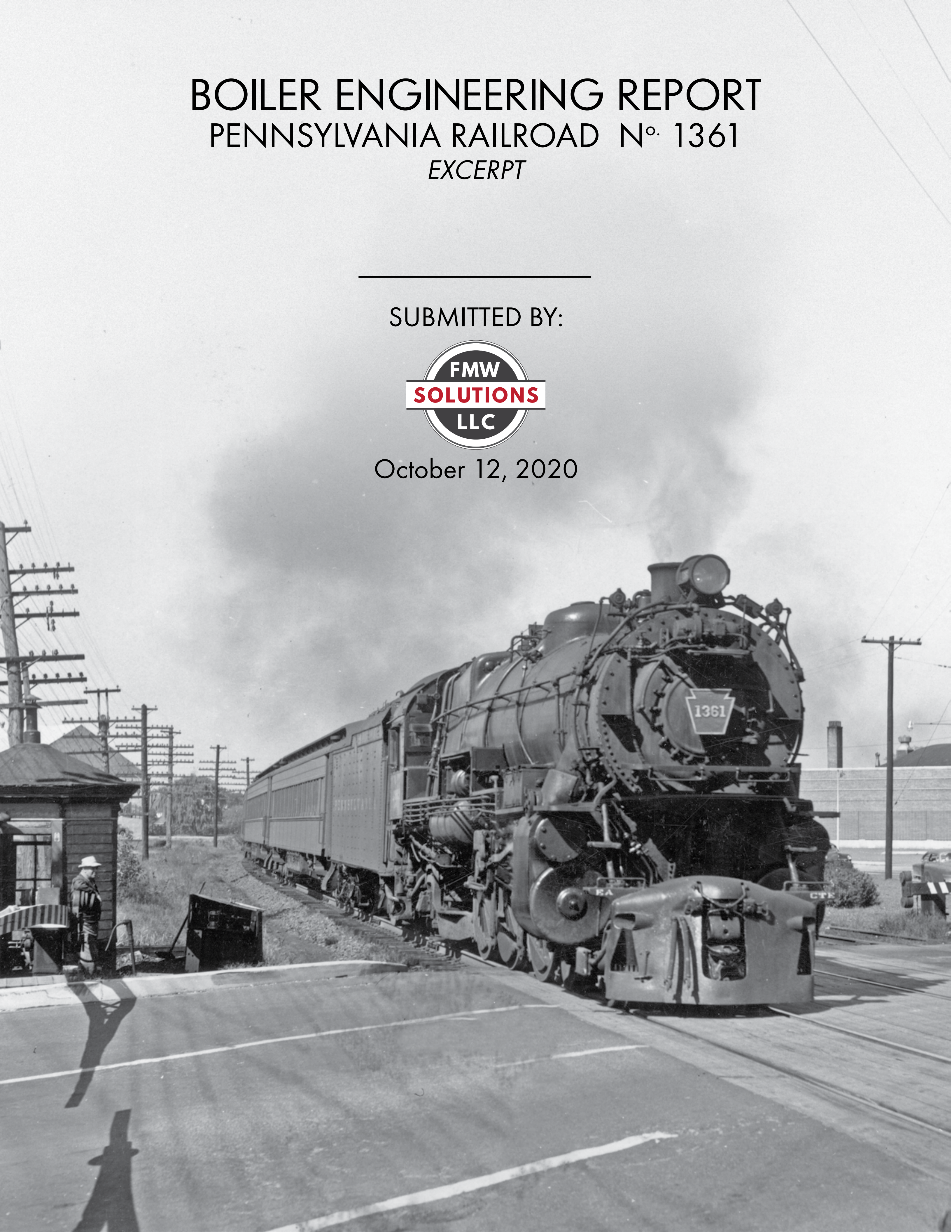
BOILER ENGINEERING REPORT
PENNSYLVANIA RAILROAD Nº. 1361
EXCERPT

SUBMITTED BY:

FMW SOLUTIONS LLC

October 12, 2020



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ON THE COVER: *PRR K4s No. 1361 hauls passenger train No. 789 at 60 MPH across a busy street crossing in Red Bank, New Jersey. This photograph, taken in October 1955, is part of the Don Wood collection and is courtesy of the Railroad Museum of Pennsylvania via the Altoona Railroaders Memorial Museum.*

INTRODUCTION

FMW Solutions LLC ("FMW") was retained by the Railroad Heritage Conservancy of Pennsylvania ("RHCP"), in conjunction with the Altoona Railroaders Memorial Museum ("RMM") to undertake an engineering study of the boiler of former Pennsylvania Railroad ("PRR") K4s class steam locomotive No. 1361 ("No. 1361"). This study focuses on, and is dedicated exclusively to, the boiler of No. 1361.

RMM Collection

Following our engineering study, inspection of work, and review of historical correspondence, we are confident that the locomotive can be returned to a safe, compliant condition. To do so, however, it is incumbent upon FMW to provide sufficient evidence and engineering to RHCP, RMM and, ultimately, the Federal Railroad Administration ("FRA") to verify that the boiler will be safe to operate, once rebuilt.

This document endeavors to provide such evidence. The following sections provide: 1) a summary of boiler work completed on No. 1361 to date; 2) findings of our detailed in-person inspection of the boiler; 3) a description of our engineering analyses; and 4) our recommended approach to boiler repair. Also included are multiple appendices providing supporting documentation relevant to the condition of the boiler and our engineering calculations.

None of the professionals that have drafted this report have been involved in the past restoration work of No. 1361, and as such, we venture to approach the subject with as objective a perspective as possible. That said, the authors of this report are confident that the existing boiler of No. 1361 can be largely reused and returned to operation, in full compliance with applicable FRA, NBIC, and ASME code requirements.

A summary of FMW's qualifications to complete this report is included in Appendix H of this document.

Respectfully submitted,

Davidson A. Ward President	Wolfgang A. Fengler VP - Engineering	D. Shane Meador VP - Mechanical

1. PRIOR RESTORATION ATTEMPTS

This photograph, from of the Don Wood collection and is courtesy of the Railroad Museum of Pennsylvania via the Altoona Railroaders Memorial Museum, shows No. 1361 during its dedication ceremony when placed on display at Horseshoe Curve in 1956.

1. PRIOR RESTORATION ATTEMPTS

Pennsylvania Railroad K4s class steam locomotive No. 1361 is perhaps one of the most well known steam locomotives in the U.S. rail preservation industry. The PRR, once regarded as "the Standard Railroad of the World," was at its mightiest when No. 1361 and its 424 sister locomotives were in service. As such, the K4s class of locomotive hauled some of the most important passenger trains of the 20th century.

After a lengthy career, No. 1361 was retired in 1956 and placed on display at the PRR's famous "Horseshoe Curve" park, outside of Altoona, Pennsylvania. An effort some 30 years later was undertaken to return the locomotive to operation. Conrail, the successor to the PRR, removed No. 1361 from the curve in 1985, returning it to operation in 1987. Since its initial removal from "the Curve," No. 1361 has been beset with mechanical failures and restoration missteps.

While much has been rumored about the history of No. 1361, and the ability of its boiler to meet modern safety standards, FMW has sufficient historical information, coupled with more recent non destructive testing data, to verify the current state of the boiler, as well as support its return to safe operational condition.

FMW notes that previous repair work included a flush patch and pad welding in the area of the steam dome. Documentation was found to provide traceability of materials used, welding performed, and correspondence with FRA regarding the alteration. This includes the correction of cracking which resulted from an unauthorized and unnecessary repair to the steam dome flush patch weld.

Other repair work included the installation of a new rear flue sheet, a patch to the front flue sheet, a new back head with patches extending from the back head knuckle partly into the roof sheet, a small patch in the outer throat sheet, and two corner patches at the mud ring at the inner throat sheet. An all new mud ring, excluding at the throat sheet area, was fabricated and installed.

