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Research Report
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Determination of Steels in Kentucky Bridges

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### Abstract

The Kentucky Transportation Cabinet (KYTC) maintains over two hundred steel bridges constructed with types of steel which are unknown. Kentucky Transportation Center (KTC) researchers have developed a procedure for determining steel tensile properties (0.2% yield strength and ultimate tensile strength) which can be used to help identify unknown steels. The procedure involves extracting small coupons from the lower flanges of steel deck girder bridges. Coupons are then machined into sub-sized testing specimens and suitable shapes for chemical analyses. Sub-sized tensile tests returned values generally comparable to those provided in mill certifications of steels purchased for laboratory trials. Several analytical methods — X-ray fluorescence (XRF) spectroscopy, laser-induced breakdown spectroscopy (LIBS) and arc-spark optical emission spectrometry (OES) — were tested for accuracy against chemical analyses in the mill certifications. All of the methods proved capable of characterizing steel chemistries. 

Researchers performed an in-depth review of all obtainable ASTM/AASHO/AASHTO standard structural steel specifications issued from 1900 through 2016. These were incorporated into a spreadsheet along with periodic revisions. Catalogued data include year of specification/revision issuance, material type, thickness, yield and tensile strengths, and steel chemistries (including 15 potential elements). This data set was incorporated into a database management program that can be used by agency officials to devise potential classifications based on ASTM/AASHO/AASHTO standard structural steel specifications. 

For validation, coupons were extracted from two bridges with known (carbon) steel types and two bridges with unknown steels. Tensile tests were performed on sub-sized specimens cut from the coupons and 0.2% offset yield and ultimate tensile strengths were determined. Steel chemistries were analyzed using a laboratory XRF unit. The database management system was used to identify the known carbon steels (with slight modification made to the tensile values of one steel). The system also identified the two unknown steels as being high-strength, low-alloy types.

### Key Words

AASHTO, ASTM International, bridges, chemistries, identification, mechanical properties, structural steels, superstructures
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Executive Summary

The Kentucky Transportation Cabinet (KYTC) maintains approximately 200 steel bridges throughout the state for which it lacks information on steel strengths and chemical compositions. Beginning in the early 1900s, the American Society of Testing and Materials (ASTM) described steel strengths and chemistries in its standard specifications. Later, the American Association of State Highway Officials (AASHO; later rebranded as AASHTO) added specification numbering. Before that, irons and steels used in bridge building were provided to strengths and chemistries specified by steelmakers. Needing a robust method for identifying unknown steels, KYTC requested assistance from Kentucky Transportation Center (KTC) researchers.

This report describes the procedure developed by KTC researchers to discern steel strengths and chemistries and, for more modern steels, to correlate them with ASTM/AASHTO/AASHTO standard structural steel specifications. Researchers first revisited their previous work on determining in-situ strength measurement and chemical analyses of bridge steels. Ultrasonic, impact, and rebound hardness tests can be used to approximate steel ultimate tensile strengths. Portable handheld analyzers, X-ray fluorescence (XRF) spectroscopy and laser-induced breakdown spectroscopy (LIBS) can assess steel chemistries in the field, although laboratory units may provide more complete analyses. More exact steel characterization methods require more invasive testing.

Because all of the bridges addressed during this study were deck girder structures, for tensile tests and laboratory chemical analyses, KTC researchers extracted coupons from the lower flanges adjacent to the beam ends to provide material. Researchers developed a method for extracting small coupons from thick flanges that minimized the amount of material removed. Other structural types, such as trusses or tied-arch bridges (and fracture-critical bridges), would require KYTC analyses for couponing.

KTC designed sub-sized tensile specimens and tested them against tensile strengths for 0.2% offset yield and ultimate tensile strengths from mill certifications of several steels (ASTM A36 and A588). Mill certification chemistries of those steels were compared to several test methods, including laboratory XRF (at the KYTC Division of Materials), portable LIBS, and arc-spark optical emission spectrometry. KTC tensile tests and KYTC’s XRF were generally in agreement with the mill certification data and the results of the other chemical test methods.

KTC also conducted an in-depth investigation of ASTM/AASHTO/AASHTO structural steel specifications dating back to 1900. Specification data up through 2016, including year of enactment (along with revisions), tensile strengths, and chemistries for specification of structural shapes and thicknesses were catalogued in spreadsheet format. In addition, the Center developed a database management program — KYTC Analysis of Steel — to correlate data from unknown steels with each standard specification so that viable matches can be sought. Steel specification data in the spreadsheet were used as the data set for the database management program.

Researchers proceeded to evaluate two bridges with known steel types and two bridges with unknown steel types. Looking at known steel types was critical for validating KTC’s procedure. Testing bridges with two unknown steels was necessary to determine whether the method is a practical way to identify steels.

The bridges with known steel types were:

KYTC Bridge ID 034B00104R: KY 922 — Newtown Pike over New Circle Road in Fayette County (ASTM A36)
KYTC Bridge ID 120B00035N: KY 1685 — Steele Road over Glens Creek in Woodford County (ASTM A7).

The bridges with unknown steel types were:

KYC Bridge ID 115C00001N: CR 1012 — Warsaw Branch Road over Warsaw Branch in Cumberland County
KYTC Bridge ID 077C00053N: CS 1002 — Conley Street over State Road Fork in Magoffin County.

KTC extracted coupons from the lower flanges of two girders on each bridge. Specimens cut from each coupon were used for laboratory chemistry and tensile tests. Tensile specimens were tested to failure and the 0.2% yield, and ultimate tensile strength data were averaged from the two girders. Bridge chemistries of each sample were analyzed.
in the KYTC Division of Materials XRF unit and those results were averaged. Next, coupon data, construction dates, material types (all types, structural shapes, plates or bars), and thicknesses were entered into the KYTC Analysis of Steel database management program. The program readily identified the ASTM A36-62 carbon steel of the KY 922 bridge, but tensile strength values for the ASTM A7-49 steel of the KY 1685 were slightly beyond the limits of the standard specification (although the chemistry values were acceptable). The KYTC Analysis of Steel program identified the unknown steels as high-strength, low-alloy steels — ASTM A441-63 from the CR 1012 bridge and ASTM A572-92 or A572-92a for the CR 1002 bridge.

KTC’s procedure meets the KYTC requirement for identifying unknown steels. Currently, the KYTC Analysis of Steel program requires modifications to address issues related to ASTM specification procedures that were not identified during this project. Nevertheless, it is still useful for people who are familiar with the KTC procedures.
1. Introduction

The Kentucky Transportation Cabinet (KYTC) currently maintains about 200 steel bridges for which information on steel composition and strength is not available. These include older bridges nearing the ends of their design lives and newer bridges (especially smaller steel structures, primarily deck girder types) with undocumented steel specifications. Most often, the problem of missing steel specifications arises when the Cabinet assumes maintenance responsibility for bridges from local governments and plans are not provided. It is of critical importance to identify unknown steels, identify their composition/alloy designation, and articulate their mechanical properties — primarily tensile and yield strengths. Steel chemistries are relevant when the corrosion of unpainted girders is a concern or when girders or other structural elements require repairs that involve welding. Several technologies are available to perform noninvasive or minimally invasive field tests on steels to identify their makeup and strength. KYTC will benefit from procedures for employing technologies that facilitate bridge steel identification.
2. Objectives

Study objectives for this research were to:

1. Develop procedures for identifying unknown structural steels and determining their mechanical (tensile) properties.
2. Validate those procedures for future use by KYTC in evaluating unknown bridge steels.

To achieve those goals, Kentucky Transportation Center (KTC) researchers completed the following tasks:

1. Assemble a catalog of past/current ASTM/AASHO/AASHTO steel types by composition, lifetime as an active standard, and mechanical (tensile) properties.
2. Develop a software program to analyze/classify steels (ASTM/AASHO/AASHTO) using composition, age (if available), and mechanical (tensile) properties.
3. Develop experimental, noninvasive, or minimally invasive field test procedures that can be used to determine steel types/properties. Apply those procedures on known ASTM/AASHO/AASHTO steels in laboratory tests.
4. Apply test procedures on KYTC bridges with both known and unknown steel types to determine which are the most accurate for assessing steel composition and mechanical (tensile) properties.
5. Document in a final report procedures for evaluating steel by type (ASTM/AASHO/AASHTO) or non-standard steels.
3. Research Approach

3.1 Overview

3.1.1 Highway Information Needs about Bridge Metals
Since the 1980s KTC has helped KYTC officials evaluate bridge metal properties (primarily steels), including chemical composition, strength, toughness, microstructure and corrosion mechanisms, and associated steel corrosion resistance. Investigations addressed metal components on existing bridges and, in one case, metal component selection for a new bridge. KTC has primarily focused on issues related to fractures or accelerated corrosion damage in steel bridge components. In some cases, this has required field sampling or field testing bridge steels. In other cases, bridge samples were retrieved and underwent laboratory tests and evaluations. For corrosion issues, steels meeting standard specifications typical of bridge steels were purchased and tested in laboratory corrosion chambers. Where applicable in this report, previous investigations are referenced to provide insights into potential methodologies for evaluating bridge steels.

3.1.2 Standard Steel Specifications
Grades for classifying steels by composition and physical properties have been developed by several standards organizations. Since 1900 the American Society for Testing and Materials (ASTM) has issued standard specifications for structural steels, including those primarily used in bridge construction. An American Institute of Steel Construction (AISC) document (1) includes a list of these steels along with their respective tensile strength properties. As part of this work, KTC developed a database management program to correlate steel properties derived as part of this study, as well as any available bridge information, with ASTM standards. The program uses available data to provide a best-fit classification tied to ASTM standard specifications. In 1914, the American Association of State Highway Officials (AASHO; later AASHTO) was established. The organization began promulgating steel specifications in 1939. Those were verbatim copies of their ASTM equivalents.

Table 1 provides a list standard structural steels issued by ASTM/AASHO/AASHTO (2). As noted in that document, “ASTM A 709 and AASHTO M 270 were eventually developed to cover all bridge steels into a single specification and assembled using the other existing materials specifications shown in table 1 (also Table 1 in this document). Up until publishing of the 14th Edition of the AASHTO Standard Specifications for Highway Bridges in 1989, engineers were provided design values for individualized ASTM and AASHTO material specification1. The 14th Edition then unified bridge design solely around ASTM A 709 and AASHTO M 270 and this remains true to this day.” Unfortunately, that document was identified and obtained by KTC researchers too late to use it earlier during active research or incorporate much of it in this report.

Data obtained using field and laboratory tests described in this report can be useful to physically characterize steel components from bridges built prior to 1900 (when no ASTM specification existed) when conducting structural evaluations and perhaps undertaking repairs. Typically, those bridges lacked steel specifications or, when available from steelmakers, only had minimal alloying requirements and mechanical properties specified. Where provided, such specifications may be of questionable accuracy relevant to actual material found in the field.

Commonly, structural steels used in bridges are produced to specific, uniform standards issued by ASTM and AASHO/AASHTO. These standards facilitate the design, testing, and fabrication of steel bridge elements and provide owners with firm expectations for their properties and field performance. At times since 1900, steel types have been introduced that were not covered by ASTM standards. These steels have typically been proprietary and, if successful, copied by other steelmakers using different formulations or through licensing agreements with the initial patent holder. Eventually, these steels were incorporated into ASTM specifications with specific grades covering the products of various steel manufacturers. An example of this is the quenched-and-tempered structural steels originally produced under license by United States Steel Corp. under the tradename of T-1 (now owned by Mittal Steel Corp.). In the early 1960s, a few large-span bridges were built by several steelmakers using this type of steel. Among these were the I-64 Sherman Minton and the I-65 John F. Kennedy Bridges over the Ohio River at Louisville. Eventually, those steels

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1 Now ASTM International. Referred to as ASTM throughout this report.
2 Renamed the American Association of State Highway and Transportation Officials (AASHTO) in 1973.
were incorporated into ASTM A 514. Other Kentucky bridges may incorporate other types of proprietary steel, which may be correlated with initial ASTM specifications released after a steel type was initially employed on bridges.

If owners are faced with non-standard or unknown bridge steels, they may need to perform additional testing to identify their mechanical properties, and possibly chemistry, to address concerning unknowns. For instance, concerns may relate to determining the bridge posting or determining steel resistance to atmospheric corrosion. Where field welding will be performed on bridge steel, additional guidance may be needed to characterize steel and determine a proper welding process. Other problems such as brittleness or cracking may also require evaluation by a metallurgist or failure analyst and, as previously noted, may require determination of steel toughness or susceptibility to corrosion cracking. That lies beyond the scope of this report and should be addressed on a case-by-case basis by knowledgeable personnel.

3.2 Properties of Structural Steels
The main factors that differentiate steels and characterize them for use are their chemical contents, mechanical properties, and microstructures. Beyond alloying, thermo-mechanical processing related to shaping operations (e.g., continuous casting, hot or controlled-rolling, forging, or heat-treatments such as quenching and tempering) play a key role in microstructure formation and the resulting mechanical properties. A structural steel’s inherent ability to resist corrosion depends primarily on its alloying elements. Structural steel alloys that resist atmospheric corrosion are termed weathering steels.

Structural steels (other than specialty forgings) can be characterized as:

1) Carbon steels (e.g., ASTM A 36);
2) Weathering steels (e.g., ASTM A 588);
3) High-strength, low-alloy steels (e.g. ASTM A 572); and
4) Quenched-and-tempered steels (e.g. ASTM A514).

The current ASTM A 709 equivalents to those specifications are grades 36, 50W, 50S, HPS 50W, HPS 70W, 100 and 100W. Steel strength and chemistry, along with thermo-mechanical forming processes (and weld properties), may factor into any modifications or repairs to bridge steel involving heat-straightening and welding.

