GPR Application	Methodology			Processing		Results		Complementary Tests (NDT, coring, etc.)	Ref.
	Antennas & Acquisition parameters	Testing Set-up	Equipment	Filters & Algorithms	Software	Achievements	Inconveniences & Limits		
[Fired tunnel walls] To estimate the depth of damaged concrete and provide information on the fault extension	900 MHz: time length of 20 ns 1.5 GHz: time length of 15 ns	Three longitudinal profile lines in three zones with different levels of damage	GSSI model SIR-10H	900 MHz: average of 4 traces, low-cut filter at 250 MHz and high-cut filter at 1800 MHz 1.5 GHz: average of 4 traces, low-cut filter at 400 MHz and high-cut filter at 4000 MHz	NP	(i) It can be stated that most of the concrete is heterogeneous (with a large number of cracks) and that different layers exist, which is most certainly caused by the heat from the fire; (ii) thickness estimation; (iii) higher signal amplitude values due to water intrusion bleeding through the wall and by the filling of all cracks and micro-delamination	NP	Seismic refraction method	[186]
[Bored Tunnel] [Water Supply Tunnel - concrete lined circular tunnel] To map tunnel lining condition and locate concrete deterioration and voids	1 GHz: 30 ns time window and 5 cm sampling interval	Tunnel surveyed in both directions A modular wooden push cart was designed with a counter-balanced antenna support arm mounted on a rotating head	Sensors and Software Noggin Conquest Odometer wheel attached to the antenna to trigger radar readings	Time-zero correction; Dewow; SEC gain; Background subtraction; 2D migration	NP	(i) concrete liner thickness; (ii) presence of reinforcement and delineated zones where mesh roof supports and construction support timbers are embedded in the liner; (iii) locations and orientations of faults that intersect the tunnel; (iv) minor voids; (v) honeycomb sections; (vi) areas of rock-liner separation	(i) Radar responses to voids, slight liner-rock separation, hollows under liner, and embedded wood, had slightly different characters, but were not always uniquely distinguishable from each other; (ii) a 1 cm reading interval and 40 ns time window was found to create unmanageable data volumes and problems with data integrity; (iii) distance errors were attributed to roughness of the concrete ceiling of the tunnel affecting the small measure wheel on the antenna	NP	[188]

[Shield tunnel] To detect the grout thickness behind the lining segments of metro lines	250 MHz: step length of 2.5 cm, 75 ns time window and 188 samples 500 MHz: step length of 2 cm, 50 ns time window and 250 samples 1 GHz: step length of 1 cm, 24 ns time window and 241 samples	Longitudinal profile lines (along the axis direction of the tunnel)	Noggin GPR	Gain	MATLAB (500 MHz and 1 GHz data) and PIPEGPR 2.3 (250 MHz data)	(i) Steel bars in segment; (ii) thicknesses of segment layer; (iii) thicknesses of grouting layer	(i)There are so much noise signals from utilities such as power cables in the tunnel, which can difficult to detect grouting; (ii) slower speed of collecting data provides better GPR imaging resolution, while the real time detection needs faster data collection and a whole cross section scanning. Thus, future research is going to develop other GPR facilities for the higher speed data collection and the complete cross section scanning	FDTD numerical modelling	[189]
[Cast-in-situ reinforced concrete structure] To develop an automatic criterion for recognizing the lining layer and estimating the thickness of second lining	900 MHz (Ground-coupled antenna): time window of 25 ns (maximum depth of 800 mm), scanning frequency of 64 Hz and sampling rate of 512 samples per second	Three profile lines located at the vault and left and right shoulders (along the axis direction of the tunnel) with an average line spacing of 1 m	GSSI SIR-3000	Algorithm for automatic recognition	NP	(i) Automatic recognition of second lining layer and thickness	NP	NP	[190]