Substantial replacement portions of the side sheets have been fabricated and partially installed. However, the workmanship on these items was marginal with noticeable welding warpage and inaccurate placement of staybolt holes. The two upper, extreme-most backhead braces were also fabricated new and replaced.

ABOVE: *The boiler of No. 1361 as FMW first inspected it in December 2019*

2. FMW INSPECTIONS OF K4s No.1361

2. FMW INSPECTIONS OF K4s No. 1361

FMW completed in depth visual inspections and oversaw the non-destructive testing ("NDT") of the boiler materials in late 2019 and early 2020. The following two sections outline our methods and findings of the two visits.

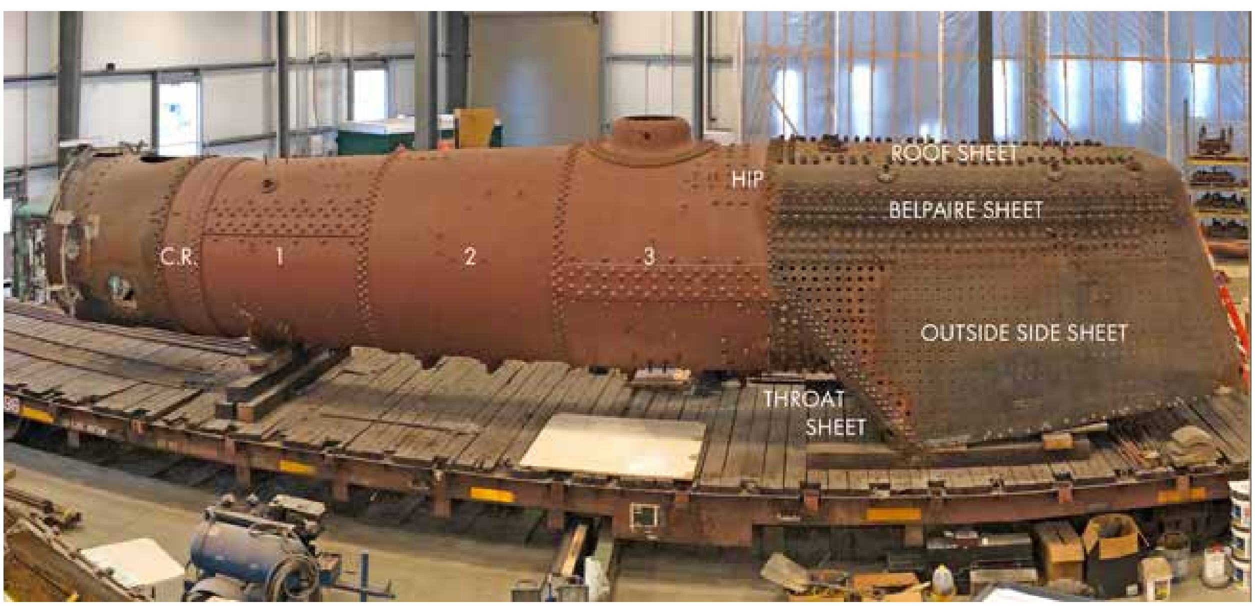
2.1 DETAILED VISUAL INSPECTION | DECEMBER 2019

FMW undertook a four day site visit to the RMM in Altoona in early December 2019. FMW President Davidson Ward and FMW VP-Mechanical Shane Meador were hosted on site by Joe DeFrancesco, Dr. Andy Mulhollen, and Mike Reindl.

This visit had two primary goals: 1) review all historical documentation available to identify, save, and reorganize relevant historical technical information related to the boiler; and 2) perform an in-depth visual inspection of the boiler to begin cross-referencing the historical documentation with work performed on the boiler.

Our findings indicated that the majority of the boiler is in sufficiently sound condition to merit its reuse, something FMW verified on a subsequent visit through advanced non-destructive testing ("NDT") methods. The documentation present at the RMM, combined with follow up NDT inspection, provides sufficient documentation to support engineering the re-use of a majority of the existing pressure vessel.

FMW performed a general inspection and undertook select UT spot measurements of the existing boiler. This process took two days to complete, and was helpful in confirming items uncovered during the document review process. Below is a photograph of the boiler barrel providing our labeling of the courses.



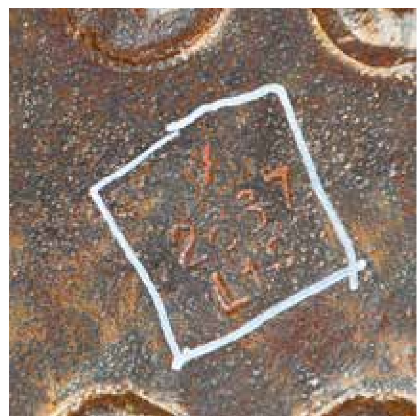
The following is a summary of general findings, organized from front to back on the boiler.

2.1.1 CONNECTING RING ("C.R.")

The first barrel section on the K4s boiler is a very short, non-tapered course that consists of the front flue sheet and is riveted to the smokebox and the first course. The flue sheet in No. 1361 had a welded patch installed in the early 2000s. This patch consists of approximately the bottom sixth of the flue sheet, which was a common place for corrosion on steam locomotives given the difficulty of removing the mud and scale around the bottom knuckle during boiler washes [shown below left and on page 5].

Difficulty cleaning out behind the front flue sheet knuckle is further exacerbated on the K4s boiler given the position of the bottom washout plug to the flue sheet and the large doubler plate at the bottom of the second course, which would have the tendency to act as a "dam" for the water and mud [shown below middle].

Finally, FMW noticed that the front flue sheet appears to be stamped for L1s locomotive with boiler No. 2637 [shown below right]. The PRR L1s 2-8-2 locomotives had (nearly) identical boilers to those of the K4s, thus FMW surmises that the flue sheet was placed into this boiler during an overhaul sometime during the steam era. It might have been slated for installation in the 2-8-2 but was installed in this boiler to expedite a previous PRR overhaul.



2.1.2 FIRST COURSE

The first course of the boiler contains three washout plugs, positioned approximately at the 2 o'clock, 6 o'clock and 10 o'clock positions. The bottom of the first course contains a large doubler plate that corresponds with a large front boiler waist sheet brace [shown above center and at right]. The majority of the front flue sheet braces are riveted to this boiler course, except for the top two most front flue sheet braces. This tapered course appears to be in sound condition, with no visible exceptions noticed.

2.1.3 SECOND COURSE

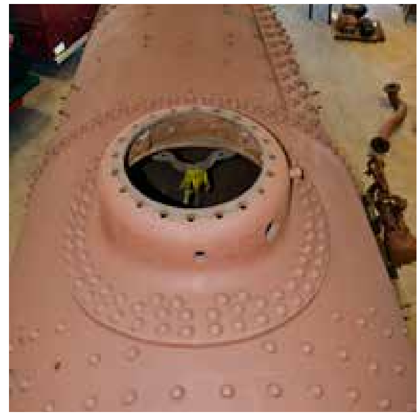
The second course of the boiler is a tapered course. It contains neither washout plugs nor openings. The two middle-most front flue sheet braces are riveted along the top of this boiler course, and it also contains two additional waist sheet support brackets along its bottom [see below left]. It appears a few of the rivets attaching the waste sheet supports to the course have been replaced [see below right].

2.1.3 THIRD COURSE

The third course is the most complex course from an engineering perspective. It is made of two halves, which meet at the 3 o'clock and 9 o'clock positions with riveted seams – the 9 o'clock seam between the halves can be seen in the photo above left. The front end of the course is cylindrical, and the back end transitions into the hips at the top and into the throat sheet at the bottom. The bottom also contains a small, partial combustion chamber. The steam dome is positioned towards the front top, on the boiler center line, and the back head braces are anchored to brackets directly behind the steam dome. The bottom also contains a large number of studs to hold various appliances, as well as a bottom washout plug and two waste sheet support brackets.

The photographs below show the steam dome flush patch [arrow] with new dome rivets and weld repair [below left], the bottom washout plug [below middle] and the back head brace bracket array [below right].

