UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
RAIL TRANSPORTATION AND ENGINEERING CENTER
RAILTEC

TECHNICAL NOTE

TECH NOTE NO: 2
TITLE: Preliminary Strain Gauge and Matrix Based Tactile Surface Sensor Instrumentation of Rail and Fasteners
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DATE/REV: 09/08/11

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1. Introduction

This technical note summarizes the results of an experiment focused on the preliminary strain gauge and matrix based tactile surface sensor (MBTSS) instrumentation of a segment of rail and the attached fasteners, hereafter referred to as “Tech Note 2”. The experiment tested the feasibility of building a load cell via instrumenting a segment of rail and the fastening system as well as measuring pressure distribution in the rail seat. There were 22 strain gauges placed on the system: 14 total strain gauges placed on the rail and 8 total gauges on the elastic fasteners. The MBTSS was placed at the interface between the concrete rail seat and the abrasion frame of the fastening system. The instrumented system and configuration of loading for this experiment is shown in Figure 1.

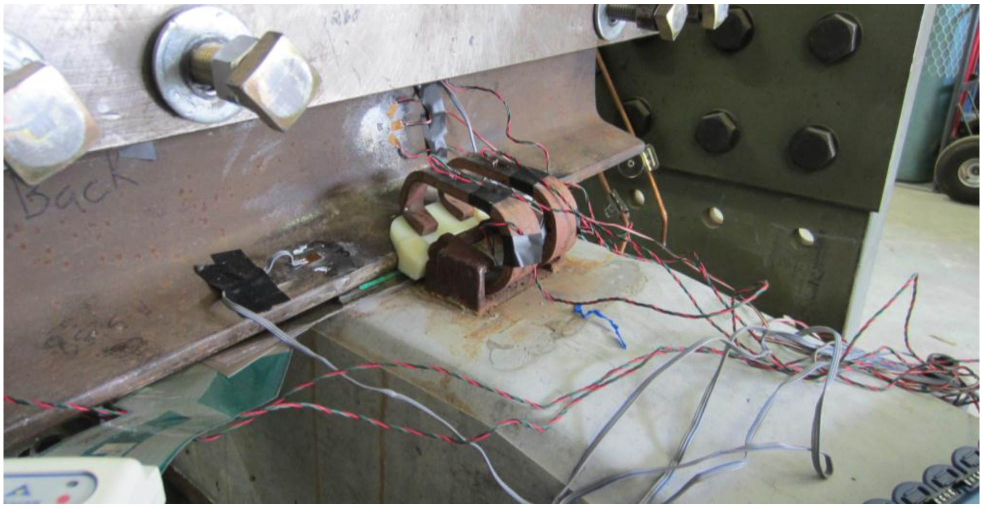


Figure 1: Rail and fastening system with applied strain gauges and MBTSS

2. Experiment

A 24" segment of rail was instrumented for use in this experiment. The segment was taken from the field, and therefore showed significant signs of head wear. We know that the height of the rail is about 6½'', so a 115 lb. AREMA Rail is assumed.

The segment of rail was instrumented with a total of eight (8) longitudinal strain gauges: two (2) on the top fillet near the rail head and two on the rail base of each side: gauge and field. Similarly six (6) gauges were placed at the center of each rail: three (3) on each side. These gauges were placed as rectangular rosettes. The center rosette was horizontal, and the two others were offset 45 degrees. The clips were instrumented with eight (8) strain gauges: two (2) on the top surface of the each clip and two (2) on the top surface of the clip base. Table 1 provides a detailed location of the gauges.

Table 1: Gauge placement

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Bottom				Top				Clip #1				Clip #2				Rosette #1			Rosette #2		
Gauge		Field		Field		Gauge		Bottom		Top		Bottom		Top							

Figure 2 and 3 shows a model of the rail segment and fastener with the locations of gauges from one side highlighted. This instrumented segment of rail was fastened by the clips and the loading frame was bolted in 4 locations across the head of the rail and can be seen in figure 1. The load was applied to the loading frame and distributed continuously across the full head of the rail.