NOTE: Characterization of thermo-mechanical properties other than hot rolling (i.e., heat treating) can be typically surmised via physical properties such as the high yield and tensile strengths of quenched-and-tempered (QT) steels versus other standard structural steels that are hot formed.

3.2.1 Field Analysis of Structural Steel Chemistry
There are many production grades of steel. Each grade has specified levels of iron, carbon, and other elements in small quantities that provide specific mechanical properties and other characteristics (e.g., weldability and corrosion resistance). Knowing the elemental composition of an alloy is useful for identifying a steel’s specification, mechanical properties, and other characteristics. The standard for determining steel chemistry is ASTM A 350-18 (Standard Test Methods for Chemical Analysis of Carbon Steel, Low-Alloy Steel, Silicon Electrical Steel, Ingot Iron, and Wrought Iron).

Previously, KTC has investigated metal constituents for KYTC by acquiring samples and testing them in the laboratory (including classical wet chemical analyses) to identify steel constituents and their respective concentrations, which are typically given by weight percentages. Today, most steel chemical analyses are performed using spectroscopic analysis methods where the electromagnetic spectrum is used to determine the composition matter at an atomic scale.

Spectroscopic analysis methods offer rapid nondestructive testing capabilities. Several spectroscopic methods commonly used for elemental analysis of structural steels include X-ray fluorescence (XRF) spectroscopy, arc-spark optic emission spectrometry (OES) and laser-induced breakdown spectroscopy (LIBS). Portable, handled devices suitable for fieldwork are available to conduct XRF and LIBS. Other common laboratory/benchtop spectroscopic methods include scanning electron microscope/energy dispersive spectroscopy (SEM-EDS), X-ray diffraction (XRD), and inductively coupled plasma (ICP) mass spectroscopy. These methods are not addressed in this report. However, they can potentially be used to confirm results generated via XRF, OES, or LIBS should questions arise. Laboratory methods should be chosen by experienced laboratory personnel based upon test requirements.
In some cases (i.e., welding), the carbon and sulfur contents of structural steel are important. Methods of analyzing those elements include:

- Infrared absorption method
- Emission spectroscopy
- Wavelength dispersion X-ray method
- Non-aqueous titration
- Chromatography
- Electrochemical method
- Online analysis method

The latter method is a manufacturing method and is not applicable to analyzing steel on existing structures.

XRF testing uses a weak radiation source to excite a test material with X-rays or gamma rays and thereby generate secondary or fluorescent X-rays that are characteristic of the atoms in the material. Those are detected by sensors that internal microprocessors correlate with element types and surface concentrations (weight percent of test surface). XRF can analyze the surface content of metals accurately with typical limitations of element detection below silicon (atomic number of 11). It cannot detect or quantify the presence of carbon (atomic number 12) in the low percentages typical of structural steel. Most structural steels limit carbon to 0.30% or less, and accurately measuring carbon in those steels is not usually a concern unless addressing issues related to welding or fracture toughness.

A wide range of handheld XRF units are available from a number of manufacturers. They vary in terms of weight, operating time, element detection capabilities, analyses/outputs, and ruggedness (a good property for field use). For this project, an Olympus Delta Professional portable handheld XRF analyzer was used for field analyses (Figure 1). Because XRF units generate a small amount of radiation, they require worker training and recordkeeping of the unit. Under normal safe use, no hazards should be encountered.

KTC’s portable XRF unit has a calibration disc made of American Iron and Steel Institute (AISI) Type 304 stainless steel. The unit must be calibrated with that reference standard before it is used to analyze materials. It is capable of taking one reading every 30 seconds. The unit’s LCD screen lets users view test results (given in weight percentages of elements detected on the surface of the steel as well as trace elements detected below the measurable threshold). The unit has a small camera at the radiation end pointing toward the surface where the measurement is taken. This allows for detection of any potential anomalies (e.g., contamination, inclusions, pits) that might impact readings. The unit can also store the element constituents of standard steel types (AASHTO, ASTM, AISI, SAE), which may be compared to readings using best fit analysis. KTC has used this unit frequently for field tests on bridges. In 2017, it was used on five small bridges in Trimble County, Kentucky, to identify unknown steel types and their potential corrosion resistance (4). In 2019, it was used in conjunction with tensile testing of an extracted specimen to classify the steel of a bridge in Hardin County, Kentucky (5).

Handheld LIBS analyzers (HH-LIBS) work by directing a pulsing laser onto a small area of the test sample (approximately 50 µm in diameter) for a few nanoseconds. This vaporizes a small amount of the test material on the surface, causing light to be emitted in the ultraviolet, optical, and infrared spectrums. LIBS analyzers use a spectrometer to measure the wavelengths of emitted light, and internal microprocessors/software compares spectral lines with known wavelengths to identify the elements present and the intensity of the lines to quantify their concentrations.

Arc-spark OES spectrometers contain an electrical source that generates an arc which causes atoms to emit energy in the form of an optical emission (light) characteristic of an element. The analyzers contain a diffraction grating that separates light into element-specific wavelengths and determines their intensities. A microprocessor in an analyzer converts the measured intensities into their specific elemental concentrations by percent weight in a metal sample.

3.2.2 Mechanical Properties
The chemical composition (alloying) of a steel, steelmaking, and thermo-mechanical processing (including, forging, forming (by rolling), and heat-treating) all work together to control the mechanical properties of structural steel. Forging is used for some smaller steel bridge parts, but typically not for larger structural shapes like beams. Forming
processes typically involve hot or controlled rolling of steel from large semi-finished shapes, such as ingots or slabs (in the case of continuous casting), into beams and girders that are of interest in this research. Finished shapes include plates, bars, rounds, and structural shapes (angles, channels, and I-beams). The size/thickness of a structural member also factors into the mechanical properties of structural steel. Steel I-beams are typically rolled in one solid piece, while large girders are typically built up of from plates and possibly bars joined by riveting (in older bridges) or, most commonly, welding. Most bridge members incorporating heat-treated steel are built-up (welded) from simple shapes such as plates or bars that are heat-treated by quenching and tempering after rolling.

A main concern of bridge engineers is bridge strength. Strength is the product of design, dimensions, and the mechanical (physical) properties of materials from which bridges are constructed. For bridge steel, the primary mechanical properties are typically the tensile yield and ultimate strengths. Other mechanical properties (e.g., hardness, toughness, elongation) may be relevant in some cases, but those are usually subordinate to the primary strength properties. Tensile properties of bridge steel are primarily obtained by performing engineering tensile testing on steel specimens. It provides basic design information on the strength of steels and is used as an acceptance test for steel specification.

3.2.2.1 Tensile Testing
The primary mechanical properties of structural steels are obtained using a uniaxial tensile test. In a typical tensile test, a specimen is attached to grips that transmit tensile force from a movable cross-head on a universal test machine. The cross-head is driven hydraulically or by a servo-controlled set of screws located in the test machine load frame (Figure 2). The tensile testing machine is equipped with a load cell located in the cross-head that measures the force applied to a test specimen as hydraulic pressure or the rotation of screws moves the cross-head and applies a tensile strain to the specimen. The strain on the specimen can be determined by an extensometer attached on the gage section of the specimen. Tests are typically run at fixed cross-head movement or extensometer-driven strain rates for servo-controlled test machines.

3.2.2.2 Tensile Testing Specifications
A standard for uniaxial tensile testing in the U.S. is ASTM E8 (Standard Test Methods for Tension Testing of Metallic Materials) (6) That specification addresses specimen shapes/sizes, grips; describes test methods (for yield and ultimate tensile strengths); gives details on reporting, test precision, and bias; and includes an appendix on factors affecting tensile testing results. Also, ASTM A 370/AASHTO T 244 (Standard Method of Test for Mechanical Testing of Steel Products) addresses testing structural steels for commercial purposes (7).

Tensile specimens can be prepared in various shapes depending on the type of material being tested. Specimens have grip areas/shoulders at each end that taper down to a center gauge section. The constant cross-section of the gage section is reduced, which produces a higher stress there when the sample is loaded with a tensile force (Figure 3). Metal properties are determined based upon the steel response in the gage section.

For structural steels, the most common shapes have rectangular (flat) or rounded sections. Flat specimens are attached to the grips by wedging or pinning, and rounded sections are attached by threading. ASTM E8 provides standard dimensions for tensile specimens of both regular and sub-sized specimens. The latter may be necessary due to a shortage of test material. A full-size rectangular specimen has an overall length of 18”, a gage length of 8”, a shoulder width of 2”, a gage width of 1.5” and a specimen thickness of 0.188” (min.). A sub-sized rectangular specimen has an overall length of 4”, a gage length of 1”, a shoulder width of 0.375”, a gage width of 0.25”, and a specimen thickness of 0.25” (min.). A standard round specimen does not have the overall length or a shoulder diameter specified. This accommodates potential variances in the sizes of threaded grips. For specimens with a gage-length-to-diameter ratio of four, the specimen has an overall reduced section length of 2.25”, a gage length of 2” and a specimen diameter of 0.500”. ASTM E 8 provides for several sub-sized round specimens with dimensions ranging from/to: overall reduced section length — 1.75” to 0.625”, a gage length —1.40” to 0.45” and specimen diameter — 0.350” to 0.113”.

Wrought steel products, including those that are rolled, typically have anisotropic tensile strengths due to forming operations producing directional effects on steel microstructures. This results from the elongation of grains in the rolling direction. Steel plates welded into girders are typically aligned with the rolling direction parallel to lines of stress. Therefore, the longitudinal axis of tensile specimens is typically cut parallel to the rolling direction as that is commonly the orientation of the steel along the length of the final beam/girder. It is perpendicular to the maximum applied stresses in a beam/girder. Therefore, strength values of beam/girder are also of concern in that orientation.
3.2.2.3 Tensile Test Data

Modern test machines like the one used in KTC’s test program are computer controlled, with load cell and/or cross head movement recorded versus load cell readings. The dimensions of specimen gage length and gage section area are programmed into the computer which calculates stresses and strains/deflections. The load cell (note the arrow in Figure 2) measures the force applied to the specimen.

The computer generates a plot of the engineering stress-strain curve showing stress on the vertical axis (based upon the applied loads and original cross-sectional area of the specimen in gage length) versus both elastic and plastic strain. Along with the plot, the computer provides maximum applied force on the specimen, modulus of elasticity, yield strength, and ultimate tensile strength (Figure 4).

In uniaxial load testing of materials, the *elastic limit* is defined as the point on the stress-strain curve beyond which the material will not return to its original shape if the stress is removed. For many materials — including steels — determining this point is challenging. Instead, the *yield point* is used. At the yield point some fraction of the deformation becomes permanent (plastic deformation). The yield point is given as a percent of strain offset from the elastic slope of the stress-strain curve (Figure 5). *Yield strength (stress)* is the stress in a tensile specimen at the yield point. Several methods are used to assess yield strength, but the offset method is most widely used. To determine yield strength, a 0.2 % offset strain value is commonly used in the U.S. Yield stress has importance for the working stress design (allowable stress design) method. It assumes that the behavior of steel occurs in the linear-elastic region and that structural safety is preserved by limiting stresses in the members to working loads that only induce stresses in the linear portion of the stress-strain curve. The allowable stress is some fraction of the yield strength. The reciprocal of that fraction is termed the *factor of safety* (8). Yield strength is used in specifying modern ASTM structural bridge steels (e.g., ASTM A 709 50 grade steel has a yield strength of 50 ksi).

*Ultimate tensile strength (stress)* is equal to the maximum applied force on a tensile specimen divided by the original cross-sectional area along the gage length. For ductile materials such as structural steels, this occurs after the yield point in the region of plastic deformation (9). In this region, the stress increases as the specimen strain hardens due to microstructure changes brought on by deformation of steel in the gage section. After the tensile specimen reaches it maximum tensile stress, ductile metals begin to exhibit a type of localized deformation called necking (a reduction in the cross-sectional area due to plastic flow). The specimen continues to neck until it fails at the narrowest cross-sectional area. Ultimate tensile strength is used in the ultimate strength design method (also termed the limit state or load factor design method) (10). It is also employed for quality control, because of the ease of testing. It is also used to roughly determine material types in unknown samples.

*Elongation* in a tensile test is the increase in specimen length as it is pulled in tension. It is usually recorded as % elongation, which is the percent change in specimen length before and after fracture. Measurements of the specimen gage length are generally taken before and after testing. The amount of elongation depends on specimen size and geometry. Specimens with longer gage lengths usually exhibit greater % elongation values. To permit comparisons between tests, standard full-size specimens are commonly used. Elongation is a measure of a specimen’s *ductility*. Ductility is the ability of a material to deform plastically prior to failure.

*Reduction of area* is change in specimen cross-sectional area as it is pulled in tension. It is typically recorded as % reduction of area, which is the percent change in the cross-sectional area before and after fracture, with the post-fracture cross-section measured at the smallest cross section which is at the point of failure. As with elongation, reduction of area depends on specimen size and geometry and is commonly referenced relative to standard full-size specimens. Reduction of area is also considered an indicator of ductility. Often, both elongation and reduction of area are reported values for tensile tests especially in material acceptance testing. In those cases, specimen geometry and dimensions are typically reported.