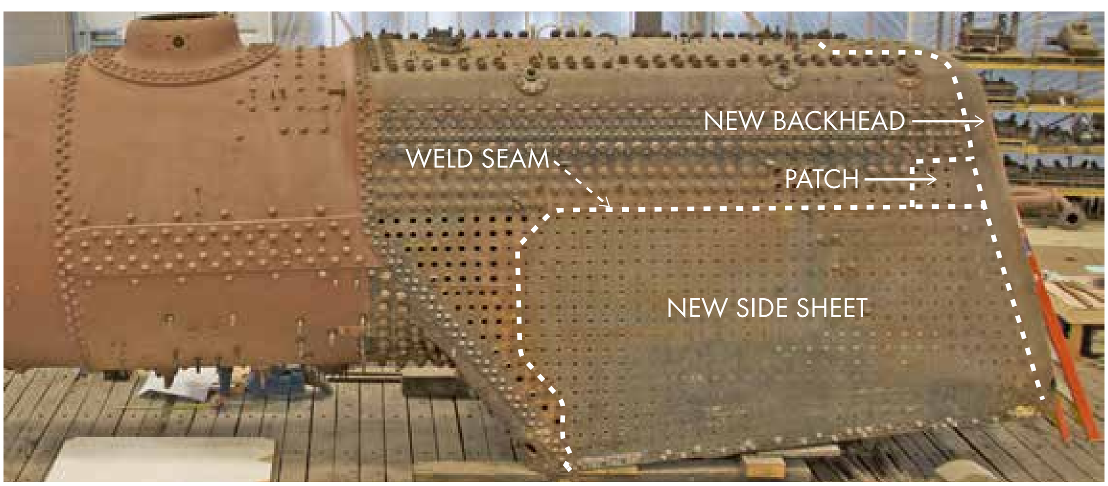
The following two photographs show the view of the top of the boiler, including the transition from the boiler barrel to the roof sheet [BELOW LEFT] and general view along the top of the boiler [BELOW RIGHT].



The photograph ABOVE LEFT shows the right hand top corner of the roof sheet where it intersects with the third course. The third course steel was originally 1" thick and the "hip" corners were flanged into the "square" shape. The roof sheet of the firebox, which is somewhat gray in appearance in this photograph, was originally designed to use 3/8" thick steel, but the PRR replaced the original roof sheet with in 1939. Given some of the UT readings we have taken, which are well above .375" in thickness, our understanding is that PRR replaced the original 3/8" sheet with 7/16" thickness (0.4375") plate. We will address this further in the following section of this report. The photo ABOVE RIGHT shows the field of back head brace bracket rivets (bottom) as well as the new dome rivets. These rivets were tested during FMW's NDT inspection to verify their metallurgical composition.

2.1.4 FIREBOX

The firebox of No. 1361 has been modified significantly since 1985. These modifications include: 1) a new rear flue sheet; 2) new portion of the front left inside side sheet (partially completed); 3) new portion of the mud ring; 4) new door sheet (uninstalled); 5) new back head and rear portion of the roof sheet; 6) new outside side sheets (partially installed); and 7) an outside throat sheet patch. The photograph BELOW shows the new portions of the outside of the firebox – the modifications are mirrored on the other side of the boiler. The crown sheet, inside throat sheet, BELPAIRE sheet, and majority of the roof sheet are original to the PRR.



2.1.4.1 Rear Flue sheet

The rear flue sheet of No. 1361 was fabricated and installed circa 1999. FMW notes this flue sheet is bowed approximately one inch along its vertical axis as a result of improper bracing during fabrication / installation [see below left]. FMW also noted that there is substantial "mismatch" or "high-low" at the weld seam between the flue sheet and the crown sheet [see below right]; this will need to be repaired during the restoration.

2.1.4.2 New Inside Side Sheets

The original inside side sheets from No. 1361 were removed and only a small replacement portion of the front left inside side sheet has been installed. The photograph below left shows areas where the installed portion of the front left side sheet was improperly drilled for staybolts, requiring the incorrect bolt holes to be welded up. The photograph below right shows the cut out portions of the inside side sheets. FMW also identified issues with lack of weld penetration where the left hand side sheet was welded to the existing throat sheet. This will need to be addressed during the restoration.

2.1.4.3 Mud Ring Repair

In the early 2000s, a substantial portions of the mud ring was removed and replaced. This consisted of a "U-shaped" portion of the mud ring extending from the furnace bearer supports at the throat sheet around the entirety of the firebox. The material making up the mud ring repair was full penetration butt welded at their joints. Some of the new mud ring can be seen in the right hand photo above.

2.1.4.4 New Door Sheet

A new door sheet was sourced and flanged – according to the MTR data at the RMM, the sheet was acquired sometime around 1997 – it is not yet installed on the boiler. This material was sourced at the same time as the back head and was, presumably, flanged and formed at that time as well. We noticed that this material, as well as all other firebox sheets installed, was not stamped to indicate its type, though MTRs indicate A515 Grade 60 material was used for the back head and door sheet.

2.1.4.5 New Back Head

The new back head has been installed on the boiler, including riveting all of the brace connections. As with the door sheet, we had this material tested to verify composition with the MTRs on file during the follow up inspection. The photographs BELOW show the old back head [LEFT], and the new back head [MIDDLE AND RIGHT].



2.1.4.6 New Outside Side Sheets

New outside side sheets have been installed on the boiler. FMW noticed some dishing of the side sheets near where they intersect with the existing "BELPAIRE" sheets on the boiler and where the back head brace brackets were riveted. This is most noticeable on the left hand side of the boiler, as shown BELOW LEFT in the vicinity of the weld seam between the new and old side sheet. Shown BELOW RIGHT is the new left outside side sheet.


2.1.4.7 Existing Crown and Roof Sheets

The crown sheet, roof sheet, and Belpaire sheets are original to No. 1361 from its time on the PRR. The crown sheet is the top of the inside firebox, the roof sheet is the corresponding "top" portion of the boiler, and the Belpaire sheets are unique to Belpaire fireboxes and are the outside side sheet portions that connect the lower outer side sheets to the roof wrapper sheet, to which the transverse stays are attached.

The crown sheet appears to have been replaced by the PRR with 7/16 inch plate, versus the original 3/8 inch plate specified in the builders card. Spot UT thickness testing revealed some thicknesses well in excess of 0.375" (e.g. 0.415," 0.433," etc.). Many of the crown staybolts were replaced as part of the rebuild effort since 1985, and they were up-sized to 1" diameter bolts over the 7/8" diameter bolts originally installed. The front-most row of crown bolts in the vicinity of the rear flue sheet are the original 7/8" diameter bolts.

The roof sheet appears to be the most problematic design feature of the K4 boilers. It features a variable staybolt pitch (spacing) as wide as 5.125" in one direction [right], which is an issue given staybolt diameter and boiler pressure. FMW outlines an engineering solution to this issue in Section 4 of this report.

2.2 NDT AND VISUAL INSPECTION | JANUARY 2020

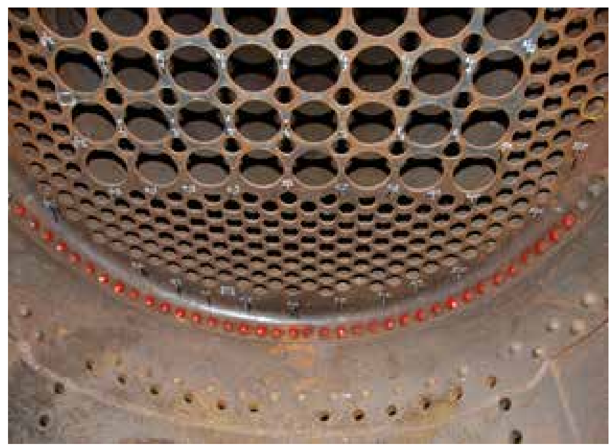
FMW undertook an eight day site visit to the RMM in late January 2020. This visit enabled FMW to perform additional visual inspections and to oversee a detailed, non-destructive testing ("NDT") survey of the boiler from No. 1361, including ultrasonic thickness ("UT") testing as well as laser induced breakdown spectroscopy ("LIBS") using a mobile spectrometer known as a "Z-Analyzer." The NDT work was performed by World Testing, Inc.

