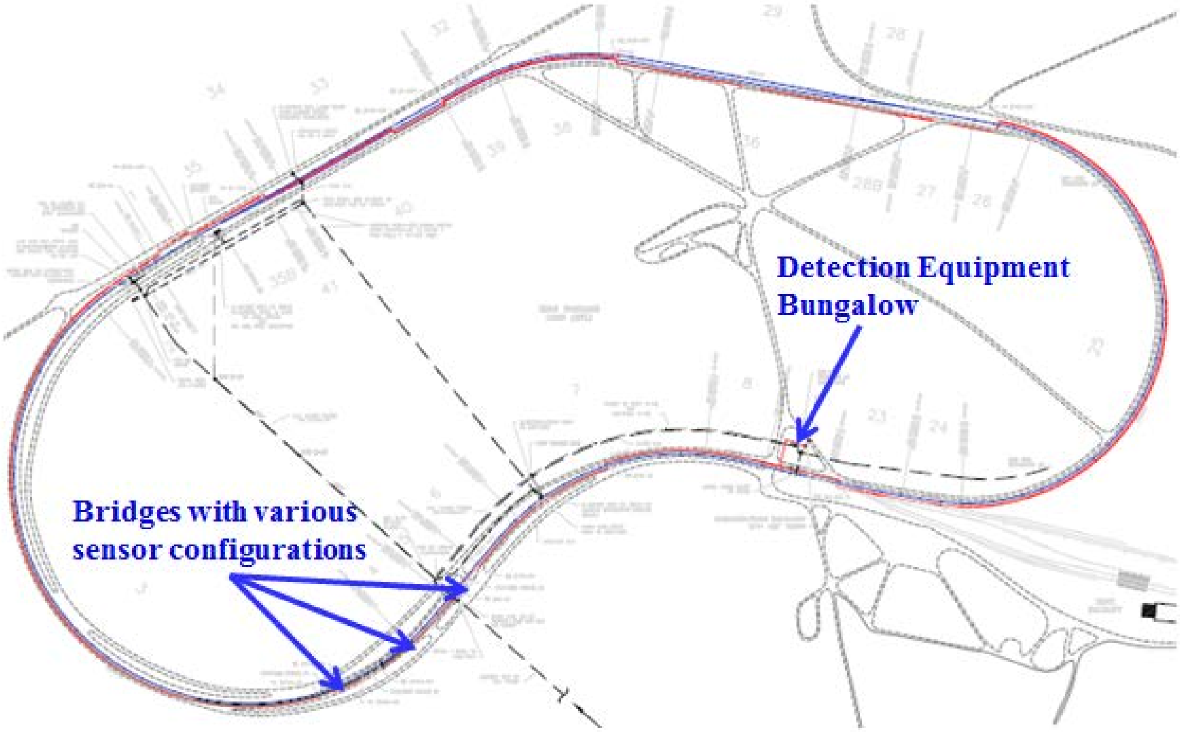
U.S. Department of
Transportation

**Federal Railroad
Administration**

Feasibility Study of Fiber-Optic Technology for Broken Rail Detection

Office of Research
and Development
Washington, DC 20590



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This report describes the activities and presents the results of a feasibility study to examine the viability of using fiber-optic acoustic technologies to detect broken rails in railroad tracks. A fiber-optic test bed was constructed at Transportation Technology Center (TTC) that consisted of fiber-optic cable (and related electronics) installed alongside the track of the High Tonnage Loop (HTL) at TTC's Facility for Accelerated Service Testing (FAST). The cable was used as an acoustic detector to monitor acoustic energy transmitted by the HTL track through the earth to the cable. Data from the acoustic detector was then analyzed to see if acoustic events from the track could be correlated to broken rails when they occurred during train operations at FAST.

During the study, analysts were able to identify and locate rail breaks. Follow-on efforts should focus on enhancing the existing capabilities of the fiber-optic test bed to enable it to detect additional acoustic events such as flat wheels and other railcar defects, as well as train position (including head-end and end-of-train detection), train velocity, length of train, braking issues, and the presence of railway trespassers.

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LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

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LENGTH (APPROXIMATE)

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1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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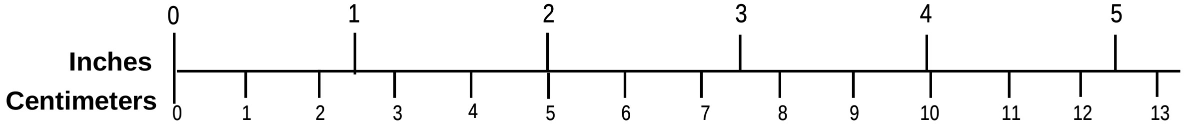

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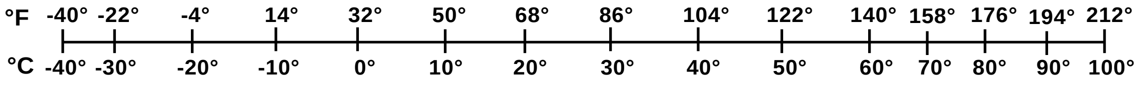

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Executive Summary

The Federal Railroad Administration (FRA) funded a feasibility study to examine the viability of using fiber-optic acoustic and seismic technologies to detect broken rails in railroad tracks. The test took place at Transportation Technology Center (TTC) in Pueblo, CO.

Initial investigation of the acoustic signature of broken rails indicates a definite change in the detected acoustic/seismic signal characteristics of a train passing over a section of rail at least five train passes prior to a rail break occurring in that section. This change is visible in the data of more than one data set, but much more data will have to be analyzed to reach a conclusion on this aspect of the project.

To enable the study to be performed, a fiber-optic test bed was designed and constructed at TTC. In essence, the test bed consisted of fiber-optic cable (and related electronics) installed alongside the track of the High Tonnage Loop (HTL) at TTC's Facility for Accelerated Service Testing (FAST). The cable was used as an acoustic detector to monitor acoustic energy transmitted by HTL track through the earth to the cable. Data from the acoustic detector was then analyzed to see if acoustic events from the track could be correlated to broken rails when they occurred during train operations at FAST.

The objective of the feasibility study was to evaluate the potential of fiber-optic acoustic and seismic detection technologies to detect broken rails as a train passes over them, including the potential to detect incipient rail breaks.