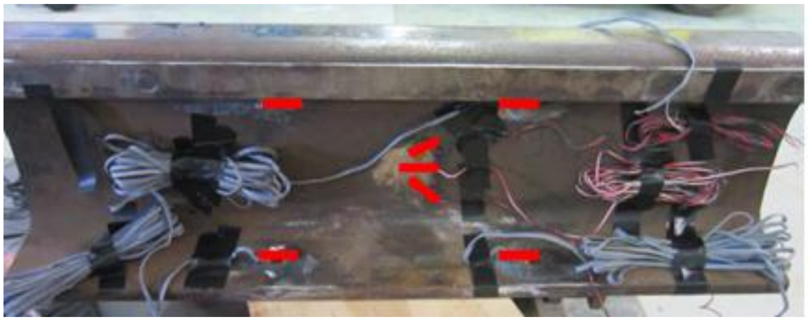


Figure 2: Section of rail showing placement of strain gauges (in red).

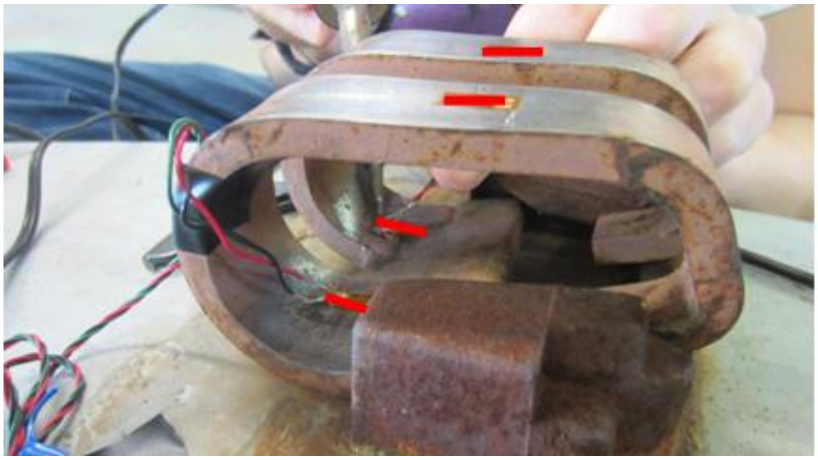


Figure 3: Gauge side fastener showing placement of strain gauges (in red).

The MBTSS was inserted at the interface between the concrete rail seat and the black plastic abrasion frame. This was to measure the distribution of pressure into the rail seat as the applied force from the actuators transferred downwards through the rail, fastening system components, and into the concrete crosstie. Figure 4 shows the layout in the rail seat with layers of Mylar and Teflon on either side of the sensor to protect from abrasion and shearing of the sensor during loading. This test was also the first time making use of the ability to trim the sensors to a desired geometry. The original sensor dimensions are too large for the rail seat, thus trimming it removes extraneous data collection as well as prevents damage to the sensor. Figure 5 shows the trimmed sensor with an overlay representing the area collecting rail seat pressure as well as gauge and field sides.