While previous restoration efforts had undertaken thickness surveys, the grid layout and data tracking methodology employed from the most recent survey data, circa 1994, did not allow for specific locations on the boiler to be located with sufficient resolution so as to reliably identify any potential problem areas. In addition, with some 26 years having passed since the last survey and a number of repairs having been made since that survey, it was deemed wise to establish a current baseline of thickness readings to a defined grid.

FMW's review of records left by previous restoration teams indicated that material identification data was missing. Furthermore, records indicate that some of the rivet material purchased and installed is not of an appropriate alloys for boiler use. The LIBS technology allows accurate characterization of various materials including carbon content via a hand-held device. Given the mixed provenance of work previously performed on the boiler, all boiler sheets were surveyed with the LIBS instrument to confirm metallurgy. In addition, all rivets in seams where documentation established that rivet replacement had taken place were also subjected to LIBS testing. Rivets of improper alloy were thus positively identified and marked for later replacement.

Volunteers from the RRM had already laid out an inspection grid on the majority of the boiler by the time FMW arrived on site. Davidson Ward and Shane Meador completed the grid, finalizing the intersection points in paint marker, and labeled the grid according to each boiler section. This work, in addition to further inspection, took place from Friday, January 24 through Sunday, January 26.

On Monday, January 27, Wolf Fengler and FMW Subcontractor World Testing, Inc. ("WTI"), arrived on site to begin the testing and data entry. WTI first undertook two days of LIBS work. This hand-held spectrometer is able to determine the chemical composition of materials, outlining percentages of key components, such as percent carbon. The photo above shows the small "Z-Analyzer" at work using LIBS technology to test boiler sheets.



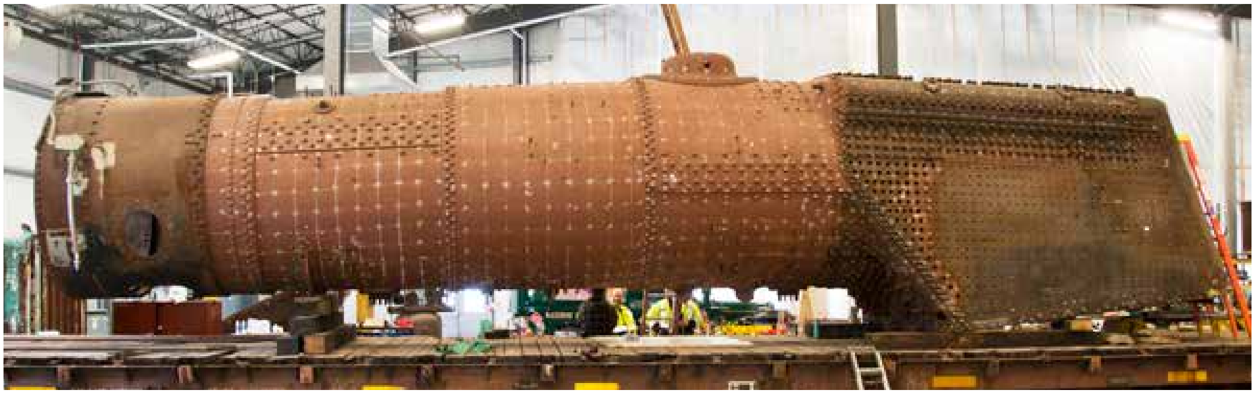
The photographs above show the laser etchings from the tests [left] and some of the rivets marked for replacement due to carbon content being too high [right].

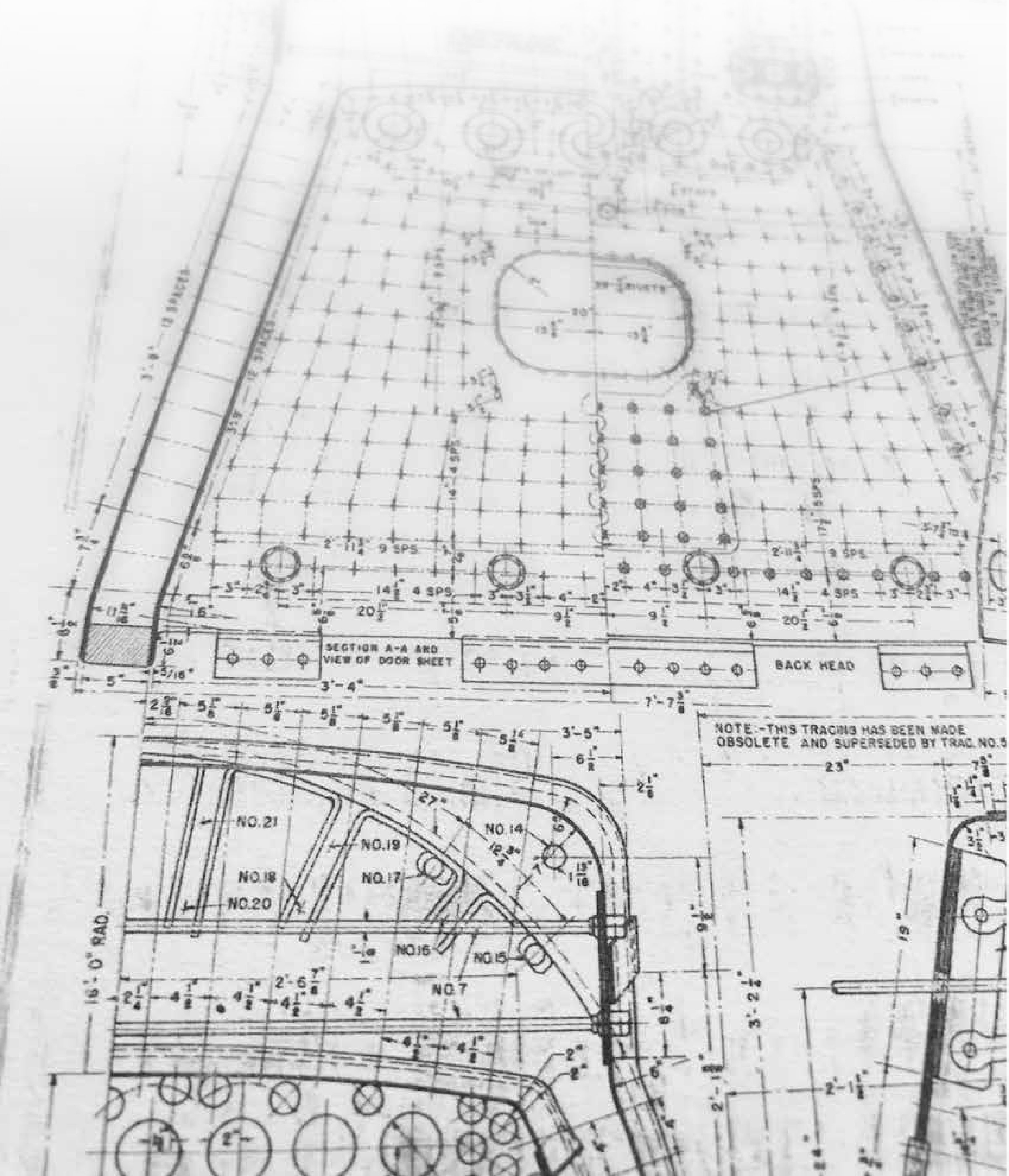
Once the Z-Analyzer work was completed, FMW and WTI completed a UT survey of the boiler. UT readings were taken at the intersection point of the eight-by-eight inch grid, as well as anywhere else within the grid where visual inspection warranted further investigation. The gridded boiler is shown at the top of the following page. The UT inspection took an additional two days to complete, wrapping up on Thursday, January 30. Throughout this process, FMW was able to directly enter the UT data into its engineering matrix and, as needed, work with the WTI team members to inspect potentially-suspect areas in greater depth.

