U.S. Department of Transportation

Federal Railroad Administration

Ground Penetrating Radar (GPR) Technology Evaluation and Implementation: Appendices A Through F

Office of Research, Development and Technology
Washington, DC 20590

DOT/FRA/ORD-20/18

Final Report
May 2020

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Van Buren Trip Report (November 13, 2015)

Jerry Malone

November 24 through November 26, 2015, Van Buren, AR, A4G3.B.4 Federal Railroad Administration (FRA) task order 357

The purpose of this trip was to investigate the proposed placement of Global Positioning System (GPS) equipment on the FRA's DOTX220 track geometry (TG) inspection coach. The DOTX220 and DOTX218 test cars were in Van Buren that week for scheduled maintenance. Representatives from Balfour-Beatty Rail, Inc. (BBRI) and Zetica, the Ground Penetrating Radar (GPR) supplier, were present, as were personnel from ENSCO who operated and maintained the test cars.

Very little room is available on the undercarriage or trucks DOTX218 car for the GPR antennas—although similar antennas were temporarily mounted in front of cow catchers for a one-time test at Transportation Technology Center, Inc. (TTCI)—so this car was eliminated from consideration.

There are two each of the 2 GHz antennas and 400 MHz antennas to be mounted under the DOTX220 car. The car has available space on the trucks and undercarriage. Possible places to mount the antennas include the rear end—observation end—of the car between the holding tank and the truck (Figure A 2), between the rear truck and the rear end of the car, and between the trailing end of the lead truck and the storage forward storage compartments. ENSCO expressed a desire to reserve the space at the rear end of the car for future equipment. It was also decided to keep the area aft of the leading truck clear, so that maintenance crews have free access to service the TG measurement system (Figure A 3). Approximately 7 inches of both potential spaces must be kept clear for truck rotation.

It was agreed that the most practical location to mount the antennas are the storage compartments just aft of the lead truck (Figure A 1). The 2 GHz antennas will fit in this space, toward the outside of the carbody. The storage compartments must be modified. At least one of the 400 MHz antennas can be mounted in the center of this space; the other may be mounted slightly aft in the air compressor compartment, or on the rear of the car near the holding tank compartment if this proves impractical. Additional stringers must be added to the bottom of the storage compartments for strength. Convenient access for cabling can be had by drilling directly through the floor of the coach in the uninterruptible power supply (UPS) room—power locker—and through the floor of the compartment. It may be necessary to use 90- or 45-degree connectors to accommodate the cable, as large bending radii are required.

It is not possible to meet Plate A requirements with the antennas in this location. However, it is possible to meet Plate C requirements.

Plywood mock-ups were provided and placed at various potential locations (Figure A 1). Measurements were taken, and Balfour-Beatty agreed to make Computer-Aided Dispatch (CAD) drawings of the modified storage compartment.

Space for the control unit equipment is available in the equipment racks in the coach. However, it will be will be necessary to move existing equipment around in the racks to accommodate the electronics.

This work was planned for January through March 2016, at the Letterkenny Army Depot in Chambersburg, PA.

Figure A 1. DOTX220 storage compartment with plywood mockup of 2 GHz antenna

Figure A 2. DOTX220 available space between tank and rear truck

Figure A 3. DOTX220 TG measurement system with ALD detector

Appendix B.
BB/Zetica -ZR0345-15-KML02-A (Ravenna 2017 GPR Survey)

These images show the survey limits on the Ravenna Subdivision and the fouling depth layer (FDL) (note, this is used interchangeably with free draining layer [FDL]) and ballast fouling index (BFI) metrics for both the hi-rail vehicle and DOTX220.

1. Subdivision – Ravenna
2. BFI – Ballast Fouling Index
3. FDL – Fouling Depth Layer
4. Truck – Balfour Beatty Rail, Inc. (BBRI) Hi-Rail
5. Train – FRA DOTX220
6. For the blown-up section, you can see three line which represent metrics for the left/right shoulder and center of track.

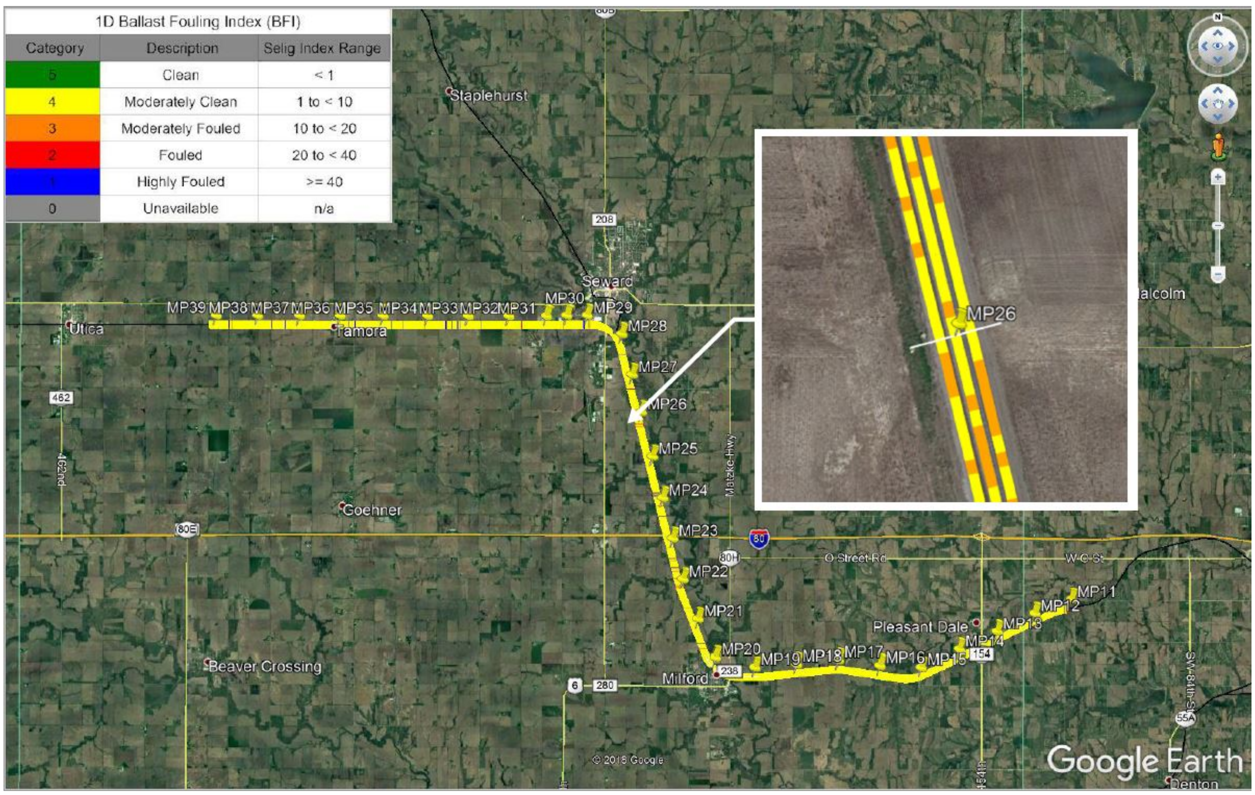

Figure B 1. BFI with train insert

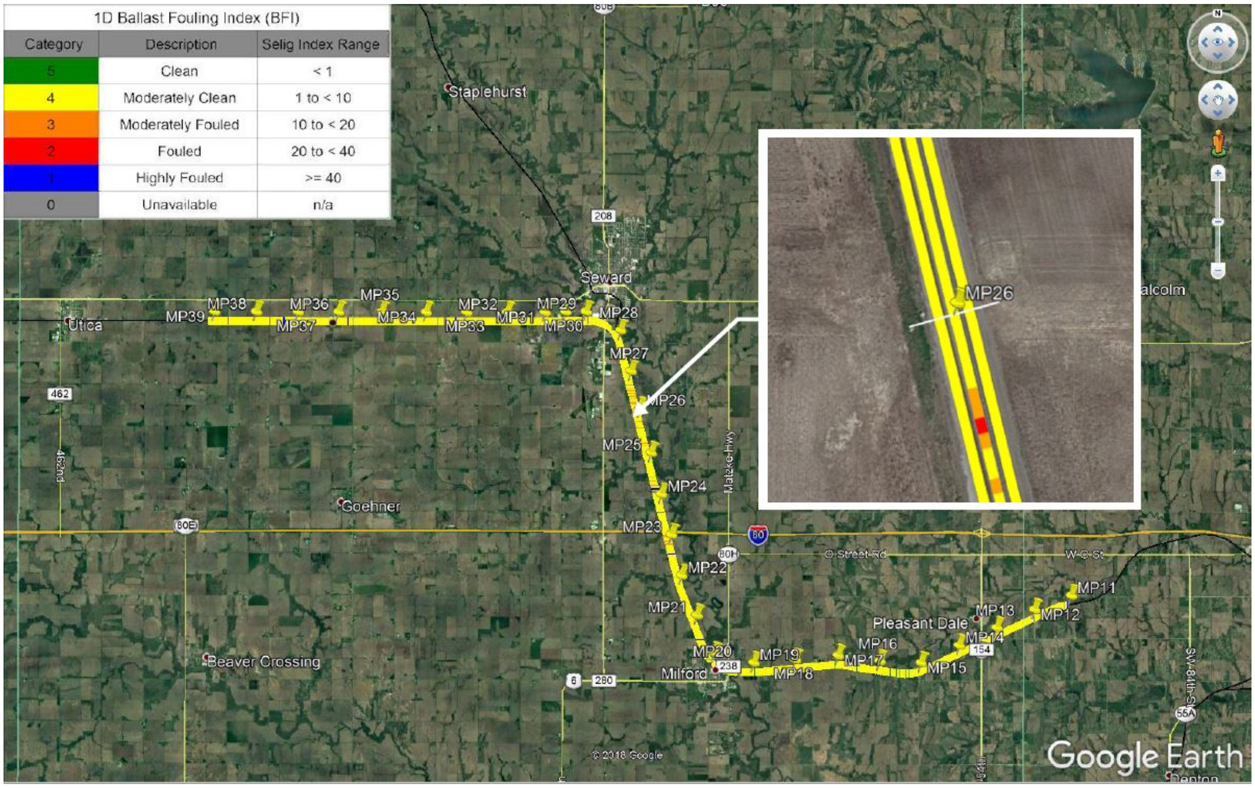

Figure B 2. BFI truck with insert

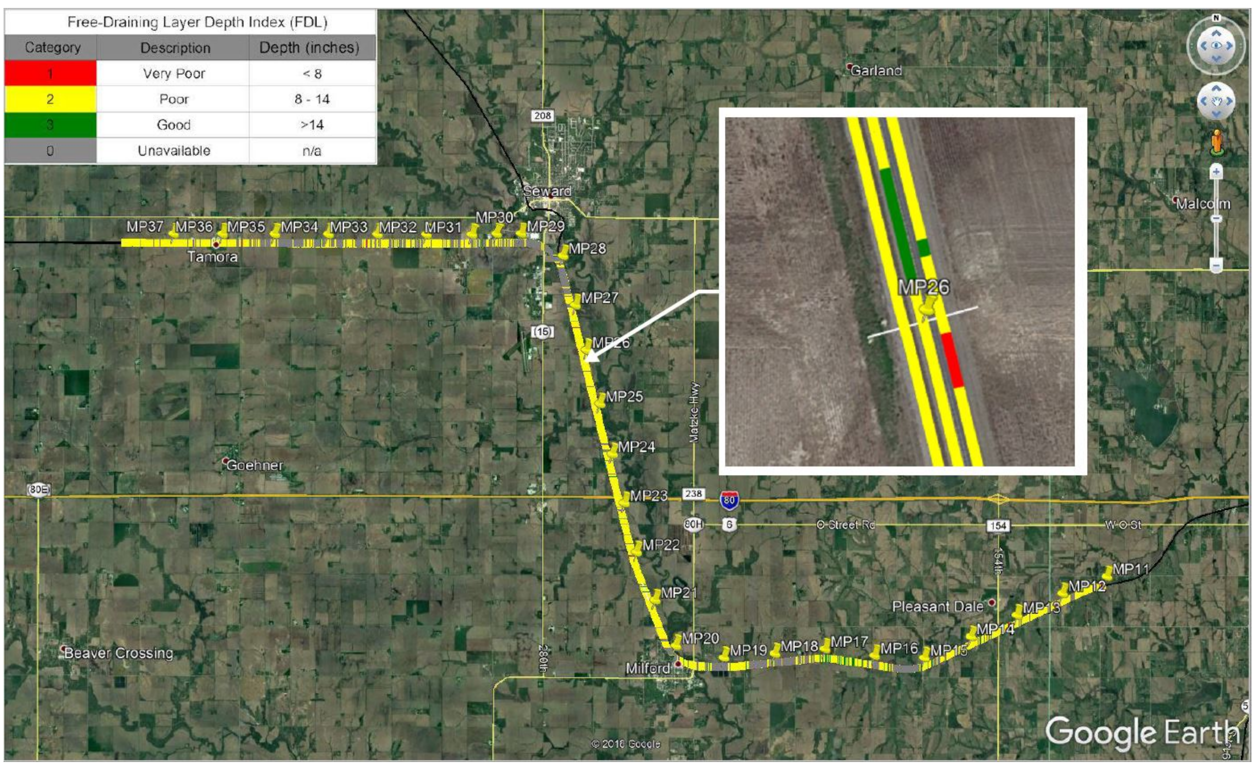

Figure B 3. FDL train with insert

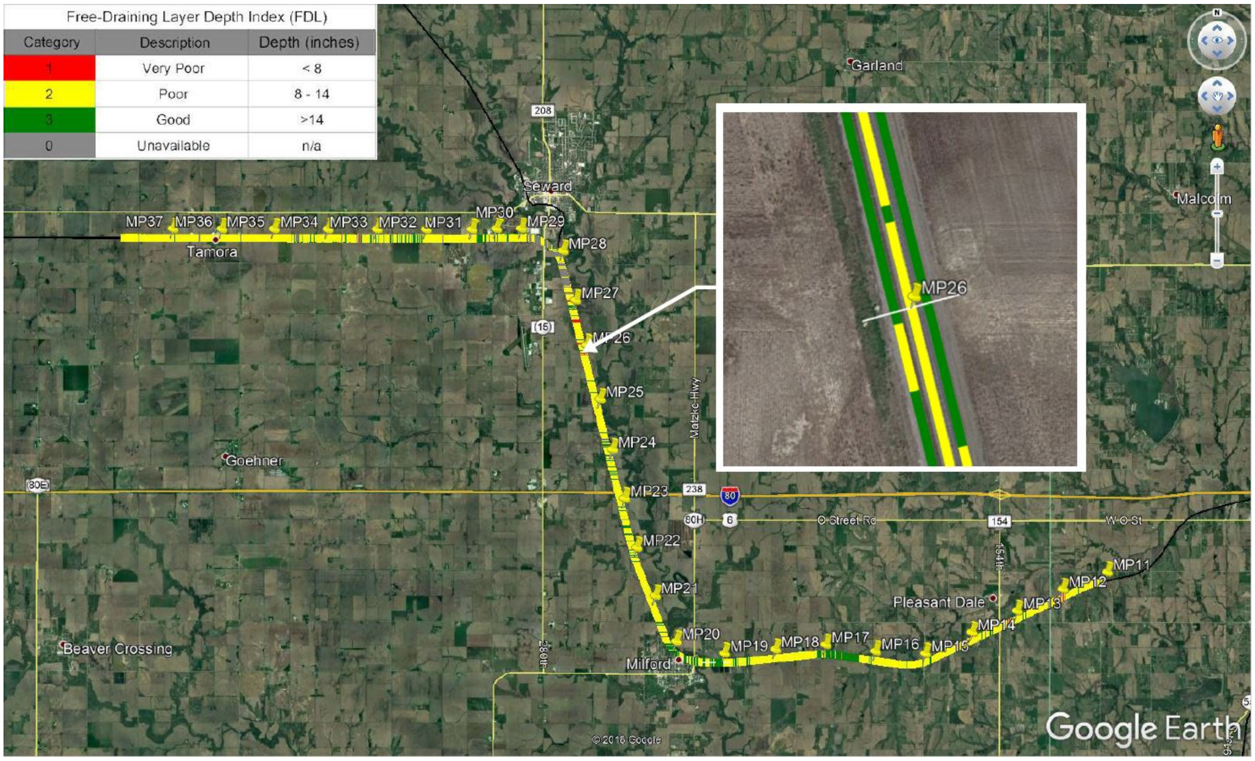

Figure B 4. FDL truck with insert

Washed vs Un-washed Ballast Samples

Comparison between Burlington Northern Santa Fe Railway (BNSF) and TTCI samples

Location 8

Table C 1. Passing #200 Sieve (%), Samples 8L, 8C, 8R

Sample	Passing #200 Sieve (%)	
	Unwashed (TTCI)	Washed (BNSF)
8L+0	2.1	4.0
8C-2		9.0
8C+0	1.6	7.9
8C+2	1.7	
8R+0	0.3	5.1
8R-2		3.9
Average	**1.4**	**6.0**

Location 13

Table C 2. Passing #200 Sieve (%), Samples 13L, 13C, 13R

Sample	Passing #200 Sieve (%)	
	Unwashed (TTCI)	Washed (BNSF)
13L-2		6.4
13L+0	0.6	
13C-2		13.4
13C+0	1.0	
13C+2	0.7	
13R-2		3.3
13R+0	0.4	
Average	**0.7**	**7.7**

Location 29

Table C 3. Passing #200 Sieve (%), Samples 29L, 29C, 29R

Sample	Passing #200 Sieve (%)	
	Unwashed (TTCI)	Washed (BNSF)
29L-5		7.7
29L-7		4.5
29L+0	1.9	
29L+2	2.1	
29C-5		7.0
29C-7		5.2
29C+0	2.3	
29C+2	2.2	
29R-5		9.7
29R-7		8.3
29R+0	0.4	
29R+2	0.3	
Average	**1.5**	**7.1**

Conclusion

- BNSF samples had significantly higher percent passing #200 sieve
  - Average % Passing #200
    - TTCI: 1.3%
    - BNSF: 6.8%
  - Does not consider the differences in individual samples at each location
- However, likely that washing produced a much higher, and more accurate, percent passing the #200 sieve

Appendix D.
Sol Solution - Final PANDA® Report

PANDOSCOPES®
TRACK SUB-STRUCTURES INVESTIGATIONS

N° Line:	BNSF LINE 4
Section:	Ravenna Subdivision
For:	TTCI
Track:	1 - 2
Number of tests:	40
MP:	022.700 - 039.871
Starting Date:	08/29/2017
Ending Date:	09/02/2017
Indice:	0

Week 35					
Y. Haddani					
Reporting date		Modifications			Auditor
2017/10/06					F. Ranvier

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L'INNOVATION SUR DE SOLIDES APPUIS
SOL SOLUTION

Pandoscope®: Presentation of the Methodology

1) PANDA®: Mechanical investigation test

The PANDA® test is a variable energy dynamic penetration test that is standardized in France for compaction control. Its use in the railway environment has been approved and is commonly accepted in France.

The tests consist of driving a set of steel rods equipped with a conical tip into the soil by hammering with a standardized hammer. At each hammer blow, the energy is measured in the anvil with energy gages.

Other sensors measure simultaneously the settlement or vertical displacement of the cone. All the data is transmitted to the acquisition unit equipped with a custom software.

The results are given as penetrograms, graphs that show the evolution of cone resistance (Qd) according to depth.

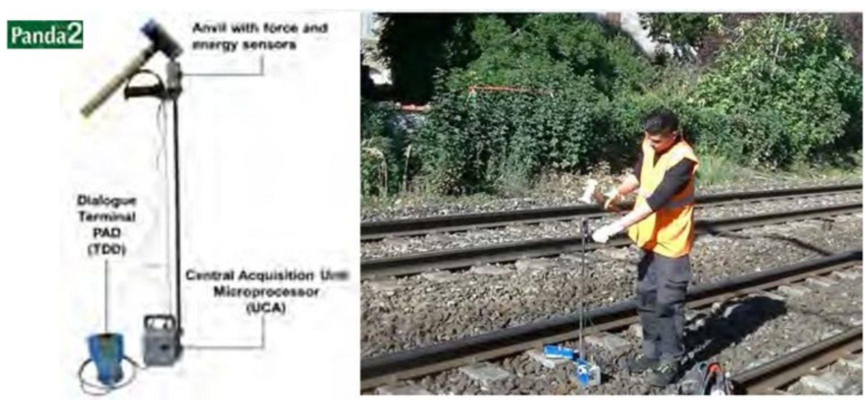


Figure D 1. <u>PANDA</u>®: principles

2) Geoendoscopy: Nature and visual Characterization of materials

Geondoscopy tests introduce a small diameter (8 mm) endoscopic probe into the hole previously made by PANDA® tests or any other boring. A video is then continuously recorded to characterize the different soil layers. Images extracted from this video are computed using automatic image analysis programs to provide information for each layer (i.e., thickness, nature, humidity, etc.).

PANDA® results are presented in a penetrogram given the evolution of cone resistance according to depth.

Endoscopic images and PANDA® data are processed at the same time to define and characterize the different substructure layers.

Interpretation of the soundings

Table D 1. PANDA® data to define and characterize different substructure layers

Layer	Visual Criteria
Ballast	Voids between ballast grains are filled with air
Fouled ballast	Voids are partially or completely filled with fine grained material
Interlayer	Mix of the upper layer ballasted and lower layer
Sub ballast layer	Backfill material that is present only in new lines
Subgrade	Usually natural soil, but may be artificial, can fill in embankments and approaches

Three levels of moisture were determined using endoscopic images:

- Dry
- Wet
- Saturated

The positions of the sounding and the distances are given according to the following figures:

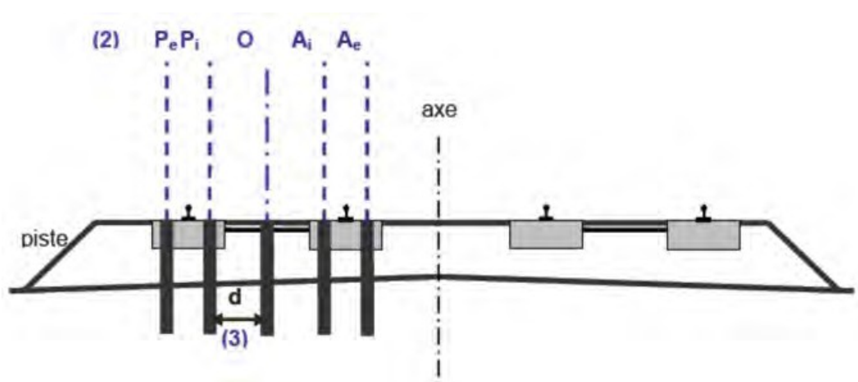


Figure D 2. Double tracks

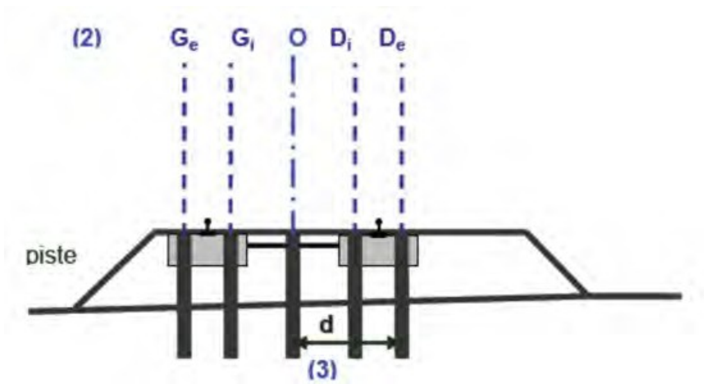


Figure D 3. Single tracks

Field Conditions

Day Wednesday 08/29/2017 - Sunny

7 tests Main 2 - Milepost (MP) 035.558–039.871

Observations: None

Day Thursday 08/30/2017 - Sunny

1 test Main 1–MP 025.788

14 tests Main 2 - MP 025.791–027.243

Observations: None

Day Friday 08/31/2017 - Sunny

11 tests Main 1 - MP 025.788–027.754

Observations: None

Day 09/02/2017 - Sunny

7 tests Main 1 - MP 022.700–022.772

Observations: None

Metrology

Table D 2. PANDA® equipment reference No. date of calibration

PANDA®	Equipment	Ref	Date of calibration
	UCA	7	01/11/17
	TDD	7	12/13/16
	Tête	17	08/11/16
Geoendoscope		Ref	Date of calibration
		7	02/20/17
GPS		Ref	Date of calibration
		None	

Pandoscope Tests Summary

Table D 3. Line 4 Main 1 MP 022.700–027.754

	Line 4 Main 1 MP 022.700 - 027.754								
	Distance to the top of the tie (ft)	Ballast		Sandy Ballast		Interlayer		Subgrade	
	Depth/Top of the tie TOT (ft)	Depth/ TOT (ft)	Qd ave - Zc (CBR)	Depth/ TOT (ft)	Qdave (CBR)	Depth/ TOT (ft)	Qdave (CBR)	Depth/ TOT (ft)	Qd ave (CBR)
Average	0	8	39	14	107	24	202	33	82
Std dev	0	3	22	4	54	5	72	4	68
min	0	1	7	9	31	15	96	28	17
max	0	12	86	23	210	31	324	38	158

	Number of tests	%	Depth min	Depth max	Average depth
PANDA® refusal	4	21	1.26 ft.	2.07 ft.	1.78 ft.
Saturation	0	0	none	none	none
All tests	19	100	1.26 ft.	3.15 ft.	2.22 ft.

Table D 4. Interlayer, subgrade, nature, and compaction degree/ree/quality level

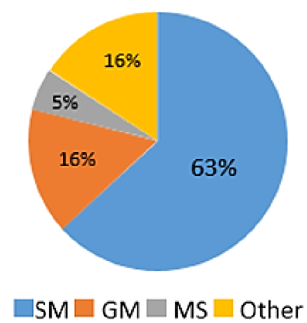
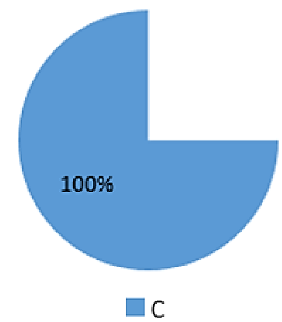
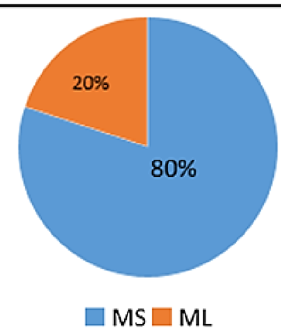
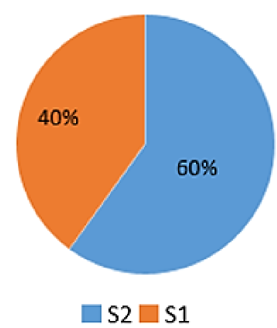
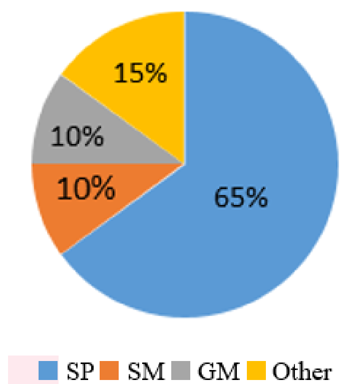
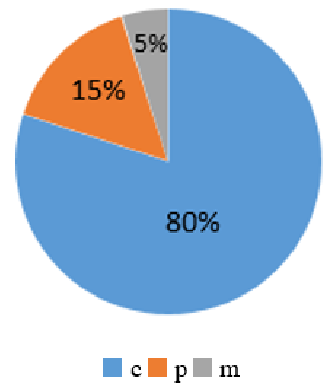
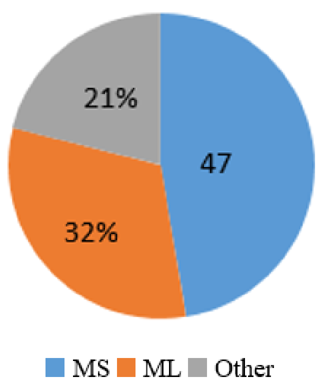
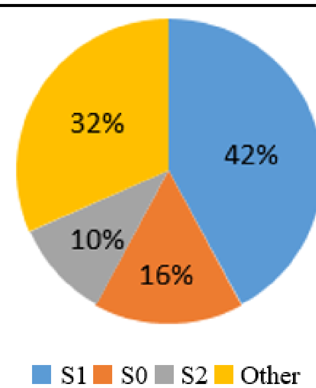
	Nature	Compaction deg/ree/Quality level
Interlayer (19/19)		
Subgrade (5/19)		

Table D 5. Main 2 Test Summary

	Line 4 Main 2 MP 025.791 - 039.871								
	Distance to the top of the tie (ft)	Ballast		Sandy Ballast		Interlayer		Subgrade	
	Depth/Top of the tie TOT (ft)	Depth/ TOT (ft)	$Q_{d\ ave}$ - Zc (CBR)	Depth/ TOT (ft)	Q_{dave} (CBR)	Depth/ TOT (ft)	Q_{dave} (CBR)	Depth/ TOT (ft)	$Q_{d\ ave}$ (CBR)
Average	0	7	32	11	85	26	108	32	19
Std dev	0	4	14	4	63	4	65	4	20
min	0	3	13	3	18	20	14	24	5
max	2	16	64	20	292	31	244	39	83

	Number of tests	%	Depth min	Depth max	Average depth
PANDA® refusal	1	5	1.68 ft.	1.68 ft.	1.68 ft.
Saturation	6	29	1.67 ft.	2.55 ft.	2.22 ft.
All tests	21	100	1.67 ft.	3.29 ft.	2.60 ft.

Table D 6. Interlayer, subgrade, nature, and compaction degree/quality level

<table>
<tr><th></th><th>Nature</th><th>Compaction degree/Quality level</th></tr>
<tr><td>Interlayer
(20/21)</td><td>
</td><td>
</td></tr>
<tr><td>Subgrade
(5/19)</td><td>
</td><td>
</td></tr>
</table>

Pandascope® tests

STATE

N°	Date	MP	Position	Distance to the middle of the track (ft.)	Depth max of geo-endoscopic test (ft.)	Depth max of PANDA test (ft.)	Ballast: Distance to the top of the sleeper (ft.)	Ballast: Bottom of the ballast layer (ft.)	Ballast: Cone resistance (CBR)	Ballast: Standard deviation (CBR)	Ballast: Bottom of the Sandy ballast layer (ft.)	Ballast: Cone resistance (CBR)	Ballast: Standard deviation (CBR)	Ballast: Nature of pollution
51	9/2/17	022.700	O	0	1,62	1,79	0	0,64	50,59	35,84	1,07	117,1	81,77	n
60	9/2/17	022.717	Pe	-2,69	1,56	1,65	0	0,92	52,31	42,57	1,22	162,7	73,03	n
61	9/2/17	022.717	O	0	1,42	1,56	0	0,54	48,79	31,27	1,15	154,7	96,05	n
70	9/2/17	022.734	Pe	-2,69	2,37	2,41	0	0,74	50,19	48,35	1,18	79,38	46,62	n
71	9/2/17	022.734	O	0	2,38	2,59	0	0,69	43,63	27,44	1,15	79,19	33	n
80	9/2/17	022.772	Pe	-2,69	2,36	2,47	0	0,92	30,14	15,55	1,28	209,6	118,2	n
81	9/2/17	022.772	O	0	1,16	1,38	0	0,58	38,7	25,67	0.84*	51.19*	20.29*	n*
110	8/31/17	025.788	Pe	-2,69	2,26	2,43	0	1,04	32,57	35,38	1,94	103,1	48,99	n
111	8/30/17	025.788	O	0	2,88	2,89	0	0,82	59,02	43,18	1,68	95,07	43,1	n
120	8/31/17	026.737	Pe	-2,69	2,89	2,9	0	0,95	38	46,21	1,25	40,2	20,11	n
121	8/31/17	026.737	O	0	1,48	1,74	0	0,56	52,63	50,85	1,04	161,9	105,9	n
122	8/31/17	026.737	Ae	2,69	3,15	3,15	0	0,9	37,07	30,52	1,3	167,1	83,24	n
131	8/31/17	026.763	O	0	1,1	1,26	0	0,53	86,13	101,9	1,1	192,1	116,7	n
140	8/31/17	027.729	Pe	-2,69	2,2	2,49	0	0,61	67,77	55,73	1,31	93,35	49,41	n
141	8/31/17	027.729	O	0	1,7	2,64	0	0.08*	5.65*	4.91*	0,74	35,23	22,12	n
142	8/31/17	027.729	Ae	2,69	2,67	2,67	0	0,53	8,42	3,04	1,12	107	80,07	n
150	8/31/17	027.754	Pe	-2,69	2,32	2,49	0	0,25	8	4,43	0,82	102,7	69,46	n
151	8/31/17	027.754	O	0	2,22	2,47	0	0,22	6,02	0,91	0,97	66,81	45,99	n
152	8/31/17	027.754	Ae	2,69	2,15	2,47	0	0,38	20,23	10,57	0,72	38,55	13,32	n

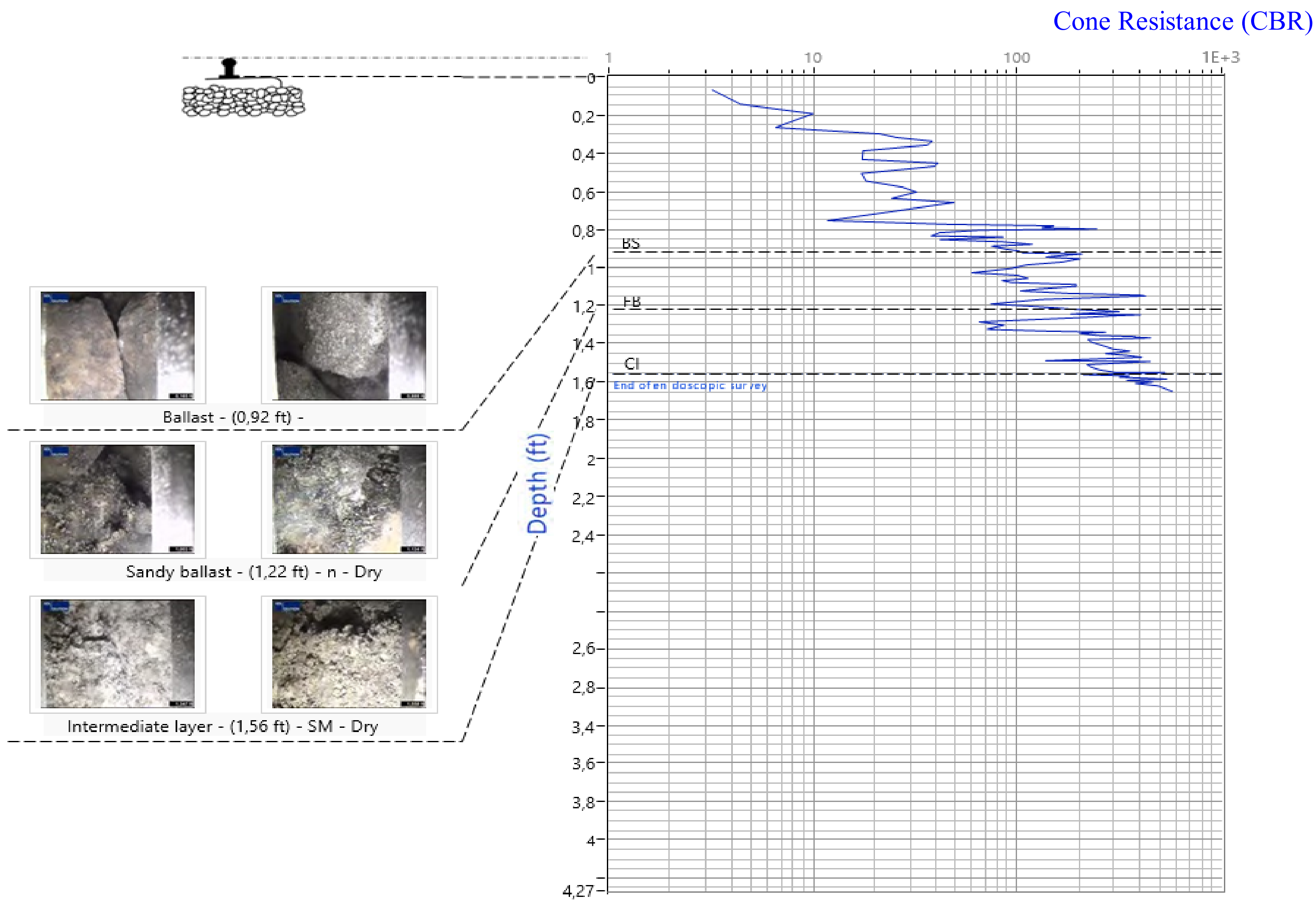
N°	Sub-Ballast Layer: Bottom of the sub-ballast layer (ft.)	Sub-Ballast Layer: Nature	Sub-Ballast Layer: Cone resistance (CBR)	Sub-Ballast Layer: Standard deviation (CBR)	Sub-Ballast Layer: Consistence	Interlayer: Depth (ft.)	Interlayer: Nature	Interlayer: Cone resistance (CBR)	Interlayer: Standard deviation (CBR)	Interlayer: Compaction degree	Subgrade: Depth (ft.)	Subgrade: Nature	Subgrade: Cone resistance (CBR)	Subgrade: Standard deviation (CBR)	Subgrade: Compaction degree	Subgrade: Quality class
51	-	-	-	-	-	1,62	SM	195,8	117,2	c	-	-	-	-	-	-
60	-	-	-	-	-	1,56	SM	266,5	88,8	c	-	-	-	-	-	-
61	-	-	-	-	-	1,42	SM	324,1	108,2	c	-	-	-	-	-	-
70	-	-	-	-	-	2,33	SM	143,6	55,0	c	-	-	-	-	-	-
71	-	-	-	-	-	2,38	-	241,3	117,7	c	-	-	-	-	-	-
80	-	-	-	-	-	1,85	SM	228,3	86,3	c	2,36	MS	153,6	38,51	c	S2
81	-	-	-	-	-	1.39*	-*	247.6*	128.1*	c*	-	-	-	-	-	-
110	-	-	-	-	-	2,26	SM	180,1	63,9	c	-	-	-	-	-	-
111	-	-	-	-	-	2,58	SM	135,2	57,3	c	2,87	ML	31,83	16,91	p	S1
120	-	-	-	-	-	2,43	MS	102,1	65,5	c	2,89	MS	17	2,32	m	S1
121	-	-	-	-	-	1,48	SM	277	86,7	c	-	-	-	-	-	-
122	-	-	-	-	-	2,51	SM	233,9	89,8	c	3,15	MS	49,96	22,73	c	S2
131	-	-	-	-	-	1.26*	-*	314.6*	97.6*	c*	-	-	-	-	-	-
140	-	-	-	-	-	2,12	SM	155	65,45	c	2,48	MS	150,4	90,01	c	S2
141	-	-	-	-	-	1,7	SM	148,7	70,99	c	-	-	-	-	-	-
142	-	-	-	-	-	2,67	SM	280,6	98,5	c	-	-	-	-	-	-
150	-	-	-	-	-	2,32	GM	95,3	62,0	c	-	-	-	-	-	-
151	-	-	-	-	-	2,22	GM	144,1	98,4	c	-	-	-	-	-	-
152	-	-	-	-	-	2,15	GM	116,1	54,1	c	-	-	-	-	-	-