The scope of the study was multifaceted and included:

- Creating a fiber-optic test bed on the HTL at FAST;
- Installing fiber-optic-related test equipment and data acquisition systems for acquiring acoustic/seismic data from the track during train operations at FAST;
- Storing and managing the data for potential subsequent processing and analysis;
- Monitoring train operations at FAST and documenting rail breaks (typically two rail breaks per 3 days of operations) on the HTL;
- Processing and analyzing data related to the rail breaks to determine if there was a correlation between the two; and
- Potentially providing data to vendors interested in trying to use it for developing rail break detection algorithms.

The study focused on using normally occurring rail breaks on the HTL to provide acoustic signature data for collection and study. The research process involved collecting data on rail breaks before, during, and after the breaks occur, and it included exploring the potential of the technologies to alarm on a rail break. It also included examining the potential to possibly detect incipient rail breaks based on studying and characterizing the acoustic signatures that evolve as internal rail flaws propagate to rail failure.

By analyzing the level of change in acoustic or seismic signatures of the rail before, during, and after a break, TTCI engineers were able to gather enough data to clearly pinpoint rail breaks using data processing techniques developed during the study. Currently, this data processing approach is a very time-intensive effort to post-process data into usable results. Further

development of data processing methods is needed to streamline this process into a system that can detect broken rails and alarm on such events in near real time.

Additional follow-on work for this test bed at TTC should focus on enhancing the existing capabilities of the fiber-optic test bed to enable detection of additional acoustic events. With this and other projects, TTCI has explored flat wheels, broken rail, and additional railcar defects. It is the opinion of TTCI that this system has many capabilities that may or may not have been explored to date. The system should be able to detect additional rail events such as train position (including head-end and end-of-train detection), train velocity, length of train, braking issues, and the presence of railway trespassers. Each of these events may also have multiple uses. In addition, further exploration of other vendors with similar types of technology is needed to see that universal multivendor post-processing methods can be developed.

1. Introduction

This report describes the activities and presents the initial results of a feasibility study to examine the viability of using fiber-optic acoustic and seismic technologies to detect broken rails in railroad tracks. FRA funded the study under Task Order 317 and TTCI conducted tests in 2012 and 2013 at TTC in Pueblo, CO.

To enable the study to be performed, a fiber-optic test bed was designed and constructed at TTC. In essence, the test bed consisted of fiber-optic cable (and related electronics) installed alongside the track of the HTL at FAST. The cable was used as an acoustic detector to monitor acoustic energy transmitted by HTL track through the earth to the cable. Data from the acoustic detector was then analyzed to see if acoustic events from the track could be correlated to broken rails when they occurred during train operations at FAST. Initial results are promising, and an additional investigation is warranted.

1.1 Background

The use of fiber-optic technologies for acoustic and seismic detection has been ongoing in several industries such as oil and gas, pipeline, security, and military for a number of years. However, the use of these technologies for functions other than communications or optical applications is relatively new to the railroad industry.

For approximately the last 5 years, fiber-optic acoustic detection technologies have been used in the United Kingdom (UK) for a number of railroad-specific applications, including dynamic en route train length, speed, and location determination, trespasser presence and location detection, and verification of ongoing maintenance-of-way activities. Building on the success of the UK applications, CSX Transportation Corporation conducted a proof of concept (POC) demonstration at TTC in 2011 to examine the potential of using these technologies for wayside car health detection. During the POC demonstration, data was acquired for railcar wheels rolling over mechanical rail joints. Initial analysis of this data suggested the potential for these fiber-optic technologies to detect broken rail locations.

Noting the vast amount of fiber-optic cable already installed in the right-of-way or very near existing railroad infrastructure, FRA expressed an interest in further evaluating the effectiveness of these technologies to detect broken rail locations. As a result, TTCI was tasked to conduct more thorough and detailed investigations.

1.2 Objectives

The feasibility study was conducted to evaluate the potential of fiber-optic acoustic detection technologies to detect broken rails, including the potential to detect incipient rail breaks.

1.3 Scope

The scope of this project is multifaceted and includes:

- Creating a fiber-optic test bed on the HTL at FAST;
- Installing fiber-optic-related test equipment and data acquisition systems for acquiring acoustic/seismic data from the track during train operations at FAST;
- Storing and managing the data for potential subsequent processing and analysis;

- Monitoring train operations at FAST and documenting rail breaks (typically two rail breaks per 3 days of operations) on the HTL;
- Processing and analyzing data related to the rail breaks to determine if there was a correlation between the two; and
- Potentially providing data to vendors interested in trying to use it for developing rail break detection algorithms.

This study focuses on using normally occurring rail breaks on the HTL to provide acoustic signature data for collection and study. The scope includes collecting data on rail breaks before, during, and after the breaks occur and exploring the potential of the technologies to alarm on a rail break. It also includes examining the potential to possibly detect incipient rail breaks based on studying and characterizing the acoustic signatures that evolve as internal rail flaws propagate to rail failure.

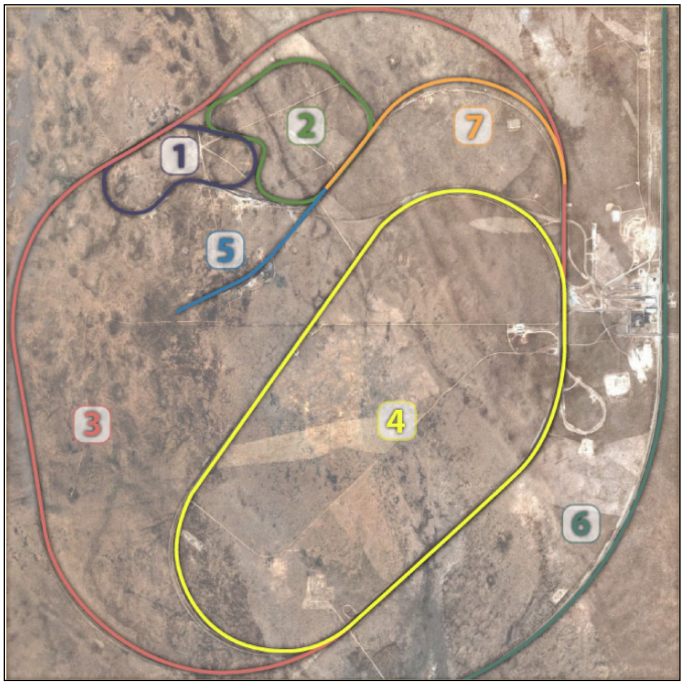
2. Study Approach

The study approach included three primary tasks:

1. Creating the fiber-optic test bed,
2. Gathering rail break data, and
3. Analyzing the broken rail data.

2.1 Task 1: Creating the Fiber-Optic Test Bed

The intent of Task 1 was to install fiber-optic cable around the HTL at FAST. The HTL is principally used for track component reliability, wear, and fatigue research under heavy axle loads (HAL). Operations are restricted to a maximum 40 miles per hour. The HTL is divided into test sections that generally correspond to tangents, spirals, curves, and turnouts. Additionally, FAST was built to test the effects of increased axle loads on track structure and rolling stock. The HTL and HAL program have reliably produced improvements in track structure, component design, construction practices, inspection technologies, training, and maintenance procedures. Figure 1 shows test tracks at TTC. The HTL's location is indicated by the number 1.