On Friday, the FMW partners spent the morning performing additional spot-UT measurements of suspect areas to diagnose any potential anomalies. The FMW Team members left the RRM around noon on Friday, January 31, ending their trip.

As mentioned earlier, a number of the rivets installed since 1985 will need to be removed and replaced with material of the proper specification and certifications. This is due to the high level of carbon content in some, but not all, of the new rivets which, in some cases, was nearly twice the permissible amount. This high carbon content results in rivets being too brittle for reliable or safe use. The defective rivets have been marked for removal.

Additional photos of the NDT inspection are shown BELOW.




SECTION A-A AND
VIEW OF DOOR SHEET
BACK HEAD
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OBSOLETE AND SUPERSEDED BY TRAC. NO.5
NO.21
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16'-0" RAD.

3. ENGINEERING ANALYSES

FMW performed detailed engineering analyses of the boiler using established formulas as compiled in the Engineering Standards Committee compendium. Those formulas were themselves assembled by the committee from appropriate sources including the 1952 ASME Boiler and Pressure Vessel Code and the Baldwin Locomotive Works Standard Practices. All calculations were undertaken to determine if the allowable stresses and factor of safety established in 49 CFR 230 were met.

This report includes a comprehensive Form 4 analysis of the boiler as it is currently configured, which is included in Appendix A. This report also includes engineering to repair deficiencies in the firebox of No. 1361, which is included in Appendix B.

FMW's calculations resulted in the establishment of baseline minimums, and areas which were determined to require substantially new construction were recalculated using the 2017 ASME Boiler and Pressure Vessel Code. These areas included the wrapper roof and side sheets, as well as the back head, door sheet, and firebox side sheets. The cross stays were also evaluated using the 2017 ASME code. The key proviso comes from 49 CFR §230.24(a)

> *The maximum allowable stress value on any component of a steam locomotive boiler shall not exceed ¼ of the ultimate tensile strength of its material.*

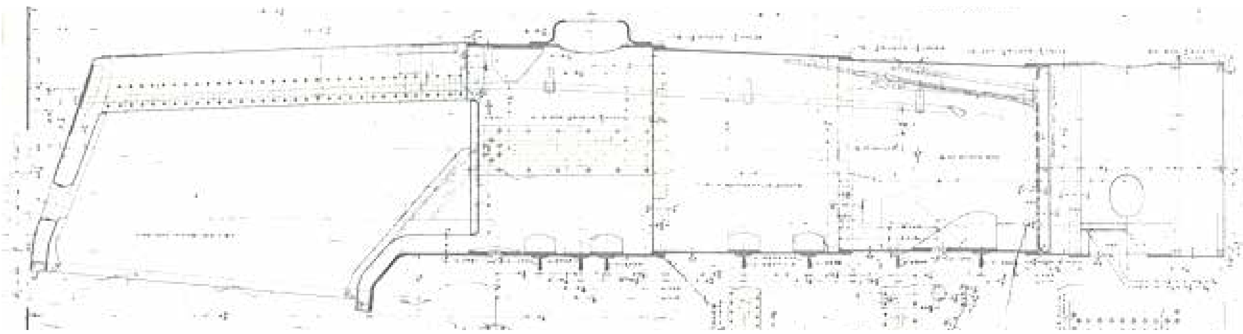
Speaking in general, it is clear that the PRR designed these boilers such that the barrel courses would last a long time, as they are substantially built, but the firebox itself appears to have been designed with the intention of "replacability." Indeed the historical records indicate that the entire firebox of No. 1361 was replaced in 1939. This was likely a result of PRR seeking to minimize firebox weight, material expense, and accommodate the harsh nature of coal combustion in a locomotive.

According to FMW's review of historical PRR engineering standards and documentation, it appears PRR engineers reported their staybolt calculations based on average spacing - particularly for the crown stays. Furthermore, the boiler specification card of the era [see Appendix C] was filed with the maximum staybolt stress reported, without taking the combustion chamber staybolts into account or the difference in stresses between the smaller diameter rigid crown stays and the larger diameter flexible crown stays. The conservative approach would be to take the bolts under highest stress regardless of the type and location of the bolt.

Despite the questionable nature of how the boiler was originally designed and certified by PRR, FMW was able to identify some simple changes which are sufficient to bring the boiler into compliance with 49 CFR § 230. This situation also proves the value of the revised steam locomotive inspection requirements. The lack of data required by the old boiler specification card [see Appendix C] allowed for gaps in the calculations and assumptions regarding the fitness of the boiler design to propagate without being investigated. This report also includes select historical engineering drawings in Appendix D.

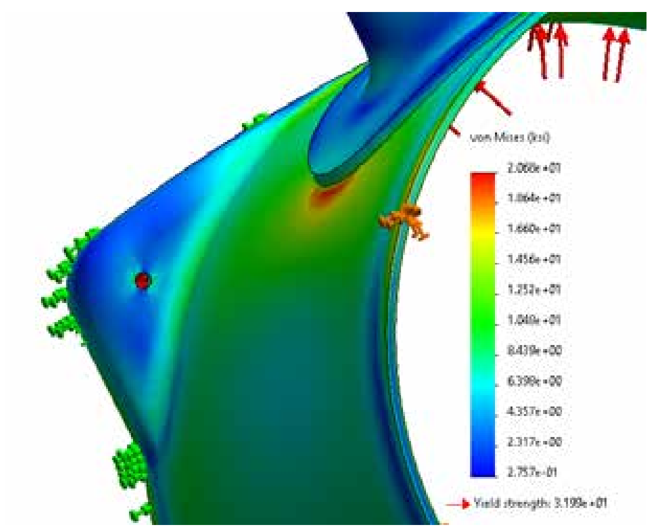
3.1 BOILER BARREL

The barrel of No. 1361 consists of three main cylindrical courses and one short cylindrical course adjacent to the smokebox. The boiler consists of a typical tapered barrel, save for the third course, which includes a transitions into both the throat sheet (bottom) and the hip / Belpaire sheet at the top. A boiler elevation drawing is included below:



From an engineering perspective, the original boiler barrel is in sound condition. This is due to the known materiality of the boiler barrel materials, the remaining thickness, and the repairs made on the boiler to-date. As referenced in Section 4 of this report, FMW will propose a series of relatively minor repairs to the barrels (e.g. replacing rivets that have too high a carbon content and changing washout plug types), but the overall condition of the barrel is sound.

FMW has performed limited finite element analyses ("FEA") of some boiler components, including the stresses associated with the dome course and its transition to the hip [shown at right]. These calculations indicate that all stresses are well below the maximum afforded in the CFR. The FMW Team has also undertaken a study of the stresses internal to the back head brace brackets [refer to section 3.3]. Unlike most locomotives, where back head braces are riveted to the boiler barrel / wrapper sheet, the back head braces on No. 1361 are connected to riveted brackets, between one and three braces per bracket.



One particular item requiring FRA review and acceptance is the status of the third course dome flush patch repair. As referenced in Section 1, there was a substantial amount of work, and re-work, attributed to this flush patch. We have included copies of FRA correspondence available on hand at the RMM in Appendix E as well as copies of relevant additional dome patch information. FMW believes that the dome patch has been repaired appropriately, with all necessary supporting documentation, but recommends final FRA review of the documentation regarding this repair and the supporting documentation to confirm acceptance of the repair.