N°	Moisture: Ballast	Moisture: Fouled Ballast	Moisture: Sub-ballast Layer	Moisture: Interlayer	Moisture: Subgrade	GPS Position: Latitude	GPS Position: Longitude	GPS Position: Altitude	Weather conditions	Observations	PANDA® File
51	-	Dry	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - heterogeneous interlayer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S051_P
60	-	Dry	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - /	LXXXXXX_20170829_FXXX XX_C1_V1_S060_P
61	-	Dry	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - /	LXXXXXX_20170829_FXXX XX_C1_V1_S061_P
70	-	Dry	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - /	LXXXXXX_20170829_FXXX XX_C1_V1_S070_P
71	-	-	-	-	-	[illegible]	[illegible]		Sunny	Plain Track - Scattered pollution in Sandy ballast layer - Heterogenous interlayer - /	XXXXX_20170829_FXXX XX_C1_V1_S071_P
80	-	Dry	-	Dry	Dry	[illegible]	[illegible]		Sunny	Plain Track - heterogeneous subgrade - /	LXXXXXX_20170829_FXXX XX_C1_V1_S080_P
81	-	-*	-	-*	-	[illegible]	[illegible]		Sunny	Plain Track - /	LXXXXXX_20170829_FXXX XX_C1_V1_S081_P
110	-	-	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - / 11 PE	LXXXXXX_20170829_FXXX XX_C1_V1_S110_P
111	-	-	-	Dry	Dry	[illegible]	[illegible]		Sunny	Plain Track - Scattered pollution in ballast layer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S111_P
120	-	-	-	Wet	Wet	[illegible]	[illegible]		Sunny	Plain Track - Scattered pollution in sandy ballast layer - heterogeneous interlayer - Wet interlayer - wet subgrade - /	XXXXX_20170829_FXXX XX_C1_V1_S120_P
121	-	-	-	Wet	-	[illegible]	[illegible]		Sunny	Plain Track - Panda refusal at 1.74 ft. - Scattered pollution in sandy ballast layer - heterogeneous interlayer - Wet interlayer - /	XXXXX_20170829_FXXX XX_C1_V1_S121_P
122	-	-	-	Wet	Wet	[illegible]	[illegible]		Sunny	Plain Track - Scattered pollution in ballast layer - heterogeneous interlayer - Wet interlayer - Wet subgrade - /	XXXXX_20170829_FXXX XX_C1_V1_S122_P
131	-	-	-	-*	-	[illegible]	[illegible]		Sunny	Plain Track - Panda refusal at 1.26 ft. - /	LXXXXXX_20170829_FXXX XX_C1_V1_S131_P
140	-	-	-	Dry	Dry	[illegible]	[illegible]		Sunny	Switch - Endoscopic refusal R2 at 2.16 ft. - heterogeneous interlayer - / TVD	XXXXX_20170829_FXXX XX_C1_V1_S140_P
141	-*	Wet	-	Wet	-	[illegible]	[illegible]		Sunny	Switch - Panda refusal at 2.04 ft. - [illegible]enous interlayer - Wet interlayer - /	XXXXX_20170829_FXXX XX_C1_V1_S141_P
142	-	-	-	Dry	-	[illegible]	[illegible]		Sunny	Switch - Panda refusal at 2.67 ft. - heterogeneous interlayer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S142_P
150	-	-	-	Wet	-	[illegible]	[illegible]		Sunny	Plain Track - heterogeneous interlayer - Wet interlayer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S150_P
151	-	-	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - heterogeneous interlayer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S151_P
152	-	-	-	Dry	-	[illegible]	[illegible]		Sunny	Plain Track - heterogeneous interlayer - /	LXXXXXX_20170829_FXXX XX_C1_V1_S152_P

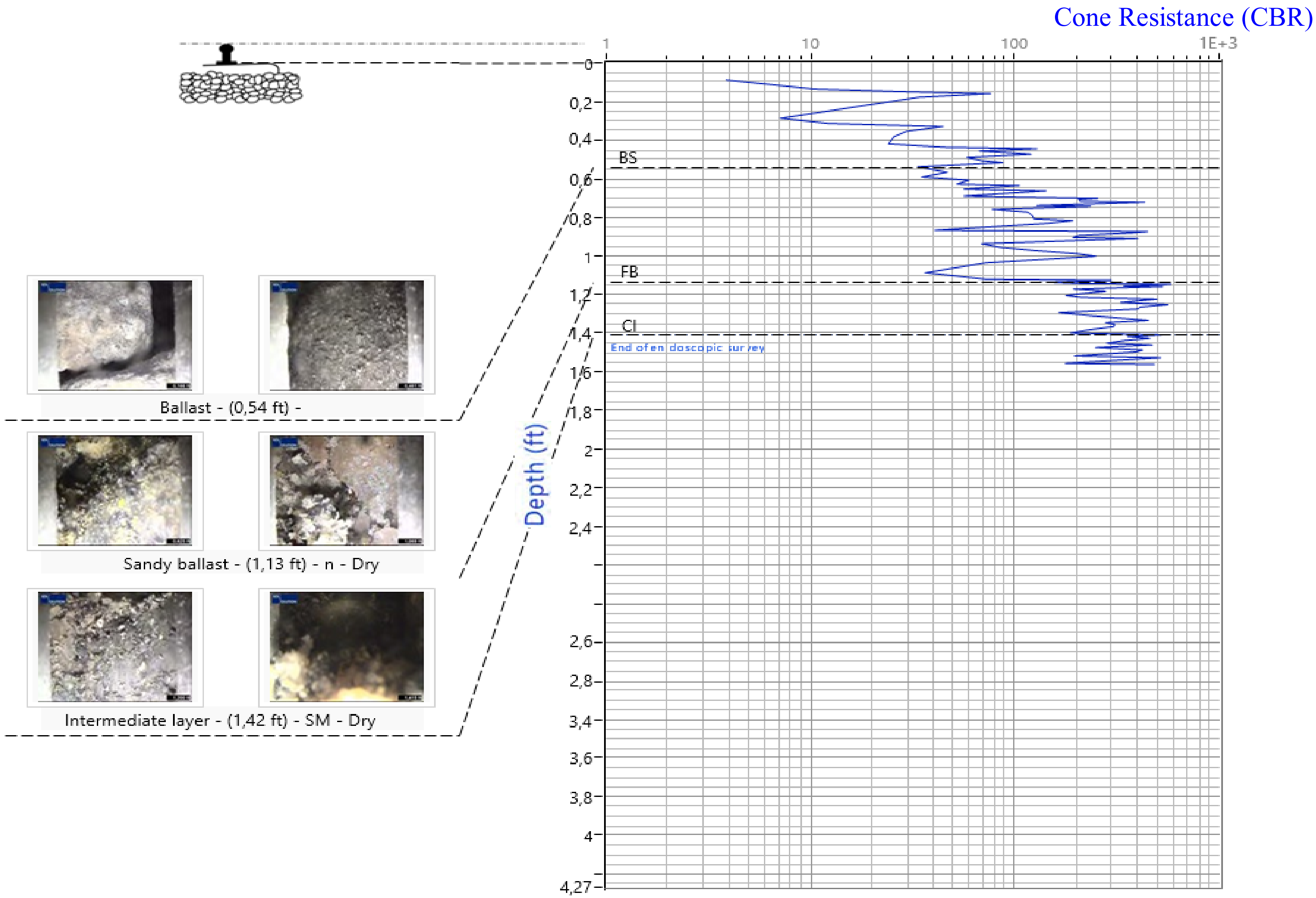
Table D 7. Pandoscope® tests

O Center of the track (test number finishing by ..1)
Ae Right of the track (test number finishing by ..2)
Pe Left of the track (test number finishing by ..0)

1 - Scattered pollution in Ballast: presence of a fouled ballast layer with a thickness lower than 0.33 ft
2 - Endoscopic refusal R1 is related with a mechanical refusal to drive the endoscopic rod
3 - endoscopic refusals R1 are due to the presence of fine elements in the endoscopic rod
* Interpretation is based on PANDA® data only
\+ downgraded because of the water saturation

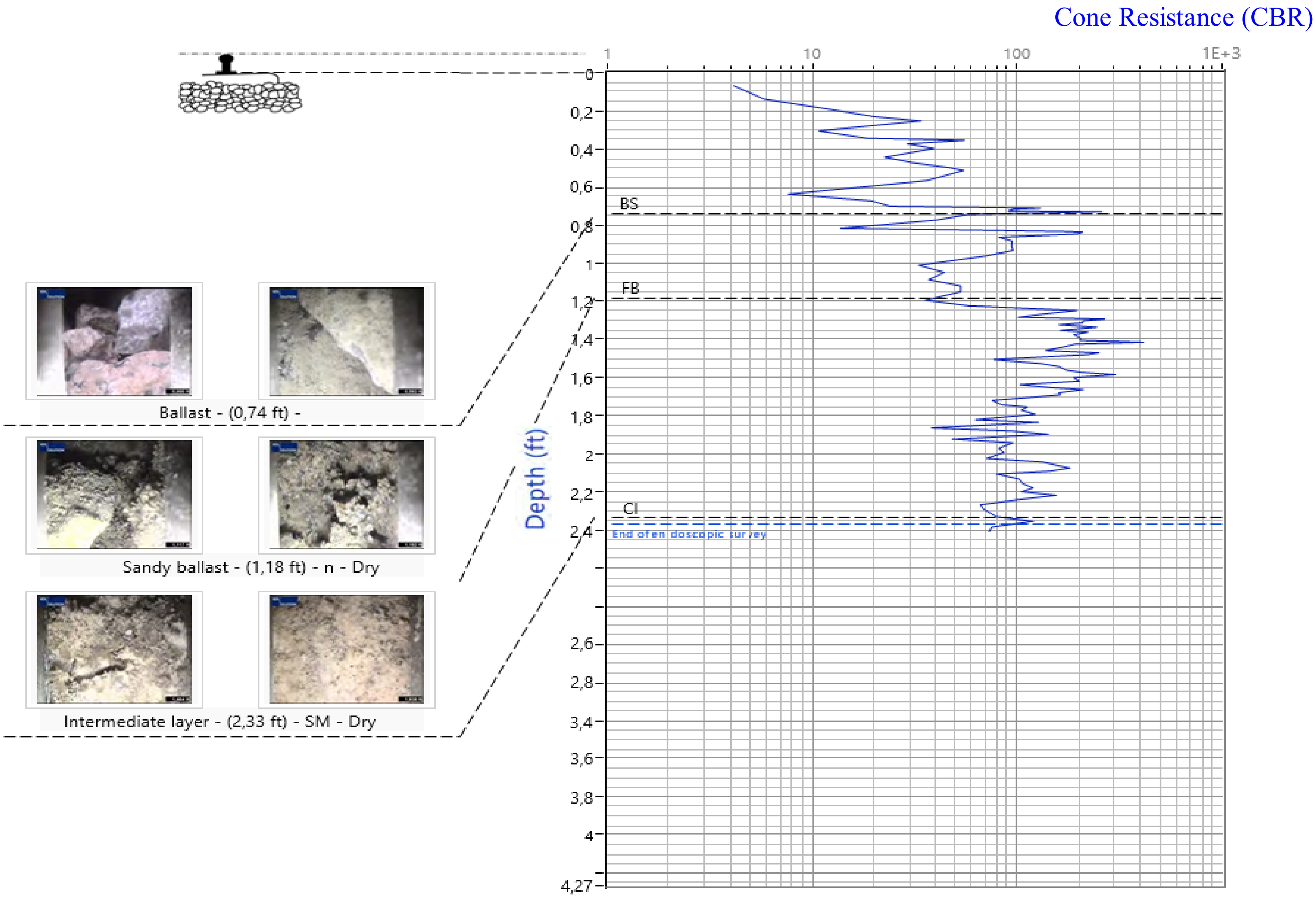


PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 1	**MP:** 022.717	**Pos:** Pe **Area:** Plain Track	**Test:** 060

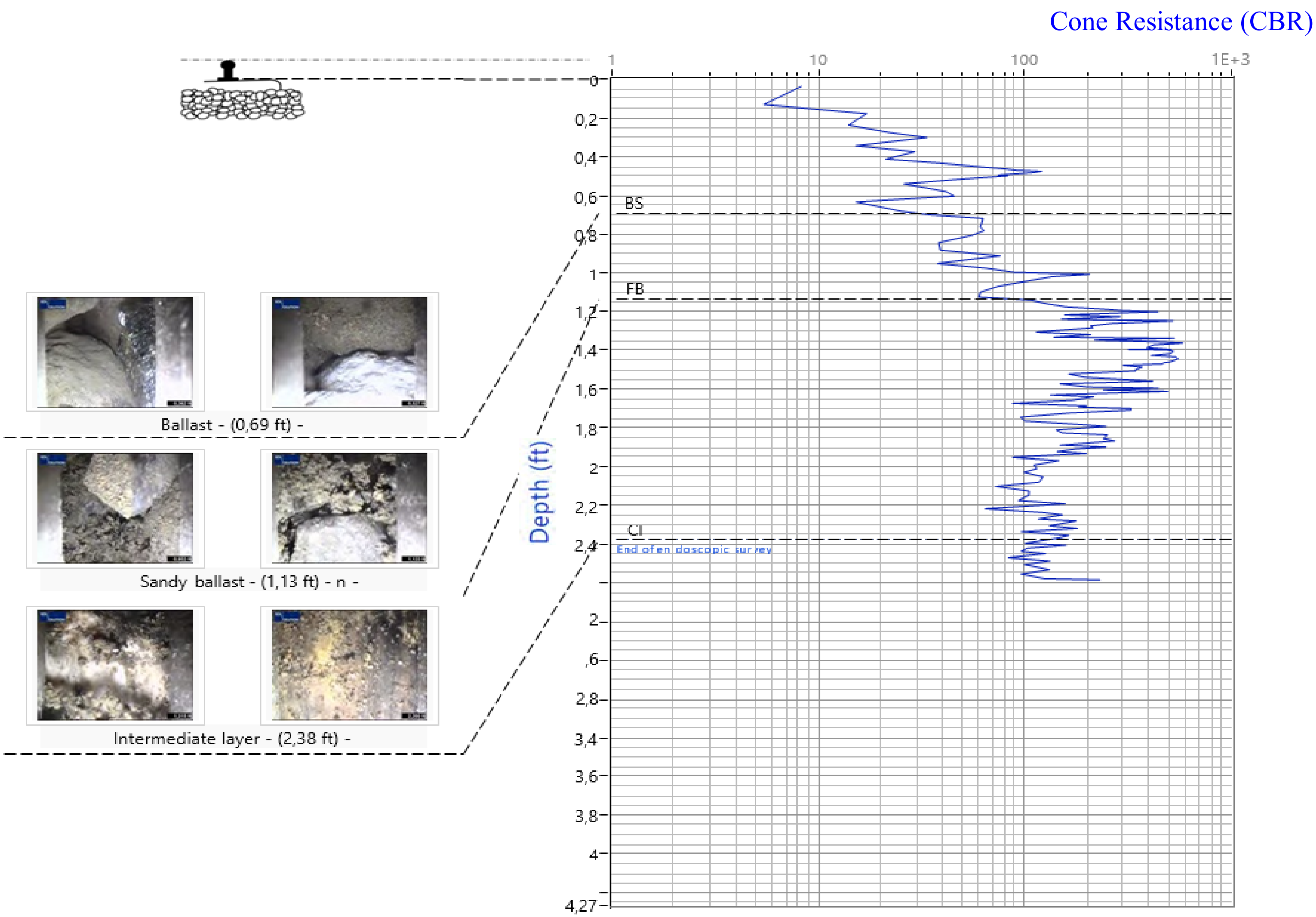


PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 022.717	**Pos:** O	**Area:** Plain Track	**Test:** 061

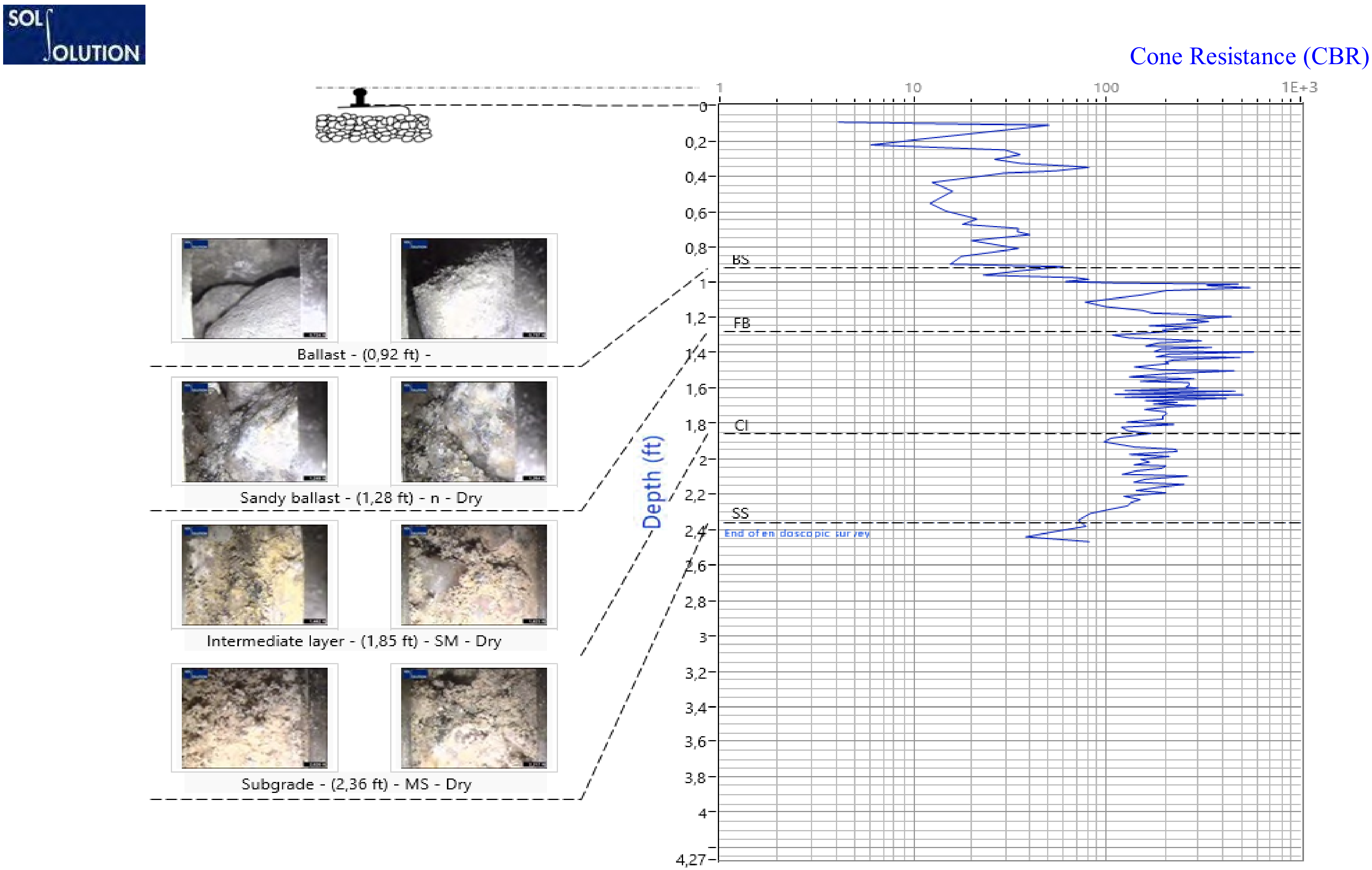
SOL OLUTION



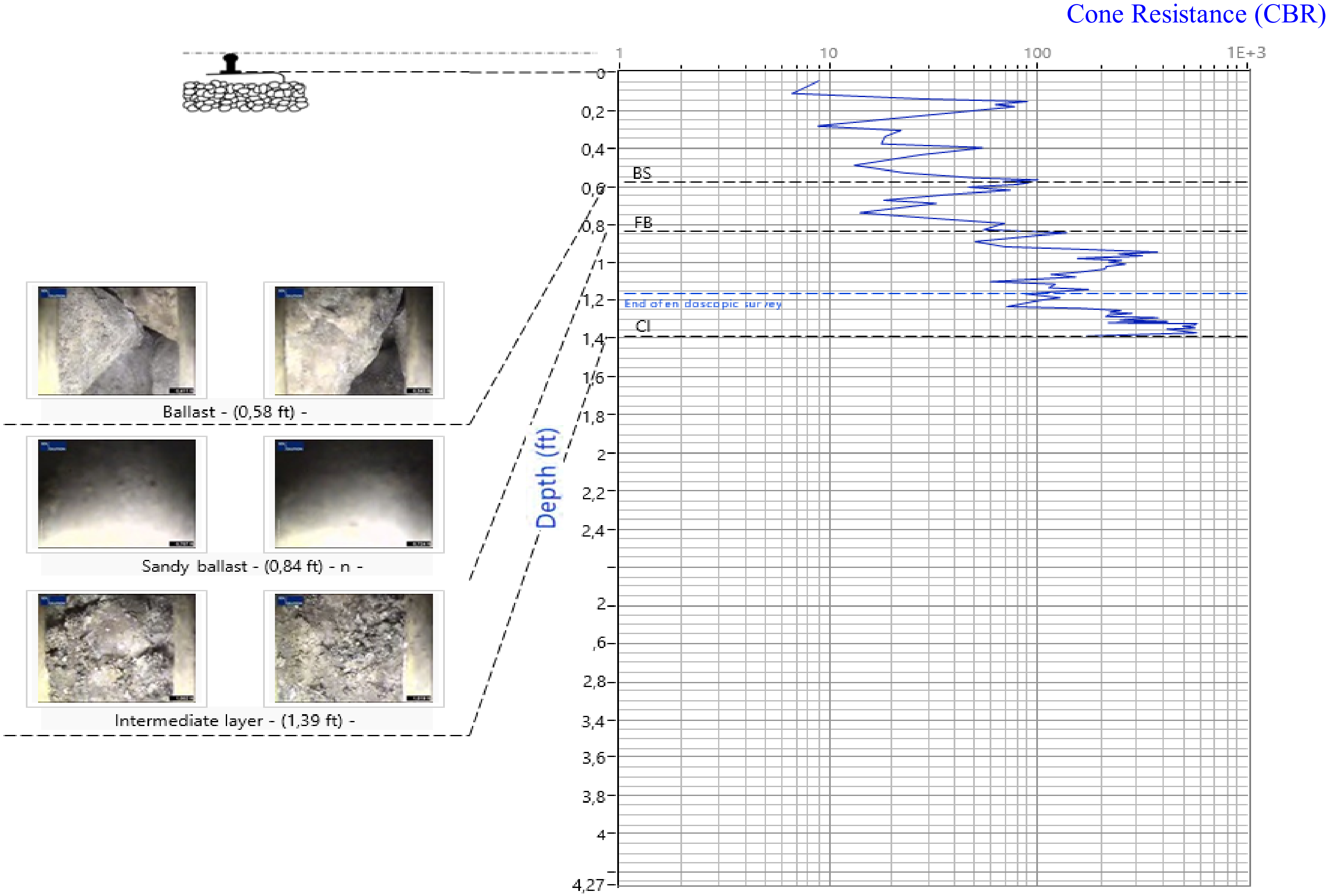
PANDOSCOPE®	Site: BNSF LINE 4	Line: 4	Track id: 1	MP: 022.734	Pos: Pe	Area: Plain Track	Test: 070



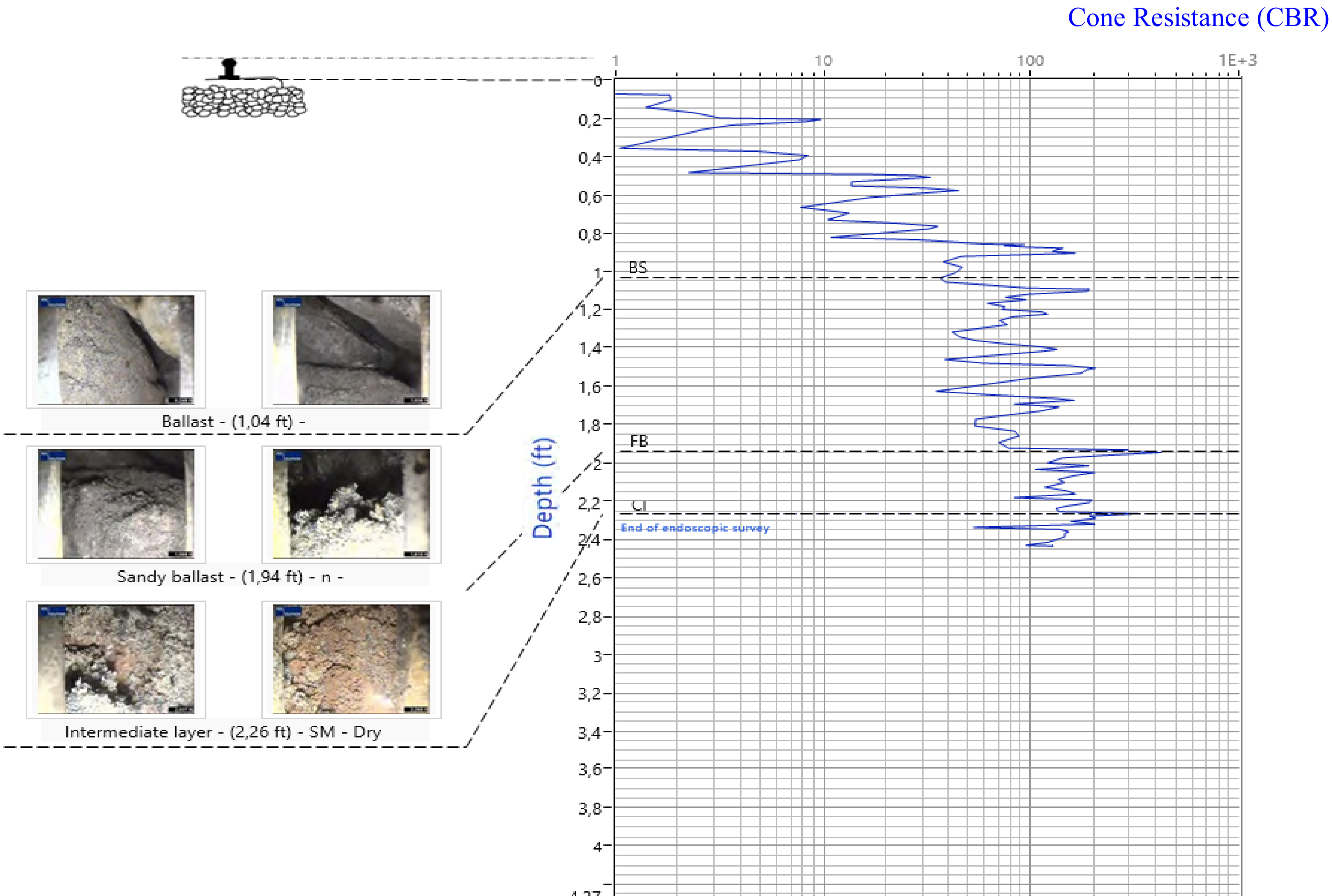
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 022.734	**Pos:** O	**Area:** Plain Track	**Test:** 071



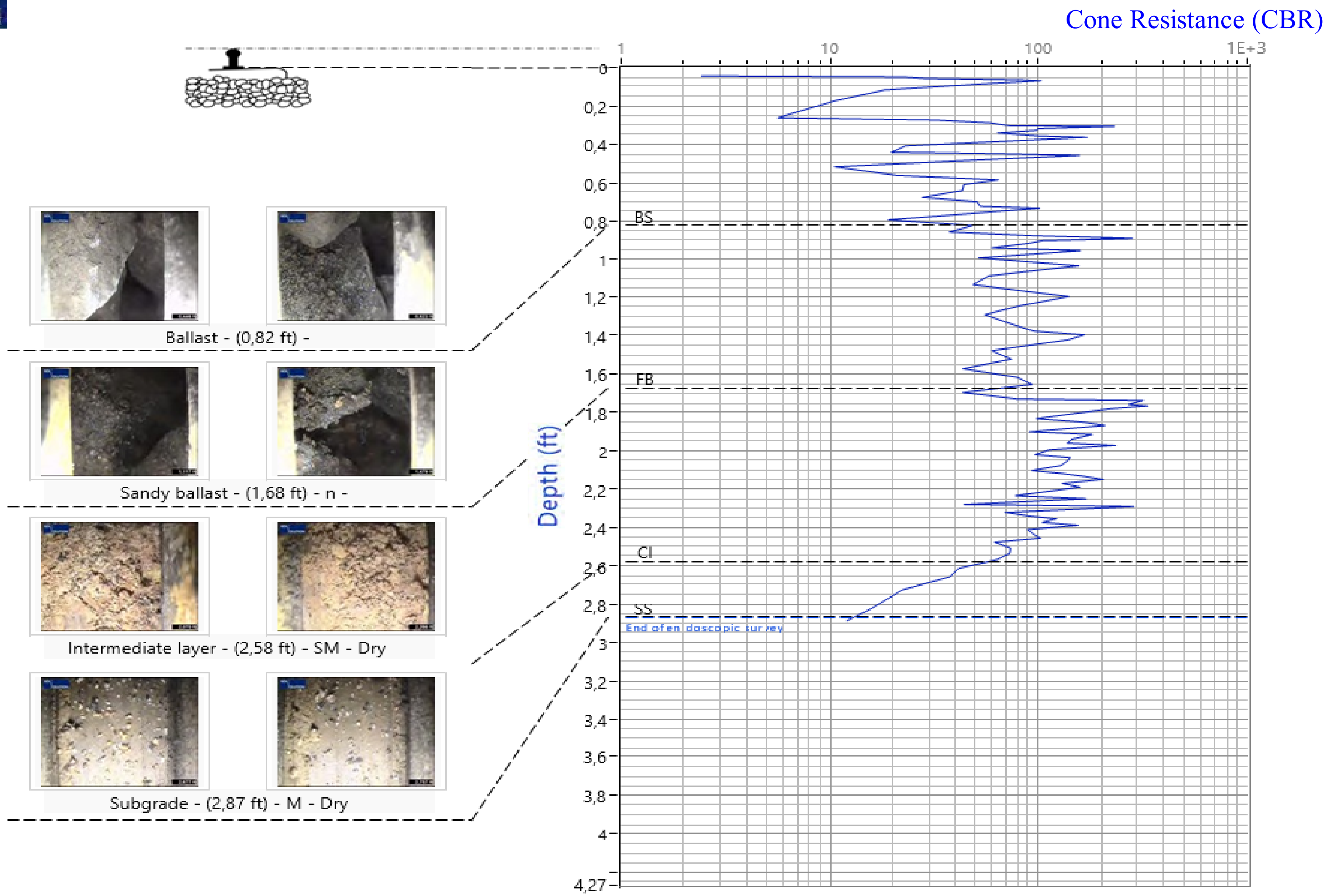
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 022.772	**Pos:** Pe	**Area:** Plain Track	**Test:** 080



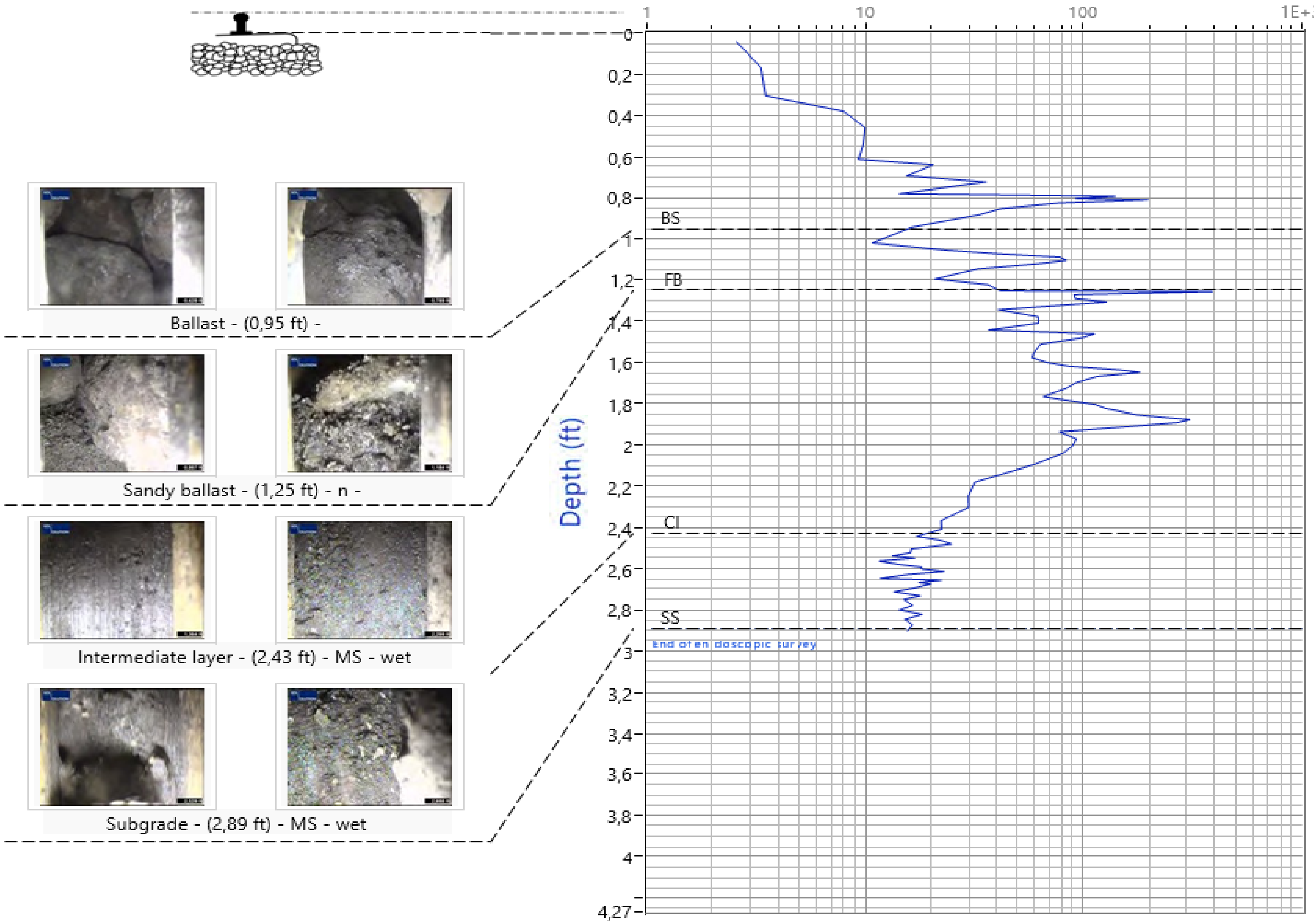
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 022.772	**Pos:** O	**Area:** Plain Track	**Test:** 081



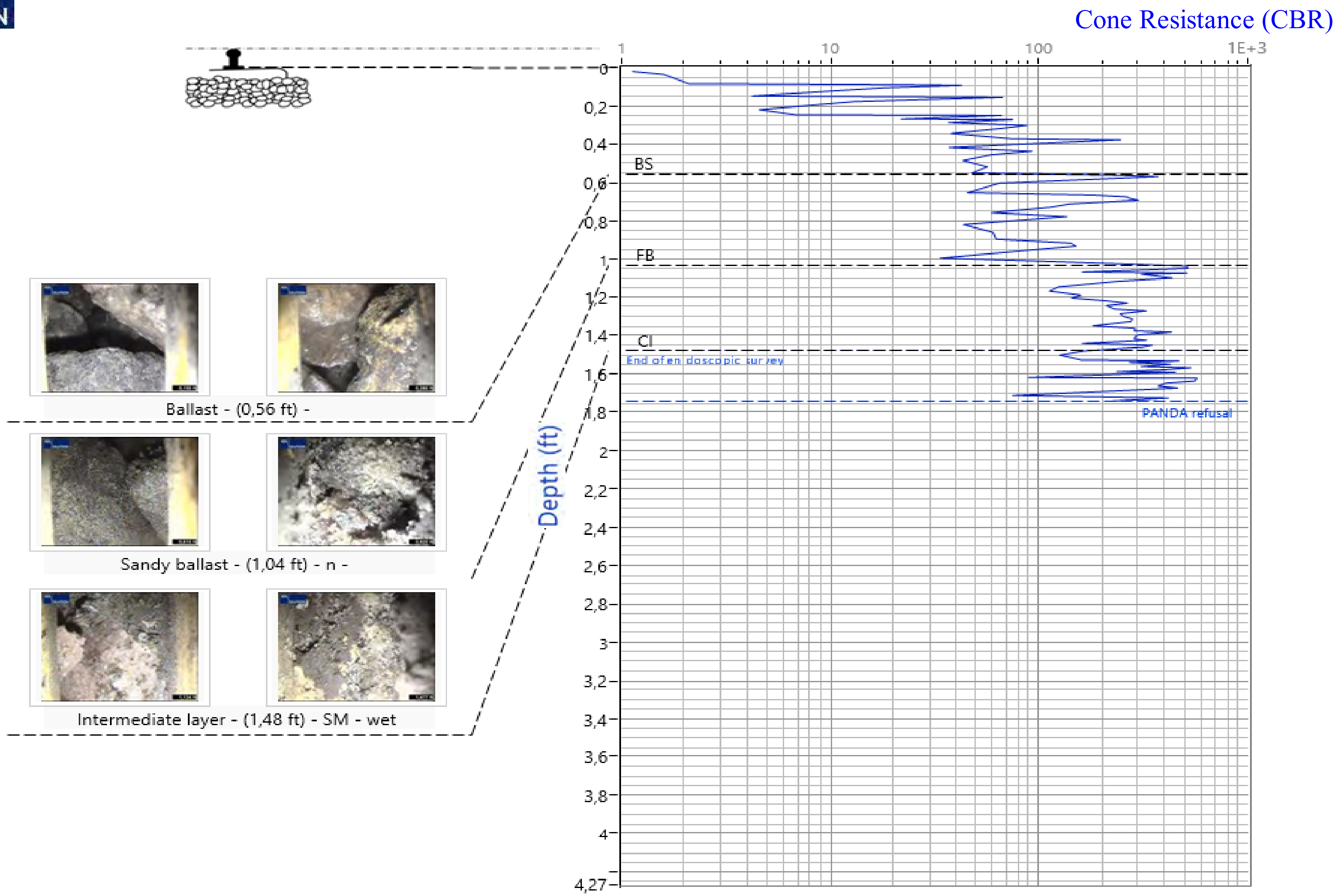
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 025.788	**Pos:** Pe	**Area:** Plain Track	**Test:** 110