1. High Tonnage Loop
2. Wheel Rail Mechanism
3. Railroad Test Track
4. Transit Test Track
5. Impact Track
6. Precision Test Track
7. Train Dynamics Track

Figure 1: Test Tracks at TTC

The fiber-optic cable was planned to be installed around the HTL, using an installation configuration geometry representative of that used by the North American railroad industry for installing fiber-optic cable on revenue service routes. In addition to this operationally representative configuration, the installed layout was planned to encompass unique and experimental configurations that would allow for additional levels of monitoring. Dual fiber lines, coiled fiber test zones, multiple track detection zones and varied depth, enclosure type, and ducting were explored. The fiber-optic cable was intended to be installed in such a way that its physical installation parameters would allow for changing configurations with relative ease.

2.2 Task 2: Gathering Rail Break Data

The overall approach for gathering data consisted of monitoring train operations at FAST on the HTL and recording track-generated acoustic and seismic data with fiber-optic data acquisition systems using detection techniques similar to those of an optical time domain reflectometer (OTDR).

The planned data gathering approach used a fiber-optic distributed acoustic sensing (DAS) unit purchased from a small UK-based company to process and record the backscatter data from the fiber-optic cable. The DAS unit was chosen as the main set of test equipment both for its open and adaptable formatting as well as the level of technical support available from the manufacturer of the unit.

The chosen fiber-optic DAS unit was initially designed and built for use in the oil and gas industry. This type of unit demonstrates potential for use in many other applications such as security and railroad health monitoring.

The basic functionality of the fiber-optic DAS works by using an optical cable of up to 40 km long to act as tens of thousands of individual real-time vibration sensors. The vibrations can be detected in a multitude of frequencies and amplitudes. Frequency detection potential with the DAS installed at TTC ranges from 1 to 25,000 Hz. The fiber-optic DAS functions by directing a predefined pulse width and pulse repetition frequency of laser light through a single mode fiber-optic cable. The unit, much like a common OTDR, then reads and records the Rayleigh backscatter from many points along the fiber. The same unit then receives and records the strength of the return light pulse along with the time the pulse takes to return. The data from the DAS is then recorded and displayed in a real-time waterfall graph. The system is able to detect acoustic and seismic activities by interpreting changes in the Rayleigh backscatter triggered by those events. The data from an acoustic or seismic event contains frequency, magnitude, and distance from the DAS along the fiber-optic cable. Laser pulse width and repetition frequency settings determine the frequency and spatial resolution potentials of the data collected by the system. The maximum data acquisition potential of the system installed at TTC is 25,000 Hz at 0.67-meter resolution.

For further analysis of data, a second unit was required to parse and separate data of interest. This second unit is referred to as a data analysis unit (DAU) and is a Linux-based server that allows data to be parsed into smaller usable segments and also allows the user to manipulate filter settings and replay data files to better display defined events in data.

2.3 Task 3: Analyzing Broken Rail Data

Historical data about rail breaks at FAST on the HTL suggests that it is practical to expect about a dozen such events in the proposed 6-week testing period. Breaks in the rail on the HTL are presently detected using a traditional track circuit-based broken rail detection system. When a break occurs and the traditional signal system detects the broken rail, the time and location of the break are logged in the so-called FAST event log. The testing approach planned that this data would be provided to the test team daily in order to compare the log data with the data from the fiber-optic detection system.The study team would then process and analyze the data to determine if there were correlations between patterns in the recorded data and the rail break events listed in the FAST event log.

3. Summary of Test Activities

The following sections describe test activities associated with each of the three primary tasks in the testing portions of the feasibility study.

3.1 Task 1 Activities: Creating the Fiber-Optic Test Bed

An overview of the fiber-optic cable and its installation includes the following:

- The main sensing fiber is Superior Essex Series W7001KU101 FTTP (fiber to the premises) cable. It is loose tube, single jacket cable with 12 single-mode fibers in an FTTP profile.
- The fiber installation was performed as close as practical to the method of fiber installation along live track in revenue service to best represent real world installation scenarios. Single mode fiber was buried on average 36 inches deep and 15 feet from centerline of track.
- The cable was buried beneath the ground using both direct burial and directional boring techniques.
- Thirteen splice vaults were installed in predetermined locations around the perimeter of the HTL to allow for easy manipulation of the fiber-optic cable in future tests.
- The fiber was installed starting and ending at the FAST communications bungalow (located near HTL Section 9) to allow for multiplying fiber lengths should a fiber length of more than 3 miles be required. The bungalow provided environmental controls and adequate space for working and monitoring testing activities.

TTCI installed a fiber-optic test section that roughly parallels the HTL. The cable used for the installation was a 12-strand Superior Essex FTTP type. This cable was chosen for its ability to be installed in an outdoor environment without the thick outside cladding used in many fiber-optic cables as a means of protection and strength. The FTTP cable is a loose tube, gel-filled fiber-optic cable that uses solid core fiberglass strengthening members to allow for outdoor use and a high pull rating greater than 300 pounds. Figure 2 shows a diagram of the cable.

The fiber-optic cable deployed at the HTL test site is 3 miles long. A 328-foot section that does not parallel the track directly is used as a transition zone from the test bungalow to the HTL track. The fiber cable is installed on average 15 feet from track centerline. The cable is buried at depths of 18 to 42 inches, averaging 36 inches in most sections directly paralleling the track. Directional boring was also used as a means of perpendicular track crossings as well as in the section of track between sections 35 and 36 of the HTL. The bypass track is located in this section and directional boring between the two tracks serves as a method of monitoring both the mainline and bypass track equally.