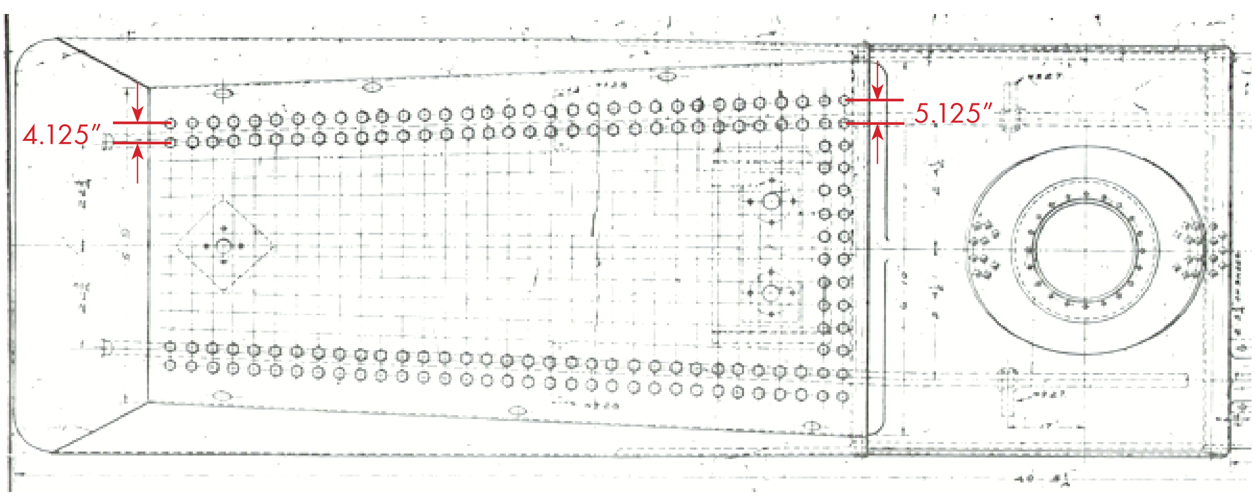
3.2 FIREBOX

Only two railroads in the U.S. embraced the Belpaire firebox in any great quantity: the Great Northern Railway and the PRR. This unique design of firebox, which was introduced to the U.S. in the 1880's, was developed by Belgian mechanical engineer Alfred Belpaire. To quote from William L. Withuhn's work American Steam Locomotives: Design and Development, 1880-1960:

> *The new, "square" shape of the firebox hid insights into both boiler maintenance and stress. The straight connection of staybolts to inner and outer sheets was the most important feature. A flat crown and roof, together with fully parallel alignment of large portions of inner and outer side sheets, meant that most stays could be installed at a true 90 degrees to the sheet areas.… accurate calculation of stress was therefore easier.… Compared to standard fireboxes of the 1870s and 1880s of similar grate width and area, Belpaire's shape gave a little more furnace volume and significantly more steam space above the crown sheet.*

In reviewing engineering completed in the past, as well as cross referencing the original design engineering of the PRR, it is apparent that the original designers of the K4s class of boiler had weight and cost on the mind. The Belpaire firebox is inherently heavier than a radial stayed firebox due to additional steel material.

As part of the FMW engineering analyses, the area of greatest concern when reviewing the boiler of No. 1361 is the relation of the crown sheet to the roof sheet. In particular, the spacing of the roof stays increases transversely from the rear of the boiler to the front, due to the tapered geometry of the crown / roof sheet. An engineering drawing of the firebox is shown below that outlines the increased transverse bolt spacing from back to front:

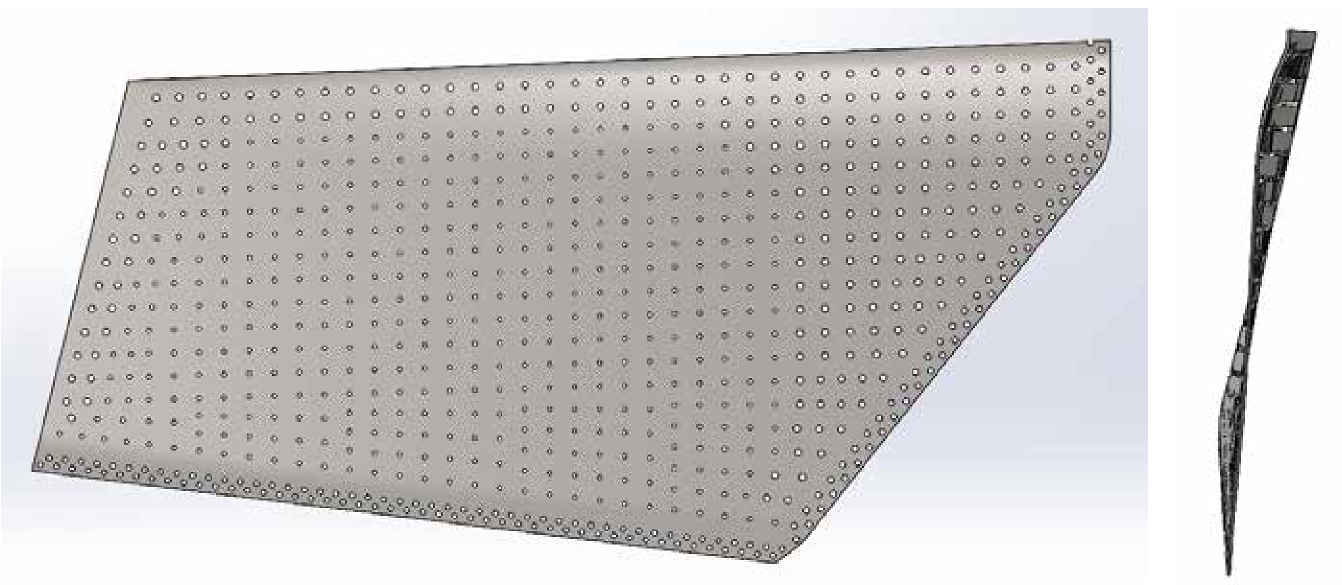


The unusual nature of the Belpaire firebox requires the crown stay and cross stay stresses be calculated in the same manner as those of the side sheets i.e. as flat plates. Though present, the curvature of the crown sheet and wrapper roof sheet is negligible. Furthermore, the angle of the crown stays relative to those sheets is also negligible. These two geometric conditions indicate that the loading on the crown and transverse stays is therefore mathematically akin to the loading of stays on flat plates, hence those calculation methods being appropriate for the crown and transverse stays [see Appendix A and Appendix B].

An additional complication regarding the calculations came through the transverse spacing of the crown stays.

Careful study of the original drawings revealed that just as the roof sheet tapers from its widest at the hip to its narrowest at the back head [SEE PAGE 23], so too do the crown stays taper in their transverse spacing. This means that approximately 35% of the original 7/8 inch rigid staybolts would have internal stresses above the permitted limit of 7,500 PSI. FMW notes that this limit was well established in ASME, ICC, and manufacturer practices of the time (as well as is currently used in 49 CFR § 230), and our hypothesis is that PRR (improperly) utilized average staybolt spacing in its calculations to permit the use of smaller diameter staybolts.

The following graphics speak to the relative complexity of the fabrications associated with the repair, and speak somewhat to the quality issues evidenced in our visual inspection of the locomotive. Shown BELOW is the right hand side sheet from the locomotive. In elevation [BELOW LEFT], this appears to be a flat sheet, but in section [BELOW RIGHT], the "twisted" profile of the sheet is clearly evident.



FMW has outlined its proposed approach to returning the firebox to a state of good repair in Section 4. In brief, the repair will involve the replacement of much of the firebox, save for the mud ring, back head, door sheet, inside throat sheet, and rear flue sheet. By renewing the roof sheet to a thickness of 7/16" and utilizing 1" diameter staybolts throughout, the issues associated with geometry and spacing of the crown stays will be resolved.

3.3 BACK HEAD BRACE BRACKETS

The BELPAIRE firebox design, with the complex array of staybolts and cross stays between the crown sheet and roof sheet, make it impractical to use the typical arrangement of back head braces that extend between the top of the back head and the wrapper sheet and/or top of the adjacent boiler course. Due to the geometric constraints, these back head braces are, instead, connected to brace brackets ("brackets") that hang down from the top of the third boiler course. These brackets enable the braces to extend at a shallow enough angle to avoid contact with the various rows of cross stays. There are four designs of non-standard backhead brackets included on No. 1361, known as brackets "AA," "BC," "EF," and "G."