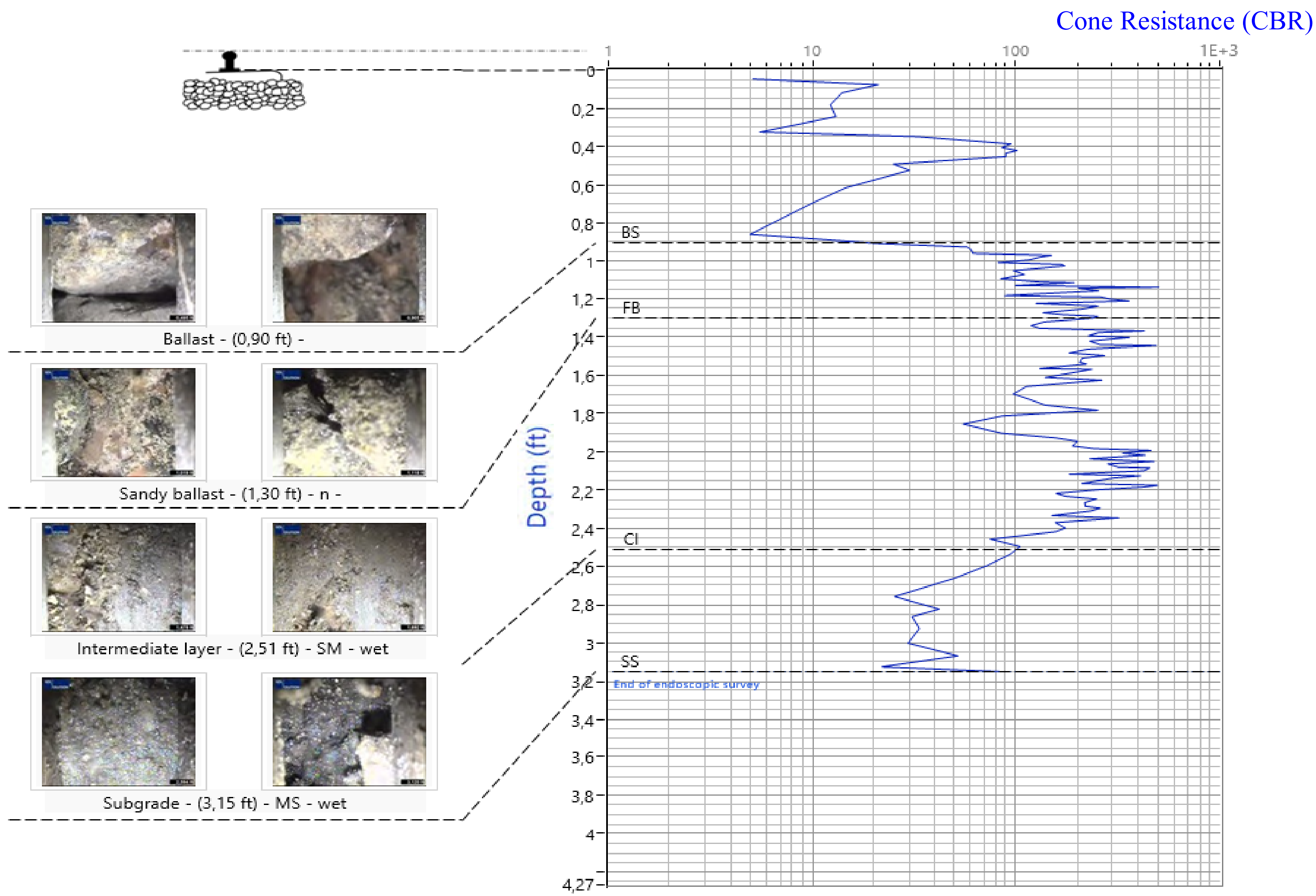
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 025.788	**Pos:** O	**Area:** Plain Track	**Test:** 111



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 026.737	**Pos:** Pe	**Area:** Plain Track	**Test:** 120

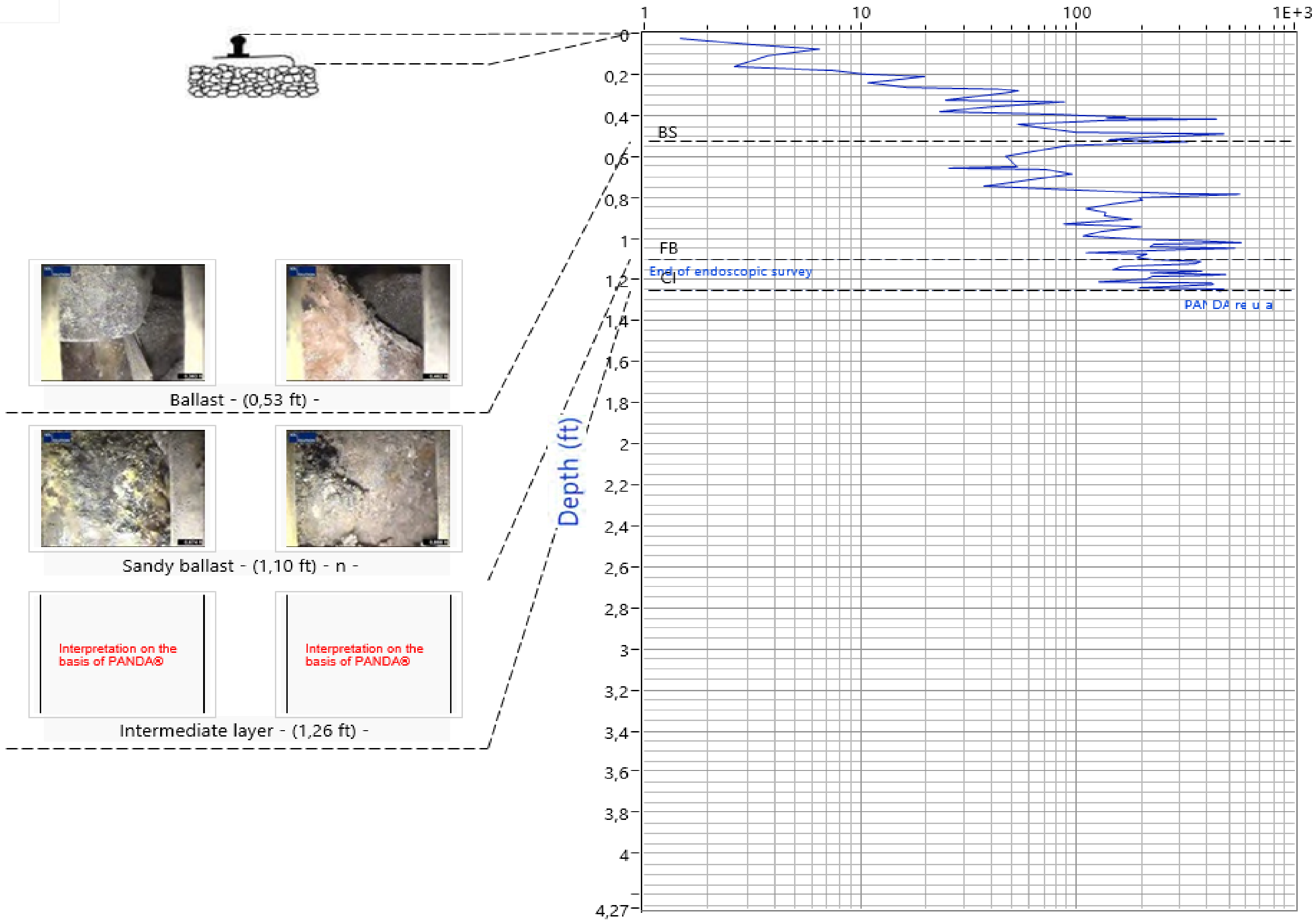


PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 026.737	**Pos:** O	**Area:** Plain Track	**Test:** 121

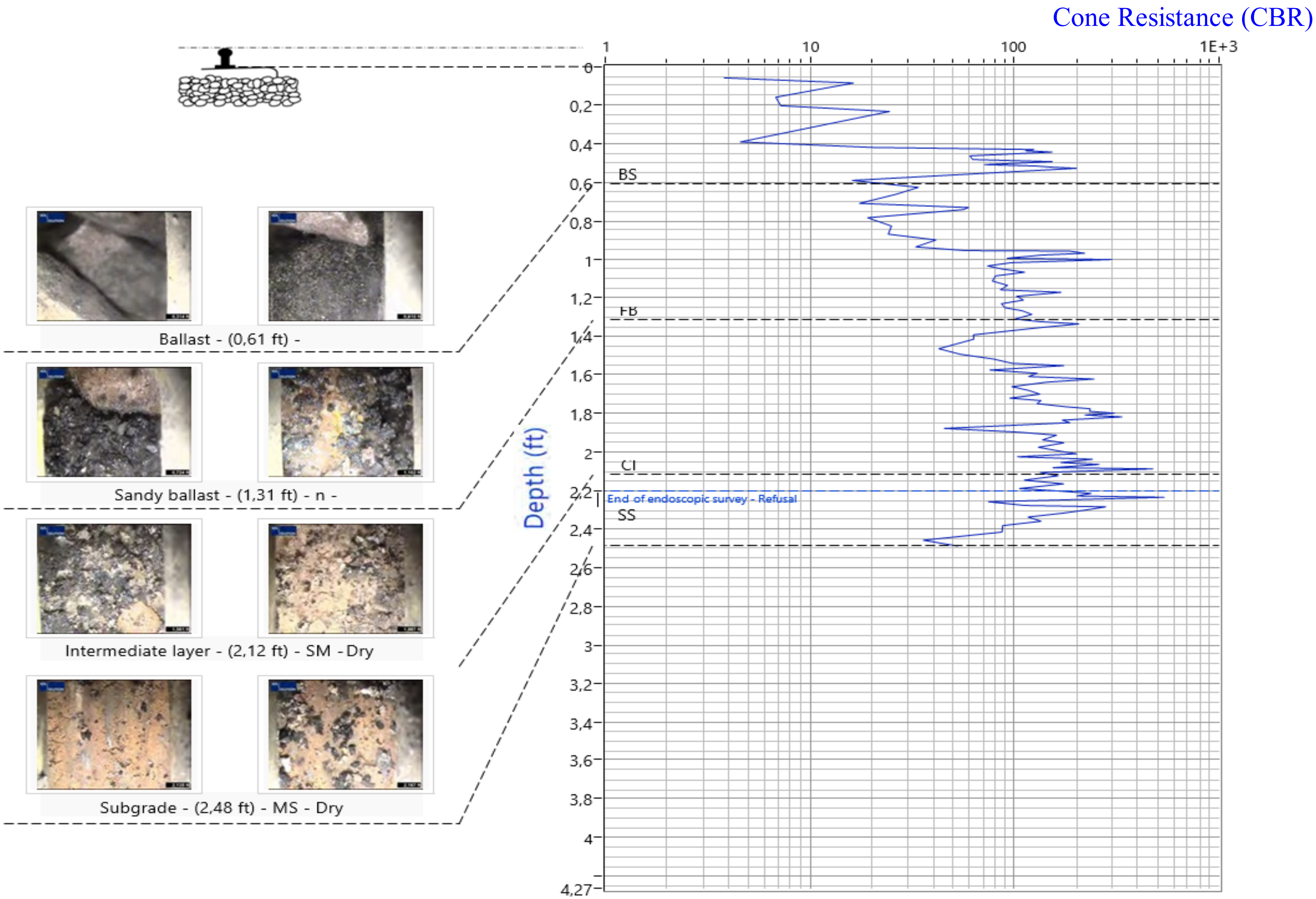


PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 1 **MP:** 026.737 **Pos:** Ae **Area:** Plain Track **Test:** 122

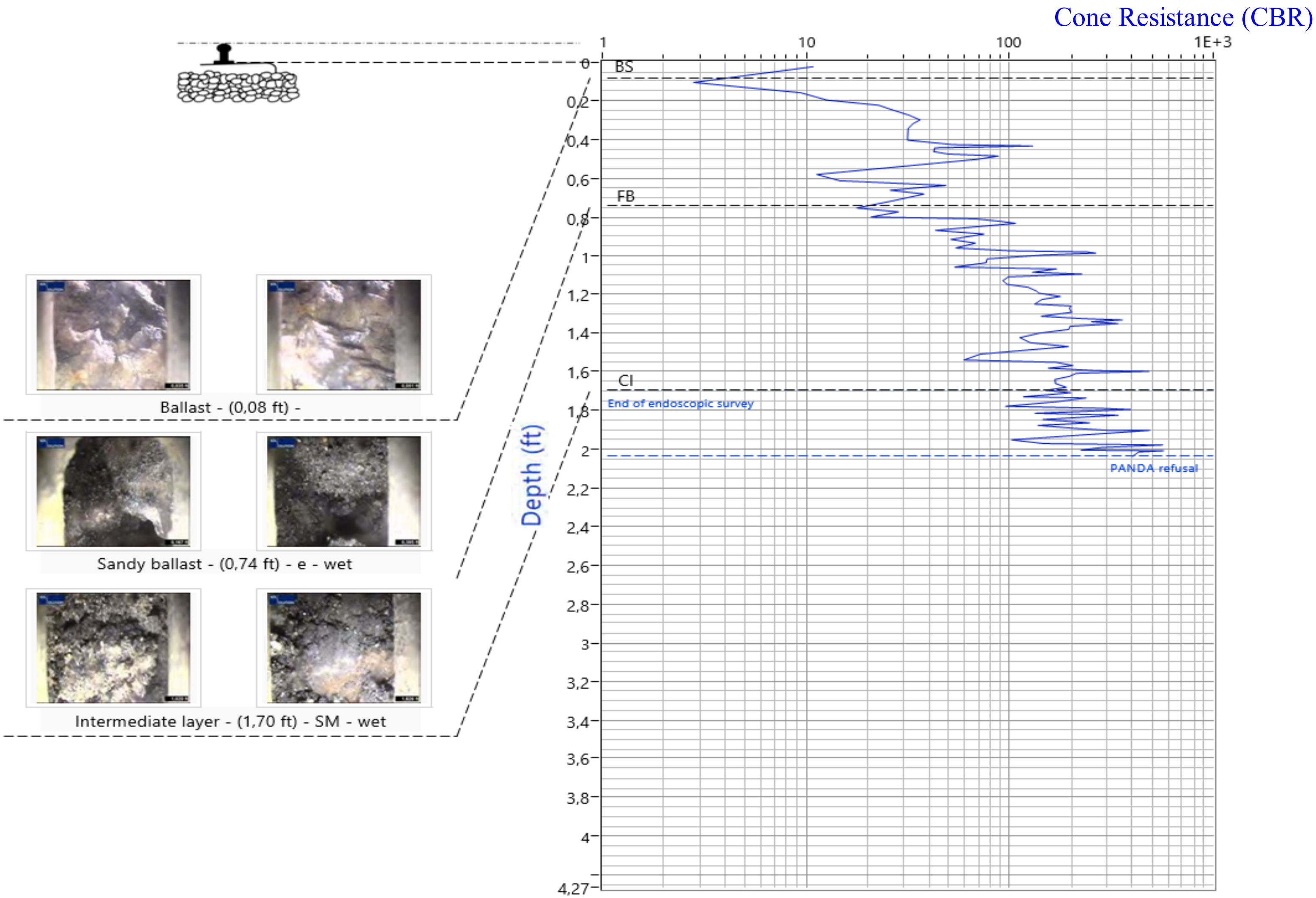
Cone Resistance (CBR)



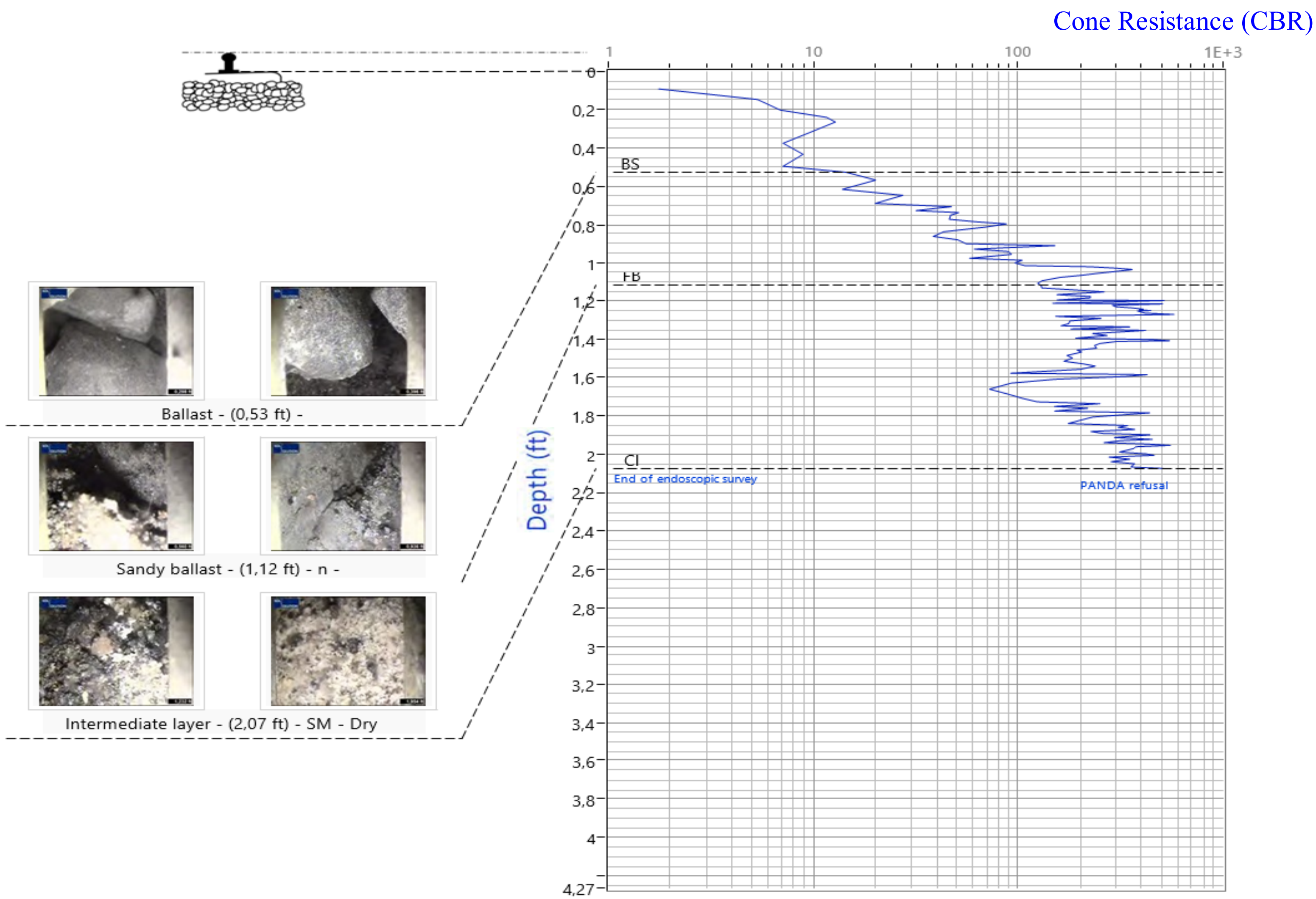
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 026.763	**Pos:** O	**Area:** Plain Track	**Test:** 131



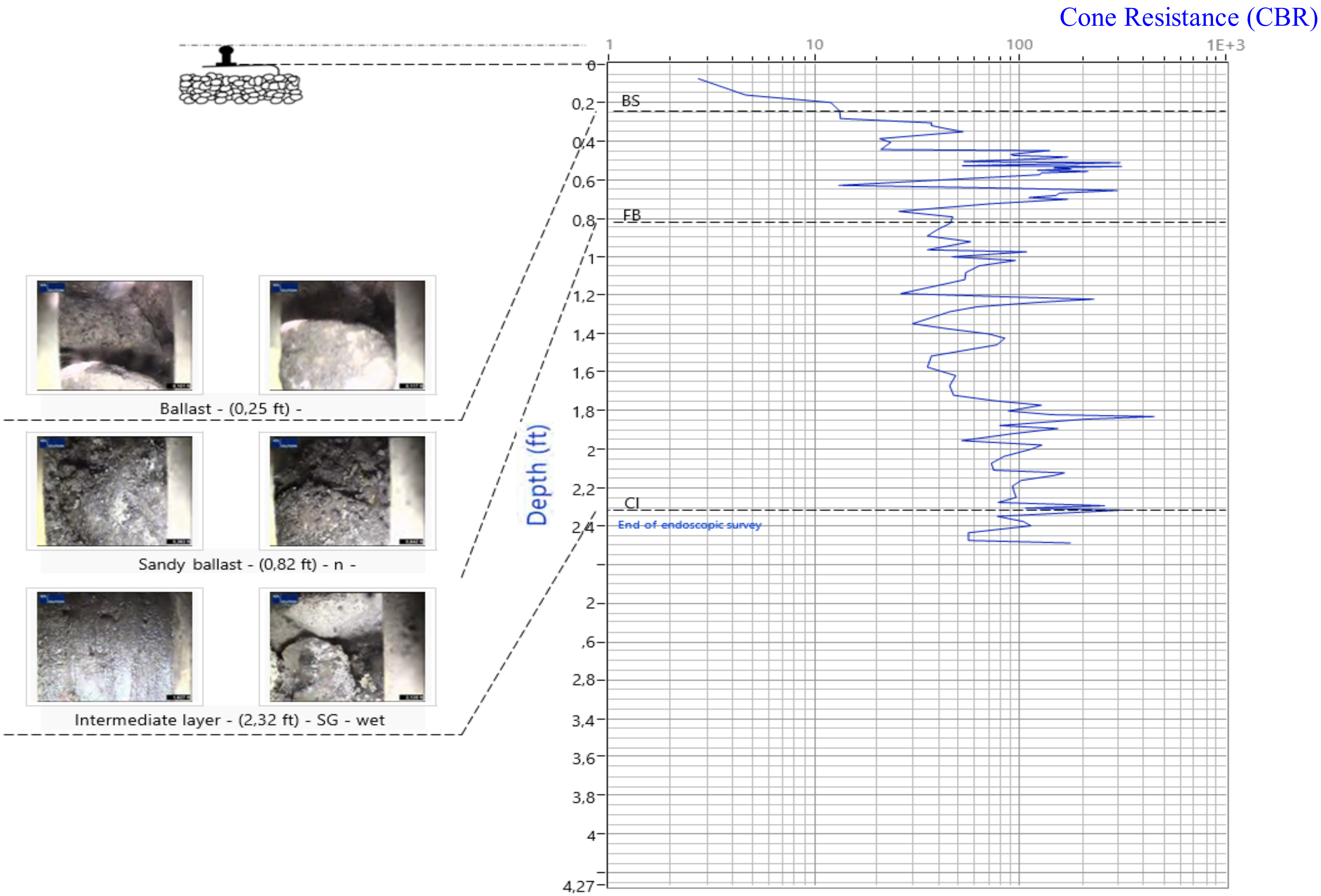
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 027.729	**Pos:** Pe	**Area:** Switch	**Test:** 140



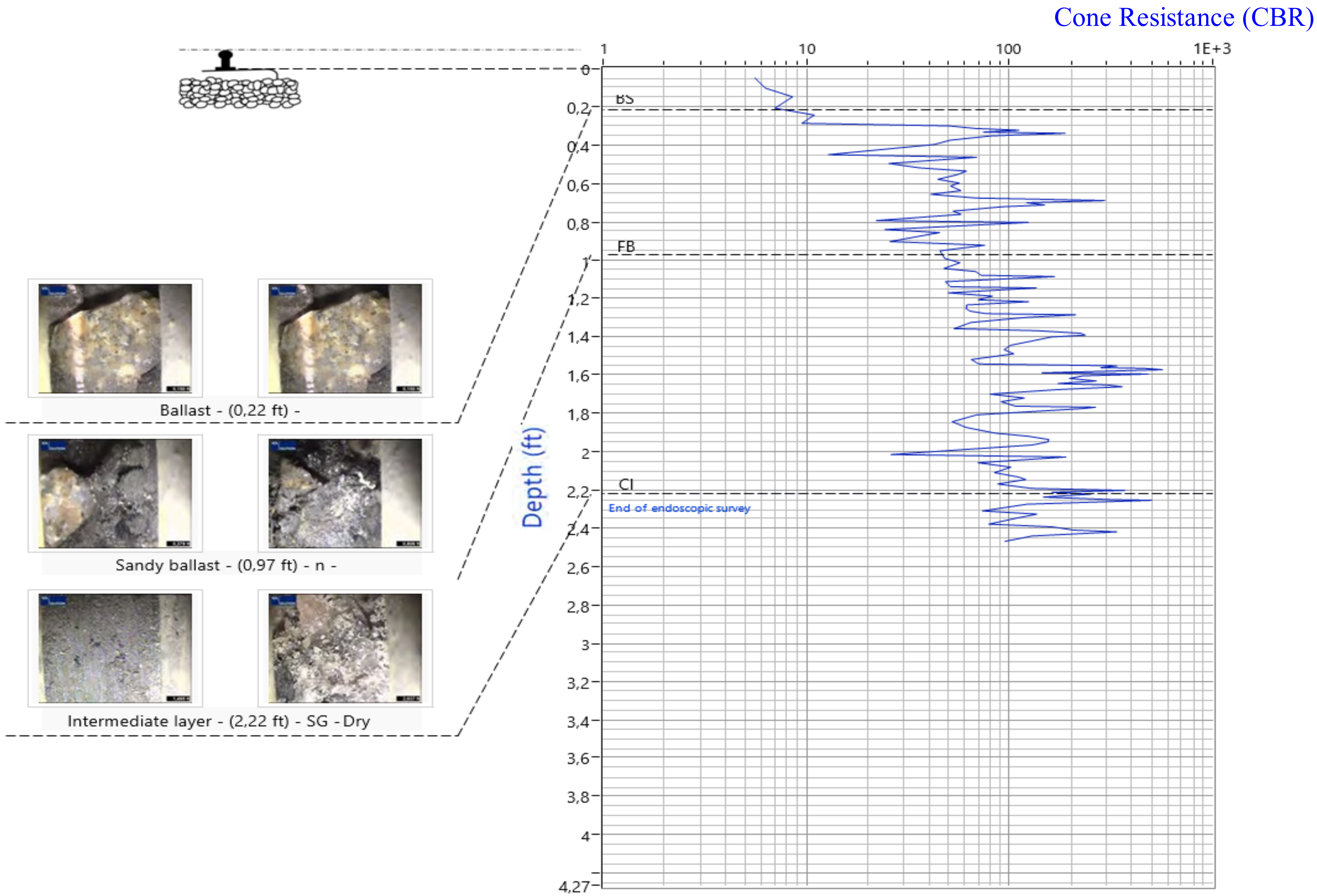
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4	**Track id:** 1	**MP:** 027.729	**Pos:** O	**Area:** Switch	**Test:** 141



PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 1 **MP:** 027.729 **Pos:** Ae**Area:** Switch **Test:** 142

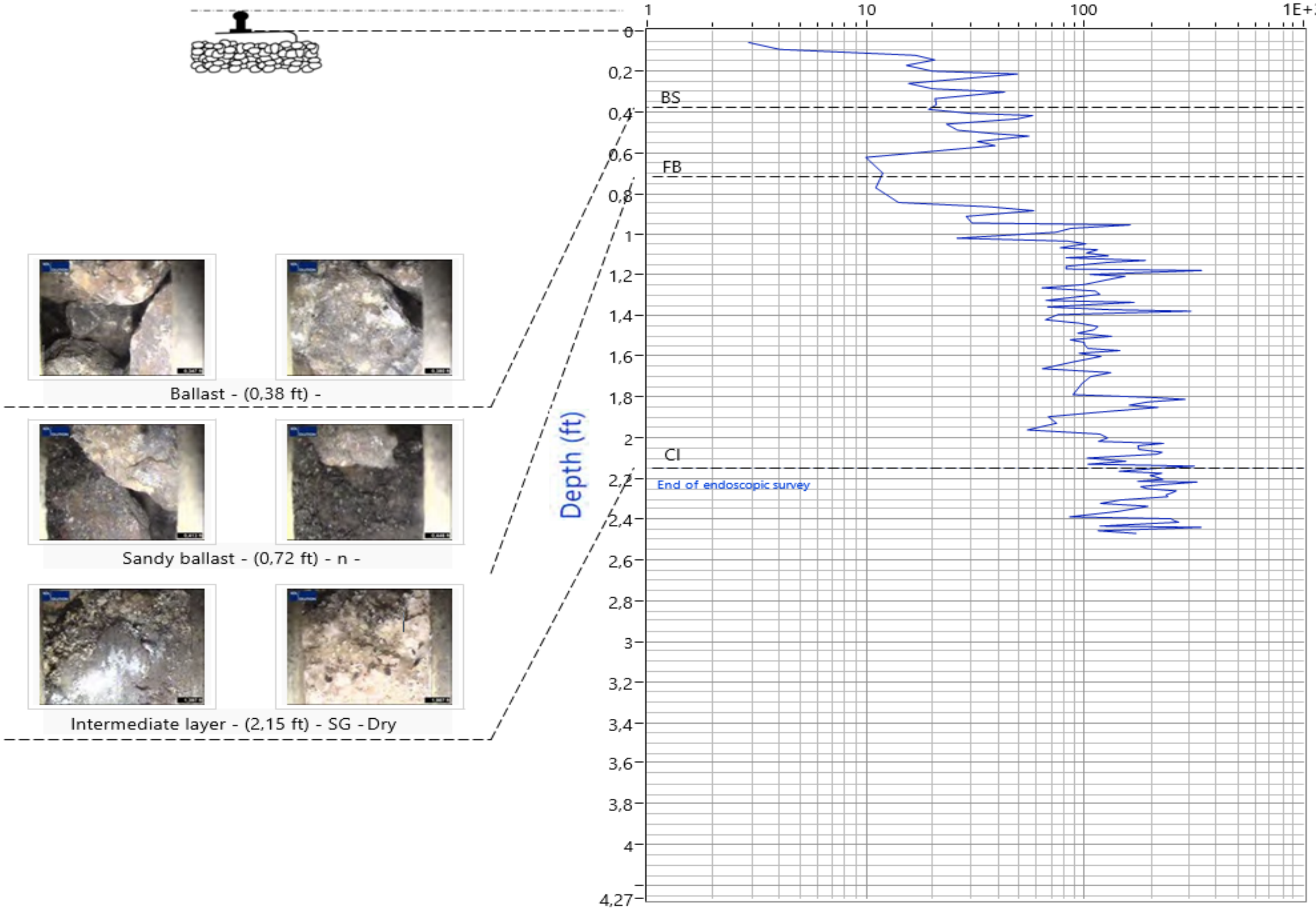


PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 1	**MP:** 027.754	**Pos:** Pe **Area:** Plain Track	**Test:** 150



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 1	**MP:** 027.754	**Pos:** O	**Area:** Plain Track	**Test:** 151

Cone Resistance (CBR)



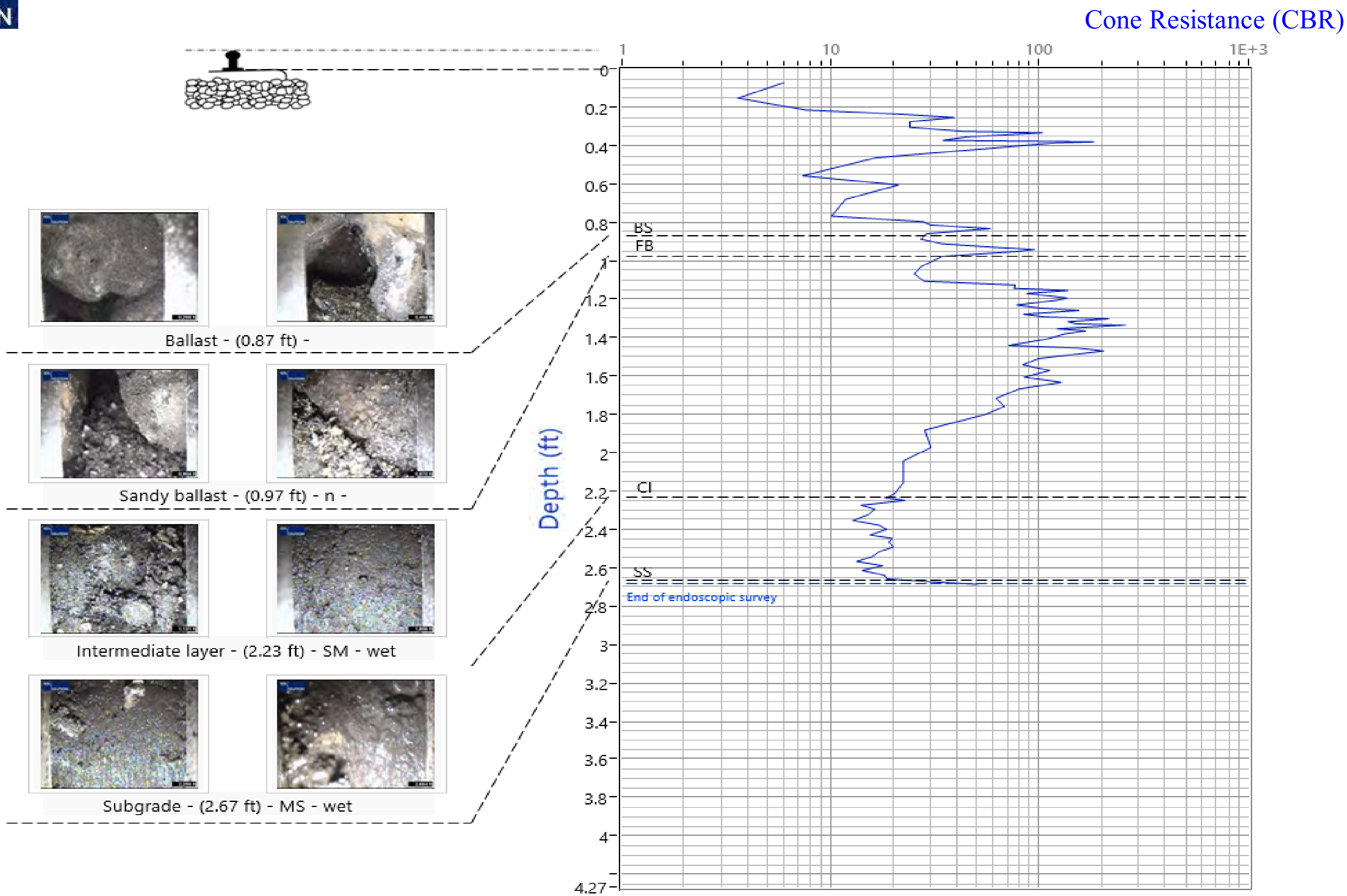
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 1	**MP:** 027.754	**Pos:** Ae	**Area:** Plain Track	**Test:** 1