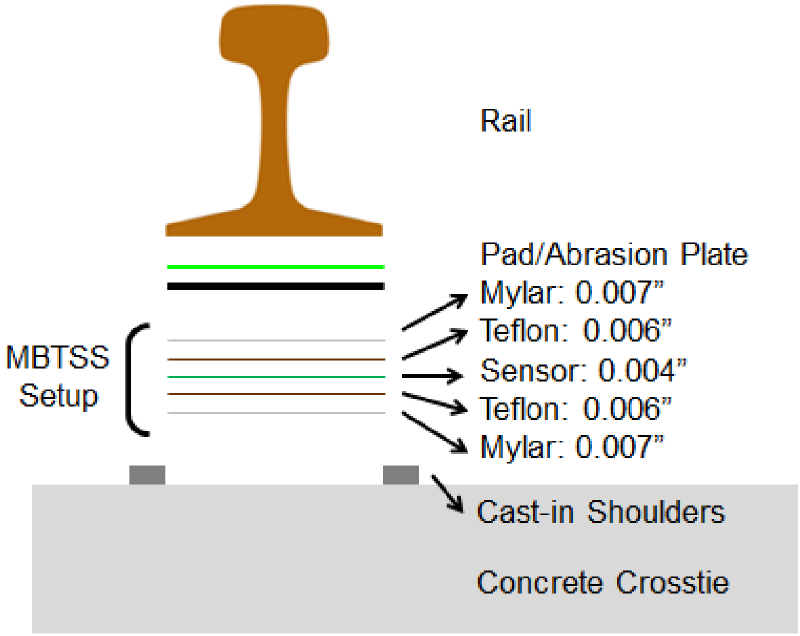


Figure 4: Layout of MBTSS Installation on rail seat

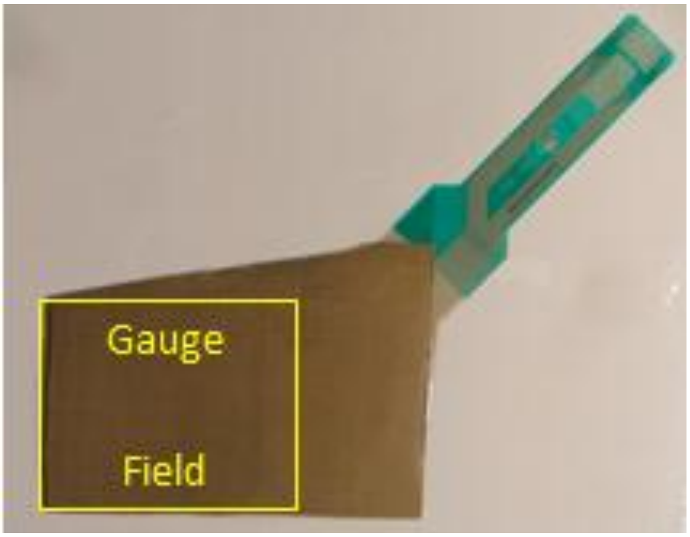


Figure 5: Trimmed Sensor with overlay representing rail seat area

3. Loading history

Static and dynamic loads were both tested under multiple magnitudes using the Pulsating Load Testing Machine (PLTM) located at the Advanced Transportation Research Engineering Laboratory (ATREL) at the University of Illinois at Urbana-Champaign (UIUC). Table 1 shows the static loading history, and Table 2 shows the dynamic loading history. The maximum percent load referred to in each table is based on a vertical load of 32,500 lbs. and lateral load of 16,900 lbs. for the L/V ratio of 0.52, and a vertical load of 32,500 lbs. and lateral load of 8,125 lbs. for the L/V ratio of 0.25. At each load, strain gauge data was acquired through the Compact DAQ system, and MBTSS data was acquired through the sensor data handle to the I-Scan software.

Table 1: Static loading history of rail segment

Loading History of Rail Segment*

Load Number	Percent Maximum Load (%)
1	5
2	20
3	40
4	60
5	80/100
6	40
7	60
8	80

*Load Numbers 1-5 were conducted with L/V = 0.52
Load Numbers 6-8 were done with L/V = 0.25

Table 2: Dynamic loading history of rail segment

Loading History of Rail Segment*

Load Number	Percent Maximum Load (%
1	20
2	40
3	60
4	80
5	100
6	20

*Load Numbers 1-5 were conducted at 0.5Hz (L/V =0.52)
Load Number 6 was done at 1Hz (L/V =0.52)

4. Results

The strain data that was output from these tests was ridden with noise and drift. The source of these has not yet been determined. The gauges were not zeroed at the start of each test, so some of the results directly from the test show strain already existing in the gauges.

These loading conditions were applied in relatively short spans of time, around 45 seconds to a minute, so any error due to drift was minimized by shortening the test period. Regardless, another test was performed and very little analysis was done on the data from this test. In particular, results from gauge #12 on the bottom of a gauge side clip were completely inaccurate and discarded from the analysis entirely.