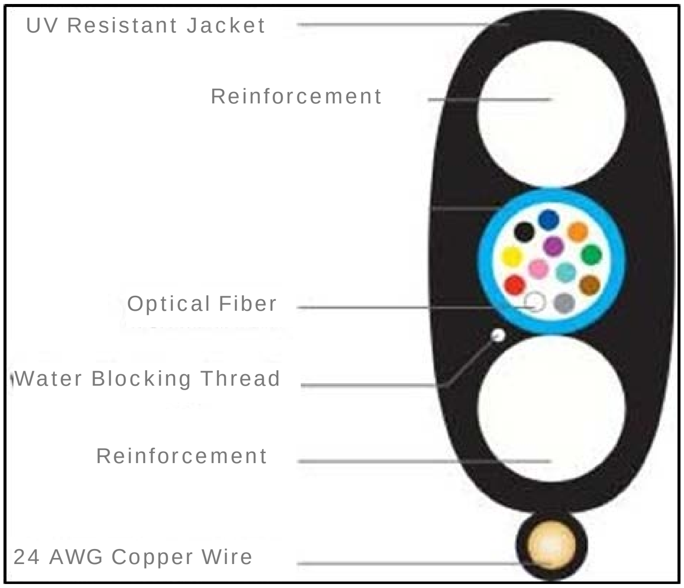


Figure 2: Superior Essex FTTP

Fiber installed in the bypass section was buried at an average depth of 42 inches. All other fiber buried in open trench was installed at 36 inches with the exception of one purposefully designed installation depth test zone. This depth test zone is located in section 3 for 650 feet paralleling the track, and it has a double cable of fiber, one at 36 inches and a second at 18 inches deep. The purpose of this fiber depth test zone is to study the effects of fiber installation depth on the fiber-optic data system. All fiber-optic burial cable installed in open ditch was surveyed using high accuracy GPS. This survey will serve as a reference for both depth and location to track for this and future studies. Figure 3 shows a fiber installed location and corresponding GPS data overlay of the cable's location. As shown, there is excellent correlation between the installed and GPS-determined locations. Figure 4 shows an overview of the fiber-optic cable location around the HTL.

The test area also incorporates smaller test sections with the capability of adding customized experimental zones designed to collect specific event data. These test zones will be multifunctional and can be easily reconfigured to test additional events. Installation location varies according to track geometry in the given track section (i.e., edge of ballast installation location varies with superelevation of track).

Figure 3: Side-by-Side Comparison of Installation Photo and GPS Survey Overlay

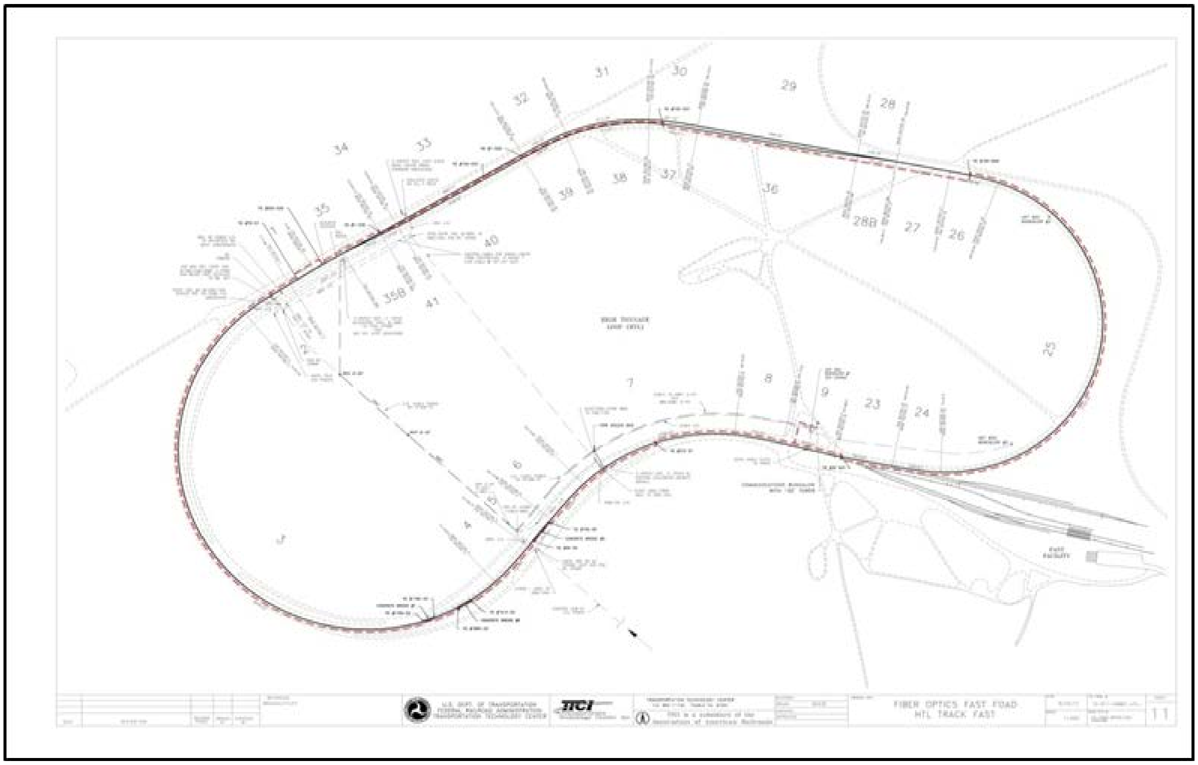


Figure 4: Overview of Fiber-Optic Cable Location at the HTL

Before the fiber-optic cable installation process began, TTCI studied historical rail break data of the HTL to aid in choosing the most prominent track areas for rail breaks. Statistical data suggests more than 70 percent of rail breaks occur on the outside rail in the curve of sections 3 and 25. For this reason, the fiber in these sections has been installed on the outside of the track to better lend it to broken rail detection studies.

Installation of the fiber-optic cable between sections 35 and 36 was performed using directional boring at a depth of 42 inches. Directional boring was chosen as an installation method in these sections to allow the fiber to be installed at equal distances from both the mainline and bypass sections of the HTL. Because the track spacing in this area does not lend itself well to the direct burial installation method, directional boring was used as a means of best-case installation method for this area.