N°	Date	MP	Position	Distance to the middle of the track (ft.)	Depth	Depth max of PANDA ® test (m)	Ballast								Sub-Ballast Layer					Interlayer					Subgrade						Moisture					GPS Position			Weather conditions	Observations	PANDA® File
							Distance to the top of the tie (ft.)	Bottom of the ballast layer (ft.)	Cone resistance (MPa)	Standard deviation (MPa)	Bottom of the Fouled ballast layer (ft.)	Cone resistance (MPa)	Standard deviation (MPa)	Nature of pollution	Bottom of the sub-ballast layer (ft.)	Nature	Cone resistance (MPa)	Standard deviation (MPa)	Consistence	Depth (ft.)	Nature	Cone resistance (MPa)	Standard deviation (MPa)	Compaction degree	Depth (ft.)	Nature	Cone resistance (MPa)	Standard deviation (MPa)	Compaction degree	Quality class	Ballast	Fouled Ballast	Sub-ballast Layer	interlayer	Subgrade	Latitude	Longitude	Altitude			
261	8/29/17	035.558	O	0	1,42	1,68	0	1,3	44.62	49.12	1,68	292.3	108.3	n	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	saturate	-	-	-	40.894377	-97.214906		Sunny	Plain Track - Refusal Panda® 0,513 m - water saturation in fouled ballast - / Corrected MP: 35.581	XXXX_20170829_FXXXXX_C1_V2_S261_P
270	8/29/17	037.771	Pe	0	2,57	2,57	0	0,81	41.6	33.58	1	75.53	46.89	n	-	-	-	-	-	2,3	SM	238.6	107.4	c	2,57	ML	10.81	1.99	m	S0	-	-	-	Dry	Dry	40.894433	-97.256791		Sunny	Plain Track - Scattered pollution in ballast layer - /	LXXXXXX_20170829_FXXXXX_C1_V2_S270_P
271	8/29/17	037.771	O	0	2,15	2,46	0	0.38*	47.10*	31.47*	0.87*	102.68*	61.11*	n*	-	-	-	-	-	2,15	GM	162.1	70.59	c	2.44*	-*	13.04*	2.30*	m*	- *	- *	- *	-	saturate	- *	40.894433	-97.256791		Sunny	Plain Track - Heterogenous nterlayer - Water saturation in interlayer - Mud up to 0.7 ft. - /	XXXX_20170829_FXXXXX_C1_V2_S271_P
272	8/29/17	037.771	Ae	0	2,39	2,39	0	0,64	63.88	40.76	1,04	175.4	82.95	n	-	-	-	-	-	2,33	-	167.1	111.4	c	2,39	MS	12.74	1.39	m	S1	-	-	-	-	Wet	40.894433	-97.256791		Sunny	Plain Track - Heterogenous Interlayer - Wet subgrade - /	LXXXXXX_20170829_FXXXXX_C1_V2_S272_P
280	8/30/17	026.732	Pe	-2,69	1,54	2,56	0	0,25	36.5	27.15	0,74	102.8	64.58	n	-	-	-	-	-	1,93	MS	25.57	32.12	p	2.51*	-*	7.88*	1.06*	m*	- *	-	-	-	Wet	- *	40.870723	-97.089179		Sunny	Plain Track - Endoscopic refusal R2 at 1.53 ft. - Heterogenous Interlayer - Wet interlayer - /	LXXXXXX_20170829_FXXXXX_C1_V2_S280_P
281	8/30/17	026.732	O	0	1,03	2,55	0	0,31	29.35	11.77	1,1	105.3	89.09	n	-	-	-	-	-	2.31*	-*	97.13*	32.85*	c*	2.55*	-*	4.76*	0.53*	m*	- *	-	-	-	- *	- *	40.870723	-97.089179		Sunny	Plain Track - Mud up to 0.80 ft. - /	LXXXXXX_20170829_FXXXXX_C1_V2_S281_P
282	8/30/17	026.732	Ae	2,69	2,25	2,45	0	0,22	28.81	14.96	0,31	22.11	7.86	n	-	-	-	-	-	1,79	SM	42.11	26.99	p	2,41	MS	13.76	1.96	m	S0+	-	-	-	Wet	saturate	40.870723	-97.089179		Sunny	Plain Track - Heterogenous Interlayer - Wet interlayer - Water saturation in subgrade - /	LXXXXXX_20170829_FXXXXX_C1_V2_S282_P
290	8/29/17	039.871	Pe	0	2,05	2,44	0	0,63	34.25	29.73	0,82	110.5	79.21	n	-	-	-	-	-	1,72	SM	94.62	54.96	c	2,05	MS	15.02	0.57	m	S1	-	-	-	Dry	Dry	40.894447	-97.296814		Sunny	Plain Track - /	LXXXXXX_20170829_FXXXXX_C1_V2_S290_P
291	8/29/17	039.871	O	0	1,99	2,48	0	0,36	16.84	12.68	0,94	42.48	15	n	-	-	-	-	-	1,68	SM	154	99.41	c	1,99	ML	11.44	1.52	m	S0	-	-	-	saturate	saturate	40.894447	-97.296814		Sunny	Plain Track - Scattered pollution in ballast layer - Water saturation in Interlayer - Water saturation in subgrade - /	LXXXXXX_20170829_FXXXXX_C1_V2_S291_P

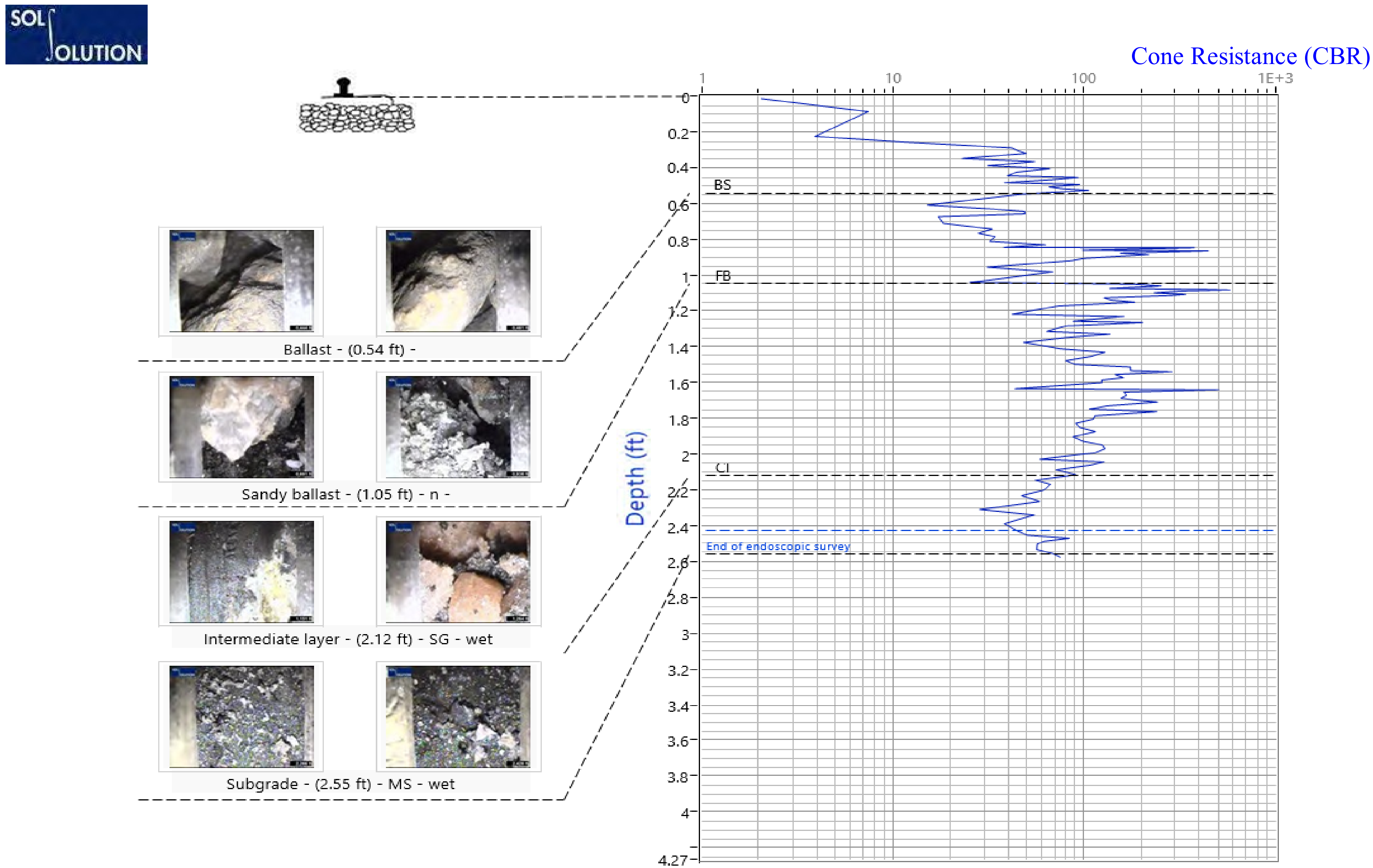
Table D6. Additional Pandoscope® Tests

O Center of the track (test number finishing by …1)
Ae Right of the track (test number finishing by …2)
Pe Left of the track (test number finishing by …0)

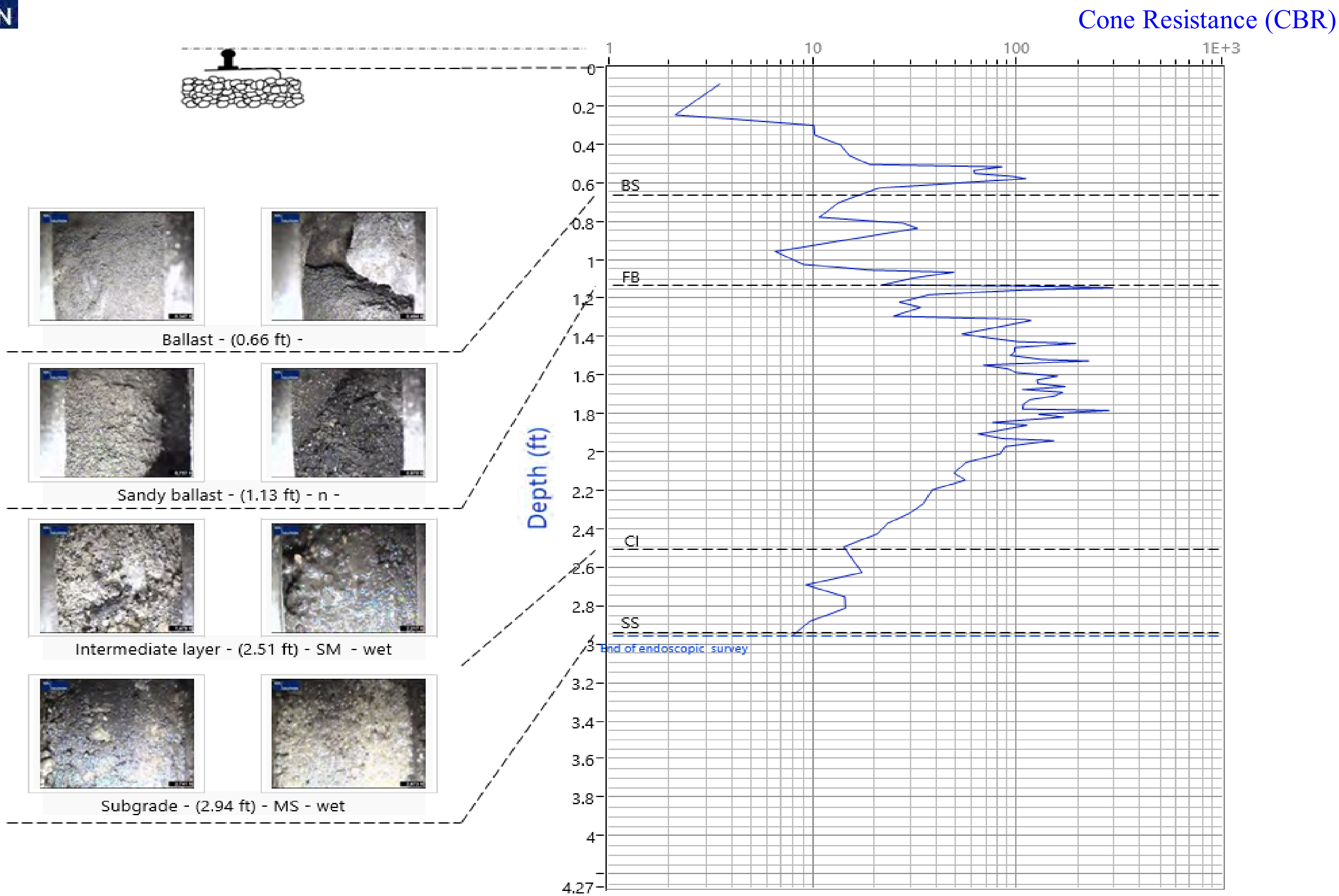
1 – Scattered pollution in Ballast: presence of a fouled ballast layer with at thickness lower than 0.33 ft.
2 – Endoscopic refusal R1 is related with a mechanical refusal to drive the endoscopic rod
3 – Endoscopic refusals R1 are due to the presence on fine elements in the endoscopic rod
* Interpretation is based on PANDA® data only
+ Downgrade because of the water saturation



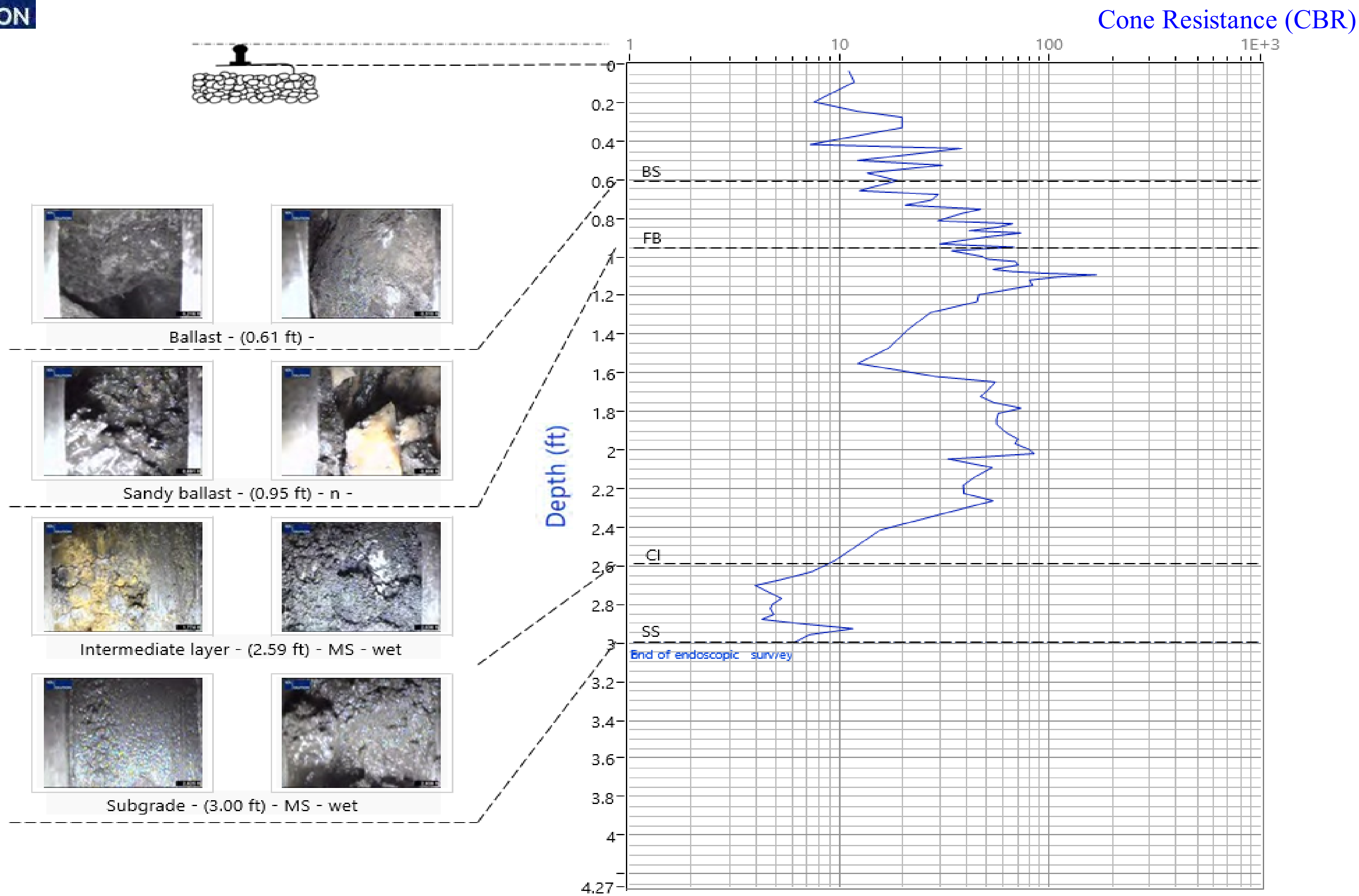
PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 2 **MP:** 025.791 **Pos:** Pe **Area:** Plain Track **Test:** 220



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 025.791	**Pos:** O	**Area:** Plain Track	**Test:** 221

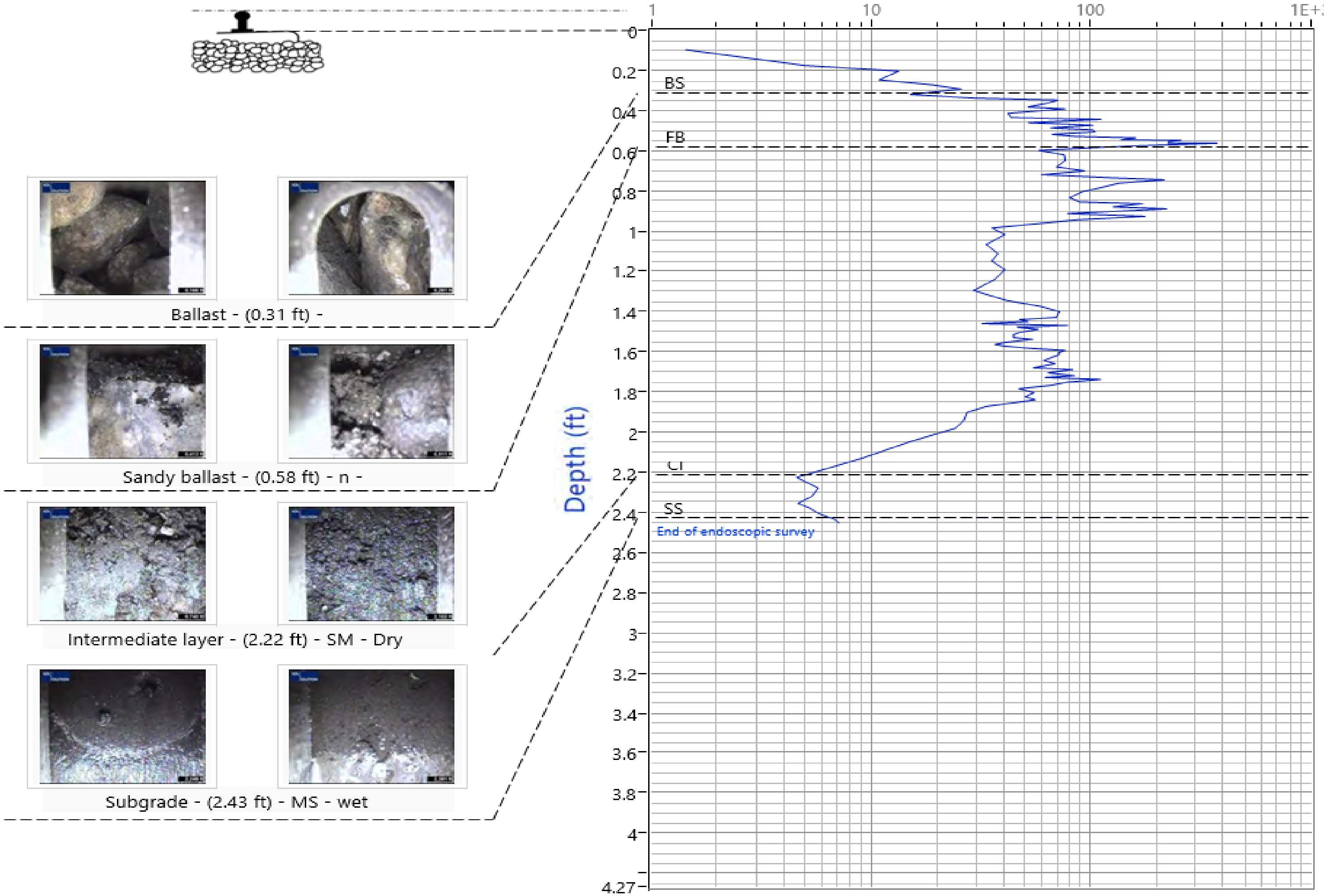


PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 025.791	**Pos:** Ae	**Area:** Plain Track	**Test:** 222



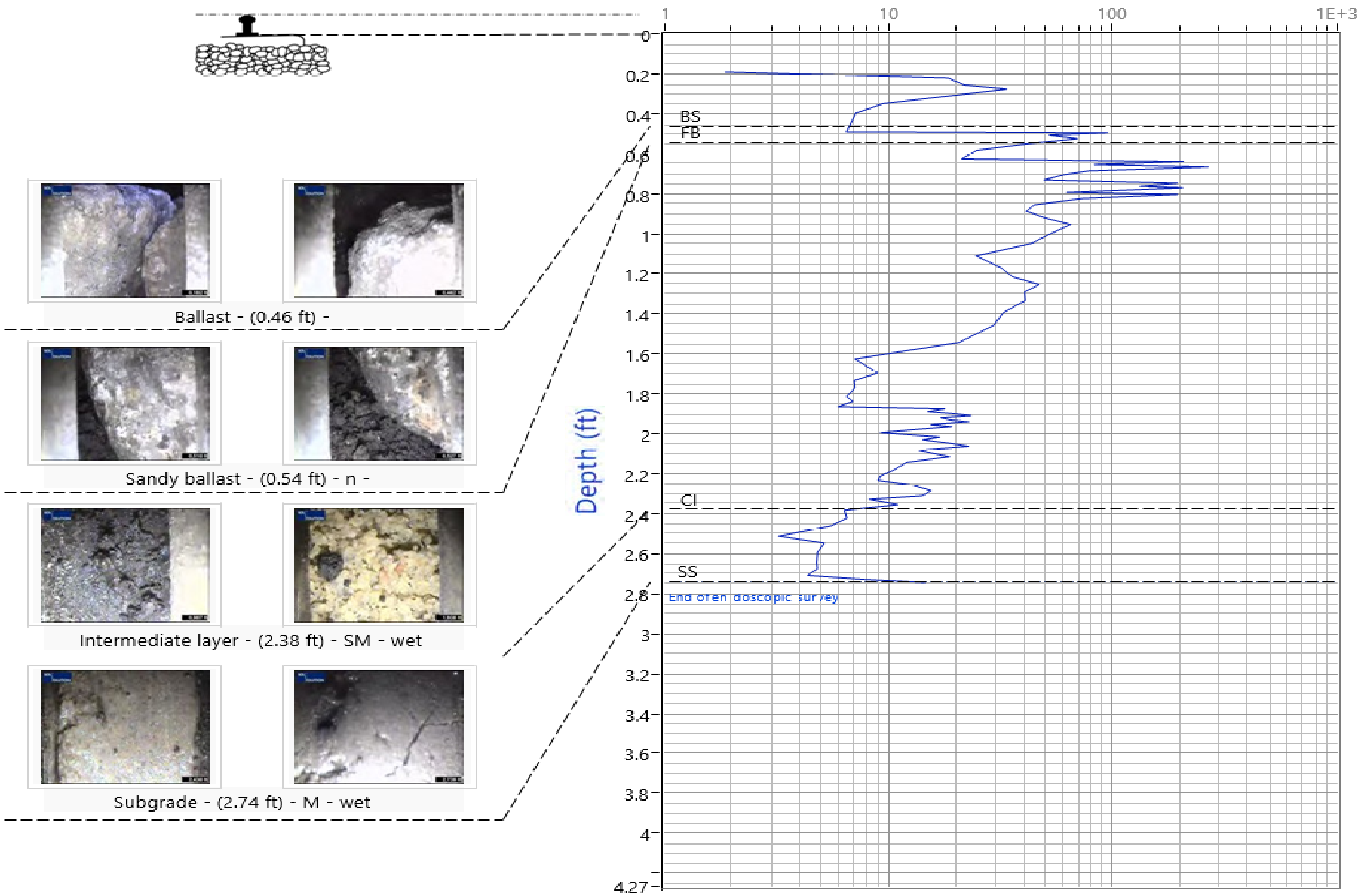
PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 2 **MP:** 026.766 **Pos:** Pe **Area:** Plain Track **Test:** 230

Cone Resistance (CBR)

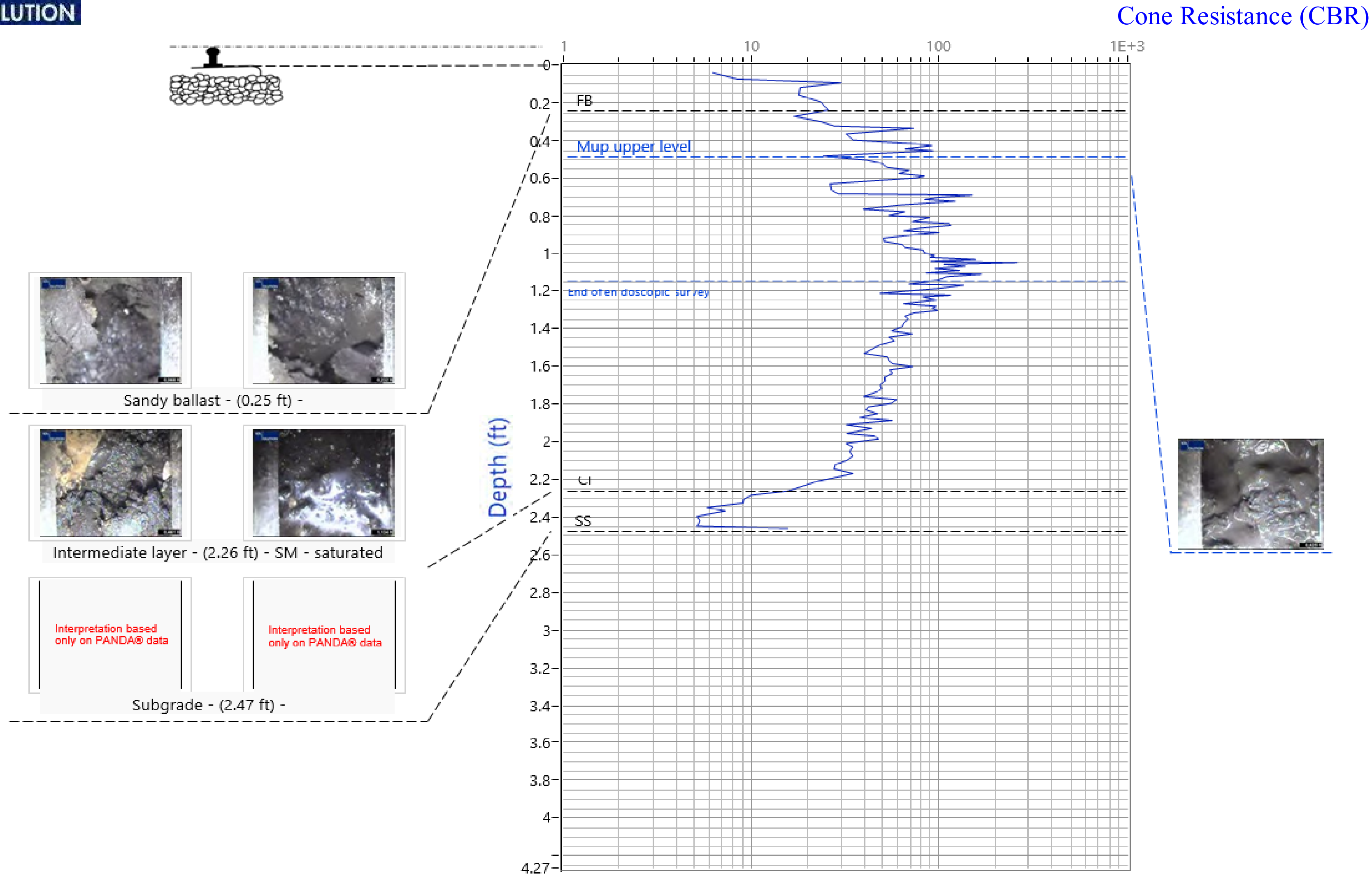


PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 2 **MP:** 026.766 **Pos:** O **Area:** Plain Track **Test:** 231

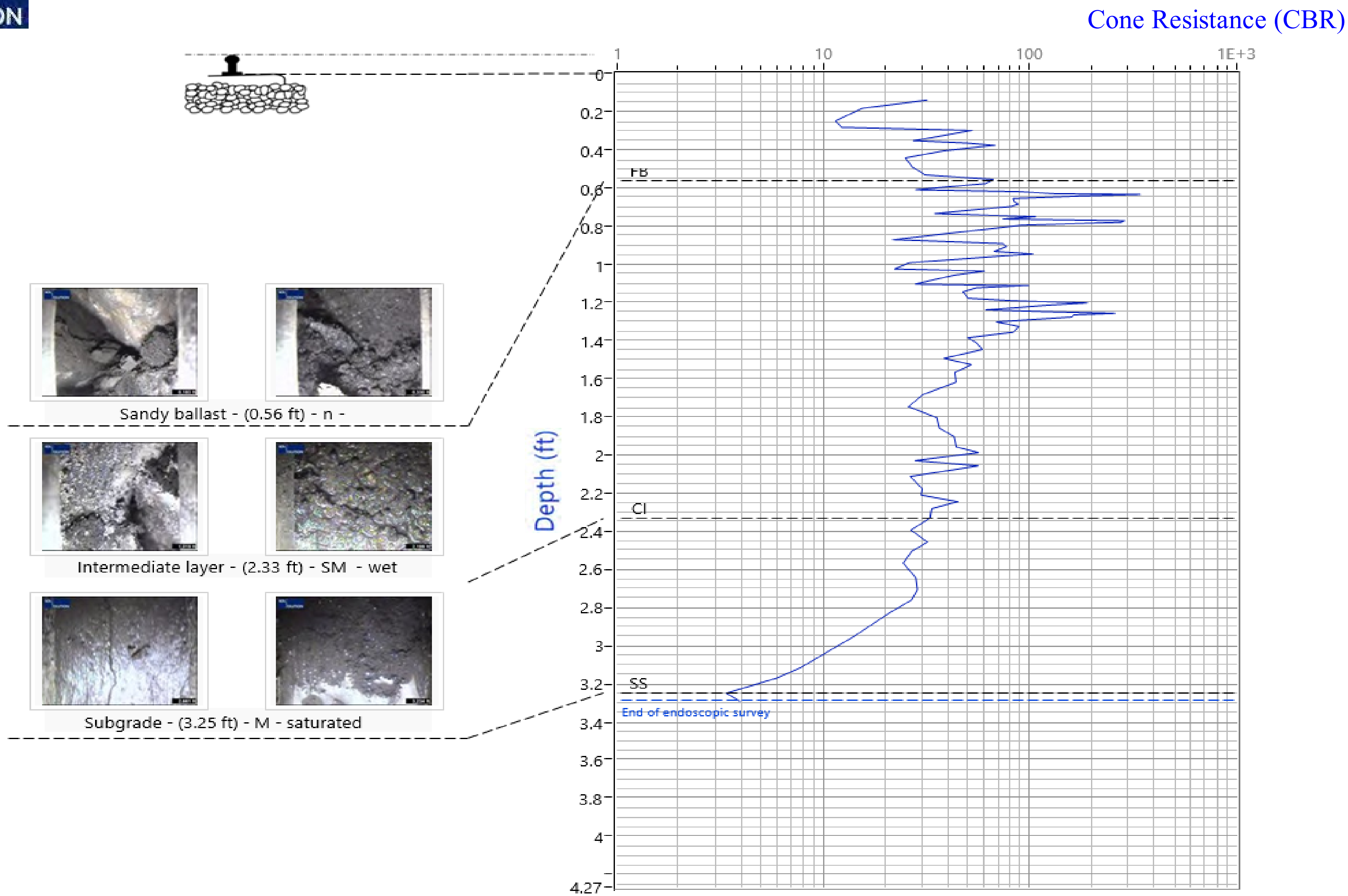
Cone Resistance (CBR)



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 027.178	**Pos:** Pe	**Area:** Plain Track	**Test:** 240



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 027.178	**Pos:** O	**Area:** Plain Track	**Test:** 241



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 027.178	**Pos:** Ae	**Area:** Plain Track	**Test:** 242

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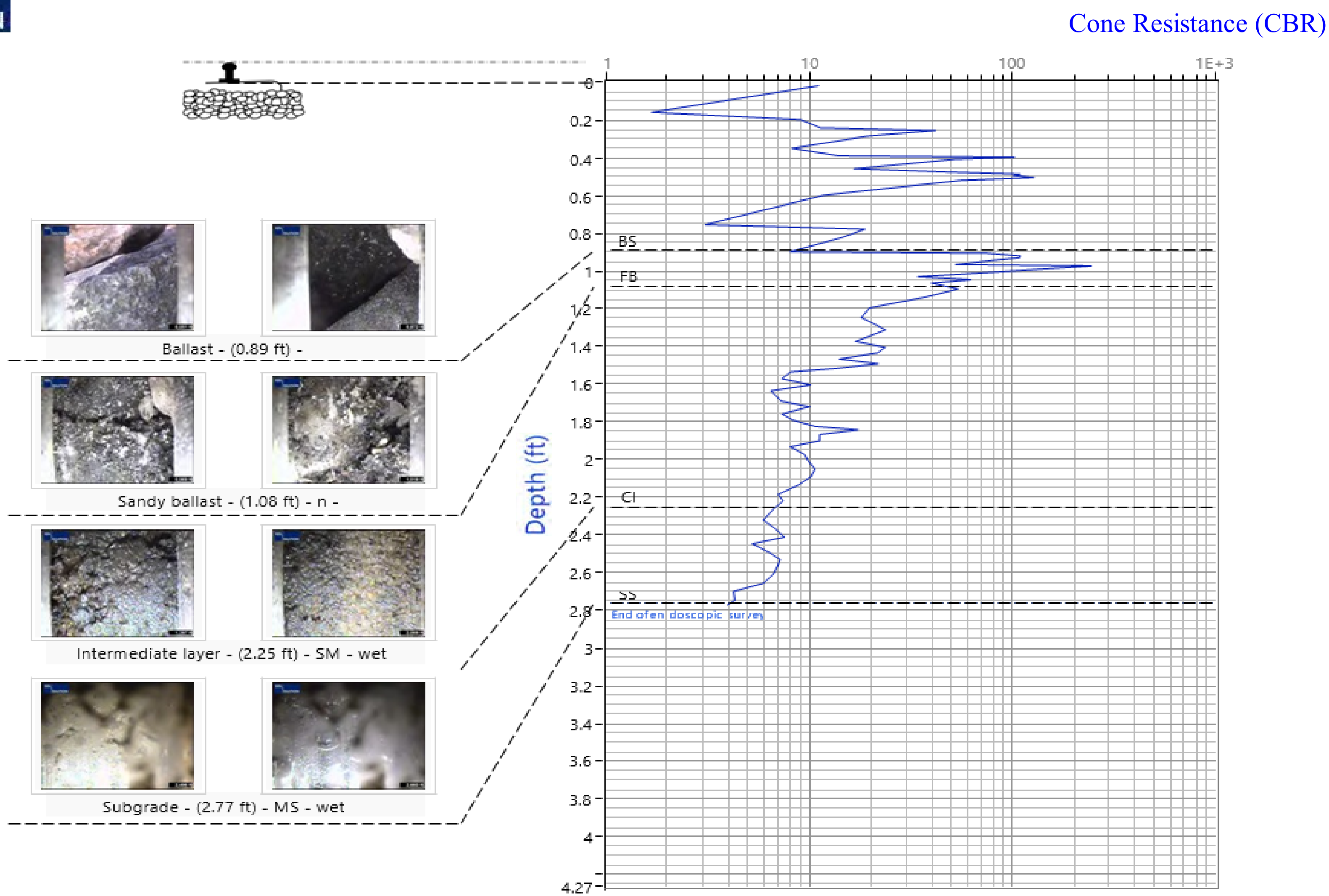
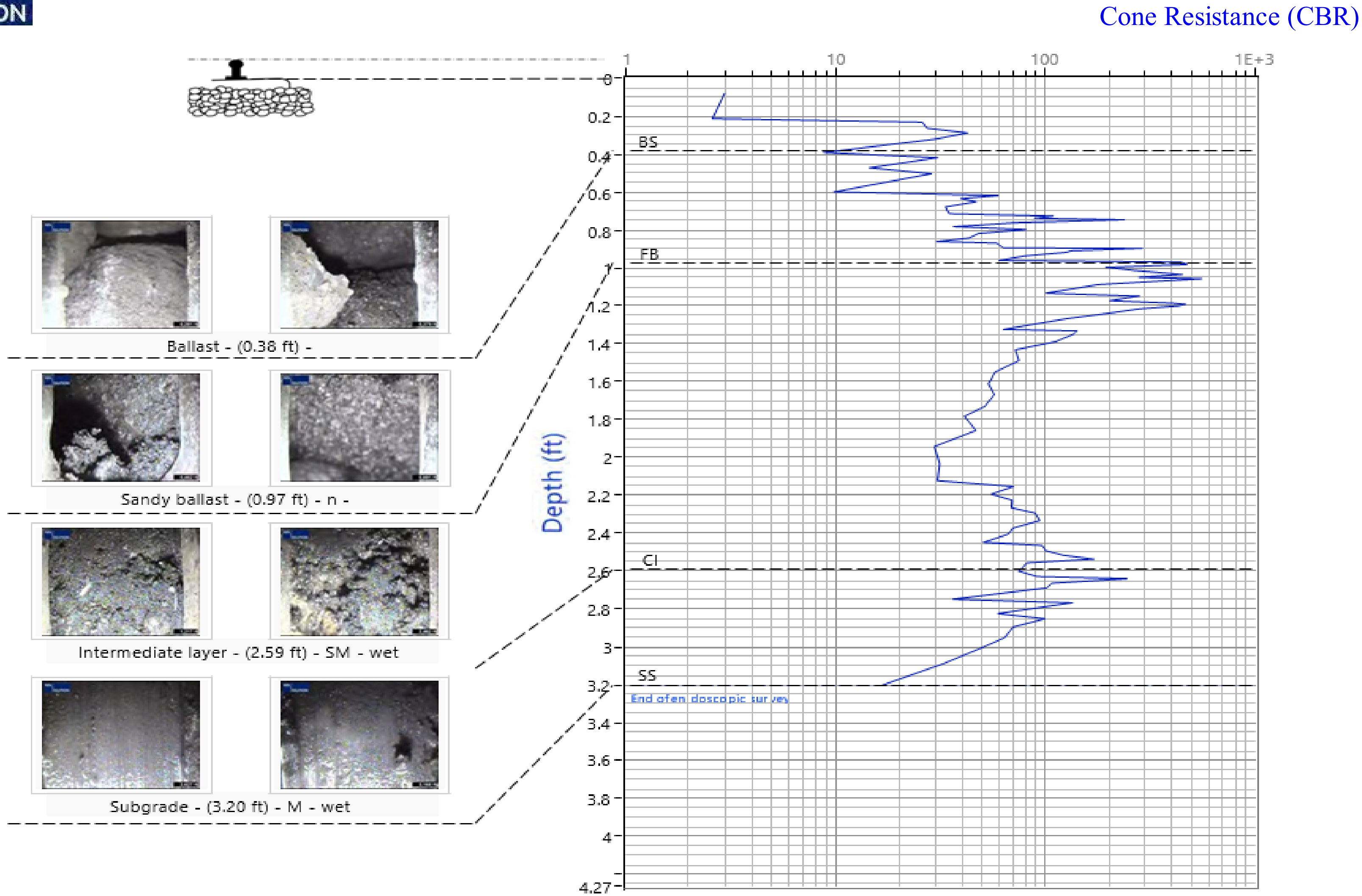
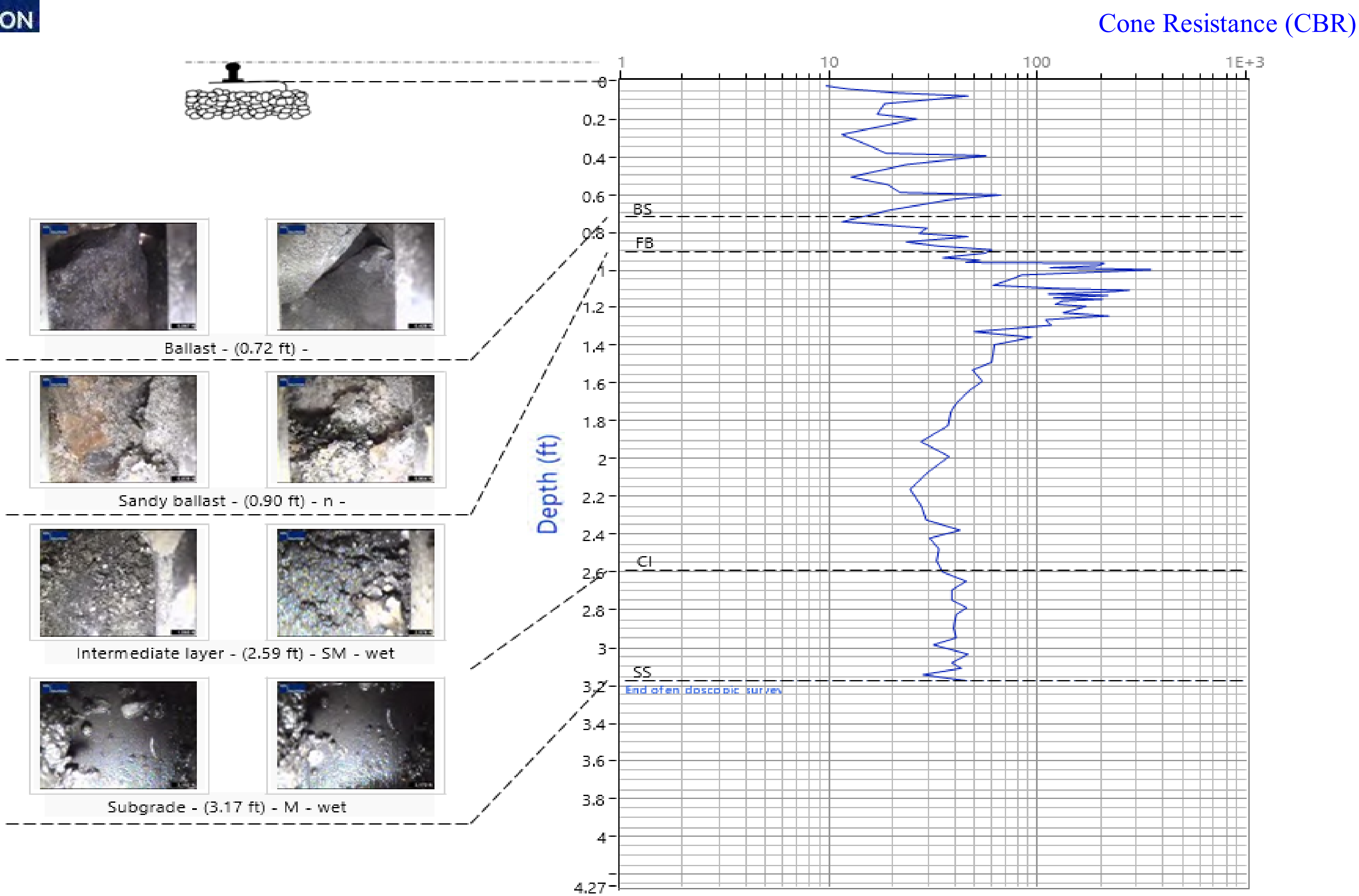


