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Remaining Prestress Force in Concrete Ties Removed from Track after 25 Years

SUMMARY

This report highlights research conducted to determine the remaining (residual) prestress force in prestressed concrete ties that had performed well in track and were subsequently removed after 25 years of service. Concrete tie designers can use this information to develop better-performing ties.

This research was part of a larger project, "Developing Qualification Tests to Ensure Proper Selection and Interaction of Pretensioned Concrete Railroad Tie Materials," conducted by Kansas State University (KSU) and sponsored by the Federal Railroad Administration from 2015 through 2019. The full technical report can be downloaded from the K-State Research Exchange.

The prestress force in concrete ties diminishes over time due to drying shrinkage and creep, and stress-relaxation in the prestressing wires (or strands). Modern ties may have a significantly higher residual prestress force than older ties due to the current practice of stressing tendons to 80 percent of ultimate tensile strength (UTS) versus the 70 percent UTS level used previously. This increase is likely due to an industry emphasis on maximizing the bending capacity of the ties before a crack develops. However, higher prestressing forces in current designs make these ties more susceptible to longitudinal splitting cracks caused by bursting stresses.

Researchers evaluated remaining prestress force in ties using a new method where ties were loaded in direct tension. The data from this method was accurate to within 1 percent. The residual prestress force in a majority of the older ties was significantly lower than in new ties. The fact that these older ties performed well for over 25 years in track indicates that newer ties may contain more prestress force than necessary, thus increasing the likelihood of longitudinal splitting cracks.

BACKGROUND

Prior research on the effect of concrete and prestressing steel properties on bond and transfer length [1–5] shows that high bonding stresses can lead to longitudinal splitting cracks along a tie.

Longitudinal splitting can drastically reduce the load-carrying capacity of a tie and can appear in new ties prior to installation. To reduce splitting risks in new tie designs, it is important to understand how the properties of concrete and prestressing steel relate to splitting. Data show that concrete cover and prestressing wire indent characteristics [1], along with the concrete mix design [2], are strongly correlated to splitting risk.

OBJECTIVES

Researchers developed a new test method to determine the residual prestress force in concrete crossties. Testing included many new and old, service-proven ties to compare the level of internal prestress force between older and newer designs.

METHODS

KSU researchers obtained over 60 older ties for this study from the DOT Transportation Technology Center (TTC) facility in Pueblo, Colorado (Figure 1) and from several Class I railroads. The ties were in good condition after their extended service in track, with minimal or no cracking and no significant abrasion.

The team collected 12 different tie designs with varying geometry, and type and number of prestressing tendons. Table 1 details the type and number of prestressing tendons for each design group and lists the tie manufacturers.

Table 1: Description of existing tie designs

Tie Design	Manufacturer	Tendon Type	Indentations	No. of Tendons	Diameter
A	ITISA	Wire	Non-indented	4	0.415 in.
B	Abetong	Strand	Non-indented	7	0.375 in.
C	Florida East Coast (F.E.C.)	Strand	Indented	6	0.375 in.
D	Santa Fe/San Vel	Strand	Indented	8	0.375 in.
E	CXT 497S	Wire	Indented	18	5.30 mm
F	Con-Force Costain	Wire	Indented	26	4.86 mm
G	Koppers	Strand	Indented	8	0.385 in.
H	Rocla	Wire	Indented	24	4.97 mm
J	Rocla	Wire	Indented	24	4.94 mm
K	Costain	Wire	Indented	24	4.95 mm
L	CXT	Wire	Indented	28	4.97 mm
M	Rocla	Wire	Indented	28	5.02 mm

Researchers included a few newer ties for comparison. The new ties consisted of heavy-haul Vossloh 101L ties manufactured by Rocla, heavy-haul turnout ties by Nortrak, and CXT 505S ties. Table 2 lists the number of prestressing tendons, initial prestress force, and the manufacturing year for the new ties.

Table 2: Description of new tie designs

Manufacturer	Year Manufactured	Tendon Type	No. of Tendons	Indentations	Diameter	Initial Prestress* (kips)
Rocla	2016	Wire	18	Indented	5.25 mm	123.7
Nortrak	2014	Wire	24	Indented	5.32 mm	168.0
CXT	2011	Wire	20	Indented	5.32 mm	140.0

*After jacking and seating losses

Testing began by evaluating three existing test methods to determine the remaining prestress force:

1) Flexural testing to determine the crack re-opening load
2) Installation of strain gages on wires and then cutting the wires to eliminate tension
3) Careful extraction of wires and measuring the change in wire length

Researchers verified how well each method worked by testing it on newly-cast ties with a known prestress force. These test ties contained internal vibrating-wire strain gages (VWSGs) located at the center of the prestress force matrix to provide a standard reference to evaluate the external force measurement methods. None of these test methods produced acceptable results because the data did not closely match the internal strain data from the VWSG system. Table 3 summarizes the results.