To perform a condition assessment aiming to locate the rebar, estimate the thickness of the second lining, and determine the presence and distribution of any damage for an annual inspection	500 MHz (Ground-coupled antenna): 2 cm of trace-interval and 40 ns time window composed of 512 samples per trace	Three longitudinal testing lines set against the left haunch, right haunch and vault	RAMAC GPR system from MALA Geoscience	Time-zero correction; Subtract-DC; Band-pass (Butterworth); Manual gain Automatic rebar location: a symmetry-based algorithm and hyperbola match	NP	(i) total rebar number (with some missing rebar areas); (ii) first-second lining interface (thickness estimation); (iii) damages (cracks/fractures) spanning the entire tunnel	NP	FDTD numerical modelling	[195]
[Shield tunnel] To estimate the thickness of the grouting layer and to determine the presence and distribution of any damage	800 MHz (Ground-coupled antenna): Sampling rate of 50 scans/s and 40 ns time window composed of 512 samples per trace	Two horizontal/ longitudinal testing lines and two vertical lines	RAMAC GPR system from MALA Geoscience	Time-zero correction; Energy decay; Subtracting average; Band-pass (Butterworth); Running average	NP	(i) Estimation of the segment and grouting layers thicknesses; (ii) defects in the grouting layer such as low density, voids, cracks or fissures	(i) The existence of the rebar in the segment could affect the detection of damage	FDTD numerical modelling	[196]
[Bored Tunnel] To locate rebar, check second lining thickness and the existence of any karst conduit or significant rock fractures beneath the tunnel	200 MHz, 600 MHz and 2 GHz	Grid lines at intervals of 10 cm	The TR-HF (2 GHz) and RIS MF Hi-Mod (200–600 MHz) antennas	NP	IDS GRED data analysis software	(i) Rebar location and depth estimation; (ii) existence of gaps in lining; (iii) detection of incomplete grouting; (iv) presence of karst conduits and voids	(i) If the intervals between readings are excessive, the data acquired will be insufficient to provide a clear overview of the sub-structures; (ii) complications in interpreting and analysing the data (e.g. effects of near-filed antenna coupling or induction effects, oscillations in antenna radiation patterns, inhomogeneous, anisotropic and loose materials)	NP	[201]

[Railway tunnel] A train-mounted GPR system for tunnel health assessment at the normal operating speed of the train	300 MHz (air-launched; horn antenna): scanning rate of 976 scans/sec., sampling point interval of 5 cm (maximum speed of 175 km/h), 60 ns time window and 512 samples/trace	Six channels/sets of antennas fixed on the train (six profile lines)	NP GPS/GIS	DC-level correction; Removing background; Vertical filtering; Horizontal filtering; Automatic Gain Control; Gain function	Multi-channel processing software (the data from the six channels displayed together)	(i) Steel arch on the lining surface; (ii) shotcrete reinforcement; (iii) thickness of the lining; (iv) rock disturbance behind the lining; (v) water seepage of vault	(i) Air-launched antennas can be mounted on a vehicle with a certain distance to the wall. However, due to the diffusion attenuation, some energy is lost in the air and the probing depth is shallower than ground-coupled antennas	NP	[197] [206]
[Immersed tube tunnel] Establishing the design configuration of at several immersion joint locations	900 MHz and 2 GHz	Survey performed by manoeuvring the antenna over the surface (roof) of the tunnel in a grid pattern 40 cm spacing (longitudinal and transversal scans)	RIS MF Hi-Mod multi-frequency System and hand-held RIS FastWave GPR system, TR-HF (IDS Georadar)	Rubber-band interpolation; Time-zero correction; Band-pass; Background removal; Smoothed gain	IDS GRED HD3 software	(i) Identification of the position and depth of the Omega Seals (immersion joint); (ii) two layers of rebar; (iii) rebar spacing of the concrete cover; (iv) thickness of shotcrete; (v) thickness of Rockwool Rollabats layer (insulation)	(i) No odometer was used to prevent difficulties caused by wheel slippage. These might have been caused by a layer of consolidated dirt/dust/particles covering the tunnel ceiling, which made it slippery to work on; (ii) although the depth of the GPR penetration has been blocked to a large extent by the presence of two layers of rebar, it was possible to penetrate at a depth of up to 200 cm approximately	NP	[207] [208]

Table S6. Tunnelling: relevant on-site GPR surveys (NP = Not Provided; Ref. = Reference).