3.2.2.4 Other information of potential value from field tests of steel

Besides identifying steel chemistry and tensile strength properties, other tests may prove useful when instruments are not available or field specimens cannot be obtained. Also, there are some circumstances where chemical or common physical tests may not provide suitable information. Some other approaches are available for obtaining necessary data. While most of the following information lies beyond the scope of this research, a brief discussion is provided as guidance KYTC can use for potential material identification/evaluation circumstances that might arise in the future.
3.2.2.4.1 Issues with Older Bridges
For historic bridges, there are issues not only with steel properties, but with whether a structural member is even made from steel. It is probable that most metal bridges built prior to about 1880 used cast or wrought iron. A transition from iron to steel bridges occurred approximately between 1880 to 1900, although iron may possibly be present in bridges constructed through the early 1920s (11). The Phoenix Iron Company was prominent during the latter part of the nineteenth century. It was involved in making catalog bridges beginning in 1884 and began using steel for bridge members in 1889 (12). Its subsidiary, the Phoenix Bridge Company, built several iron/steel bridges in Kentucky, including the Central Bridge at Newport (demolished in 1990) and the Big Four Bridge at Louisville (now a pedestrian bridge). Because some old truss bridges may have been constructed during this transitional period, questions can arise about the strength of metal components and alloy types. Some old truss bridges may have a mix of components consisting of steel, wrought iron, and cast iron. Another difficulty associated with older structures is that they tend to be complex (e.g., trusses) and use built of members consisting of plates, angles, and lacing that are usually riveted together. They commonly employ pinned connections that are difficult to access. These factors make in-situ testing more practical than material extraction (couponing).

For older structures, Sparks recommended that a materials characterization approach relying on microstructure, chemistry, and hardness be used to provide proxy data in lieu of tensile test data (13). He stated that the classical spark test could be used on bridge components in the field as a preliminary way to sort metal components (14, 15). Polishing and etching can be used to assess the material microstructure and assess grain size in the field using a portable optical microscope. This can also be used to identify ferrous alloys. A metallurgist can also identify potential problems in those microstructures. Sparks noted that chemical analyses could be used to identify alloys and determine the consistency and quality of bridge members. He added that chemical constituents strongly influence the strength, ductility, and weldability of metals. In structural steels, the main determining alloys are carbon (C), manganese (Mn), sulfur (S), and phosphorus (P). Sparks stated that portable OES testing using arc excitation could be employed to rapidly assess multiple structural members in both steel and cast iron. Due to the presence of slag stringers in wrought iron, chemical analyses and their implications for material quality are more complex. He recommended field hardness testing to:

- Screen for insufficient ductility,
- Indicate the variability of the material within an individual member,
- Correlate the properties of one class of members with another, and
- Estimate the tensile strength of the materials.

Sparks discussed the use of an ultrasonic hardness tester for field testing (a type used previously used by KTC and KYTC). Other options for hardness testing are discussed below.

As noted, ASTM structural steel standards were first issued in the early 1900s (1). Prior to that, steel specifications were typically set by companies supplying bridges. Those specifications were typically simple and had limited data on phosphorous and sulfur content, while sometimes also identifying other constituents such as carbon, silicon, and manganese. Mechanical properties of steels included minimum yield and tensile strengths, elongations (based on the gage length of the tensile specimens) and possibly a minimum mandrel bend radius as a measure for ductility. In Kentucky, most bridges built using early steels and iron were through-truss structures. Any evaluation of their metallurgical properties should be undertaken as special projects and, depending on KYTC informational needs, potentially subject to test methods more in-depth than those provided in this report.

3.2.2.4.2 Hardness Testing
Hardness is a measure of a metal’s ability to resist indentation. For steels, hardness values for both Brinell and Rockwell hardness tests have been found to be nearly proportional to steel ultimate tensile strengths down to an ultimate tensile strength value of about 56 ksi, which is roughly the lowest tensile strength listed for an ASTM structural steel (16). Hardness tests are used in the field because they can be done rapidly and do not require extracting a specimen from a structural member for laboratory tensile testing. There are several potential portable hardness test methods (e.g., indentation, rebound, impact, ultrasonic). In the past, KTC researchers have used impact and ultrasonic hardness testing to detect improperly heat-treated (fine-grain) ASTM A514 steel on several interstate bridges by evaluating hardness values found to relate to steel toughness in that situation (17).
3.2.2.4.3 Microstructure Analysis
Microstructure analysis is useful for identifying types of ferrous alloys used in older bridges. It can also be beneficial for analyzing potentially problematic steel bridge members in modern bridges. During the aforementioned hardness testing (17), low test values were encountered on one structural member. A consulting firm working with KTC performed field polishing and etching (alcohol with 2% nitric acid) on the bridge member and made an impression on the prepared surface using an acetate plastic replica tape. The tape was then evaluated using an optical microscope to indirectly assess the steel microstructure and identify the problem. Taking replicas has an advantage over field microscopy in that it can performed in the field by a technician, with the replica tape assessed later in a laboratory by a metallurgist. Replica tape can also be used where vibrations in bridge members make field microscopy problematic. Microstructure testing is useful in cases where bridges are exposed to excessive heat (e.g., tanker fires), questions exist over the type of ferrous metal present (e.g., wrought iron or steel), or cracking problems are detected (e.g., brittle steel).

3.2.2.4.4 Miniature Specimens
Miniature specimens have been used successfully by others for both tensile and fracture toughness (linear elastic fracture mechanics (LEFM)) specimens (18). They are useful when large specimens cannot be removed from structural members or when limited amounts of steel are available. KTC previously had a consultant use a miniature tensile specimen on a project where larger (sub-compact) specimens of the same steel were used (19). In that project, the miniature “dog bone” specimens had an overall length of 1”, a gage length of 0.3” and a thickness of 0.06”. Tensile test results from the miniature specimens were about 10 percent higher than for the sub-compact specimens. However, the tensile testing was too limited to draw firm comparisons based on specimen sizes.

3.2.2.4.5 Fracture Toughness Testing and Instrumented Indentation Testing
Fracture toughness is commonly given as the impact energy absorbed by a notched specimen at a specific temperature (e.g., Charpy tests). However, when identifying unknown steels in existing bridges, that property is typically not considered (unless a steel bridge member has experienced a fracture). In a failure analysis investigation, sub-sized Charpy specimens were tested due to a limitation of test material thickness. Results were corrected for size, giving an equivalent temperature shift for a full-size specimen (19, 20). Conversion factors are available to provide fracture mechanics test values based on Charpy tests. A formula provided in the API 579.1/ASME FFS-1 2007 *Fitness for Service* assessment standard refers to a lower bound static fracture toughness from the Welding Research Council, WRC 265 (*Interpretive Report on Small Scale Test Correlations with Kc Data*). That provides the following correlation:

\[(1) \quad K_{lc} = 8.47 \times (CVN)^{0.63}\]

Where: CVN = Charpy impact energy (ft-lb) taken at 40°F

\[K_{lc} = \text{Critical stress intensity } - \text{ mode I cracking (ksi } \cdot \text{in}^{0.5})\]

The Rolfe-Novak-Barsom equation had been proposed to calculate the stress intensity values for upper shelf Charpy correlations with $K_c$ (21):

\[(2) \quad \left(\frac{K_{lc}}{\sigma_{ys}}\right)^2 = 5(CVN/\sigma_{ys} - 0.05)\]

Where: CVN = Charpy impact energy (ft-lb) taken at 40°F

\[K_{lc} = \text{Critical stress intensity } - \text{ mode I cracking (ksi } \cdot \text{in}^{0.5})\]

A special instrumented hardness tester — ABI Services Automated Ball Indentation® tester — can determine both yield and tensile strengths (along with LEFM fracture toughness values) both in the laboratory and the field (Figure 6). It was previously used to evaluate heat-treated and standard structural steels for yield and tensile strengths as well as fracture toughness values. This method has the advantage of providing mechanical properties, including fracture toughness (22, 23). It can use the master curve method per ASTM 1921 (*Standard Test Method for Determination of Reference Temperature, T0, for Ferritic Steels in the Transition Range*) to provide fracture toughness values over a wide range of temperatures. The method is relatively noninvasive for field use, although positioning and powering the unit would pose some challenges. For laboratory use, it would enable testing of small specimens, thus minimizing the size necessary to provide tensile and fracture toughness values compared to standard or sub-sized specimens. Unfortunately, cost factors prevented further investigation of that technology during this project.
4. KTC Research

4.1 Scoping Testing to Characterize Bridge Steels
In the 1970s, the FHWA published a report on research addressing the testing of early bridge steels (24). That testing involved known samples of bridge steels dating from the early 1900s through the 1930s specified as ASTM A7 Low Carbon Structural Steel. Chemical and spectrographic tests were performed to evaluate the elemental constituents of those steels. Tensile tests evaluated the mechanical properties of the steels relative to those specified in the ASTM standard. Additionally, optical microscopy was used to evaluate the steel microstructures, and other tests were performed, including transmission fractography drop-weight tear testing, Charpy testing, and fracture toughness testing. Those latter tests generally fall outside of the scope of this research. While the objectives and overall scope of the FHWA’s work differ from this project, that report provided insights into what steps should be included in our work.

Based on initial discussions with KYTC’s Study Advisory Committee, researchers discerned that most of the Cabinet’s steel identification needs related to determining 1) the mechanical properties of those steels, and 2) whether unknown bridge steels are of plain (non-weathering) or weathering grades. The latter was typically important where unpainted (and unknown) bridge steel was present. Identifying applicable ASTM/AASHTO standards, though a worthwhile goal, was of secondary importance to KYTC officials. The three main project tasks were: 1) steel strength determination, 2) steel chemistry identification, and 3) identification of ASTM/AASHTO steel specification.

In commissioning this research, KYTC initially sought to perform completely non-invasive in-situ testing of bridges to characterize their steel. That approach was anticipated for field tests on exposed steel surfaces, incorporating indentation hardness tests to obtain mechanical steel properties and the use of field spectrographic analyses for both quantitative and qualitative elemental analysis.

4.2 Determination of Steel Tensile Properties
At the outset of this study, KTC researchers hoped that indentation testing would prove viable for obtaining necessary mechanical properties. However, while the method can be used to estimate ultimate tensile strengths of structural steels, it does not correlate sufficiently well with yield strengths to identify alloys (25). It was anticipated that most KYTC steel identification needs would relate to rolled beam and welded plate girder bridges constructed of carbon and high-strength low-alloy (HSLA) structural steels. Potential for ultimate tensile strength overlaps between those steel types made indentation testing impractical for this project. KTC researchers determined that conventional hardness testing was not suitable for this project. The only other option was extracting coupons from bridges to obtain conventional tensile specimens for laboratory testing.

4.2.1 Laboratory Tensile Testing
Because most, if not all, of the structural members to be evaluated would either be I-beams or girders on simple span structures, the optimal locations for extraction is on the outer edges of lower beam flanges at the ends of the beams/girders. Those flanges provide most of the strength, and in the bearing areas are subject to compressive forces. Coupon size was minimized to let the beam retain most of its strength. The first step was to identify a suitable tensile specimen. Second, was formulating and testing a method for extracting coupons from flanges. The third preparatory step was simulating the extraction procedure using a piece of ASTM standard structural steel representative of a beam flange, machine the resulting coupon into tensile specimens, and conduct tensile tests to confirm that the proper yield and ultimate stresses would be obtained. The trial tested the feasibility of the extraction and tensile testing procedure.

4.2.1.1 Tensile Specimen Sizing
The use of full-size tensile specimens was considered impractical as they require coupons too large for safe extraction from beams/girders. To minimize the size of coupons extracted from bridge structural members, specimen size was reduced. A sub-sized specimen design (Figure 7) was developed similar to a small-size specimen shown in “Figure 4—Standard 12.5-mm (0.500”) Round Tension Test Specimen with 50-mm (2”) Gauge Length and Examples of Small-Size Specimens Proportional to the Standard Specimen” of ASTM A 370/AASHTO T 244 (7). The tensile specimen design suited the extraction plan (below) and could be used with tensile test machine grips available at the UK Department of Chemical and Materials Engineering laboratory where testing was performed.

4.2.1.2 Coupon Extraction Procedure
To develop an extraction procedure researchers used 50 grade steel (meeting ASTM A588(15)/ASTM A709(16A)50W and ASTM A588-A/B) because it is more resistant to cutting than softer ASTM A36. A one-inch thick plate was obtained for testing. In addition, a 1” thick plate of ASTM A36 was obtained for comparison (meeting ASTM A36(14)/A709(16A)/ASME SA36(15) and AASHTO M270(15)36). Mill certifications accompanying those plates served as standard references for steel tensile properties and steel chemistry (Tables 2 and 3, respectively).

Based on past experiences with sub-sized and miniature tensile specimens, KTC researchers looked at methods of coupon extraction from I-beams/girders KYTC would find acceptable in most cases. For flanges thicker than 1”, a triangular section with two 1” legs was cut from the edge of the lower flange at the bearing area provided a sufficiently large coupon to accommodate the necessary cross-sectional area of the tensile specimen (Figure 8). That would only reduce a flange cross-section by 0.5 in.² which would likely not pose a strength problem in I-beams/girders at the bearing areas. Later, KTC researchers limited the triangular coupons to flanges with thicknesses greater than 1”. For rolled beam girders having a flange thicknesses of 1” or less, cuts were made normal to the flanges instead of at an angle. For those coupons, the cut width was 1”. A coupon length of about 7” yielded sufficient material to fabricate two tensile specimens. A taper of about 45° was proposed at each end of the cut to provide a gradual transition to eliminate stress risers in the flange after coupon removal.