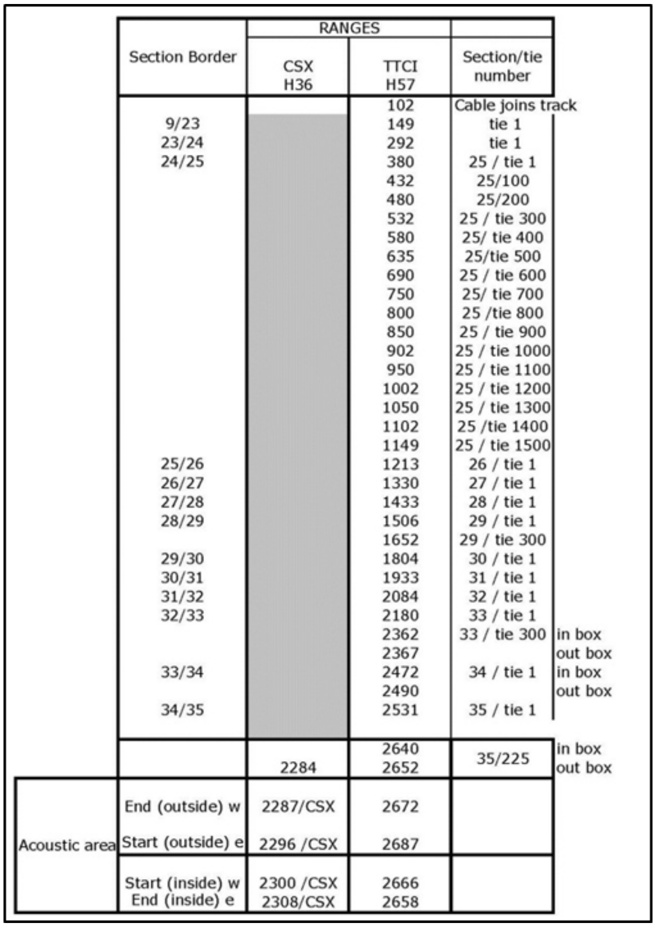
There are three bridges on the HTL, two precast concrete and one steel in composition. Each of the bridge spans hosts a different set of test objectives and materials. TTCI concluded after studying railroad bridge fiber-optic transition methods used on revenue service lines that the use of a small diameter ridged steel conduit affixed to the lower side of the bridge ballast curb (see Figure 5) was the most prominent installation method to use. This installation method coincidentally also provides a secure connection between the bridge structure and the fiber-optic cable, allowing for a usable amount of acoustic coupling. During testing, TTCI test personnel observed that the bridge sections generated a large amount of incipient noise from wind and acoustic coupling of other activities taking place on the same track farther down the line.

For approximately one-quarter of the track, the HTL runs parallel to the Railroad Test Track (RTT) with track centerline distances being separated by approximately 20 feet. By installing the fiber under and on the outside of the RTT in a portion of this test section, the cable configuration provides the capability to collect single track data during testing (by excluding RTT traffic during test runs) and offers the potential to acquire double-track data in future testing, when the defect detection algorithms are more mature.

Figure 5: HTL Bridge with Fiber-Optic Conduit

3.2 Task 2 Activities: Gathering Rail Break Data

After installation of the fiber-optic DAS unit and fiber-optic cable was complete, a spatial calibration was performed. A spatial calibration is a means of verifying system integrity as well as a method to easily identify wayside points of interest in the data systems. Because a system must have a baseline to compare, spatial calibration is necessary after any new installation or after any splices or modifications have been made to the fiber media. A spatial calibration is done by generating an acoustic event at a predefined position along the fiber while the DAS monitors changes in the Rayleigh backscatter. This point of interest is denoted in the Helios Web Interface (HWI) and in supporting documentation. Figure 6 is an example of a spatial calibration sheet.



		RANGES			
	Section Border	CSX H36	TTCI H57	Section/tie number	
			102	Cable joins track	
	9/23		149	tie 1	
	23/24		292	tie 1	
	24/25		380	25 / tie 1	
			432	25/100	
			480	25/200	
			532	25 / tie 300	
			580	25/ tie 400	
			635	25/tie 500	
			690	25 / tie 600	
			750	25/ tie 700	
			800	25 /tie 800	
			850	25 / tie 900	
			902	25 / tie 1000	
			950	25 / tie 1100	
			1002	25 / tie 1200	
			1050	25 / tie 1300	
			1102	25 /tie 1400	
			1149	25 / tie 1500	
	25/26		1213	26 / tie 1	
	26/27		1330	27 / tie 1	
	27/28		1433	28 / tie 1	
	28/29		1506	29 / tie 1	
			1652	29 / tie 300	
	29/30		1804	30 / tie 1	
	30/31		1933	31 / tie 1	
	31/32		2084	32 / tie 1	
	32/33		2180	33 / tie 1	
			2362	33 / tie 300	in box
			2367		out box
	33/34		2472	34 / tie 1	in box
			2490		out box
	34/35		2531	35 / tie 1	
			2640	35/225	in box
		2284	2652		out box
Acoustic area	End (outside) w	2287/CSX	2672		
	Start (outside) e	2296 /CSX	2687		
	Start (inside) w	2300 /CSX	2666		
	End (inside) e	2308/CSX	2658		

Figure 6: Example Spatial Calibration Sheet

After spatial calibration, train operations on the HTL were monitored for a period of 4 weeks. During this test period, a multitude of rail breaks and weld breaks occurred. The data gathered was compared and correlated with the FAST event log used to monitor and log the time and location of rail breaks and other anomalies. All data was logged and stored for subsequent analysis and acoustic signature classification. Once the data was collected, a post-processing hardware unit was used to subset and convert the data to a format usable in most types of analytics software.

The parsing functionality of the DAU proved to be quite useful in early testing, as data file potentials from the DAS are quite large. On an average night of testing on the HTL, the unit produced upwards of 150 data files (of which most were larger than 16 gigabytes each), the sum of which was around 3 terabytes per night of testing and up to 15 terabytes per week. In early testing, the DAU proved to be an excellent tool to allow parsing of data files into more manageable sizes.

For each day of testing, the DAS unit saved the data to a 48-terabyte network accessible storage (NAS) system to be stored and used for further analysis. The NAS system chosen for this phase of testing was a Thecus N16000. This system was chosen for its large storage capabilities and for its economic pricing. The Thecus NAS system was able to store and transfer data to and from the DAS, the Thecus, and later in testing, directly to a MATLAB server. The data storage centric local area network (LAN) architecture proved to be valuable during testing, as it allowed data to be easily accessible from many servers and users.

