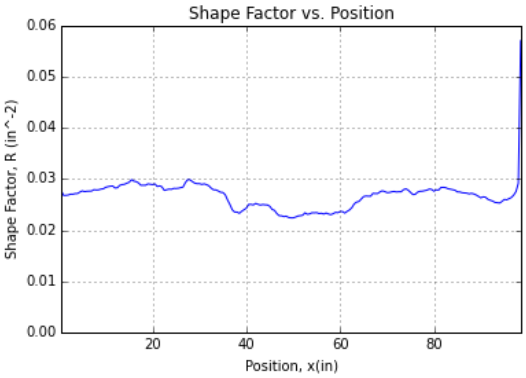
Processed Data:



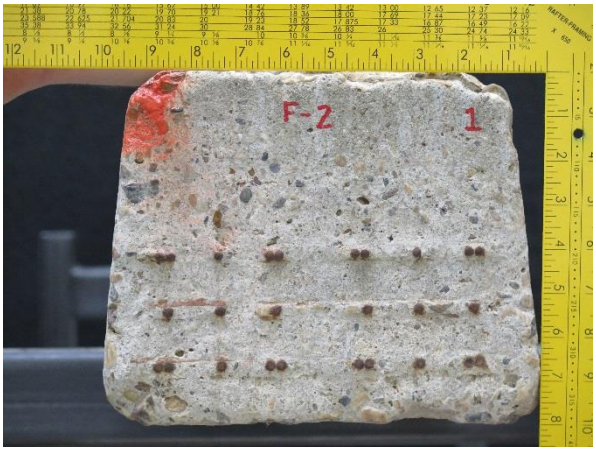


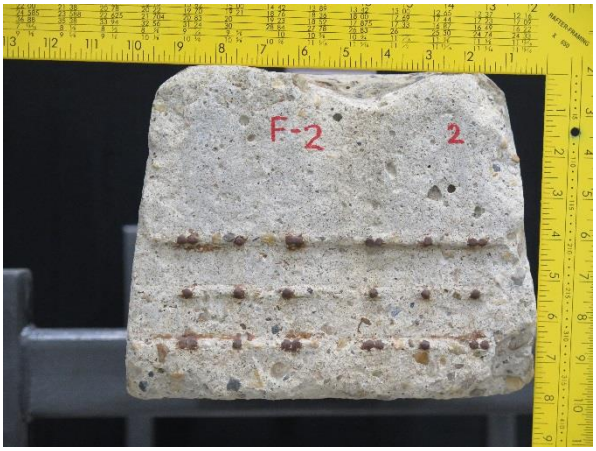






End Pictures:





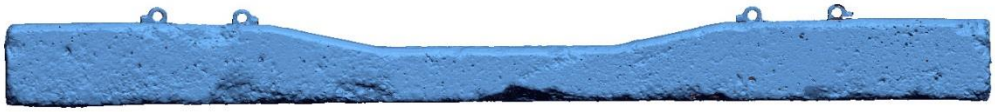
Damage:

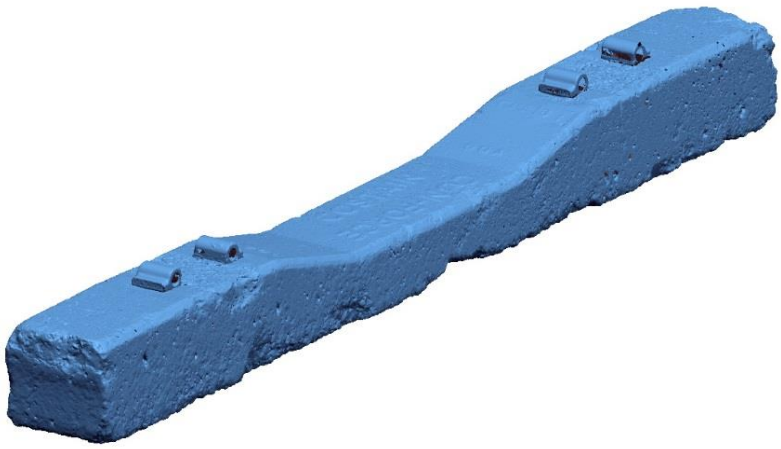
Notes: Moderate abrasion on rail seat.

Report for Tie F-3

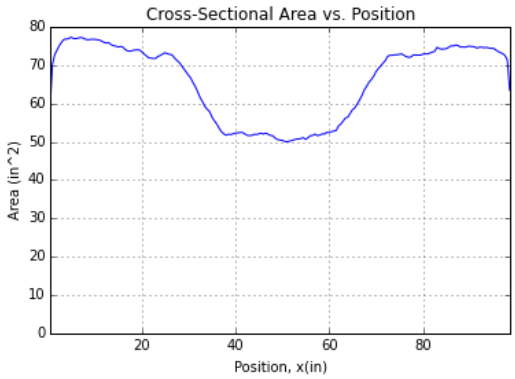
```
+-------------------------------------------------------------------+
|               Test Report                      07/01/2017   Ver1  |
+-------------------------------------------------------------------+
|  Identification                                                   |
|    ID Numbers   : F3                                              |
|    Manufacturer : CONFORCE COSTAIN                                |
|    Alternate ID : CN 60A                                          |
|    Tie Length   : 8’3”                                            |
+-------------------------------------------------------------------+
|  Test Data                                                        |
|    Wire Centroid                                                  |
|      Left  : 2.594 in                                             |
|      Right : 2.635 in                                             |
|      Avg.  : 2.615 in                                             |
|                                                                   |
|    Wire Info                                                      |
|      Type    : WIRE (INDENTED)                                    |
|      Diameter: 4.86 mm                                            |
|      Tendons : 26                                                 |
|      Pattern : 10-6-10                                            |
|                                                                   |
|    Critical Points (Scan)                                         |
|                      Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.53             50.41                |
|         I   [in^4]       360.99            115.48                |
|       Y_cog  [in]          4.21              3.20                |
|       height [in]          8.05              5.67                |
|         e    [in]          1.56              0.59                |
|                                                                   |
|    Estimated Prestress Force                                      |
|      P_prestress  = 82.4 [kips] (F-6)                             |
|                                                                   |
|    Coverage Avg.                                                  |
|                      End #1         End #2                        |
|        Left  [in]      1.28           1.12                        |
|        Right [in]      1.35           1.23                        |
|        Top   [in]      4.19           4.38                        |
|        Bottom[in]      1.29           1.34                        |
|                                                                   |
|    Observations                                                   |
|      Abrasion Severity : Moderate                                 |
|      Cracking Severity : None                                     |
+-------------------------------------------------------------------+
```

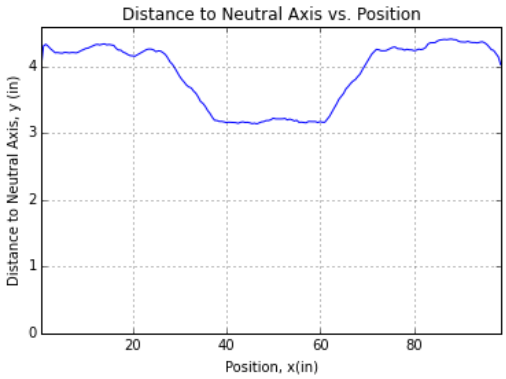
Model Views:

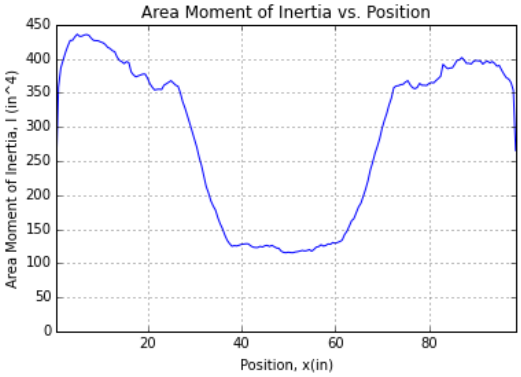


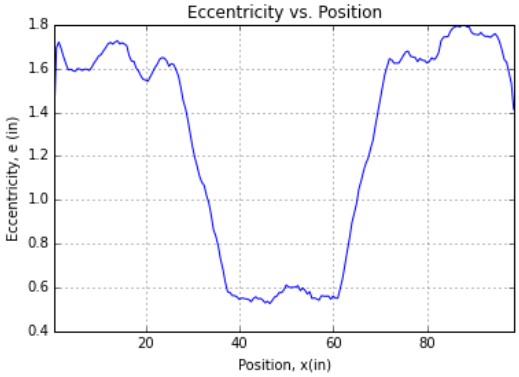


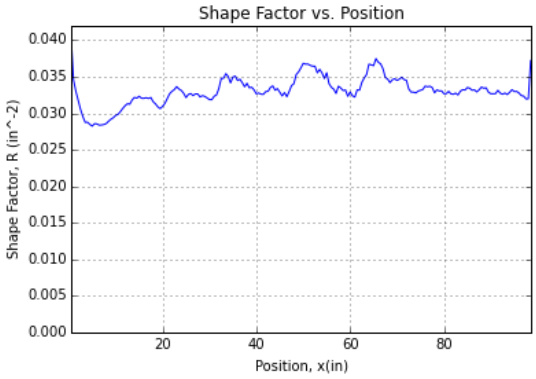
Processed Data:











End Pictures:

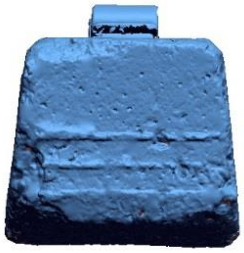
Damage:

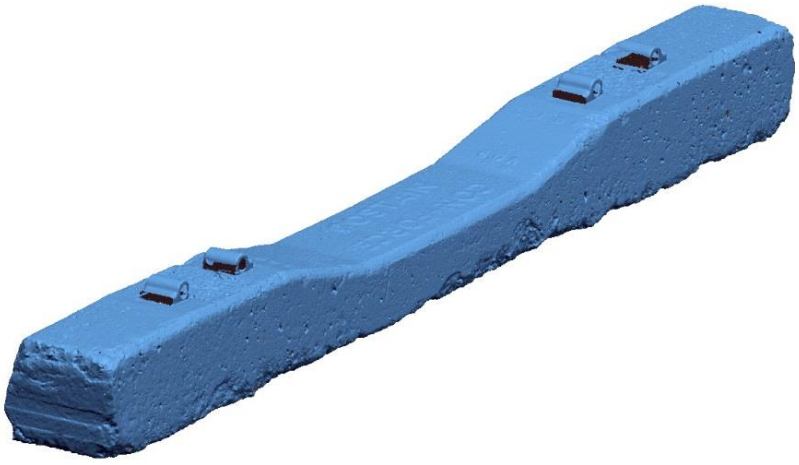
Notes: Moderate abrasion observed on rail seat.

Report for Tie F-4

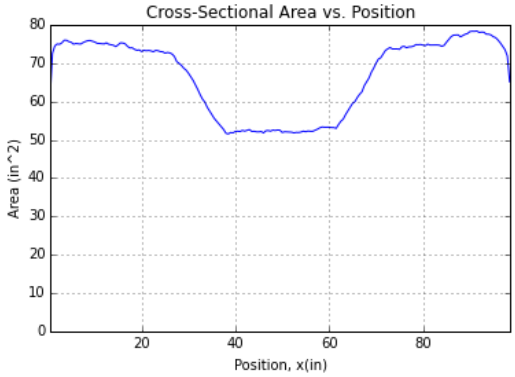
```
+-------------------------------------------------------------------+
|               Test Report                      07/01/2017   Ver1  |
+-------------------------------------------------------------------+
|  Identification                                                   |
|    ID Numbers   : F4                                              |
|    Manufacturer : CONFORCE COSTAIN                                |
|    Alternate ID : CN 60A                                          |
|    Tie Length   : 8’3”                                            |
+-------------------------------------------------------------------+
|  Test Data                                                        |
|    Wire Centroid                                                  |
|      Left  : 2.613 in                                             |
|      Right : 2.617 in                                             |
|      Avg.  : 2.615 in                                             |
|                                                                   |
|    Wire Info                                                      |
|      Type    : WIRE (INDENTED)                                    |
|      Diameter: 4.86 mm                                            |
|      Tendons : 26                                                 |
|      Pattern : 10-6-10                                            |
|                                                                   |
|    Critical Points (Scan)                                         |
|                      Rail Seat Avg.     Center Span               |
|         A   [in^2]        73.78             52.47                |
|         I   [in^4]       381.07            130.76                |
|       Y_cog  [in]          4.14              3.02                |
|       height [in]          8.23              5.87                |
|         e    [in]          1.53              0.40                |
|                                                                   |
|    Estimated Prestress Force                                      |
|      P_prestress  = 82.4 [kips] (F-6)                             |
|                                                                   |
|    Coverage Avg.                                                  |
|                      End #1         End #2                        |
|        Left  [in]      1.05           1.15                        |
|        Right [in]      1.39           1.13                        |
|        Top   [in]      4.40           4.33                        |
|        Bottom[in]      1.18           1.33                        |
|                                                                   |
|    Observations                                                   |
|      Abrasion Severity : Moderate                                 |
|      Cracking Severity : None                                     |
+-------------------------------------------------------------------+
```

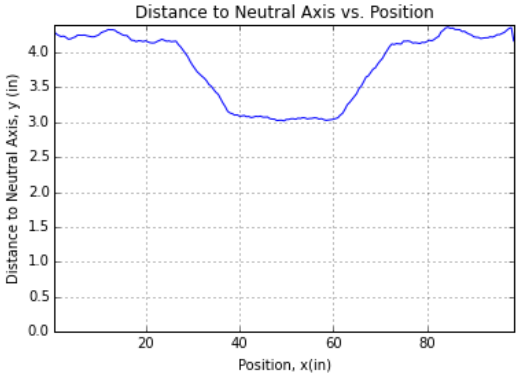
Model Views:

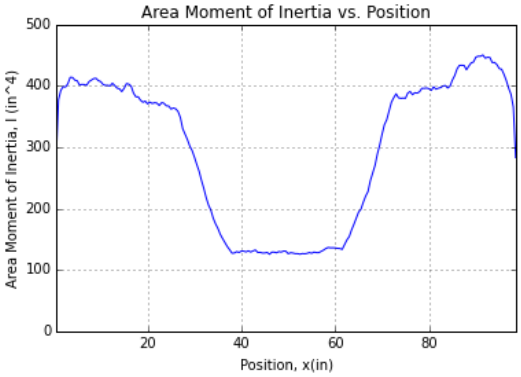


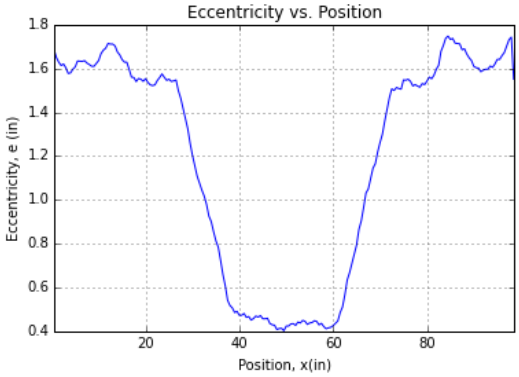


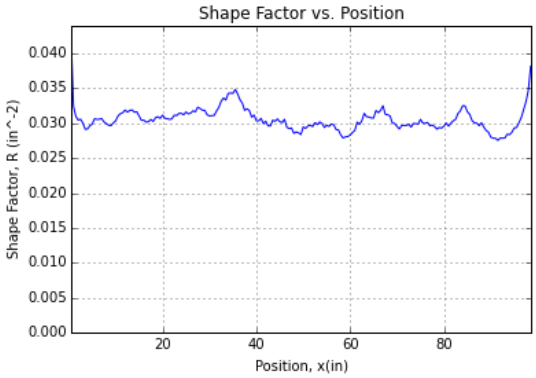
Processed Data:



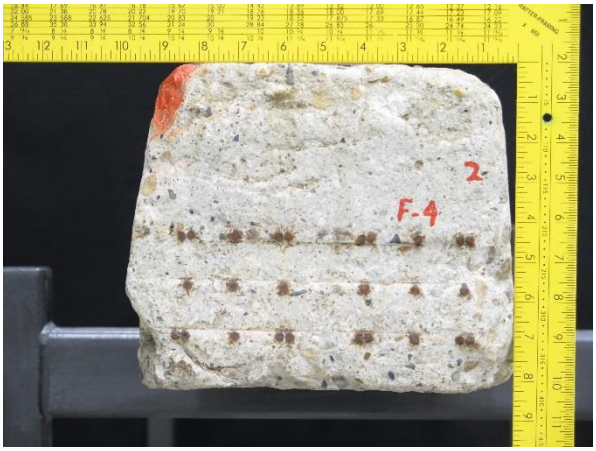








End Pictures:



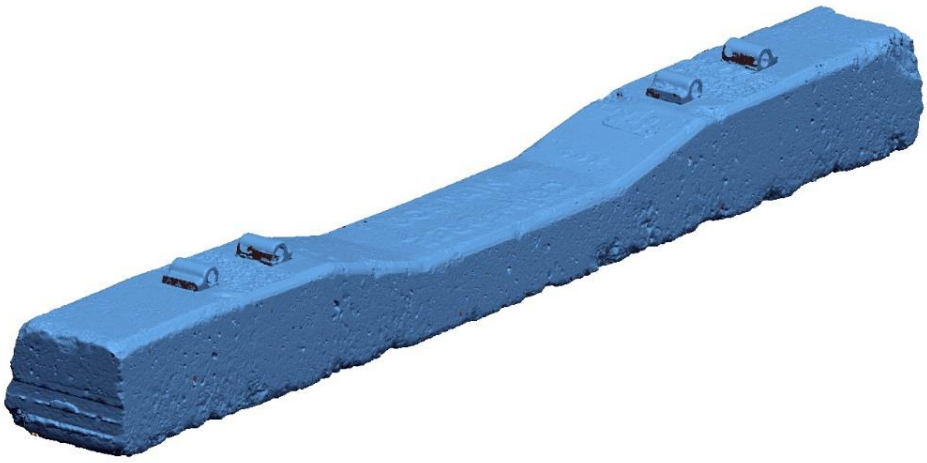
Damage:

Notes: Moderate abrasion on rail seat.

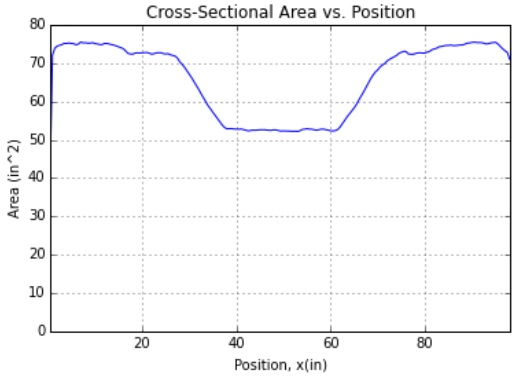
Report for Tie F-5

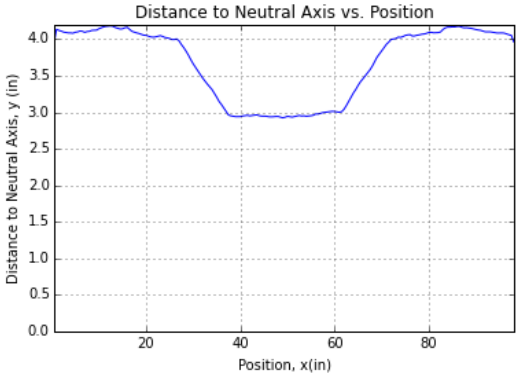
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : F5                                               |
|    Manufacturer : CONFORCE COSTAIN                                 |
|    Alternate ID : CN 60A                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 2.505 in                                              |
|      Right : 2.415 in                                              |
|      Avg.  : 2.460 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.86 mm                                             |
|      Tendons : 26                                                  |
|      Pattern : 10-6-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.60             52.26                  |
|         I   [in^4]       357.65            127.59                  |
|       Y_cog  [in]          4.05              2.93                  |
|       height [in]          8.01              5.79                  |
|         e    [in]          1.57              0.47                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 82.4 [kips] (F-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.22           1.41                         |
|        Right [in]      1.39           1.11                         |
|        Top   [in]      4.31           4.29                         |
|        Bottom[in]      1.33           1.29                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

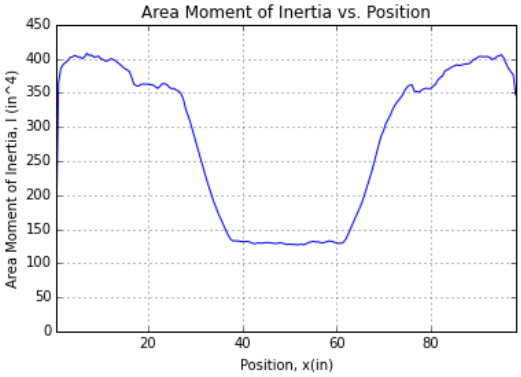
Model Views:

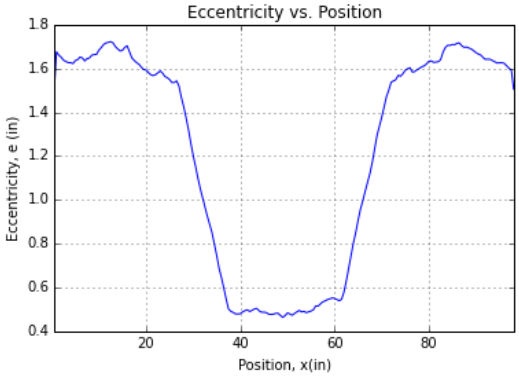


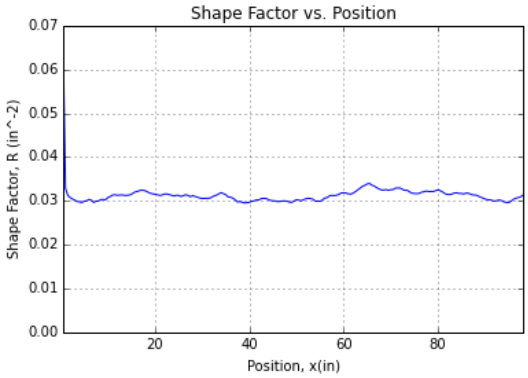
Processed Data:



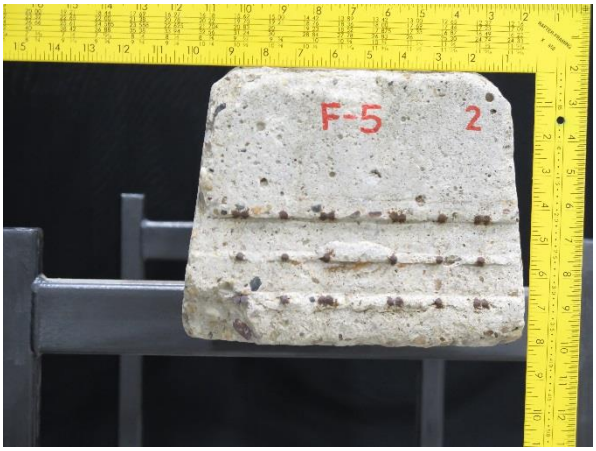








End Pictures:



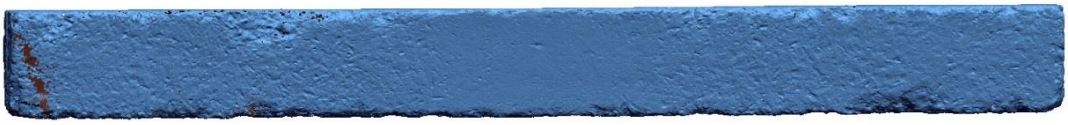
Damage:

Notes: Moderate abrasion on rail seat.

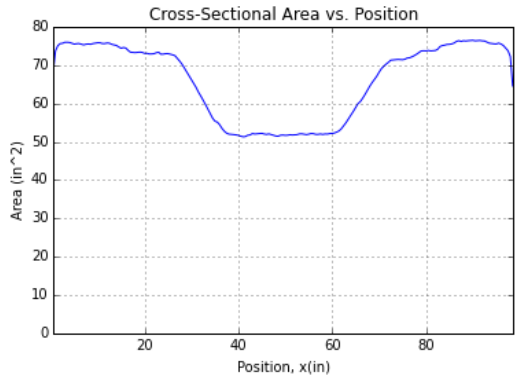
Report for Tie F-6

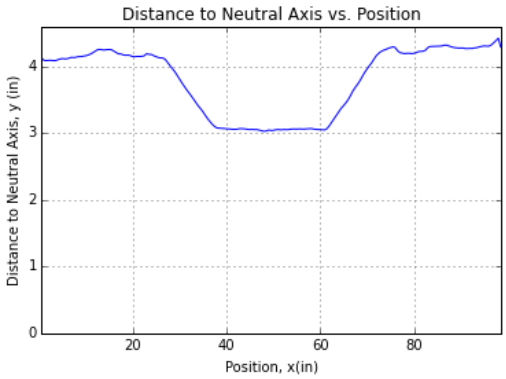
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : F6                                               |
|    Manufacturer : CONFORCE COSTAIN                                 |
|    Alternate ID : CN 60A                                           |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 2.354 in                                              |
|      Right : 2.368 in                                              |
|      Avg.  : 2.361 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.86 mm                                             |
|      Tendons : 26                                                  |
|      Pattern : 10-6-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        72.83             51.72                  |
|         I   [in^4]       361.02            124.16                  |
|       Y_cog  [in]          4.17              3.04                  |
|       height [in]          8.17              5.87                  |
|         e    [in]          1.79              0.68                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 82.4 [kips] (F-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.29           1.29                         |
|        Right [in]      1.15           1.25                         |
|        Top   [in]      4.45           4.32                         |
|        Bottom[in]      1.19           1.21                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

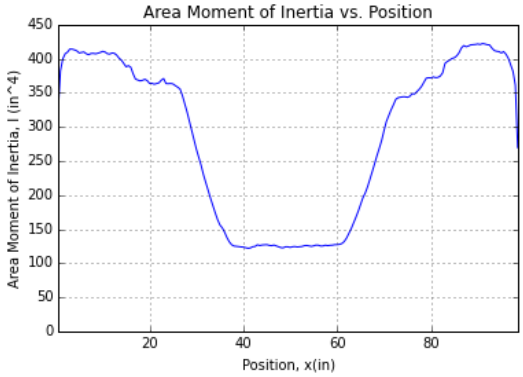
Model Views:

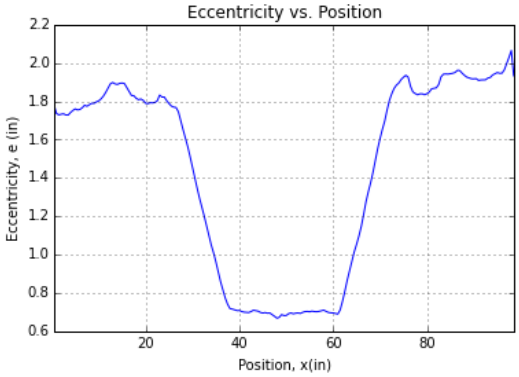


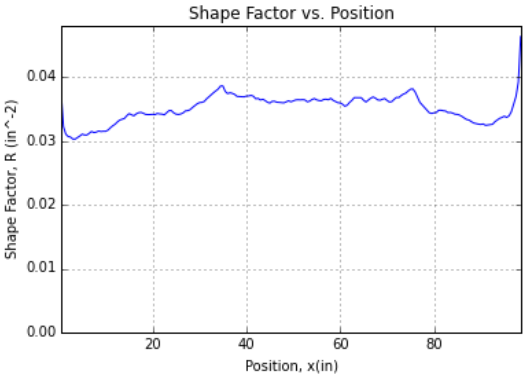
Processed Data:



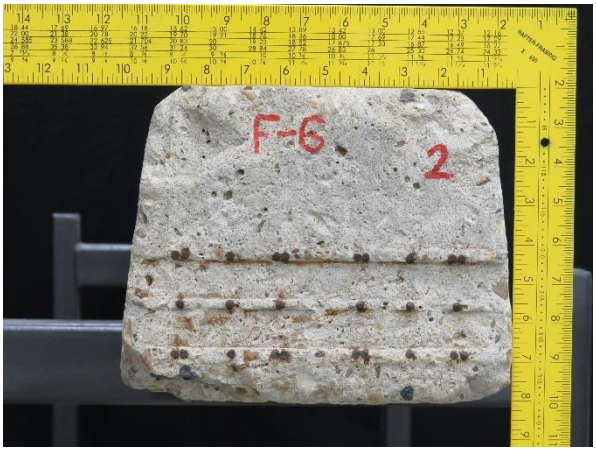








End Pictures:



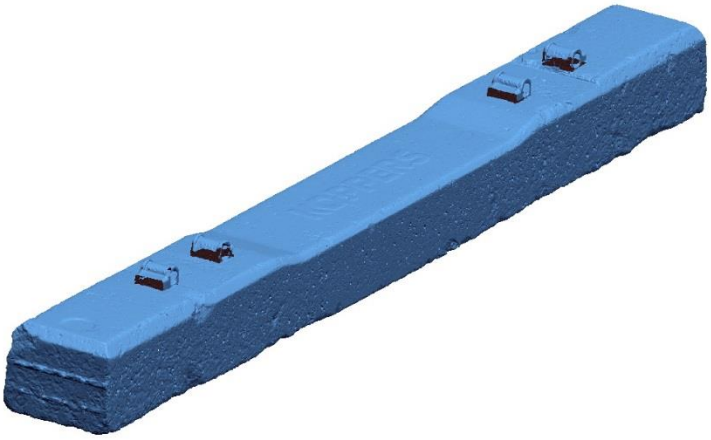
Damage:

Notes: Moderate abrasion on rail seat.

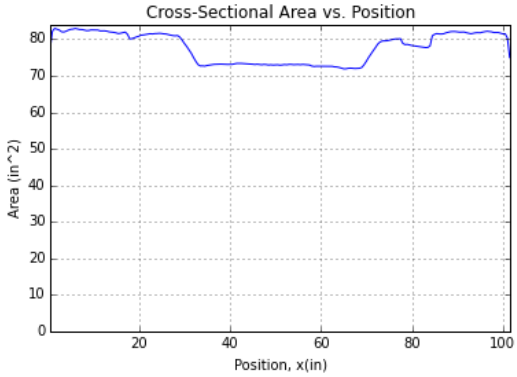
Report for Tie G-1

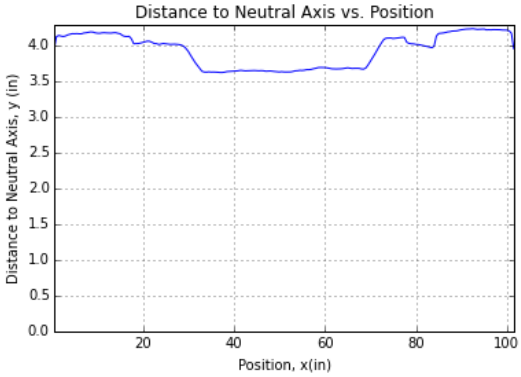
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G1                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.505 in                                              |
|      Right : 3.472 in                                              |
|      Avg.  : 3.489 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        80.01             72.90                  |
|         I   [in^4]       408.11            303.43                  |
|       Y_cog  [in]          4.03              3.64                  |
|       height [in]          8.02              7.22                  |
|         e    [in]          0.54              0.15                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.82           2.32                         |
|        Right [in]      2.33           1.79                         |
|        Top   [in]      3.70           3.61                         |
|        Bottom[in]      2.22           2.25                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

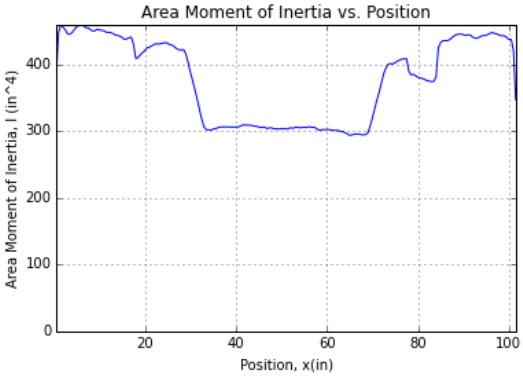
Model Views:

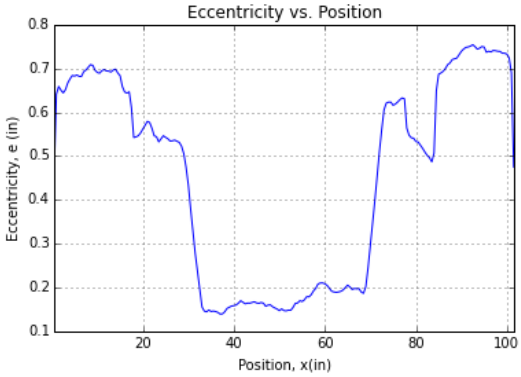


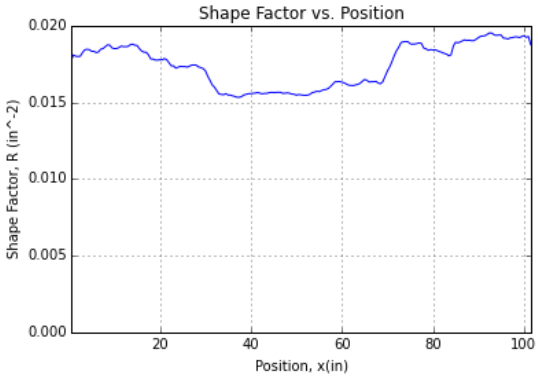
Processed Data:











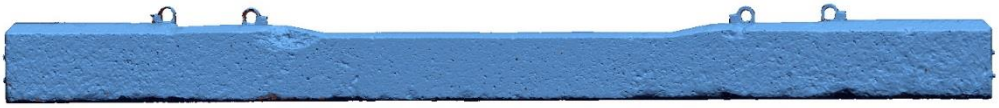
End Pictures:

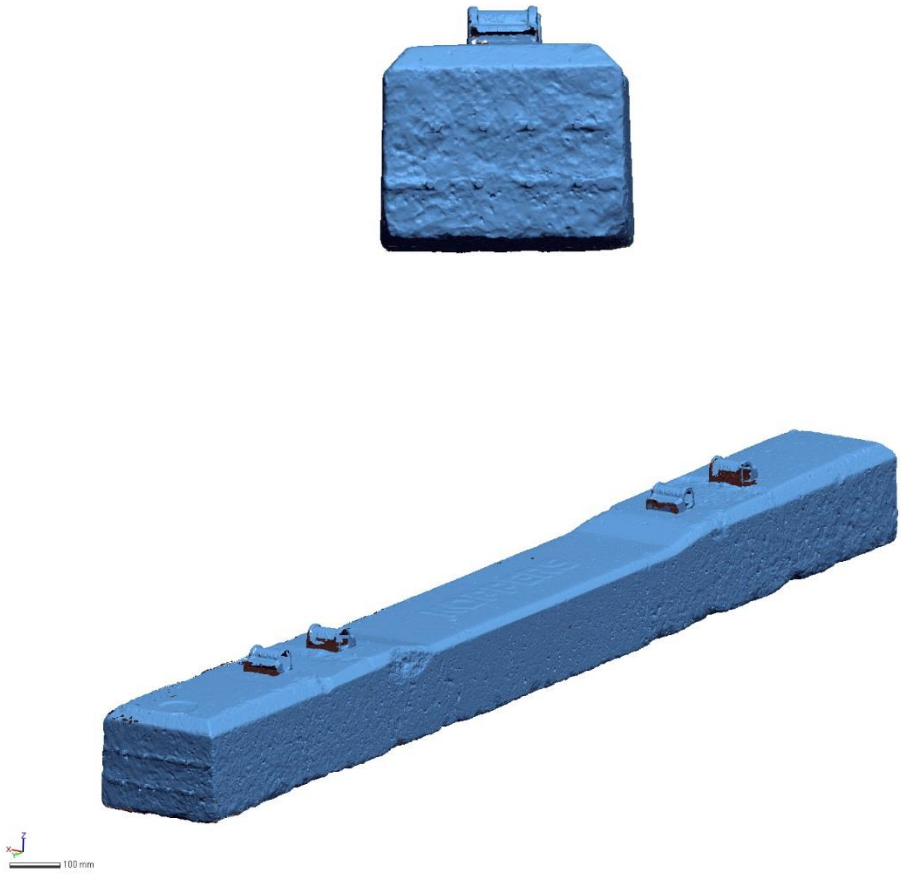
Damage:

