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A 3D SCANNING METHOD TO MEASURE CONCRETE CROSSTIE GEOMETRY

SUMMARY

This report documents the measurement of 3D geometrical properties associated with prestressed concrete railroad ties. This work supports FRA-sponsored research at Kansas State University (K-State) to improve the design and performance of crossties.

K-State used a Creaform HandySCAN 700 3D hand-held scanner to scan the surface of crossties removed from service to a spatial resolution of about 1 mm, resulting in a 3D solid body CAD model of each tie (Figure 1). K-State developed a high-speed algorithm to process the detailed cross-section geometrical parameters to an axial resolution of 0.5 inch. To assess and verify the accuracy of the 3D scanning procedure, the scanned results were compared to known 3D CAD model geometry. The results reveal a show good match between the CAD model cross-section dimensions and the scanned results. This new measurement technique is an efficient method to collect the geometric parameters of a tie that influence pre-stress transfer length, including the shape factor. A detailed technical report summarizing all individual test results for each tie is available at https://krex.k-state.edu/handle/2097/41317.

BACKGROUND

Concrete railroad ties are commonly fabricated by casting concrete around pre-tensioned steel wires or strands. The stress transfers from the wires or strands to the concrete gradually from each end of the concrete tie. The transfer length is defined as the length required to fully develop the prestressing force.

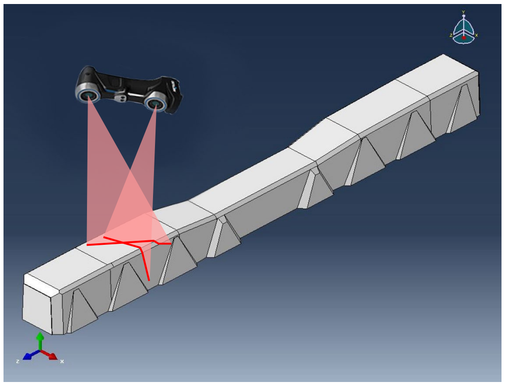


Figure 1. 3D optical scanning of railroad crosstie

The transfer length is affected by the tie’s shape factor, R(x), a geometrical parameter determined by the cross-sectional characteristics. The shape factor and underlying prestress force distribution, P(x), determine the longitudinal strain profile of the crosstie, S(x) = P(x)R(x)/E, where E is Young’s modulus of elasticity. The variation in the shape factor along the length of a tie results in strain profiles that can vary considerably from the ideal bilinear surface strain profile associated with a constant cross-section (prismatic) shape.

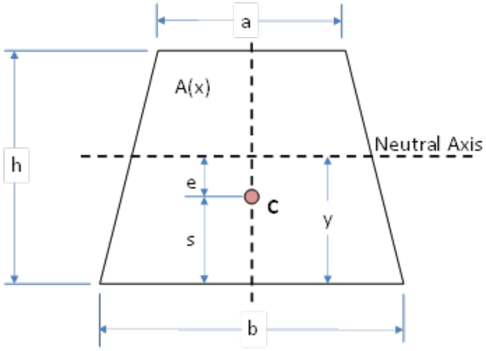


Figure 2. This trapezoidal shape defines crosstie cross-sectional parameters.

Figure 2 shows the trapezoidal shape used to define the important geometrical parameters associated with an arbitrary crosstie cross-section. These 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 area moment of inertia of the cross-section of the concrete tie at the location of x. C is the location of the centroid of the cross-section. The shape factor R(x) is defined by:

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

Figure 3 shows the normalized ($R(x)/R_0$) shape factor variation for a typical U.S. concrete crosstie. This variation in shape factor influences the strain profile along the tie and the distance from the end of the tie required to fully transfer the pre-stressing force to the concrete. Shape factor must be accounted for when using transfer length as a quality control parameter for tie design and production.