Remote access was also configured for outside access to the fiber-optic test track segregated LAN. Remote access was established using a Cisco ASA5505 router. The ASA5505 supported multiple virtual private networking (VPN) clients. However, for ease of use, TTCI decided on a single client, AnyConnect SSL. The ability for remote access from on- and off-site locations allowed TTCI engineers working on the project to gain access to data from anywhere with Internet access. The VPN access worked well to streamline work efforts and to make the most efficient use of time.

The DAS, DAU, Thecus, Cisco router, and MATLAB server systems were housed in a secured data enclosure along with other supporting networking equipment, all in the confines of a segregated high speed LAN. The segregated LAN environment allowed for increased data transfer speeds of up to 10 gigabits per second. High-speed networking was essential to allow the large volumes of data to be recorded to the NAS in real time. This segregated LAN architecture for the system was also designed around keeping the data secured from out of network influence to ensure data results remained intact. Figure 7 shows a diagram of the Helios enclosure and LAN topology.

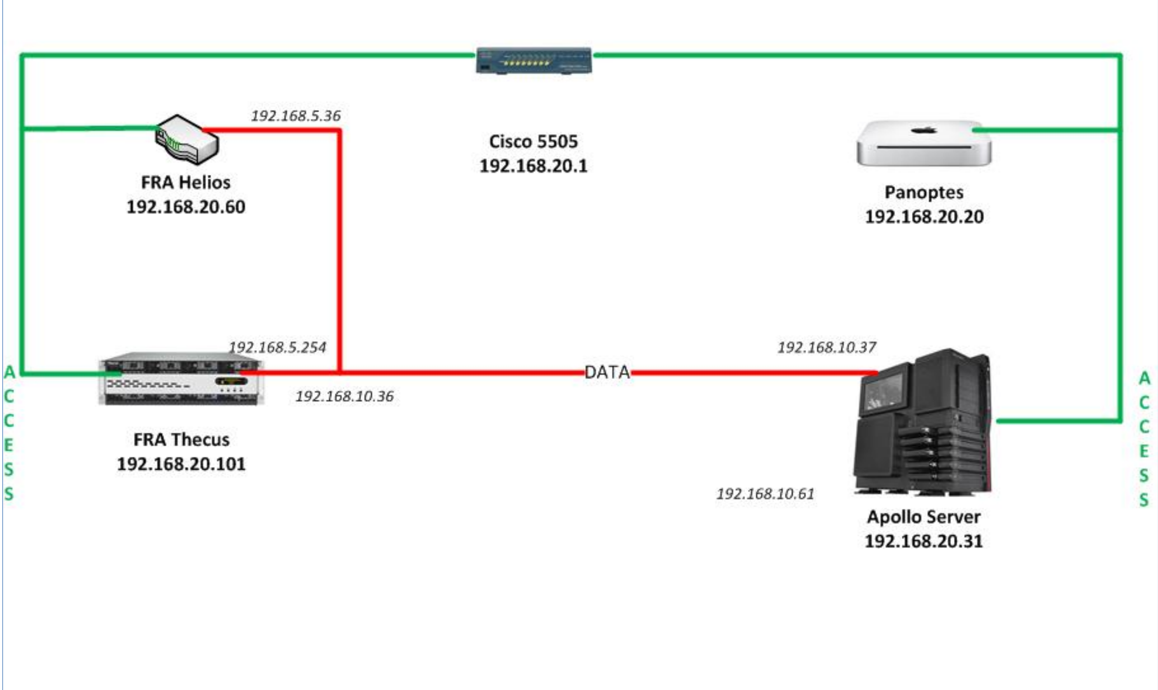
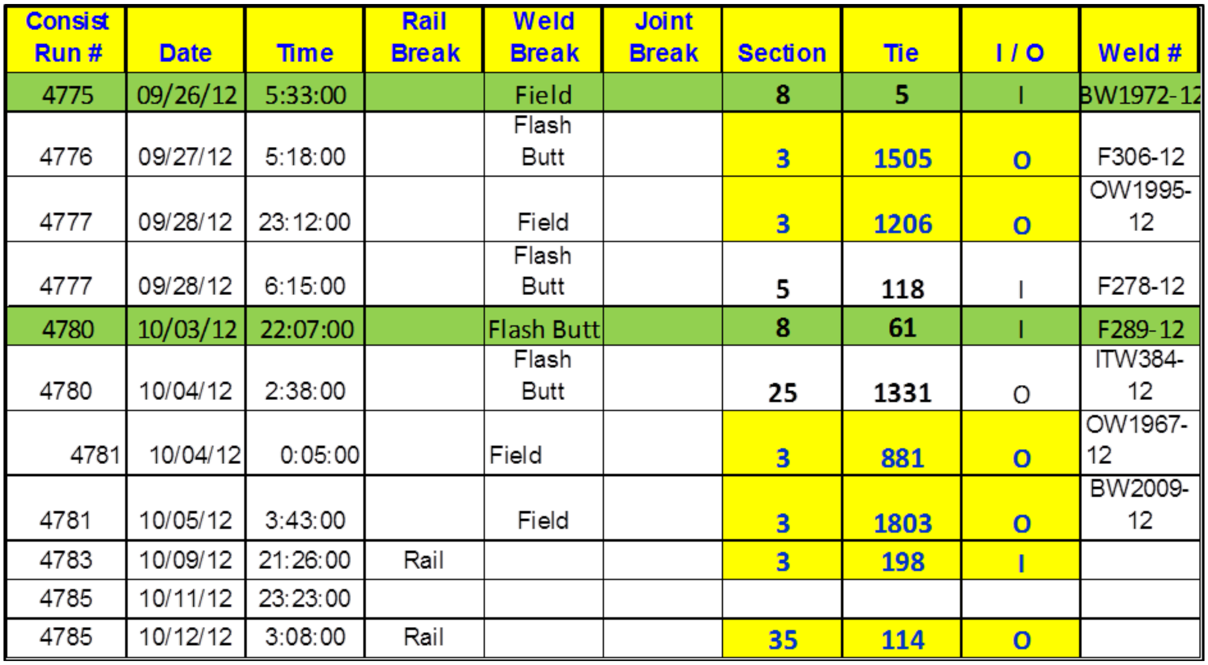


Figure 7: Helios Enclosure and LAN Topology

Most test data was collected in a semi-automated fashion by using a script file to start and stop data captures in 4-minute increments during running hours of the test train at FAST. Four-minute data files were chosen to keep files within workable size parameters of under 16 gigabytes. Data was then accessed via VPN connection for further analysis.