The strains for each gauge was determined by taking the median value of strains in the duration of that static load. These values are recorded in table 3. Note the erroneous data from gauge #12.

Table 3: Median strain per percent maximum load of each gauge (με).

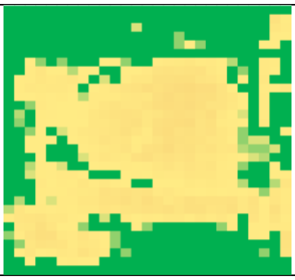
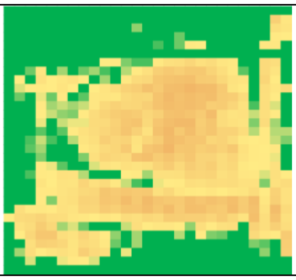
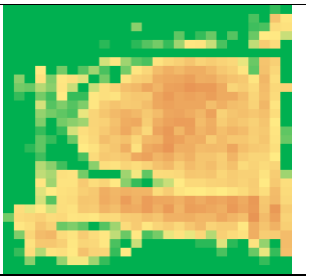
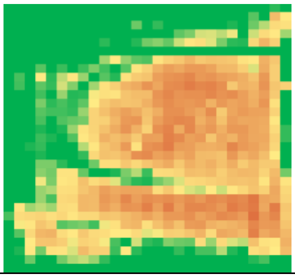
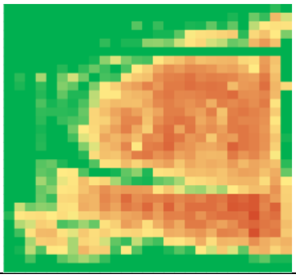
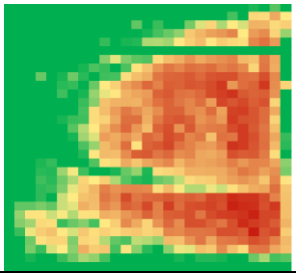
Gauge #	5%	20%	40%	60%	80%	100%
1	-51.0	-51.8	-50.8	-47.8	-28.2	-24.9
2	-40.9	-40.7	-41.0	-38.4	-14.6	-11.9
3	-40.2	-49.3	-57.8	-75.5	-265.0	-322.0
4	-49.3	-54.0	-59.5	-83.0	-282.0	-339.5
5	-85.5	-87.3	-89.5	-89.9	-97.1	-99.9
6	-29.1	-29.2	-29.7	-28.8	-26.8	-22.5
7	-214.0	-214.0	-210.0	-201.0	-162.0	-134.5
8	105.0	119.0	131.5	177.0	-20.2	-45.3
9	-2.1	-8.7	-25.2	-87.5	-291.0	-309.5
10	98.1	101.0	90.6	47.7	-135.0	-131.5
11	21.0	11.2	0.5	-1.9	-49.6	-35.3
12	2521.0	19674.0	11633.0	-788.0	31809.0	2521.0
13	62.0	59.4	51.4	34.1	68.4	40.4
14	-25.9	-29.8	-32.1	-33.6	32.6	26.6
15	-110.0	-115.0	-130.0	-149.5	-244.0	-271.0
16	-59.3	-68.0	-76.2	-94.3	-184.0	-202.5
17	8.1	2.9	7.9	25.3	163.0	238.0
18	17.5	19.4	23.7	39.0	156.0	198.0
19	42.1	40.1	40.9	44.5	91.5	160.5
20	-3.5	0.7	-2.3	-17.1	-139.0	-220.5
21	-7.0	-6.8	-7.5	-12.0	-57.6	-73.3
22	-173.0	-175.0	-181.0	-208.0	-396.0	-479.0

The pressure distribution data collected from the MBTSS was exported to excel for further analysis and for uniformity in visual representation. Table 4 shows the frame of maximum force reading for each of the six static loading scenarios, as well as the maximum pressure reading for each frame in pounds per square inch.