This complex arrangement is shown AT RIGHT. The rear flue sheet and crown sheet are shown at bottom. The crown staybolts are in a vertical array, and the cross stays are the two horizontal rows of steel rods. The two rows of back braces are snaked between the "grid" established by the crown and cross stay bolts. The brackets to which those braces are attached, however, are non-standard boiler design features.

As outlined in 49 CFR §230.24(a):

> *The maximum allowable stress value on any component of a steam locomotive boiler shall not exceed ¼ of the ultimate tensile strength of its material.*

In reviewing its initial calculations of the brackets, FMW had concerns that the internal stresses of the relatively-thin bracket material would exceed ¼ of the ultimate tensile strength of the steel. As such, FMW undertook finite element analysis ("FEA") of each brace bracket to verify the safety factor of each. Table 1, below, outlines the findings of the initial FEA.

TABLE 1 - BRACE BRACKET SAFETY FACTOR

BRACKET	SAFETY FACTOR	IN COMPLIANCE?
AA	1.72	NO
BC	1.99	NO
EF	2.22	NO
G	3.13	NO

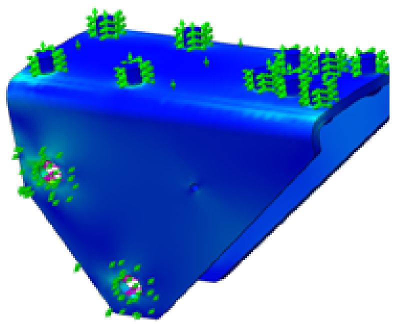
To ensure the brackets meet compliance, FMW has engineered a series of fixes that replace some of the brackets entirely, or modifies existing brackets to increase their safety factor. FEA analysis of each proposed repair are included as follows.

<u>Bracket AA, BC, and EF</u>

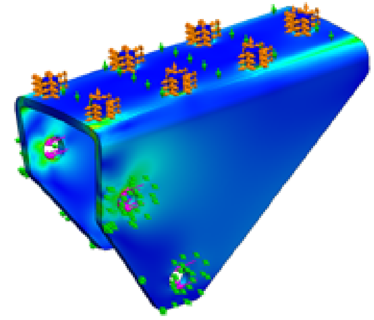
Brackets AA, BC, and EF are to be replaced with a series of weldments of thicker material. These weldments are to be made of a comparable steel to the boiler barrel (e.g. SA516-60) and will be attached via accepted welding practice.

The graphics on the top of the following page show the FEA analysis of the original brackets. The key issues with each included sizing of rivets and thickness of the bracket material. These undersized features resulted in a low safety factor.

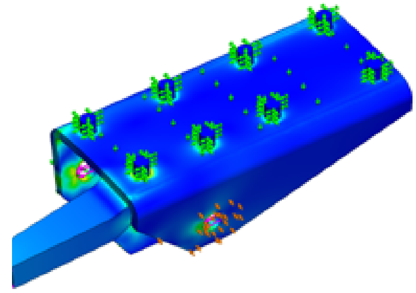
BASELINE AA



BASELINE BC

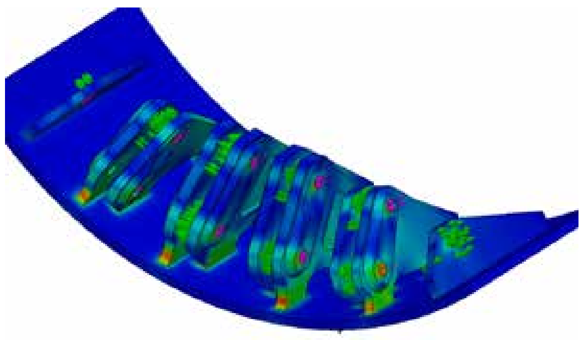


BASELINE EF

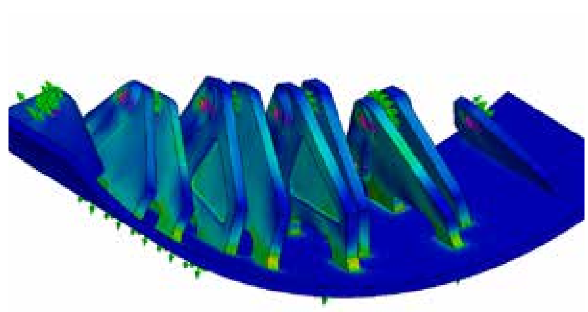


The following graphics [BELOW] show the combined weldments that will replace brackets AA, BC, and EF. The outer two most brackets are the two "G" brackets, discussed below.

VIEW FROM THE BACK



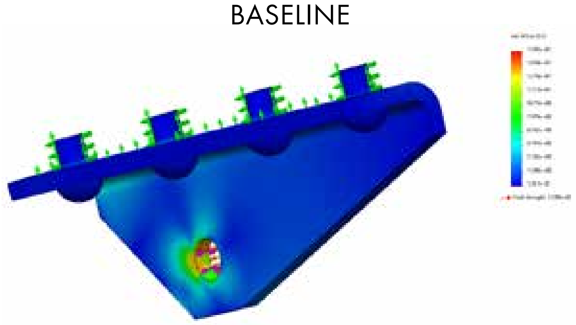
VIEW FROM THE FRONT



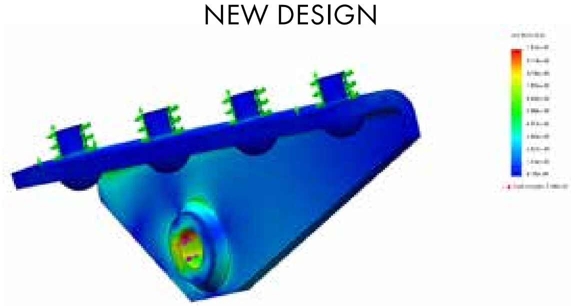
Bracket G

Bracket G can be modified to meet the safety factor by welding on a stiffener plate, but it can use the same, original riveted connection. Below are graphic readouts of the FEA.

BASELINE



NEW DESIGN



With these modifications made to the brace brackets, they will be brought into compliance with 49 CFR §230.24(a). A summary of the new safety factors, and proposed modifications are included in Table 2.

TABLE 2 - MODIFIED BRACE BRACKET SAFETY FACTOR

BRACKET	ORIG. SF	NEW SF	REPAIR
AA	1.72	4.00	NEW BUILD WELDMENT
BC	1.99	4.00	NEW BUILD WELDMENT
EF	2.22	4.00	NEW BUILD WELDMENT
G	3.13	4.95	WELD ON STIFFENER PLATE

We note that, as material selection and detailed engineering are completed, the safety factor is likely to increase. This factor was made using the baseline assumption of a 50 KSI steel material, and the selected material will have a higher tensile strength, as will be reported on its material test report. Furthermore, detailed design will also inform the final means of welded connection for brackets AA, BC, and EF.

A summary of FMW's proposed boiler repairs, including these brace bracket repairs, are included in Section 4.

4. RECOMMENDED APPROACH TO BOILER REPAIRS

4. RECOMMENDED APPROACH TO BOILER REPAIRS

Taking into consideration the findings outlined in Section 2 and Section 3 of this report, as well as the engineering calculations provided in Appendix A, FMW has developed the following approach to repairing the existing boiler of No. 1361. Detailed calculations regarding the firebox repairs are included in Appendix B. As work on any historic boiler may necessitate a change in approach, the calculations, or repair methodology, may also be expected to change prior to final submission.