Report for Tie G-2

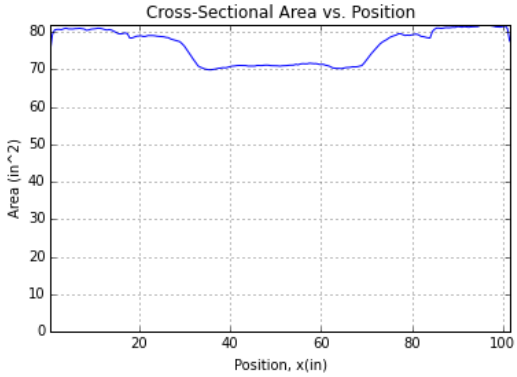
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G2                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.518 in                                              |
|      Right : 3.571 in                                              |
|      Avg.  : 3.544 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        79.13             70.90                 |
|         I   [in^4]       394.04            280.32                 |
|       Y_cog  [in]          4.10              3.67                 |
|       height [in]          8.07              7.20                 |
|         e    [in]          0.56              0.10                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.91           2.22                        |
|        Right [in]      2.15           1.88                        |
|        Top   [in]      3.56           3.51                        |
|        Bottom[in]      2.27           2.32                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

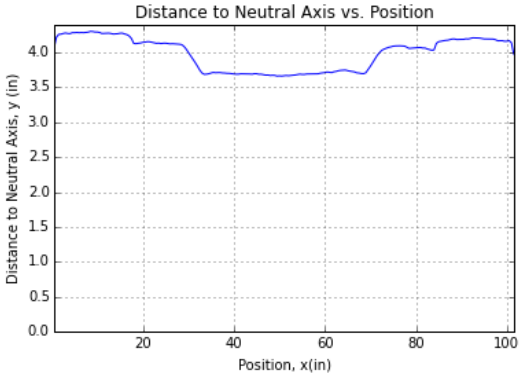
Model Views:

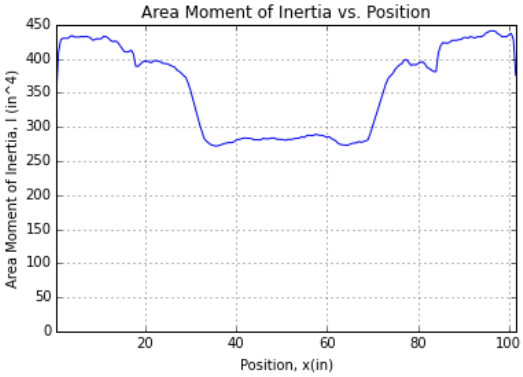


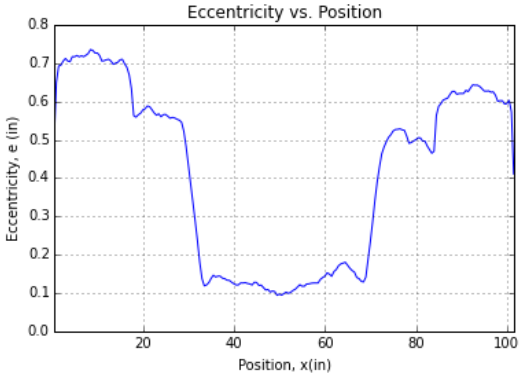

100 mm

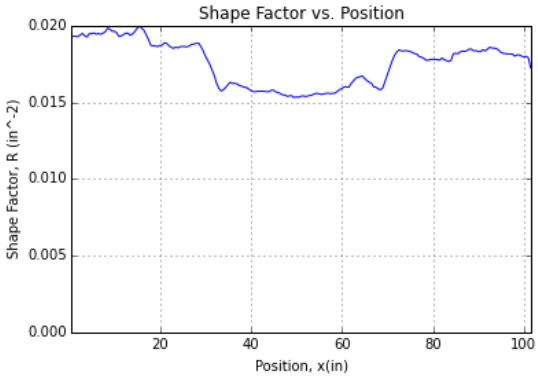
Processed Data:



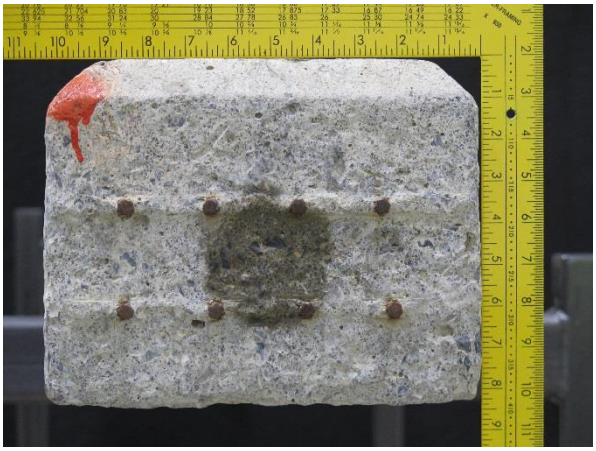


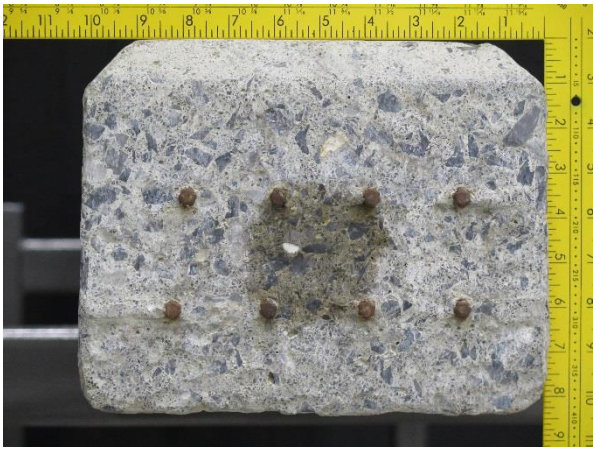






End Pictures:





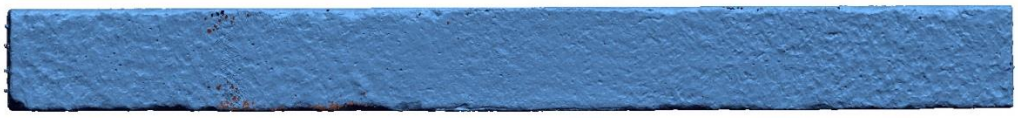
Damage:

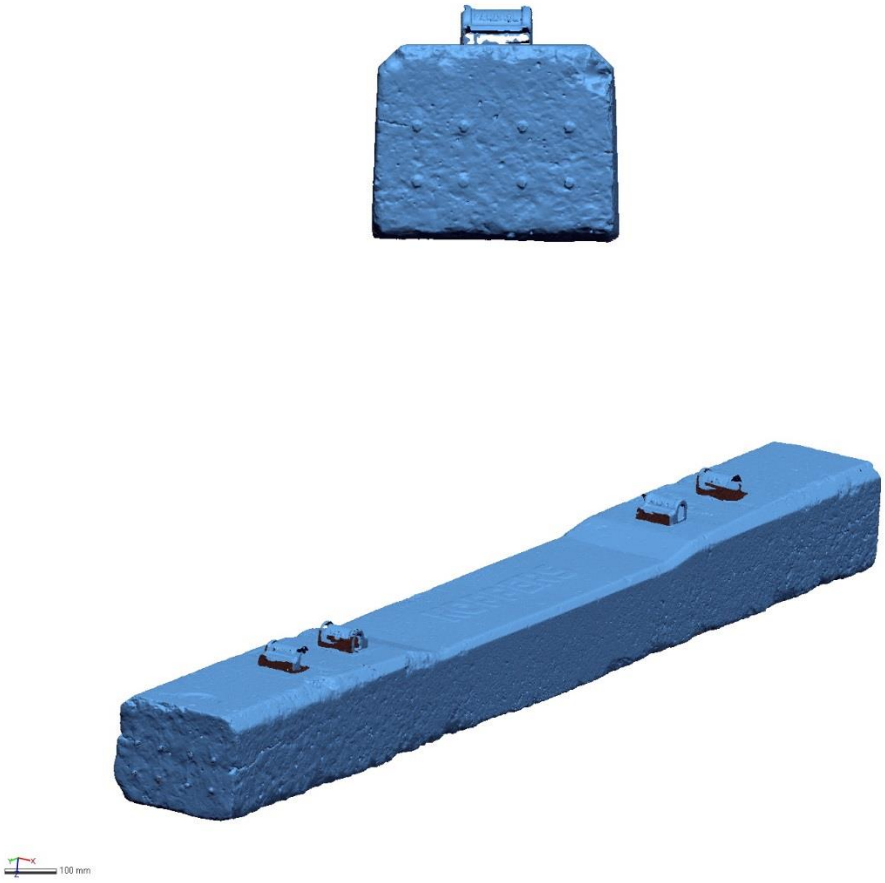
Notes: Low abrasion on rail seat.

Report for Tie G-3

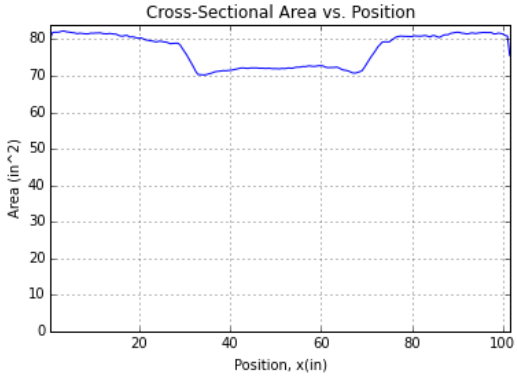
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G3                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.506 in                                              |
|      Right : 3.686 in                                              |
|      Avg.  : 3.596 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        79.98             71.90                 |
|         I   [in^4]       406.67            291.73                 |
|       Y_cog  [in]          4.07              3.61                 |
|       height [in]          8.15              7.20                 |
|         e    [in]          0.49              0.02                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.92           1.75                        |
|        Right [in]      1.55           1.87                        |
|        Top   [in]      3.49           3.56                        |
|        Bottom[in]      2.27           2.22                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Severe                                    |
+--------------------------------------------------------------------+
```

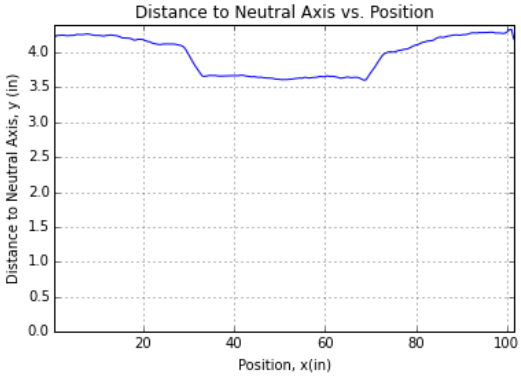
Model Views:

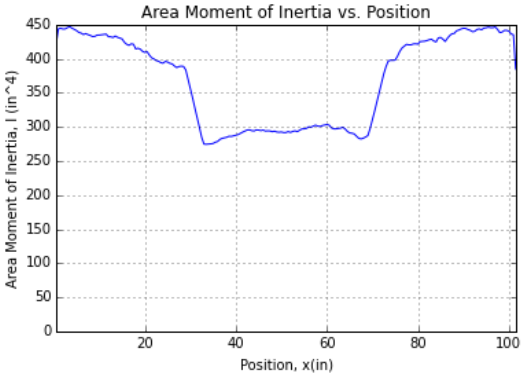


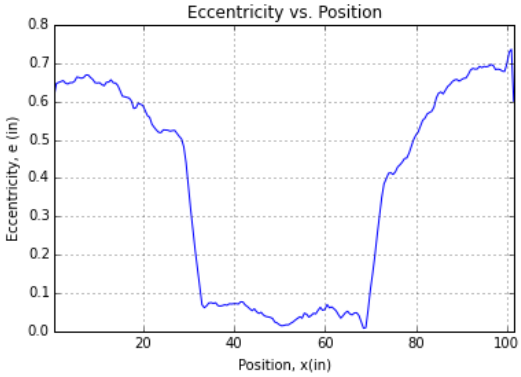

100 mm

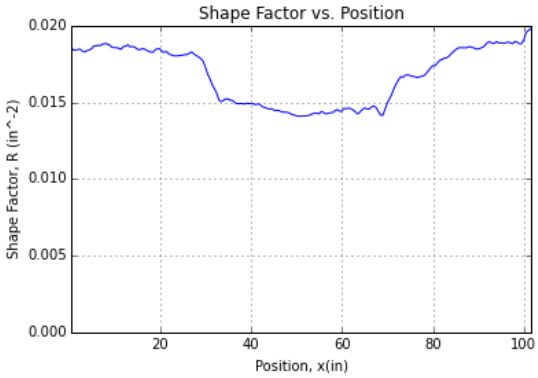
Processed Data:



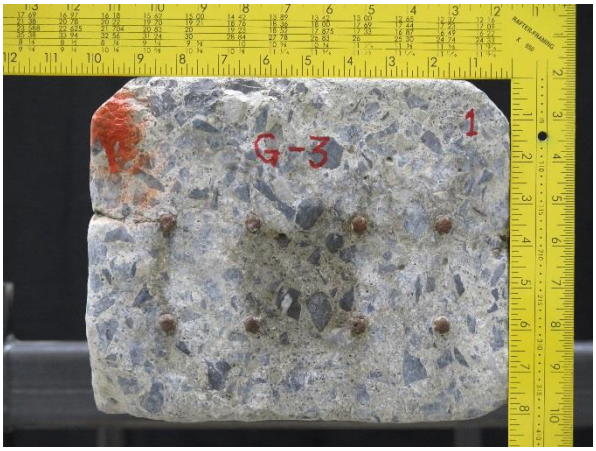


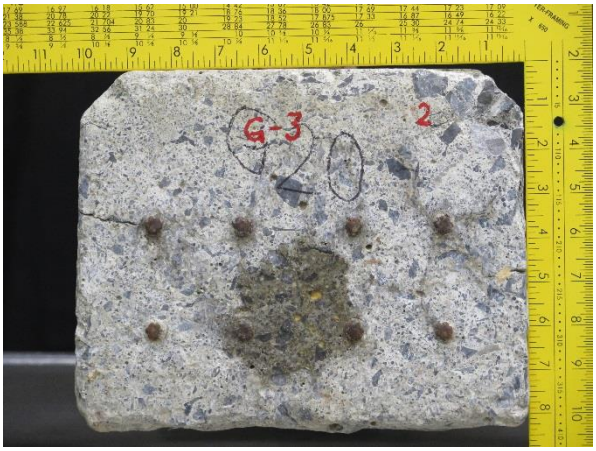






End Pictures:



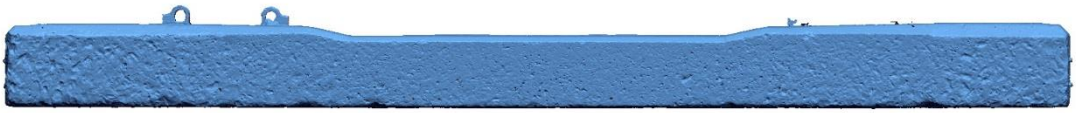


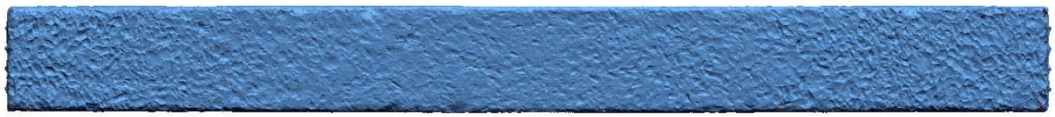
Damage:

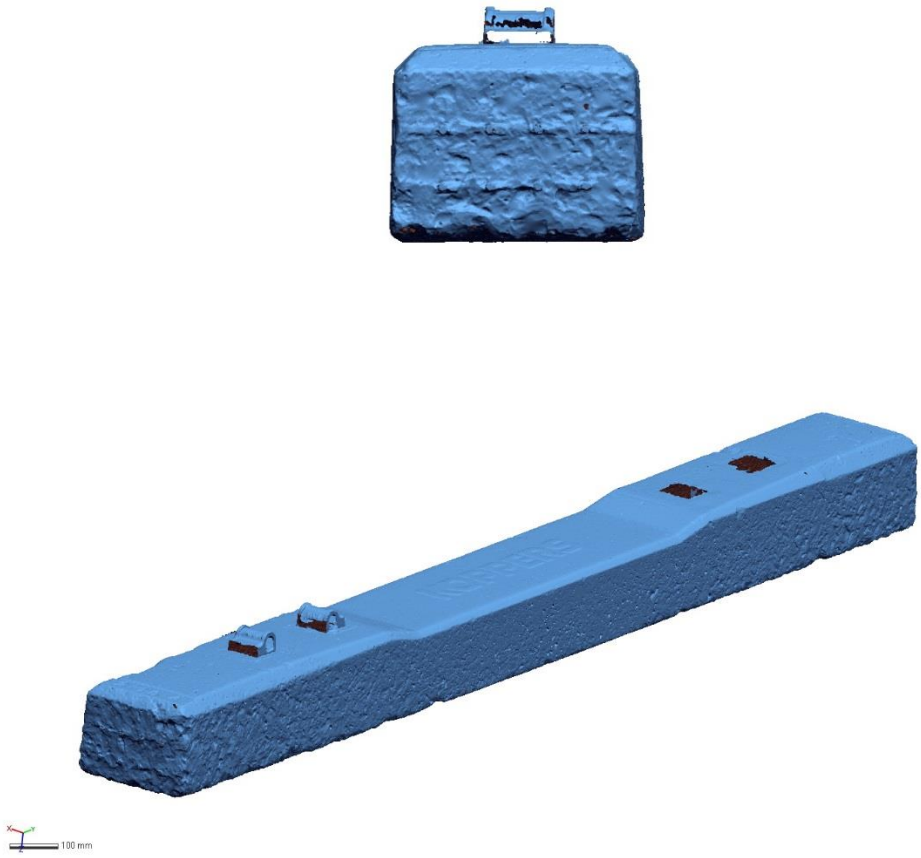
Report for Tie G-4

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G4                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.246 in                                              |
|      Right : 3.540 in                                              |
|      Avg.  : 3.393 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        78.49             69.96                  |
|         I   [in^4]       391.62            273.17                  |
|       Y_cog  [in]          4.05              3.56                  |
|       height [in]          8.05              7.09                  |
|         e    [in]          0.66              0.16                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.12           2.10                         |
|        Right [in]      2.00           2.06                         |
|        Top   [in]      3.49           3.43                         |
|        Bottom[in]      1.94           2.07                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

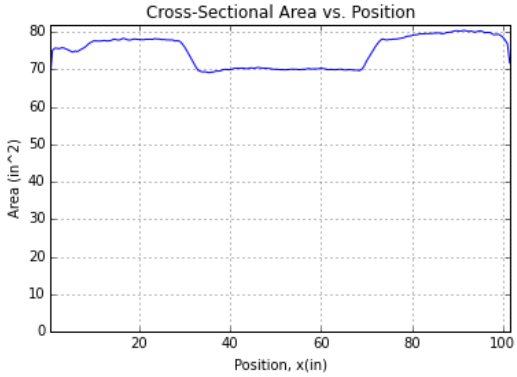
Model Views:

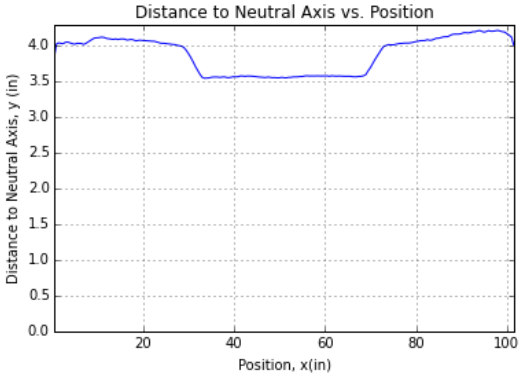


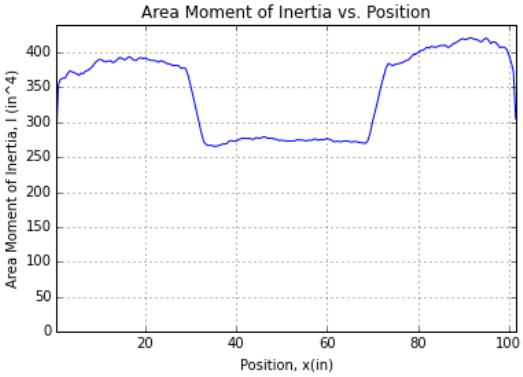


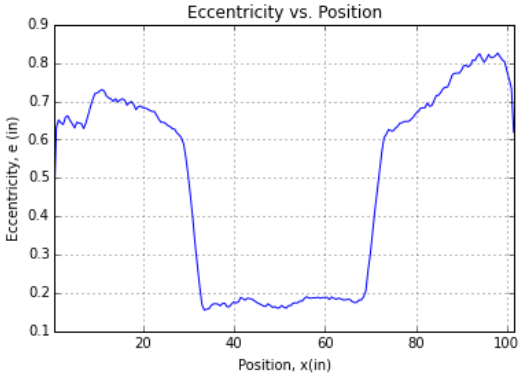

100 mm

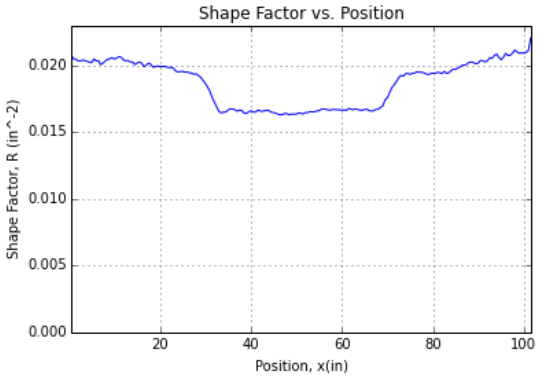
Processed Data:



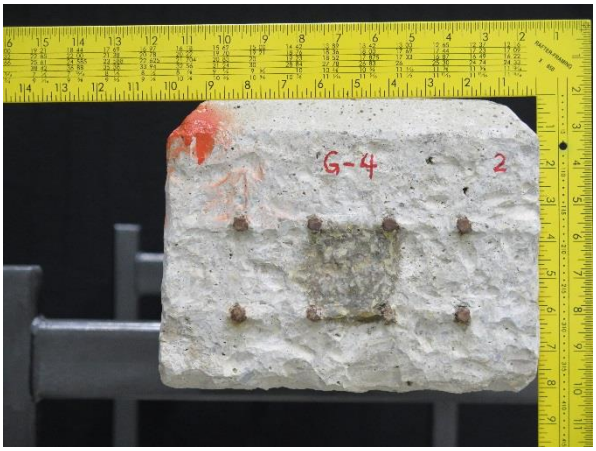








End Pictures:

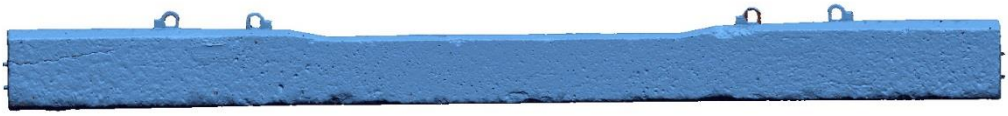


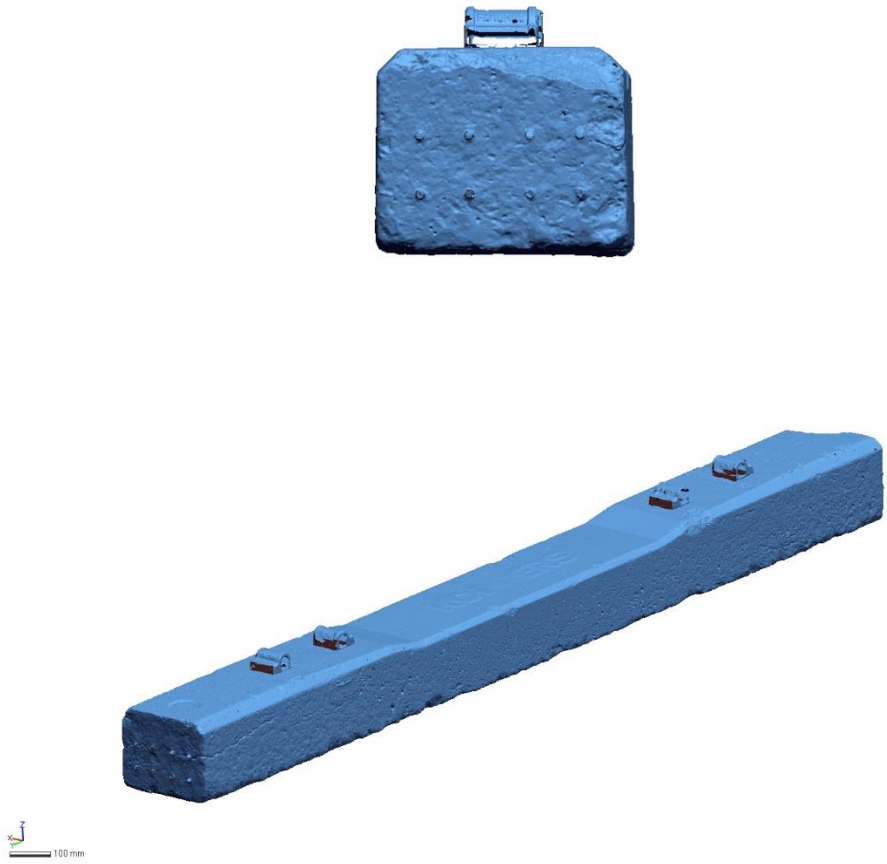
Damage:

Report for Tie G-5

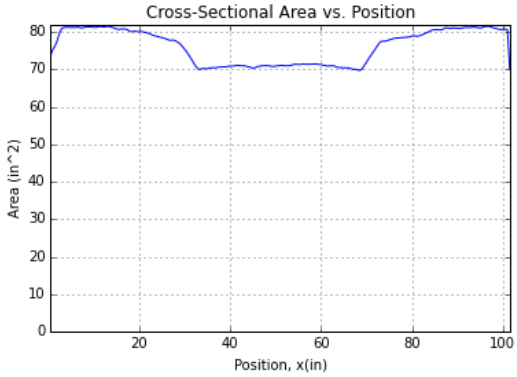
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G5                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.349 in                                              |
|      Right : 3.361 in                                              |
|      Avg.  : 3.355 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        78.91             71.06                 |
|         I   [in^4]       393.78            286.05                 |
|       Y_cog  [in]          4.19              3.76                 |
|       height [in]          8.19              7.28                 |
|         e    [in]          0.82              0.41                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.85           1.74                        |
|        Right [in]      1.68           1.85                        |
|        Top   [in]      3.53           3.44                        |
|        Bottom[in]      2.19           2.24                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

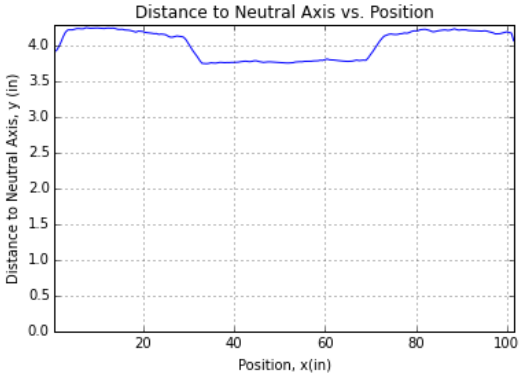
Model Views:

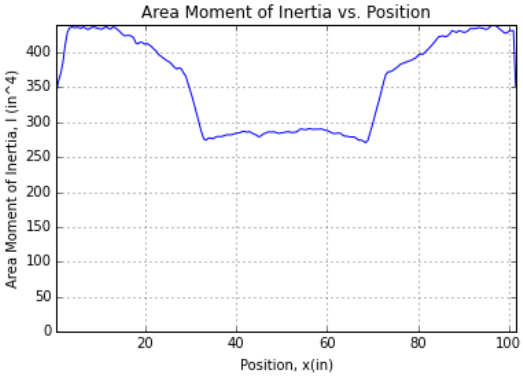


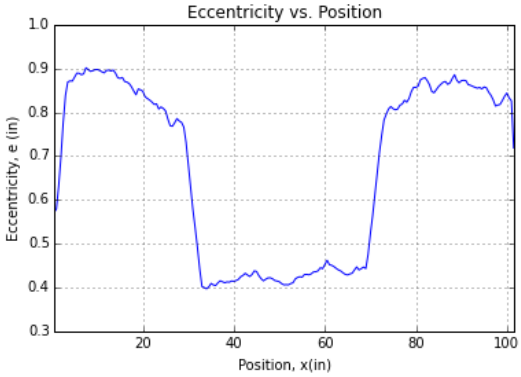

100 mm

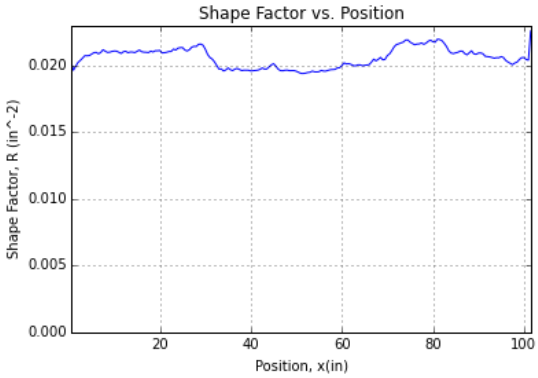
Processed Data:



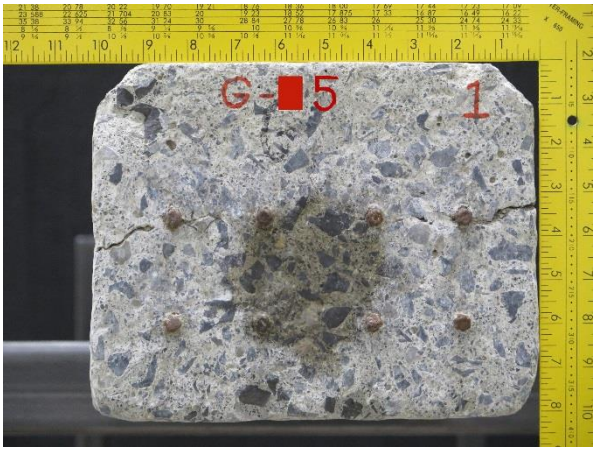




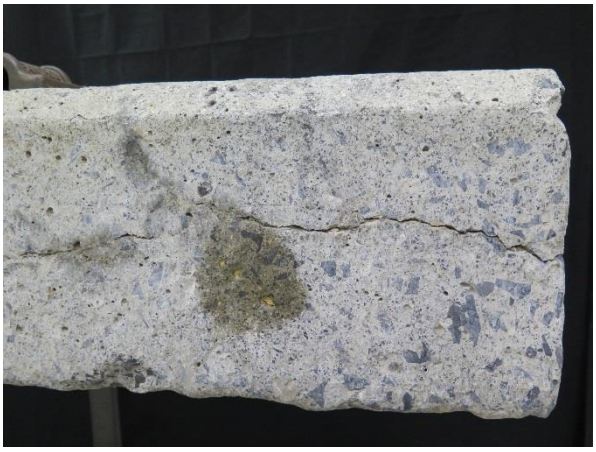


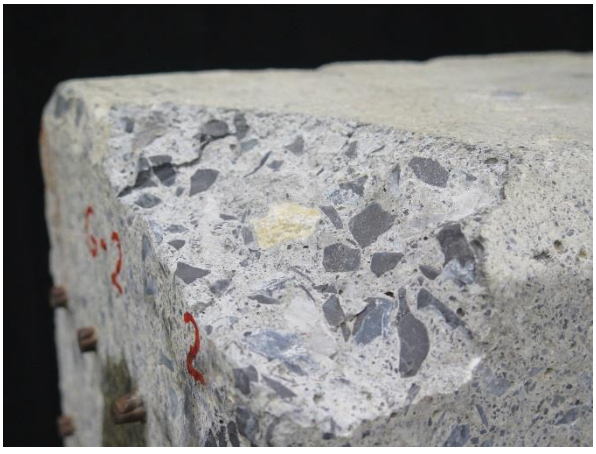


End Pictures:



Damage:

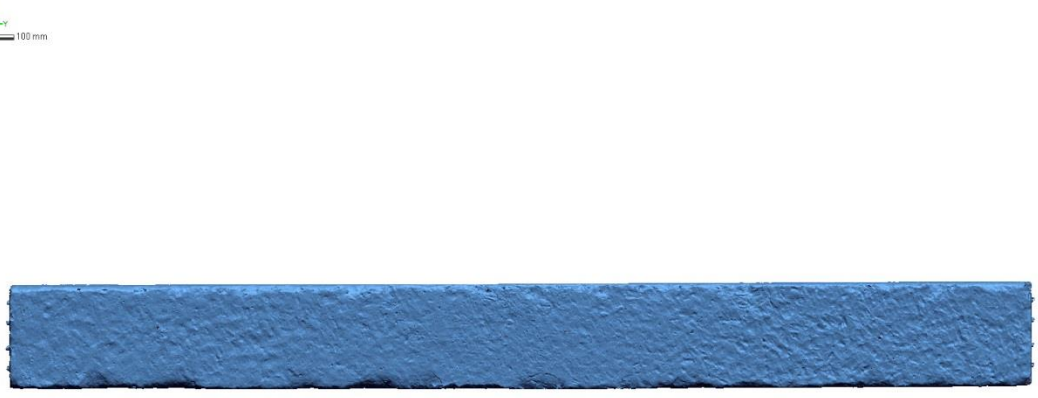


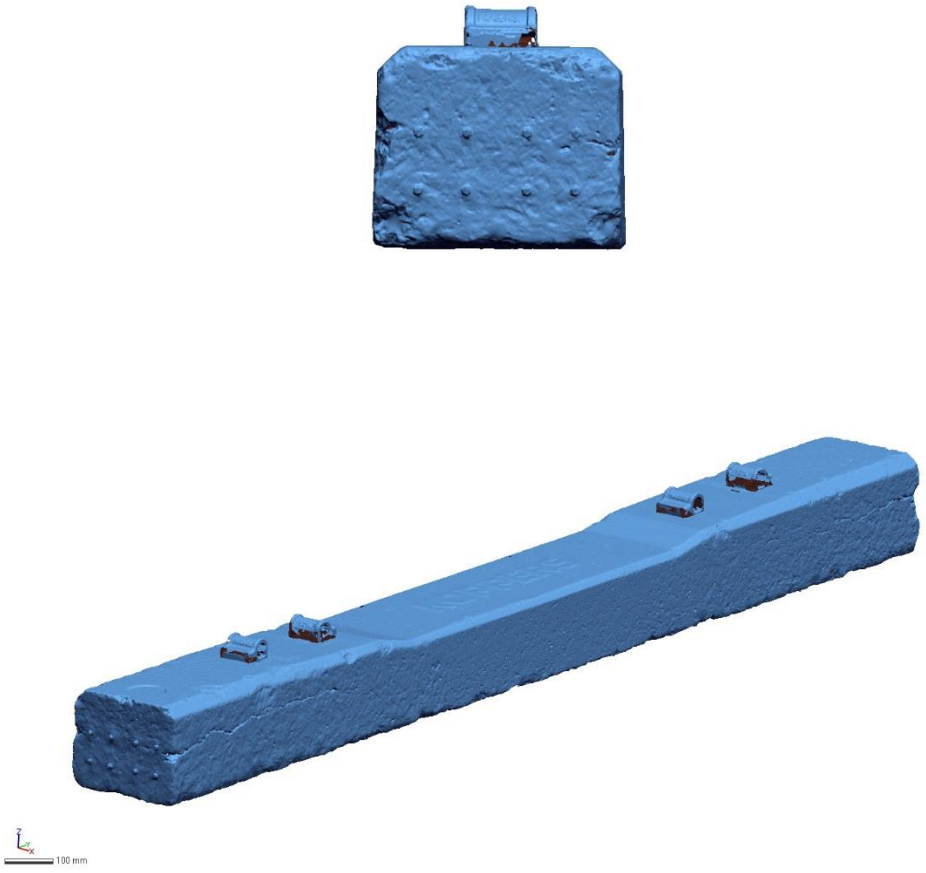


Report for Tie G-6

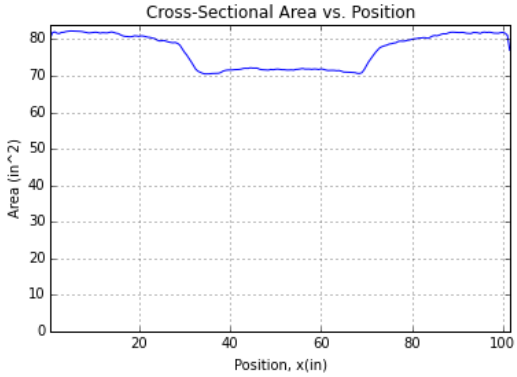
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : G6                                               |
|    Manufacturer : KOPPERS                                          |
|    Alternate ID : CSX                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.553 in                                              |
|      Right : 3.487 in                                              |
|      Avg.  : 3.520 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : STRAND (INDENTED)                                   |
|      Diameter: 0.385 in                                            |
|      Tendons : 8                                                   |
|      Pattern : 4-4                                                 |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        80.00             71.75                 |
|         I   [in^4]       411.96            294.14                 |
|       Y_cog  [in]          4.08              3.60                 |
|       height [in]          8.17              7.20                 |
|         e    [in]          0.53              0.08                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.94           1.74                        |
|        Right [in]      1.60           1.81                        |
|        Top   [in]      3.65           3.64                        |
|        Bottom[in]      2.39           2.25                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Moderate                                  |
+--------------------------------------------------------------------+
```