A mock-up test of the angled cutting procedure was performed in KTC’s laboratory to determine the feasibility of the proposed coupon extraction. A 1” thick ASTM A588 steel plate was used to replicate a bridge flange. A 7” grinder equipped with a cutting disc was used to make a plunging cut into the plate at a 45° angle to the plate’s surface. To achieve this, a steel guide was clamped onto the flange replica plate 1” from its edge (Figure 9). The cutting disc was laid against the guide, letting the operator cut at the proper angle (Figure 10). One 7” long cut was made with grinder, followed by two cuts at about a 45° compound angle to complete the tapers at the end of the coupon. A die grinder with a deburring bit was used to clean up the transitions between the cut surface parallel to the edge of the flange and the two taper cuts on the ends (Figure 11). As noted, this complex cut was to be used on girders with thick flanges (greater than approximately 1”). For I-beam flanges 1” thick or less, the simpler normal cut facilitated coupon extraction.

4.2.1.3 Laboratory Tensile Test Procedure

The piece extracted in the laboratory field simulation was machined into several of the KTC-designed sub-sized tensile specimens at the UK Physics Department machine shop (Figure 12). Prior to testing, specimen cross sections in the gage were measured to obtain stress data (Figure 13).

Tensile tests were performed on a 22,500-lb. capacity Instron 3382 electromechanical universal test machine at UK’s College of Chemical and Materials Engineering laboratory (Reference Figure 2). A 1” gage length extensometer was attached to a test specimen to enable accurate determination of the 0.2% offset yield strength (Figure 14). A workstation connected to the extensometer and tester controlled the loading process, indicating when that yield strength was achieved (Figure 15). It also logged the load/strain/crosshead deflection data and provided a stress/strain/deflection plot in real time. During the tests, the cross-head speed was set 0.079 in/minute. Later it was discovered that this was about five times as great as specified in ASTM E8. After a specimen yielded, the test was temporarily halted to remove the extensometer. Then, the specimen was pulled to failure (Figure 16). The workstation recorded the total movement of the crosshead and the maximum load prior to failure and calculated the ultimate tensile stress based upon the specimen cross-sectional area.

**ASTM A 588 Steel** — Qualification tensile testing using the sub-sized KTC specimen design was performed using samples of ASTM A 588 and A 36 steels. In testing five ASTM A 588 specimens, the tensile 0.2% offset yield strengths varied from 60 to 62 ksi (mean = 61 ksi) and the ultimate tensile strength ranged from 76 to 82 ksi (mean = 80 ksi). In comparison, plate test data from the mill certification (Table 2) showed a 0.2% offset yield stress of 51 ksi and an ultimate tensile stress of 83 ksi. The ASTM specification for ASTM A 588(15) steel used for the tensile specimens had a minimum 0.2% offset yield stress of 50 ksi and minimum ultimate tensile stress of 70 ksi. In reviewing the mill certification, note that columbium (Co) and Niobium (Nb) are two names applied to the same element.

For the ASTM A 588(15) steel, the ultimate tensile stress values for the four KTC sub-sized specimen tests and the mill certification test were close (within about 1.2 percent). KTC’s sub-sized specimens provided a higher yield stress — about 15 percent greater than that of the mill certification. KTC’s tests were run at a strain rate of about 0.079 inches/inch/minute, slightly greater than the rate specified in AASHTO T 244 (7) of 0.0625 inches/inch/minute and
substantially greater than that specified in ASTM E8 (6) of 0.015 inches/inch/minute. There is a strain rate effect on the yield strengths of steels (26). However, it is unlikely that the strain rate KTC used significantly affected the values obtained; the 0.2% offset strain rates obtained for the ASTM A 588 steel were within three percent of each other, indicating that those tests provided a very consistent result. KTC tensile test results of other sub-sized structural steel specimens at even higher strain rates showed no apparent increases in yield strengths. The low (51 ksi) 0.2% offset yield strength for the mill certification is somewhat questionable. KTC subsequently purchased a set of 2” thick ASTM A588 plates from the same steel supplier. Those had greater 0.2% offset yield stresses (58 and 61 ksi) and ultimate tensile strengths (88 and 91 ksi), respectively, for two mill certification tests.

ASTM A36 Steel — KTC tensile testing of two ASTM A 36 specimens produced 0.2% yield strengths of 54 and 60 ksi (mean = 57 ksi) and the ultimate tensile strengths were 75 and 72 ksi, respectively (mean = 73.5 ksi). In comparison, plate test data from the mill certification (Table 4 – two tests) showed 0.2% offset yield stresses of 56 and 62 ksi (mean = 59 ksi) and ultimate tensile stresses of 69 and 76 ksi (mean = 72.5 ksi), respectively. The resulting tensile data included a 0.2% offset yield stress of 60 ksi and an ultimate tensile stress of 82 ksi. The ASTM specification for the ASTM A 36(14) steel used for the tensile specimens had a minimum 0.2% offset yield stress of 36 ksi and allowable ultimate tensile stresses in the range of 58 to 80 ksi.

For the ASTM A 36 steel, the mill certificate for the two tensile tests showed a 0.2% offset yield stress variance of 10% and an ultimate tensile stress variance of 4%. Average KTC test 0.2% offset yield values differed from the average of the mill certification values by 3.4%, average KTC test ultimate tensile stress values varied by 1.3%.

Overall, average strength values of the sub-sized specimens were very close to the mill certification ones, indicating that KTC’s specimen design and test procedure could provide accurate 0.2% offset yield and ultimate tensile test values to use in identifying unknown bridge steels.

4.2.2 Field Extraction of Coupons and Tensile Testing

The Cabinet asked KTC researchers to extract coupons from four bridges for this project. Two bridges had known bridge steels and two possessed unknown steel types.

The bridges with known steel types were:

- KYTC Bridge ID 034B00104R: KY 922 — Newtown Pike over New Circle Road in Fayette County (Figure 17)
- KYTC Bridge ID 120B00035N: KY 1685 — Steele Road over Glens Creek in Woodford County (Figure 18).

The bridges with unknown steel types were:

- KYC Bridge ID 115C00001N: CR 1012 — Warsaw Branch Road over Warsaw Branch in Cumberland County (Figure 19)
- KYTC Bridge ID 077C00053N: CS 1002 — Conley Street over State Road Fork in Magoffin County (Figure 20).

All of the bridges are deck girder structures having welded plate girders. KTC personnel extracted steel coupons from two beams on each bridge. Prior to coupon extraction, XRF tests were performed on the candidate beams to verify the steel type was consistent (see below). This ensured that the coupons’ strengths would be representative of the I-beams, thus helping to confirm that the steel type used in the beams throughout the bridges was consistent.

Flange thicknesses on all bridges were less than 1”, allowing for cuts normal to the flanges. The back face of the guide when clamped to the flanges facilitated the perpendicular cut (Figure 21). Once the plunging cut was made parallel to the edge of the flange, taper cuts were made at both ends with the grinder/cutting disc (Figure 22). A reciprocating saw was used to finish cutting off the coupon, and a die grinder was used to smooth the transition between the cuts (Figures 23a and b). A flapper disc was fitted to the grinder to clean up the freshly cut surfaces on the flanges, and then the cut surface was painted to prevent future corrosion (Figure 24a and b). Extracted coupons were taken to the UK Physics Department machine shop to produce the sub-sized tensile specimens (Figure 25).
Two or three tensile specimens were produced from each coupon. The gage section diameter of each specimen was measured by KTC to three decimal places. This information was programmed into the tensile test machine workstation for each test. Tests began with the KY 922 (Fayette Co.) bridge steel. Across the six tensile tests run for that bridge steel, the crosshead rate varied from 0.08 in./min to 0.25 in./min with no apparent effect on the 0.2% offset yield stress values. Therefore, the latter strain rate was used for remainder of the tensile testing. Test data were recorded by the workstation for each test and 0.2% offset yield, and ultimate tensile stress values are provided in Table 4.

4.3 Identification of Steel Chemistry

KTC used a handheld portable XRF unit (DELTA (Olympus) Professional Alloy Plus Analyzer) in previous evaluations of bridge steel chemistry (4, 5). The unit was obtained several years before this study began and had been successfully used to identify ASTM-specified structural steel alloys on several projects. The unit’s portability, ease and speed of testing, ability to test a range of elements critical to structural steels, and capacity to immediately read test results and store them for future retrieval were features that motivated its use for both field and laboratory tests.

4.3.1 Laboratory Tests to Evaluate XRF Performance

The structural steel plates meeting ASTM A36/A709(16A)36/AASHTO M270(15)36 and ASTM A588(15)/A709(16A)50W/ASTM A588-A/B that KTC acquired served as sources for initial laboratory tensile tests and comparative testing of spectrogrophic analyses by the KTC XRF unit, arc spark spectroscopy using an AMTEK Spectrotest TXC03, and laser-induced breakdown spectroscopy using a LIBS (Sci-Aps Model Z 200). While the KTC DELTA XRF readings compared well to the mill certifications, a problem became evident with the unit after performing the field testing that required it to be returned Olympus for repairs. A substitute laboratory XRF unit, a Panalytical Zetium DY2013, at the KYTC Division of Materials was used to repeat the XRF test series, including both the laboratory and field steel samples. In the past, the KTC DELTA analyzer had been loaned to the Division of Materials for comparison testing when the Division acquired its unit. At that time, Division of Materials personnel noted the test results of the two units compared well.

Samples of the two steels were sent to a test consulting firm for the arc-spectroscopic testing and to Sci-Aps, Inc. for the LIBS testing. Tables 2 and 3, respectively, detail the mill certifications for the mechanical properties of the two steels and their chemistries. Based on information from several major steelmakers, the mill certification chemistries could have been taken by several methods, though one representative of a major steelmaker said that their firm used the OES method. Comparative chemistry results of the two outsourced tests and the KYTC Division of Materials XRF tests are provided in Tables 5 (ASTM A36 steel) and 6 (ASTM A588 steel) along with those of the mill certifications. Each method was used to test two pieces of the same steel type. Results were averaged and are provided in the two tables. To perform correlations, mill certification values for ASTM A 36 and A 588 were chosen as the reference standards. Average test values for each element were correlated between the various test methods. A half point was awarded to each method which detected an element in the mill certifications and another half point was awarded if the weight percentages from the mill certification and the test methods agreed within 50 percent. For the ASTM A 36 steel, the mill certification correctly identified 15 out of 16 elements; it did not provide a value for iron. The XRF had 10 out of 16 potential correlations, the arc-spectroscopy 14 out of 16, and the LIBS 10 out of 16. Where the three methods detected an element provided by the mill certification, weight percentages were usually close to the mill values. For iron, the weight percentages detected by the XRF and arc-spectroscopy were close, while no value was provided by the mill certifications or the LIBS. For the ASTM A 588 steel, the mill certification identified 14 out 15 elements. For that steel, boron was not detected or provided by the mill certification or the test methods. The XRF detected 11 out of 15 potential correlations, the arc-spectroscopy 14 out of 15, and the LIBS 11 out of 15. Again, the XRF and arc-spectroscopy were close in weight percentages of iron that were not provided by the mill certification or detected by the LIBS.

The results indicated some differences in the elements detected due to test limitations of the various units. The arc-spark spectroscopy detected the greatest range of elements and the method used is probably similar or identical to the one that provided the results in the mill certifications. All of the test methods provided similar results within the limitations of their testing capabilities over the potential range of elements in the steels. The laboratory XRF unit is sufficiently accurate to detect most of the elements in steel for purposes of characterizing and potentially identifying related steel specifications. However, the XRF and LIBS methods have the advantage of being performed using handheld portable units, which can be used for in-situ field testing.
4.3.2 Field Tests Using XRF

Before identifying a potential problem with the DELTA XRF unit, KTC researchers used the device in the field to analyze the chemistries of the known and unknown bridge steels. The surface flanges of sampled I-beams were ground and solvent wiped to remove paint and other surface contaminants before performing the XRF tests (Figures 26a and b). KTC researchers evaluated field data to ensure that the chemical compositions of the I-beams used for coupon extractions had similar chemical analyses. As noted, an issue with the DELTA unit prompted KTC to obtain laboratory XRF analyses of steel samples using the KYTC Division of Materials laboratory XRF analyzer. Table 7 summarizes the laboratory XRF chemical analyses of the steels from the four bridges having known or unknown steel types. The bridge steel samples used for those tests came from pieces of tensile test specimens. Those pieces did not properly fit into the laboratory XRF analyzer and KTC had to heat them to a high temperature (about 1300 °F) to reshape them so they would fit properly into the XRF unit. After doing so, the XRF unit detected a small amount of tungsten that might have been contamination from the KTC shaping process. Its presence was noted in all of the bridge samples indicating that it was likely from an extraneous source rather than the steel itself. Subsequent re-testing of unprocessed tensile specimen pieces using the repaired KTC XRF unit did not detect any tungsten. Its trace presence is still noted in Table 7.

4.4 Development of Computer Program to Identify Steels By ASTM/AASHTO Standard Specifications

One project task was the development of a computer program correlate to ASTM/AASHO/AASHTO steel specifications with tensile test and chemistry data from unknown bridge steels. KTC researchers found that several spectrographic analyzers equipped with software that enabled limited correlations with standard specification metal alloys based on the chemistries identified. While KTC’s DELTA XRF analyzer had that capability, due to software limitations, it is not suited for categorizing standard structural steels. Researchers worked to address this capability by creating a PC database management program. In doing so, they encountered several issues that complicated the level of correlations they sought. Software program development is discussed below along with relevant factors. This discussion clarifies the capabilities and limitations of the program for identifying standard (ASTM/AASHO/AASHTO) steel specifications using available parameters, including test results for steel tensile and chemistry properties.