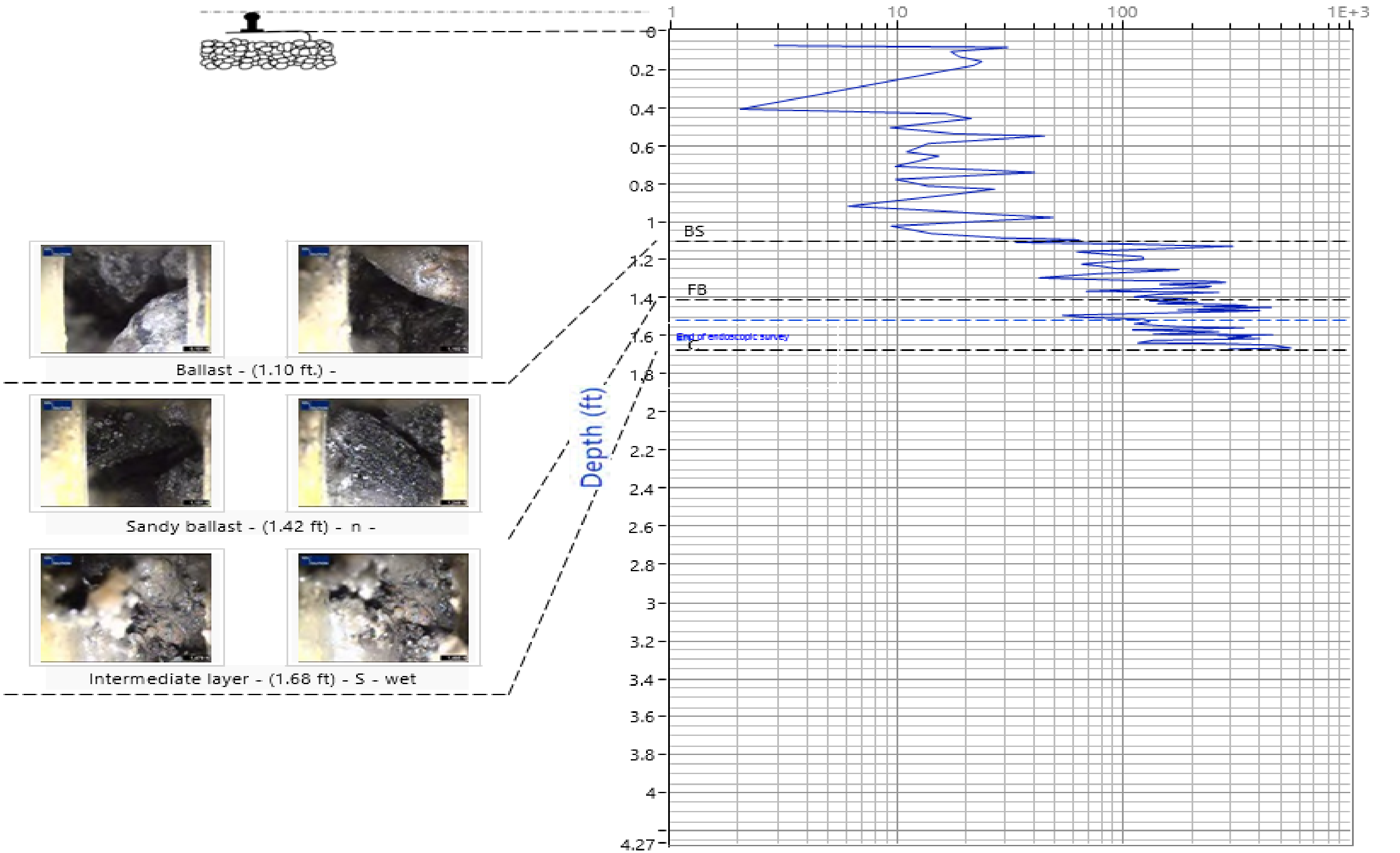
PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 2 **MP:** 027.243 **Pos:** Pe **Area:** Plain Track **Test:** 250



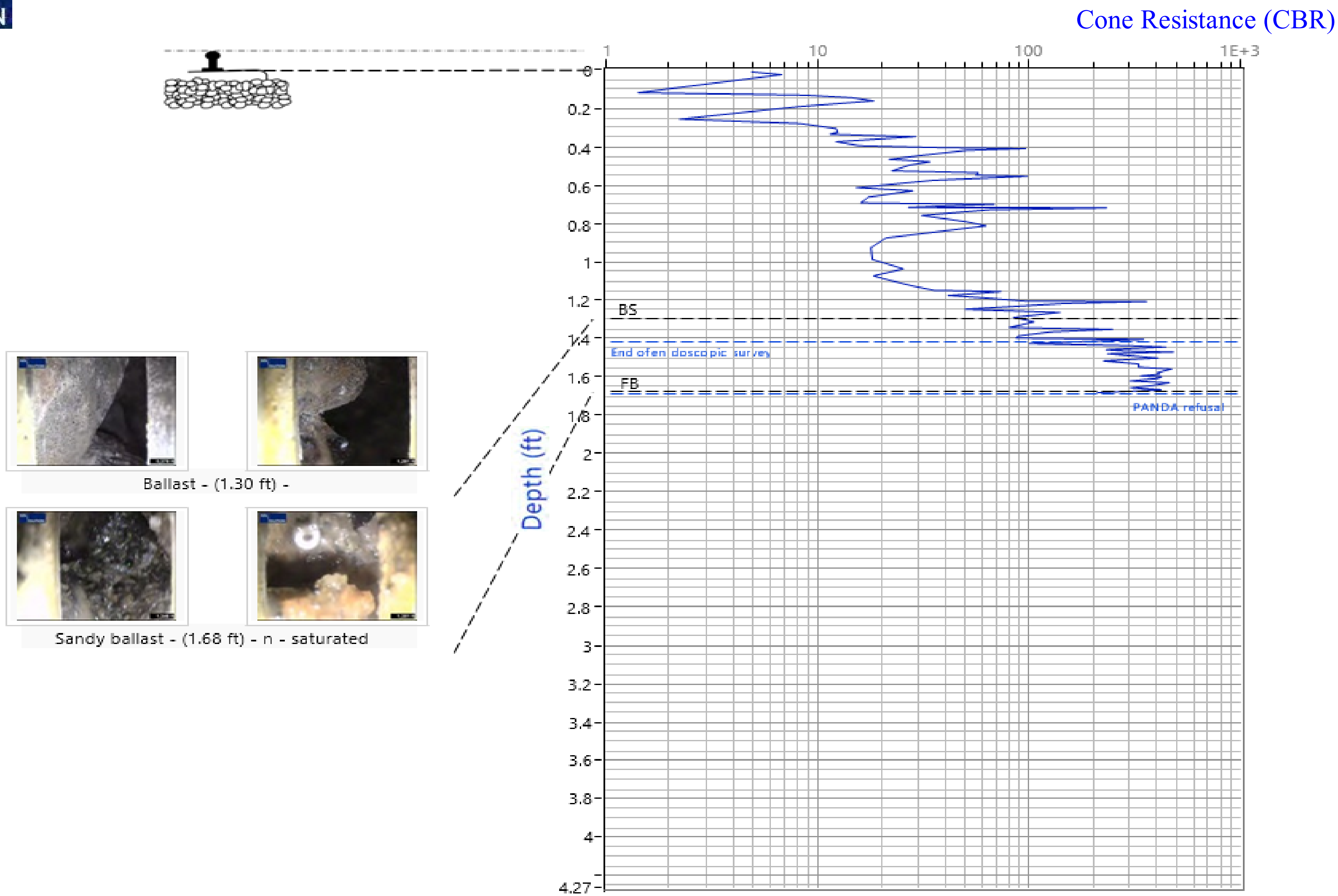
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 027.243	**Pos:** O	**Area:** Plain Track	**Test:** 251



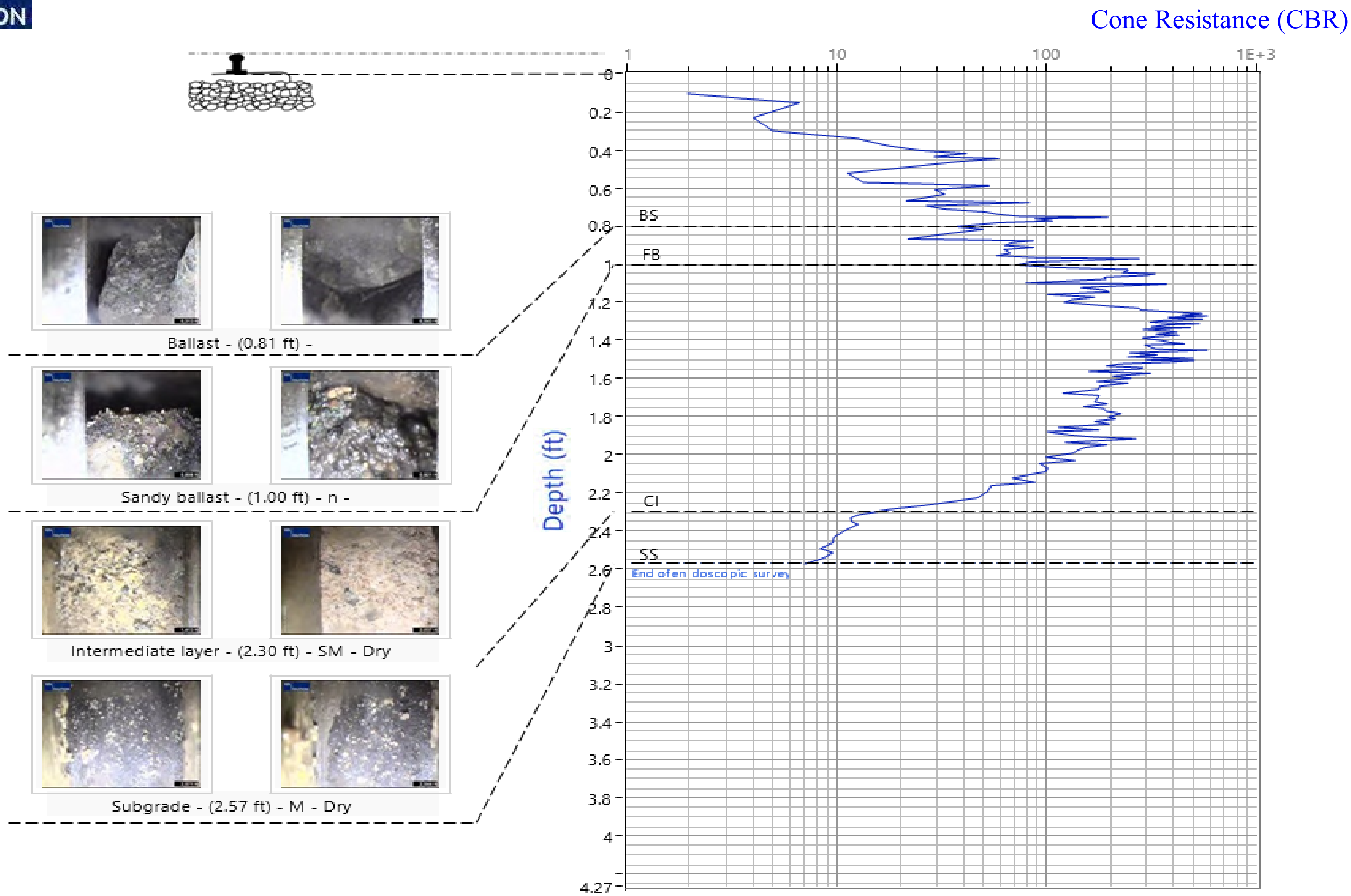
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 027.243	**Pos:** AE	**Area:** Plain Track	**Test:** 252



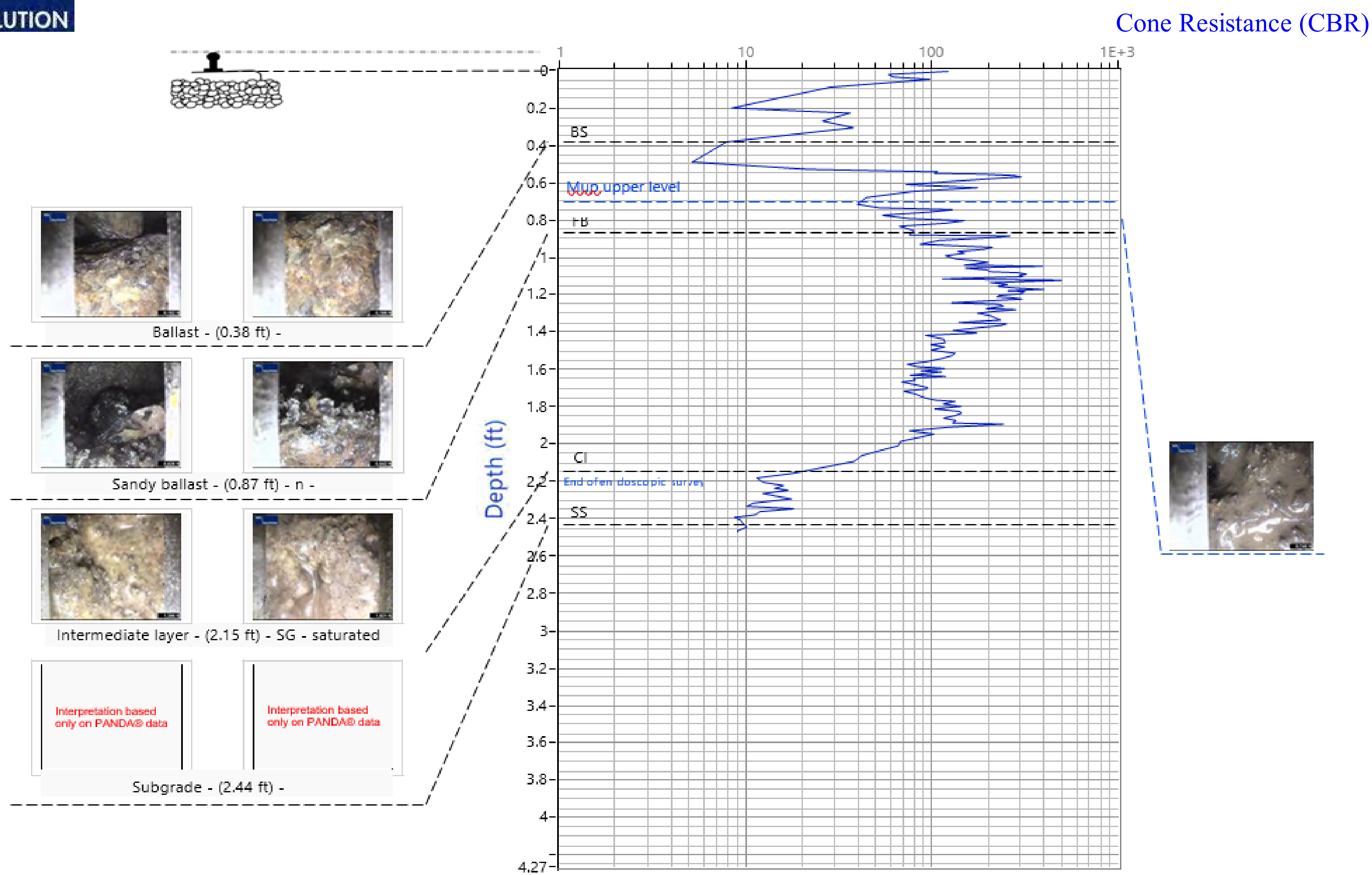
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 035.558	**Pos:** PE	**Area:** Plain Track	**Test:** 260



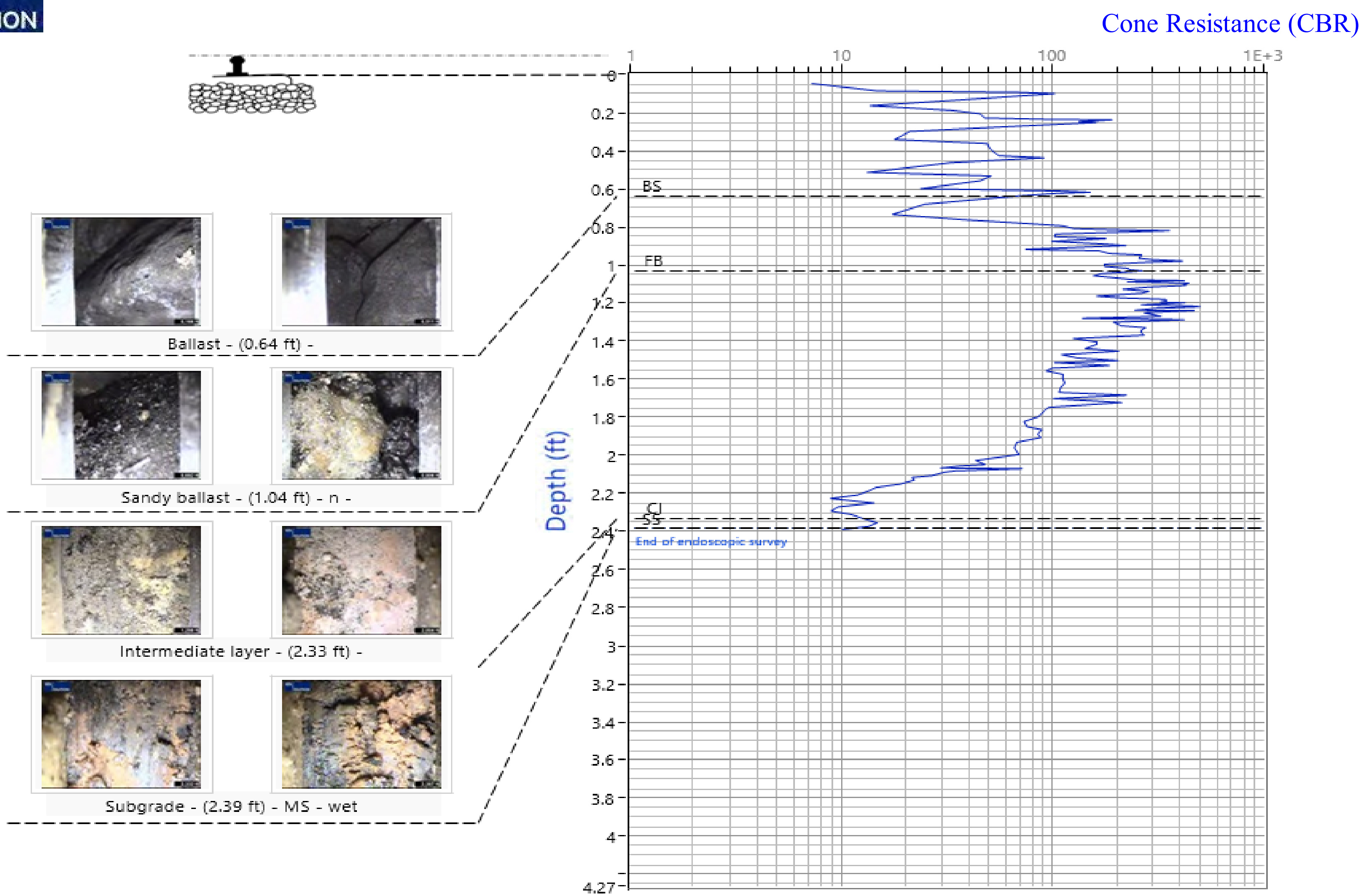
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 035.558	**Pos:** O	**Area:** Plain Track	**Test:** 261



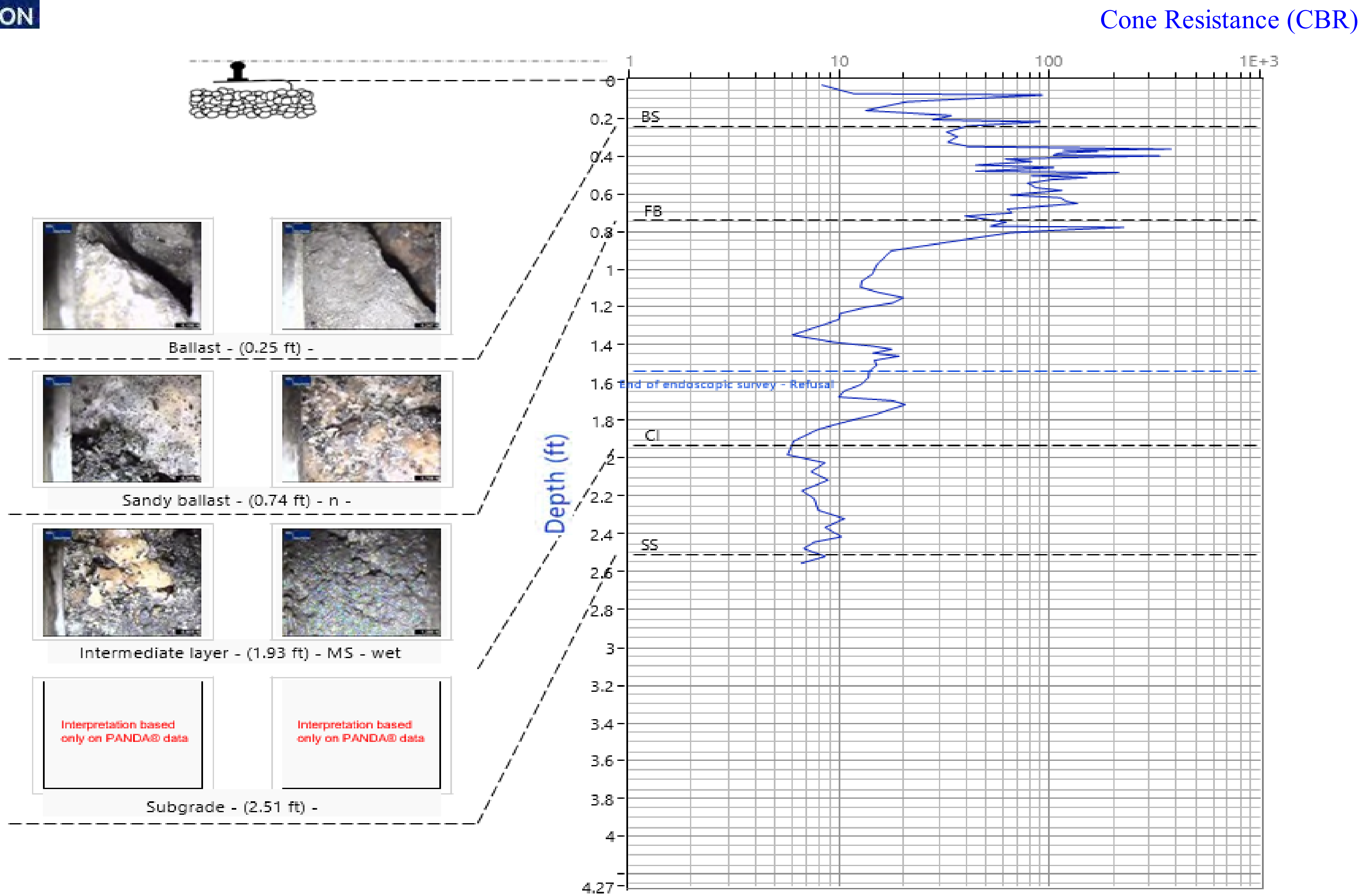
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 037.771	**Pos:** Pe	**Area:** Plain Track	**Test:** 270



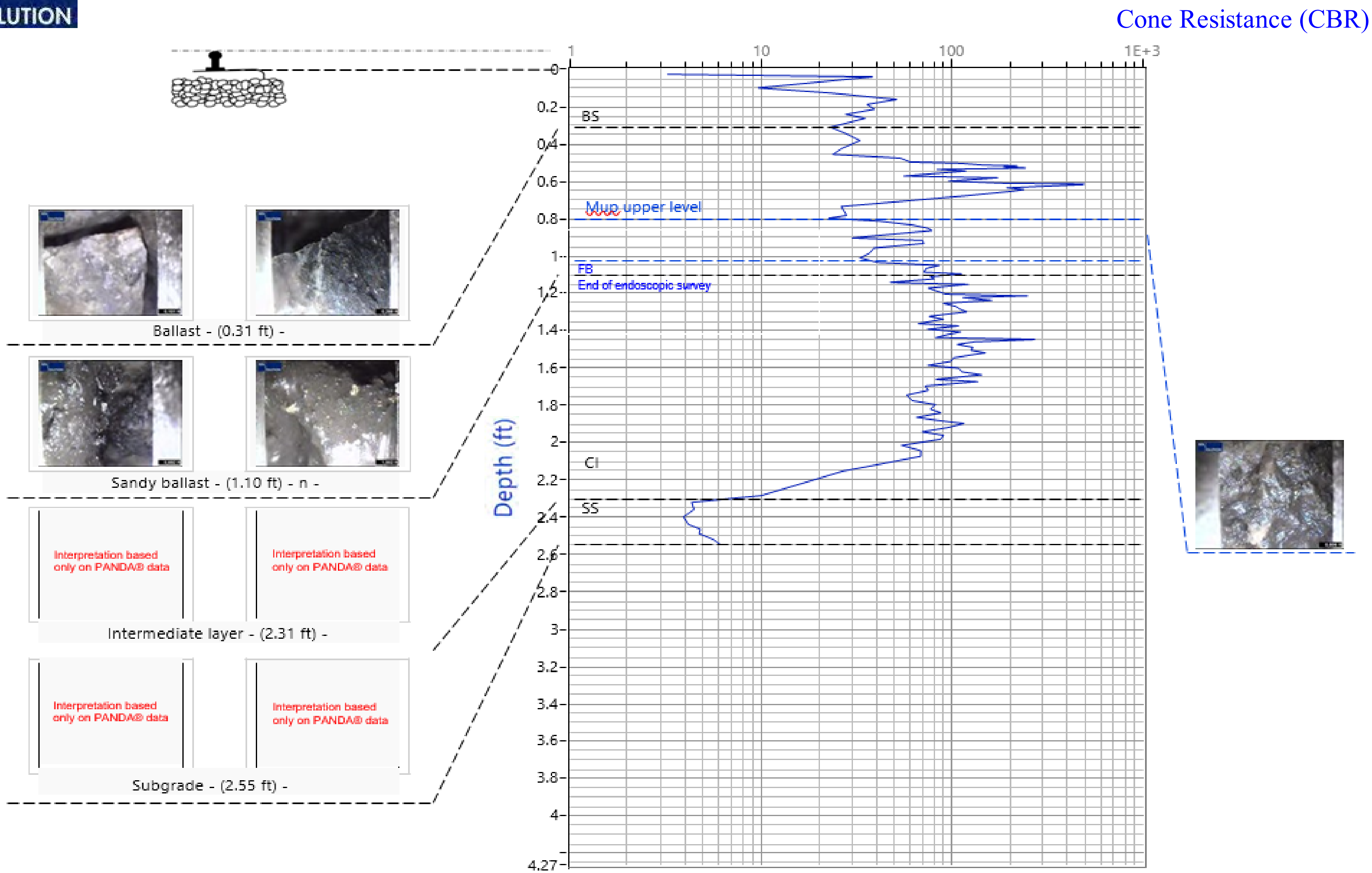
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** XXXXX	**Track id:** 2	**MP:** 037.771	**Pos:** O **Area:** Plain Track	**Test:** 271



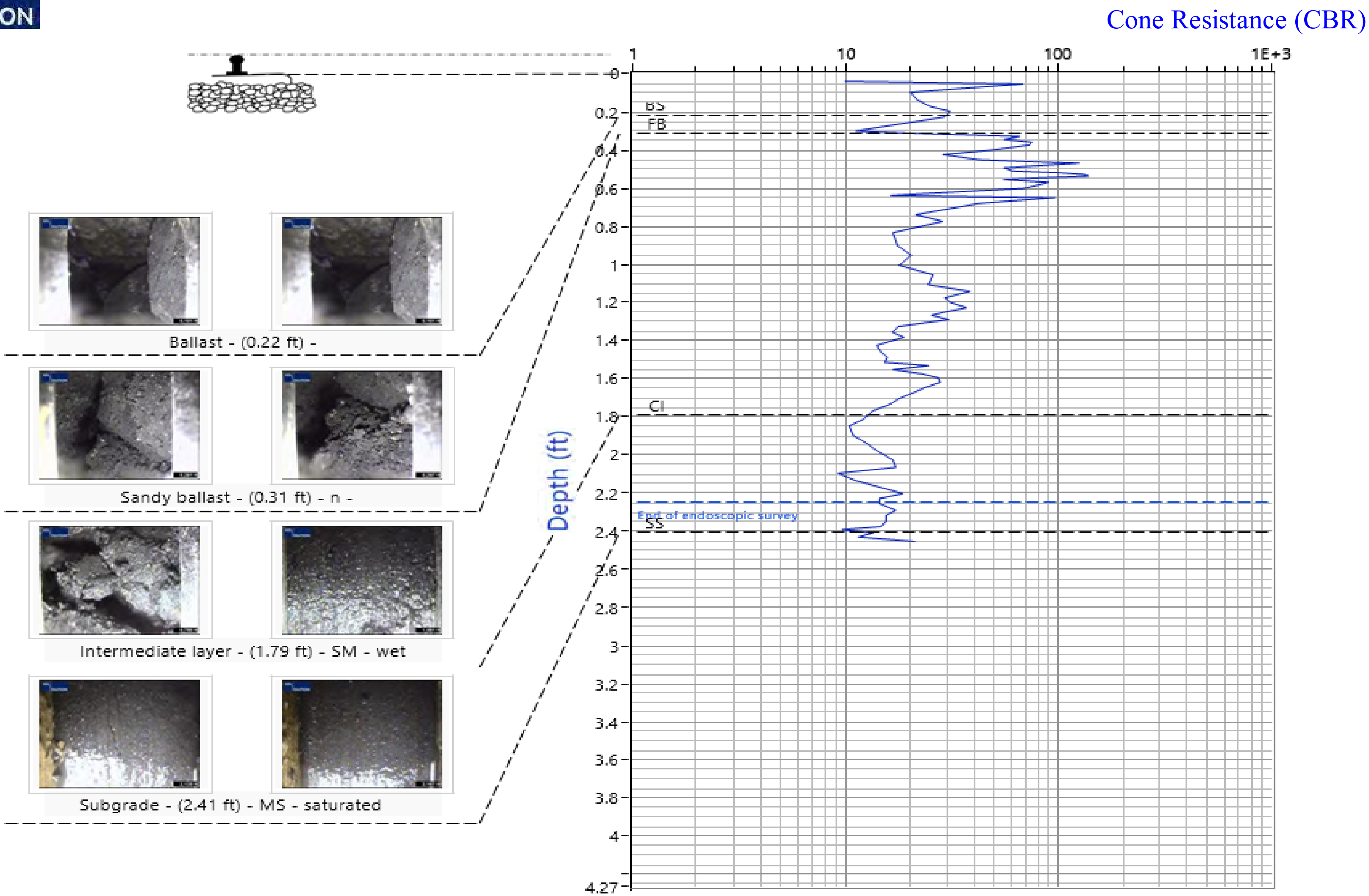
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 037.771	**Pos:** Ae**Area:** Plain Track		**Test:** 272



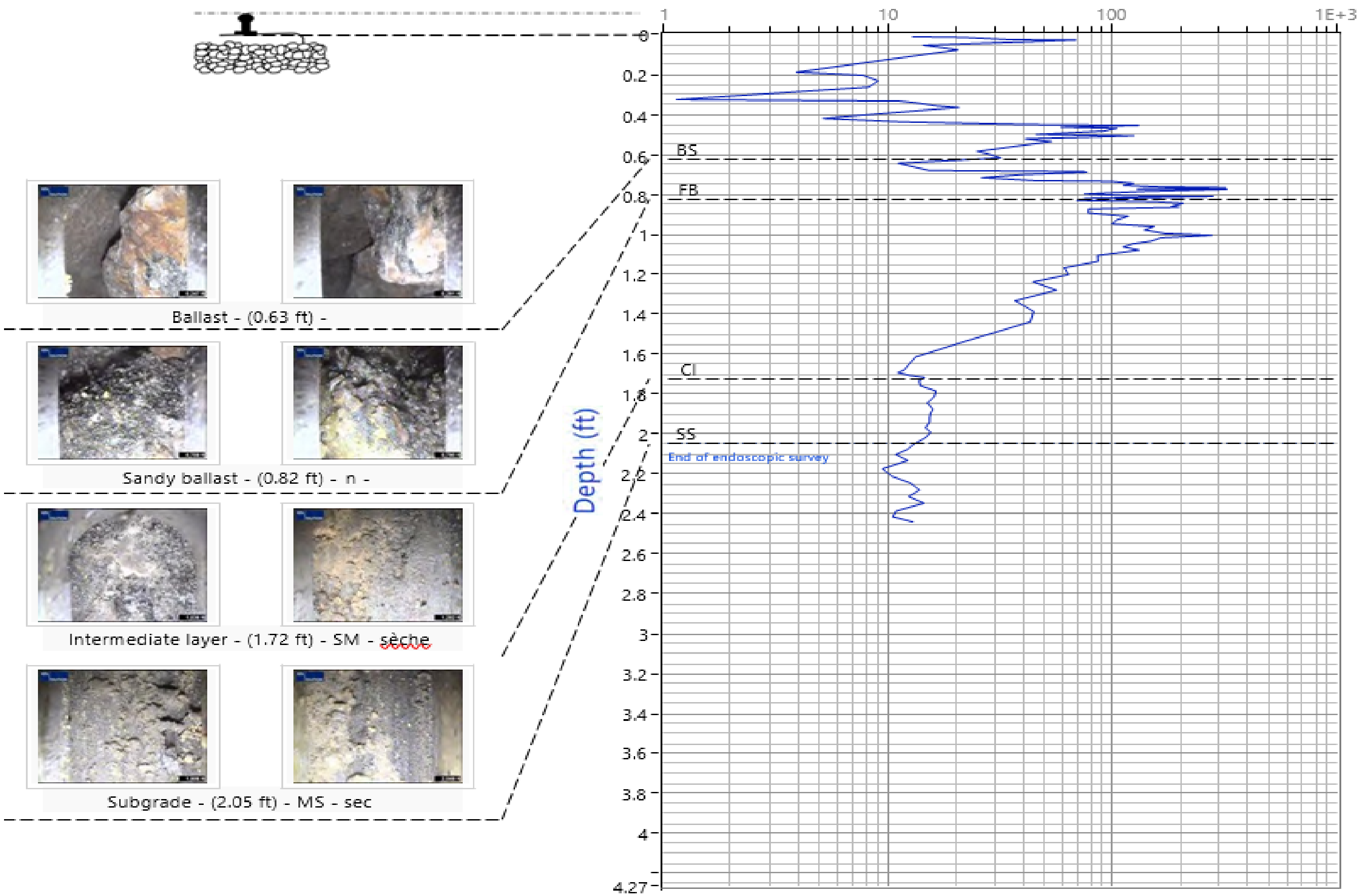
PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** XXXXX	**Track id:** 2	**MP:** 026.732	**Pos:** Pe **Area:** VC	**Test:** 280



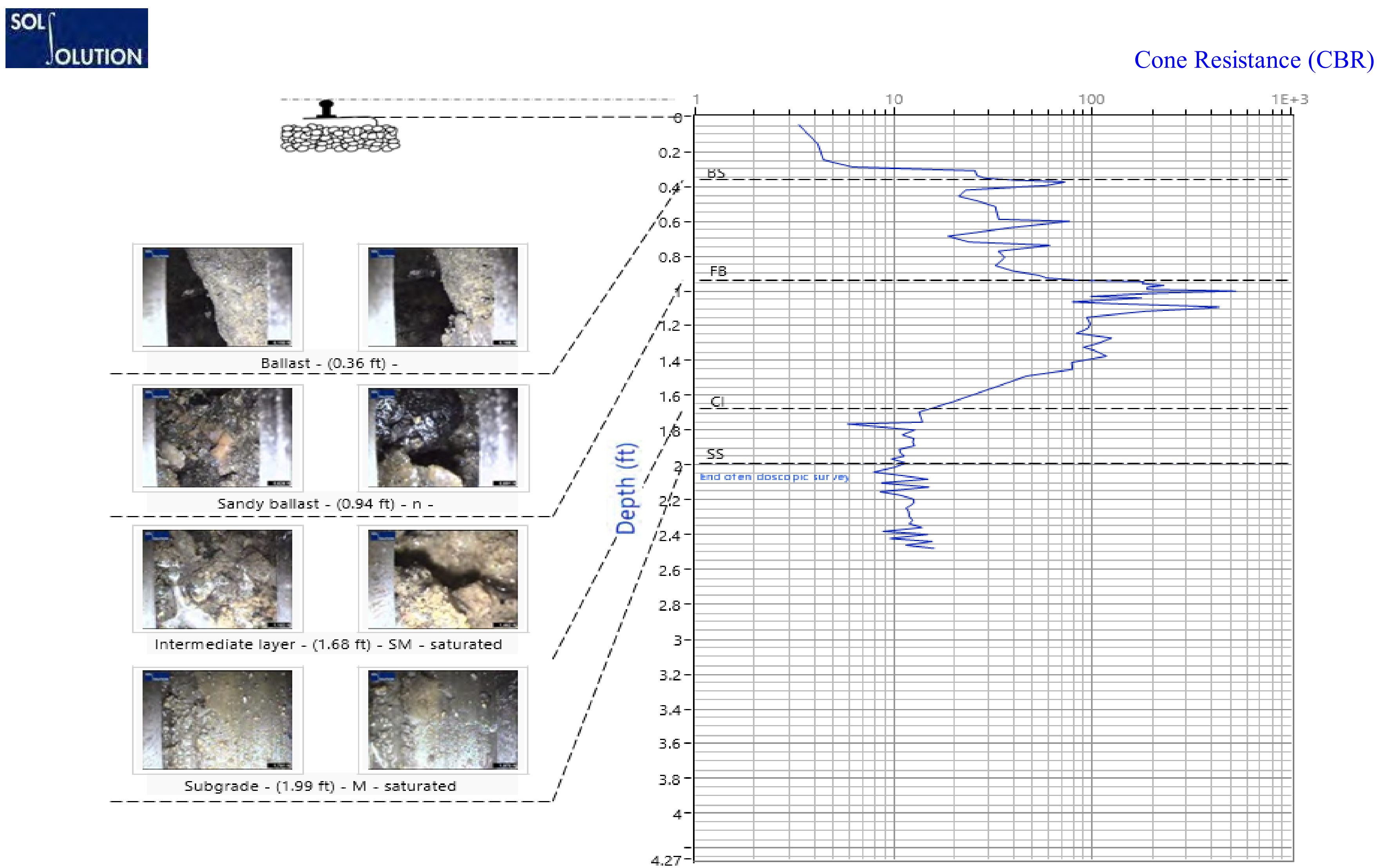
PANDOSCOPE® **Site:** BNSF LINE 4 **Line:** 4 **Track id:** 2 **MP:** 026.732 **Pos:** O **Area:** Plain Track **Test:** 281



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 026.732	**Pos:** Ae	**Area:** Plain Track	**Test:** 282



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** 4 **Track id:** 2	**MP:** 039.871	**Pos:** Pe	**Area:** Plain Track	**Test:** 290



PANDOSCOPE®	**Site:** BNSF LINE 4	**Line:** XXXXX	**Track id:** 2	**MP:** 039.871	**Pos:** O	**Area:** VC	**Test:** 291

Appendix E.
BB/Zetica - ZR0345-15-R01-B (Ravenna Sampling Report) - 12.06.17b

Introduction

- Zetica/BBRI was commissioned by FRA and TTCI to assist with the validation of the GPR data being acquired using FRA's track inspection car DOTX220.