Testing was monitored for a period of 6 weeks. Within this test period, a multitude of rail and weld breaks occurred. The data gathered from testing over this timeframe was compared and correlated with the FAST event log (Figure 8). All data was logged and stored for subsequent analysis and acoustic signature classification.



Consist Run #	Date	Time	Rail Break	Weld Break	Joint Break	Section	Tie	I / O	Weld #
4775	09/26/12	5:33:00		Field		8	5	I	BW1972-12
4776	09/27/12	5:18:00		Flash Butt		3	1505	O	F306-12
4777	09/28/12	23:12:00		Field		3	1206	O	OW1995-12
4777	09/28/12	6:15:00		Flash Butt		5	118	I	F278-12
4780	10/03/12	22:07:00		Flash Butt		8	61	I	F289-12
4780	10/04/12	2:38:00		Flash Butt		25	1331	O	ITW384-12
4781	10/04/12	0:05:00		Field		3	881	O	OW1967-12
4781	10/05/12	3:43:00		Field		3	1803	O	BW2009-12
4783	10/09/12	21:26:00	Rail			3	198	I	
4785	10/11/12	23:23:00							
4785	10/12/12	3:08:00	Rail			35	114	O	

Figure 8: Example of FAST Event Log

There were also a few small-scale verification tests performed during testing. These small-scale tests involved the use of a light locomotive making low speed passes over a known broken rail, while the Helios recorded the acoustic events generated (see Figure 9). This type of testing was performed early in the testing phase to help TTCI engineers understand what type of acoustic frequencies and magnitudes are generated by a broken rail event under a passing train. In the controlled environment, rail break acoustic data was able to be collected with the most control and least amount of background noise available. The small-scale testing proved to be valuable for the remainder of testing, as it demonstrated clearly the acoustic frequencies and magnitudes generated by wheel and rail impacts in a broken rail event.

Train Runs

Time	File	MPH	Direction	Frequency (kHz)	High/Low Band (Hz)
Broken Rail					
14:26	1	5	E->W	10	1500/50
14:31	2	10	W->E	10	1500/50
14:46	3	10	W->E	5	1500/50
14:46	3	10	E->W	5	1500/50
14:52	4	10	E->W	2.5	1250/50
14:52	4	10	W->E	2.5	1250/50
	5	10	E->W	2.5	1250/50
Joint Bars Applied					
15:20	6	10	W->E	2.5	1250/50
15:20	6	10	E->W	2.5	1250/50
15:23	7	10	W->E	5	1250/50
15:23	7	10	E->W	5	1250/50
15:29	8	10	W->E	10	2500/50
15:29	8	10	E->W	10	2500/50

Figure 9: Light Locomotive Broken Rail Test

3.3 Task 3 Activities: Analyzing Broken Rail Data

TTCI used the data collected in Task 2 to begin examining the potential of detecting rail breaks by using the level of change in acoustic or seismic signatures of the rail before, during, and after a break was detected in the rail. When a break occurred, the data from the fiber-optic detection unit was flagged. TTCI then analyzed the data relating to the broken section of rail to determine if fiber-optic acoustic systems were capable of detecting broken rail and weld events.

Two main software methods were used during the analysis task of this test, HWI Sound Field and MATLAB filtering. The HWI Sound Field is a built-in functionality of the DAS system. This front-end analysis allows the raw data to be filtered for specific anomalies such as frequency range, magnitude, and distance along the fiber. The data is displayed in waterfall graph form at nearly real time while data is being collected. Raw data can be processed at near real time with predetermined parameters, but it can also be reprocessed at a later time with changed filters, should a differing output be desired. Using newly gained knowledge of rail and wheel impact frequencies and magnitudes from this test, TTCI engineers were able to set the HWI Sound Field to clearly filter for broken rails in most instances (see Figure 10). Special challenges during the use of HWI Sound Field arose while detecting broken rails with long, heavy train consists at or near bridges or switches because these areas produce significantly more noise in these special trackwork areas than in the general HTL track installation. Filtering techniques will need to be explored more closely in future development efforts.

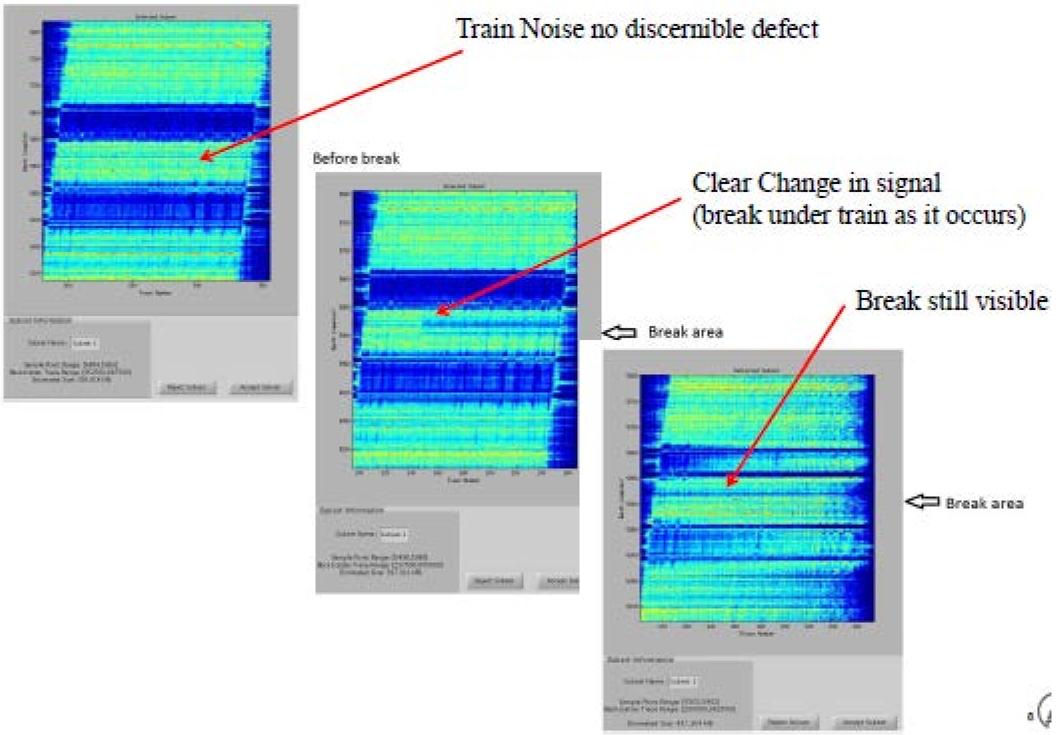


Figure 10: HWI Detection of Rail Weld Break (Three train passes)