4.4.1 ASTM/AASHO/AASHTO Current/Past Specifications Related to Common Bridge Steels

When this project began, a listing of standard ASTM/AASHO/AASHTO steel specifications was found in the AISC document (op. cit. 1). KTC researchers then learned that the FHWA was starting work on a compendium of bridge steels. They offered to assist the FHWA with that task, but for the duration of this project FHWA did not actively pursue the initiative and KTC proceeded on its own to address that effort within the scope of this project. KTC based its work on the AISC document and sought copies of ASTM structural steel specifications from the UK Engineering Library and, thereafter, libraries throughout the US through interlibrary loans. This included all types of structural steels along with subsequent revisions. After that effort was completed, ASTM was approached by KTC researchers seeking missing revisions were identified in subsequent document revisions (as ASTM had identified the previous revision in succeeding ones). ASTM had outsourced document sales of outdated standards. However, KTC determined that the supplier did not have all of the steel specification revisions. KTC contacted ASTM and located a few additional revisions through them. However, several older revisions were not found. For the period covered (1900-2016), most of the available specifications had chemistries and tensile mechanical properties that bridged the missing ones.

At the end of the specification search, KTC had acquired 70 ASTM specifications/revisions. While not 100 percent complete, most of the ASTM specifications for structural steels of potential interest were obtained by the Center. Those provided comparative steel chemistries and tensile mechanical properties needed to create a database to correlate unknown bridge steels with standard ASTM/AASHO/AASHTO steel specifications.

Very late in the project, KTC researchers discovered that ASTM steel specifications were used as tentative standards prior to their formal adoption (termed interim standards by AASHO/AASHTO). For example, the ASTM A 36 Carbon Structural Steel specification was available as a tentative standard in 1960, but the initial formal version was not standardized and adopted until 1962. KTC compared dates of bridge construction with ASTM/AASHO/AASHTO specifications (and revisions) based upon the year of their formal adoption. KTC was not certain if the Cabinet had ever built bridges using tentative specification steels. Unfortunately, this discovery was made too late to be incorporated in the KTC database management program.

4.4.1.1 Mechanical Properties In ASTM/AASHO/AASHTO Structural Steel Specifications
Issued in 1900, the first ASTM bridge steel specification was A7 (Standard Specifications for Structural Steel for Bridges). It contained specifications for yield strength (point) and ultimate tensile strengths for rivet steel, soft steel, and medium steel. All succeeding ASTM/AASHO/AASHTO structural steel specifications contain mechanical properties, including engineering yield and ultimate tensile strengths. As noted, KTC used only steel 0.2% offset yield strengths and ultimate tensile strengths as the mechanical properties for attempting to classify unknown steels as ASTM/AASHO/AASHTO standard specified types. Typical engineering mechanical properties in those specifications also included total elongation (based on standard specimens). In later specifications, reduction-in-area (based on standard specimens) and hardness values were sometimes provided. Elongation and reduction-in-area were not employed in the correlation software prepared by KTC due to the use of sub-sized specimens. KTC did not use hardness test values, although hardness values could be used if coupons cannot be cut from structural members. ASTM tables enabled the conversion of hardness values to ultimate tensile strengths, although they would not produce accurate yield strengths.

In ASTM/AASHO/AASHTO specifications, yield and ultimate tensile strengths were usually specified as minimum values. Some early ASTM standards, however, specified ranges for both yield and ultimate tensile strengths. In those cases, yield points were sometimes specified as a percentage of ultimate tensile strengths, providing potential ranges for those as well. In KTC’s software, where applicable, ranges for yield points and tensile strengths were used for correlation purposes. In all the other cases, yield point and ultimate tensile strengths were considered valid correlations when the KTC test values exceed the minimums found in ASTM/AASHO/AASHTO specifications.

In the 1905 ASTM specification for A7 (Standard Specification for Structural Steel for Bridges) yield strengths were based on dropping the test machine beam as the load was applied. According to that specification, yield strength was to be noted, but unlike the ultimate tensile strength, no quantitative value was specified. KTC researchers did not determine when ASTM began specifying the 0.2% offset yield strength, but continued to provide yield values termed yield point in the steel specifications based on different test criteria.

In later ASTM/AASHO/AASHTO specifications, provisions were made for reduced mechanical properties due to increased thickness of plates and other shapes and sizes of rolled beams. Additional datasets were needed for each specification revision where those accommodations were made.

4.4.1.2 Chemical Properties In ASTM/AASHO/AASHTO Structural Steel Specifications

The 1905 ASTM A7 specification included the first chemistry requirements in the form of maximum content limitations on phosphorous and sulfur expressed as a percentage weight of the steel. In 1949, copper was added to ASTM A7 as a minimum content (when specified by the user). In 1958 ASTM A373 (Structural Steel for Welding) was introduced as the first structural steel that limited carbon content and had a required range for manganese. With the advent of newer alloys, more alloying elements were specified along with required minimums, maximums, or ranges, all given in weight percentages. To date, alloying elements addressed in the various structural steel specifications have included carbon, manganese, phosphorous, sulfur, silicon, copper, vanadium, columbium, nitrogen, chromium, nickel, zirconium, titanium, molybdenum, boron, and aluminum.

In addition, changes were sometimes made in steel chemistries for increased section types, thicknesses, and specific grades within a specification/revision related to steel types from various manufacturers. Those needed to be noted and accounted for in the KTC software. As a consequence, all the ASTM/AASHO/AASHTO specifications/ revisions that KTC obtained resulted in nearly 550 datasets to correlate with field/laboratory test data and provide specification correlations. Those data encompassed most, but not all, past ASTM/AASHO/AASHTO specifications through 2016.

4.4.2 KTC Software Program for Performing Steel Correlations

Work progressed in compiling the ASTM/AASHO/AASHTO structural steel specification spreadsheet, providing the range of years that specifications were valid, minimum or range of yield strengths (points), minimum or range of ultimate tensile strengths, and minimum/maximum/ranges of alloying elements (as previously noted). A database management system, KYTC Analysis of Steel, was developed by KTC to correlate unknown steel data with each specification and seek viable matches.

To facilitate use of the database a simplified front end was developed for data entry (Figure 27). The data entries are:
- Bridge name (includes route number and KYTC bridge number) and location (county and feature(s) spanned)
- Date of construction
- Material type (plate, bar, or shape)
- Thickness (in.)
- Yield point/strength (psi)
- Tensile strength (psi)
- Chemical makeup (% by wt.)
  - Carbon
  - Manganese
  - Phosphorous
  - Sulfur
  - Copper
  - Vanadium
  - Columbium
  - Nitrogen
  - Chromium
  - Nickel
  - Zirconium
  - Titanium
  - Molybdenum
  - Boron
  - Aluminum

For the chemical compositions, other elements might be present. However, they were not provided in any ASTM/AASHO/AASHTO specification (at least the ones that KTC obtained) and, therefore were not included for consideration in the database. In addition, a checkbox is provided for the program to ignore data entry boxes where chemical testing indicated some elements were not detected. A query button is provided to run the database program and produce correlations with the list of ASTM/AASHO/AASHTO specifications in the KTC-compiled dataset. A refresh button is also included to reset the program form to prepare for another data entry. The program will provide a listing of potentially applicable specifications along with the number of entries that matched those in a particular specification (e.g., 4 out of 6 if 4 out of 6 entries matched specification data).

To test the correlation capabilities of the database, tensile strength and alloying data for the ASTM/AASHTO steel mill certification of the steel supplied to meet ASTM A36(14)A709(16) AASHTO M270(15)36 as shown in Table 3 was entered into the database with the resulting output shown in Figure 28. Year of purchase was used as the year of construction. The database returned the highest correlations with the ASTM A709(16) for grades 36 and 50S which is the steel type shown (4 out of 4 items for grade 36 steel and 10 out of 12 for type 50S steel). The steel was purchased from a steel warehouse that probably furnished the higher-grade product as it also met the ASTM A36 standard. They probably supplied the qualifying steel that they had on stock. That assumption seems to be borne out by the high yield strengths for the material shown in the mill certification, which would meet ASTM A572 requirements.

The ASTM/AASHTO steel mill certification of the steel supplied to meet ASTM A588 as shown in Table 2 was entered into the database with the resulting output shown in Figure 29. The database management program did not meet the requirements for ASTM A588 Types A and B steels listed on the mill certification. Inspection of the KTC-prepared steel specification spreadsheet revealed that the certification chemistry for manganese and titanium were slightly high (for manganese 1.29 wt. % vs. a maximum of 1.25 wt. % and for titanium 0.101 wt. % vs. a maximum of 0.100 wt. %). It is believed that there are some tolerances for steel chemistries. By the time this issue arose, it was too late in the project to modify the program to address it. By slightly changing the database to meet the allowable limits for those two elements, the program provided the output shown in Figure 30. The program identified the ASTM A588 Types A and B weathering steels with a high degree of correlation (13 out of 13 items).

4.5 Validation of Test Procedure
The test procedure for identifying unknown bridge steels involves:
1) Testing the steel chemistry of bridge flanges (assuming girder/beam bridges are candidates) using a laboratory XRF analyzer,
2) Measuring flange thickness,
3) Extracting representative steel coupons from bridge flanges,
4) Tensile testing of sub-sized coupons to determine steel 0.2% yield strength and ultimate tensile strength,
5) Obtaining the date of bridge construction (if available), and
6) Using the KTC database program, KYTC Analysis of Steel, to correlate tensile strength data, steel chemistry data, and other relevant parameters (e.g., date of construction, material thickness) to seek a best fit correlation with ASTM/AASHO/AASHTO standard bridge steel specifications.

As noted, validation testing involved two bridges with known steel types and two bridges with unknown steels. The following subsections describe these validation efforts.

4.5.1 Bridges with Known Steel Specifications

**KYTC Bridge ID 034B00104R: KY 922 — Newtown Pike over New Circle Road in Fayette County**
The steel for this bridge was identified by KYTC as ASTM A36 carbon steel. The bridge was constructed in 1964. The test sample was taken from lower flanges of a steel girder (steel plate 0.938” thick). The average 0.2% offset yield strength was 40.2 ksi and the ultimate tensile strength was 65.2 ksi (Table 4). This agrees with ASTM A36-62 (the age-appropriate variation of the specification) which specifies a minimum 0.2% offset yield strength of 36 ksi and an ultimate tensile strength in the range of 58-80 ksi. Entering the KTC average tensile strengths, section thickness, year of construction, and average steel chemistry from the KYTC XRF element data for the specimen (Table 7) into the KYTC Analysis of Steel database program returned an output for ASTM/AASHO/AASHTO structural steel specifications indicating that the steel met ASTM A36-62 (Figure 31). The steel did not possess the customary 0.2% by weight copper usually added to bridge steels to provide enhanced corrosion resistance.

**KYTC Bridge ID 120B00035N: KY 1685 — Steele Road over Glens Creek in Woodford County**
The steel for this bridge was identified by KYTC as being ASTM A7 carbon steel. The bridge was constructed in 1956. The test sample was taken from lower flanges of a steel girder (steel plate 0.625” thick). The average 0.2% offset yield strength was 40.1 ksi and the ultimate tensile strength was 58.9 ksi (Table 3). This varies slightly from ASTM A7-49 (the age-appropriate variation of the specification) which specifies a minimum 0.2% yield strength range of 33-36 ksi and an ultimate tensile strength in the range of 60-72 ksi. To test the KYTC Analysis of Steel database program for this steel, the KTC tensile data entered for ASTM A7 steels was changed by entering the KTC 0.2% offset yield strength as 36 ksi instead of the tensile test value. The KTC ultimate tensile test strengths were slightly below the minimum for ASTM A7 steels during this period (58.9 ksi vs. 60 ksi specified minimum). However, the KTC ultimate tensile test values were very consistent, with only 0.1 ksi variance across six tests. It is likely that the bridge steel was slightly below the specified minimum tensile strength for ASTM A7. Also, the ASTM A7 phosphorous and sulfur limits were changed from ladle to check analyses maximums. To accommodate the specification, KTC also entered the minimum specified ultimate tensile strength value (60 ksi) into the KYTC Analysis of Steel database program. Entering the modified strength data, section thickness, year of construction, and steel chemistry from the KYTC XRF element data for the specimens (Table 7) into the program gave an output ASTM A7-49 structural steel (Figure 32). KTC did not have any of the subsequent revisions of ASTM A7 until the last one — ASTM A7-61T — which post-dated construction of this bridge.

4.5.2 Bridges with Unknown Steel Specifications

**KYC Bridge ID 115C00001N: CR 1012 — Warsaw Branch Road over Warsaw Branch in Cumberland County**
The bridge was constructed in 1974. The test sample was taken from lower flanges of a steel girder (steel plate 0.625” thick). The average 0.2% offset yield strength of the KTC specimens was 58.3 ksi and the average ultimate tensile strength was 79.9 ksi (Table 3). This agrees with high-strength, low-alloy structural steel specifications used in the late 1960s through 1974, which specified minimum 0.2% offset yield strengths in the range of 42-60 ksi and minimum ultimate tensile strengths in the range of 60-80 ksi. Entering the KTC average tensile strengths, section thickness, year of construction, and steel chemistry from the KYTC XRF element data for the specimens (Table 7) into the KYTC Analysis of Steel database program returned an output of ASTM 441-63 structural steel (Figure 33). Note that a slight reduction in the sulfur content (from 0.645 to 0.600 % by wt.) would add ASTM A242-63 as a potential standard specification steel.