It must be noted that the sensor had been previously used and damaged in testing, so one aspect of this experiment was to test the ability of the sensor to still record data after having been trimmed (the damaged portion was in the area that was cut off). Any discrepancy in rows collecting data may be due to this, as is noted in the row approximately 1/5 distance from the top of each frame in Table 4.

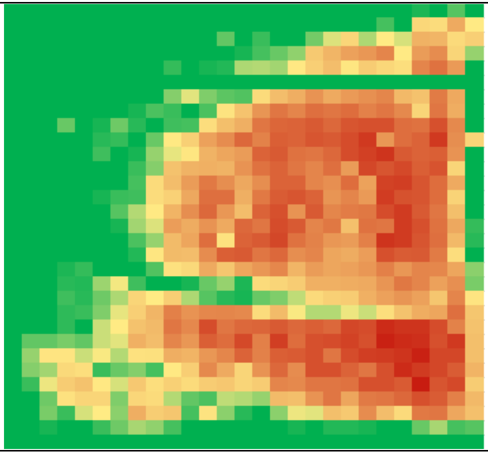
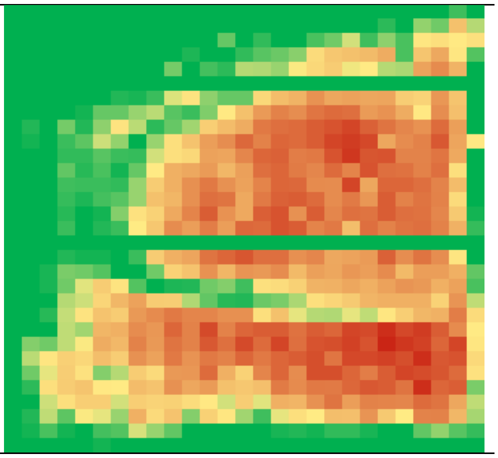
Peak pressure values were higher than expected given that the loading scenarios were similar to that used for the AREMA Test 6: Wear and Abrasion, and not that of any extreme conditions. This may be due to pad geometry and its ability to distribute pressure evenly, as it was a pad that had gone through previous testing. A less uniform distribution than expected would lead to higher peak pressure values than expected. Any further non-uniformity in distribution of pressure may also be due rail seat surface profile.

Table 4: Pressure distribution in rail seat per percent maximum load

Pressure (PSI) 0 500 1000 1500 2000 2500 3000			
% Max Load	5	20	40
Max PSI	220	715	1206
Pressure (PSI) 0 500 1000 1500 2000 2500 3000			
% Max Load	60	80	100
Max PSI	1709	2194	2708

Another set of information obtained from this test was leaving the sensor installed in the rail seat and observing the effect this had on its sensitivity. After seven days the sensor was put through several identical loading scenarios for a “before and after” comparison of pressure data. Table 5 shows a comparison of this data.

Table 5: Pressure distribution in rail seat before and after dead time

	BEFORE	AFTER
Pressure (PSI) 0 500 1000 1500 2000 2500 3000		
% Max Load	100	100
Max PSI	2708	2630
Contact Area (sq. in.)	27.39	28.70

During the dead time the sensor lost one row of data, however despite this the total contact area increased by approximately 5%. This is most likely due to settlement of the actuators and fastening components during this dead time. The sensors' sensitivity was reduced minimally, as maximum pressure recorded decreased by approximately 3%. It is assumed however that if the sensor was left installed in the field it would lose sensitivity at a much quicker rate as it would see many loading cycles from trains passing over the instrumented segment compared to this experiment where it was not loaded during the seven day dead time.

5. Final Remarks

From the noise and drift in the strain gauge data, there was a general understanding that instrumentation should progress more slowly and diligently to eliminate the noise. Trimming MBTSS appears to be feasible to rid of extraneous data collection from outside the rail seat, as well as prevent damage to the sensors. Still having the rail instrumented, it is imperative that the setup is investigated to locate sources of drift and perform more accurate tests.