GPR Application	Methodology			Processing		Results		Complementary Tests (NDT, coring, etc.)	Ref.
	Antennas & Acquisition parameters	Testing Set-up	Equipment	Filters & Algorithms	Software	Achievements	Inconveniences & Limits		
a) Ballasted track									
Railway monitoring, ballast thickness index, ballast fouling index, the fouling depth layer	Horn antennas 2 GHz (3 antennas) and 400 MHz ground-coupled (1 antenna)	4 longitudinal profile lines, one per each antenna, 2 x 2 GHz antennas on the shoulders and 1 x 2 GHz and 1x 400 MHz antennas in the centre, between rails. Maximum test speed of 128 km/h	NP	NP	Dedicated software, not specified	(i) Ballast layer thickness with 400MHz antenna; (ii) ballast fouling with 2 GHz antennas; (iii) strong relationship between fouling index (FI) and moisture content	(i) Noise at shoulder antennas, shoulder antenna difficulties over concrete ties but function properly over wood ties; (ii) estimated Ballast Fouling Index values were generally larger in the track centre than the measured FI from physical sampling and lower in the shoulders	Dynamic Cone Penetrometer Test (DCP) and Geo-Endoscopy Test	[90]
Detection of railways embankments and ballast layer continuity	Horn antennas 400 MHz (4 antennas) and 1 GHz (1 antenna)	4 parallel longitudinal profile lines, one per each antenna	GSSI model SIR-20	NP	GeoExplorer, Geo Inspector and Geo Analyzer – specified software was developed	(i) Embankment structural defects, irregularities; (ii) ballast layer discontinuities	(i) Display of 3 profile lines	NP	[91]
Development of a system dedicated to railway assessment	Ground coupled antennas: five 600 MHz; two 200 MHz and one 1.6 GHz	Longitudinal profile lines, one per each antenna, between the rails and on shoulders. Test speed up to 80 km/h	IDS GeoRadar	Time-zero correction; FIR; IIR; Gain; Background Removal	Adapted to allow survey of more than 20 km/h	(i) Ballast and subballast layers thickness; (ii) subballast defects; (iii) moist areas	NP	NP	[92]

Thickness of clean ballast, detect the trapped water and assess the ballast fouling and moisture content	1 and 2 GHz horn antennas (4 antennas)	Longitudinal profile lines, one per each antenna, between the rails and on shoulders (at least 60 cm from rails) maximum test speed of 128 km/h	Two GSSI SIR-20 control units	STFT, time frequency	NP	(i) Ballast thickness; (ii) ballast fouling; (iii) trapped water; (iv) moisture content	NP	NP	[93] [101]
Layer thickness	400 MHz (ground-coupled) antenna 1 GHz (horn air-coupled) antenna	Longitudinal profile lines. GPS	GSSI	NP	Railway Doctor	(i) Ballast and subballast thickness	NP	NP	[96]
Ballast fouling	Two 400 MHz antenna	Longitudinal profile lines. GPS	GSSI SIR-20	NP	Railway Doctor	(i) Ballast fouling	NP	NP	[100]
Ballast fouling	500 MHz, 900 MHz, 1.0 GHz, 1.6 GHz and 2.6 GHz	Longitudinal profile lines. Perpendicular and parallel orientation of antennas	NP	NP	NP	(i) Fouling Indices (FI). The 500 MHz antenna in the parallel orientation gave the best correlation (0.92) between fouling index and scan area	NP	NP	[103]
Ballast fouling, mud spot locations	2 GHz horn antennas	Longitudinal profile lines	NP	NP	NP	(i) Ballast fouling versus clean ballast	(i) Mud spot location not detected	NP	[104]
Influence of fragmentation and fouling of ballast on the GPR signal; humidity detection; the most suitable antennas survey configuration	1 GHz (Horn antenna): 4 scans per meter; 25 ns time window 2 GHz (Horn antenna): 4 scans per meter; 15 ns	Longitudinal profile lines, 0°, 45°, 90° antenna orientation	IDS GeoRadar	Dewow; background removal; band-pass filtering	NP Time and frequency domain signal processing	(i) Influence of the antenna orientation (45º is the best); (ii) ballast fragmentation (2 GHz); (iii) fouling index and moisture content (1 GHz)	(i) Lower sensitivity for lower frequency antenna	NP	[106]

b) Substructure / Embankment									
Substructure assessment, dielectric constants and moisture detection	400 MHz (512 samples/scan)	Longitudinal profile lines	GeoScan-32	NP	NP	(i) Ballast thickness; (ii) dielectric constants of subballast; (iii) moisture determination	NP	NP	[94]
Substructure settlements detection	400 MHz	Longitudinal profile line between rails	IDS GeoRadar	NP	NP	(i) Settlements at substructure level	NP	Track geometric parameters	[95] [102]
Permafrost detection	100 MHz, 200 MHz and 400 MHz (1024 samples/scan)	Longitudinal profiles	GR-III	Directly low- and high-pass filtered, and post-processing consisted only of i) block average smoothing; ii) down-sampling the traces to 1024 samples using linear interpolation (to avoid on-screen display aliasing); iii) two-fold stacking; iv) applying a linear time-varying gain; v) background removal	NP	(i) Detection and mapping of buried ice as well as for revealing structures; (ii) the make-up of permafrost sediments	NP	NP	[98]
Substructures' assessment, layer thickness	Ground-coupled antennas: 400 MHz, 800 MHz, 900 MHz, and 1.6 GHz	Longitudinal e transversal profile lines	MALA Geoscience, Inc. RAMAC system GSSI, SIR 10 (900 MHz)	NP	NP	(i) Subballast layer thickness, (ii) moisture detection	NP	NP	[105]

c) Ballastless track									
Detection of bonding condition between sleeper and slab, location of voids, layer thickness measurement	900 MHz and 1.5 GHz antennas	NP	NP	NP	NP	(i) Crack at layer interface; (ii) re-bars location	(i) No information on weak debonding detected	Impact-Echo Method (IEM) and Ultrasonic	[112]
Mud pumping at subgrade	NP	NP	NP	NP	NP	NP	NP	Impact-Echo Method (IEM)	[113]

Table S3. Railways: relevant on-site GPR surveys (NP = Not Provided; Ref. = Reference).