**KYTC Bridge ID 077C00053N: CS 1002 — Conley Street over State Road Fork in Magoffin County**
The bridge was constructed in 1995. The test sample was taken from lower flanges of a steel girder (steel plate 0.813” thick). The average 0.2% offset yield strength of the KTC specimens was 51.4 ksi and the average ultimate tensile strength was 72 ksi (Table 3). This agrees with high-strength, low-alloy structural steel specifications used in the late 1960s through 1974, which specified minimum 0.2% offset yield strengths in the range of 42-60 ksi and minimum ultimate tensile strengths in the range of 60-80 ksi. Entering the KTC average tensile strengths, section thickness, year of construction, and steel chemistry from the KYTC XRF element data for the specimens (Table 7) into the KYTC Analysis of Steel database program gave outputs of both ASTM A529-92 and A572-92a steels (Figure 34). As ASTM A572 is the more common structural steel than the other types identified by the program, it is the type likely used in this bridge.
5. Discussions/Conclusions

The methods put forward in this report can help transportation agency personnel identify properties of unknown bridge steels, especially on deck girder bridges. KTC’s approach for determining yield and ultimate tensile strengths involves extracting coupons from bridge flanges, subjecting them to elemental analyses, and performing tensile tests on sub-sized specimens cut from the coupons. The size of the sub-sized tensile specimens is small enough to limit coupon size and resultant strength losses in the girders/beams from which they are taken. Specimens are large enough to provide accurate 0.2% offset yield and ultimate tensile strengths. Unfortunately, their small size precludes acquiring elongation or reduction-in-area data that can be compared to ASTM/AASHO/AASHTO steel specifications, which are based on larger specimens. Those values are size dependent, and large coupons might compromise structural integrity.

Steels used on other bridge types — including steels from fracture-critical members — can be analyzed both in-situ and using KTC’s couponing approach. However, those applications will require a joint KYTC/KTC review to identify the best testing method.

For tensile testing, the UK laboratory acquired a new tensile testing unit that was used for most of the work. Due to technician unfamiliarity with the equipment, the strain rate used for the tests exceeded the limits set by both ASTM E8 and AASHTO T244 for determining the 0.2% offset yield stress. This may have elevated the yield stress values slightly, but did not impact values for ultimate tensile stresses. The only case where it apparently made a difference was in testing the ASTM A7 steel from the Woodford County bridge. There, the yield stress exceeded the allowable range set by ASTM A7-49. However, the resulting ultimate tensile strength values for those tests were very consistent and slightly below the minimum specified value. In any case, allowances were required for the KYTC Analysis of Steel database program to identify the appropriate ASTM steel specification. In the future, KTC will take care to apply the proper tensile test procedure outlined in AASHTO T244.

Along with providing basic engineering properties and steel chemistries, KTC assembled in an Excel spreadsheet a detailed catalogue of ASTM/AASHO/AASHTO steel specifications dating from about 1900 through 2016. That compilation was made as complete as possible given funding and time constraints imposed by the study work plan. While much of that work is not presented here, it constitutes the largest effort associated with this study. KYTC will receive a copy of the spreadsheet, which it can use to evaluate the properties of steels meeting ASTM/AASHO/AASHTO specifications, or conversely identifying ASTM/AASHO/AASHTO specifications of steels given specific chemistries or tensile strength properties. In using the spreadsheet, it is helpful to have the year of construction as well as the type/thickness of the structural component of interest to eliminate extraneous specifications that are either too old or that post-date the year of construction and which were obviously not available for use at the time of construction (with the exception of tentative specifications).

KTC also developed a database management program to take available bridge data from coupon extraction and tensile testing along with construction year (if available) and type/thickness of the structural component (e.g., a plate if extracted from the flange of a welded girder). The database, while potentially beneficial, has some issues that were only discovered at the end of the project and could not be resolved. It can be useful, but requires some knowledge of the spreadsheet from which data for the database management program is taken. Several shortcomings relate to basic function of the database which were not resolved by KTC researchers. Two issues with the data pertain to: 1) the use of the date of issuance of a specification, as ASTM sometimes allowed provisional use of specifications several years prior to their formal implementation (as noted in Table 1 provided by the FHWA), and 2) tolerances in steel chemistry, a subject which was not addressed by KTC. To improve the accuracy of database outputs, the database functionality and data set need to be addressed. The scope of that effort has proved beyond the scope this study.
6. Recommendations

1. When KYTC needs to identify a steel, it should implement KTC’s approach to analyze steel properties and standard type. Additionally, the Cabinet will benefit if KTC performs coupon extraction, composition analysis, and tensile testing. Because KTC researchers are also familiar with the database management program, ideally, they should be called upon to use the program to identify the best fit ASTM/AASHO/AASHTO specifications based on available data.

2. The KYTC Analysis of Steel database management program has some utility when used by KTC researchers familiar with its limitations. The program has considerable promise but needs further development. As the program potentially has national benefit, its development should be sponsored by an agency outside of KYTC (e.g., FHWA, AASHTO).
7. References


16. ASTM A 370-6 “‘Standard Method of Test for Mechanical Testing of Steel Products,” Table 2 Approximate Hardness Conversion Numbers for Non austenitic Steels (Rockwell C to Other Hardness Numbers) and Table 3 Approximate Hardness Conversion Numbers for Non austenitic Steels (Rockwell B to Other Hardness Numbers), 2006.


8. Tables
Table 1 Table of common ASTM and AASHO/AASHTO structural steel specifications (taken from Table 1 in Reference 2)

<table>
<thead>
<tr>
<th>ASTM Specification</th>
<th>Year of First Tentative Draft or Adopted by ASTM</th>
<th>Year Withdrawn by ASTM</th>
<th>Equivalent AASHO/AASHTO Material Specification</th>
<th>Year First Published by AASHO/AASHTO</th>
<th>Year Withdrawn by AASHO/AASHTO</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 7</td>
<td>1901</td>
<td>1966</td>
<td>M 94</td>
<td>1939</td>
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<td>1912</td>
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<td>M 96</td>
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<td>M 95</td>
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<td>1966</td>
<td>M 165</td>
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<td>M 188</td>
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<td>M 270</td>
<td>1977</td>
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</table>

a Exact year of withdrawal not identified. It was published in the 1966 9th Edition Standard Specifications for Highway Materials and Methods of Sampling and Testing; however, it was not published in the 1971 10th Edition, nor reported in the 10th Edition when it was withdrawn. In 2000, AASHTO discontinued all their individualized steel material specifications except for M 270.

Table 2 Mill certification for ASTM A588 steel plate used in laboratory procedure evaluation tests. Note Cb was the periodic chart symbol for columbium. The current symbol is Nb.
Table 3 Mill certification for ASTM A36 steel plate used in laboratory procedure evaluation tests. Note Cb was the periodic chart symbol for columbium. The current symbol is Nb.
Table 4 Known and unknown steels extracted from bridge beams
<table>
<thead>
<tr>
<th>Known Steels</th>
<th>Route – Location</th>
<th>Year Built</th>
<th>I-beam Depth (in.)</th>
<th>Flange Width (in.)</th>
<th>Flange Thick. (in.)</th>
<th>Beam Number</th>
<th>0.2% Yield Stress (ksi) Avg. {Range (ksi)}</th>
<th>Ult. Tensile Stress (ksi) Avg. {Range (ksi)}</th>
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<td>034B00104R</td>
<td>KY 922 – Newtown Pike over New Circle Road in Fayette County</td>
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<td>35-5/8</td>
<td>12</td>
<td>15/16</td>
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<td>40.6 [38.9-41.7]</td>
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<td></td>
<td></td>
<td>2</td>
<td>39.7 [38.9-40.7]</td>
<td>64.9 [64.9 x 3 tests]</td>
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<td>Avg.</td>
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<td>5/8</td>
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<td>58.9 [58.8, 58.9]</td>
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<td>39.2 [38.4, 39.9]</td>
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Table 5 Comparative test results for XRF (KTC), arc spectroscopy and laser-induced spectroscopy (LIBS). Samples 1 & 2 are ASTM A36 steel

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<th>%Co (Nb)</th>
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Table 6 Comparative test results for XRF (KTC), arc spectroscopy and laser-induced spectroscopy (LIBS). Samples 3 & 4 are ASTM A588 steel

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<td>%Co (Nb)</td>
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Table 7: Steel elements from actual bridge beams of known and unknown compositions from KYTC laboratory XRF tests.
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**Unknown Steels**

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9. Figures
Figure 1 DELTA Portable XRF Analyzer. Note the LCD screen on the back face of the instrument that displays elements present and their concentrations by percent weight.

Figure 2 Instron 3382 electro-mechanical universal testing machine with round tensile specimen mounted. Note the load cell attached to the cross-head above the specimen (arrow).
**Figure 3** Sub-sized rectangular tensile test specimen with a constant thickness (dimensions in inches)

![Sub-sized rectangular tensile test specimen with a constant thickness](image)

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**Figure 4** Typical software output data from a computer linked to a universal testing machine

![Typical software output data](image)
Figure 5 Typical stress-strain curve showing the yield strength at 0.2 percent strain offset

Figure 6 ABI Services Automated Ball Indentation® tester being used to evaluate an eyebar pin on a railroad bridge
Figure 7 Subcompact tensile specimen used by KTC. Dimensions are in inches.

Figure 8 Proposed coupon extraction (looking at half-section of I-beam)
Figure 9 Guide used to make angled cut in flange replica

Figure 10 Operator using guide to make proper angled cut into the flange replica
Figure 11 Smoothing the cut surface of the flange replica cut using (a) grinding disc (b) deburring bit

Figure 12 Tensile specimens from coupon and threaded grips for mounting in tensile testing machine
Figure 13 Specimen cross-section measurement in the gage area

Figure 14 A one-inch extensometer attached to a tensile specimen on the Instron test machine
Figure 15 A workstation used to control tensile tests, log test data and display resulting force/deflection and resulting stress/strain outputs

Figure 16 Tensile specimen pulled to failure.
Figure 17 KY 922 - Newtown Pike over New Circle Road in Fayette County.

Figure 18 KY 1685 – Steele Road over Glens Creek in Woodford County.
Figure 19 CR 1205 Warsaw Branch Road over Warsaw Branch in Cumberland County.

Figure 20 CR 1002 Conley Street over State Road Fork in Magoffin County.
Figure 21 Guide clamped to a flange for a perpendicular cut.

Figure 22 Use of the guide to make a plunging cut into a flange using a grinder and cutting disc.
Figure 23 Finishing coupon extraction (a) completing taper cut with a reciprocating saw; (b) smoothing cut intersections with a die grinder.

Figure 24 Cleaning cut surface of flange (a) using grinder with flapper disc to remove sharp edges (b) cut area of flange after painting.
Figure 25 Coupon extracted from a bridge flange.

Figure 26 Grinding a flange for XRF testing; b) Performing XRF testing.
Figure 27 Database front end for entering available data for unknown structural steels.

Figure 28 Structural steel specifications that the database correlated with the ASTM A 36 steel certification data from steel purchased by KTC.

Figure 29 Applicable structural steel specifications that the database correlated with the ASTM A 588 steel certification data from steel purchased by KTC using ASTM specification limits.
Figure 30 Applicable structural steel specifications that the database correlated with the ASTM A 588 steel certification data from steel purchased by KTC using slightly modified mill certification values to match ASTM limits for manganese and vanadium for A 588 Types A and B steels.

Figure 31 Applicable structural steel specifications that the database correlated with ASTM A 36-62 steel from KY 922 – Newtown Pike over New Circle Road in Fayette County.
Figure 32 Applicable structural steel specifications that the database correlated with ASTM A 7-49 steel from KY 1685 over Glens Creek in Woodford County.

Figure 33 Applicable structural steel specifications that the database correlated with ASTM A 441-63 steel from CR 1012 Warsaw Branch Road over Warsaw Branch in Cumberland County.

Figure 34 Applicable structural steel specifications that the database correlated with ASTM A 572-92a steel from CR 1012 Warsaw Branch Road over Warsaw Branch in Cumberland County.
Determination of Structural Steel Properties/Probable ASTM Steel Type Identification: KY 2212 over Pawley Creek in Hardin County (Bridge 047B00134N)
Determination of Structural Steel Properties/Probable ASTM Steel Type Identification: KY 2212 over Pawley Creek in Hardin County (Bridge 047B00134N)

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Program Manager

Theodore Hopwood, P.E.
Research Engineer

and

Christopher Goff
Transportation Technician

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

In Cooperation With
Kentucky Transportation Cabinet
Commonwealth of Kentucky

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May 2019
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Introduction
The KY 2212 bridge over Pawley Creek in Hardin County (047B00134N) has a superstructure consisting of six rolled beams whose type and mechanical properties were both unknown (Figure 1). The beams are 18” deep with 71/2” wide flanges that are 1/2" thick (Figure 2). On April 17, 2019, Kentucky Transportation Center (KTC) researchers performed site work to help the Kentucky Transportation Cabinet (KYTC) determine the elemental and mechanical properties of the beam steel and find a best match with ASTM standard steels. Researchers performed onsite elemental identification and extracted steel samples from the beams. Thereafter, the samples were taken to the University of Kentucky, machined into test specimens, and subjected to tensile loading to failure to determine their mechanical properties (i.e., yield and ultimate strengths). The elemental and mechanical properties were compared with similar ASTM specifications for structural steels to determine the best match(es).

Element Testing
X-ray fluorescence testing (XRF) was performed on the steel beams to determine their elemental content. This method is widely used in the identification of alloy steels. Its main limitation is it cannot identify elements with atomic numbers below 11 (sodium). It also cannot detect or quantify the presence of carbon (atomic number 12) in the low percentages typical of structural steel. Most structural steels limit carbon to about 0.30% or less, and accurate determination of carbon in those steels is not usually a concern unless addressing welding or fracture toughness issues.