The validation process comprised:

- Comparison of the data acquired using DOTX220 with concurrent data collected using one of BBRI's hi-rail GPR inspection cars.
- Comparison of the modeled ballast fouling index (BFI) and fouling depth (FDL) determined from the DOTX220 and hi-rail datasets against calculated Selig Fouling Index (FI) results obtained from particle size analysis of bulk ballast samples and measured depths to fouling observed in the sampling tubes.
- Provision of example Trackbed Inspection Reports (TBIRs) for selected locations within the survey area to illustrate the role of the GPR data for general analysis of subsurface trackbed condition such as the presence of formation failure, mud pumping and ballast pockets.

Survey

- Multi-channel GPR data was acquired between August 21st and 23rd and September 7th and 8th, using BBRI's Truck #3 GPR survey car and FRA DOTX220 inspection car respectively.
- Data collected over an approximate 29-mile section of dual-track between MP 11 and MP 40 on Line Segment 4 of the BNSF Ravenna Subdivision.

Figure E 1. (Left) FRA's track inspection cars, T218 and T220 in consist with BNSF locomotive. (Right) BBRI hi-rail inspection car fitted with six-channel GPR and mobile terrestrial laser scanner

Sample Locations

- Ballast samples acquired at a total of 9 no. locations on the Ravenna Subdivision west of Lincoln, NE.

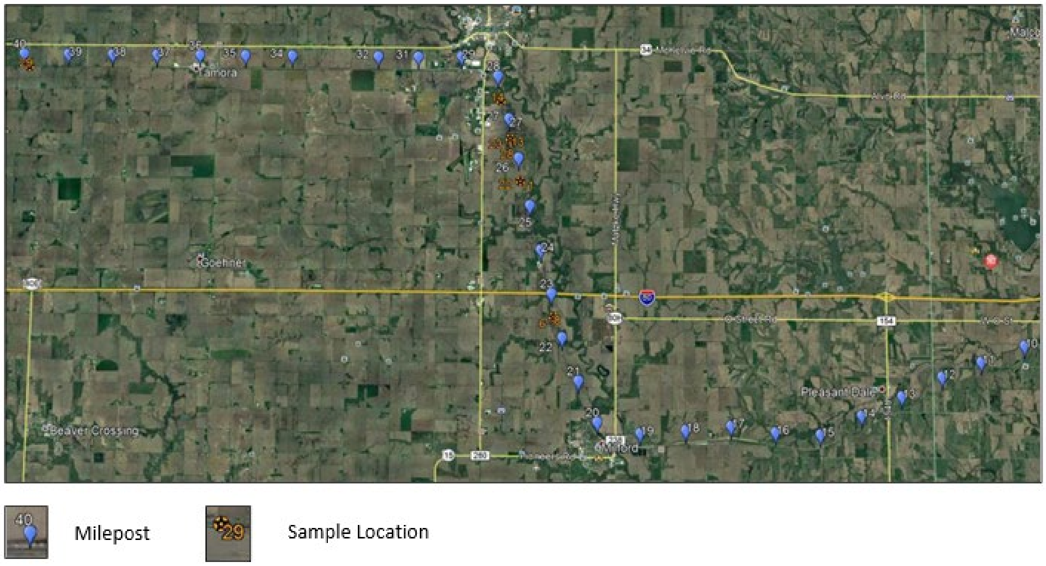


Figure E 2. Ballast samples acquired at Ravenna Subdivision locations

- Samples were collected in the cribs at each sample location, and additionally on the ballast shoulders where time allowed, resulting in a total of 24 no. sample positions (Table E1)
- Locations also selected to ensure even distribution of samples from both wood and concrete crosstie areas
- Co-location of the ballast samples and the GPR data was achieved by measuring the offset to reference track assets (i.e., road crossings, switches) that could be identified within the GPR data

Table E 1: Ballast sampling locations

Subdivision	Sample #	Line Segment	Track ID	Tie Type	Reference Asset	Offset from Asset (ft) (+ve up Milepost / railroad west)	Milepost (from registered GPR data)	GPS Latitude	GPS Longitude	Left	Center	Right
Ravenna	6	4	1	Concrete	O Street Xing @ MP22.747	-172.5	22.7178	40.813824	-97.070531	Yes	Yes	No
	8	4	1	Concrete	O Street Xing @ MP22.754	81.5	22.7722	40.814565	-97.070772	Yes	Yes	Yes
	11	4	1	Concrete	Superior Road Xing @ MP25.769	90.0	25.7874	40.858102	-97.085016	Yes	Yes	Yes
	13	4	1	Concrete	Fletcher Road Xing @ MP26.859	-148.8	26.8306	40.871994	-97.089538	Yes	Yes	Yes
	14	4	1	Wood	Switch Heater @ MP27.696	88.5	27.7169	40.884255	-97.093537	Yes	Yes	No
	22	4	2	Wood	Superior Road Xing @ MP25.769	116.3	25.7907	40.858161	-97.085102	Yes	Yes	Yes
	23	4	2	Wood	Fletcher Road Xing @ MP26.861	-436.0	26.7704	40.871221	-97.089348	No	Yes	Yes
	28	4	2	Wood	Fletcher Road Xing @ MP26.861	-601.0	26.7361	40.870791	-97.089206	Yes	Yes	Yes
	29	4	2	Wood	Road xing @ MP39.620	1293.0	39.8691	40.894447	-97.296765	Yes	Yes	Yes

Sampling Procedure

- Ballast samples acquired by driving sampling tubes into the ballast using BNSF's testing research and development (TR&D) vibro-sampler attached to the hi-rail backhoe, bottom left
- Where possible, samples were collected in pairs, separated by a crib, at each sampling position, bottom right. The ballast particle size distribution (PSD) results from these pairs were averaged to provide a single result for comparison with the 5-m averaged GPR-derived BFI.

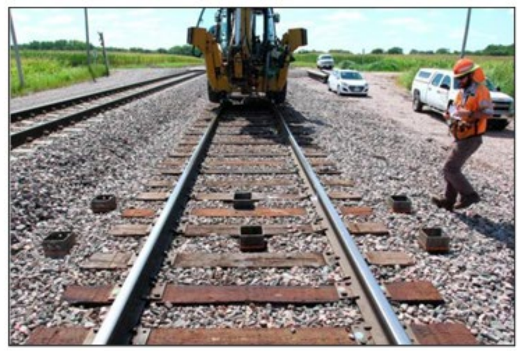


Figure E 3. (Left) BNSF TR&D vibro-sampler in operation at sample location #29. (Right) Emplaced sampling tubes at sampling location #22

- Table E2, to the right, details the measured FI values for each of the bulk ballast samples.
- Values are calculated based on the percentage by mass of particles passing the #4 and #200 sieves.
- Variability between sample pairs is generally observed to be low. The standard deviation of the absolute differences in FI between pairs is less than 3.
- Greater inhomogeneity between sample pairs observed for the most fouled sample locations, such as 23R, 14C and 29L.

Sampling Procedure

Table E 2: Measured Selig FI—all samples

Sample #	Track Position	Measured FI (Selig)			Abs.Diff
		Sample 1	Sample 2	Average	
6	C	12.2	n/a	12.2	
	L	1.9	n/a	1.9	
	R	n/a	n/a	n/a	
8	C	14.7	14.4	14.6	0.3
	L	7.8	n/a	7.8	
	R	1.9	n/a	1.9	
11	C	1.3	0.7	1.0	0.6
	L	0.4	n/a	0.4	
	R	0.3	n/a	0.3	
13	C	11.5	8.2	9.9	3.3
	L	7.4	n/a	7.4	
	R	4.3	n/a	4.3	
14	C	30.3	20.8	25.6	9.5
	L	13.4	n/a	13.4	
	R	n/a	n/a	n/a	
22	C	10.5	10.7	10.6	0.2
	L	4.2	4.5	4.4	0.3
	R	6.5	6.6	6.6	0.1
23	C	18.1	17.3	17.7	0.8
	L	n/a	n/a	n/a	
	R	27.1	19.5	23.3	7.6
28	C	17.3	12.4	14.9	4.9
	L	14.1	12.4	13.3	1.7
	R	20.6	24.0	22.3	3.4
29	C	25.0	27.1	26.1	2.1
	L	20.6	27.3	24.0	6.7
	R	3.0	1.7	2.4	1.3
				Standard Dev.	2.9

- Tubes were driven to a maximum depth of 16 inches—from the ballast surface—to match the averaging depth used in the BFI)modeling. The volume of each sample pair was ~2,050 cubic inches.
- Bulk ballast samples hand excavated from the sampling tubes and transferred to sealed buckets for transfer to TTCI's facility in Pueblo for PSD and the percentage of moisture analysis.
- Shoulder samples were positioned 6 inches beyond the end of tie to match the position of the shoulder GPR data acquired using the hi-rail trucks.

Sampling Procedure

Figure E 4. Bulk ballast samples hand excavated from the sampling tubes and transferred to sealed buckets

Data Collection

- Data collection on the two survey vehicles was carried out using slightly differing configurations of 2 GHz and 400 MHz GPR antennas as detailed in the figures below.
- Note:
    - The shoulder antennas on DOTX220 are mounted in-board of the ends of the ties whilst on the hi-rail GPR truck they are ~6 inches beyond the ends.
    - The center 400 MHz antenna on DOTX220 is mounted at ~15 inches above top of tie compared to 11 inches on the hi-rail GPR truck.

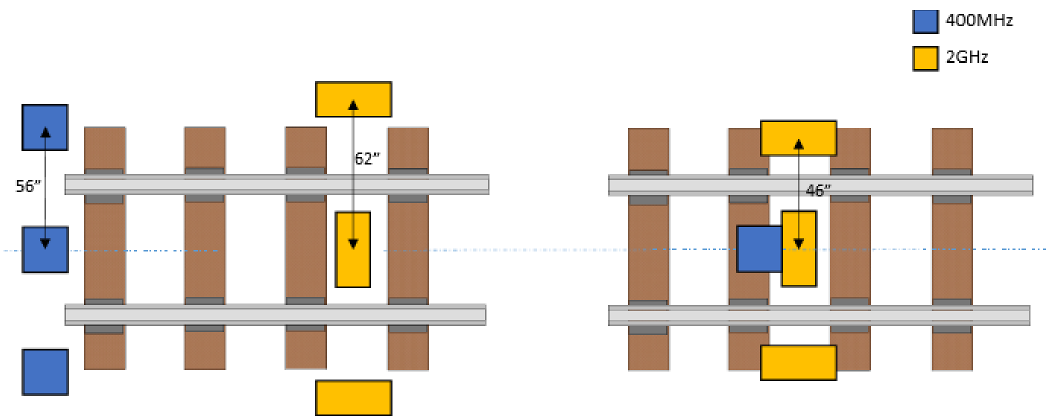


Figure E 5. (Left) Hi-rail. (Right) DOTX220

Data Processing

- The data obtained from both the train and the hi-rail truck are raw 32-bit files.
- Prior to modeling of the BFI and FDL depth the 2 GHz data is registered to the customer's network and then pre-processed using several custom algorithms:
  1. Antenna matching – This process utilizes the results of antenna plate tests to normalize the frequency response of the individual 2 GHz antennas to that of a reference antenna.
  2. Bandpass filter – To remove system noise and other horizontal artifacts in the data.
  3. Custom filter – Applies a frequency filter to correct the data for the effects of the antenna's analogue electromagnetic interference (EMI) filter.
  4. Tie removal – Advanced filtering to help minimize the effects on the data of crossties, particularly concrete, and other noise sources. The filter is applied irrespective of tie- type.
  5. Image Quality Enhancement – Applies gain to improve the visual appearance of the radargrams for layer interpretation.

Data Processing – Tie Removal

- Example of the effect of the tie removal filter for 2 GHz data collected over concrete ties in the track center.

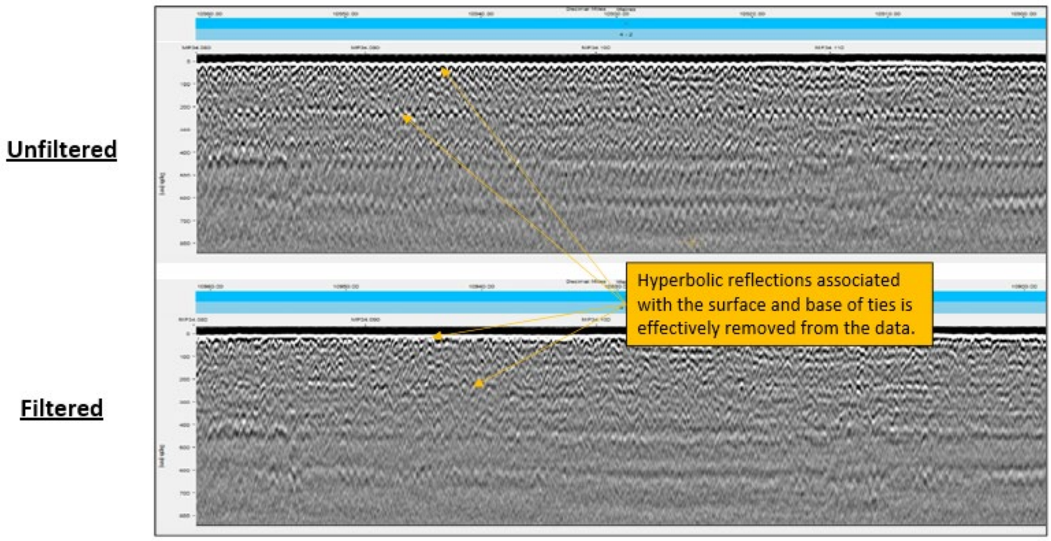


Figure E 6. Tie removal filter effect over concrete ties in track center

Trackbed Condition Metrics – Ballast Fouling Index

- Calibrated measure of the level of fouling within the ballast from surface to a specified depth, typically 16 inches. Below is an example not from Ravenna.

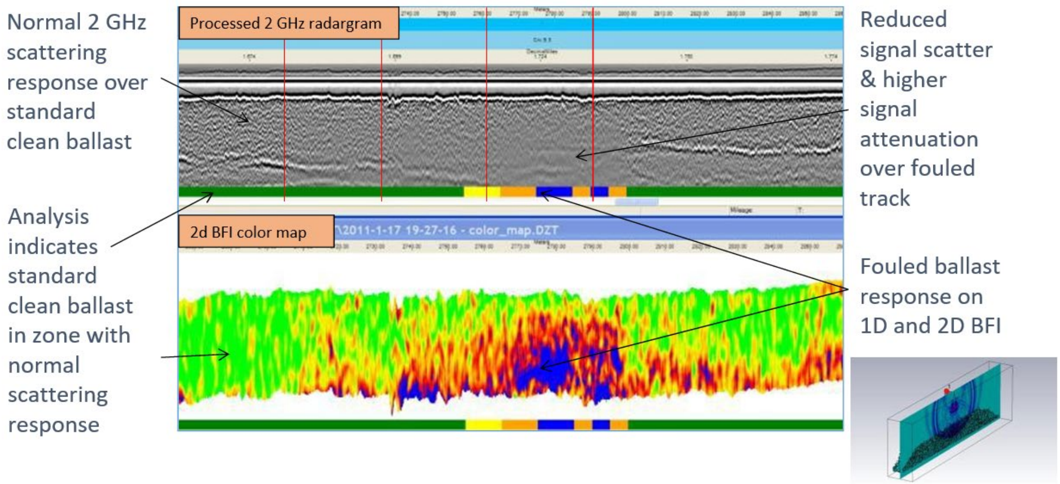


Figure E 7. Calibrated measure of level of fouling with ballast from surface

- The Free-Draining Layer (FDL) Depth reports the modeled thickness of clean ballast as measured from the ballast surface.
- Sufficient FDL thickness is important to:
    - Ensure adequate track drainage
    - Prevent accelerated deterioration of wood crossties
    - Manage subgrade stresses – to prevent subgrade deterioration (deformation and failure).
- The FDL is modeled based on analysis of the 2D BFI.
- Identifies BFI threshold, typically 20, within the image.
- Takes account of signal-to-noise within the data.

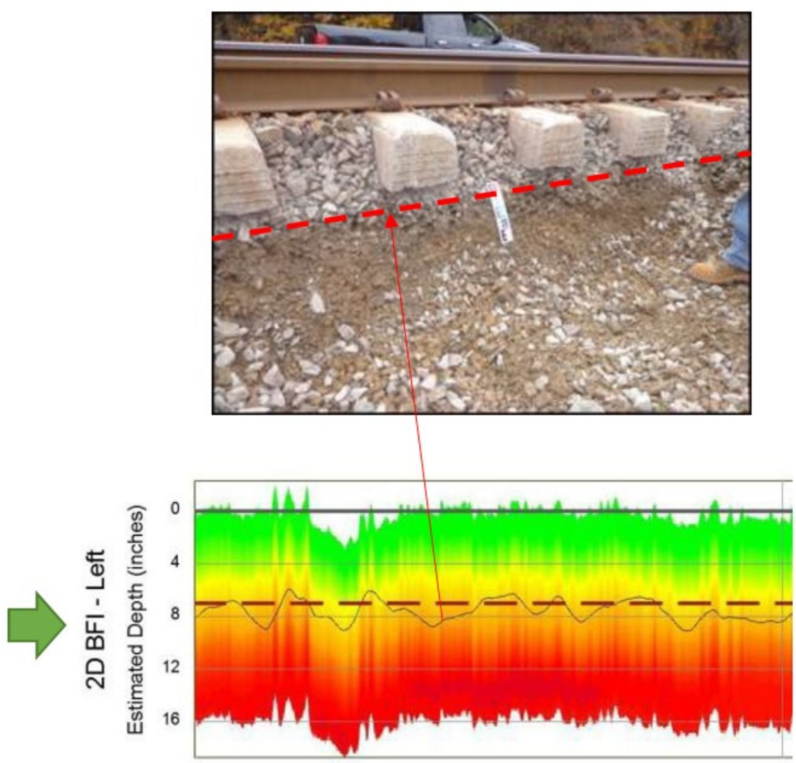


Figure E 8. Two-dimensional BFI; left estimated depth

Trackbed Inspection Reports (TBIRs)

- Designed to provide railroads with detailed information on the subsurface condition of the trackbed based on GPR and other available inspection data
- Comprises a ½ mile plot of the GPR and other available metrics and a summary description of the trackbed condition highlighting any observed trackbed defects (e.g., formation failure, mudspots, ballast pockets)
- Designed to support detailed geotechnical analysis of problem trackbed locations associated with repeat surface defects/slow orders

BNSF Trackbed Inspection Report - Summary

zeticarail

ZETICA TBIR_ID	2017_0012
DIVISION	
SUB-DIVISON	
LINE SEGMENT	
TRACK ID	
TBIR LIMITS	

RDM	n/a
RDM Office	n/a
RDM Cell	n/a
RDM Email	n/a

Trackbed Condition Summary	The overall condition of the trackbed within this 1/2 mile is classified by the CTQI as Moderate. A short section of Poor quality trackbed is identified either side of the road crossing at MP359.718. The modelled BFI throughout the 1/2 mile in the track center is Highly Fouled and the modelled free-draining layer (FDL) depth is typically less than 4 inches, indicating minimal clean ballast. On the shoulders the ballast condition is slightly better with predominantly Moderately Fouled ballast and a slightly deeper average FDL (~8 inches). Despite the high fouling the layer interfaces within the trackbed are relatively flat with no significant evidence of sub-grade failure resulting in the Moderate CTQI rating.
Trackbed Layer Summary	A well-defined primary layer interface, interpreted as the base of ballast, is evident throughout the majority of the 1/2 mile on both shoulders at a modelled depth of between 8 to 20 inches. In the center the interface lies at similar modelled depths but is less continuous. As indicated in the Trackbed Condition Summary above, the profile of the interface is typically smooth suggesting that the trackbed is relatively stable. There is no evidence within the GPR data of the formation of ballast pockets or developing mud spots. On the right shoulder a secondary interface identified from MP359.539 to MP359.604 and from MP359.876 to MP360.000 at modelled depths of between 32 - 48 inches, has been interpreted as the likely top of sub-grade.
Trackbed Defects Summary	No significant trackbed defects identified within this 1/2 mile.

Surface Defect List

GEO CAR NME	TEST DT	DEF NBR	DEF PRTY	DFCT STAT CD	DEF TYPE	DEF GROUP	FIRST LS	FIRST MP	FIRST TRACK	REPT GC NME	REPT DFCT TST	REPT DFCT NBR
No reported surface defects within this 1/2 mile												

TBIR Ref: #2017_0012, Report Generated: 03/05/2017

Figure E 9. BNSF trackbed inspection report/summary

- One-half mile per page plots subdivided into four categories: Geometry, Ballast Condition, Layering and Subsurface Defects

Trackbed Inspection Reports (TBIRs)

Figure E 10. One-half mile per page plots subdivided into Defects, Layering, Ballast Condition, and Geometry


Results
RASC
Balfour Beatty
Rail
zeticarail

Results – Comparison of DOTX220 & Hi-Rail Data

- Comparison of center 2 GHz data from DOTX220 from the top and hi-rail from the bottom over section of wood ties on Main 2 at ~MP 11.760. Color bar below radargrams is modeled BFI category

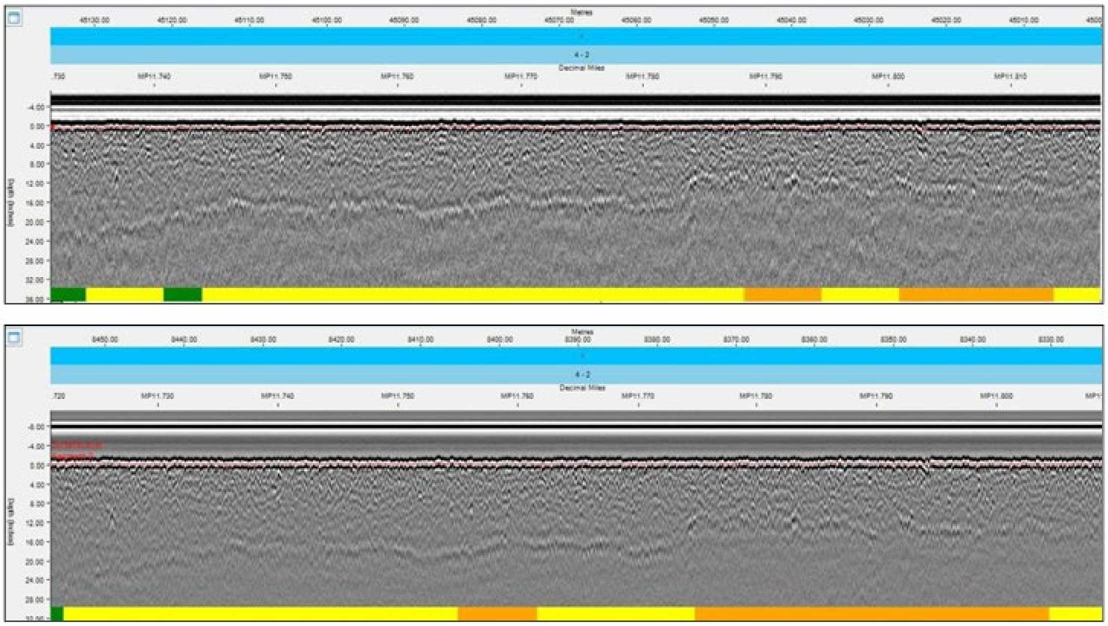


Figure E 11. (Top) DOTX220, (bottom) hi-rail

- Comparison of the right shoulder 2 GHz data from DOTX220 from the top and hi-rail from the bottom over section with wood ties on Main 2 at ~MP 13.450. Color bar below each radargram is modeled BFI category. The lower red line on each image is the modeled base of the FDL.
- Comparison of right shoulder 2 GHz data from DOTX220 from the top and hi-rail from the bottom over section with concrete ties. The train data is being affected by interference from surface reflections, believed to be associated with the reinforcing within the ties and the orientation of the shoulder antennas. This issue is addressed in more detail below.

Results – Comparison of DOTX220 & Hi-Rail Data

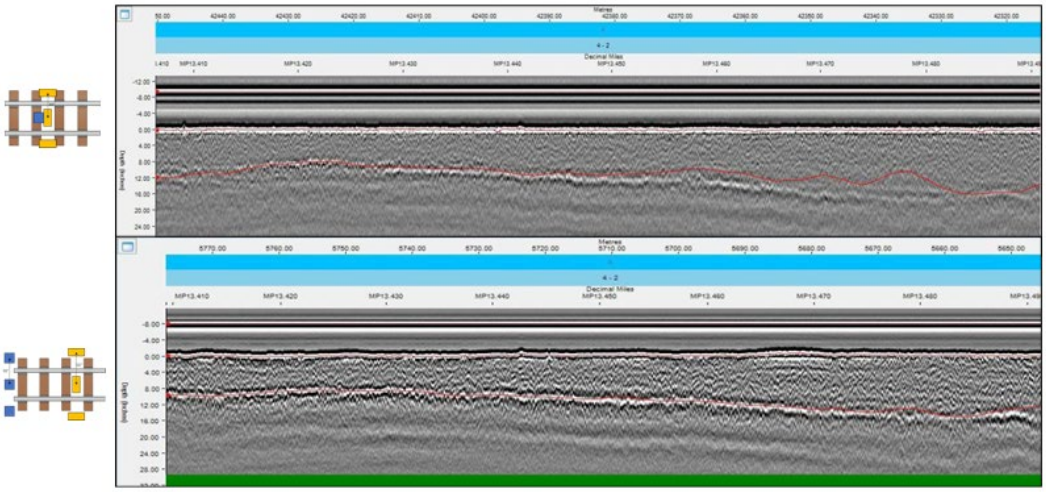


Figure E 12. (Top) DOTX220, (bottom) hi-rail

- Comparison of center 400 MHz data from hi-rail at the bottom and DOTX220 at the top over section of concrete ties on Main 1 around MP 22.330
- The primary and secondary layer interfaces evident in the hi-rail data are less apparent in the DOTX220 data, which also suffers from increased interference in the near-surface (~0–12”).

Results – Comparison of DOTX220 & Hi-Rail Data

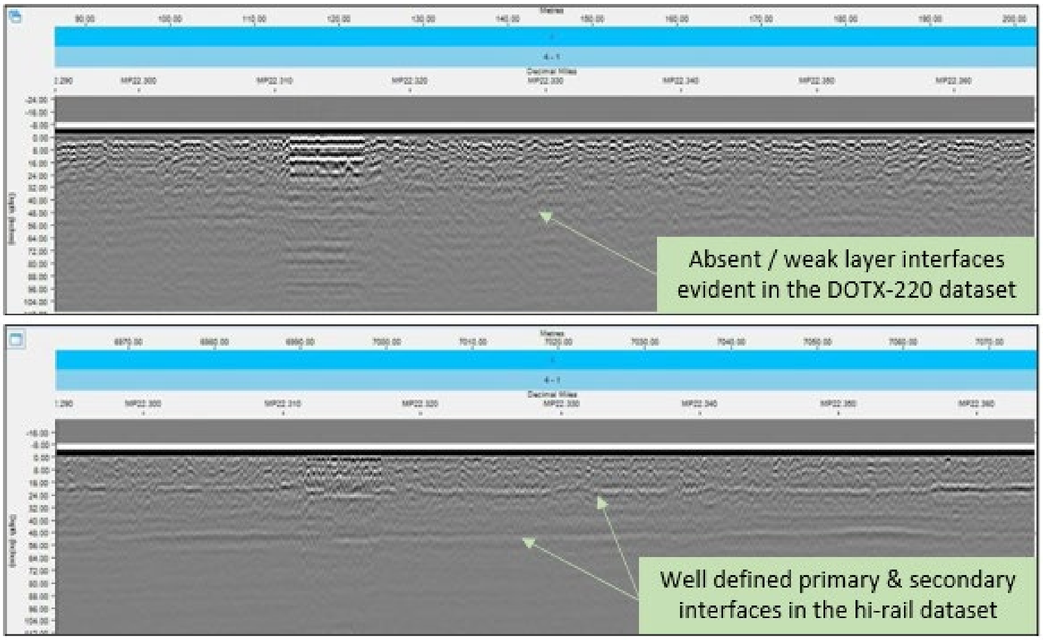


Figure E 13. (Top) DOTX220, (bottom) hi-rail

- The 400 MHz data from DOTX220 at the bottom acquired over wood ties on Main 2 is similarly of reduced quality in terms of definition of sub-surface layer interfaces when compared to the hi-rail dataset.

Results – Comparison of DOTX220 & Hi-Rail Data

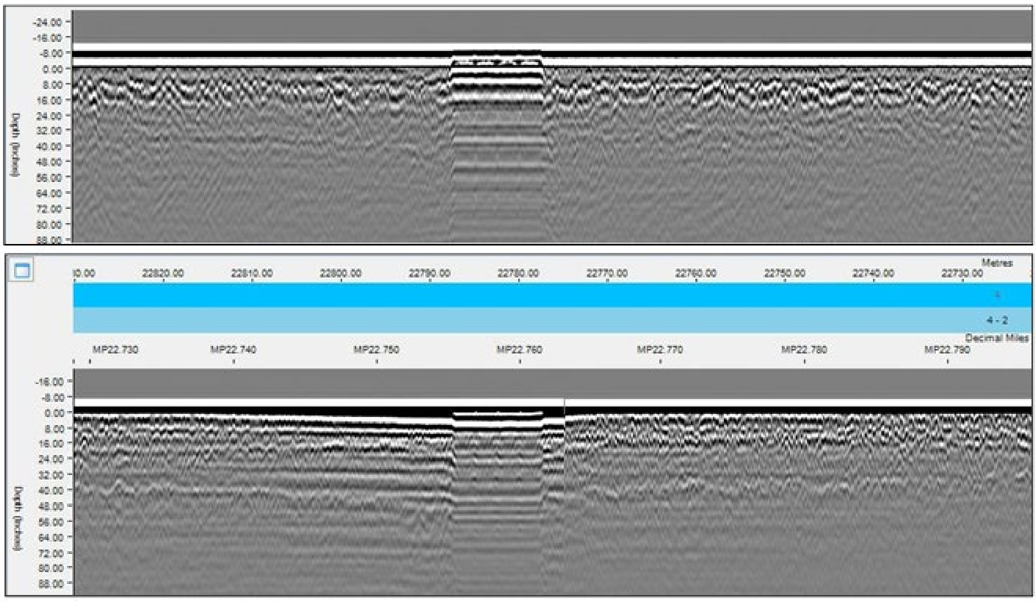


Figure E 14. (Top) DOTX220, (bottom) hi-rail

- Where layer reflections are observed in the DOTX220 400 MHz dataset the polarity of the reflection is reversed compared to the same reflection in the hi-rail data.
- This points to a potential problem with the 400 MHz antenna on DOTX220 during the Ravenna survey.

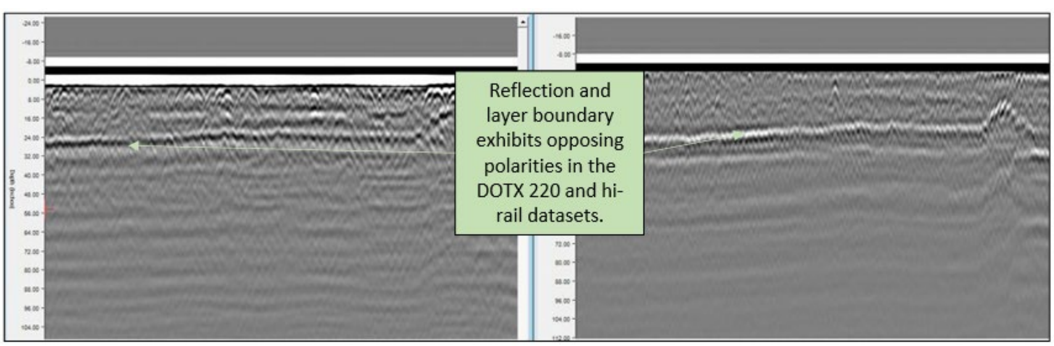


Figure E 15. (Left) DOTX220, (right) hi-rail

- The figures below confirm that the 400 MHz data collected with DOTX220 on the CSX Peninsula Subdivision in March 2017 was comparable, both in terms of reflection amplitude and phase, with the data acquired using BBRI's T#4 hi-rail GPR truck.