Table 3: Results from existing test methods

Method	Result
Flexural Testing	Large errors due to minor variations in eccentricity and load measurement difficulties (+/- 15% accuracy)
Strain Gaging	Wire curling and bending issues (>100% errors)
Wire Extraction	Very difficult to perform (+/- 9% accuracy)

Undeterred, the team developed a new test method in an attempt to improve the measurement accuracy. This direct tension test, employs a large testing frame to apply direct tension to the entire tie cross-section. This method involved the following steps.

1) Saw-cut a shallow (3/4") groove around the perimeter of the tie at mid-length.
2) Pre-crack the top and bottom faces of the tie at the saw-cut location in flexure (Figure 3).
3) Encapsulate the ends of the ties in concrete blocks (Figure 4).
4) Jack between the concrete end-blocks until the concrete fully cracks in tension at the saw-cut location (Figure 5).
5) Remove the jacking force and install crack-opening (clip) gages across the saw-cut.
6) Uniformly jack between the blocks and determine the load that causes crack re-opening on all faces (Figure 5).

Figure 3: Loading at saw-cut to induce cracking

Figure 4: Spiral cage and concrete forming at tie ends

Figure 5: Jacks, LVDTs, and clip gage

RESULTS

Researchers plotted the applied load versus crack opening displacement for each tie and estimated the prestress force in the tie as the beginning of the second linear portion of the loading curve (Figure 7). This is the point where the applied load has overcome all the compressive force remaining in the reinforcements from the initial tie fabrication. The data point that first intersects a best-fit line marks the beginning of the post crack-opening region and serves to estimate the prestress force for the tie (circle in Figure 7). Subsequent work refined this load estimation by accounting for the weight of the top block (above the saw-cut).

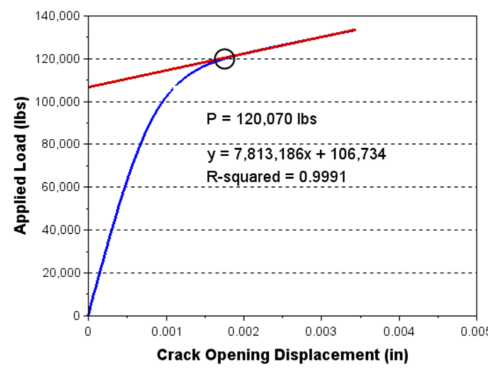

Figure 7: CXT 505S test results

Table 4 shows the comparison of prestress force determined using the direct tension method and by direct calculation from internal VWSG readings for two newer ties. The direct tension method produced results within 1 percent of those from internal VWSG readings. This method was the most accurate of the four, and the team used it for all subsequent tests.

Table 4: Comparison of prestress force results for new tie designs

Tie	Prestress Force Determined from VWSG Readings (kips)	Prestress Force Determined from Direct Tension Test (kips)
Rocla	102.6	101.8
Nortrak	143.4	144.6

Table 5 provides the prestress force data for the older ties. All these ties had an internal prestress force under 100 kips, with five ties having an internal force under 90 kips. Note that there were four Santa Fe/San Vel ties tested because Amtrak engineers cited their superior performance history in track. These four ties had a remaining prestress force between 85.9 and 92.9 kips.

Table 5: Comparison of prestress force results for ties removed from service after 25 years

Tie	Manufacturer	Prestress Force (kips)
A-6	ITISA	61.2
B-7	Abetong	87.5
D-2	Santa Fe/San Vel	90.8
D-4	Santa Fe/San Vel	91.7
D-7	Santa Fe/San Vel	92.9
D-8	Santa Fe/San Vel	85.9
F-6	Con-Force Costain	82.4
H-3	Rocla	99.2
K-5	Costain	93.0
L-6	CXT	88.5

CONCLUSIONS

The team developed a new, direct tension test method to experimentally determine the residual prestress force in a concrete tie. The method used the entire tie as the test specimen rather than extrapolating the data from the response of one component, or region of the tie. This new approach minimized the effect of small measurement errors. Validation of the method with a VWSG-instrumented tie revealed an error rate of less than 1 percent.

Older ties have significantly less residual prestress force (82–93 kips) than newer tie designs (101–144 kips), yet these older ties are service-proven to be excellent performers. The amount of prestress force in current designs may be excessive, but many factors are involved in concrete tie design. Recent tie failures due to longitudinal splitting cracks provide an indication of the negative effects of high prestressing forces coupled with the minimal concrete cover provided in tie designs. The bursting stresses within the tie are not always adequately constrained by the concrete.

FUTURE ACTION

Given the industry's practice of tensioning reinforcements to 80 percent UTS, KSU researchers are currently studying the relationship between concrete cover and splitting propensity to identify methods to design split-resistant concrete ties. This research is intended to yield effective and efficient methods to test tie designs for splitting risk prior to production-level manufacturing.

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