To perform the testing, surfaces on the top faces of the lower flanges of Beams 1 (referred to as West End) and 6 (referred to as East End) were prepared by power tool grinding with abrasive disc. They were then wiped with lacquer thinner to remove residual soils. This established a flat shiny metallic surface suitable for XRF testing. Researchers used an Olympus DELTA Profession handheld XRF analyzer. The device uses an atomic source to provide radiation that stimulates atoms in the test material and produces secondary or fluorescent X-rays that can be analyzed for energies typical of the atoms present in that material.

Four XRF tests were performed on Beam 1 and eight tests were conducted on Beam 6 (Figure 3). Prior to testing, a preliminary calibration was run on a Type 304 stainless steel reference standard. The DELTA Professional XRF analyzer will not run unless the alloy reading matches a value previously stored in its memory. For all of the XRF tests, the primary elements identified were manganese (Mn), ranging from 0.89% to 1.00%; silicon (Si), ranging from 0.33% to 1.09%; chromium (Cr), ranging from 0.029% to 0.049%; nickel (Ni), found in 8 of 12 tests and ranging from 0.08% to 0.12%; and cobalt (Co) found in 5 of 12 tests and ranging from 0.54% to 0.70%. Lead (Pb) and zinc (Zn) were found in several tests and are probably associated with bridge paint. Some of the surfaces had a few pits that may have trapped those elements. Sulphur (S) and phosphorous (P) were below the XRF analyzer’s limits of detection (~0.01%). A sample printout from the analyzer is shown in Appendix A. The analyzer can match the reading with pre-stored alloys (ferrous and non-ferrous) housed in its memory. In this case, its matching algorithm matched this set of readings with a carbon steel. In 10 of the 12 tests, where matches were made, the analyzer identified the test materials as a carbon steel. The analyzer also has a camera mounted on the test aperture that stores an image of the test surface when the reading is taken. The image shows an adjacent pit that may have impacted the test reading. A box in the printout also includes the breakdown of the intensity readings for the XRF related to the characteristic energy levels for specific elements. The major peak indicates iron (Fe) with the shorter peaks related to alloying elements in the steel. Due to the sporadic detection of cobalt and nickel in the tests, it is assumed these are probably tramp elements in the steel.

Mechanical Testing
To assess the steel’s mechanical properties, ~1” x ~7” x 1/2” samples were cut from the lower flanges of Girders 1 and 6 about 12” from an abutment (Figure 4). The ends of the cuts were angled and the intersections of the cuts rounded by grinding and subsequently painted (Figures 5 and 6). The extracted samples were machined to form 12 cylindrical test specimens (Figure 7).

Tensile tests were performed on a 22,500-lb. capacity Instron 3382 electromechanical universal test machine at the University of Kentucky College of Chemical and Materials Engineering laboratory (Figure 8). A 1.00” gage length extensometer was attached to a test specimen to enable accurate determination of the 0.2% offset yield strength (Figure 9). A workstation connected to the extensometer and the tester controlled the loading process, indicating when that yield strength was achieved (Figure 10). It also logged the load/strain/crosshead movement data and provided a stress/strain/deflection plot in real time. After a specimen yielded, the test was temporarily halted to remove the extensometer. Thereafter, the specimen was pulled to failure (Figure 11).
A typical test data output from the universal test machine workstation is shown in Appendix B. The deflection scale on the stress/strain curve plot is not accurate because the actual specimen gage length is 1.25” rather than 1.00”, which was used for the extensometer readings to determine the 0.2” offset yield strain. The specimen size used by KTC is a non-standard (2” or 8” gage lengths are typical). While that gives the same tensile yield and ultimate stresses for a steel as the larger specimens, the elongation values will be higher. However, elongation is typically not a relevant parameter for our purposes in classifying structural steels, or in providing information used by structural engineers for design/ remediation/load rating purposes.

The tensile strengths of the steel are provided in Table 1. The range of the test values were within acceptable limits and the average values of the tensile yield and ultimate strengths (48.86 and 72.98 ksi).
Table 2: Tensile Properties of Beam Steel — Hardin County 047B00134N Over Pawley Creek in Hardin County

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tensile Yield Stress  (ksi at 0.2 % offset)</th>
<th>Tensile Stress At Maximum Force (ksi)</th>
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<tbody>
<tr>
<td>Beam 1 west end-1</td>
<td>49.45</td>
<td>73.63</td>
</tr>
<tr>
<td>Beam 1 west end-2</td>
<td>48.67</td>
<td>72.31</td>
</tr>
<tr>
<td>Beam 1 west end-3</td>
<td>48.37</td>
<td>73.1</td>
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<tr>
<td>Beam 1 west end-4</td>
<td>48.21</td>
<td>73.37</td>
</tr>
<tr>
<td>Beam 1 west end-5</td>
<td>48.98</td>
<td>73.78</td>
</tr>
<tr>
<td>Beam 1 west end-6</td>
<td>48.81</td>
<td>72.19</td>
</tr>
<tr>
<td>Beam 6 east end-1</td>
<td>50.46</td>
<td>73.43</td>
</tr>
<tr>
<td>Beam 6 east end-2</td>
<td>49.59</td>
<td>72.06</td>
</tr>
<tr>
<td>Beam 6 east end-3</td>
<td>48.47</td>
<td>72.14</td>
</tr>
<tr>
<td>Beam 6 east end-4</td>
<td>49.73</td>
<td>72.79</td>
</tr>
<tr>
<td>Beam 6 east end-5</td>
<td>47.88</td>
<td>73.83</td>
</tr>
<tr>
<td>Beam 6 east end-6</td>
<td>47.78</td>
<td>73.24</td>
</tr>
<tr>
<td><strong>Avg.</strong></td>
<td><strong>48.86</strong></td>
<td><strong>72.98</strong></td>
</tr>
<tr>
<td><strong>Max. Value</strong></td>
<td><strong>50.46</strong></td>
<td><strong>73.83</strong></td>
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</table>
Matching of Test Data with Standard ASTM Structural Steel Types

Mechanical Properties
The tensile properties of steel specimens from the bridge test data potentially fall into the ranges for both carbon and high-strength low-alloy (HSLA) steels for rolled structural shapes (beams). The potential carbon steels match ASTM A7, A373 and A36 while the HSLA steels include ASTM A 242, A440, A441, A572 and A588.

A review of the tensile strengths for those steels in rolled shapes is as follows:

ASTM A7 – the specified tensile yield strength is 33 ksi (min.) and the ultimate strength ranges from 60 to 75 ksi (although higher values may be acceptable).

ASTM A373 – the specified tensile yield strength is 32 ksi (min.) and the ultimate strength ranges from 58 to 75 ksi (although higher values may be acceptable).

ASTM A36 – the specified tensile yield strength is 36 ksi (min.) and the ultimate strength ranges from 58 to 80 ksi (although higher values may be acceptable).

ASTM A242 – For Groups 1 and 2 structural shapes, the specified tensile yield strength is 50 ksi (min.) and the ultimate strength is 70 ksi (min).

ASTM A440 – For Group 1 structural shapes, the specified tensile yield strength is 50 ksi (min.) and the ultimate strength is 70 ksi (min).

ASTM A441 – For Groups 1 and 2 structural shapes, the specified tensile yield strength is 50 ksi (min.) and the ultimate strength is 70 ksi (min).

ASTM A572 – For Groups 1 and 2 structural shapes, the specified tensile yield strength is 60 ksi (min.) and no ultimate strength is listed.

ASTM A588 – For all structural shape Groups, the specified tensile yield strength is 50 ksi (min.) and the ultimate strength is 70 ksi (min).

Alloy Compositions
A review of the typical alloy compositions specified for those steels in rolled shapes is as follows:

ASTM A7 – the specified alloy limits are 0.33% (max.) C, 0.04% (max.) P, and 0.05% (max.) S. All other potential alloying elements in the steel (Mn, Si, Ni, Cr, Co, etc.) are not listed and may be present as tramp elements from scrap steel. Cu may be present when specified.

ASTM A373 – the specified alloy limits are 0.30% (max.) C, 0.04% (max.) P, and 0.05% (max.) S. All other potential alloying elements in the steel (Mn, Si, Ni, Cr, Co, etc.) are not listed for Group 1 and 2 structural shapes but may be present. Cu may be present when specified.

ASTM A36 – the specified alloy limits are 0.33% (max.) C, 0.04% (max.) P, and 0.05% (max.) S. All other potential alloying elements in the steel (Mn, Si, Ni, Cr, Co, etc.) are not listed for Group 1 and 2 structural shapes but may be present. Cu may be present when specified.

ASTM A242 – the specified alloy limits for Type 1 alloy are 0.15% (max.) C, 0.15% (max.) P, 0.05% (max.) S, 1.00% (max.) Mn, and 0.20% (min.) Cu. The specified alloy limits for Type 2 alloy are 0.20% (max.) C, 0.04% (max.) P, 0.05% (max.) S, 1.35% (max.) Mn, and 0.20% (min.) Cu. For the Type 2 Alloy, Cu may be deleted if steel contains both Cr (0.50% min.) and Si (0.50% min.). All other potential alloying elements in the steel (Ni, Cr, Vn, Ti, Zr etc.) are not listed, but may be present. (Vn = vanadium, Ti = titanium and Zr = zirconium)

ASTM A440 – the specified alloy limits are 0.28% (max.) C, 0.04% (max.) P, 0.05% (max.) S, 1.10% to 1.60% Mn, 0.30% (max.) Si, and 0.20% (min.) Cu.
ASTM A441 – the specified alloy limits are 0.22% (max.) C, 0.04% (max.) P, 0.05% (max.) S, 0.85% to 1.25% Mn, 0.40% (max.) Si, 0.02 (min.) Vn, and 0.20% (min.) Cu.

ASTM A572 – there are four alloy types of this steel. The specified alloy limits are 0.26% (max.) C, 0.04% (max.) P, 0.05% (max.) S, 1.35% (max.) Mn, 0.30% (max.) Si, 0.005% to 0.05% Nb, 0.01% to 0.15% Vn, and 0.15% (min.) N. When Nb and Vn are alloyed in combination their contents are 0.05% (max.) and 0.01% to 0.15% Vn, respectively. N is added when only Vn is present. (Nb = columbium/niobium and N = nitrogen)

ASTM A588 – many grades have been available over the years (from 1968 on). One alloy requirement is Cu in all the grades ranging from 0.20% to 1.00%.

Identification of the Hardin County Bridge Steel
The 12 tensile yield strengths of the test specimens from the two bridge beams were all less than 50 ksi (mean = 48.86 ksi) although they tested near that value. As 50 ksi is the minimum specified yield strength of the HSLA steel family; this indicates the specimens are probably carbon steels. The tensile yield strength of the strongest structural carbon steel (ASTM A36) is a minimum of 36 ksi. It is common for tensile tests of that type of bridge steel, and also the earlier types (ASTM A7 and ASTM A373), to provide tensile yield strengths around 40 ksi. The average tensile ultimate strength for the steel specimens was 72.98 ksi which is in the acceptable specified limits for all three ASTM carbon steels (and all of the ASTM HSLA steels where specified).

The alloy contents of the bridge steel from the XRF field tests revealed that the steel did not contain Cu. Past corrosion damage was evident on the bridge beams even though they currently had good coats of paint. That indicates the steel lacked the corrosion protection afforded by most HSLA/copper-bearing structural steels. This removes ASTM A242 (Type 1), ASTM A440, ASTM A441, and ASTM A588 from consideration as all have Cu contents above 0.20%, which the XRF would readily detect. The only potential HSLA steel might be ASTM A242 (Type 2) where Cu could be replaced with 0.50% (min.) Cr and 0.50% (min.) Si. The XRF field tests found Cr at only about one-tenth of that value, and the Si readings were typically well below 0.50%. Therefore, ASTM A242 is an unlikely candidate steel. Based on this process of elimination, the only ASTM structural steels that are viable candidates would be the carbon steels based on the alloy contents.

The ASTM structural steels do not limit the presence of alloying agents that could be present due to the use of high amounts of steel scrap (or electric remelting furnaces). The steel beams contained, on average, about 0.3% of Si and 0.89 % to 1.00% Mn. Those alloys increase the strength of steel; in the contents present in the steel beams they could account for the high tensile yield strengths.