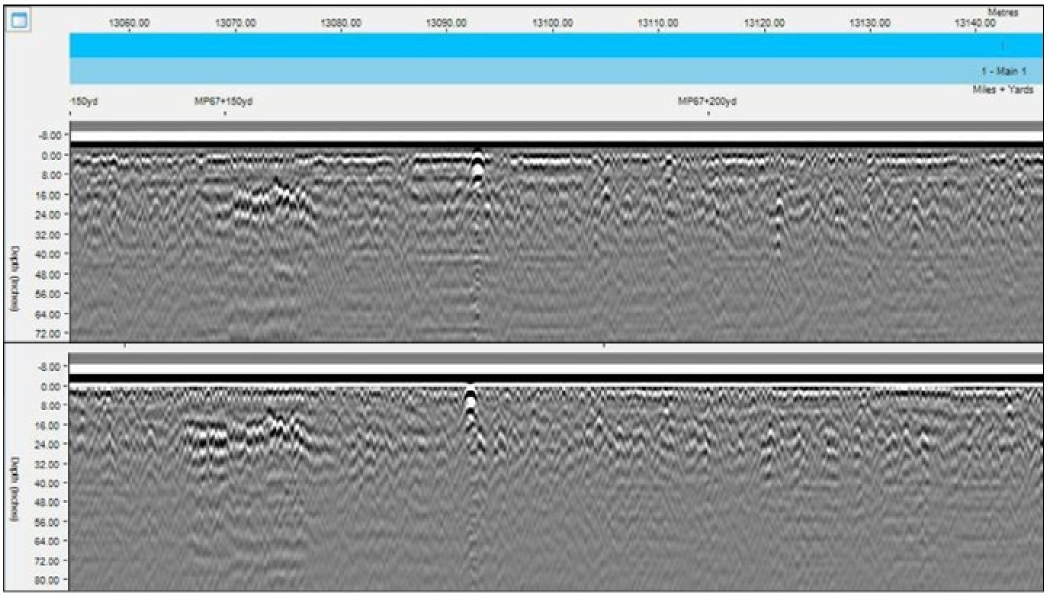


Figure E 16. (Top) DOTX220, (bottom) hi-rail

Table E 3: Modeled 5 m averaged BFI and averaged ballast sample fouling index results

Vehicle	Sample #	LS	TID	Tie Type	MP (Scaled)	GPS Latitude	GPS Longitude	Modeled 5 m BFI*			Sample FI (Average)+		
								Left	Centre	Right	Left	Centre	Right
DOTX 220	6	4	1	Concrete	22.7178	40.813824	-97.070531	14.5	39.3	10.1	1.9	12.2	n/a
	8	4	1	Concrete	22.7722	40.814565	-97.070772	12.2	23.5	12.1	7.8	14.6	1.9
	11	4	1	Concrete	25.7874	40.858102	-97.085016	9.6	3.5	12.5	0.4	1.0	0.3
	13	4	1	Concrete	26.8306	40.871994	-97.089538	7.6	20.1	9.0	7.4	9.9	4.3
	14	4	1	Wood	27.7169	40.884255	-97.093537	2.2	13.1	27.6	13.4	25.6	n/a
	22	4	2	Wood	25.7907	40.858161	-97.085102	6.0	14.2	5.7	3.5	10.6	6.6
	23	4	2	Wood	26.7704	40.871221	-97.089348	15.8	61.6	12.8	n/a	17.7	23.3
	28	4	2	Wood	26.7361	40.870791	-97.089206	11.7	52.7	9.9	13.3	14.9	22.3
	29	4	2	Wood	39.8691	40.894447	-97.296765	15.4	12.0	9.9	24.0	26.1	2.4

* To ensure accurate co-location, DOTX220 data were merged with hi-rail data using GPS latitude and longitude prior to extraction of sample location results. It should be noted that sample FI values are being compared with modeled BFIs averaged over 5 m, as per schematic below.

Results – Ballast Fouling Index (BFI)

Category	BFI	Description
1	>= 40	Highly Fouled
2	20 - < 40	Fouled
3	10 - < 20	Moderately Fouled
4	1 - < 10	Moderately Clean
5	<1	Clean

	5m track section									
1m BFI	8		14		9		18		9	
5m BFI averaged	11.6									
0.5m Crib										
Sample 1 pair of cribs										

- The Ravenna sampling results fall within the spread of results from previous ballast sampling exercises undertaken on BNSF territory as part of the original BFI calibration/validation.
- The sampling methodology utilized varied from hand dug sample holes in 2009 and 2013 to vibro- sampling in 2014 and 2017.

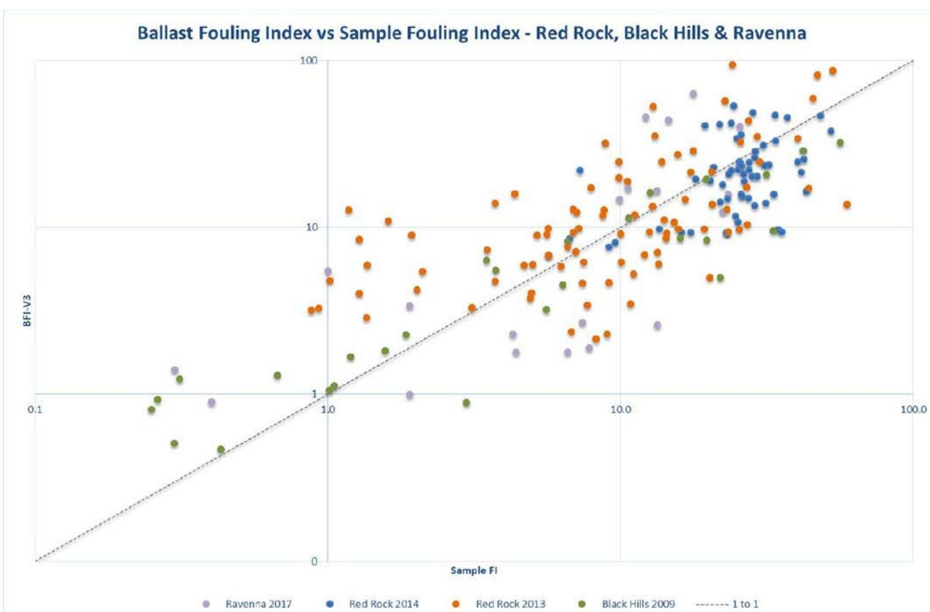


Figure E 17. BFI vs. SFI—red rock, black hills, and Ravenna

- Comparison of the BFI results for all three channels from the truck (orange) and the DOTX220 (blue) in areas of wood ties indicates the shoulders are generally slightly more fouled, particularly on the left shoulder. Results below are from Main 2 between ~MP 11.0 and MP 14.4.

- This is attributed to the closer proximity to the more fouled rail seat of the shoulder antennas on the train.

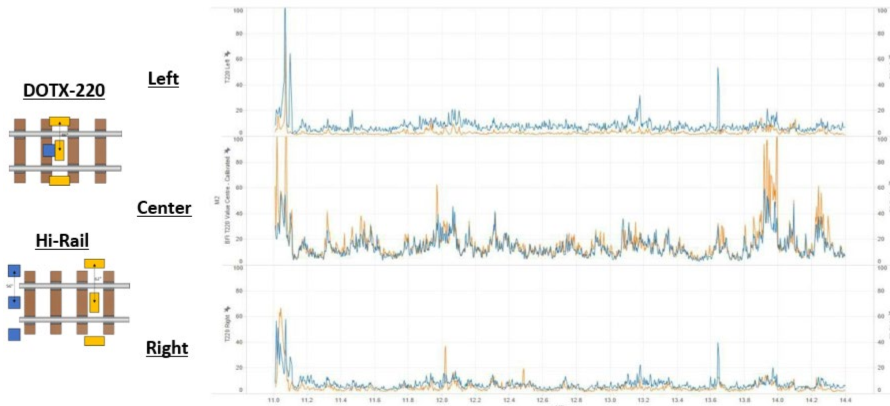


Figure E 18. Comparison of the BFI results for all three channels

Results – Analysis of Outlier Locations

- Good agreement is observed between the modeled BFI from the truck (orange) and the train (blue) over the concrete ties within the section of new dueled track between Milford and Pleasant Dale.
- Data below is from Main 1 between ~MP 16.2 and MP 20.2. An example radargram from this section is presented on the next slide. The BFI is generally low on all channels.

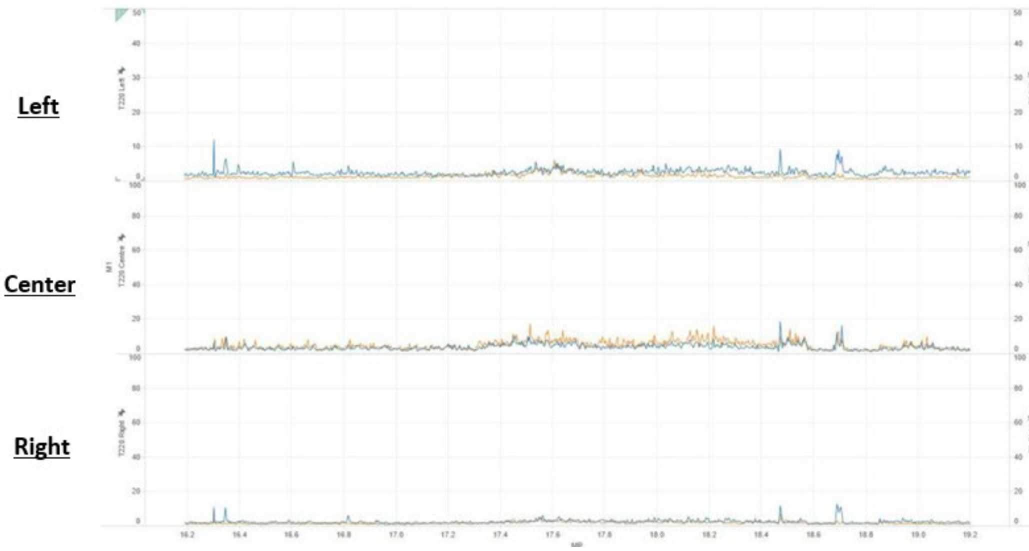


Figure E 19. Data is from Main 1 between ~MP 16.2 and MP 20.2

- The plot below presents a comparison of the modeled BFI obtained on the hi-rail truck and DOTX220 for all center samples acquired over wood and concrete ties together with the shoulder samples over wood ties on Main 2.
- Except for the shoulder data from Location #22, the match is considered to be good.

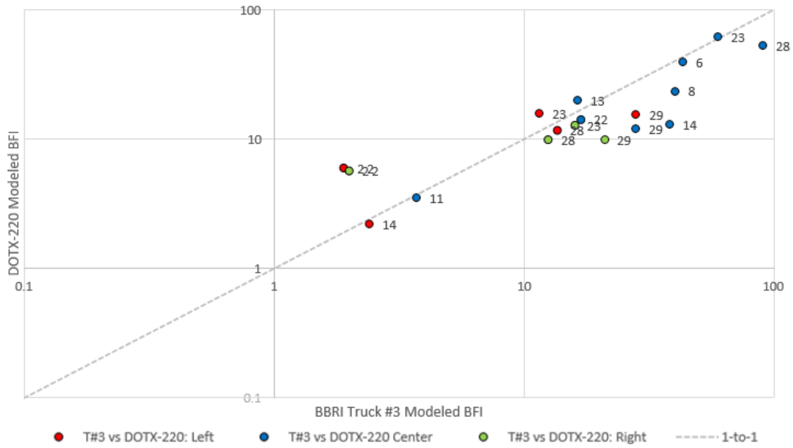


Figure E 20. A comparison of the modeled BFI obtained on the hi-rail truck and DOTX220

- Samples acquired on the ballast shoulders over concrete ties—exclusively Main 1—sit above the 1- to-1 line, indicating a discrepancy between the train and hi-rail results.
- Whilst this discrepancy may be partly due to the different positions of the shoulder antennas on the two vehicles it is also attributed to residual interference observed within the DOTX220 dataset.

Results – Analysis of Outlier Locations

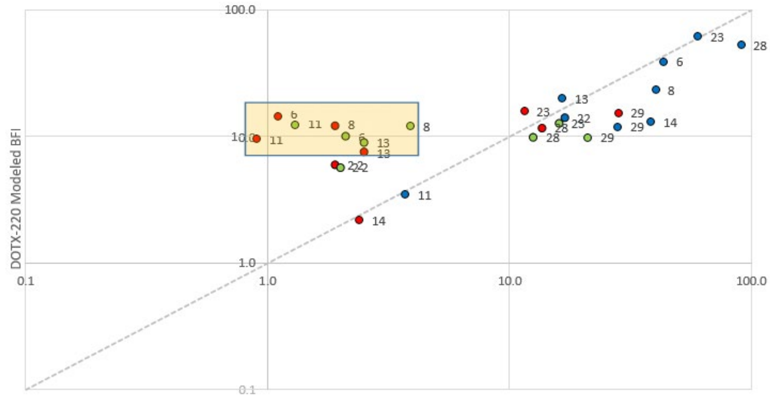


Figure E 21. Residual interference attributed to shoulder antennas on the two vehicles

- Examination of the raw 2 GHz data from these outlier shoulder locations suggests that the modeled BFI has been affected by residual near-surface hyperbolic artefacts highlighted in Figure E 22 associated with the reinforcing bars within the ties.
- This effect is not observed in the track center data due to the different orientation of the antenna, which is optimized to avoid electromagnetic coupling with the reinforcing.

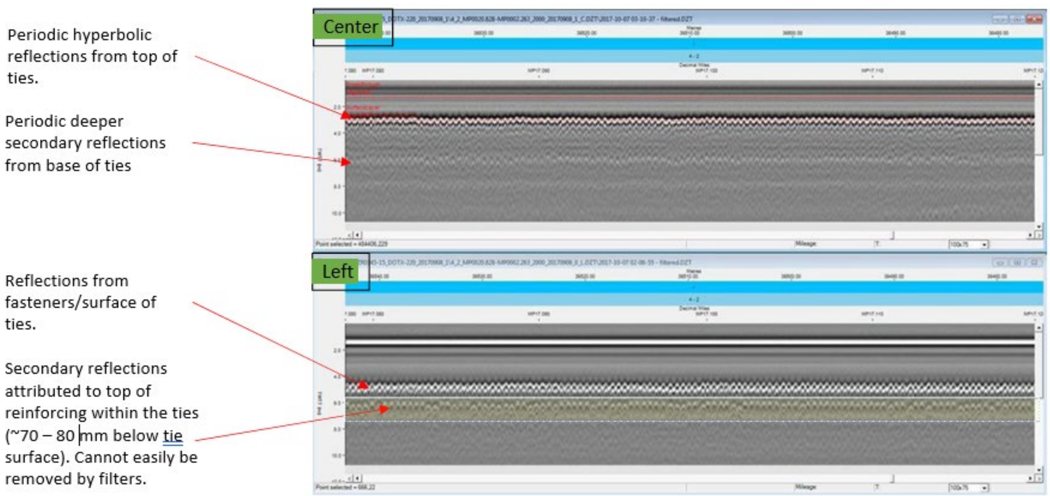


Figure E 22. BFI has been affected by residual near-surface hyperbolic artefacts

- The example in Figure E 23 illustrates the interference, also seen in Figure E 22, at the location of Sample #8. The corresponding track center data is included below for comparison. The green line on the center radargram represents the interpreted base of clean ballast.

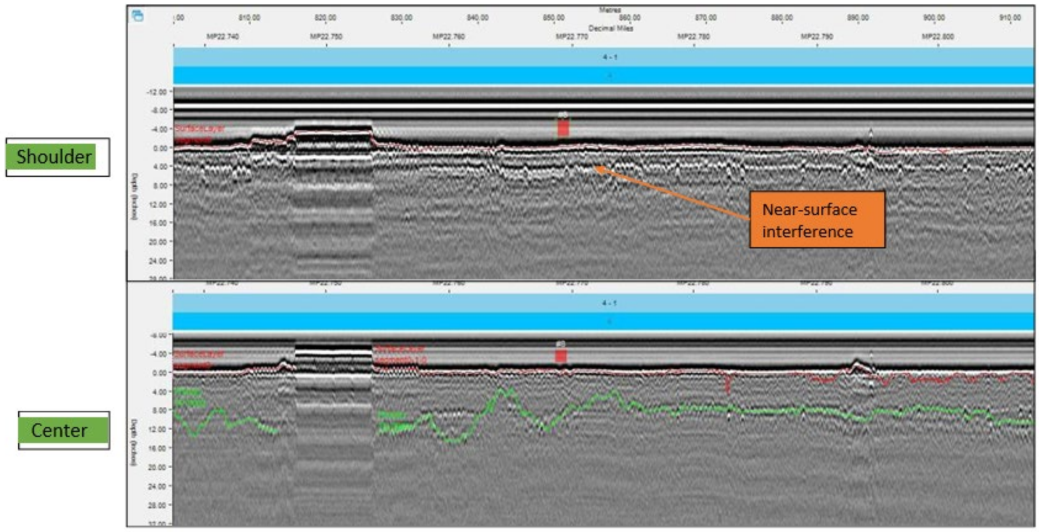


Figure E 23. Interprets the provenance of each reflection interfaces

- The diagram in Figure E 24 further illustrates the interpreted provenance of each of the reflection interfaces identified within the shoulder and center datasets from DOTX220 that are attributed to the ties:

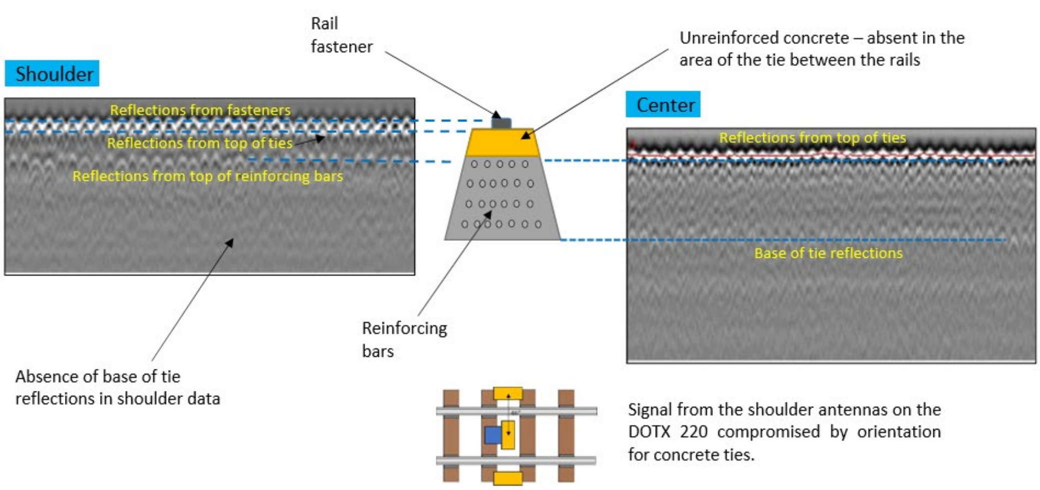


Figure E 24. Interprets provenance of each reflection interface identified within the shoulder and center datasets from DOTX220

- The effect of the interference on the shoulder data is clearly illustrated in the plot below which details the modeled BFI from the hi-rail truck (orange) and DOTX220 (blue) for a section of both wood and concrete ties on Main 2 between ~MP 11.0 and MP 16.3. The transition from wood to concrete occurs at ~MP 14.6

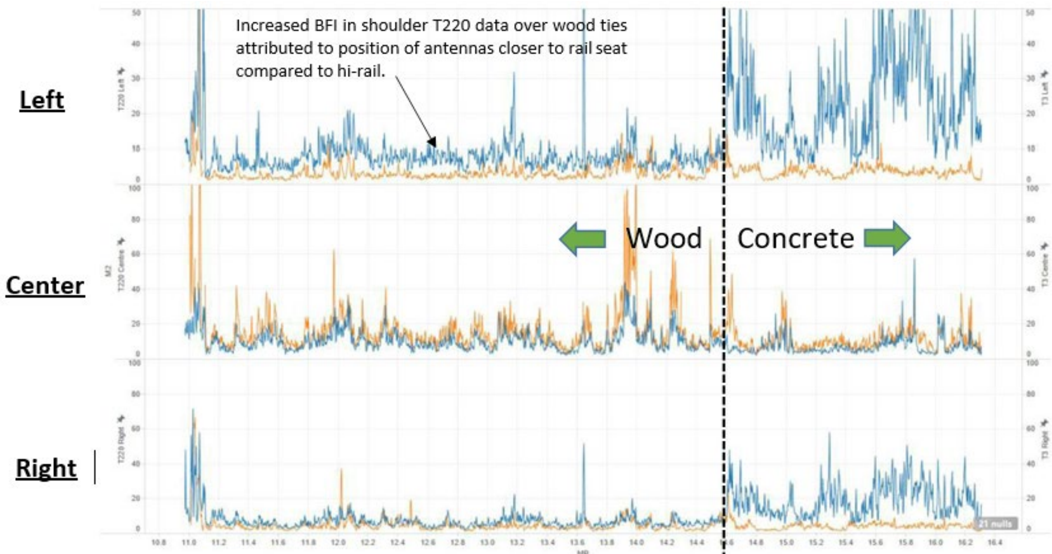


Figure E 25. Increased BFI in shoulder T220 data over wood ties

- The near-surface interference observed at the concrete tie sample locations on Main 1 and at other locations on Main 1 and Main 2 is much less apparent on the newly constructed December 2016 section of concrete tie track between Milford and Pleasant Dale.
- This suggests the interference may be associated with specific properties of the concrete ties as well as the position/orientation of the shoulder antennas relative to the ties.

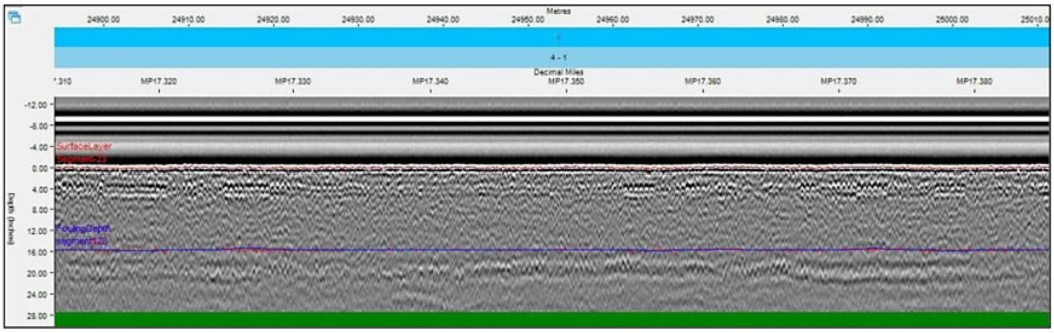


Figure E 26. Well-defined deep ballast/sub-grade interface at ~18–20 inches depth

The right shoulder 2 GHz radargram from recently constructed track on Main 1 at ~MP 17.350 illustrates well-defined deep ballast/sub-grade interface at ~18–20 inches depth, a deep FDL depth (+16 inches) and BFI of less than 5.

Results – Free-Draining Layer (FDL) Depth

Table E 4: Modeled 5 m averaged FDL and measured fouling depth

Vehicle	Sample #	LS	TID	Tie Type	MP (Scaled)	Lat	Long	FDL (5 m smoothing) (")			Measured Fouling Depth (")		
								Left	Centre	Right	Left	Centre	Right
DOTX 220	6	4	1	Concrete	22.7178	40.813824	-97.070531	6	9	10	15	8	n/a
	8	4	1	Concrete	22.7722	40.814565	-97.070772	7	8	9	13	8	15
	11	4	1	Concrete	25.7874	40.858102	-97.085016	10	16	5	16	12	16
	13	4	1	Concrete	26.8306	40.871994	-97.089538	11	10	11	12	7	13
	14	4	1	Wood	27.7169	40.884255	-97.093537	n/a	5	n/a	4	2	n/a
	22	4	2	Wood	25.7907	40.858161	-97.085102	11	6	11	n/a	8	11
	23	4	2	Wood	26.7704	40.871221	-97.089348	7	5	8	n/a	n/a	n/a
	28	4	2	Wood	26.7361	40.870791	-97.089206	8	4	8	n/a	3	4
	29	4	2	Wood	39.8691	40.894447	-97.296765	9	6	9	n/a	4	n/a

* To ensure accurate co-location, DOTX220 data were merged with hi-rail data using GPS latitude and longitude prior to extraction of sample location results. It should be noted that measured fouling depths are being compared with modeled FDLs averaged over 5 m, as per schematic below.

Results – Free-Draining Layer (FDL) Depth

Category	FDL	Inches
1	Poor	< 8
2	Intermediate	8–14
3	Good	> 14

	5m track section				
1m BFI	8	14	9	18	9
5m BFI averaged	11.6				
0.5m Crib					
Sample 1 pair of cribs					

- The modeled FDL generally shows good correlation with the measured fouling depth.
- The R2 value for a linear best fit through results acquired in the center over both wood and concrete ties and over wood on the shoulders is ~ 0.77.

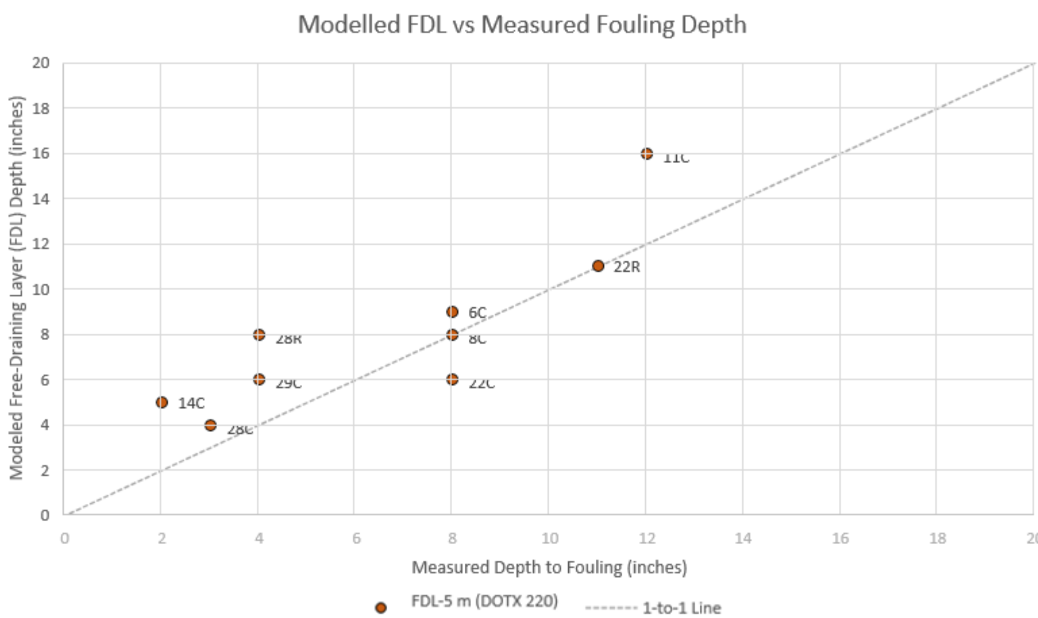


Figure E 27. Modeled FDL vs. measured fouling depth

- Samples acquired on the ballast shoulders over concrete ties, exclusively Main 1, are also affected by the residual tie interference previously discussed, with the points lying below the 1-to-1 line.

Results – Free-Draining Layer (FDL) Depth

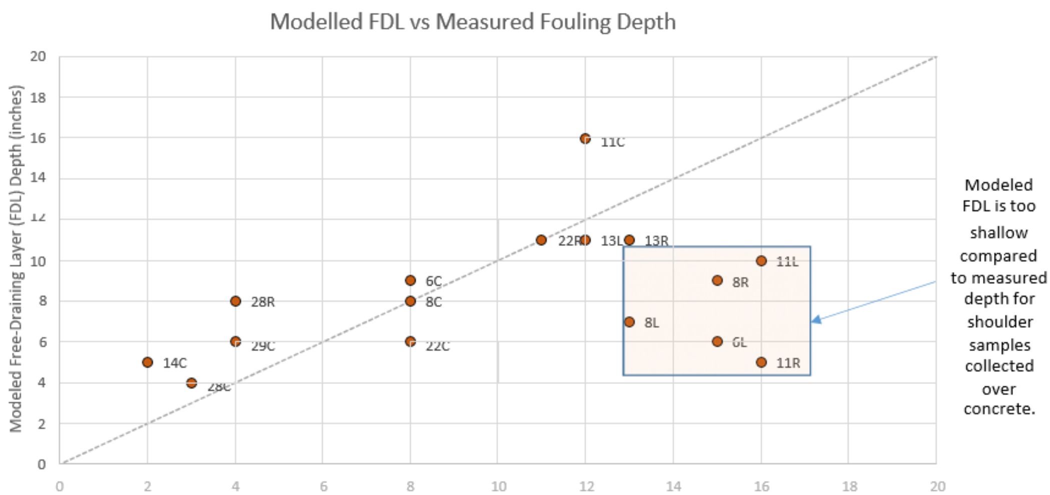


Figure E 28. Modeled FDL vs. measured fouling depth samples from Main 1

- Modeled track center FDL from DOTX220 (blue) and the hi-rail GPR truck (orange) for the main sampling area on Main 2. The agreement is excellent.

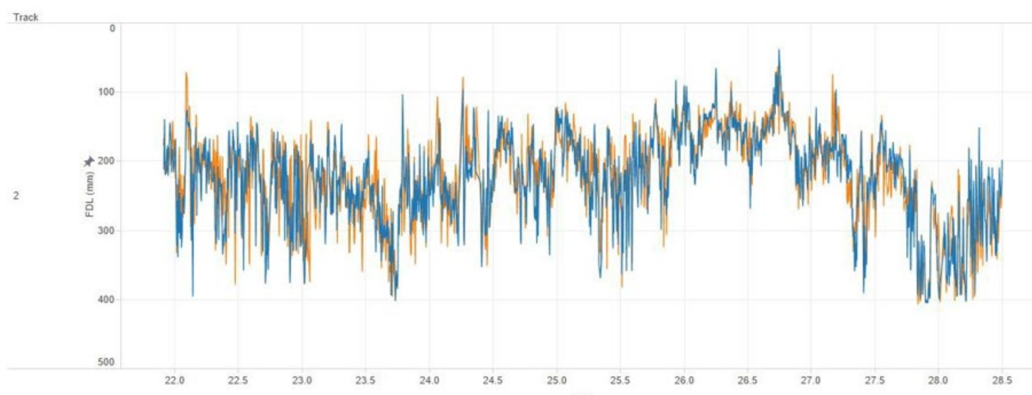


Figure E 29. Modeled track center FDL from DOTX220 (blue) and the hi-rail GPR truck (orange)

- Modeled FDL derived from the hi-rail truck datasets show improved correlation to measured fouling depth compared to the DOTX220 data. The R2 value for the linear best fit line through all the data points is ~ 0.88. Shoulder data unaffected by interference over concrete ties.

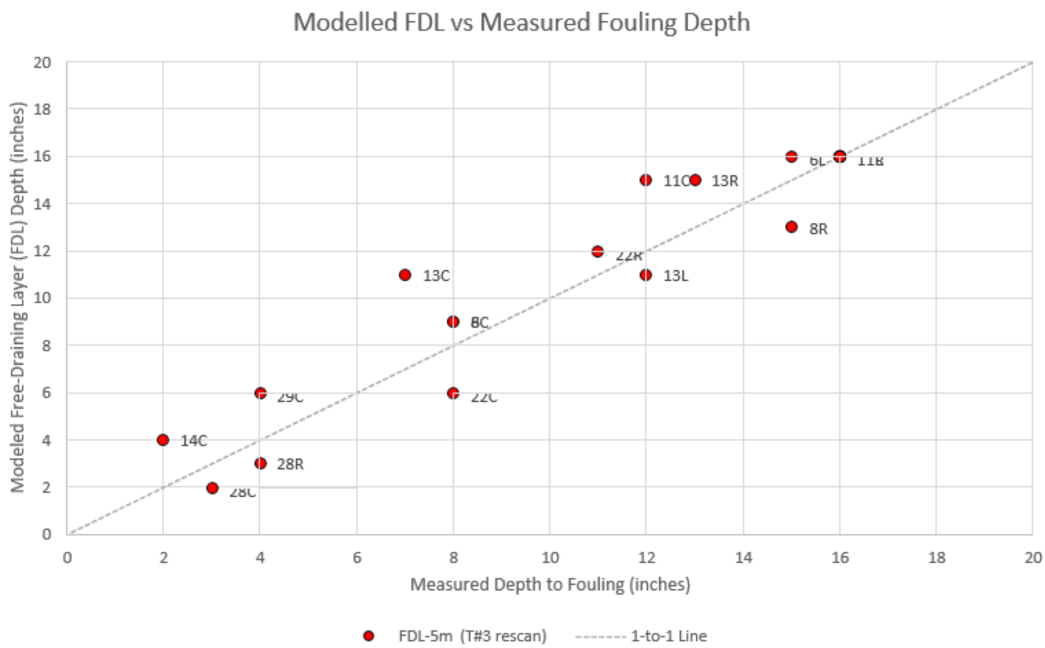


Figure E 30. Modeled FDL vs. measured fouling depth R2 value

- Plotting modeled FDL against sample fouling index for the hi-rail data indicates a better correlation than is observed with modeled BFI vs sample fouling index.

Results – Free-Draining Layer (FDL) Depth

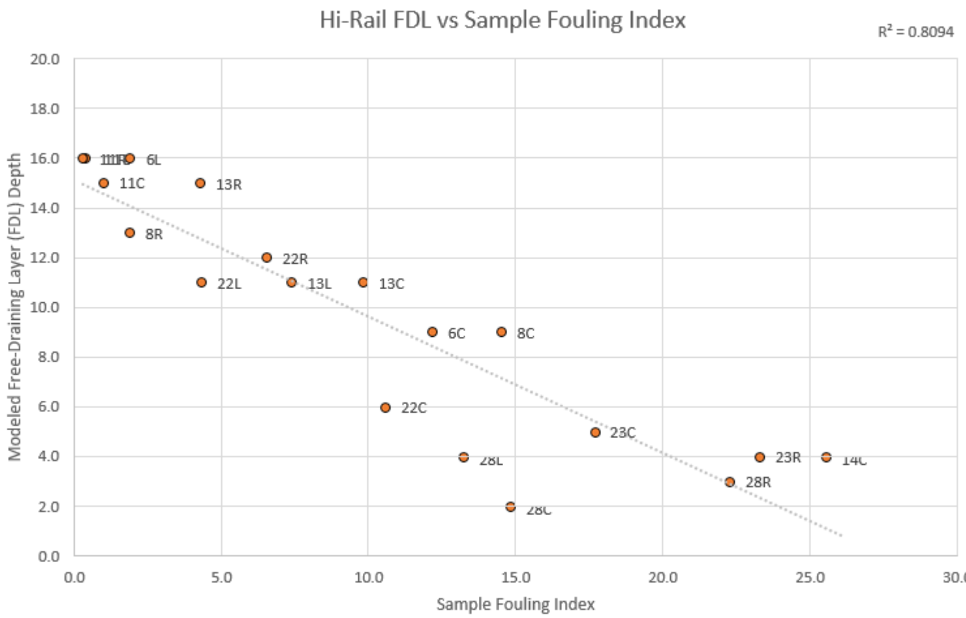


Figure E 31. Hi-rail FDL vs. sample fouling index

- Comparing modeled FDL against sample fouling index for the center samples only, the R2 values for linear best-fit lines are similar for the DOTX220 and hi-rail datasets.

Results – Free-Draining Layer (FDL) Depth

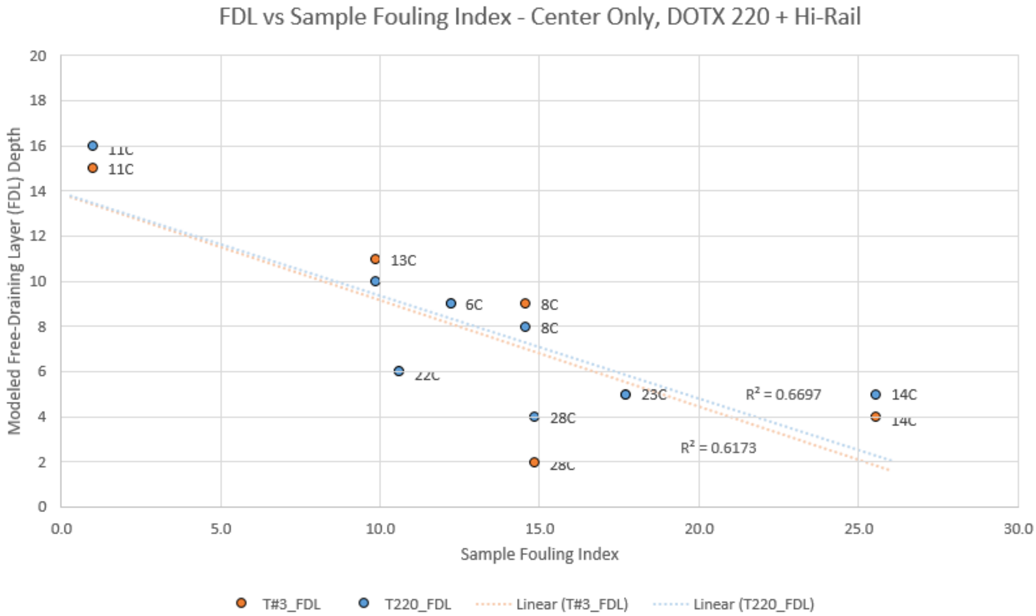


Figure E 32. FDL vs. sampling fouling index – center only, DOTX220 + hi-rail

- As discussed, the improved correlation between the hi-rail FDL results and the measured fouling depth, compared to the equivalent with the DOTX220 results is likely to be in part due to the relative positions of the 2 GHz shoulder antennas and the sampling tubes on the two platforms:

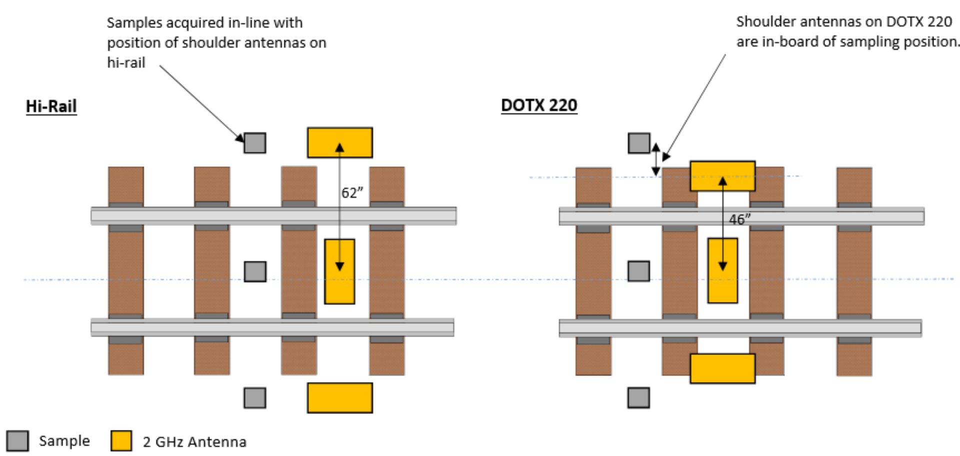


Figure E 33. Relative positions of the 2 GHz shoulder antennas and the sampling tubes on the two platforms

Results – Free-Draining Layer (FDL) Depth

- Google Earth image of the modeled FDL from DOTX220 on Main 1 through the section of new track between Milford and Pleasant Dale illustrating good depth to the base of clean ballast.
- The average FDL on all three data channels exceeds 14 inches.