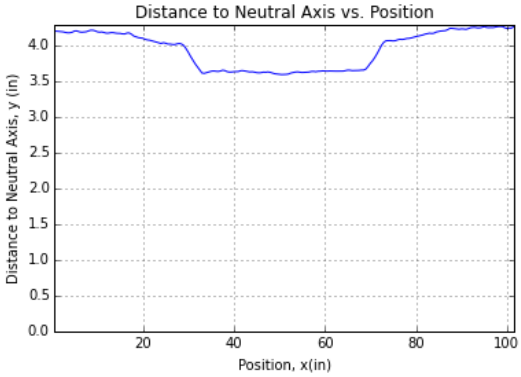
Model Views:

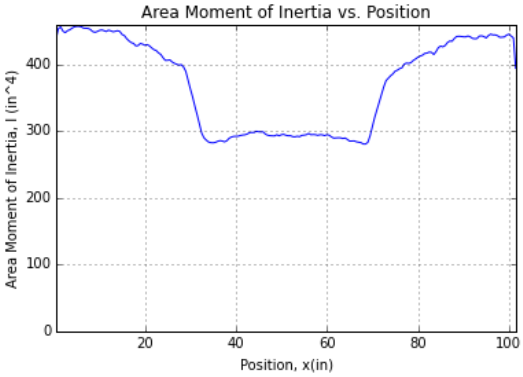


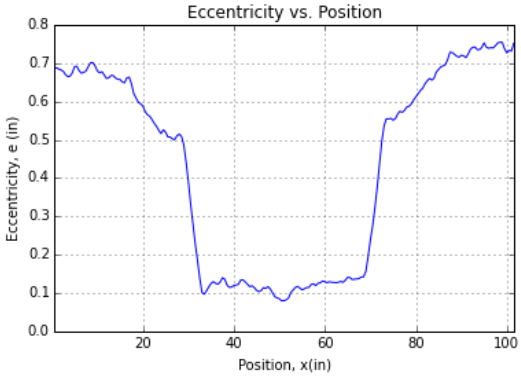

100 mm

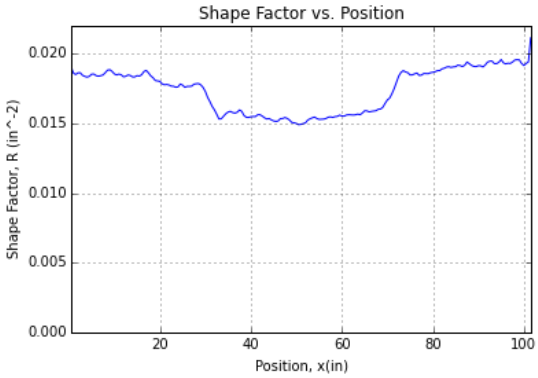
Processed Data:



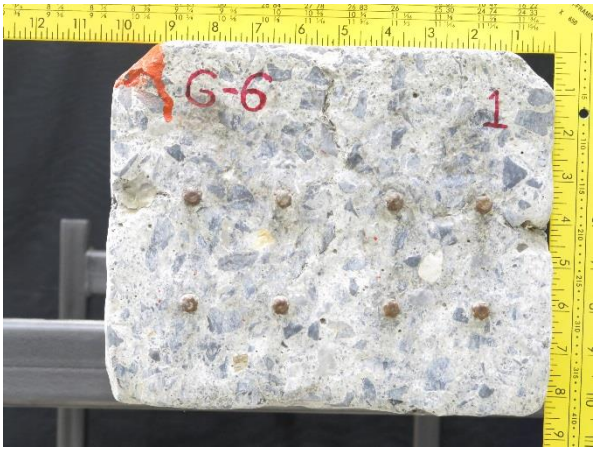


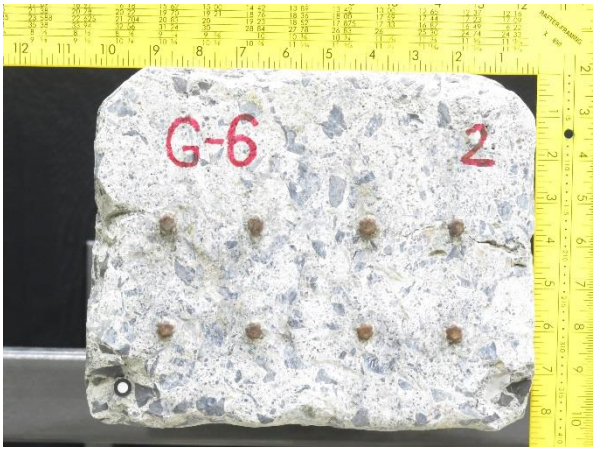






End Pictures:



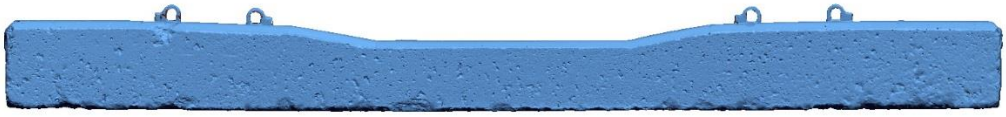


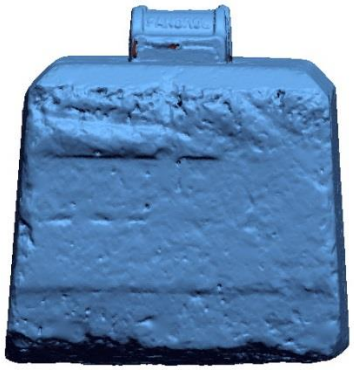
Damage:

Report for Tie H-1

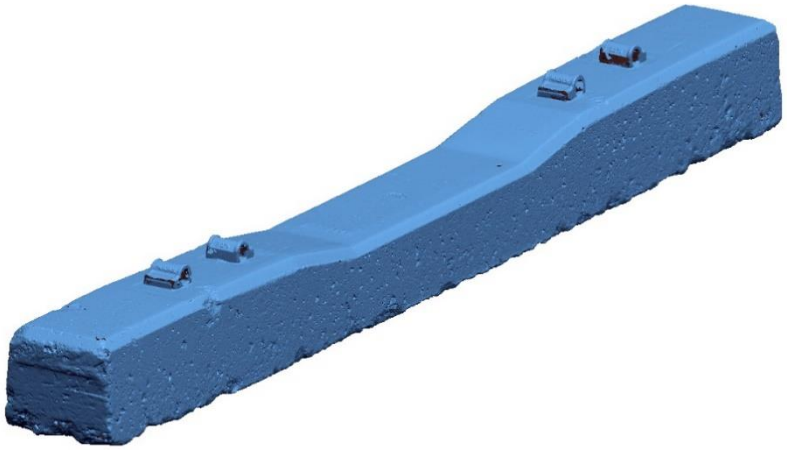
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H1                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.744 in                                              |
|      Right : 3.707 in                                              |
|      Avg.  : 3.726 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        83.98             69.13                  |
|         I   [in^4]       520.01            283.52                  |
|       Y_cog  [in]          4.39              3.42                  |
|       height [in]          8.92              7.05                  |
|         e    [in]          0.75             -0.30                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 99.2 [kips] (H-3)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      0.90           1.72                         |
|        Right [in]      1.79           0.95                         |
|        Top   [in]      3.39           3.41                         |
|        Bottom[in]      2.15           2.03                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:



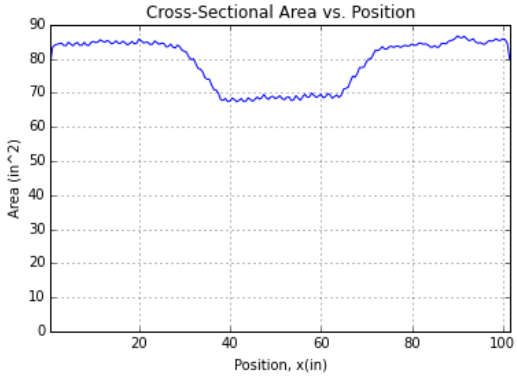


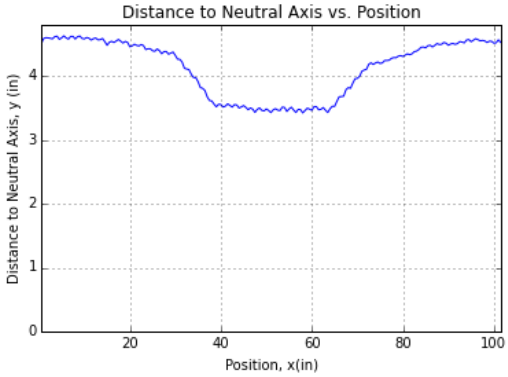
50 mm

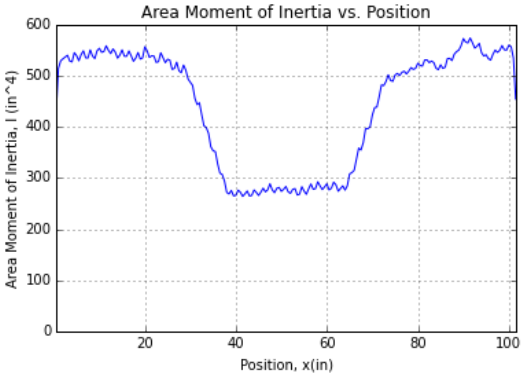


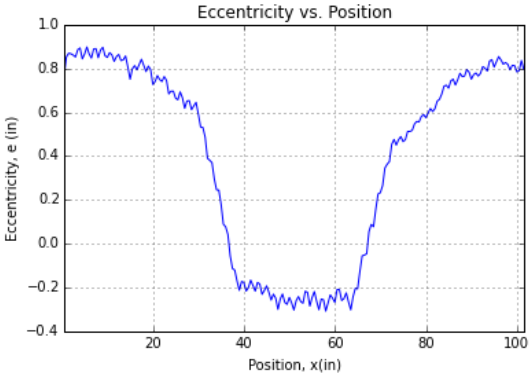
100 mm

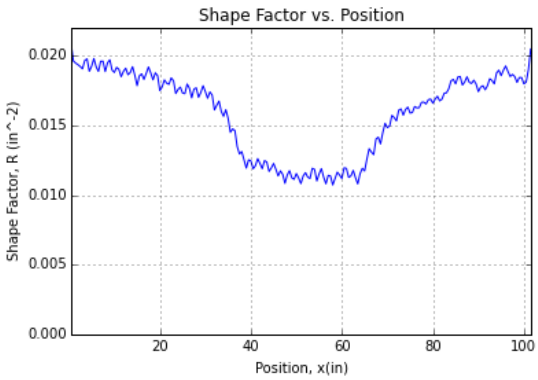
Processed Data:



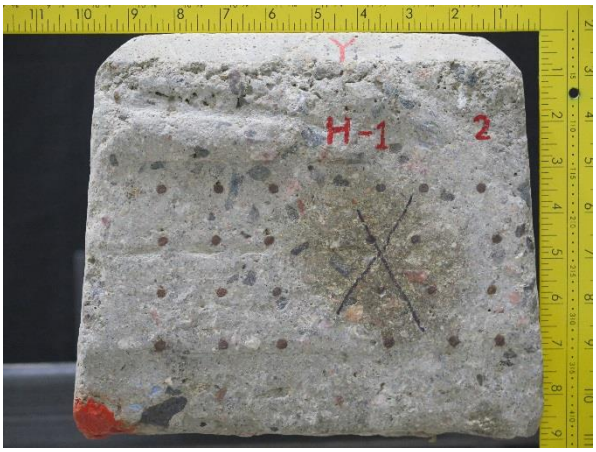








End Pictures:

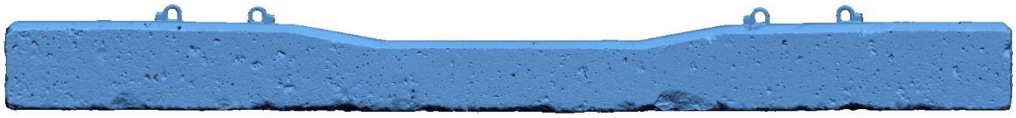


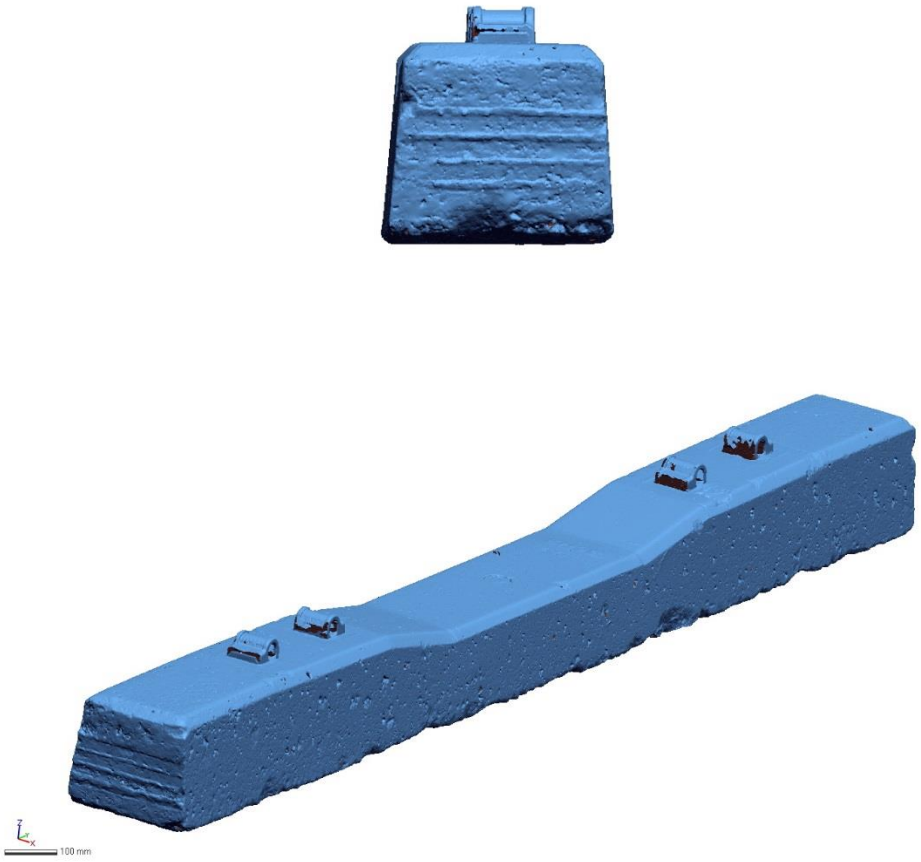
Damage:

Report for Tie H-2

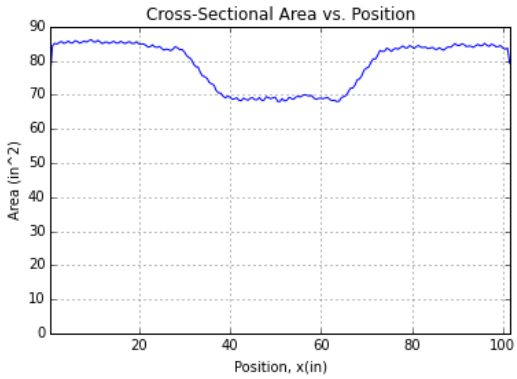
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H2                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.031 in                                              |
|      Right : 3.951 in                                              |
|      Avg.  : 3.991 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        84.19             68.02                 |
|         I   [in^4]       522.64            270.01                 |
|       Y_cog  [in]          4.60              3.70                 |
|       height [in]          9.13              7.28                 |
|         e    [in]          0.62             -0.29                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 99.2 [kips] (H-3)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      2.05           0.93                        |
|        Right [in]      0.90           2.06                        |
|        Top   [in]      3.23           3.29                        |
|        Bottom[in]      2.28           2.36                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

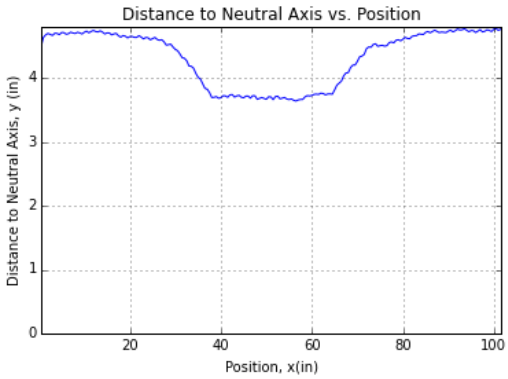
Model Views:

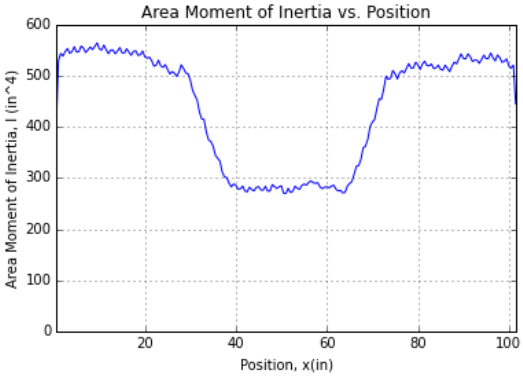


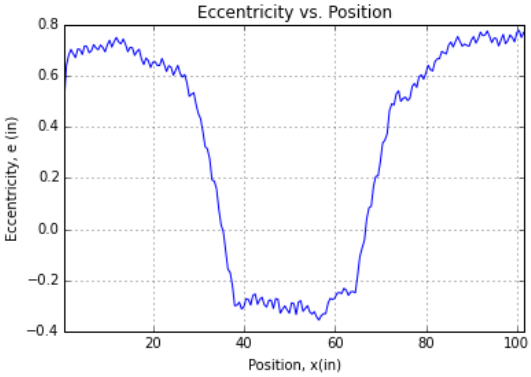

100 mm

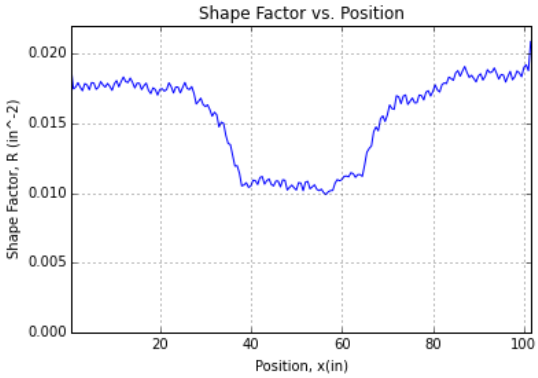
Processed Data:











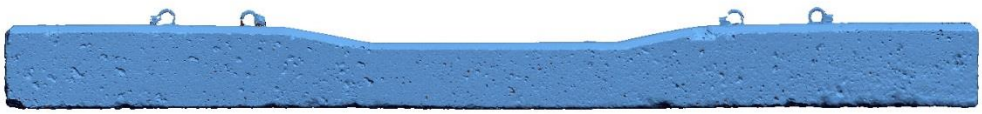
End Pictures:

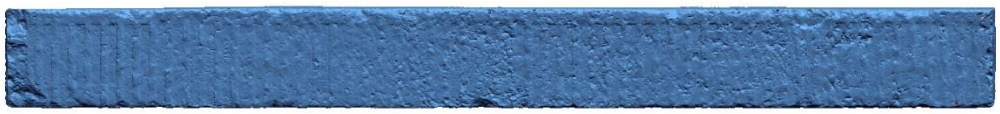
Damage:

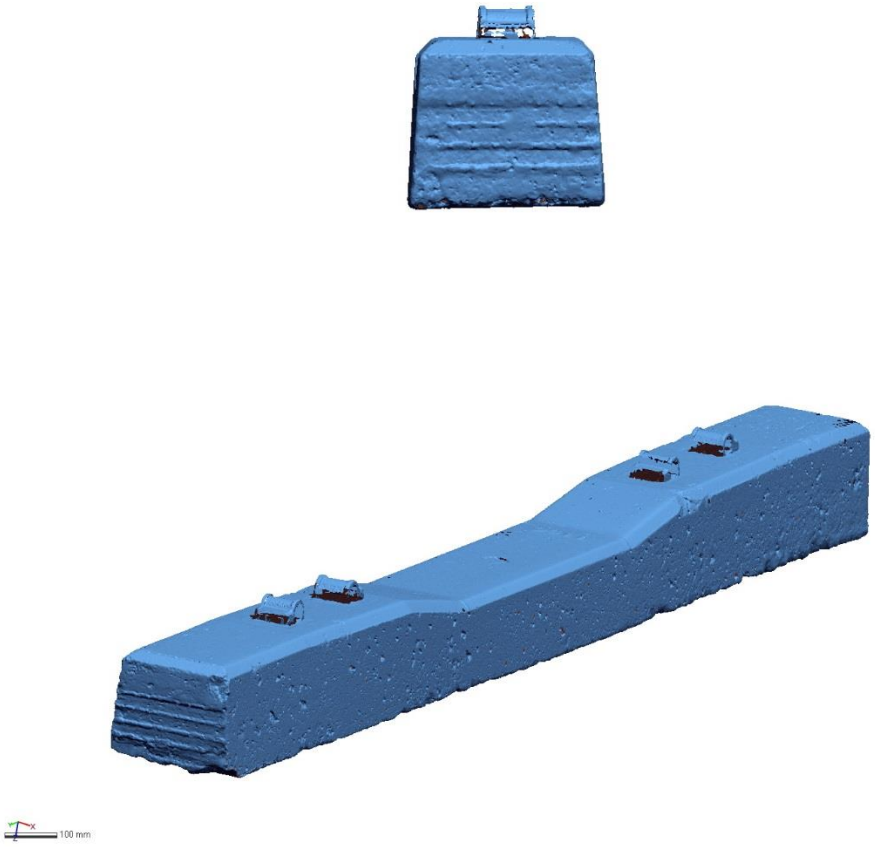
Report for Tie H-3

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H3                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.721 in                                              |
|      Right : 3.603 in                                              |
|      Avg.  : 3.662 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        82.31             66.26                 |
|         I   [in^4]       488.33            250.05                 |
|       Y_cog  [in]          4.60              3.67                 |
|       height [in]          9.00              7.17                 |
|         e    [in]          0.95              0.01                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 99.2 [kips] (H-3)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.80           0.88                        |
|        Right [in]      1.05           1.96                        |
|        Top   [in]      3.37           3.24                        |
|        Bottom[in]      2.01           1.79                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

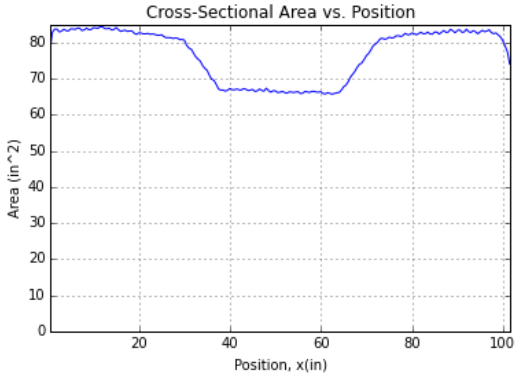
Model Views:

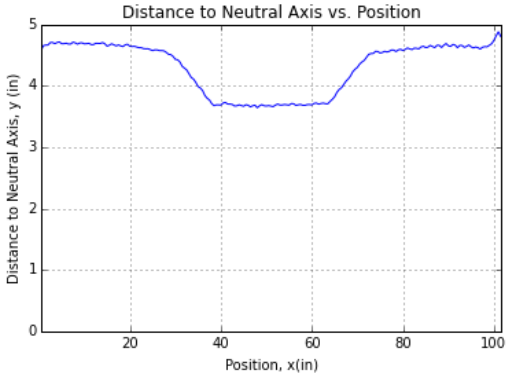


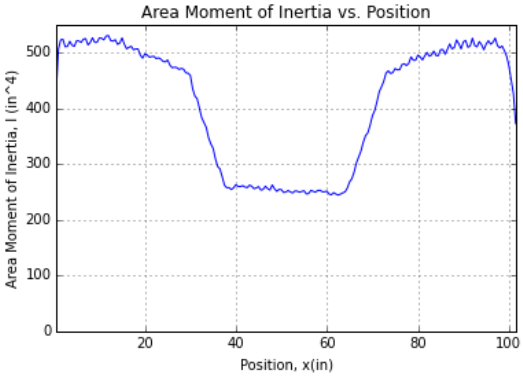


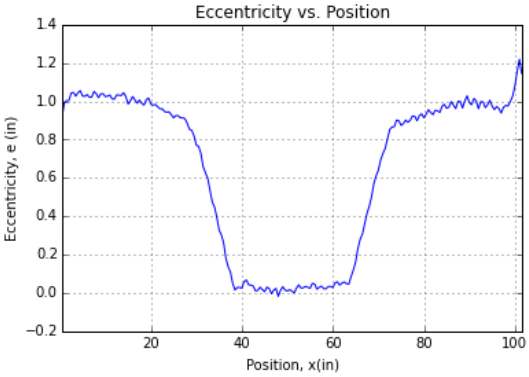

100 mm

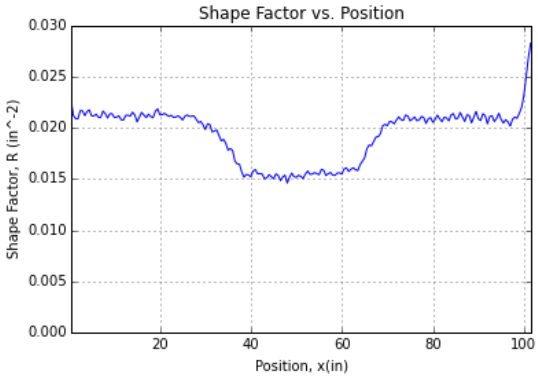
Processed Data:



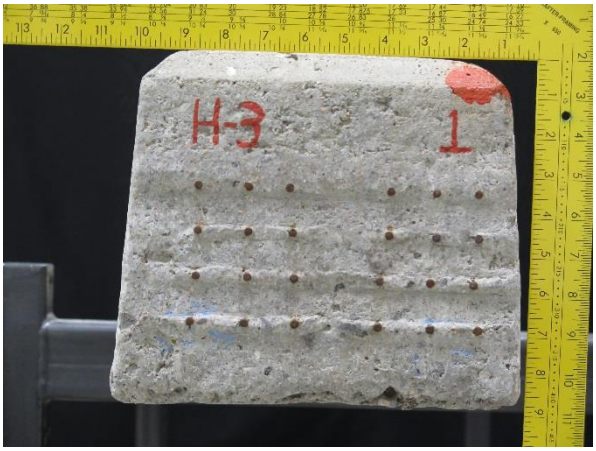


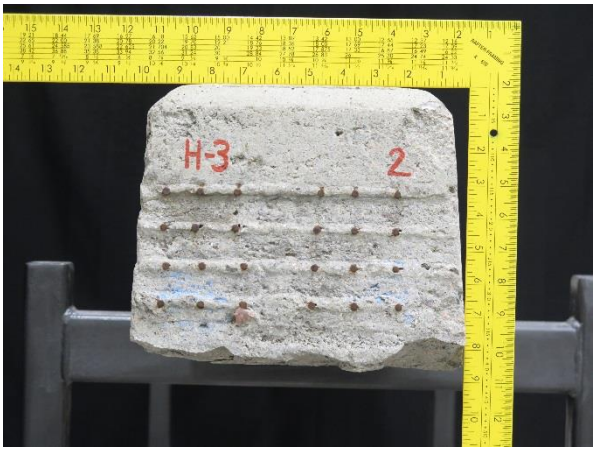






End Pictures:



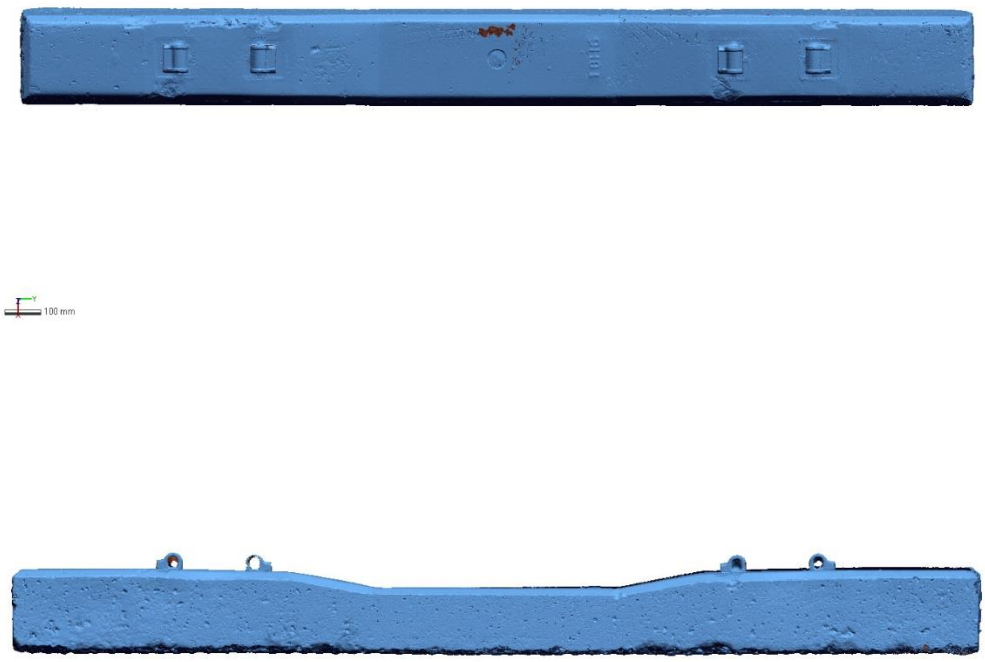


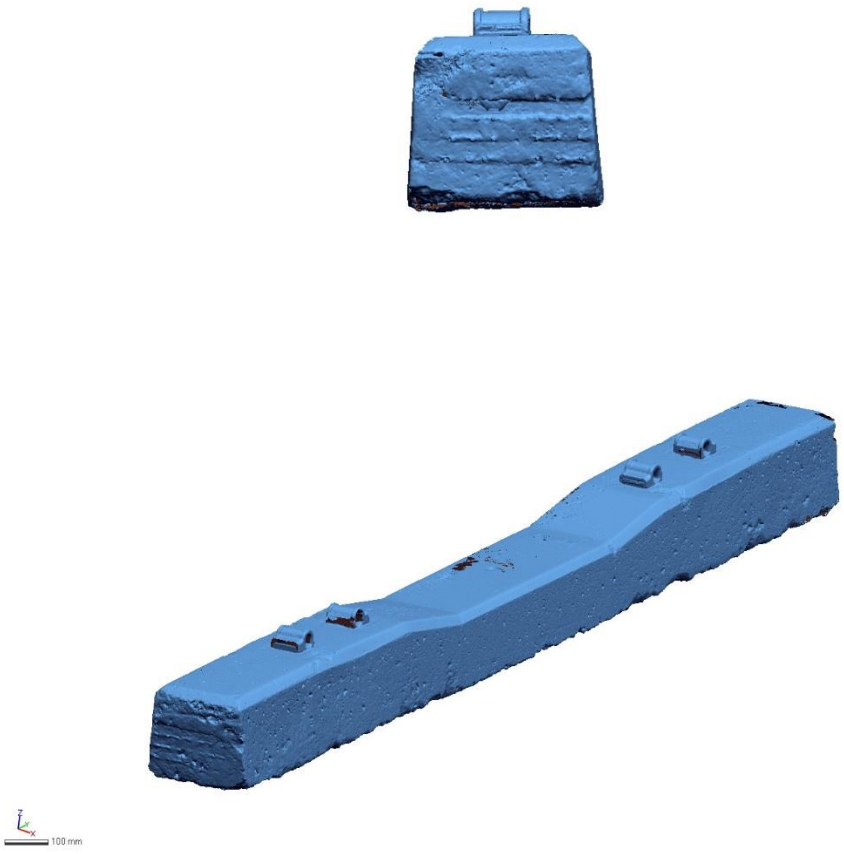
Damage:

Report for Tie H-4

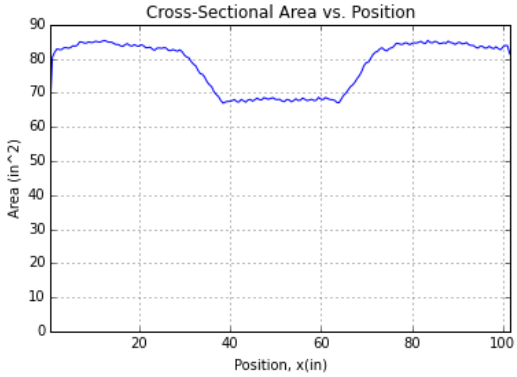
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H4                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.590 in                                              |
|      Right : 3.881 in                                              |
|      Avg.  : 3.736 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        83.66             68.08                  |
|         I   [in^4]       503.91            267.69                  |
|       Y_cog  [in]          4.55              3.58                  |
|       height [in]          9.02              7.13                  |
|         e    [in]          0.81             -0.15                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 99.2 [kips] (H-3)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      0.89           2.28                         |
|        Right [in]      2.05           0.67                         |
|        Top   [in]      3.34           3.29                         |
|        Bottom[in]      1.99           2.23                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

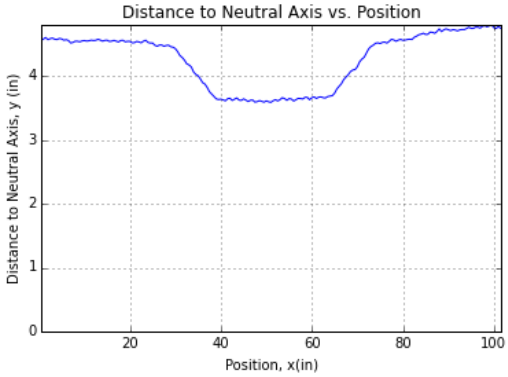
Model Views:

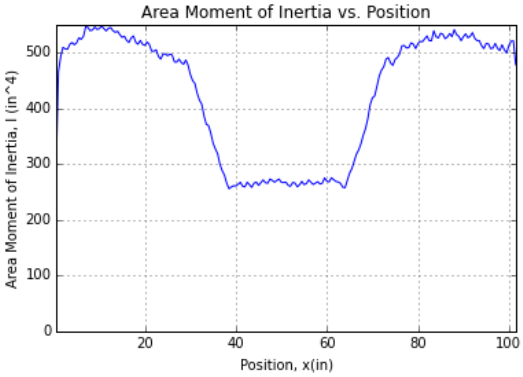


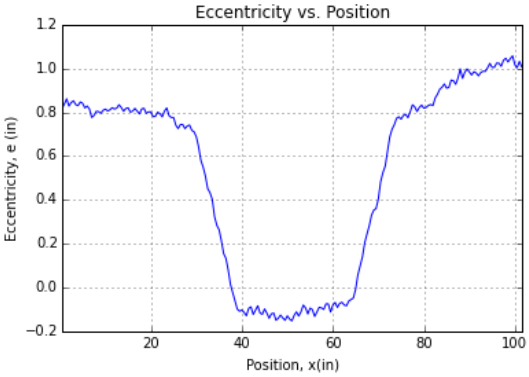

100 mm

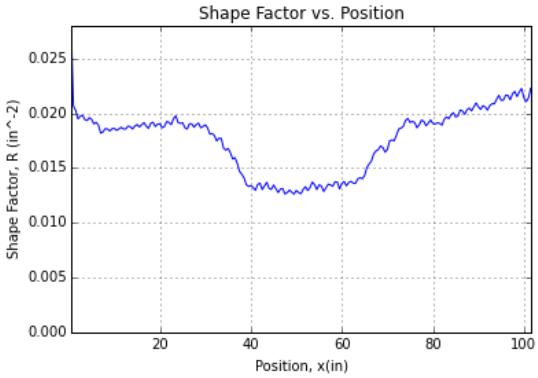
Processed Data:



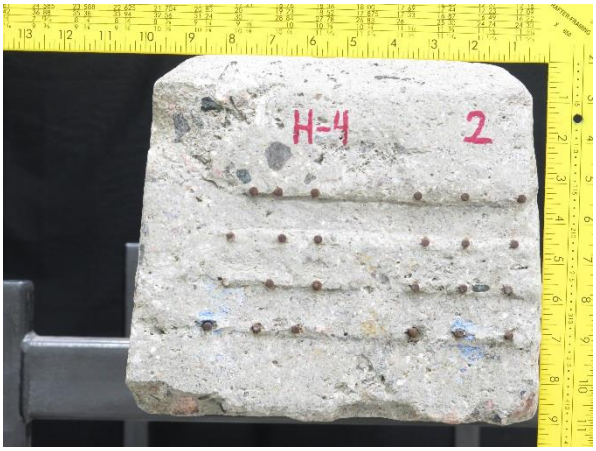








End Pictures:

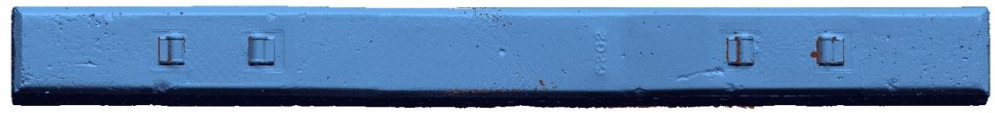


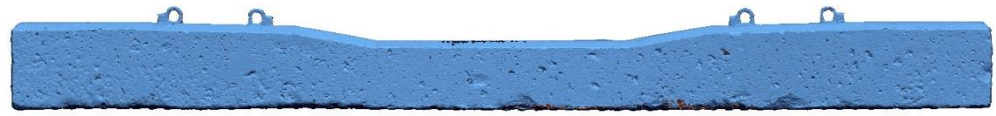
Damage:

Report for Tie H-5

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H5                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.987 in                                              |
|      Right : 3.992 in                                              |
|      Avg.  : 3.990 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        85.25             69.53                  |
|         I   [in^4]       534.18            290.38                  |
|       Y_cog  [in]          4.62              3.75                  |
|       height [in]          9.17              7.32                  |
|         e    [in]          0.60             -0.24                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 99.2 [kips] (H-3)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.05           2.03                         |
|        Right [in]      1.90           0.87                         |
|        Top   [in]      3.41           3.25                         |
|        Bottom[in]      2.28           2.35                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

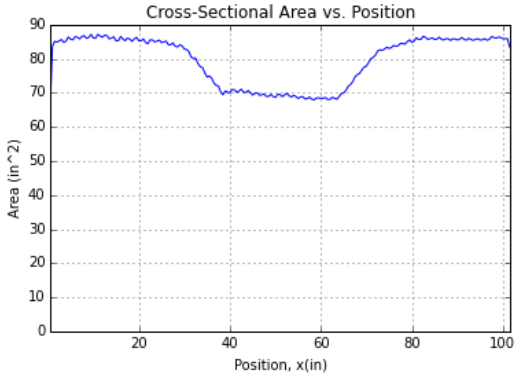
Model Views:

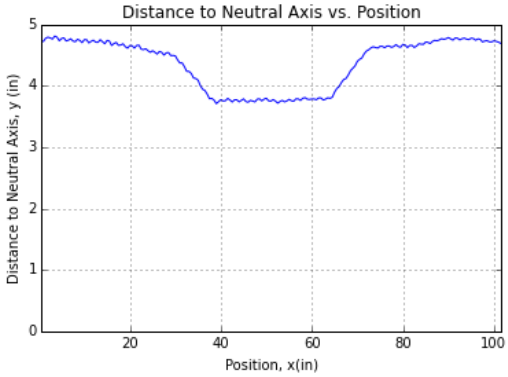


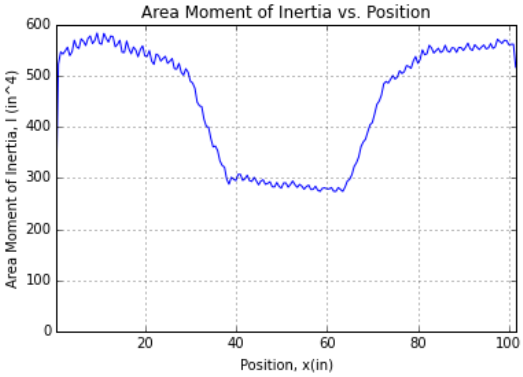


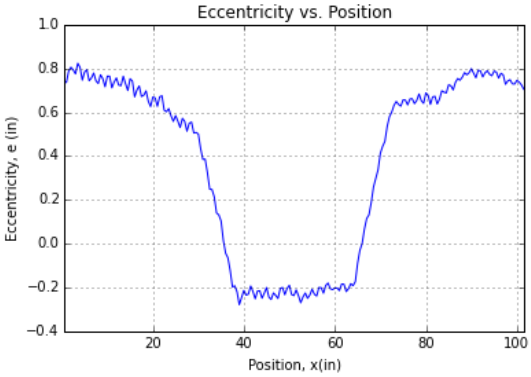
100 mm

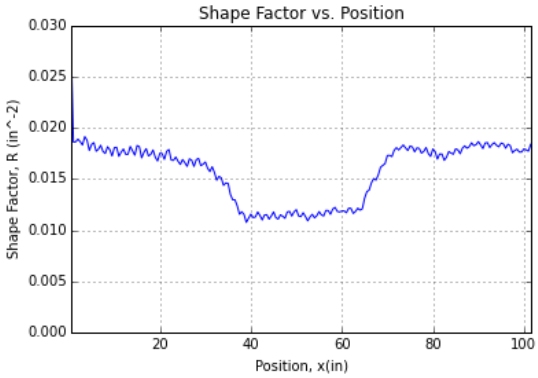
Processed Data:











End Pictures:

Damage:

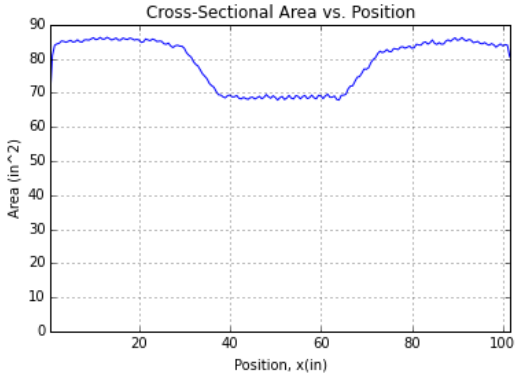
Report for Tie H-6

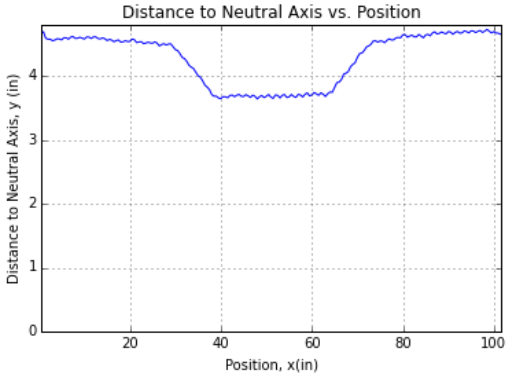
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : H6                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 4.077 in                                              |
|      Right : 3.865 in                                              |
|      Avg.  : 3.971 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        84.57             68.58                  |
|         I   [in^4]       528.79            277.17                  |
|       Y_cog  [in]          4.55              3.67                  |
|       height [in]          9.07              7.28                  |
|         e    [in]          0.53             -0.31                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  =99.2 [kips] (H-3)                               |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      0.80           2.14                         |
|        Right [in]      2.04           0.76                         |
|        Top   [in]      3.29           3.39                         |
|        Bottom[in]      2.20           2.21                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

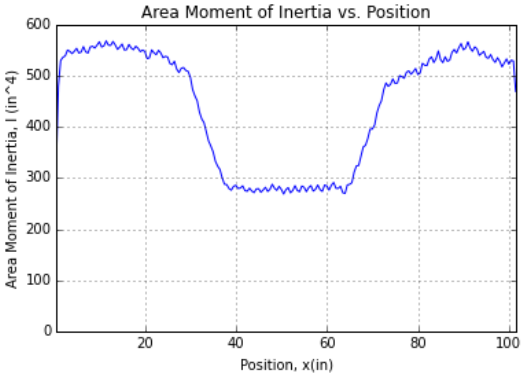
Model Views:

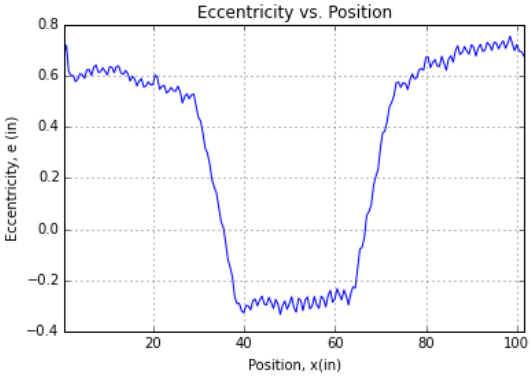
100 mm

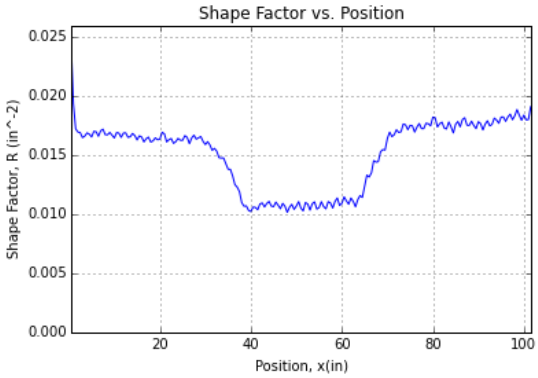
Processed Data:



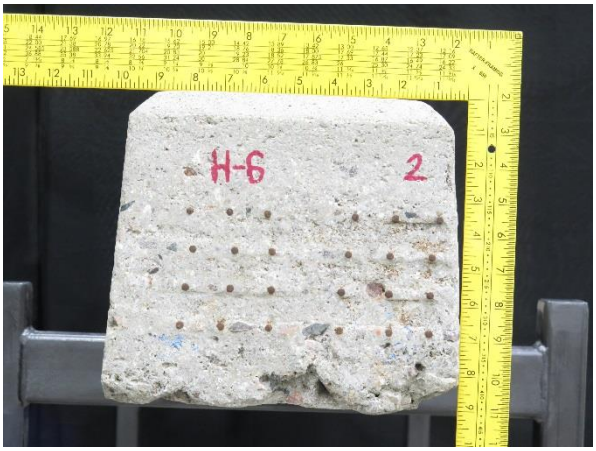








End Pictures:

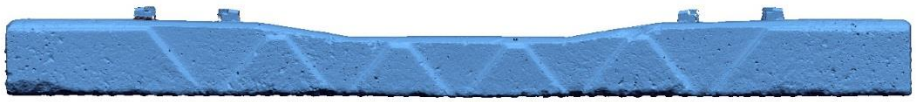


Damage:

Report for Tie J-1

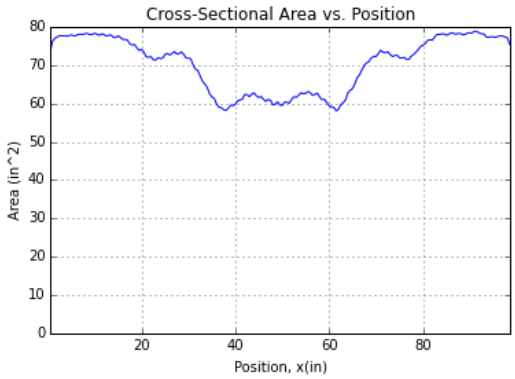
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017    Ver1 |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J1                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.132 in                                              |
|      Right : 2.961 in                                              |
|      Avg.  : 3.047 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.41             59.58                  |
|         I   [in^4]       385.53            207.79                  |
|       Y_cog  [in]          4.02              3.22                  |
|       height [in]          8.23              6.57                  |
|         e    [in]          0.78             -0.04                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.52           1.41                         |
|        Right [in]      1.37           1.48                         |
|        Top   [in]      3.37           3.54                         |
|        Bottom[in]      1.27           1.11                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

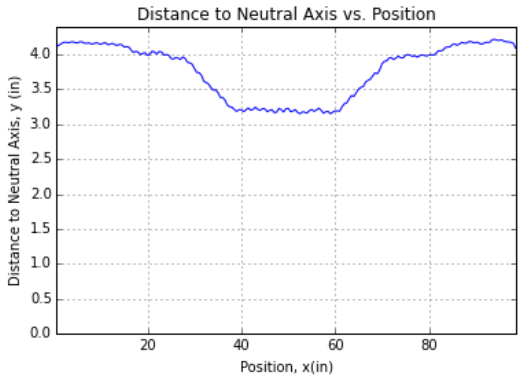
Model Views:

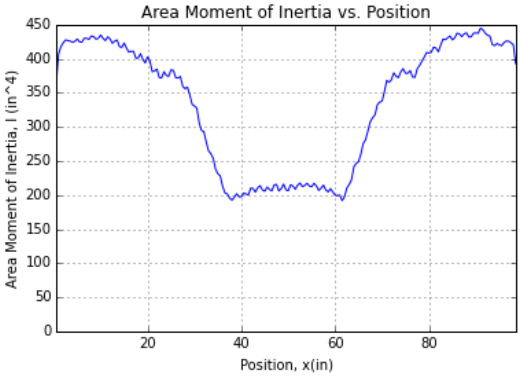


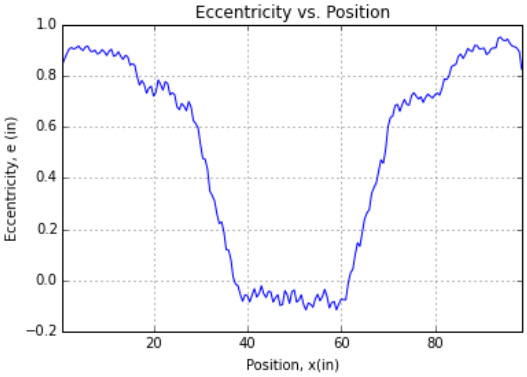
100 mm

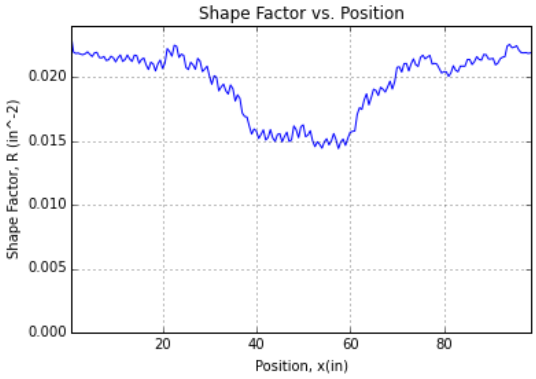
Processed Data:











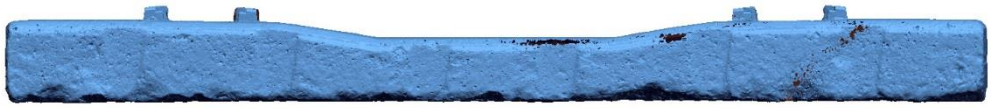
End Pictures:

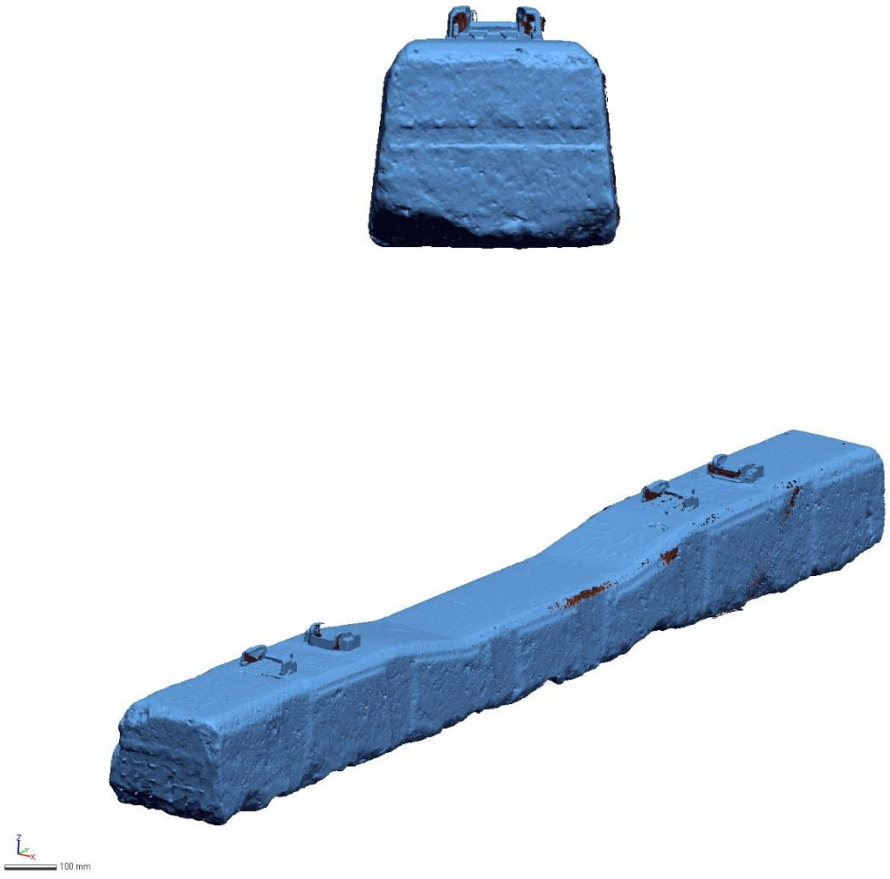
Damage:

Report for Tie J-2

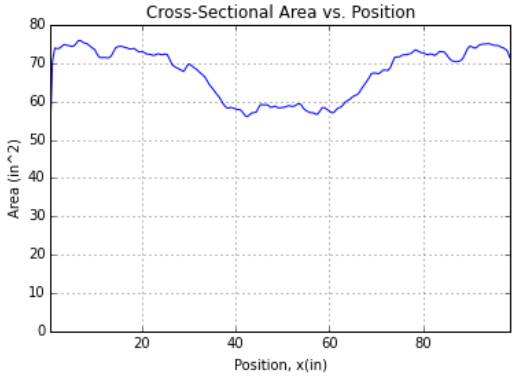
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J2                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.056 in                                              |
|      Right : 3.084 in                                              |
|      Avg.  : 3.070 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.71             58.28                  |
|         I   [in^4]       369.00            184.28                  |
|       Y_cog  [in]          4.25              3.50                  |
|       height [in]          8.41              6.77                  |
|         e    [in]          1.17              0.43                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.20           1.28                         |
|        Right [in]      1.51           1.38                         |
|        Top   [in]      3.55           3.45                         |
|        Bottom[in]      1.18           1.20                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

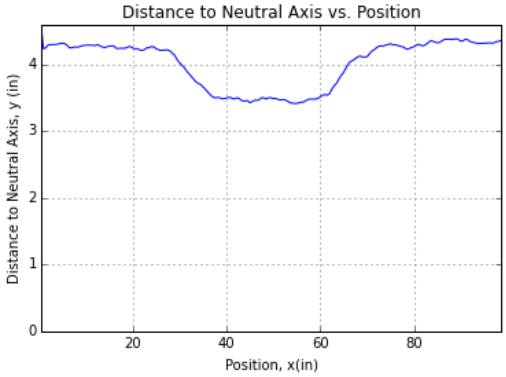
Model Views:

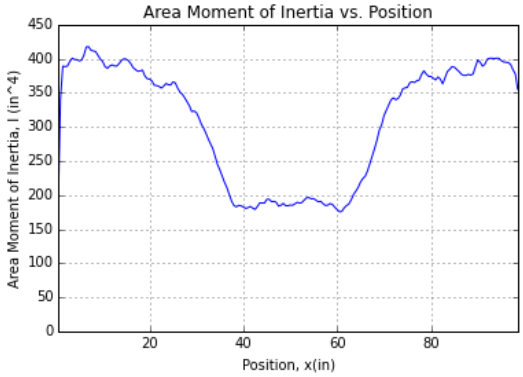


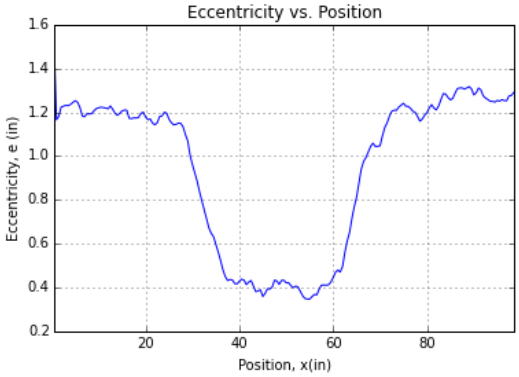

100 mm

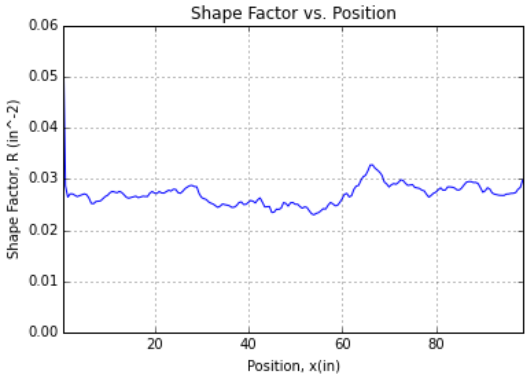
Processed Data:



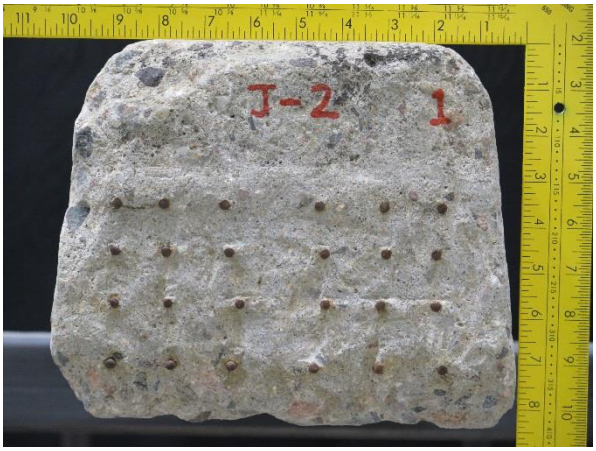


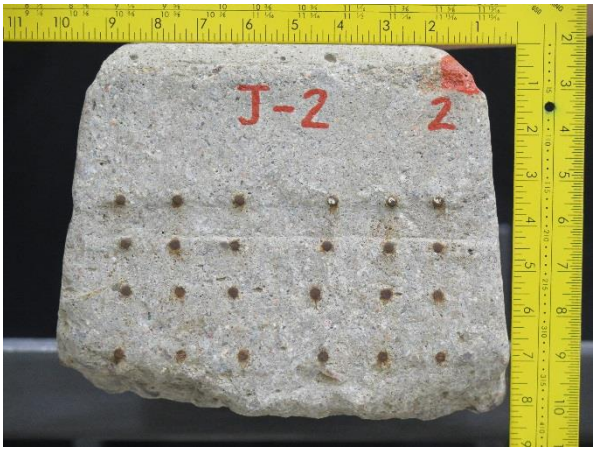




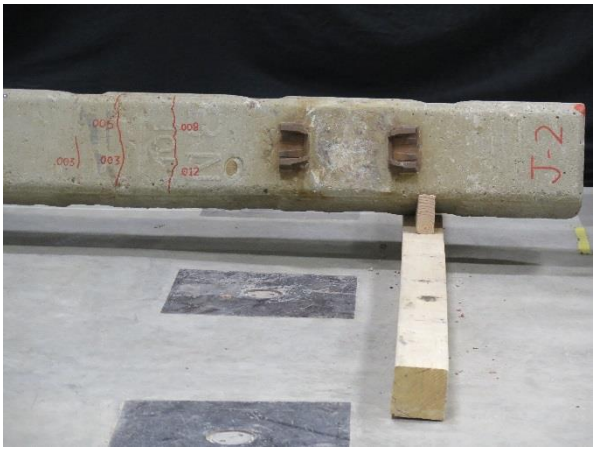


End Pictures:





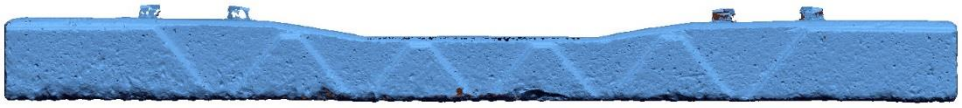
Damage:

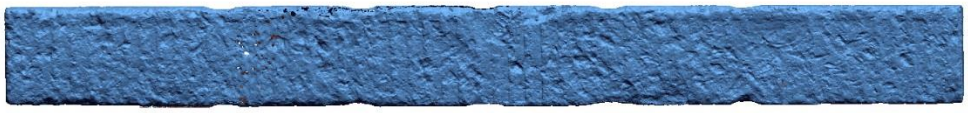


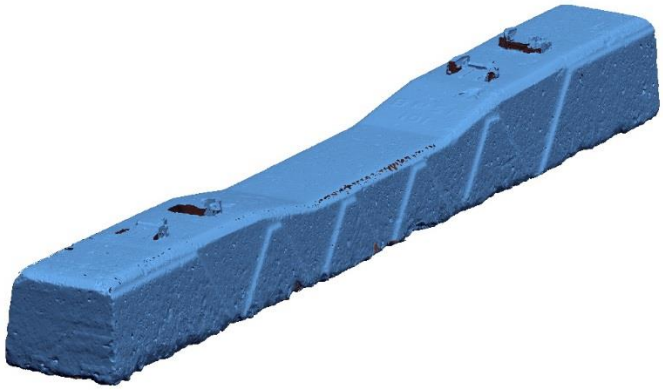
Report for Tie J-3

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J3                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.131 in                                              |
|      Right : 3.208 in                                              |
|      Avg.  : 3.169 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.62             60.50                  |
|         I   [in^4]       411.12            213.32                  |
|       Y_cog  [in]          4.38              3.62                  |
|       height [in]          8.62              7.01                  |
|         e    [in]          1.25              0.45                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.50           1.43                         |
|        Right [in]      1.35           1.28                         |
|        Top   [in]      3.49           3.54                         |
|        Bottom[in]      1.12           1.20                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

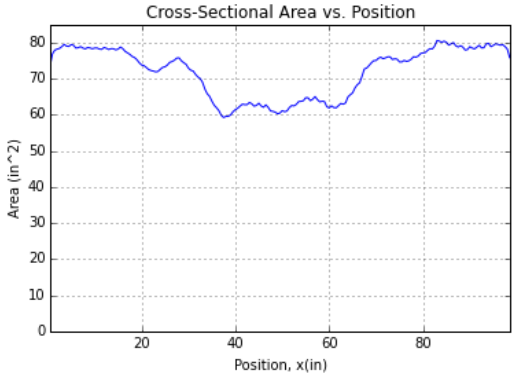


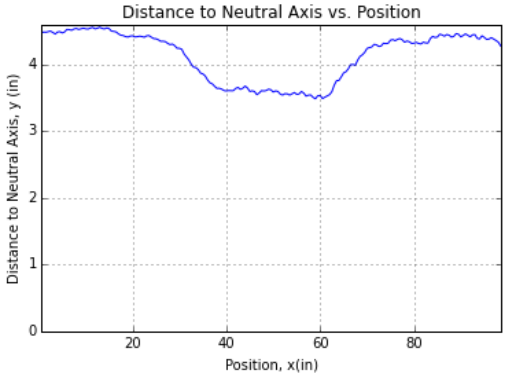


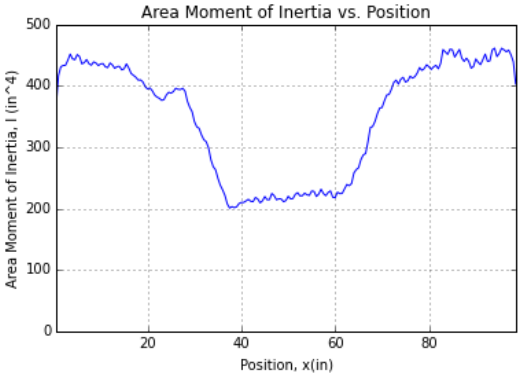


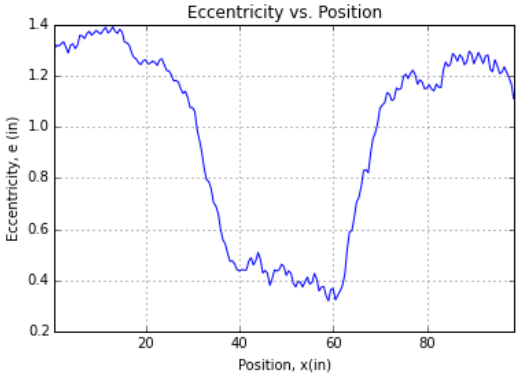
100 mm

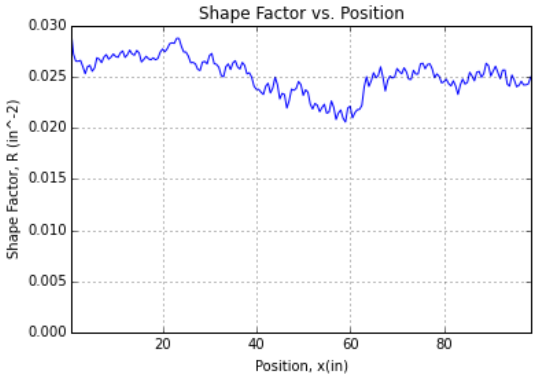
Processed Data:



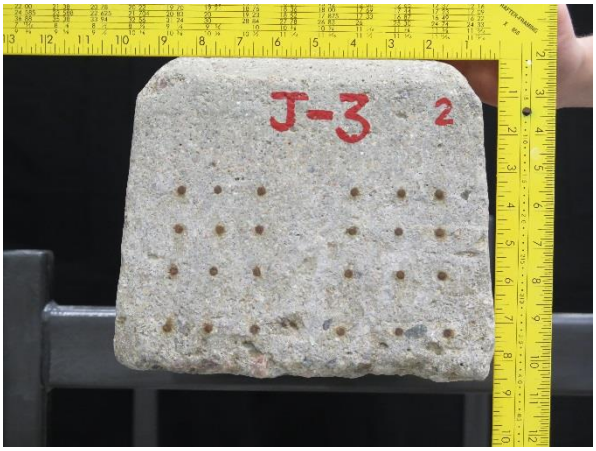








End Pictures:

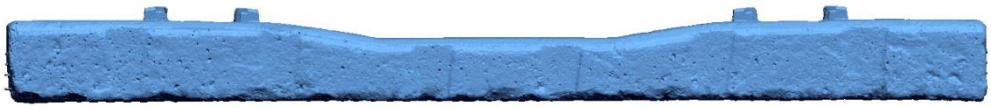


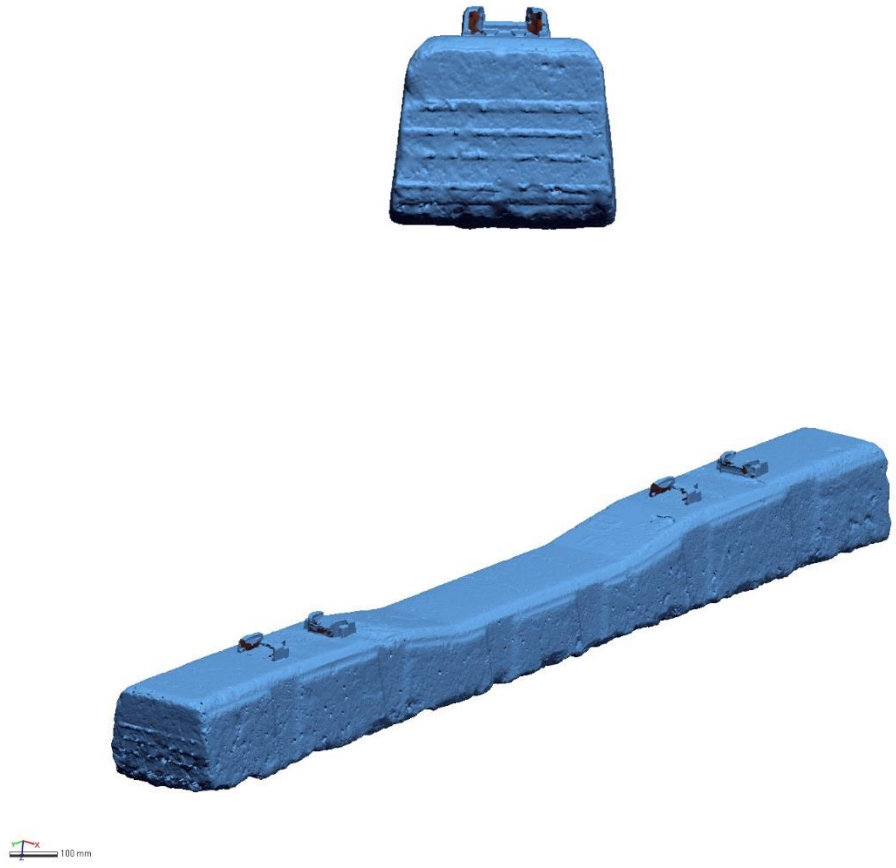
Damage:

Report for Tie J-4

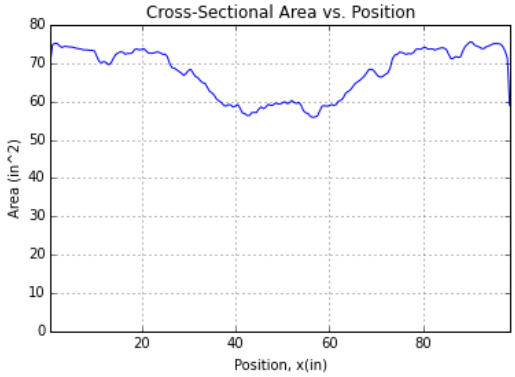
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J4                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.356 in                                              |
|      Right : 3.350 in                                              |
|      Avg.  : 3.353 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        72.91             59.28                  |
|         I   [in^4]       368.05            189.66                  |
|       Y_cog  [in]          4.11              3.36                  |
|       height [in]          8.29              6.57                  |
|         e    [in]          0.76              0.01                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.48           1.38                         |
|        Right [in]      1.24           1.32                         |
|        Top   [in]      3.32           3.40                         |
|        Bottom[in]      1.40           1.09                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : Low                                       |
+--------------------------------------------------------------------+
```

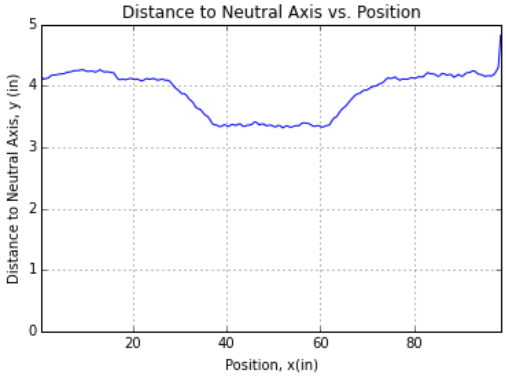
Model Views:

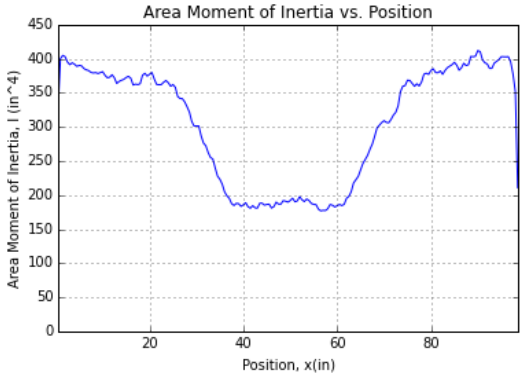


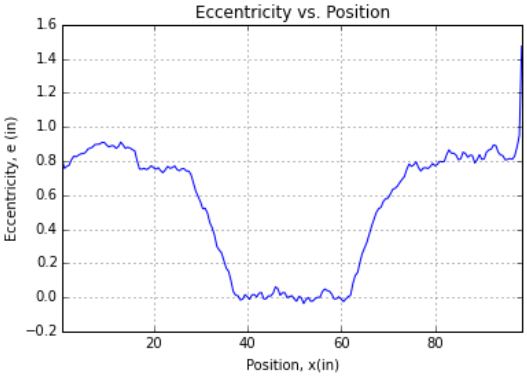

100 mm

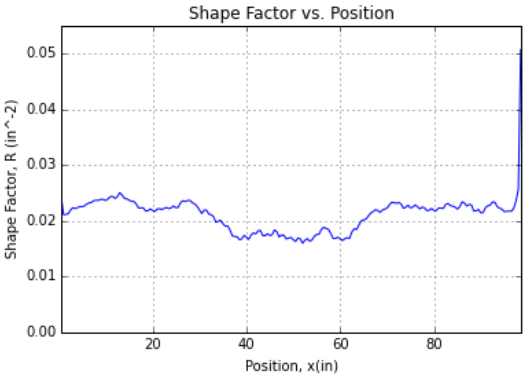
Processed Data:



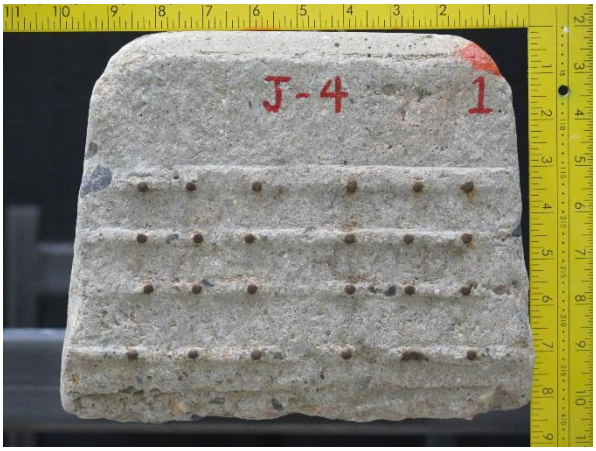








End Pictures:

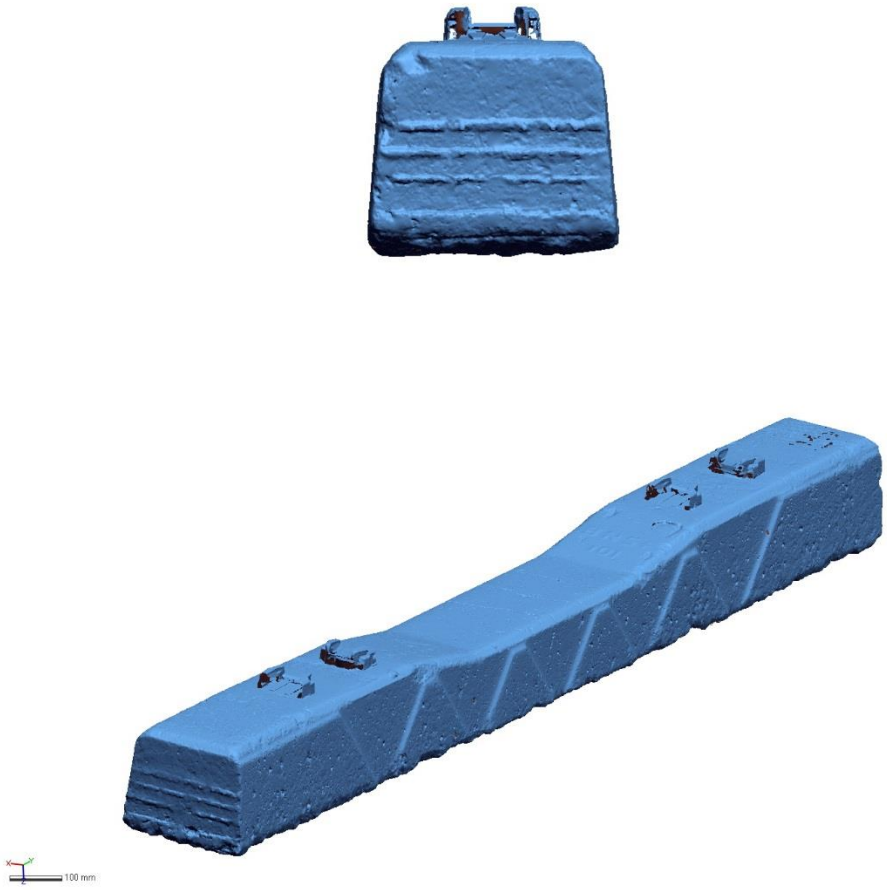


Damage:

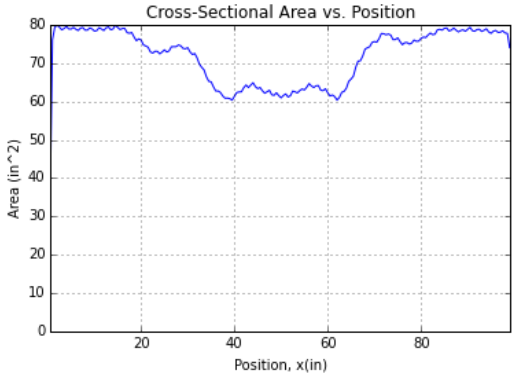
Report for Tie J-5

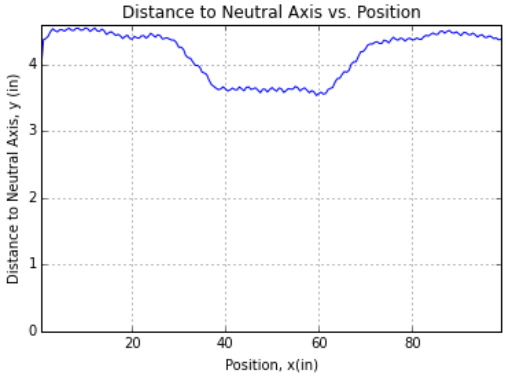
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J5                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.192 in                                              |
|      Right : 3.287 in                                              |
|      Avg.  : 3.240 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.81             61.49                  |
|         I   [in^4]       423.37            227.69                  |
|       Y_cog  [in]          4.40              3.63                  |
|       height [in]          8.74              7.09                  |
|         e    [in]          1.16              0.39                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.53           1.51                         |
|        Right [in]      1.32           1.31                         |
|        Top   [in]      3.47           3.55                         |
|        Bottom[in]      1.23           1.22                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Low                                       |
+--------------------------------------------------------------------+
```

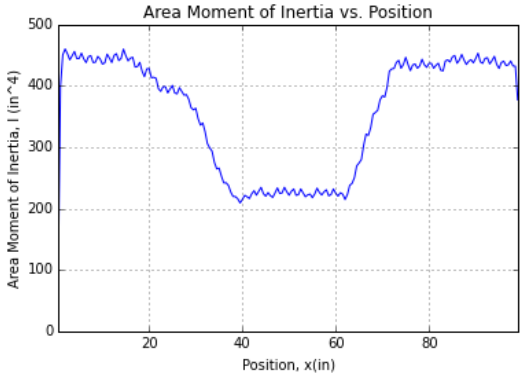
Model Views:

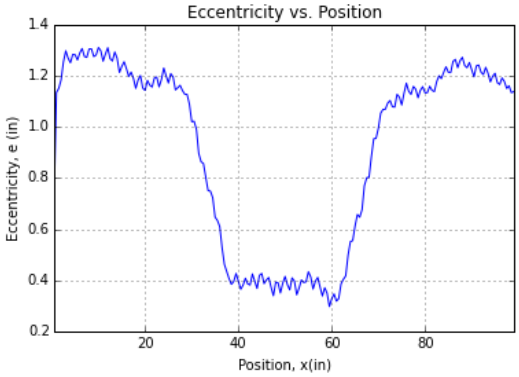

100 mm

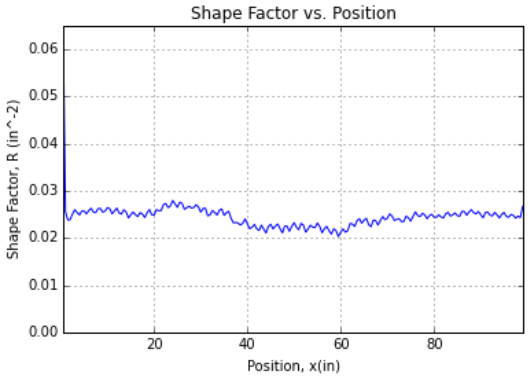
Processed Data:



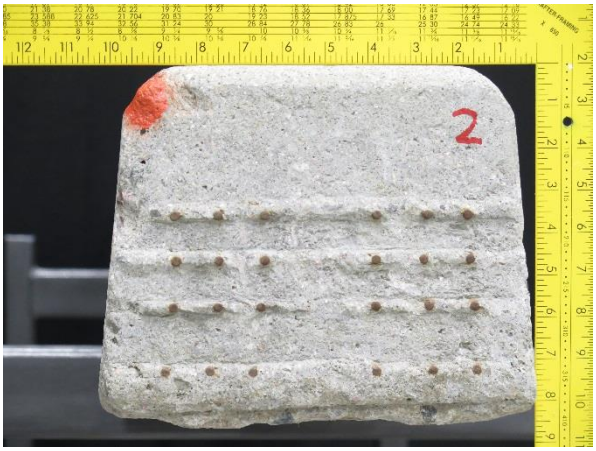








End Pictures:

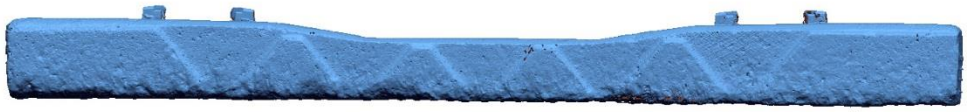


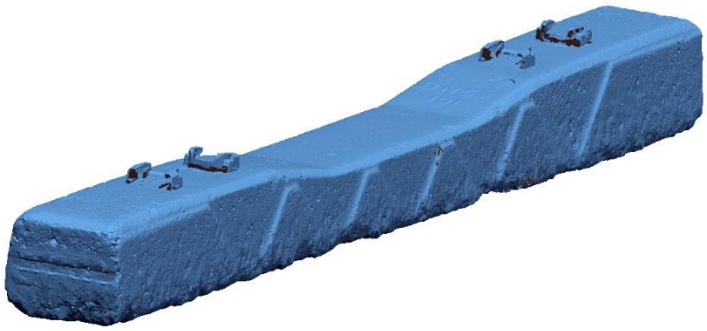
Damage:

Report for Tie J-6

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : J6                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : N/A                                              |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.059 in                                              |
|      Right : 2.981 in                                              |
|      Avg.  : 3.020 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.94 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 6-6-6-6                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        71.73             58.45                 |
|         I   [in^4]       381.33            201.88                 |
|       Y_cog  [in]          4.35              3.56                 |
|       height [in]          8.54              6.89                 |
|         e    [in]          1.29              0.54                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.29           1.32                         |
|        Right [in]      1.26           1.38                         |
|        Top   [in]      3.56           3.58                         |
|        Bottom[in]      1.12           1.32                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

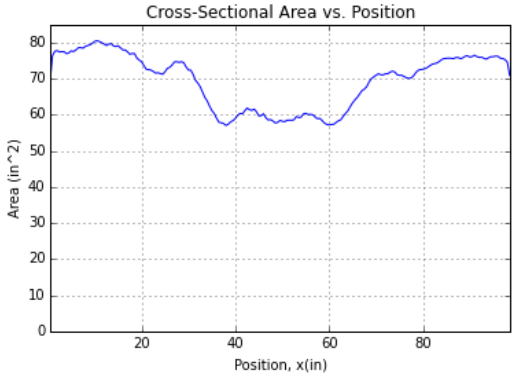
Model Views:

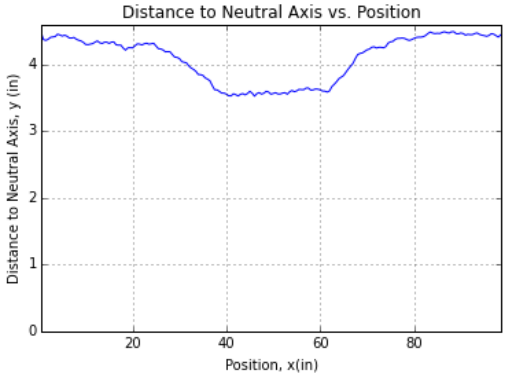


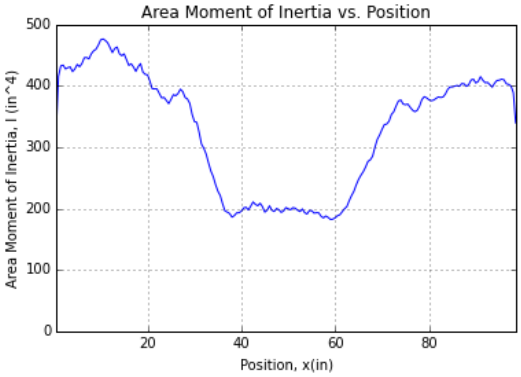


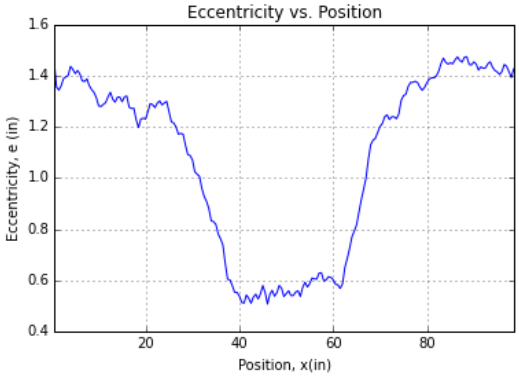
100 mm

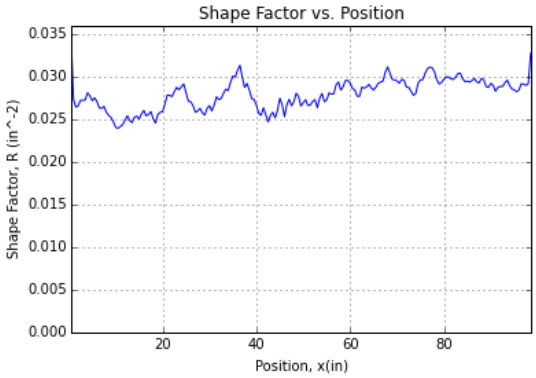
Processed Data:



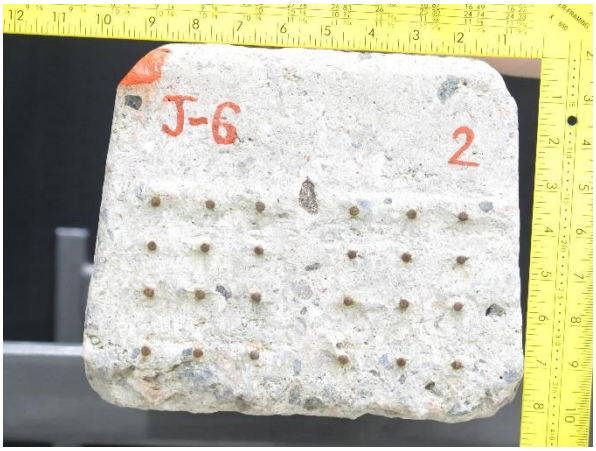








End Pictures:

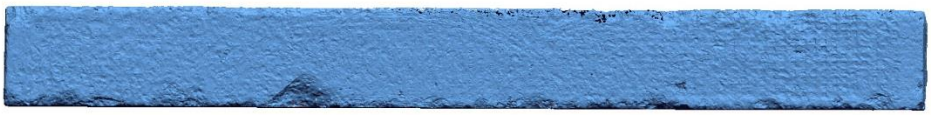


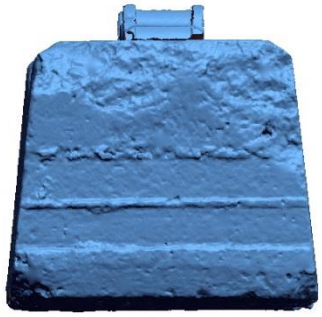
Damage:

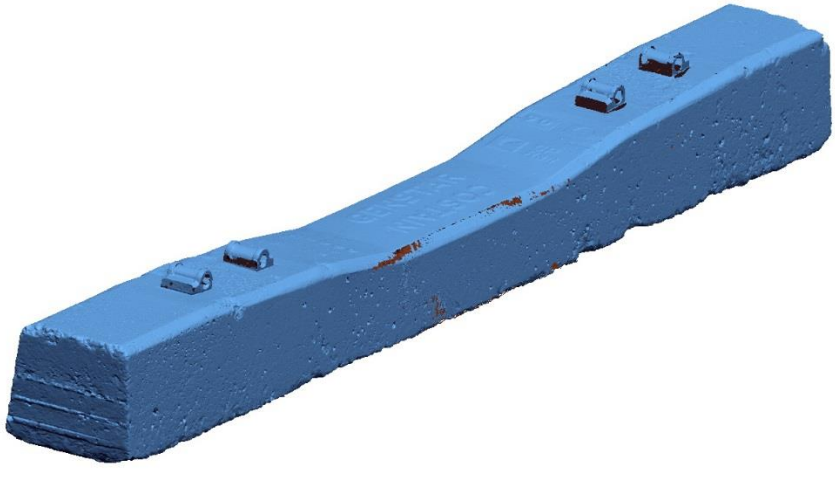
Report for Tie K-1

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : K1                                               |
|    Manufacturer : COSTAIN GENSTAR                                  |
|    Alternate ID : CP RAIL                                          |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.527 in                                              |
|      Right : 3.402 in                                              |
|      Avg.  : 3.464 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.95 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 8-8-8                                               |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        89.28             71.78                 |
|         I   [in^4]       556.48            288.60                 |
|       Y_cog  [in]          4.37              3.55                 |
|       height [in]          8.98              7.20                 |
|         e    [in]          0.82              0.08                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 93.0 [kips] (K-5)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.55           1.99                        |
|        Right [in]      1.92           1.48                        |
|        Top   [in]      4.32           4.28                        |
|        Bottom[in]      1.78           1.74                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity :  Low                                      |
|      Cracking Severity :  None                                     |
+--------------------------------------------------------------------+
```

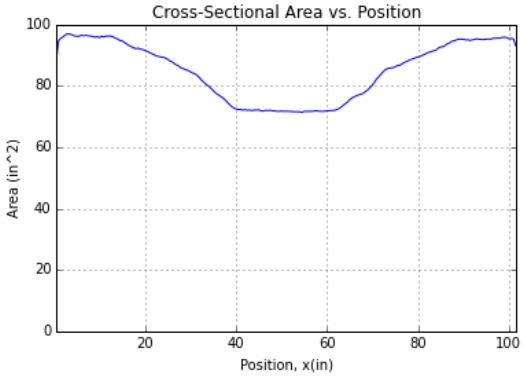
Model Views:

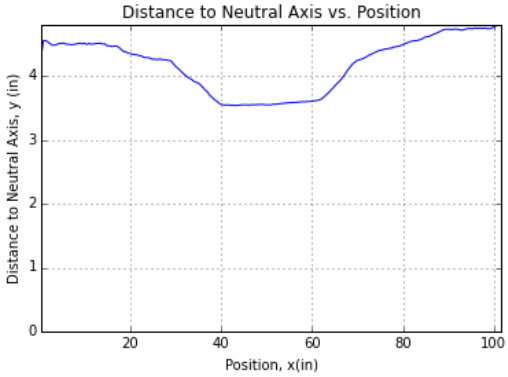


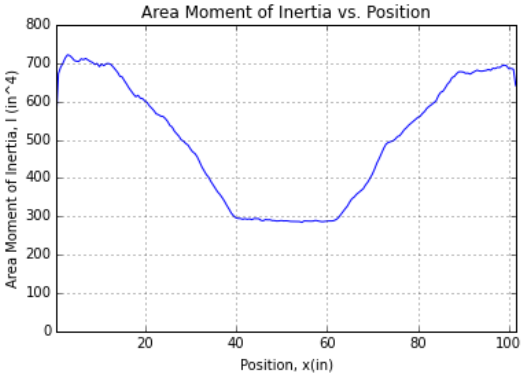


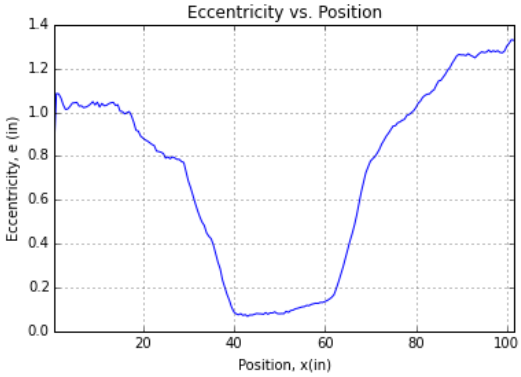


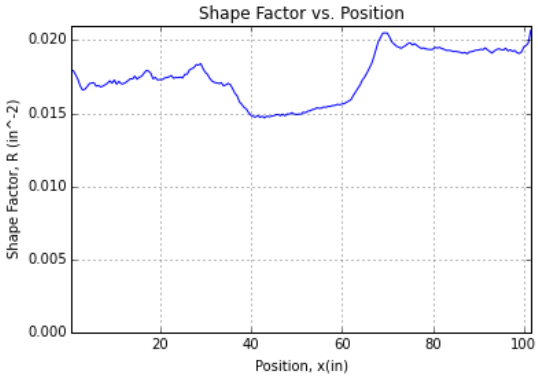
Processed Data:











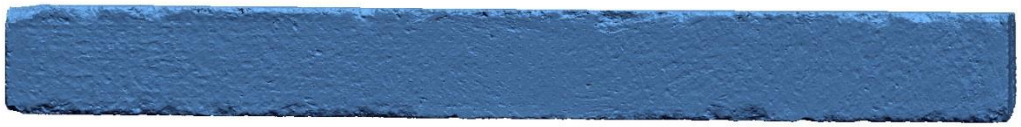
End Pictures:

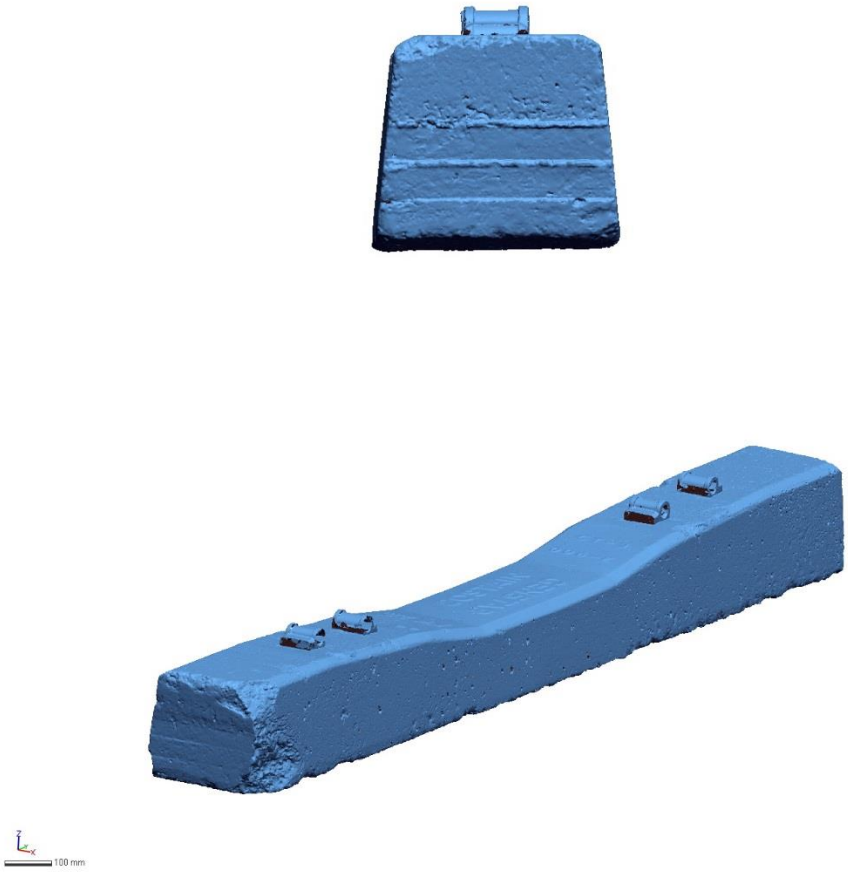
Damage:

Report for Tie K-2

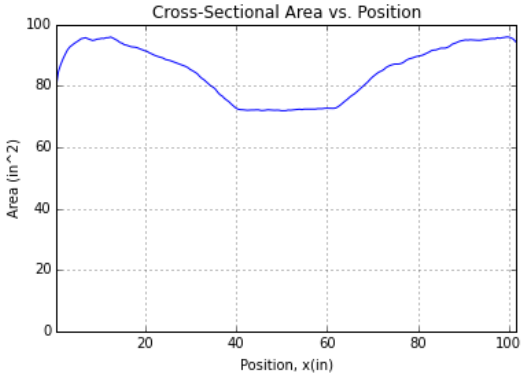
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : K2                                                  |
|    Manufacturer : COSTAIN GENSTAR                                     |
|    Alternate ID : CP RAIL                                             |
|    Tie Length   : 8’6”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.467 in                                                 |
|      Right : 3.403 in                                                 |
|      Avg.  : 3.435 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 4.95 mm                                                |
|      Tendons : 24                                                     |
|      Pattern : 8-8-8                                                  |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        89.38             71.97                    |
|         I   [in^4]       559.90            284.39                    |
|       Y_cog  [in]          4.56              3.71                    |
|       height [in]          9.17              7.32                    |
|         e    [in]          1.13              0.27                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 93.0 [kips] (K-5)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      1.95           1.52                           |
|        Right [in]      0.88           1.96                           |
|        Top   [in]      4.03           4.18                           |
|        Bottom[in]      1.75           1.69                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : None                                         |
+-----------------------------------------------------------------------+
```

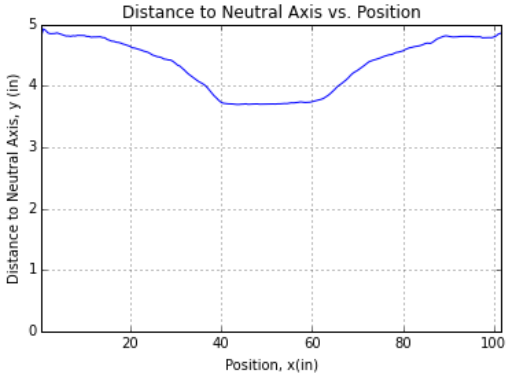
Model Views:

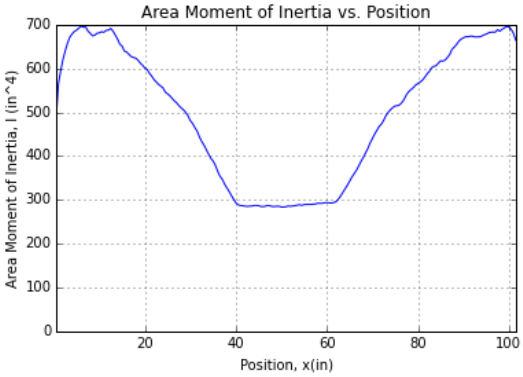


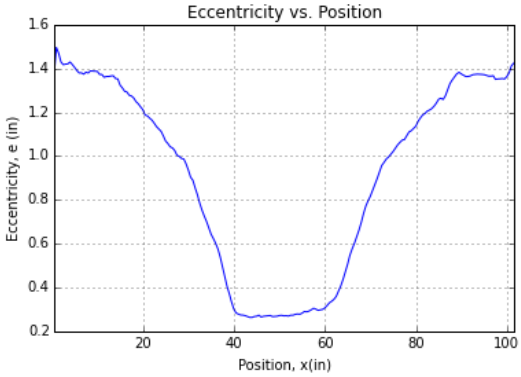

100 mm

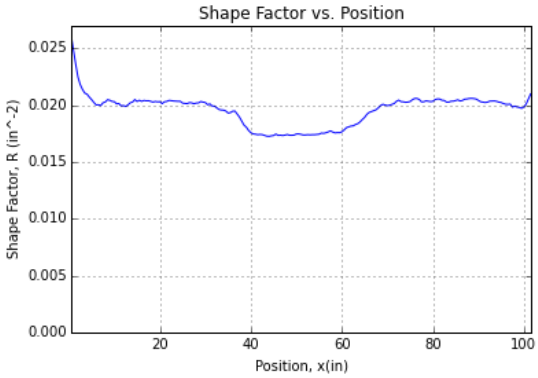
Processed Data:











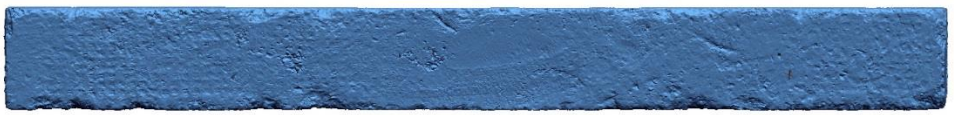
End Pictures:

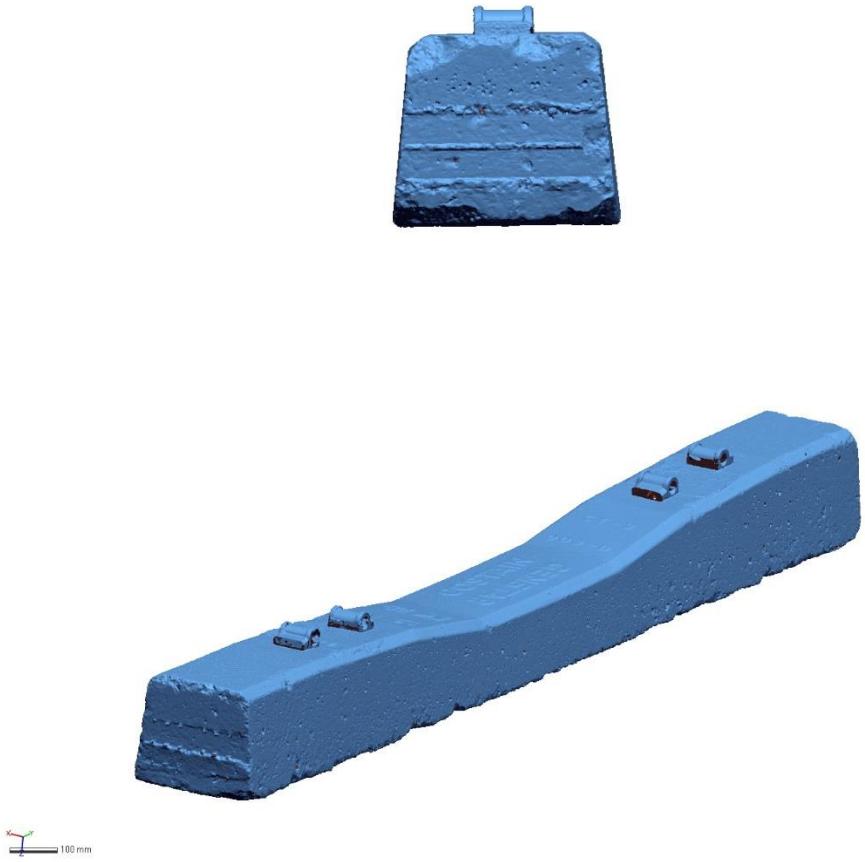
Damage:

Report for Tie K-3

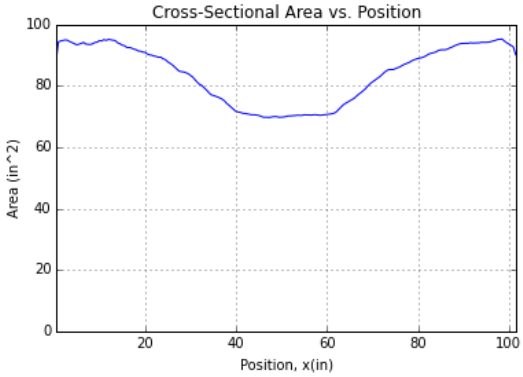
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : K3                                               |
|    Manufacturer : COSTAIN GENSTAR                                  |
|    Alternate ID : CP RAIL                                          |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.725 in                                              |
|      Right : 3.643 in                                              |
|      Avg.  : 3.684 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.95 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 8-8-8                                               |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        88.90             70.02                 |
|         I   [in^4]       552.91            264.03                 |
|       Y_cog  [in]          4.42              3.51                 |
|       height [in]          9.02              7.05                 |
|         e    [in]          0.72             -0.17                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 93.0 [kips] (K-5)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.43           1.73                        |
|        Right [in]      1.96           1.64                        |
|        Top   [in]      3.99           3.83                        |
|        Bottom[in]      1.94           1.89                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

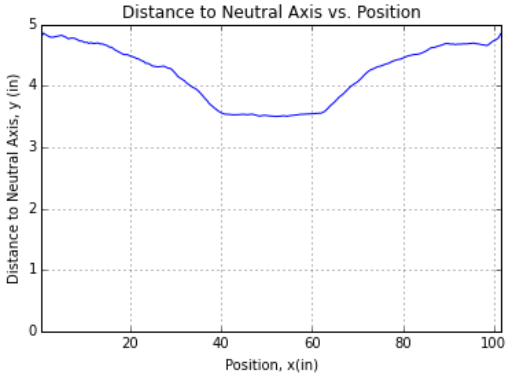
Model Views:

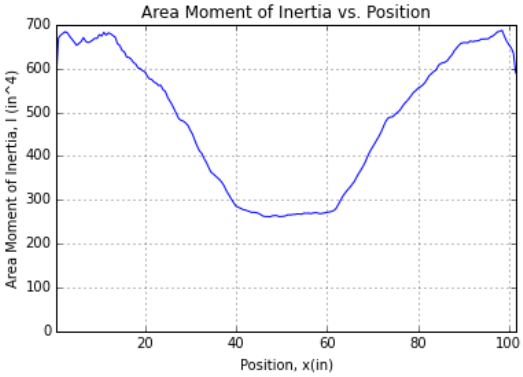


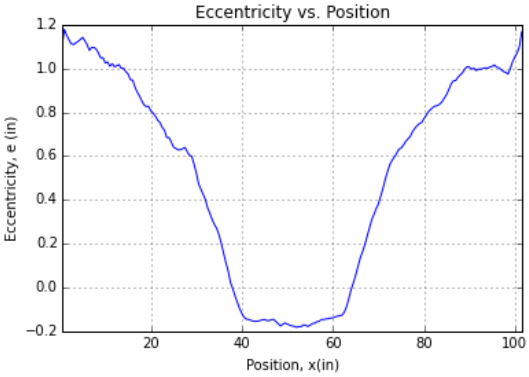

100 mm

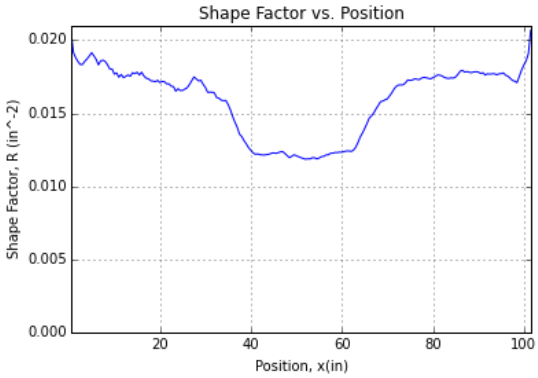
Processed Data:



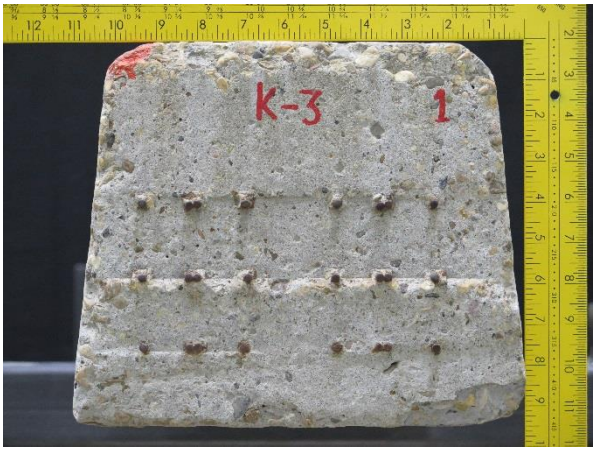


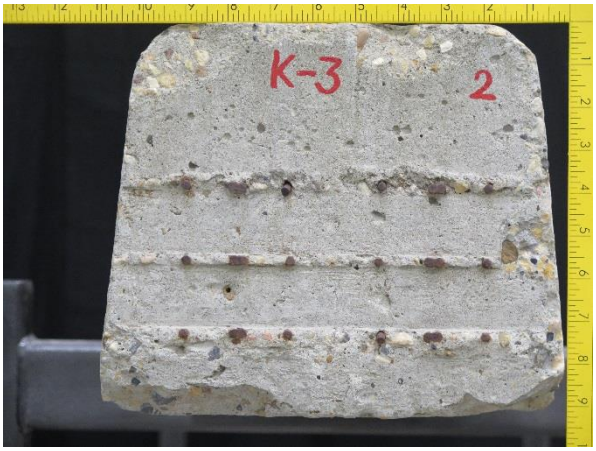






End Pictures:



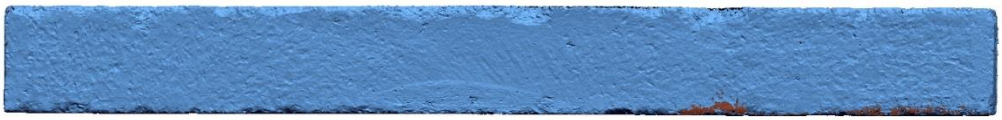


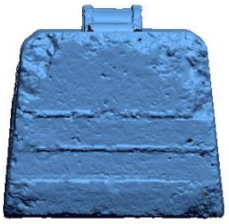
Damage:

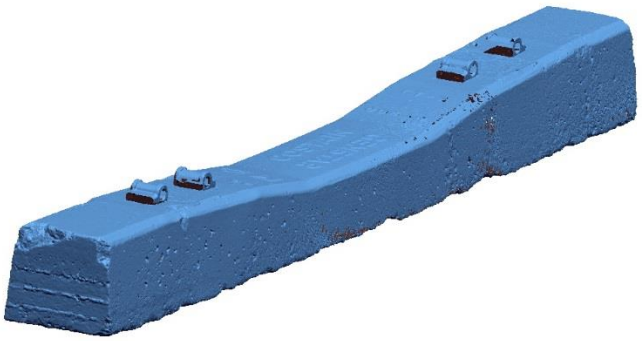
Report for Tie K-4

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : K4                                               |
|    Manufacturer : COSTAIN GENSTAR                                  |
|    Alternate ID : CP RAIL                                          |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.658 in                                              |
|      Right : 3.598 in                                              |
|      Avg.  : 3.628 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.95 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 8-8-8                                               |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        88.21             71.66                 |
|         I   [in^4]       542.25            275.17                 |
|       Y_cog  [in]          4.42              3.58                 |
|       height [in]          8.96              7.13                 |
|         e    [in]          0.82             -0.05                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 93.0 [kips] (K-5)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.77           1.57                        |
|        Right [in]      1.70           1.85                        |
|        Top   [in]      4.22           4.36                        |
|        Bottom[in]      1.68           1.76                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