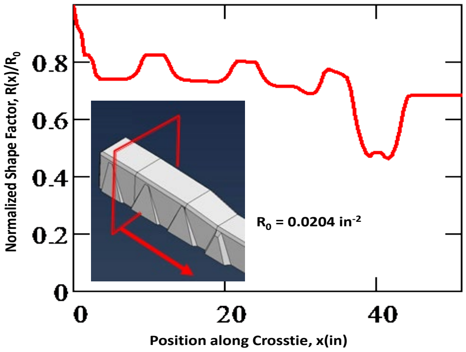


Figure 3. Shape factor variation for crosstie

OBJECTIVES

Most ties have a shape factor that varies significantly along the tie's length. These cross-section parameters must be measured or obtained from an available design data to calculate a shape factor. The objective of this project was to experiment with 3D scanning technology to efficiently measure the geometric parameters that define the shape factor.

METHODS

K-State inspected 72 ties (6 samples of 12 types) with a range of designs and service lives, including ties that had (1) been in service for up to 25 years, (2) failed in track, and (3) shown signs of distress in service.

The 3D scanning system has a maximum measurement spatial resolution of about 0.05 mm. The device projects seven intersecting laser light sheets that capture continuously changing images of the crosstie surface contour. The depth of field was large (250 mm), as was the scanning area (275 mm x 250 mm). This hand-held unit allowed manual scanning of an entire crosstie surface relative to a fixed coordinate axis. For accurate 3D scanning, it was necessary to attach self-adhesive retro-reflective points with nominal spacing of about 4 inches over the entire surface of the tie, as shown in Figure 4.

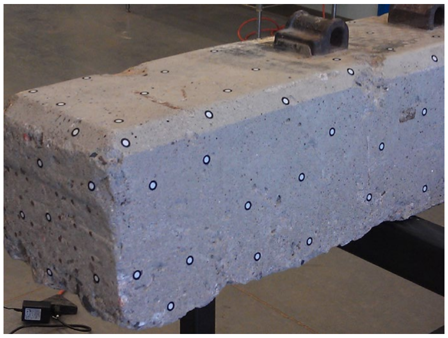


Figure 4. Retro-reflective reference points

These points provided a distributed 3D reference frame to the scanning system and were essential when scanning around sharp corners to reach features on the underside of the tie. Figure 5 shows a typical 3D rendering.

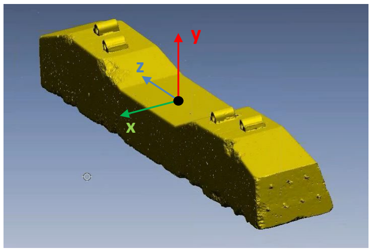


Figure 5. 3D rendering of a crosstie

RESULTS

K-State aligned the 3D models and converted them to point clouds for processing. Figure 6 shows a schematic representation of the point cloud rendering of the scanned tie surface model and the associated slicing procedure. K-State sliced the point cloud into 0.50-inch slices containing all the measured points in the interval (z - Δz/2 < z < z + Δz/2) about a given z-position. This process produced about 20,000 points around the perimeter of the slice at position z.

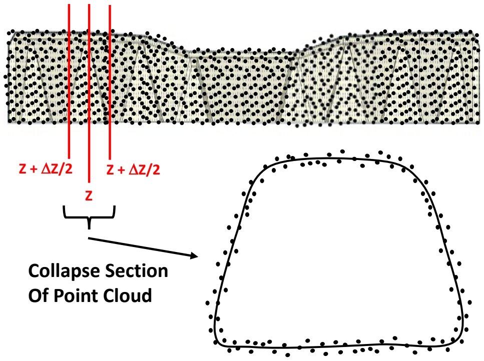


Figure 6. Collapsing a slice of the tie point cloud

K-State then collapsed the points into a single plane and grouped them into approximately 500 clusters containing about 40 points each, spaced approximately uniformly around the perimeter. The angular resolution of the resulting point clusters was about Δθ = 0.72 deg., as illustrated in Figure 7.