Category	FDL	Inches
1	Poor	< 8
2	Intermediate	8 - 14
3	Good	> 14

Figure E 34. Google Earth image of modeled FDL from DOTX220 on Main 1

Results – Trackbed Inspection Reports

- Example trackbed inspection reports have been provided for three ½ mile track sections as detailed below.
- These track sections were selected from the ~30 miles of data between MP 10 and MP 40 on the basis of the observed trackbed conditions.
- Objective of demonstrating the use of GPR in helping railroads assess the condition of their track. The TG displayed on the TBIRs was acquired concurrently with the GPR data on DOTX220.
- **Example TBIRs**:
  - **Main 1, MP 13.70 – MP 14.20, concrete ties**: irregular ballast profile and ballast pockets associated with potentially soft subgrade conditions.
  - **Main 2, MP 14.00 – MP 14.50, wood ties**: extent of surface mud, irregular ballast profile and incipient mud spots.
  - **Main 2, MP 25.50 – MP 26.00, wood ties**: Shallow free-draining layer, mud spots and localized ballast pockets.

Results – TBIR: Main 1, MP 13.70–MP 14.20

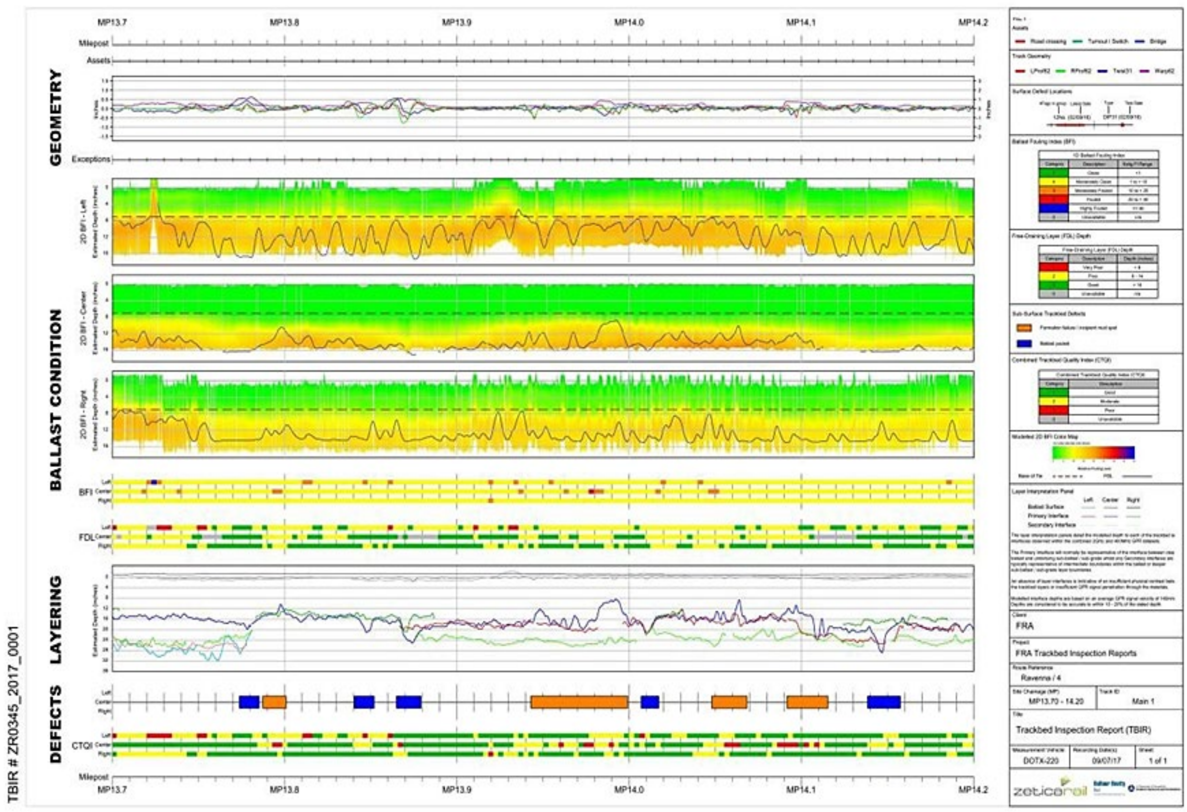


Figure E 35. TBIR: Main 2 MP 14.00–MP 14.50

Results – TBIR: Main 2, MP 14.00–MP 14.50

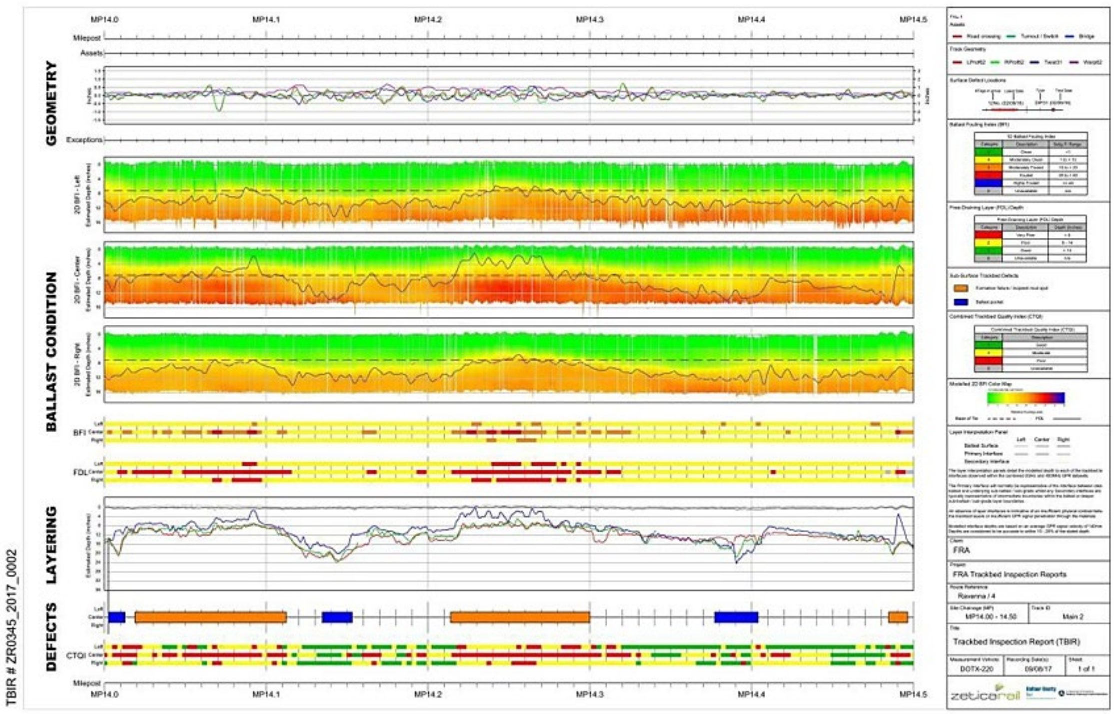


Figure E 36. TBIR: Main 2 MP 14.00–MP 14.50 (continued)

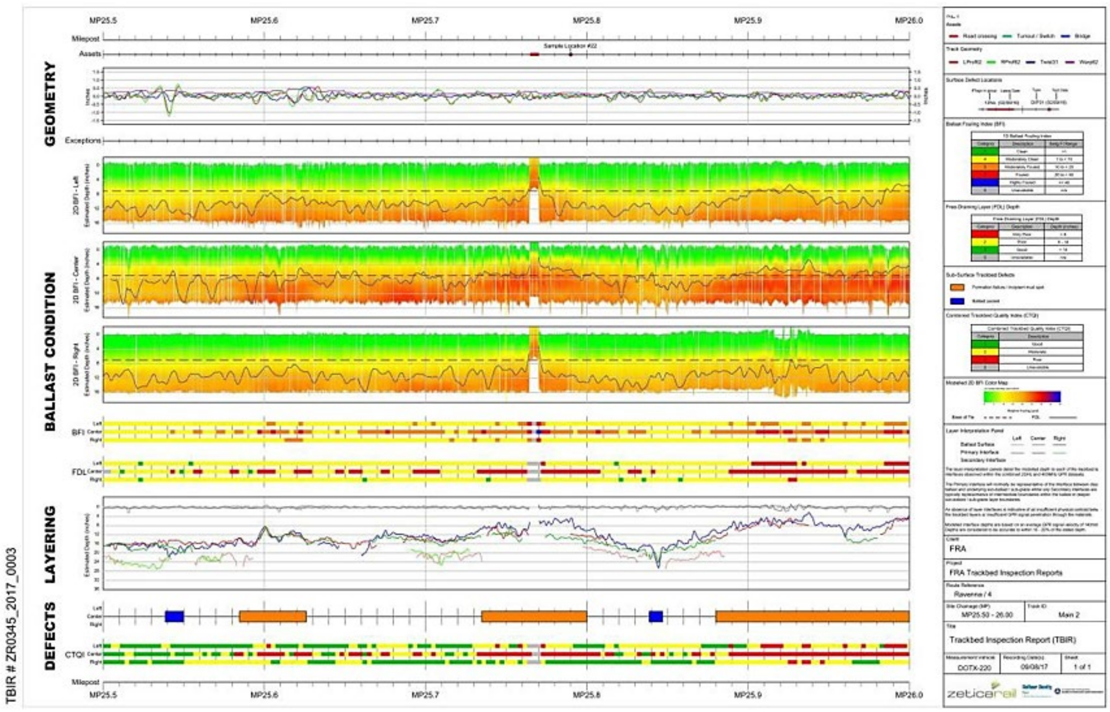


Figure E 37. TBIR: Main 2 MP 14.00–MP 14.50 (continued)

Summary

- Comparison of processed 2 GHz and 400 MHz GPR datasets from DOTX220 and the BBRI hi-rail GPR truck has highlighted:
  - **Data from the center 2 GHz antenna is comparable over both wood and concrete ties**.
  - **Data from the shoulder 2 GHz antennas is comparable over wood ties** with differences likely to be explained by the relative positions of the antennas.
  - Data acquired with the shoulder antennas on the train over some concrete ties, are being affected by interference believed to be caused by a combination of reflections from clips and reinforcing within these ties. It is likely that this interference is being exacerbated—compared to the center—by the orientation of the antennas relative to the reinforcing.
  - **The DOTX220 modeled BFI results from the sampling locations as a good match with the results from the hi-rail truck**, except for the shoulder samples acquired over Main 1 track sections with concrete ties.
  - **The DOTX220 modeled FDL results compared well with the measured fouling depths**, except for the shoulder samples acquired over Main 1 track sections with concrete ties.
- The 400 MHz data acquired with DOTX220 appears to be of reduced quality over both wood and concrete ties when compared to the equivalent hi-rail data and compared to previously assessed datasets (CSX, Peninsula Subdivision, March 2017). This suggests a problem with the 400 MHz antenna during the survey which will be investigated as soon as possible.

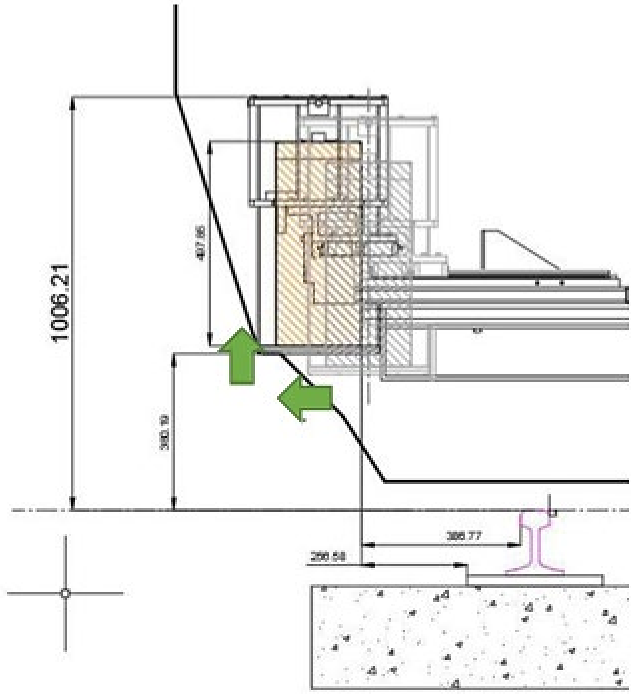


Figure E 38. Antenna data acquired

Recommendations

- To address the issues identified with the DOTX220 datasets the following recommendations are made: Consider moving the shoulder 2 GHz antennas up by ~50 mm to take advantage of the increased width of the Plate C clearance envelope at 360 mm above top of rail. This is illustrated in the figure below.
    - Repositioning of the antennas will be dependent on the available vertical clearance within the lockers and may require removal of the locker doors.
    - Results in an increased lateral offset of 120 mm from edge of rail.
    - The antennas will still partially sit over the ties (based on tie length of 8' 6 inches) and interference effects are unlikely to be fully resolved due to the orientation of the antennas relative to the reinforcing in the ties.
    - There is insufficient offset from the rails on the shoulders to rotate the antennas 90 degrees to minimize electromagnetic (EM) coupling with the ties.

1. Analysis of the poor data quality on the center 400 MHz antenna suggests that the antenna may not be functioning optimally. The antenna be removed from its housing during the vehicle's next scheduled maintenance cycle to inspect and assess its performance.
2. Collection of additional shoulder ballast samples in the area beneath the positions of the shoulder antennas as currently mounted on DOTX220.
3. After any adjustments are made, a survey was conducted of the TTCI Facility for Accelerated Service Testing (FAST), and High Tonnage Loop (HTL) loops at Pueblo using both DOTX220 and a hi-rail GPR truck.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Appendix F. BB/Zetica - ZR0345-15-PDF01-A (Ravenna, LS4, M1+M2 - Example Trackbed Inspection Reports)

Trackbed Inspection Reports (TBIRs)

The TBIR locations were selected to highlight the type of GPR response that can be expected over a range of different trackbed conditions:

- Main 1, MP 13.70–MP 14.20: Concrete ties: Irregular ballast profile and ballast pockets associated with potentially soft subgrade conditions.
- Main 2, MP 14.00–MP 14.50: Wood ties: Extent of surface mud, irregular ballast profile and incipient mud spots.
- Main 2, MP 25.50–MP 26.00: Wood ties: Shallow free-draining layer, mud spots and localized ballast pockets.

TBIRs or similar reports are designed to provide a summary of the condition of the trackbed over a specified length of track based on analysis of the GPR datasets (i.e., 2 GHz and 400 MHz) and other available inspection data (e.g., TG). The reports are typically provided to railroads for sections of track with known persistent geometry issues, as defined by repeat TG exceptions.

The full report consists of a summary page and a plot that details specific GPR-derived and other trackbed parameters and the location and extent of identified trackbed defects.

The summary page describes the overall condition of the trackbed as defined by the GPR data in terms of ballast fouling and the ballast and sub-ballast/subgrade layer profiles and details the nature of each of the identified trackbed defects. It also includes an aerial image of the area, which provides valuable geographic context, and a list of the most recent surface geometry defects.

The ½ mile plot comprises 10 No. panels detailing results for 5 No. aspects of the track:

- Assets: The location and extent of key track assets including road crossings, over and under bridges and switches.
- Geometry: A line plot of key TG parameters, typically comprising vertical profile, twist and warp.
- Ballast Condition: This is reported as color-coded plots of 2D BFI (for left, center and right) with the modeled fouling depth layer (FDL) overlain, the 1D BFI at 15-ft intervals and the categorized FDL.

- Layering: This panel detailed the interpreted depth of Primary and Secondary layer interfaces identified from the 2 GHz and 400 MHz datasets.
- Defects: This panel details the location and extent of two classes of interpreted sub-surface defect; areas of formation failure, including localized mud pumping/developing mud spots and areas of high subgrade roughness or high apparent moisture, and ballast and sub-ballast pockets. Also included in this category is the Combined Trackbed Quality Index (CTQI). The CTQI is designed to summarize trackbed condition based on a weighted averaging of available GPR-derived metrics; including the BFI, FDL, ballast thickness index (BTI), layer roughness index (LRI), and moisture likelihood index (MLI).

Trackbed Inspection Report - Summary

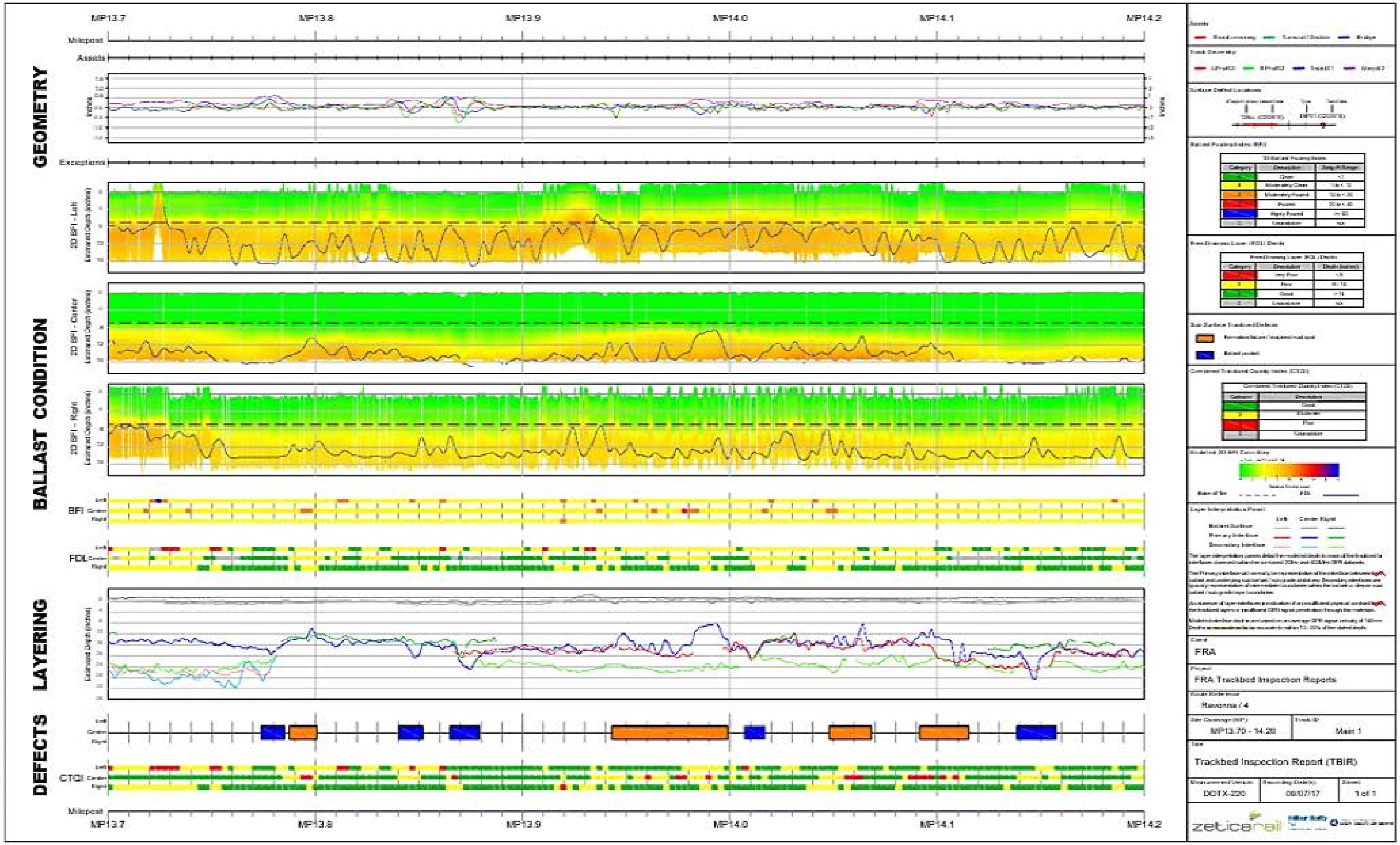
Table F 1. Trackbed inspection report summary

ZETICA TBIR_ID	ZR0345_2017_0001
DIVISION	NEBRASKA
SUB-DIVISON	RAVENNA
LINE SEGMENT	4
TRACK ID	Main 1
TBIR LIMITS	MP 13.70 to MP 14.20
VEHICLE	DOTX220/218

Trackbed Condition Summary	The general condition of the trackbed within this 1/2 mile is classified by the Combined Trackbed Quality Index (CTQI) as Good, with relatively low levels of ballast fouling (predominantly CAT 4 - Moderately Clean) on all three data channels (left & right shoulders and track center) and a Good to Poor free-draining layer depth of between 8 to +16 inches. Short sections of Moderate to Poor quality trackbed are associated with localized defects (see below). Increases in track geometry Profile and Twist have been identified at a number of locations within this section but all lie within exception limits for the posted track speed / class.
Trackbed Layer Summary	A well-defined Primary layer interface interpreted as the base of clean ballast, has been identified in the track center for the majority of the 1/2 mile and less continuously on the ballast shoulders. With the exception of a number of identified ballast defects, the modeled depth to the interface is generally at or close to design depth, lying at between 16 - 20 inches from surface. Through much of this section, local increases in reflection strength on the primary interface and attenuation of the GPR signal in the underlying materials suggest that the sub-grade is likely to comprise relatively moist, cohesive materials. On the right shoulder, the Primary interface is generally absent and is instead replaced by a more uniform Secondary interface lying at modeled depths of between 24 - 28 inches. This interface is interpreted as the base of sub-grade. Between ~MP13.700 and MP13.780 it is additionally evident within the track center and on the right shoulder.
Trackbed Defects Summary	**MP13.774 - MP13.785, MP13.840 - MP13.852, MP13.865 - MP13.879, MP14.060 - MP14.018, MP14.149 - MP14.158 - Ballast pockets:** These are characterized by localized increases in the depth to the Primary layer interface of between 4 - 8 inches indicative of possible locally soft subgrade / soil conditions. They are predominantly observed within the track center. The three anomalies between MP13.774 and MP13.879, are associated with small-scale deviations (<+/-0.5 inches) in track geometry Warp, Twist and Profile. Examination of aerial imagery of the site indicates that the defect between MP14.149 and MP14.158 coincides with an apparent cross-cutting drainage feature and may be associated with an unidentified cross-track culvert or pipe. A similar pocket has been identified at the same location in the GPR data acquired on Main 2 (see TBIR# ZR0345_2017_0002). **MP13.788 - MP13.801, MP13.943 - MP13.999, MP14.048 - MP14.069, MP14.091 - MP14.115 - Subgrade pumping / failure, mud spot development:** These defects are characterized by localized reductions in the modeled depth to the Primary layer interface, indicative of potential intermixing of the ballast and sub-ballast materials. The shallowest and most extensive of the defects occurs between MP13.943 and MP13.999. The western end of this feature is associated with a slight deterioration in track geometry quality. A similar deterioration is observed over the defect between MP14.091 and MP14.115.

Surface Defect List

GEO CAR NME	TEST DT	DEF NBR	DEF PRTY	DFCT STAT CD	DEF TYPE	DEF GROUP	FIRST LS	FIRST MP	FIRST TRACK	REPT GC NME	REPT DFCT TST	REPT DFCT NBR
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a



TBIR # ZR0345_2017_0001

Trackbed Inspection Report - Summary

Table F 2. Trackbed inspection report summary (continued)

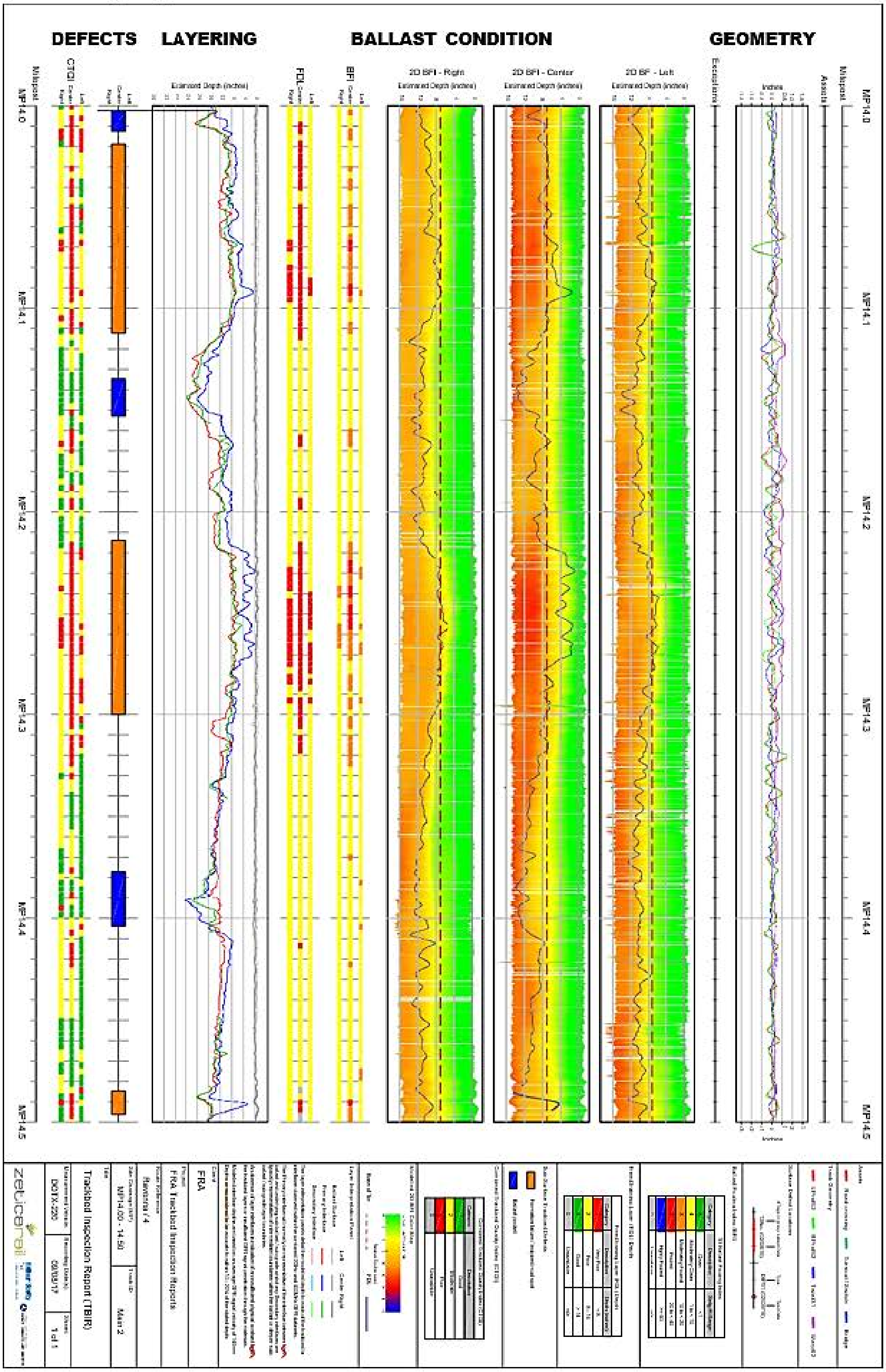
ZETICA TBIR_ID	ZR0345_2017_0002
DIVISION	NEBRASKA
SUB-DIVISON	RAVENNA
LINE SEGMENT	4
TRACK ID	Main 2
TBIR LIMITS	MP 14.00 to MP 14.50
VEHICLE	DOTX220/218

Trackbed Condition Summary	The condition of the trackbed within this 1/2 mile is classified as generally Moderate to Good within areas outside of the identified trackbed defects. The condition on the ballast shoulders is typically slightly better than that of the track center, primarily as a result of improved ballast quality. Areas of Poor quality trackbed are characterized by modeled ballast fouling ranging from Moderately Fouled to Fouled, a shallow (<8 inches) modeled free-draining layer (FDL) depth, particularly in the track center, and an irregular ballast profile.
Trackbed Layer Summary	A well-defined continuous Primary layer interface has been identified over the majority of the 1/2 mile on all three data channels (left & right shoulders and track center) at modeled depths of between <4 inches and 24 inches. The interface is variably interpreted as representing the boundary between clean ballast and fouled material, and clean ballast and sub-grade. There is no evidence of a deeper, secondary, interface within the 2GHz datasets indicating that the base of the trackbed lies below ~3 feet through this section. No 400MHz data was available from the DOTX-220 survey.
Trackbed Defects Summary	**MP14.000 - MP14.012 - Ballast pocket:** Characterized by a localized increase in the modeled depth to the Primary layer interface from ~10 - 16 inches to over 20 inches on both the left and right shoulders attributed to soft sub-grade conditions. Attenuation of the GPR signal below the interface is potentially indicative of increased % moisture within the underlying materials.
	MP14.019 - MP14.112 - Insufficient clean ballast thickness, mud spot development and surface mud: This section of track is characterized by a shallow Primary layer interface (< 8 inches in center) and correspondingly shallow FDL together with evidence of both active (surface) and developing (sub-surface) mud spots in the center and on the right shoulder. Coincident with this defect is a well-defined negative (Dip) left and right profile deviation of ~1 inch in the track geometry data, potentially indicating locally soft trackbed conditions. The deviation does not constitute a track geometry exception for the posted track speed/class.
	MP14.135 - MP14.153 - Ballast pocket: This feature comprises a relatively broad low in the ballast profile that extends to a modeled depth of ~28 inches. It is coincident with a cross-track drainage feature visible in aerial imagery of the site and may be associated with an unidentified culvert/pipe. A similar anomaly is identified here in the GPR data acquired on Main 1.
	MP14.214 - MP14.300 - Developing and active mud spots, insufficient clean ballast thickness, elevated % moisture: This defect is characterized by an irregular and very shallow (<4 inches) Primary layer interface and correspondingly shallow FDL. The elevated reflection amplitude of the Primary interface and attenuation of the signal in the underlying materials is potentially indicative of elevated moisture levels within the near-surface materials. Various TG surface parameters are slightly elevated within this section but lie within exception limits.
	MP14.376 - MP14.404 - Ballast pocket (center only), MP14.485 - MP14.495 - Active mud spot (center only): Well-defined ~30-ft wide anomaly. No significant track geometry response.

Surface Defect List

GEO CAR NME	TEST DT	DEF NBR	DEF PRTY	DFCT STAT CD	DEF TYPE	DEF GROUP	FIRST LS	FIRST MP	FIRST TRACK	REPT GC NME	REPT DFCT TST	REPT DFCT NBR
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

TBIR # ZR0345_2017_0002



Trackbed Inspection Report - Summary

Table F 3. Trackbed inspection report summary (continued)

ZETICA TBIR_ID	ZR0345_2017_0003
DIVISION	NEBRASKA
SUB-DIVISON	RAVENNA
LINE SEGMENT	4
TRACK ID	Main 2
TBIR LIMITS	MP 25.50 to MP 26.00
VEHICLE	DOTX220/218

Trackbed Condition Summary	The overall condition of the trackbed within this 1/2 mile is classified by the Combined Trackbed Quality Index (CTQI) as Moderate to Poor in the track center and generally Moderate to Good on the shoulders. The main contributing factors to areas of Poor quality trackbed in the center are elevated levels of ballast fouling (modeled ballast fouling index (BFI) of Moderately Fouled or higher), a relatively shallow modeled free-draining layer (FDL) depth (< 8 inches) and a corresponding shallow Primary layer interface (the interpreted ballast/sub-ballast interface). On the shoulders both the BFI and the FDL are typically better than in the center.
Trackbed Layer Summary	A well-defined Primary layer interface has been identified for the majority of the 1/2 mile on all three data channels (left & right shoulders and track center) at modeled depths of between 4 - 20 inches below ballast surface. The interface generally lies close to or sits slightly below the modeled FDL suggesting that it most commonly represents the boundary between clean and fouled ballast. The highly irregular depth to the interface, which is particularly evident beyond ~MP25.59, points to soft sub-grade conditions and intermixing of the ballast and sub-grade materials. An intermittent secondary interface identified in the shoulder and center data at modeled depths of between 24 - 32 inches is interpreted as the base of sub-grade.
Trackbed Defects Summary	**MP25.735 - MP25.800 & MP25.880 - MP26.000 - very shallow Primary Interface & FDL (<8 inches):** These two areas are characterized by insufficient thickness of clean ballast, as defined by a very shallow modeled free-draining layer depth and correspondingly shallow Primary layer interface, with potential for mud spot formation. The track geometry within each area at the time of the GPR survey was good with no identified exceptions for the posted track speed/class, suggesting that the trackbed is currently stable.
	MP25.839 - MP25.847 - Ballast / subgrade pocket: This defect is characterized by a localized increase in the depth to the Primary layer interface and a corresponding increase in the depth to the base of the underlying sub-grade, consistent with trackbed subsidence. The deviation in the modeled depth to the base of the Primary interface is ~12 inches over a distance of 33 feet. Examination of aerial imagery of the site indicates that the defect coincides with an apparent cross-cutting drainage feature and may be associated with an undertrack culvert.
	MP25.585 - MP25.625 - Potential incipient mud spot development / poor drainage: This defect is characterized by an interpreted localized increase in % moisture at the interface between the ballast and sub-ballast and a decrease in the modeled depth to the interface indicative of potential sub-grade failure. The increase in moisture is characterized by an increase in the GPR reflection amplitude at the boundary and a corresponding increase in attenuation below it, both in the 2GHz and 400MHz (hi-rail) datasets. The location is also characterized by slightly elevated left and right surface Profile and Twist, although all TG parameters fell below exception levels for the posted track speed/class.
	MP25.539 - MP25.550 -Trackbed subsidence: Characterized by a negative ~1.25-inch deviation in left/right profile coinciding with a localized increase in the depth to the Primary interface in the track center and a possible cross-cutting service (pipe / culvert) observed at a modeled depth of ~32 inches in the hi-rail center 400MHz data.

Surface Defect List

GEO CAR NME	TEST DT	DEF NBR	DEF PRTY	DFCT STAT CD	DEF TYPE	DEF GROUP	FIRST LS	FIRST MP	FIRST TRACK	REPT GC NME	REPT DFCT TST	REPT DFCT NBR
n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

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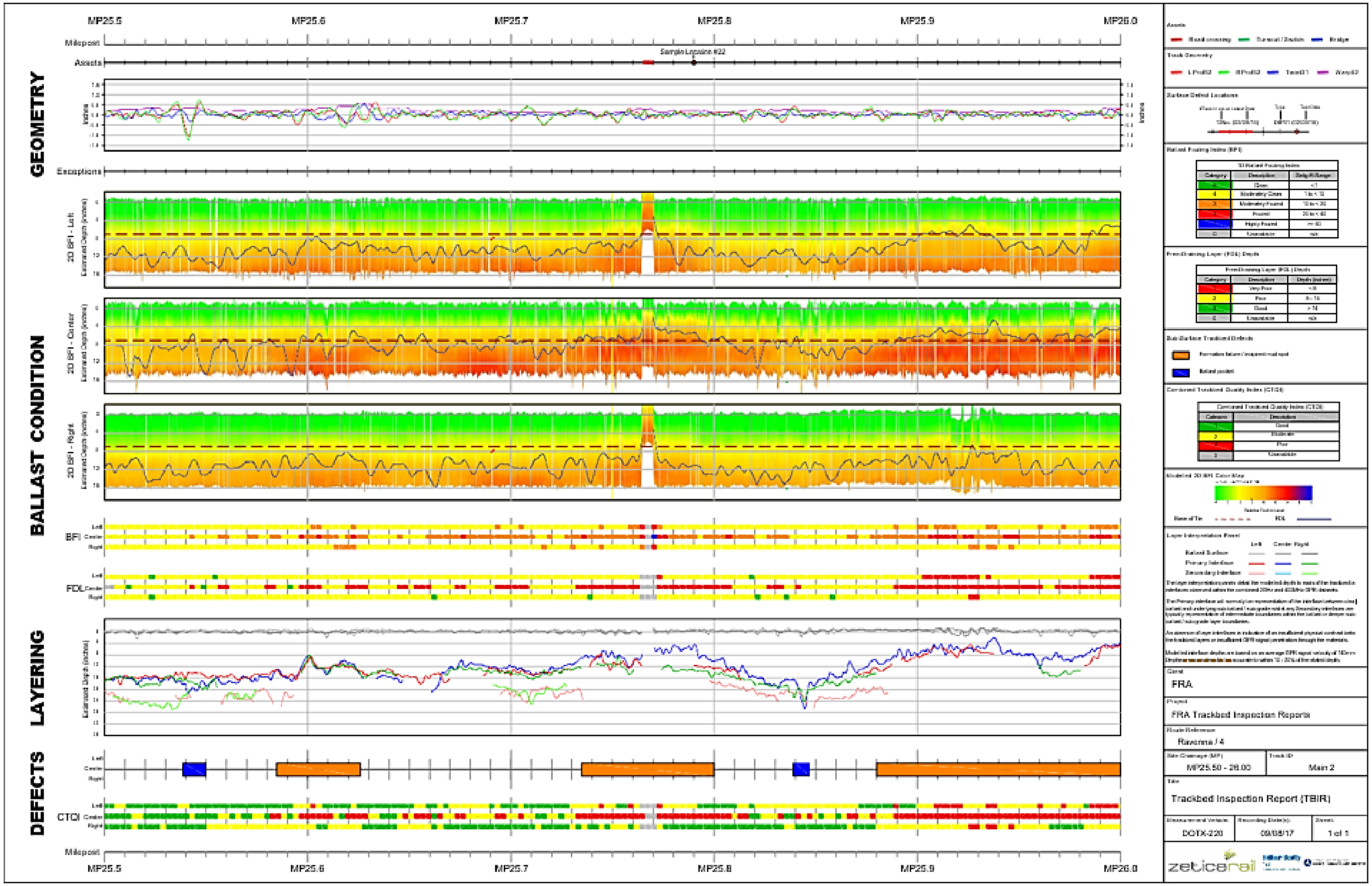

Abbreviations and Acronyms

ACRONYMS	EXPLANATIONS
BBRI	Balfour Beatty Rail, Inc.
BFI	Ballast Fouling Index
BTI	Ballast Thickness Index
BNSF	Burlington Northern Santa Fe Railway
CTQI	Combined Trackbed Quality Index
CAD	Computer-Aided Dispatch
CBR	Cone Resistance
FAST	Facility for Accelerated Service Testing
FRA	Federal Railroad Administration
FDL	Fouling Depth Layer [interchangeably Free-Draining Layer]
FI	Fouling Index
GPS	Global Positioning System
GPR	Ground Penetrating Radar
HTL	High Tonnage Loop
LRI	Layer Roughness Index
MP	Milepost
MLI	Moisture Likelihood Index
PSD	Particle Size Distribution
TR&D	Testing Research and Development
TG	Track Geometry
TBIRs	Trackbed Inspection Reports
TTCI	Transportation Technology Center, Inc.