Conclusions
KTC’s bridge tests indicate the structural steel beams on the KY 2212 bridge over Pawley Creek in Hardin County (047B00134N) are made from a carbon structural steel. That steel probably was specified as ASTM A36 Carbon Structural Steel.
Figures

Figure 2 KY 2212 bridge over Pawley Creek in Hardin County (047B00134N)

Figure 3 Bridge superstructure consisting of six steel beams
Figure 4 Element testing of Steel Beam 1 using a handheld XRF analyzer

Figure 5 Test specimen cut from a beam
Figure 6 Smoothing cut edges on beam flange with a grinder

Figure 7 Beam after specimen removal, grinding of flange, and painting
**Figure 8** KTC tensile test specimen design for unknown bridge steels

**Figure 9** Instron electromechanical universal test machine.
Figure 10 Test specimen mounted in universal test machine with extensometer attached

Figure 11 Work station connected to the universal test machine
Figure 12 Tensile specimen after it has been pulled to failure
Appendix A Typical XRF Data Sheet from Beam 1 Of KY 2212 Bridge

Your Title Here

Test Result
Test ID: 04/16/19 #2
14.9 sec
14.9 sec
Grade Match Result:
Carbon Steel - Match Number: 0.9

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<th>+/-</th>
<th>Description</th>
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<td>0.08</td>
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<tr>
<td>Mn</td>
<td>0.92</td>
<td>0.03</td>
<td>[0.00-1.50]</td>
</tr>
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<td>Co</td>
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<td>0.07</td>
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<tr>
<td>Si</td>
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<tr>
<td>Pb</td>
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<tr>
<td>Cr</td>
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<td>0.009</td>
<td>[0.00-0.10]</td>
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Not Detected
V ND < 0.01
Al ND < 0.03
Mg ND < 0.22
P ND < 0.00
S ND < 0.01
Ni ND < 0.01
Cu ND < 0.01
Zn ND < 0.01
Zr ND < 0.00
Nb ND < 0.00
Mo ND < 0.01
Pd ND < 0.03
Ag ND < 0.04
Cd ND < 0.04
Sn ND < 0.06
Sb ND < 0.07
Hf ND < 0.02
Ta ND < 0.02
W ND < 0.02
Re ND < 0.02
Ti ND < 0.01
Bi ND < 0.04

Test information
Analyzer Mode: Alloy Plus
Analyzer Serial #: 540026
Field Info
047B00134N Steel Test W. End

Signature: ___________________________ Date: ___________________________
Appendix B Typical Test Data from Instron Universal Test Machine

Sample description
047B00134N

KTC Hardin County

<p>| | |</p>
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<td>Control mode 1</td>
<td>Displacement</td>
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<td>Create a file for each specimen</td>
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</tr>
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<td>Sample number input 1</td>
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</tr>
<tr>
<td>Specimen choice input 1</td>
<td>&lt;None&gt;</td>
</tr>
<tr>
<td>Sample text input 1</td>
<td>Beam 1</td>
</tr>
<tr>
<td>Sample text input 2</td>
<td>West</td>
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<td>Sample text input 3</td>
<td>047B00134N</td>
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</table>

![Specimen 1 to 1](image)

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<tr>
<th></th>
<th>Maximum Force [lbf]</th>
<th>Modulus (E-modulus) [ksi]</th>
<th>Tensile stress at Yield (Offset 0.2 %) [ksi]</th>
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<td>1</td>
<td>3614.48</td>
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<td>49.45</td>
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<table>
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<th></th>
<th>Tensile stress at Maximum Force [ksi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>73.63</td>
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</table>
Appendix B — Technical Assistance Report KTC-TA-17-05/SPR17-533-13

Determination of Steels in Kentucky Bridges — Trimble County Bridge Steel Identification
Technical Assistance Report  
KTC-TA-17-05/SPR17-533-1F

Determination of Steels in Kentucky Bridges — Trimble County Bridge Steel Identification

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Christopher Goff  
Transportation Technician

And

Sudhir Palle  
Research Engineer

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In Cooperation With  
Kentucky Transportation Cabinet  
Commonwealth of Kentucky

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July 2017
The Kentucky Transportation Cabinet (KYTC) identified five short-span deck girder bridges in Trimble County with painted and unpainted steel I-beams. KYTC inspectors were unsure if the steel I-beams were made from weathering or standard grades of structural steel. Matthew Graves of the District 5 office contacted the Kentucky Transportation Center (KTC) about inspecting the bridges and identifying the steel. Eventually, a proposal was prepared and KYTC funded the work as part of KYSPR 17-533, “Determination of Steels in Kentucky Bridges.” As part of this project KTC is developing methods and processes to identify unknown bridge steels using elemental analyses and physical testing.

KTC researchers relied on elemental analysis of the steel alloys to identify the steels and determine alloy type. KTC performed field elemental content analyses of the bridge I-beam steel in the field using a portable X-ray fluorescence (XRF) analyzer. KTC had not yet resolved the test procedure for field extraction of steel samples to perform mechanical testing (i.e., tensile testing) and determined that testing was not necessary to evaluate whether the steel beams were corrosion-resisting weathering grades of structural steel. The XRF unit used for the testing was a DELTA (Olympus) Professional Alloy Plus Analyzer (Figure 1). It contains a miniature x-ray tube that emits low-intensity x-rays onto the surface of a test piece (i.e., the I-beam steel). When the x-rays strike the steel, they generate secondary or fluorescent x-rays from the various elements comprising the steel alloy. X-ray peaks of various intensities are emitted by elements in the steel alloy. XRF analyzers contain sensors that measure the energy and wavelengths of the secondary x-rays and identify the content of specific elements and their relative concentration by percent weight. The XRF analyzer only detects elements with atomic numbers greater than 12 (magnesium). The XRF element readings are in weight %, which can be correlated with those of standard ASTM structural steels. Steels considered included ASTM A36 low-carbon structural steel, ASTM A242 high-strength low-alloy structural steel, ASTM A441 high-strength low-alloy manganese vanadium steel, ASTM A572 high-strength low-alloy columbium-vanadium structural steel, and ASTM A588 high-strength low-alloy structural steel with 50 ksi minimum yield point to 4 in. thick. The ASTM A242 and A588 grades are considered weathering steels, with about four times the corrosion resistance of conventional low-carbon structural steels. The conventional steels can all be procured with 0.20% copper, making them copper-bearing structural steels with about twice the corrosion resistance of conventional low-carbon structural steels.

Portable XRF analyzers do not produce significant energy, and their readings reflect only surface or near-surface concentrations of elements. To obtain accurate readings, surfaces should be prepared to eliminate the typical surface impurities that can misrepresent the contents of steel. To that end, KTC developed the following surface cleaning process (Figures 2-5):

1. A wire brush on an angle grinder was used to remove any paint, rust or other debris.
2. A non-woven cleaning pad was used on an angle grinder to polish the steel.
3. A chemical cleaner was used as a final cleaning step to remove the remaining surface contaminants. The process left a polished finish on the test area.

All five Trimble County bridges are on county-maintained roads. The bridges have rolled I-beam construction with poured concrete decks. Because the I-beams are rolled, they have the same elemental (alloy) composition across the entire beam. To account for minor elemental differences and potential reading outliers due to contaminants not removed from pits, the beams were tested at five locations (Figure 6). Readings indicated the elements detected and their concentrations by weight. The readings were averaged for each beam and those averages were used to determine the chemical make-up for that I-beam. The bridges are on routes that see very little traffic. Each bridge contains many I-beams, ranging from 12 to 16 inches tall. Some of the bridges have painted beams while others have unpainted steel with rusting surfaces.

KTC tested five bridges:

- 112C00031N, Carmon Creek Bridge (Figure 7)
  - Location: Carmon Creek Road over tributary of Carmon Creek
• 112C00027N, Logan Lane Bridge (Figure 8)
  o Location: Logan Lane extended over tributary of Little Kentucky River
• 112C00032N, Hardy Road Bridge (Figure 9)
  o Location: Hardy Road over tributary to Hardy Creek
• 112C00034N, Joyce Ridge Road Bridge (Figure 10)
  o Location: Joyce Ridge Road over tributary to Corn Creek
• 112C00024N, Burkhardt Bottom Road Bridge (Figure 11)
  o Location: Burkhardt Bottom Road over Gilmore Creek

Five different steel standards were tested the steel against ASTM A242 and A588, (weathering steels) and A36, A441, and A572 (standard structural steels). Tables 1-5 summarize the alloy content of those steels, which offer a point of comparison against the XRF field readings for the bridge beams for each bridge. 112C00031N, Carmon Creek Bridge, is a small bridge with 11-12 inch rolled, unpainted I-beams. Each beam was cleaned and tested at five locations for chemical composition; average readings are provided in Table 1. The steel on this bridge has high amounts of copper (0.31% to 0.50%). All but one of the beams contain vanadium (0.027% to 0.05%), which is normally present in 50 grade structural steels. The best fit is for a 50 grade copper-bearing steel, which has better corrosion resistance than conventional carbon steel, but less than weathering grade steel. Based on elemental analysis, the apparent best fit is for ASTM A441 steel.

112C00027N, Logan Lane Bridge, is a small bridge with 7-16 inch rolled I-beams. Each beam was cleaned and tested at five locations for chemical composition. The I-beams do not have uniform alloy contents from beam to beam. (see Table 2). The beams lack copper and other alloy elements typical of 50 grade structural steels. The best match is for plain low-carbon ASTM A36 structural steel.

112C00032N, Hardy Road Bridge, is a small bridge with 6-12 inch rolled I-beams. It was cleaned and tested at five locations on each I-beam (Table 3). The steel has high levels of copper (0.23% to 0.40%) and sufficient vanadium (0.019% to 0.040%) to fit a 50 grade structural steel. The best fit is for a 50 grade copper-bearing steel, which has better corrosion resistance than conventional carbon steel, but less than weathering grade steel. Based on elemental analysis, the apparent best fit is for ASTM A36.

112C00034N, Joyce Ridge Road Bridge, over tributary to Corn Creek is a small bridge with 10-12 inch rolled I-beams. Each I-beam was cleaned and tested at five locations for chemical composition (Table 4). The steel has high levels of copper (0.32% to 0.51%), but lacks rare earth alloys such as vanadium and columbium. It could be copper-bearing steel ASTM A 36 (a 36 grade) or a weathering steel ASTM A242 (50 grade).

112C00024N, Burkhardt Bottom Road Bridge, is a small bridge with 9-16 inch rolled I-beams. Each beam was cleaned and tested at five locations for chemical composition (Table 5). The I-beams have varying chemical contents. I-beams three, four, and seven lack copper and nickel. The best fit for the I-beam steel of this bridge is ASTM A36.

The bridges tested in Trimble County provide insight into the characterization of structural steels using elemental analysis. Testing has been able to distinguish plain low-carbon steels from the copper-bearing or weathering steels. Differentiating copper-bearing and weathering grades of steel has proven more challenging. The variability of alloy content in structural steels, including those necessary to properly characterize a specific steel, makes the task difficult. Structural grades of steel typically rely on heat-level analyses taken from a small sample, usually at the beginning of the heat. There can be variability in alloying content throughout the heat/plates that may lead to inconsistencies.

To further assist in steel characterization, it will probably be necessary to take steel coupons from bridges and perform mechanical tests, at least to distinguish copper bearing low-carbon structural steel (ASTM A36) from high-strength low alloy grades (ASTM A242, A 440, A441, A572 and A588). KTC plans to investigate other types of alloying.
analysis, including arc spark spectrometry and laser-induced breakdown spectroscopy, to determine whether they offer improvements in alloy identification over XRF.

KTC recommends that the five Trimble County bridges be couponed and tested for mechanical properties and alloy contents using the other spectrographic methods. Testing of those bridges will comprise part of the field testing noted in Task 4 of the project work plan.
Figure 13 DELTA Portable XRF Analyzer. Note the LCD screen on the back face of the instrument that displays elements present and their concentrations by weight.

Figure 2 Preliminary Cleaning of Steel I-Beam using a Wire Brush on an Angle Grinder.
Figure 3 Cleaning of Wire Brushed Area with Non-Woven Pad on an Angle Grinder.

Figure 4 Final Cleaning by Wiping with a Rag Soaked with Lacquer Thinner.
**Figure 5** Prepared Surface of an I-Beam Ready for XRF Testing.

**Figure 6** Prepared Test Areas (Arrows) on I-Beam for XRF Testing.
Figure 7 Bridge 112C00031N Carmon Creek Road over a Tributary of Carmon Creek.

Figure 8 Bridge 112C00027N Logan Lane Extended over tributary of Little Kentucky River.
**Figure 9** Bridge 112C00032N Hardy Road over Tributary to Hardy Creek.

**Figure 10** Bridge 112N00034N Joyce Ridge Road over Tributary to Corn Creek.
Figure 11 Bridge 112C00024N Burkhardt Bottom Road over Gilmore Creek.
Table 1  Carmon Creek Bridge (No. 112C00031N) Comparison Between ASTM Standard Alloy Contents and XRF Test Data (Negative Correlations Noted in Red)

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<td>0.8-1.65**</td>
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<td>0.05 Max</td>
<td>0.05 Max</td>
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<tr>
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<td>0.1 Max</td>
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<td>0.2 Min*</td>
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<td>Nitrogen</td>
<td>0.015 Max</td>
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* When Copper Bearing Steel is Specified
** .8% when Plates sizes over 3/8" in Thickness
### Table 2: Logan Lane Bridge (No. 112C00027N) Comparison Between ASTM Standard Alloy Contents and XRF Test Data (Negative Correlations Noted in Red)

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<tr>
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<td>4</td>
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<td>0.15 Max</td>
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<td>0.05 Max</td>
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<tr>
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* When Copper Bearing Steel is Specified
** .8% when Plates sizes over 3/8" in Thinkness
**Table 3** Hardy Road Bridge (No. 112C00032N) Comparison Between ASTM Standard Alloy Contents and XRF Test Data (Negative Correlations Noted in Red)

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<td>0.2 Min*</td>
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<td>0.8% When Plates sizes over 3/8&quot; in Thinkness</td>
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### Table 4 Joyce Ridge Road (No. 112C00034N) Comparison Between ASTM Standard Alloy Contents and XRF Test Data (Negative Correlations Noted in Red)

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<td>0.15 Max</td>
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<td>Sulfur</td>
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<td>0.05 Max</td>
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<td>8</td>
<td>Silicon</td>
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<td>Nickel</td>
<td>0.4 Max</td>
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* When Copper Bearing Steel is Specified
** .8% when Plates sizes over 3/8" in Thinkness
### Table 5 Burkhardt Bottom Road (No. 112C00024N) (Comparison Between ASTM Standard Alloy Contents and XRF Test Data (Negative Correlations Noted in Red))

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</tr>
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<td>Manganese</td>
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<tr>
<td>6</td>
<td>Phosphorus</td>
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<tr>
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<td>Silicon</td>
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<tr>
<td>9</td>
<td>Nickel</td>
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<tr>
<td>10</td>
<td>Chromium</td>
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* When Copper Bearing Steel is Specified

** .8% when Plates sizes over 3/8” in Thickness