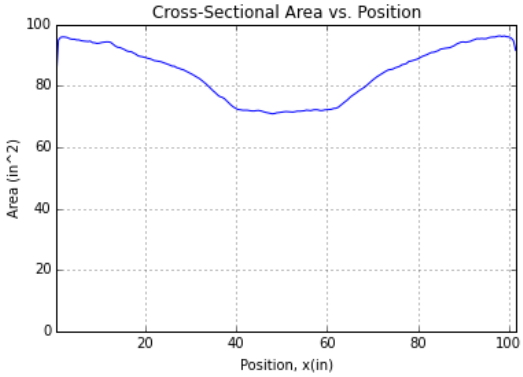


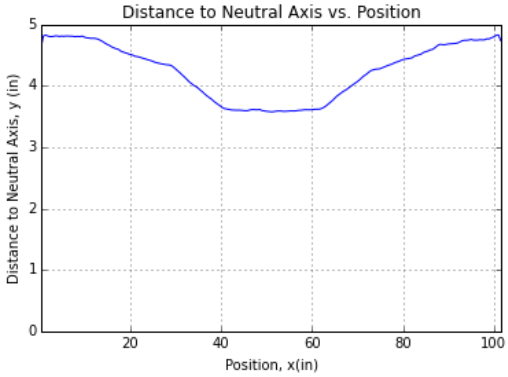


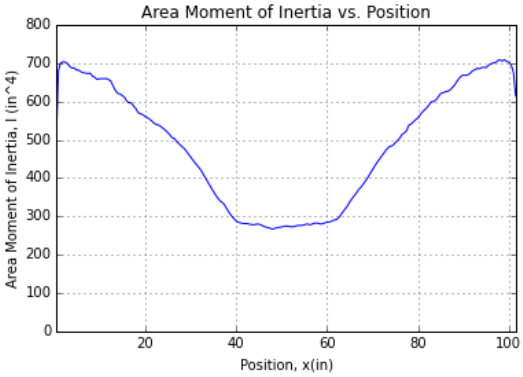


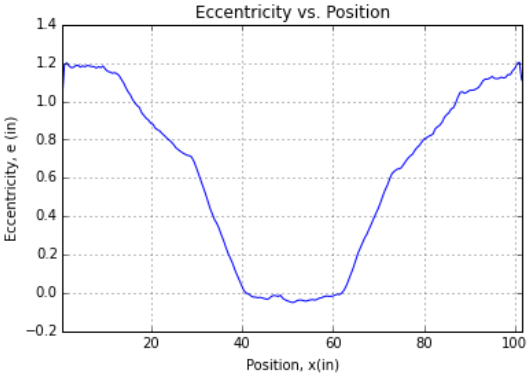
100 mm

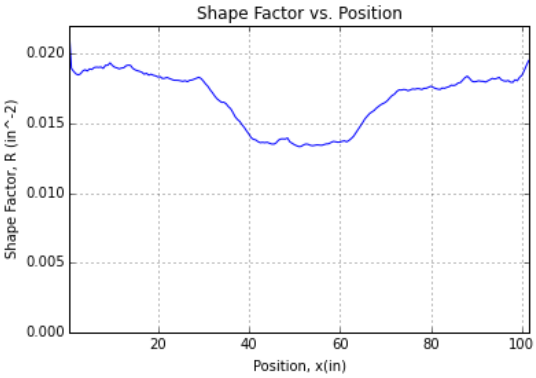
Processed Data:











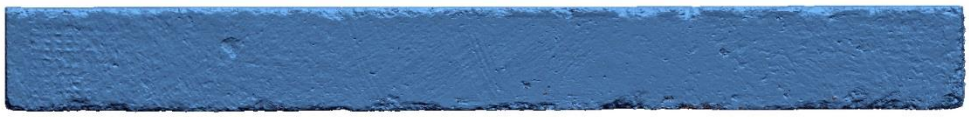
End Pictures:

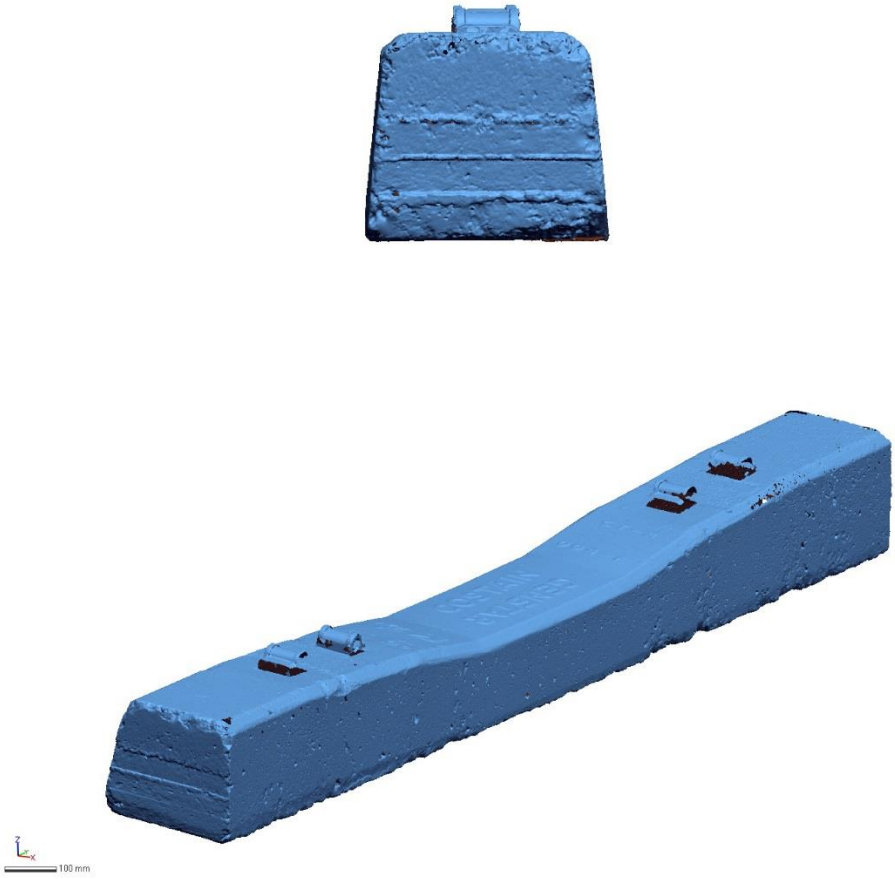
Damage:

Report for Tie K-5

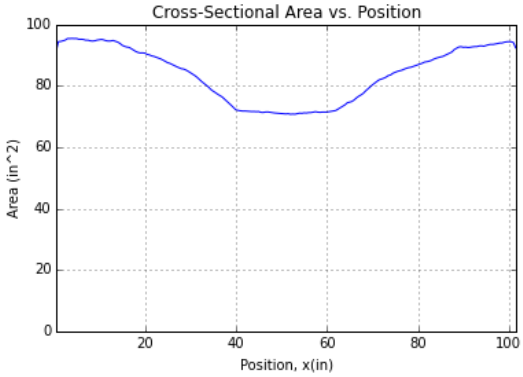
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : K5                                               |
|    Manufacturer : COSTAIN GENSTAR                                  |
|    Alternate ID : CP RAIL                                          |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.690 in                                              |
|      Right : 3.623 in                                              |
|      Avg.  : 3.656 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.95 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 8-8-8                                               |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        87.73             70.88                 |
|         I   [in^4]       531.57            275.45                 |
|       Y_cog  [in]          4.50              3.65                 |
|       height [in]          9.04              7.24                 |
|         e    [in]          0.82             -0.01                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 93.0 [kips] (K-5)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.90           1.48                        |
|        Right [in]      1.60           1.98                        |
|        Top   [in]      4.12           4.14                        |
|        Bottom[in]      1.92           1.96                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

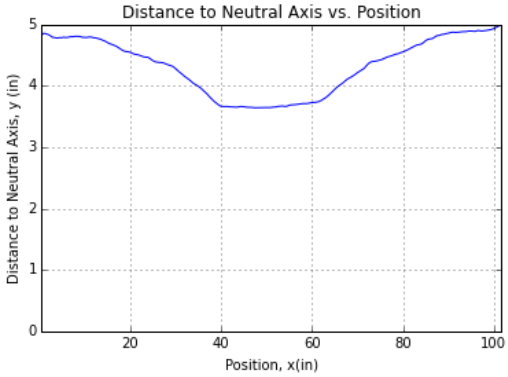
Model Views:

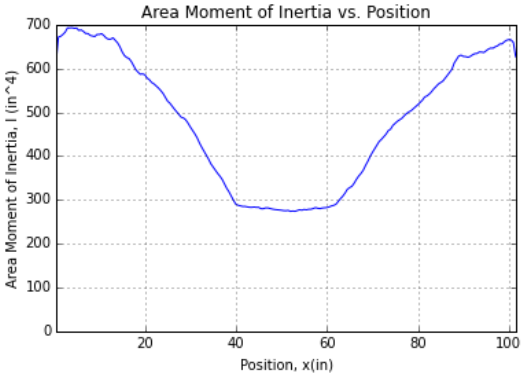


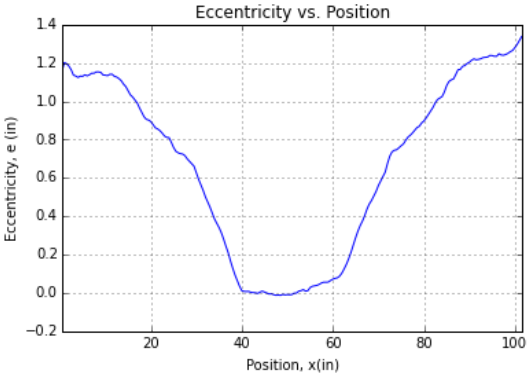

100 mm

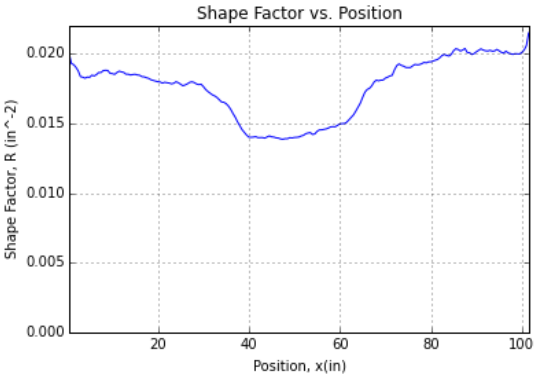
Processed Data:











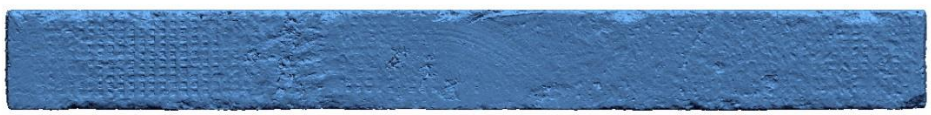
End Pictures:

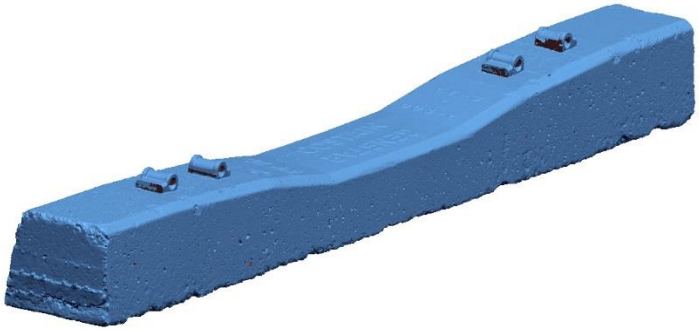
Damage:

Report for Tie K-6

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : K6                                               |
|    Manufacturer : COSTAIN GENSTAR                                  |
|    Alternate ID : CP RAIL                                          |
|    Tie Length   : 8’6”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.501 in                                              |
|      Right : 3.783 in                                              |
|      Avg.  : 3.642 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.95 mm                                             |
|      Tendons : 24                                                  |
|      Pattern : 8-8-8                                               |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        90.00             69.61                  |
|         I   [in^4]       569.76            257.45                  |
|       Y_cog  [in]          4.58              3.67                  |
|       height [in]          9.25              7.13                  |
|         e    [in]          0.91              0.03                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 93.0 [kips] (K-5)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.37           1.78                         |
|        Right [in]      2.01           1.60                         |
|        Top   [in]      4.08           3.91                         |
|        Bottom[in]      1.77           1.92                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

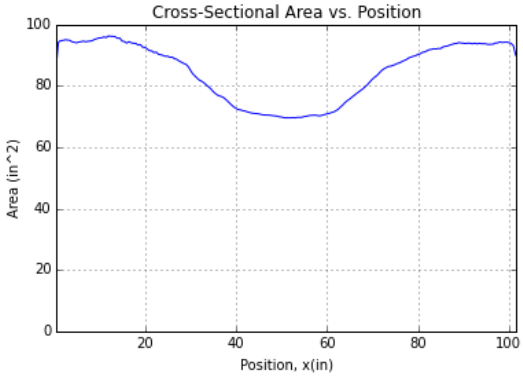
Model Views:

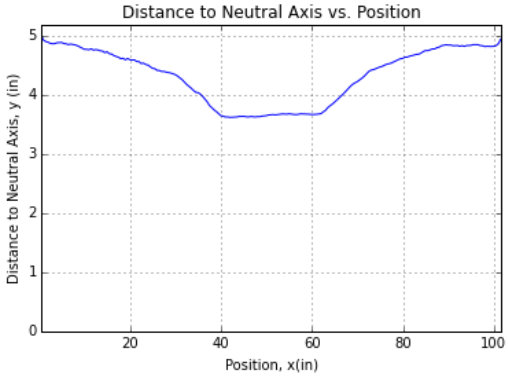


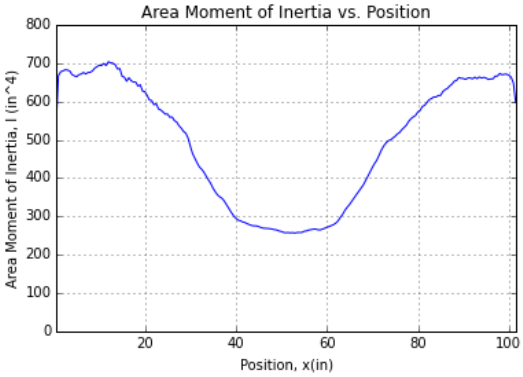


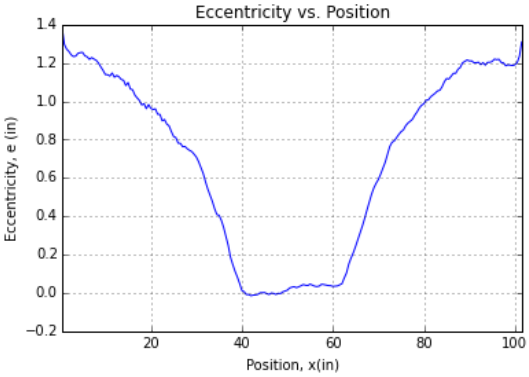
100 mm

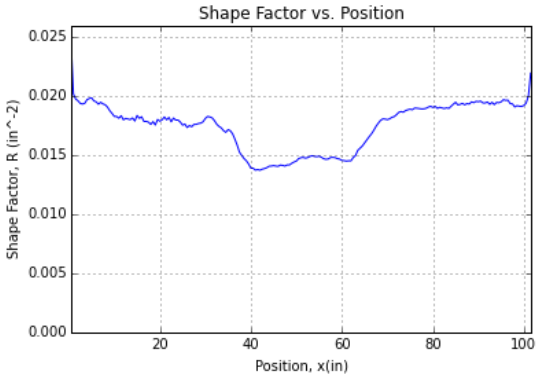
Processed Data:



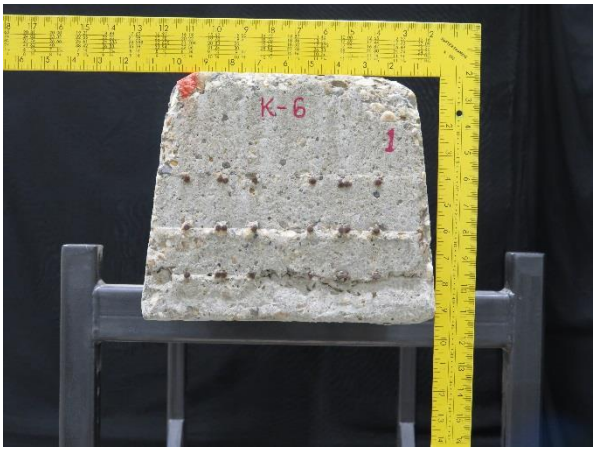


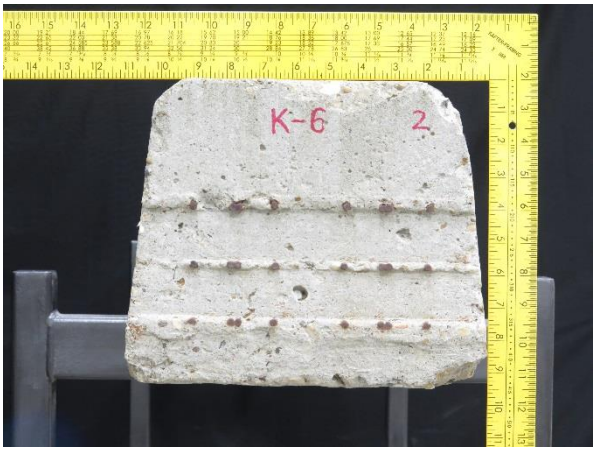






End Pictures:



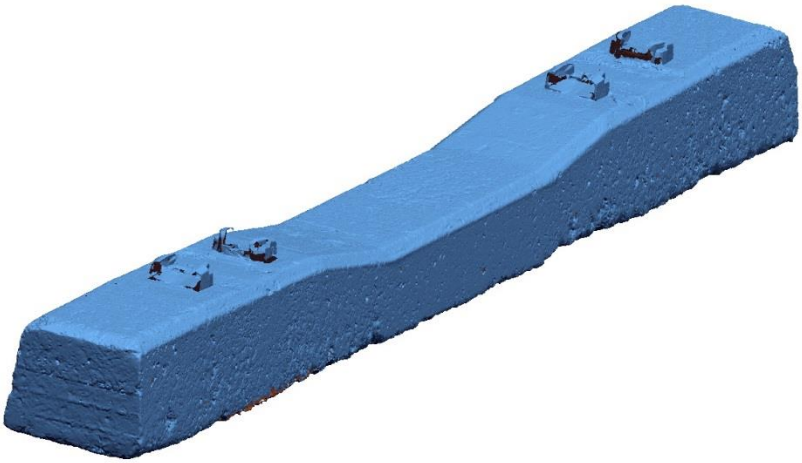


Damage:

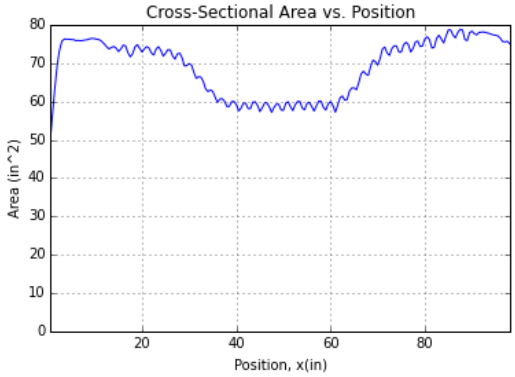
Report for Tie L-1

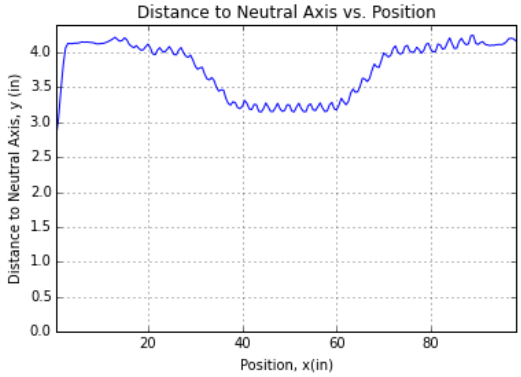
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : L1                                               |
|    Manufacturer : CXT                                              |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.121 in                                              |
|      Right : 3.411 in                                              |
|      Avg.  : 3.266 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-10-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.88             57.75                 |
|         I   [in^4]       389.53            172.57                 |
|       Y_cog  [in]          3.99              3.25                 |
|       height [in]          8.22              6.38                 |
|         e    [in]          0.78              0.05                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 88.5 [kips] (L-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.18           1.46                        |
|        Right [in]      1.39           1.18                        |
|        Top   [in]      3.49           3.41                        |
|        Bottom[in]      1.73           1.97                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

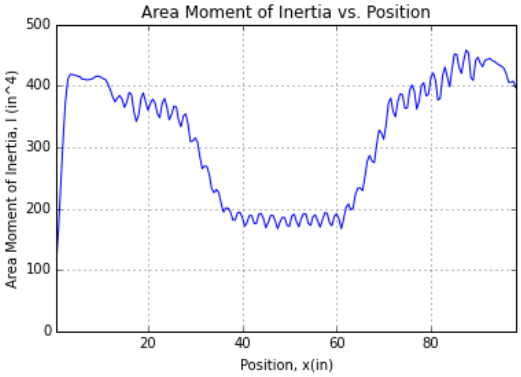
Model Views:

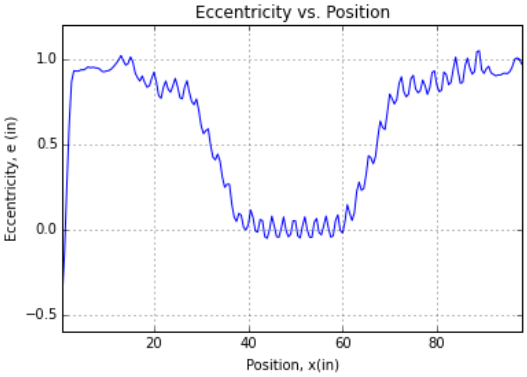


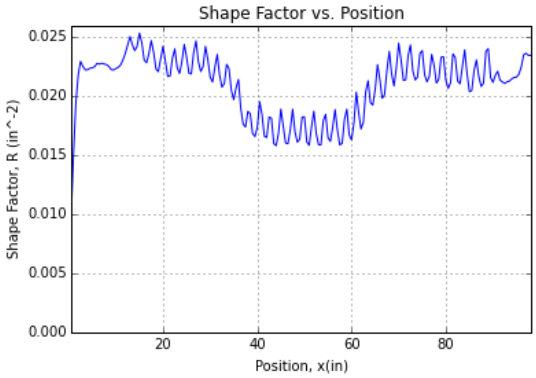
Processed Data:





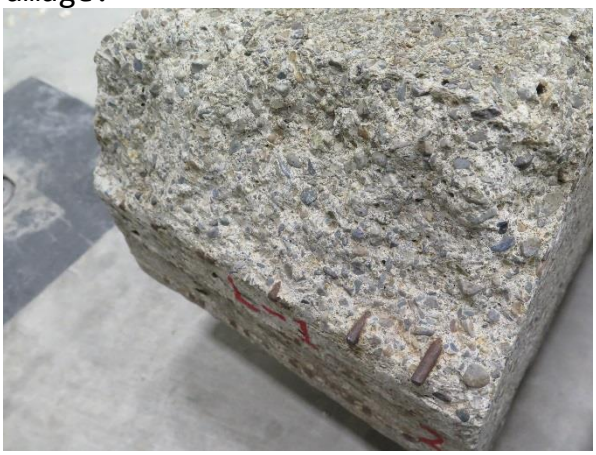






End Pictures:

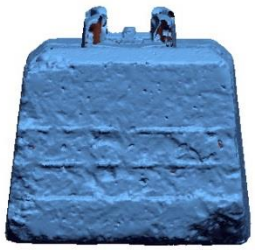
Damage:

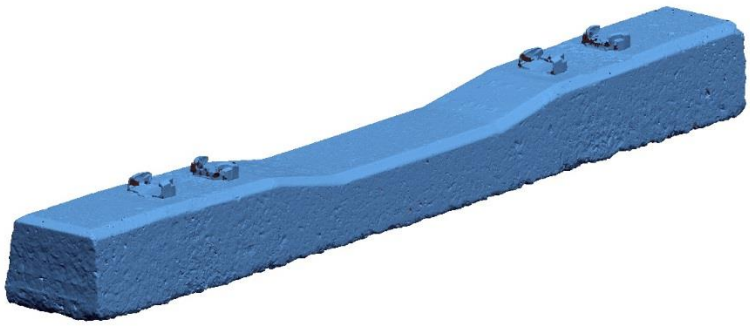


Report for Tie L-2

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : L2                                               |
|    Manufacturer : CXT                                              |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.216 in                                              |
|      Right : 3.036 in                                              |
|      Avg.  : 3.126 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-10-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        73.61             56.31                  |
|         I   [in^4]       369.85            160.51                  |
|       Y_cog  [in]          4.06              3.35                  |
|       height [in]          8.19              6.38                  |
|         e    [in]          0.94              0.22                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 88.5 [kips] (L-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.33           1.29                         |
|        Right [in]      1.22           1.30                         |
|        Top   [in]      3.52           3.52                         |
|        Bottom[in]      1.74           1.78                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

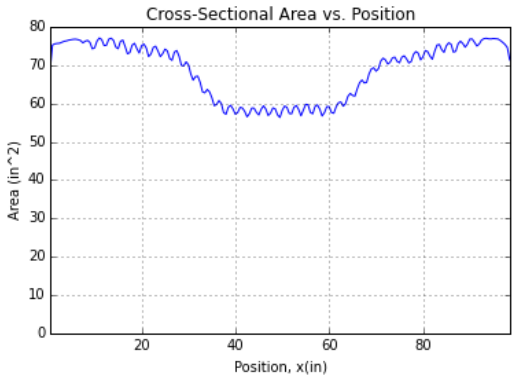
Model Views:

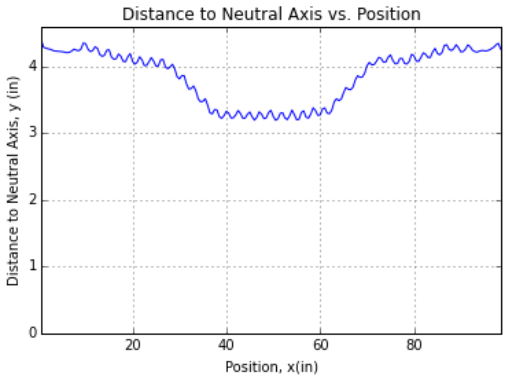


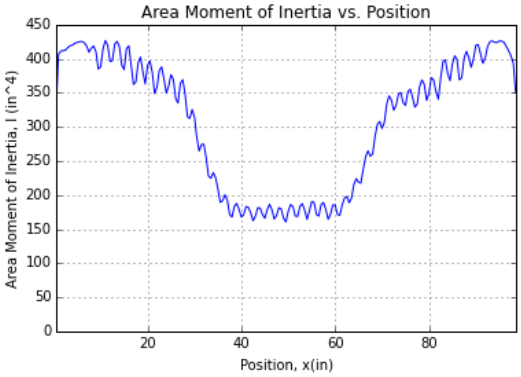


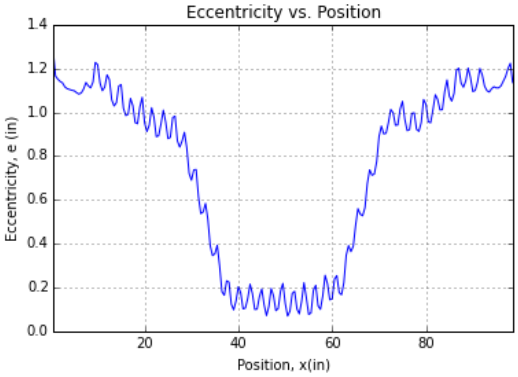
100 mm

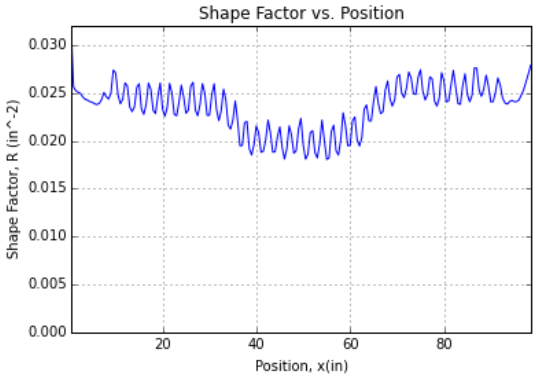
Processed Data:











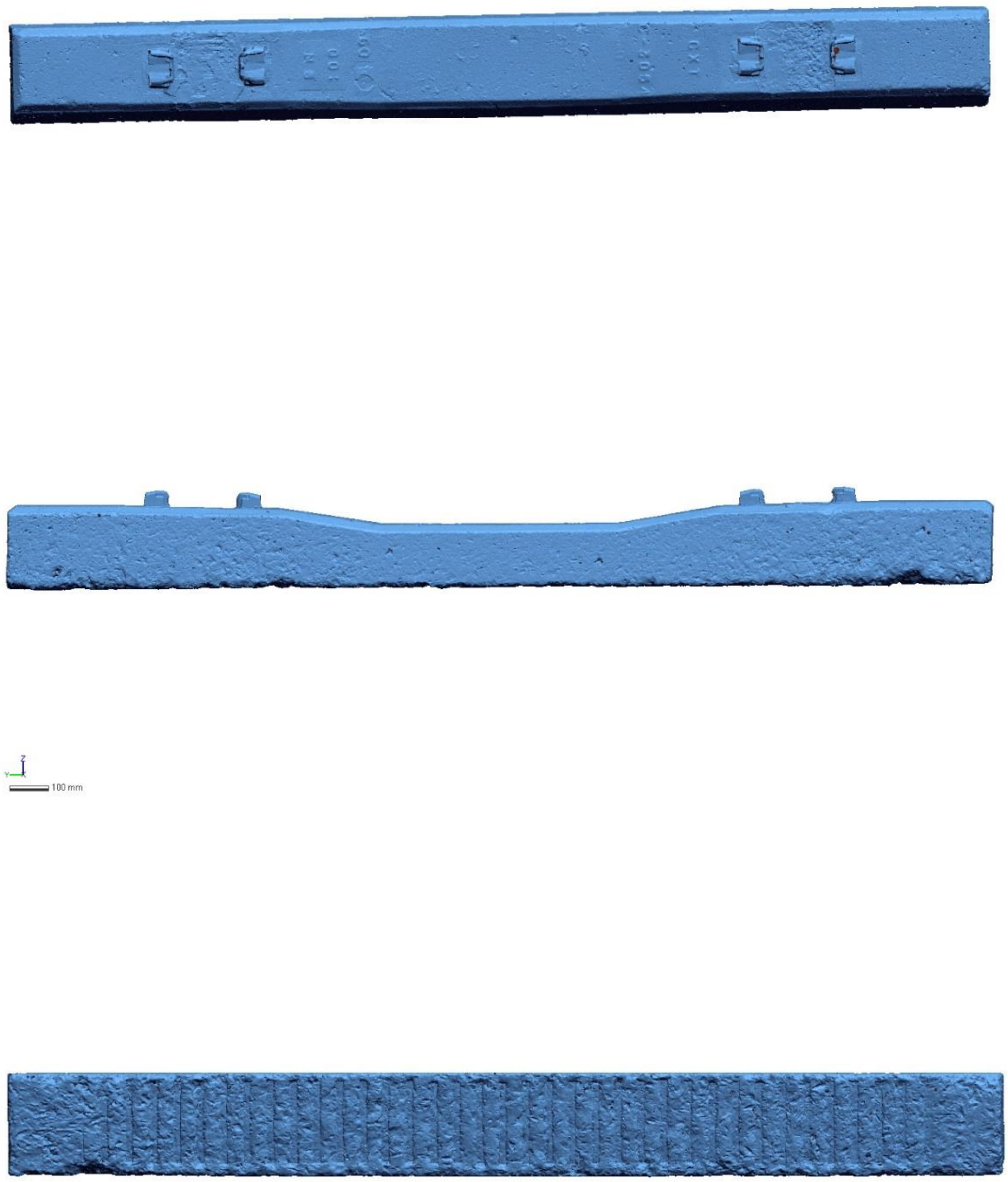
End Pictures:

Damage:

Report for Tie L-3

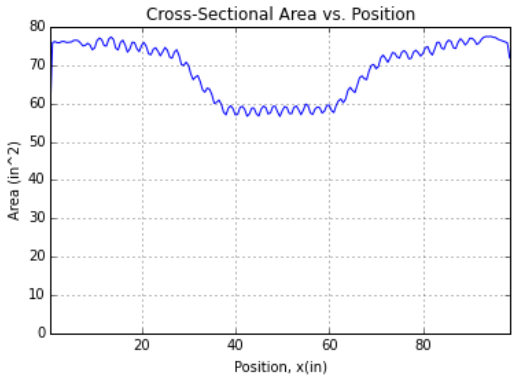
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : L3                                                  |
|    Manufacturer : CXT                                                 |
|    Alternate ID : BN100                                               |
|    Tie Length   : 8’3”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.309 in                                                 |
|      Right : 3.310 in                                                 |
|      Avg.  : 3.309 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 4.97 mm                                                |
|      Tendons : 28                                                     |
|      Pattern : 8-10-10                                                |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        74.09             56.58                    |
|         I   [in^4]       376.17            160.76                    |
|       Y_cog  [in]          4.15              3.40                    |
|       height [in]          8.31              6.42                    |
|         e    [in]          0.85              0.09                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = 88.5 [kips] (L-6)                                 |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|        Left  [in]      1.25           1.34                           |
|        Right [in]      1.34           1.22                           |
|        Top   [in]      3.56           3.56                           |
|        Bottom[in]      1.73           1.79                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Low                                          |
|      Cracking Severity : None                                         |
+-----------------------------------------------------------------------+
```

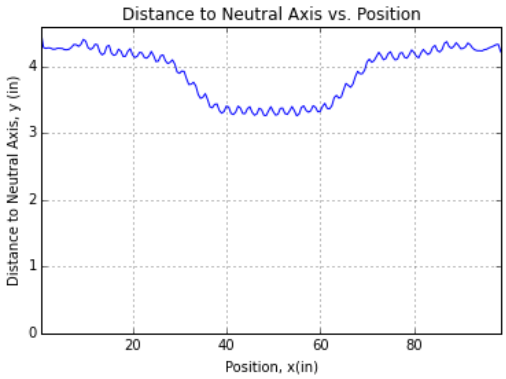
Model Views:

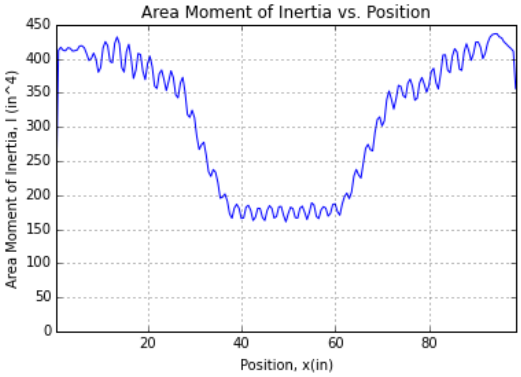


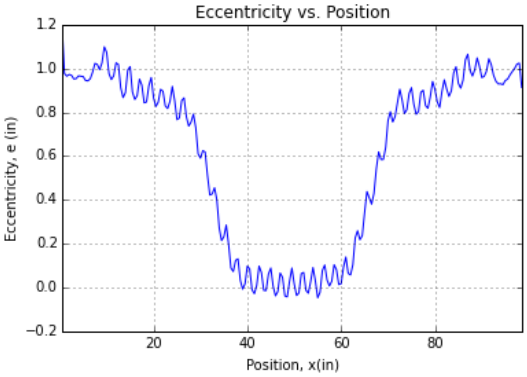
100 mm

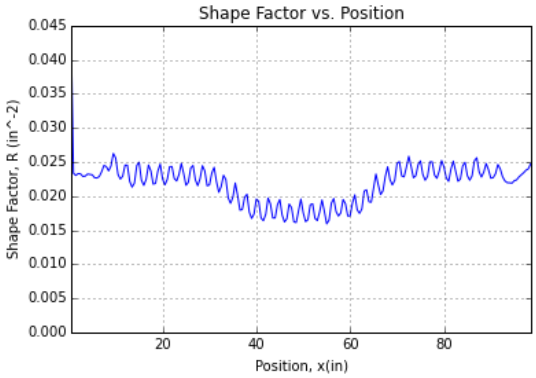
Processed Data:











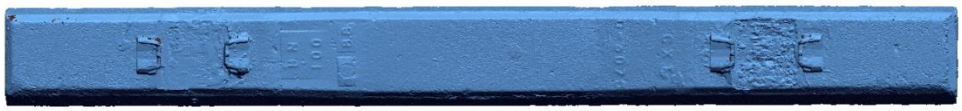
End Pictures:

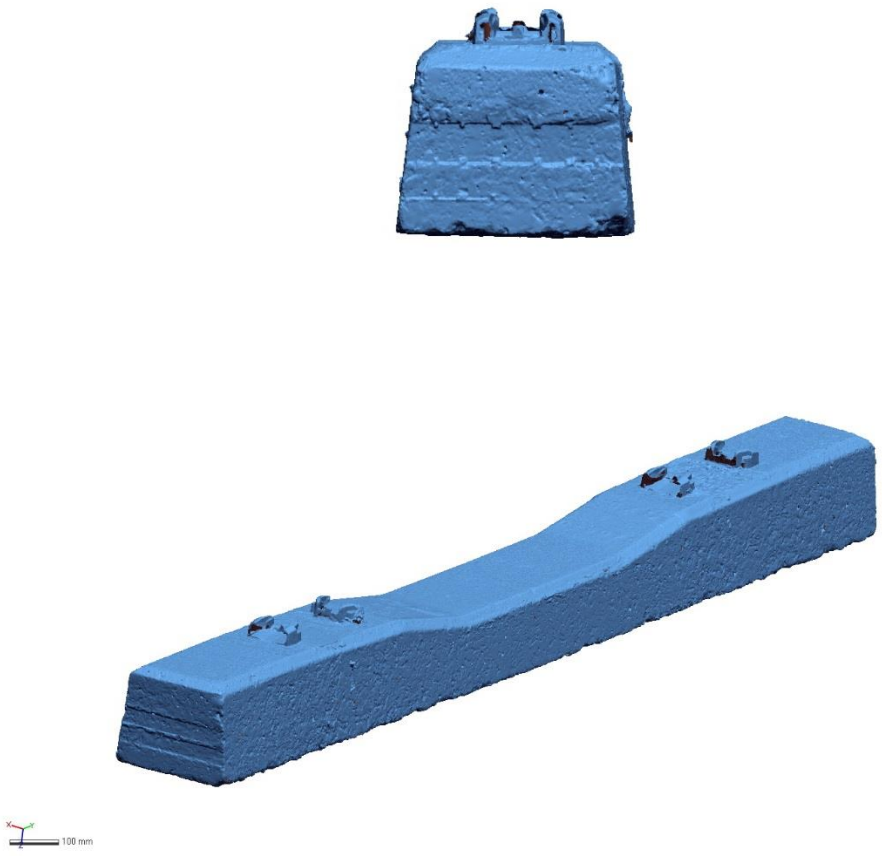
Damage:

Report for Tie L-4

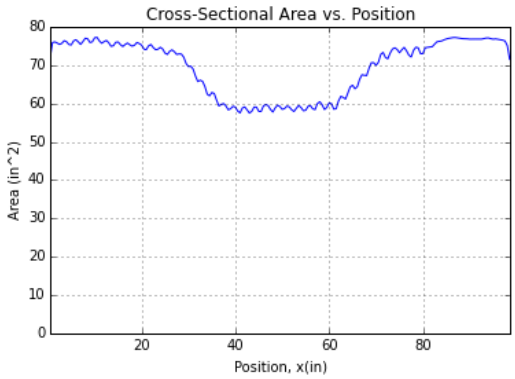
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : L4                                               |
|    Manufacturer : CXT                                              |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.351 in                                              |
|      Right : 3.129 in                                              |
|      Avg.  : 3.240 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-10-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        73.91            59.15                 |
|         I   [in^4]       374.07           184.05                 |
|       Y_cog  [in]          4.10             3.18                 |
|       height [in]          8.29             6.38                 |
|         e    [in]          0.90            -0.05                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 88.5 [kips] (L-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.28           1.41                        |
|        Right [in]      1.25           1.21                        |
|        Top   [in]      3.49           3.59                        |
|        Bottom[in]      1.76           1.67                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

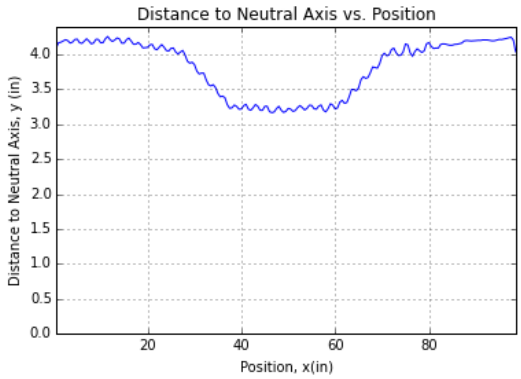
Model Views:

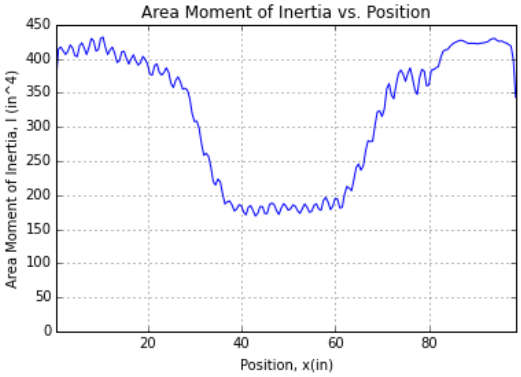


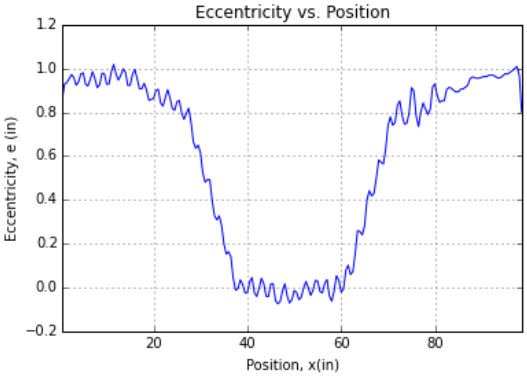

100 mm

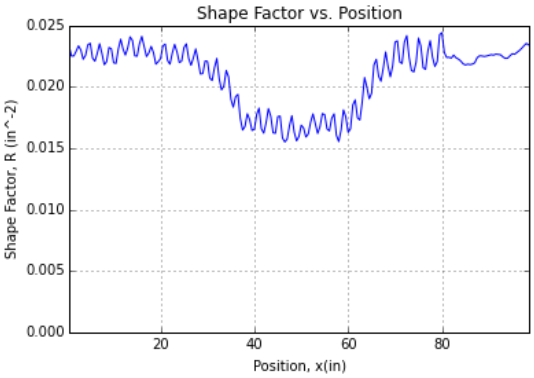
Processed Data:



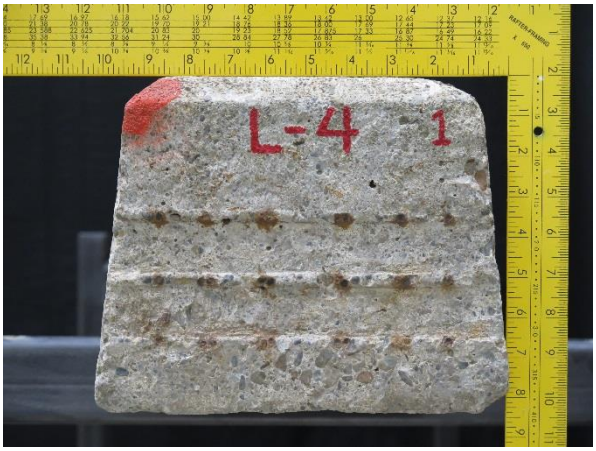


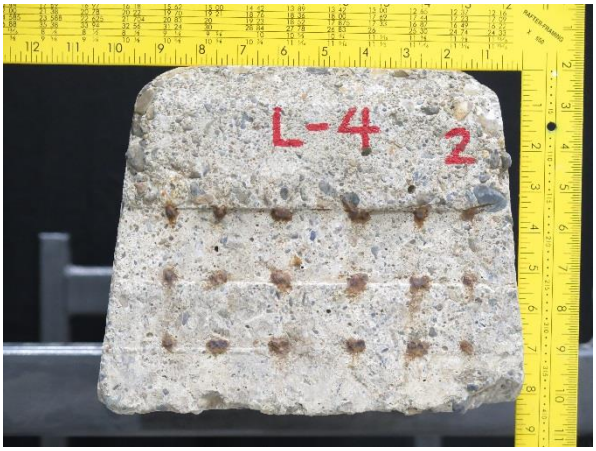






End Pictures:



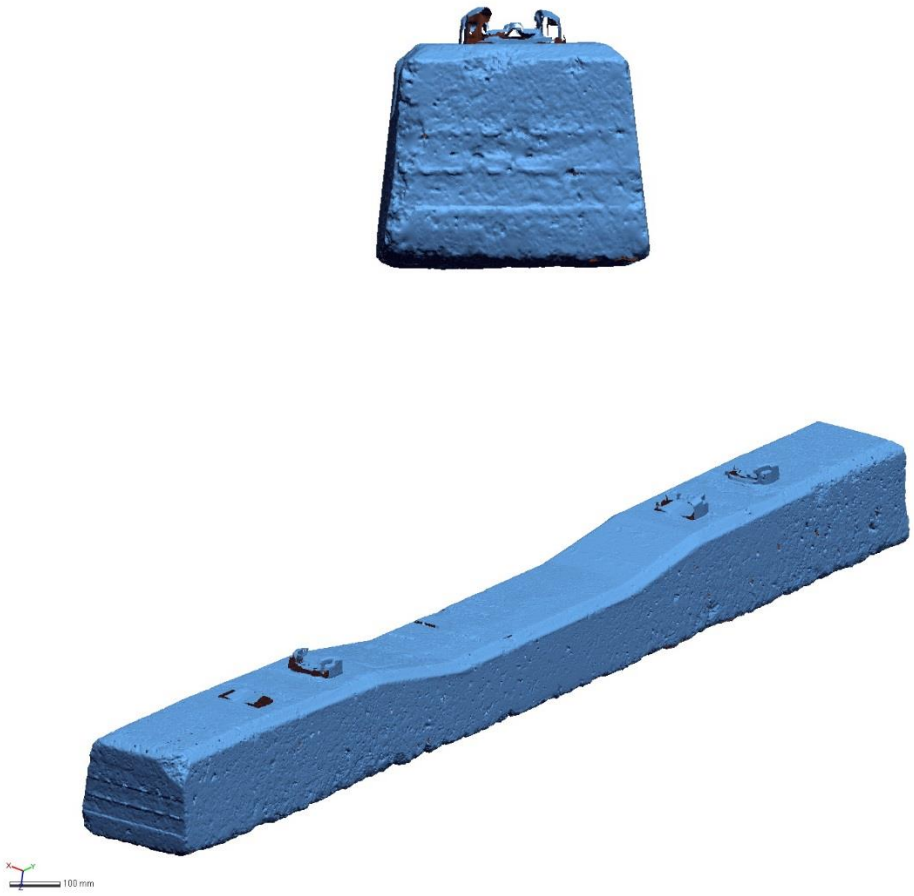


Damage:

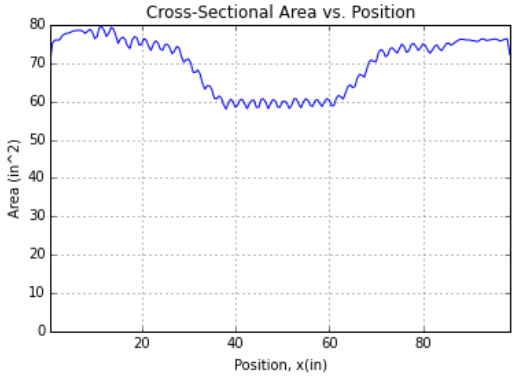
Report for Tie L-5

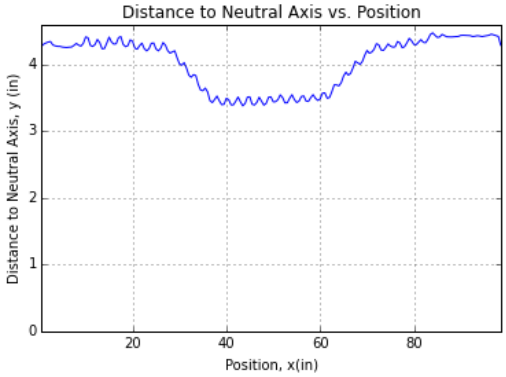
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : L5                                               |
|    Manufacturer : CXT                                              |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.131 in                                              |
|      Right : 3.387 in                                              |
|      Avg.  : 3.259 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-10-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        74.58             58.40                 |
|         I   [in^4]       384.68            176.12                 |
|       Y_cog  [in]          4.31              3.52                 |
|       height [in]          8.48              6.69                 |
|         e    [in]          0.97              0.26                 |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 88.5 [kips] (L-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.21           1.27                        |
|        Right [in]      1.29           1.21                        |
|        Top   [in]      3.44           3.46                        |
|        Bottom[in]      1.77           1.93                        |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Low                                       |
+--------------------------------------------------------------------+
```

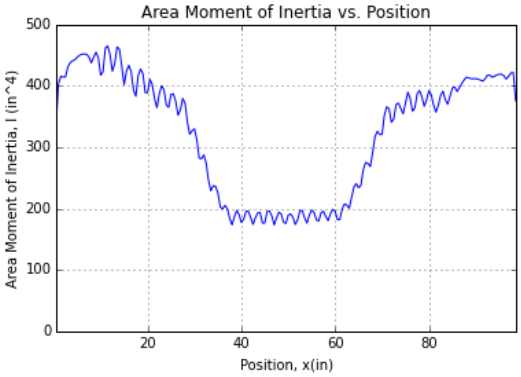
Model Views:

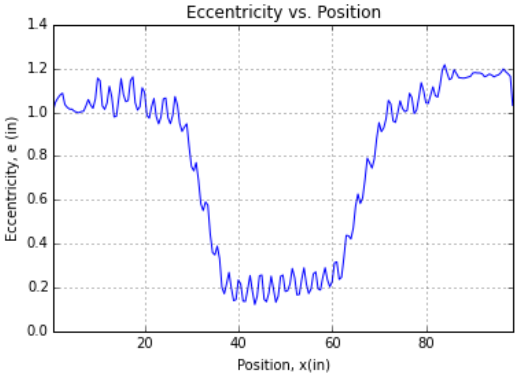

100 mm

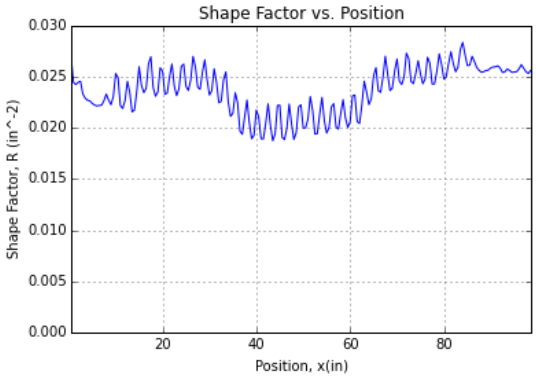
Processed Data:



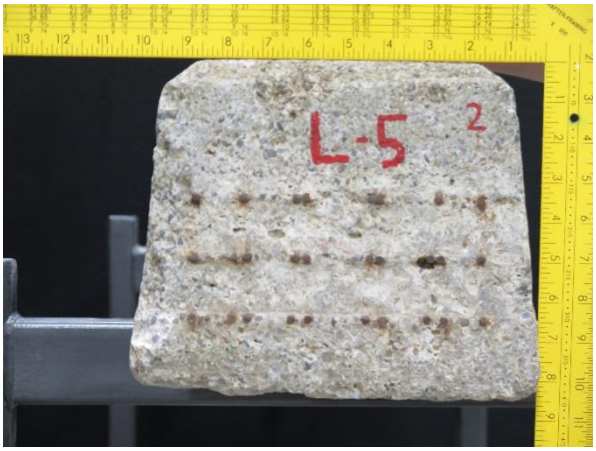








End Pictures:

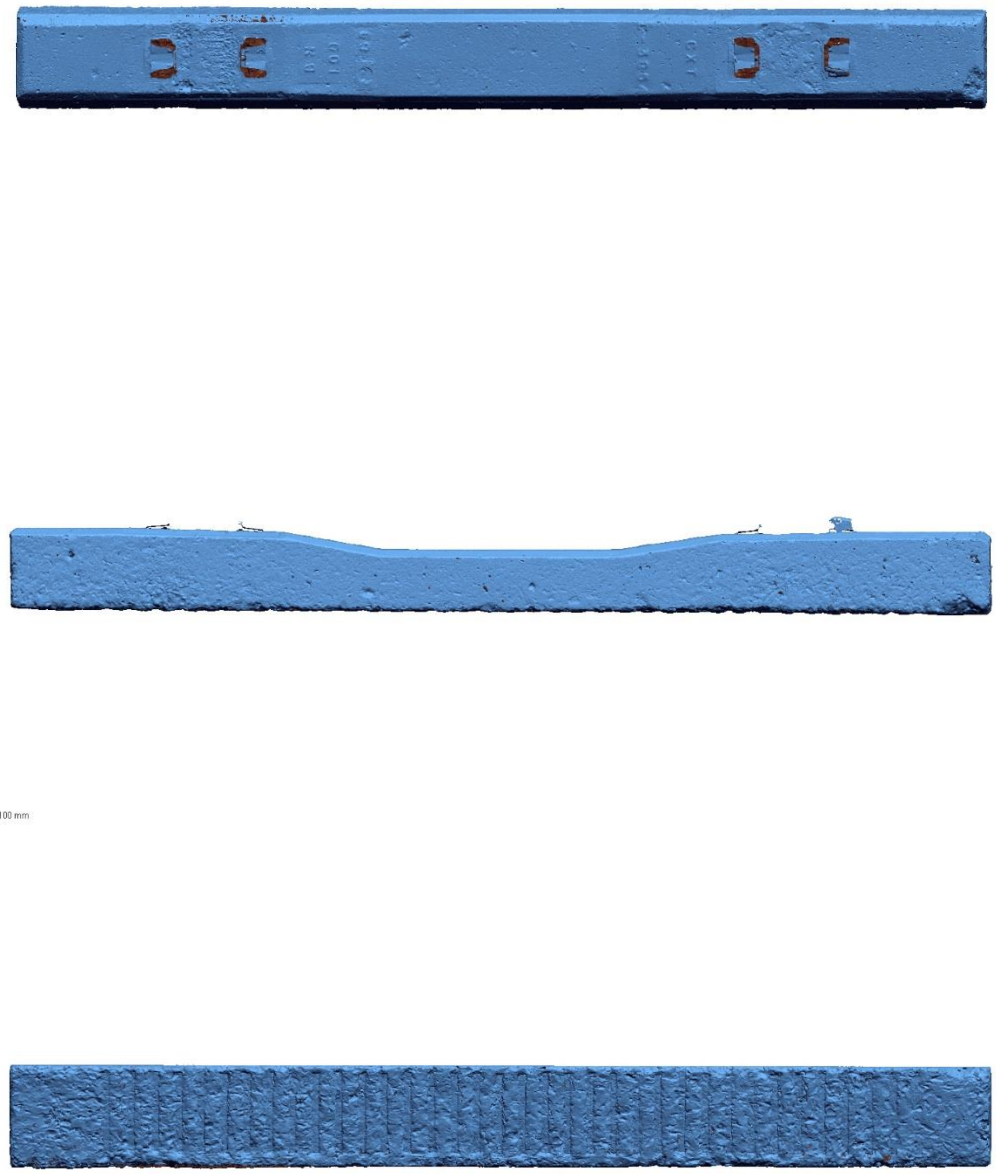


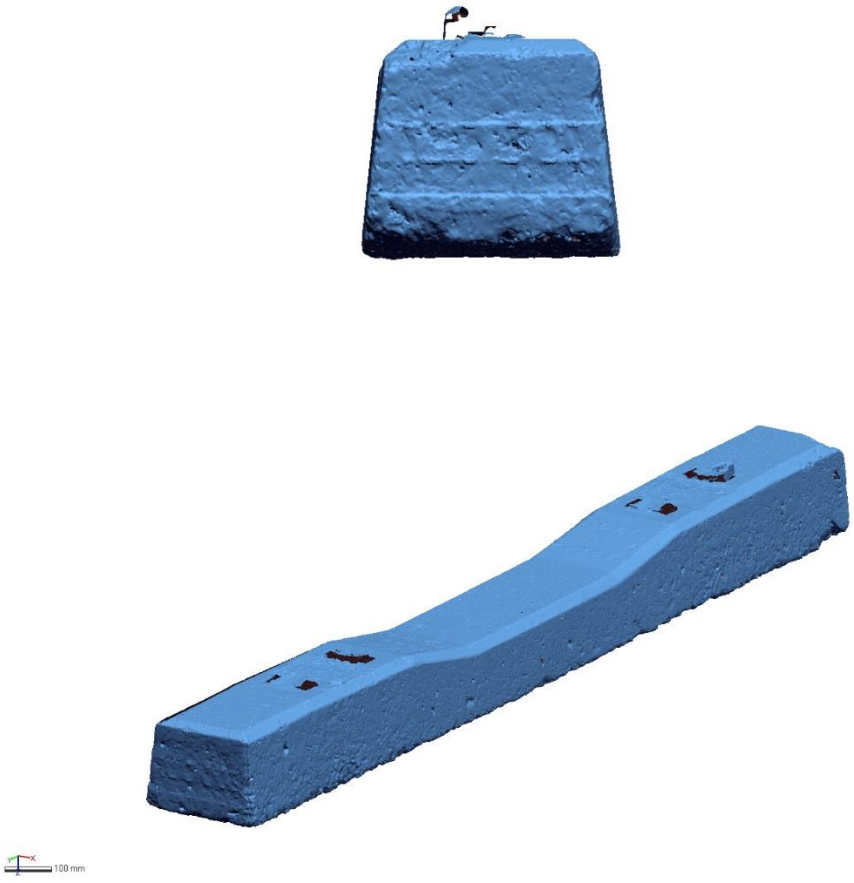
Damage:

Report for Tie L-6

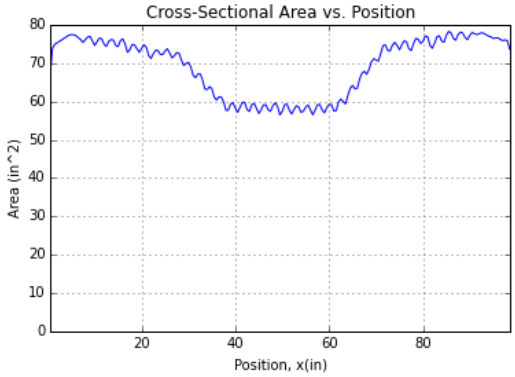
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : L6                                               |
|    Manufacturer : CXT                                              |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.248 in                                              |
|      Right : 2.963 in                                              |
|      Avg.  : 3.106 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 4.97 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-10-10                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.60             56.43                  |
|         I   [in^4]       378.62            160.27                  |
|       Y_cog  [in]          4.10              3.40                  |
|       height [in]          8.27              6.42                  |
|         e    [in]          1.02              0.29                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = 88.5 [kips] (L-6)                              |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.43           1.24                         |
|        Right [in]      1.30           1.28                         |
|        Top   [in]      3.65           3.51                         |
|        Bottom[in]      1.87           1.62                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

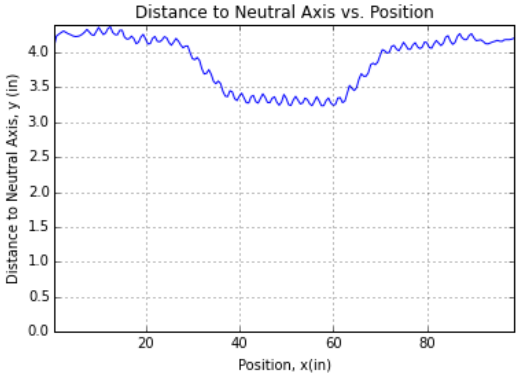
Model Views:

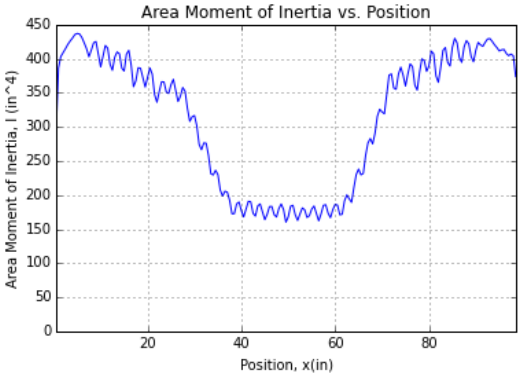


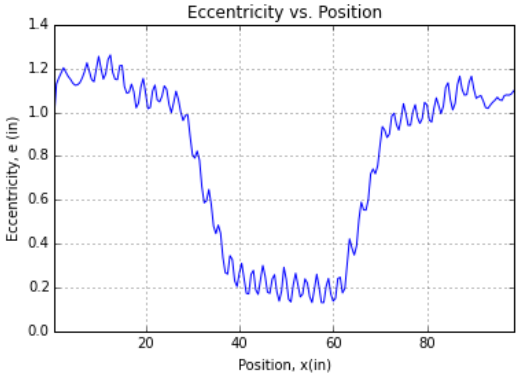

100 mm

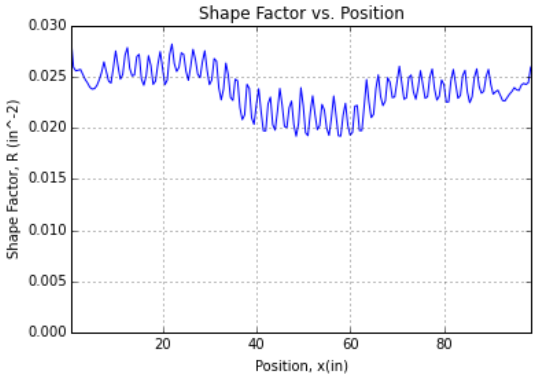
Processed Data:



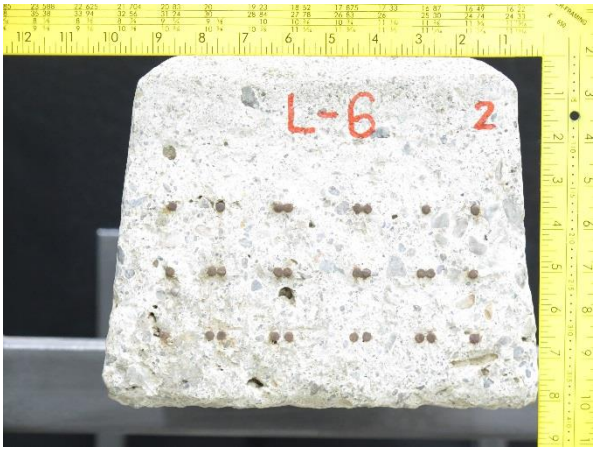








End Pictures:

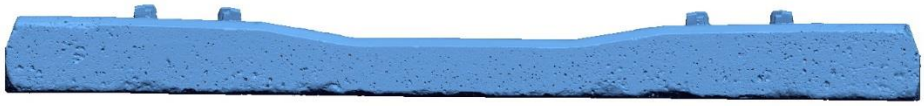


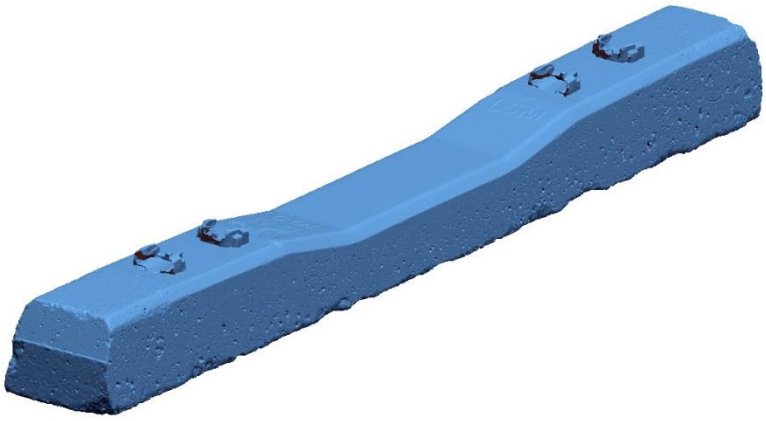
Damage:

Report for Tie M-1

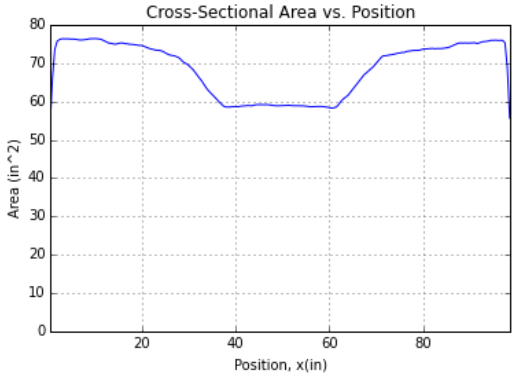
```
+-----------------------------------------------------------------------+
|               Test Report                        07/01/2017     Ver1  |
+-----------------------------------------------------------------------+
|  Identification                                                       |
|    ID Numbers   : M1                                                  |
|    Manufacturer : ROCLA                                               |
|    Alternate ID : BN100                                               |
|    Tie Length   : 8’3”                                                |
+-----------------------------------------------------------------------+
|  Test Data                                                            |
|    Wire Centroid                                                      |
|      Left  : 3.298 in                                                 |
|      Right : 3.283 in                                                 |
|      Avg.  : 3.291 in                                                 |
|                                                                       |
|    Wire Info                                                          |
|      Type    : WIRE (INDENTED)                                        |
|      Diameter: 5.02 mm                                                |
|      Tendons : 28                                                     |
|      Pattern : 8-6-6-8                                                |
|                                                                       |
|    Critical Points (Scan)                                             |
|                       Rail Seat Avg.     Center Span                  |
|         A   [in^2]        73.69             58.86                    |
|         I   [in^4]       377.49            185.64                    |
|       Y_cog  [in]          3.92              3.11                    |
|       height [in]          8.09              6.34                    |
|         e    [in]          0.61             -0.18                    |
|                                                                       |
|    Estimated Prestress Force                                          |
|      P_prestress  = N/A                                               |
|                                                                       |
|    Coverage Avg.                                                      |
|                       End #1         End #2                           |
|         Left  [in]      1.32           1.30                           |
|         Right [in]      1.30           1.28                           |
|         Top   [in]      3.44           3.44                           |
|         Bottom[in]      1.52           1.50                           |
|                                                                       |
|    Observations                                                       |
|      Abrasion Severity : Moderate                                     |
|      Cracking Severity : Severe                                       |
+-----------------------------------------------------------------------+
```

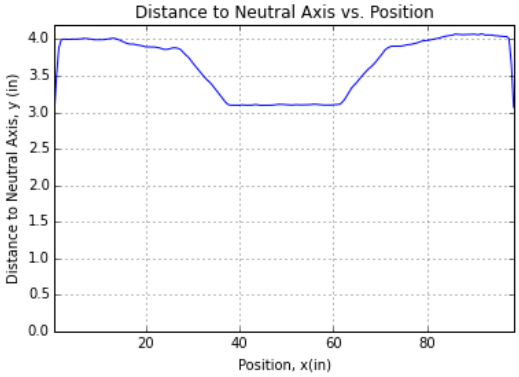
Model Views:

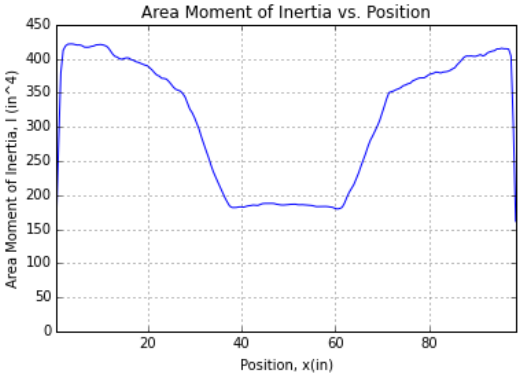


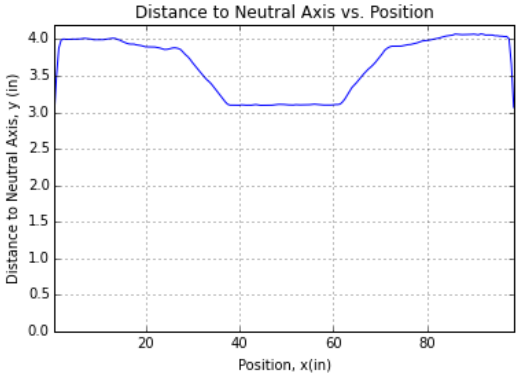


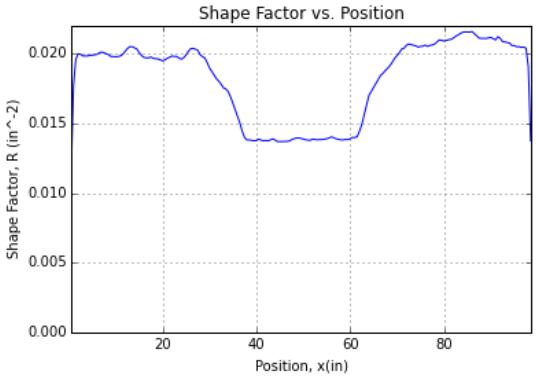
Processed Data:



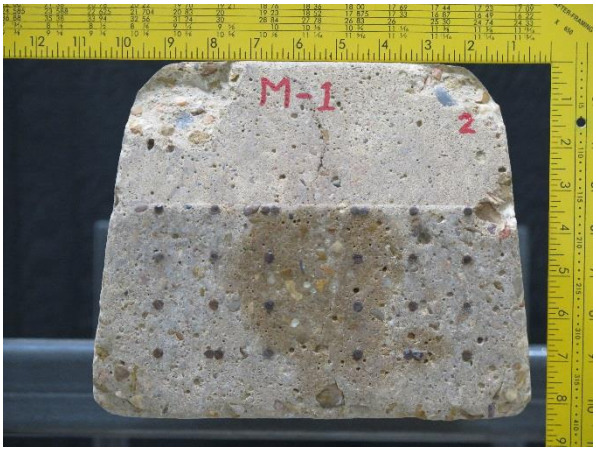








End Pictures:

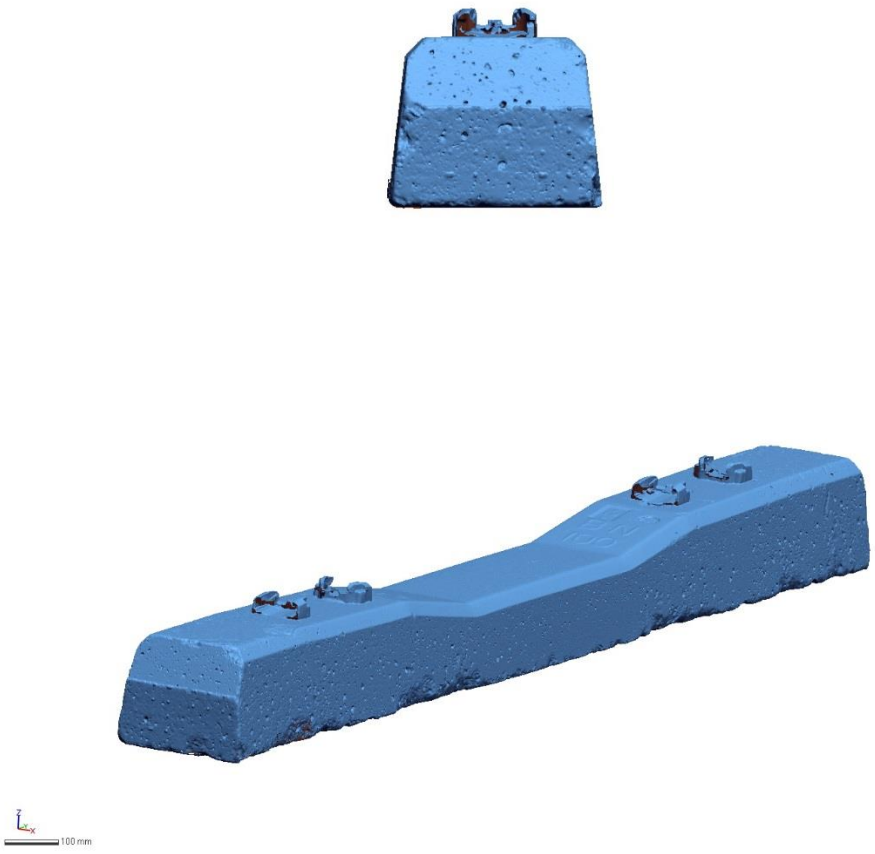


Damage:

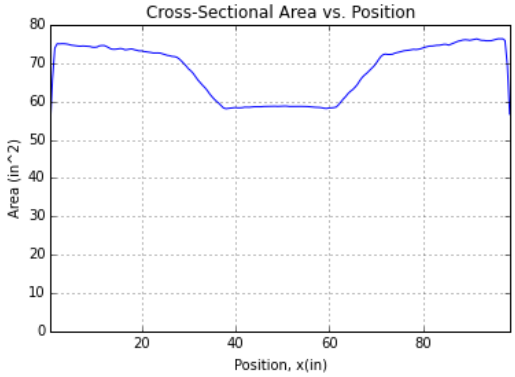
Report for Tie M-2

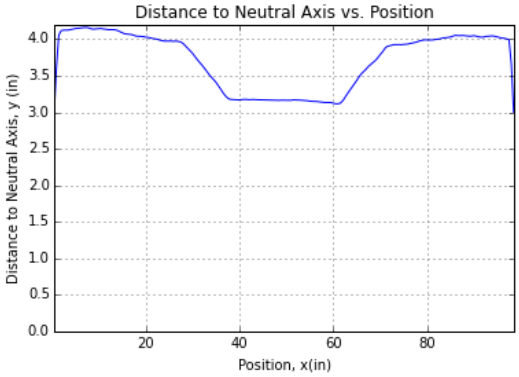
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : M2                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.219 in                                              |
|      Right : 3.289 in                                              |
|      Avg.  : 3.254 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.02 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-6-6-8                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                      Rail Seat Avg.     Center Span                |
|         A   [in^2]        73.23             58.72                  |
|         I   [in^4]       370.94            184.92                  |
|       Y_cog  [in]          3.99              3.17                  |
|       height [in]          8.15              6.38                  |
|         e    [in]          0.77             -0.09                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                      End #1         End #2                         |
|        Left  [in]      1.31           1.34                         |
|        Right [in]      1.30           1.21                         |
|        Top   [in]      3.51           3.45                         |
|        Bottom[in]      1.50           1.59                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Low                                       |
|      Cracking Severity : Severe                                    |
+--------------------------------------------------------------------+
```

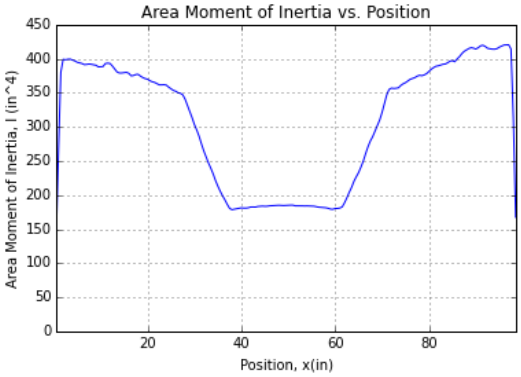
Model Views:

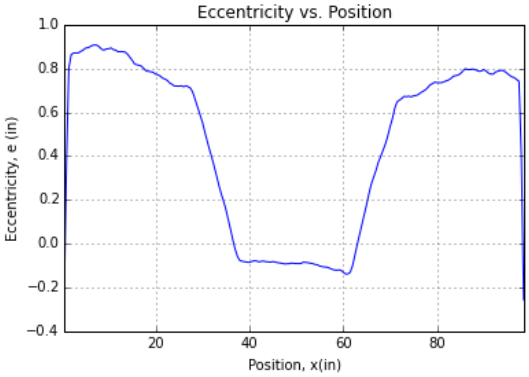

100 mm

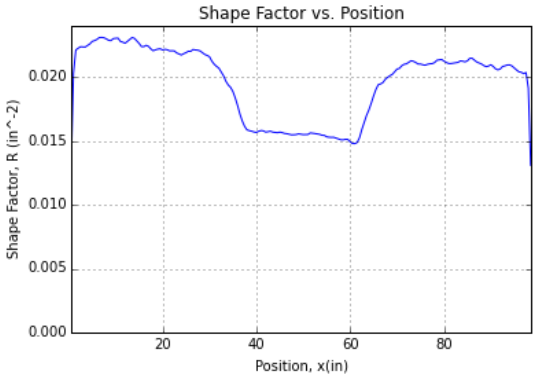
Processed Data:



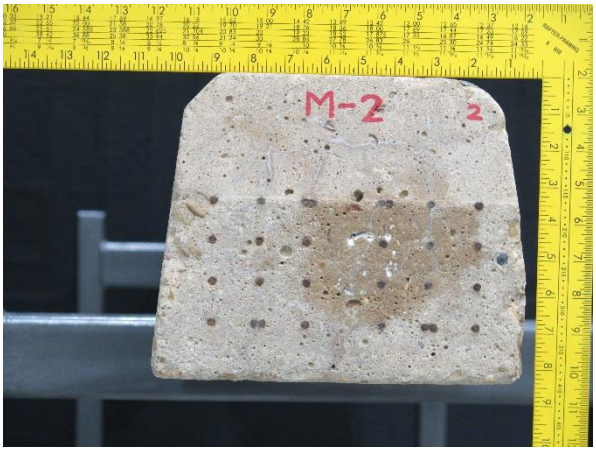








End Pictures:

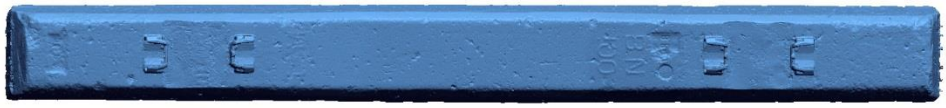


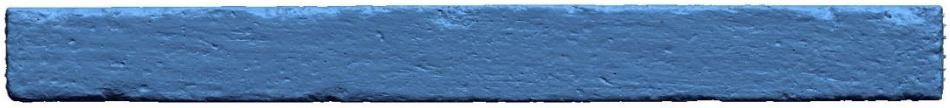
Damage:

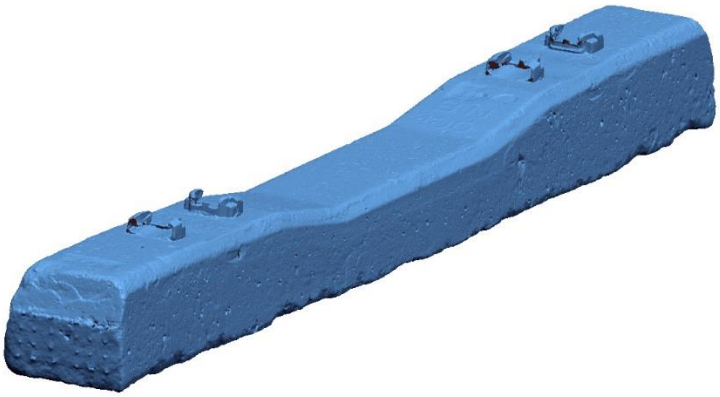
Report for Tie M-3

```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : M3                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.332 in                                              |
|      Right : 3.377 in                                              |
|      Avg.  : 3.355 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.02 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-6-6-8                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.06             60.80                  |
|         I   [in^4]       384.97            203.40                  |
|       Y_cog  [in]          3.97              3.19                  |
|       height [in]          8.23              6.54                  |
|         e    [in]          0.64             -0.16                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.00           1.39                         |
|        Right [in]      1.65           1.19                         |
|        Top   [in]      3.46           3.36                         |
|        Bottom[in]      1.58           1.49                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

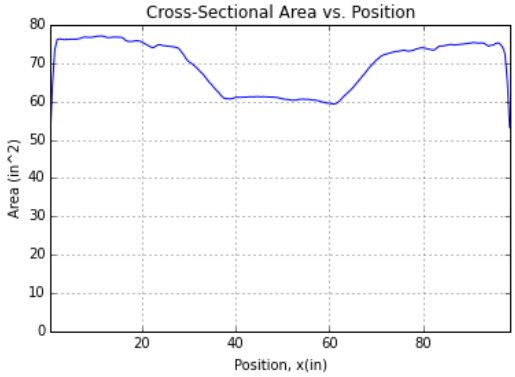


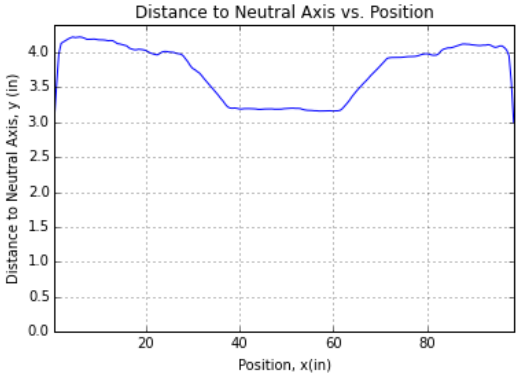


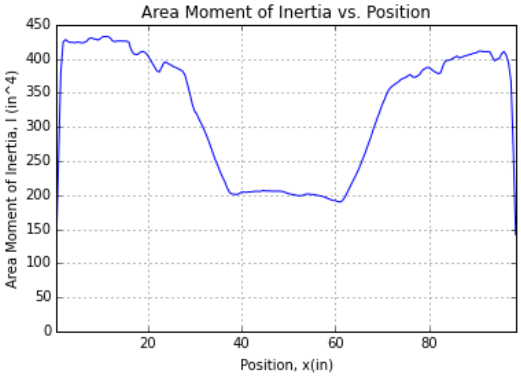


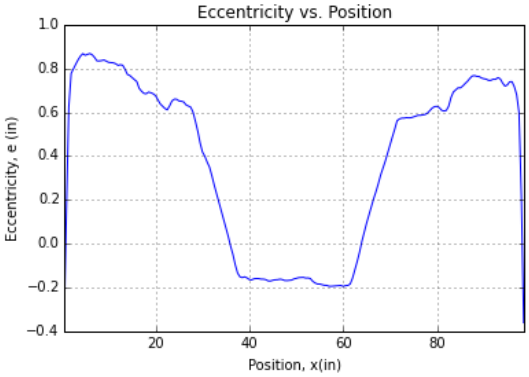
100 mm

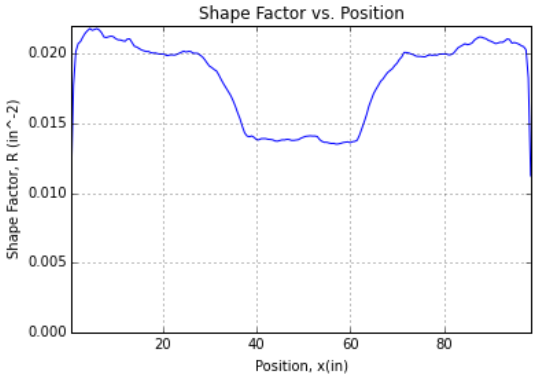
Processed Data:



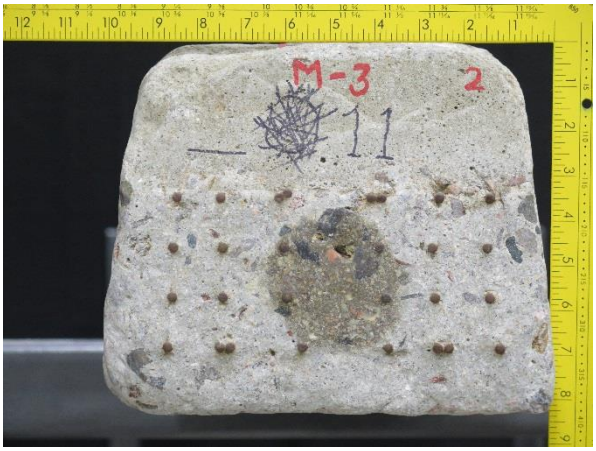








End Pictures:

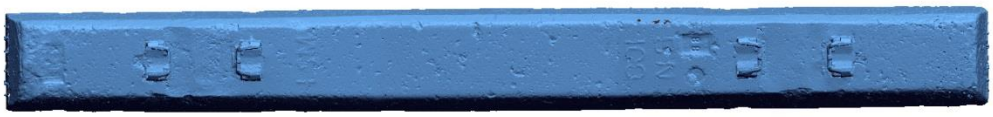


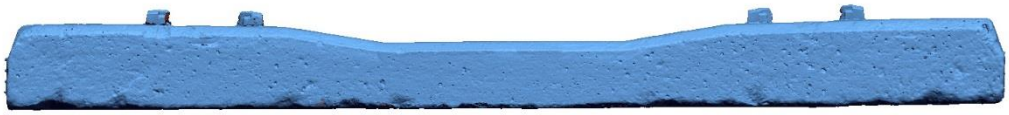
Damage:

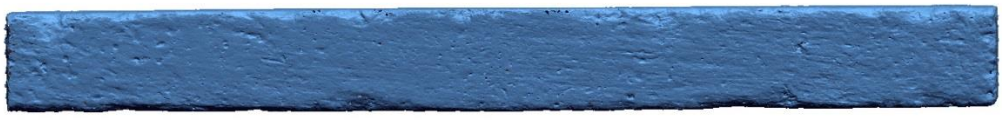
Report for Tie M-4

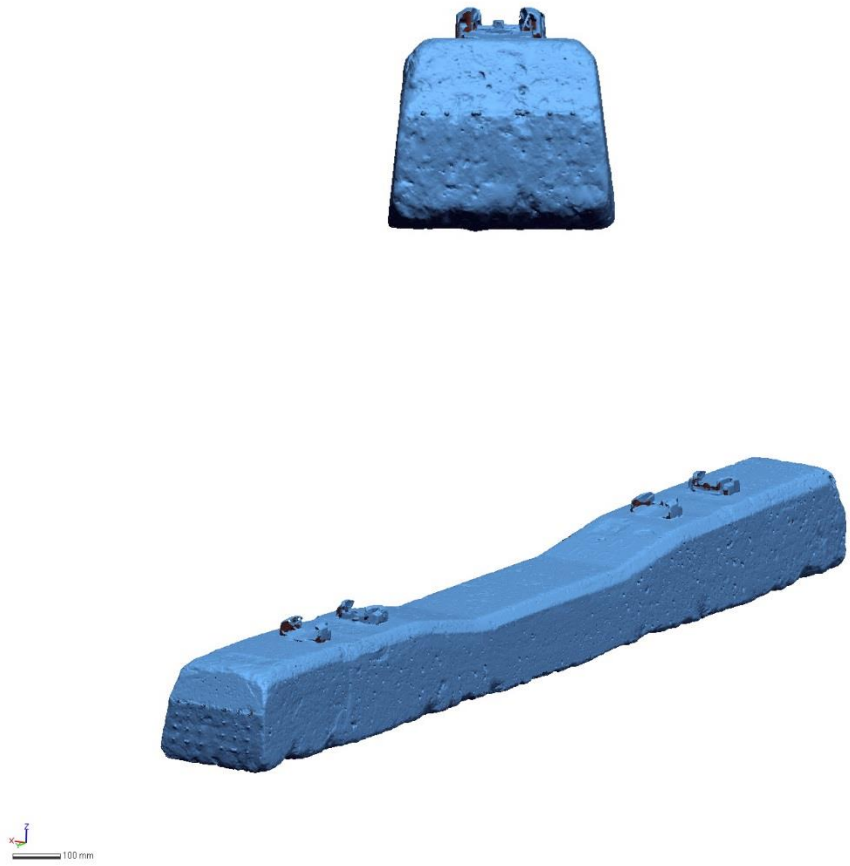
```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : M4                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.402 in                                              |
|      Right : 3.374 in                                              |
|      Avg.  : 3.388 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.02 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-6-6-8                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        75.89             62.98                  |
|         I   [in^4]       412.89            223.68                  |
|       Y_cog  [in]          4.21              3.40                  |
|       height [in]          8.58              6.85                  |
|         e    [in]          0.80              0.01                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.25           1.25                         |
|        Right [in]      1.39           1.39                         |
|        Top   [in]      3.34           3.30                         |
|        Bottom[in]      1.74           1.83                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

Model Views:

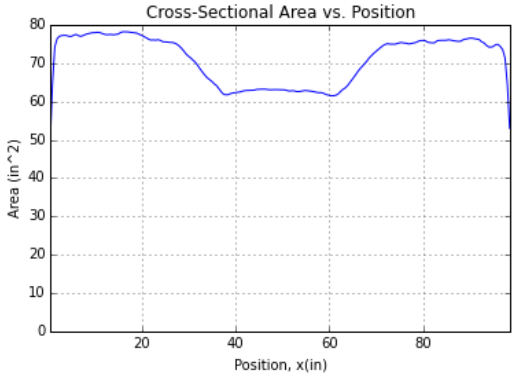


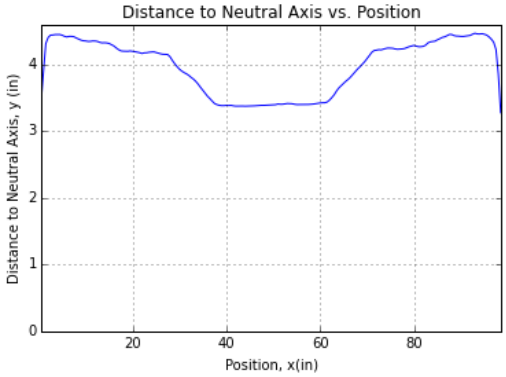


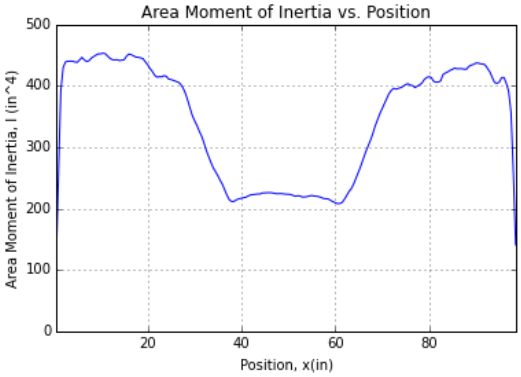


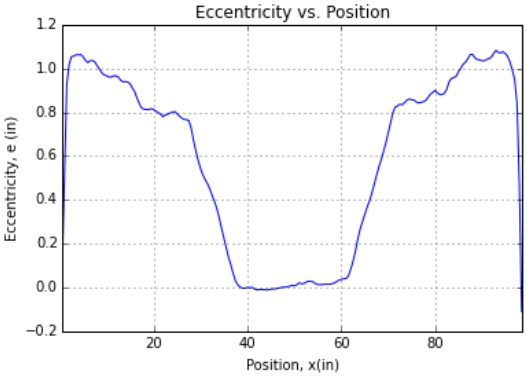

100 mm

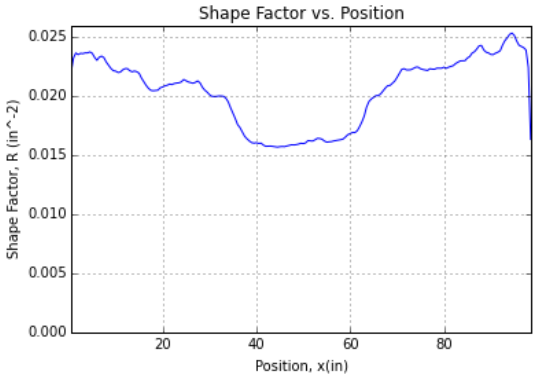
Processed Data:



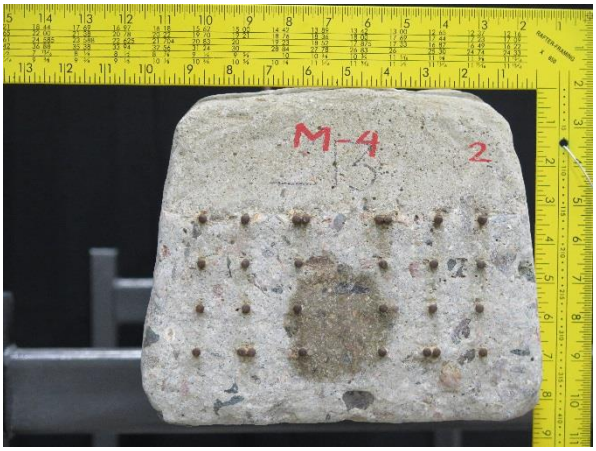








End Pictures:

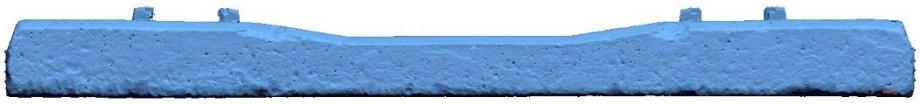


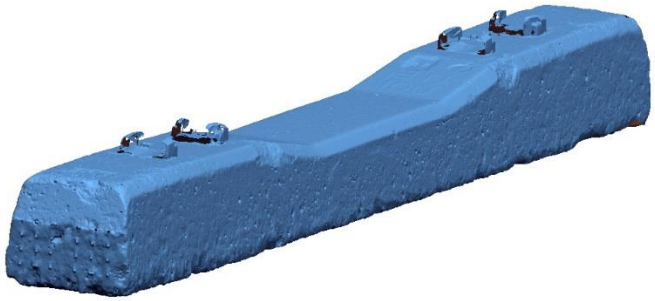
Damage:

Report for Tie M-5

```
+--------------------------------------------------------------------+
|               Test Report                      07/01/2017    Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : M5                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.337 in                                              |
|      Right : 3.408 in                                              |
|      Avg.  : 3.373 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.02 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-6-6-8                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.83             61.32                  |
|         I   [in^4]       401.74            210.89                  |
|       Y_cog  [in]          4.10              3.38                  |
|       height [in]          8.39              6.77                  |
|         e    [in]          0.78              0.00                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.52           1.21                         |
|        Right [in]      1.01           1.38                         |
|        Top   [in]      3.21           3.38                         |
|        Bottom[in]      1.68           1.61                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

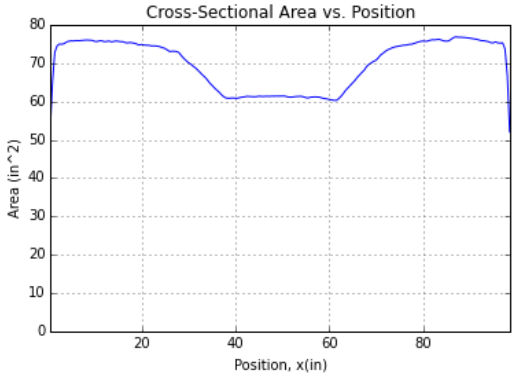
Model Views:

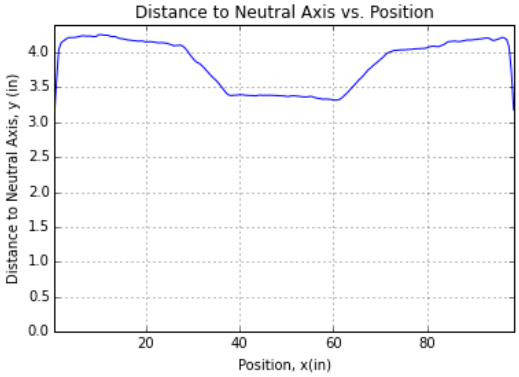


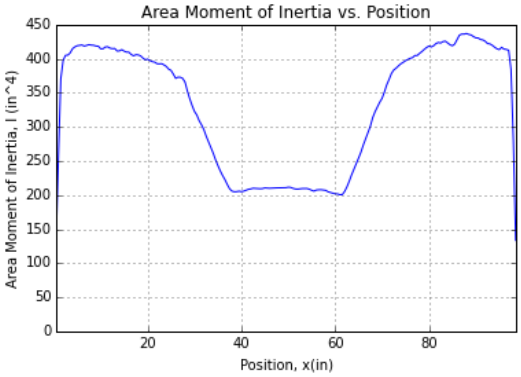


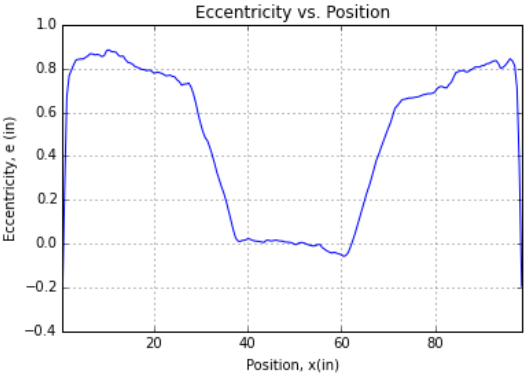
100 mm

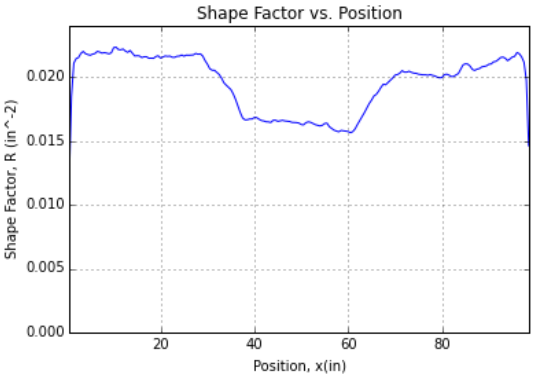
Processed Data:



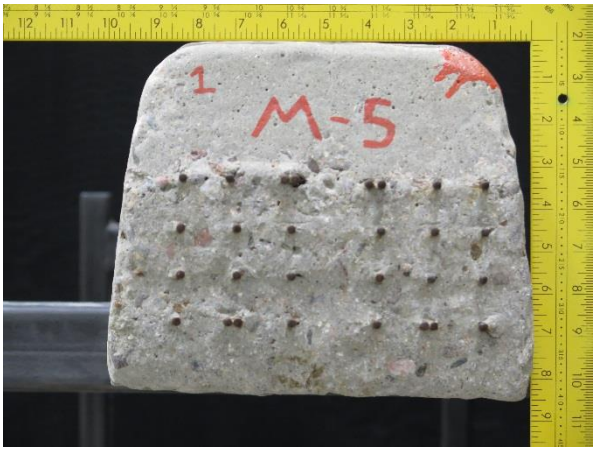


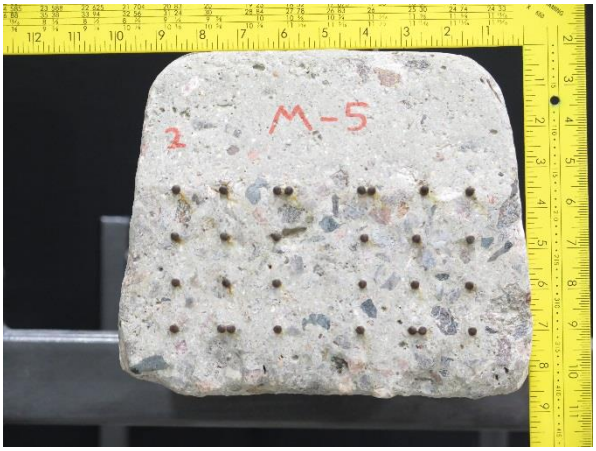






End Pictures:



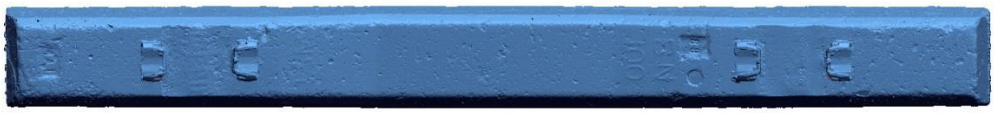


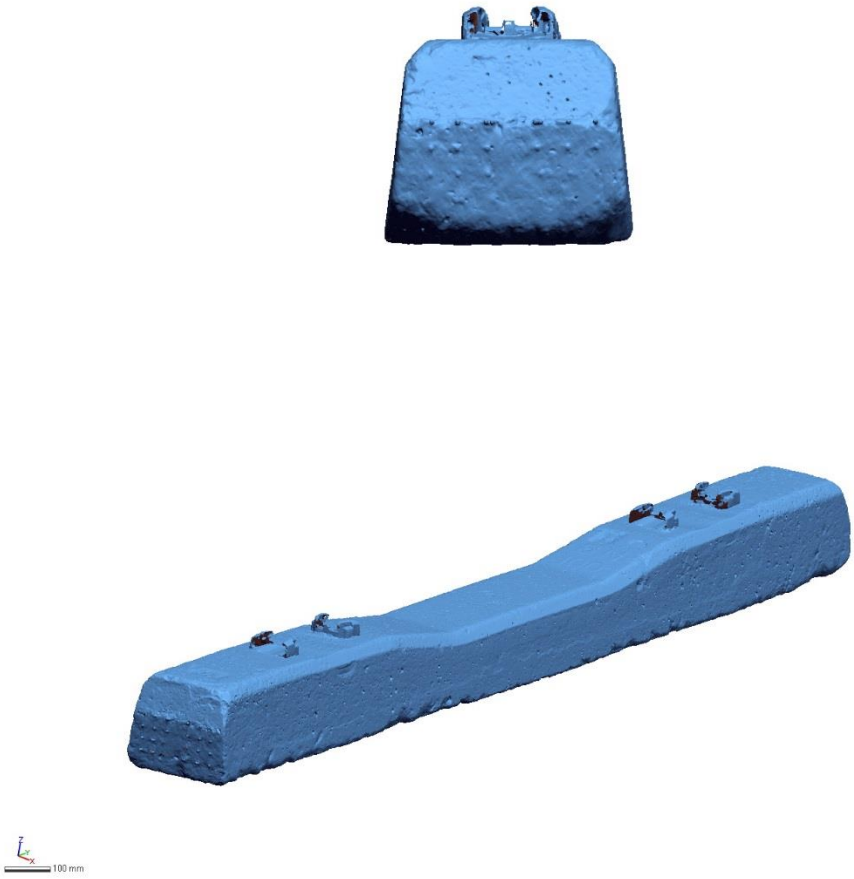
Damage:

Report for Tie M-6

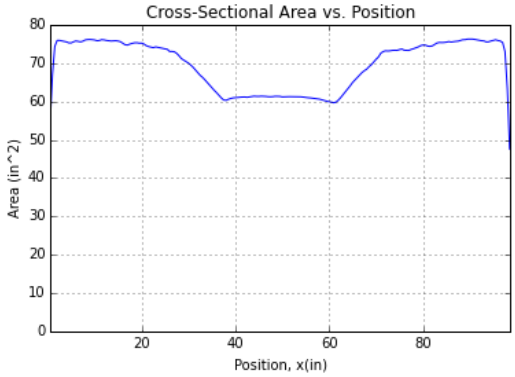
```
+--------------------------------------------------------------------+
|               Test Report                       07/01/2017   Ver1  |
+--------------------------------------------------------------------+
|  Identification                                                    |
|    ID Numbers   : M6                                               |
|    Manufacturer : ROCLA                                            |
|    Alternate ID : BN100                                            |
|    Tie Length   : 8’3”                                             |
+--------------------------------------------------------------------+
|  Test Data                                                         |
|    Wire Centroid                                                   |
|      Left  : 3.285 in                                              |
|      Right : 3.272 in                                              |
|      Avg.  : 3.279 in                                              |
|                                                                    |
|    Wire Info                                                       |
|      Type    : WIRE (INDENTED)                                     |
|      Diameter: 5.02 mm                                             |
|      Tendons : 28                                                  |
|      Pattern : 8-6-6-8                                             |
|                                                                    |
|    Critical Points (Scan)                                          |
|                       Rail Seat Avg.     Center Span               |
|         A   [in^2]        74.11             61.28                  |
|         I   [in^4]       383.50            207.90                  |
|       Y_cog  [in]          4.05              3.28                  |
|       height [in]          8.31              6.61                  |
|         e    [in]          0.75              0.01                  |
|                                                                    |
|    Estimated Prestress Force                                       |
|      P_prestress  = N/A                                            |
|                                                                    |
|    Coverage Avg.                                                   |
|                       End #1         End #2                        |
|        Left  [in]      1.51           1.35                         |
|        Right [in]      1.06           1.35                         |
|        Top   [in]      3.42           3.40                         |
|        Bottom[in]      1.48           1.73                         |
|                                                                    |
|    Observations                                                    |
|      Abrasion Severity : Moderate                                  |
|      Cracking Severity : None                                      |
+--------------------------------------------------------------------+
```

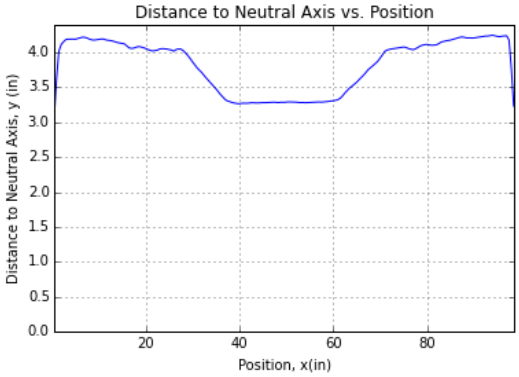
Model Views:

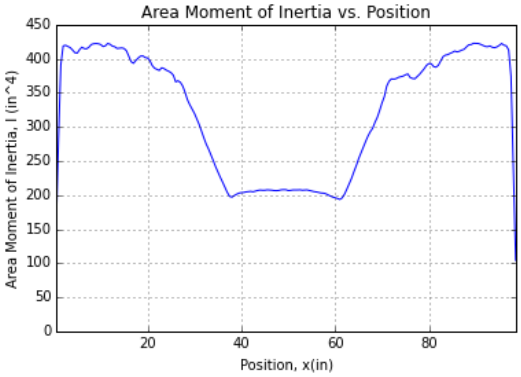


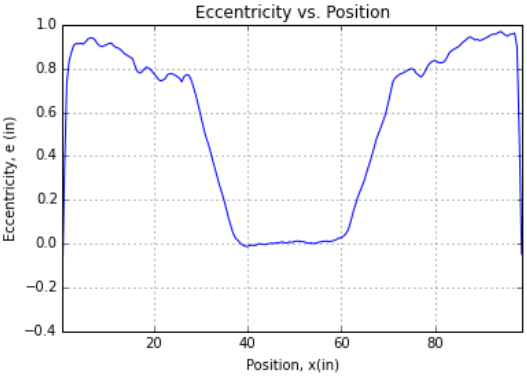

100 mm

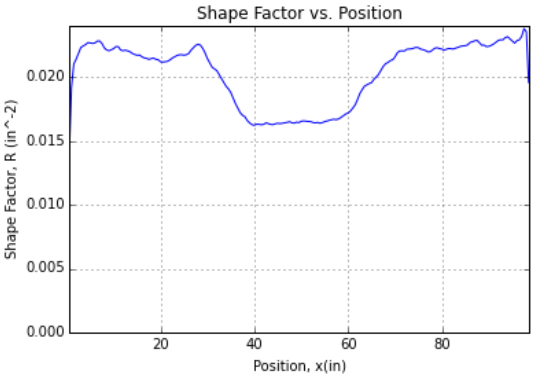
Processed Data:



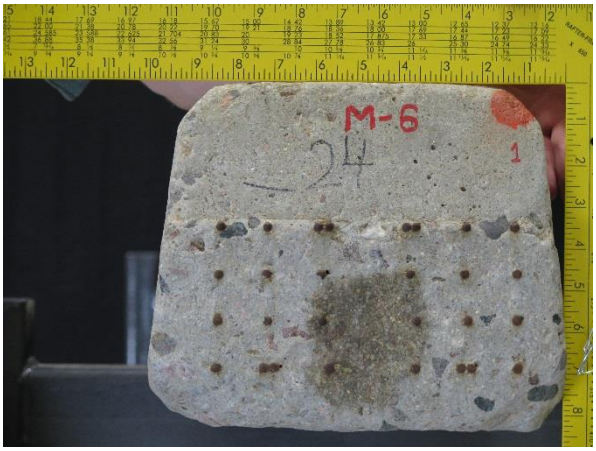


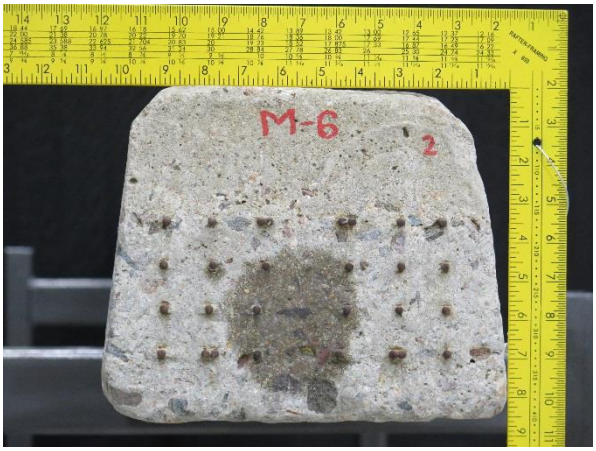






End Pictures:





Damage:

Abbreviations and Acronyms

FRA	Federal Railroad Administration
TL	Transfer Length
CL	Crack Length