4.1 REPAIRING BOILER BARREL

FMW proposes the following repairs to the boiler barrel and front flue sheet:

- Rivets
  - Replace all rivets identified with the LIDS machine as being of improper metal when installed between 1996 and 2007, including those that hold the bottom of the front flue sheet in place

- Studs/Stud Holes
  - Many of the original studs in the boiler of No. 1361 are substantially corroded. Similarly many of the stud holes will need repair
  - As required, repair stud holes
  - As required, replace corroded or incorrect boiler studs with new boiler studs

- Washout Plugs
  - Replace the existing, riveted bronze PRR-style “TZ” washout plugs with standard, “Huron” type washout plugs in the top of the first course
  - The large, PRR-style bottom washout plugs in the first and third course would remain, but would be modified with Huron sleeves and plugs
  - Replacing the washout plugs in the first course will constitute flush patch repairs, and their repair shall be made in accordance with 49 CFR § 230.33(b)&(d)

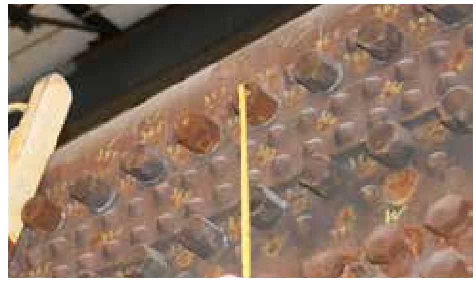
- Third Course Flush Patch
  - Verify that FRA accepts the repair documentation and the status of the existing repair
  - If required by FRA, retain an NDT firm to re-x-ray the welds to verify their integrity

4.2 REPAIRING THE FIREBOX

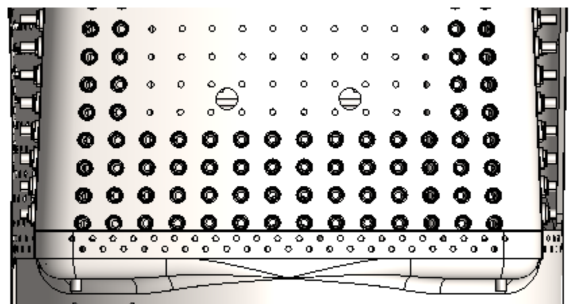
FMW proposes the following repairs to the firebox. Additional, detailed calculations provided in Appendix B:

- Wrapper Side Sheets
  - Replace both left and right sheets from forward rivet seam to back head weldment; from mud ring rivet seam to “Belpaire sheet”
  - Modify flexible staybolt pattern to better reflect the Flannery pattern using one-inch “D” type flexible stay bolts and “UW” sleeves
  - New wrapper side sheets should be fabricated of 0.4375 inch thick SA516-70 material for strength and compatibility with the existing 79 KSI replacement back head.

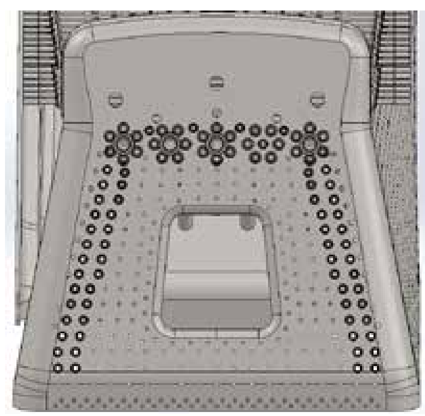
- Belpaire Sheets
  - Replace both left and right sheets with single, thicker piece, eliminating the doubler plate and rivet seam [right]
  - SA516-70 material; 0.6250" thick
  - Blend into wrapper side and roof sheets with 3:1 taper and weld
  - Include in forward rivet seam
  - Weld to back head
  - New cross stays with inside and outside nuts; outside washer per ASME code; include spherical washer to assure proper load transfer given taper of sheet



- Roof Sheet
  - Replace the wrapper roof sheet
  - Modify current "U" shaped pattern of flexible staybolts with two additional rows at hip end using one-inch type crown bolts with tapered threads at the crown sheet, "KN" nuts, and "URW" sleeves [right]
  - Rigid crown bolts to be up-sized to one-inch type bolts with tapered threads at the crown sheet.
  - New wrapper roof sheet should be fabricated of 0.4375 inch thick SA516-70 material for strength and compatibility with the existing replacement back head.



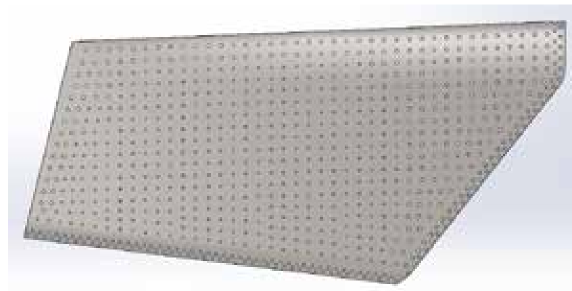
- Back Head
  - Remove existing back head
  - Modify to include "U" shaped Flannery bolt pattern of one-inch "D" type bolts and "UW" or "FW" sleeves [right]
  - This will help to minimize staybolt breakage given the more frequent heating/cooling cycles of steam locomotives in intermittent service.
  - Stress relieve
  - Reinstall back head



- Back Head Brace Brackets
  - Modifications / replacements to be made to brackets AA, BC, EF and G
  - Remove brackets AA, BC, and EF, plug weld the rivet holes in accordance with flush patch repair protocol per 49 CFR § 230.33(b)&(d)
  - Replace bracket AA, BC, and EF with thicker material of SA516-60, or similar, material
  - Modify bracket G to add stiffening ring, per Section 3.3 of this report
  - Reinstall brackets with rivets and/or weldment, as applicable

- Crown Sheet
    - Remove existing
    - Replace with SA516-70 material; 0.4375” thick to closely match the tensile of the new side, door sheet, and tube sheet to maintain a common tensile strength on all firebox sheets

- Door Sheet
    - Stress relieve existing door sheet
    - Install door sheet



- Firebox Side Sheets
    - Replace both left and right sheets in their entirety
    - SA516-70 material; 0.4375” thick
    - Replace all staybolts

- Combustion Chamber
    - The flexible staybolts which support the circular region of the lower combustion chamber were also found to be undersized for the area supported (6.500” X 4.250” spacing) - increasing these from one-inch to 1 ⅛” will reduce the staybolt stresses to within allowable limits
    - Up-size flexible staybolts in cylindrical portion with 1 ⅛” and reuse existing sleeves and caps, as able

- Rear Flue Sheet
    - The rear flue sheet, while of new construction, was found to be warped and improperly fit to the crown sheet
    - Note that the ASME code in this case requires that the mismatch in height between plates not exceed 0.125 inches [PW-9.3.1]
    - Remove, straighten, heat treat, correct alignment issues, reinstall

- Washout Plugs
    - Replace all with Huron type plugs, as required
    - Modify bottom drains to incorporate Huron plugs

- Arch Tubes
    - Longitudinal arch tubes of 3.00” outside diameter and 0.220” wall thickness seamless boiler tube (previously purchased but not installed) will be used per the original design to bear the weight of the brick arch
    - Transverse arch tubes were given serious consideration; however, given the maze of braces, crown stays, and cross stays in the space between the crown sheet and roof sheet, it would be problematic to fit these in a practical and code compliant manner.

4.3 CONCLUSION

The restoration to operation of No. 1361 is a task that requires the proper combination of project management, engineering knowledge, and technical skill. This report has endeavored to provide a clear path forward in terms of repairing the original pressure vessel to a state of good repair. Key to any next step is understanding the steps that have come before, and the combination of historical record review, forensic NDT inspection, and visual review of the pressure vessel have provided sufficient information from which to make the recommendations outlined in this report.

The next steps in the restoration of No. 1361 include receiving approval by the FRA of the flush patch repairs made to the dome, as well as having them review and comment on the balance of this report and the proposed repair plan for the firebox portion of the boiler. Once those reviews are completed, then repair work to the pressure vessel can proceed with a clear and defined path forward.

It is our sincere belief that, with transparency and the benefit of fact-based analyses, No. 1361 can again be returned to safe, reliable operational condition.

Harold Gensimore