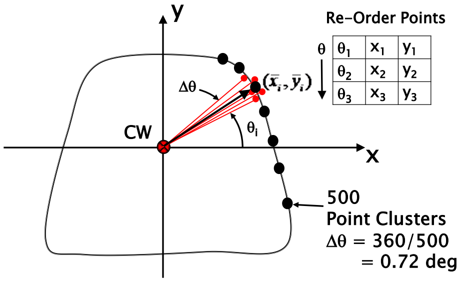
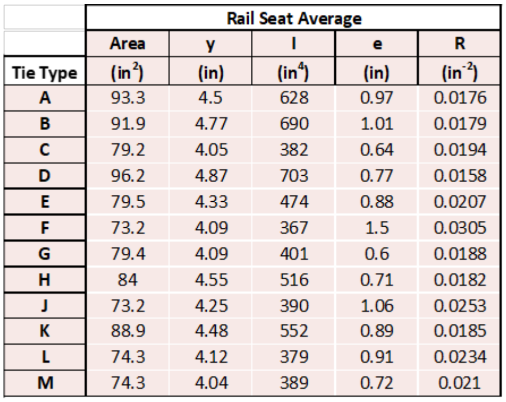


Figure 7. Formation of point clusters

The team developed a set of fast algorithms to determine of all relevant tie cross-sectional parameters (Figure 2) from the point cloud data (Figure 8).



	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 8. 3D scanning cross-section parameter results at rail seat

Figure 9 compares the scanned results with CAD data for a single tie type. The 3D scanning captured a very accurate representation of the tie cross-sectional area, with virtually negligible difference between an ideal CAD model and the measured values for this crosstie.

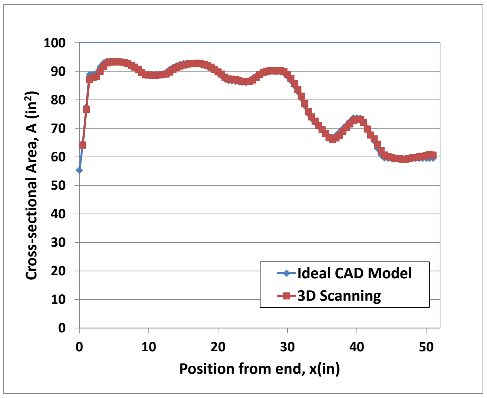


Figure 9. Cross-sectional area variation example

Similarly good results are shown for the shape factor variation given in Figure 10. The differences between the ideal CAD model and the 3D scanning results are possibly the result of errors in the determination of the neutral axis position. This position is manually determined from photographs of end of the tie.

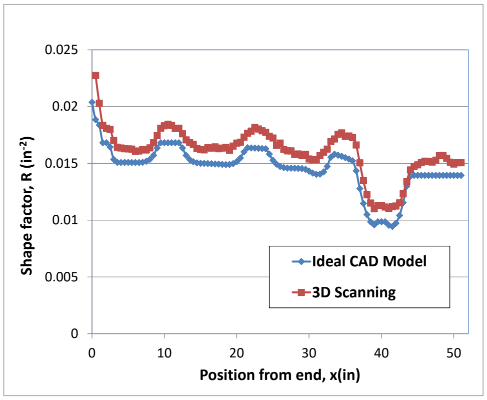


Figure 10. Variation in tie shape factor

CONCLUSIONS

K-State successfully employed a 3D scanning tool to create a detailed model of concrete crossties and analyzed these model data to extract geometric parameters that constitute the shape factor of the tie cross sections with high resolution. This scanning technique yields data that are comparable to CAD design data and is a viable method for determining the geometry of a crosstie. The 3D scanning tool coupled with the fast algorithms result in an efficient measurement process. This new method accurately measures the non-prismatic shape of the typical concrete railroad tie which is a critical parameter when using transfer length for quality control.

FUTURE ACTION

Additional development is warranted to reduce the errors associated with manually determining the neutral axis of the tie. The further application of this method for assessment of tie cross-sectional area parameters may prove valuable for quality assurance activities.

REFERENCES

Beck, B.T., Robertson, A.A., Bodapati, N.N.B., Peterman, R.J., Wu, C.-H. J., and Ryding, K.A. (2016). *Utilization of High Resolution 3D Optical Scanning of Crossties to Assess Cross-Sectional Parameters and the Effects of Long-Term Abrasion and Wear*. JRC2016-5753.

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