While the HWI did perform the task of displaying a broken rail, the analysis, tools, and filters are somewhat limited compared with a commercial analysis software such as MATLAB. For this reason, TTCI engineers used HWI in addition to data post-processed via the Apollo server for analysis in MATLAB. In an effort to streamline filtering and processing, the MATLAB analysis of the data was performed using subsets of data parsed from the full raw files. Using these subsets of data, along with other filtering methods, TTCI engineers were able to extract a clear display of a broken rail as seen in Section 3 of the HTL (Figure 11). This figure gives a much more detailed look at the broken rail location. The x-axis in Figure 11 is represented in 10-second units and the y-axis is in 2-foot units. Each of the small vertical lines in the center represents the increase in acoustic energy produced as each truck in the FAST train makes contact with the broken rail weld. As displayed in Figure 11, the focal point of the acoustic energy is at rows 13 and 14 of the figure (low level light blue noise at all other rows), which depicts a broken rail during the entire pass of a train in this area of the fiber. Due to the nature of the fiber optic cable, the acoustic signature of the rail break passing through the earth is seen in the fiber in two sensor locations, giving about a 4-foot area of track to inspect. When shown full scale, this position on the figure would show the relative position of the break on the track within a few meters.

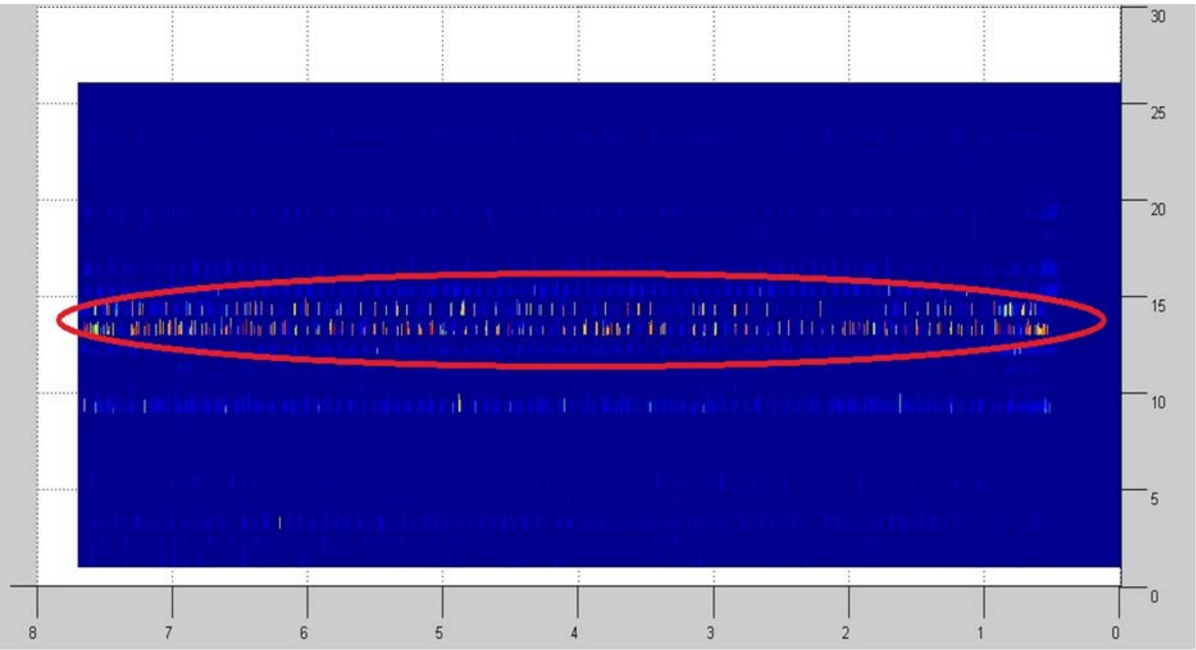


Figure 11: Broken Rail Section 3 HTL (MATLAB)

4. Conclusion and Follow-On Recommendations

By analyzing the level of change in acoustic or seismic signatures of the rail during train passes before, during, and after a break occurs in the rail, TTCI engineers were able to gather enough data to roughly locate rail breaks using both software solutions previously mentioned. Currently, this is a very time-intensive effort to post-process data into usable results. Further development of data processing methods is needed to streamline this process into a system that can detect broken rails and alarm on such events in near real time. Initial investigation of the acoustic signature of broken rails indicates a definite change in the signal as a train passes over a section of rail at least five train passes prior to a break occurring in that section. This change is visible in the data in more than one data set (more than one rail break), but much more data will have to be analyzed to reach a conclusion on this aspect of the project.

Additional follow-on work for this test bed at TTC should focus on enhancing the existing capabilities of the fiber-optic test bed to enable detection of additional acoustic events. With this and other projects, TTCI has explored flat wheels, broken rail, and additional railcar defects. It is the opinion of TTCI that this system has many capabilities that may or may not have been explored to date. The system should be able to detect additional rail events such as train position (including head-end and end-of-train detection), train velocity, length of train, braking issues, and railway trespassers. Each of these events may also have multiple uses, such as for application of a velocity algorithm and a position algorithm for crossing system development. Further exploration of other vendors with similar types of technology is needed to allow universal multivendor post-processing methods to be developed.

Abbreviations and Acronyms

DAS	distributed acoustic sensing
DAU	data analysis unit
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
FTTP	fiber to the premises
GPS	global positioning system
HAL	heavy axle load
HTL	High Tonnage Loop
HWI	Helios Web Interface
LAN	local area network
NAS	network accessible storage
OTDR	optical time domain reflectometer
POC	proof of concept
RTT	Railroad Test Track
TTC	Transportation Technology Center (facility)
TTCI	Transportation Technology Center, Inc. (company)
UK	United Kingdom