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Radar database over large debonded areas into pavement structures

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1. GENERAL INFORMATION

This database was collected by several ground-penetrating radar (GPR) systems over artificial debonded areas during an accelerated pavement testing at the carrousel of Gustave Eiffel university (<https://www.lames.ifsttar.fr/en/the-institute/mast/laboratories/lames/equipments/the-pavement-fatigue-carrousel/> see the video). GPR data have been collected over three artificial defects (tack-free, geotextile and sand-based), which were embedded between the top and the base layers. The data collection was organized in a two-stage experiments and covers the full life-cycle of the pavement structure. During the first stage that took place in 2012-13, data were collected at each of 10k, 50k, 100k, 200k, 250k and 300k loading cycles. The second measurement campaign, performed in 2019-2020, lasted up to 800k loading cycles (Dérobot et al., 2020).

1.1.FATIGUE CARROUSEL

The fatigue carrousel is a pavement facility which is devoted to road traffic simulation and allows accelerated pavement testing. It is composed of a carrousel and a circular test track. The construction was undergone in 1984 in Nantes (Autret et al., 1987) and the carrousel was then developed and managed by the same institute which evolved in three successive research institutions, namely, LCPC, IFSTTAR and now, University Gustave Eiffel.

The carrousel includes 4 arms carrying the moving heavy loads (45 kN on single wheel, 65 kN on dual wheel, 90 kN on tandem or 135 kN on tridem axles) at different speeds (maximum 100 km/h) and at different radius (15.5 to 19.5 m). The pavement test track is a 6 meter width ring with a radius going from 14.5 m to 20.5 m. Usually, it is divided into different test sections, which are simultaneously loaded (Simonin et al., 2012).

25 m of the test track, centred on the radius 16 m corresponding to the load wheel-path of the experiment, has been dedicated to study detection and monitoring of interface defect by non destructive testing (NDT) methods. The pavement structure consists of two bituminous layers (a 8-cm base layer, and a 6-cm wearing course), over a granular sub-base. Rectangular patches of defects were incorporated at the interface between the two asphalt layers to create embedded debonding areas. Patches described by materials, namely, sand (5-10 mm expected), textile, tack-coat free interface, size are listed in table 1 and their locations presented in Figure 1.

Table 1 Theoretical characteristic of the debonded zones along the test site; in bold, the largest artificial embedded defects are concerned by this database.

Name (notation 2012)	Type	Length (m)	Width (m)
I-1	Sand	0.5	2
I-2	Geotextile	0.5	2
I-3	Tack-coat free	0.5	2
I-4 – I-9	Geotextile	0.5	0.5
I-10	Geotextile	3	0.5
I-11	Sand	1.5	2
I-12	Geotextile	1.5	2
I-13	Tack-coat free	1.5	2

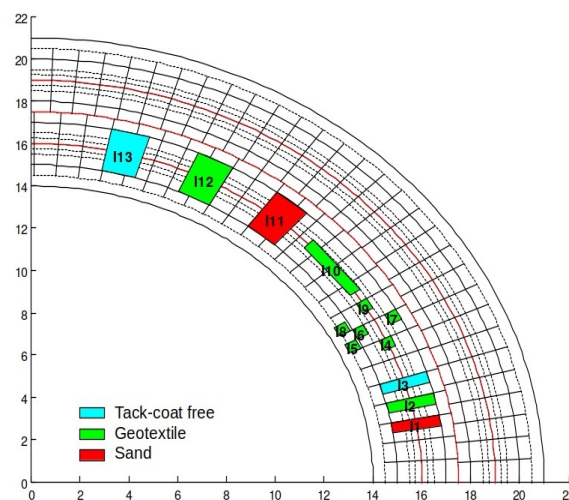


Fig. 1 Location of defect zones in the intern radius of Gustave Eiffel university carrousel (Dérobert et al., 2020)

A dynamic traffic, with a half-axle load of 6.5 T for dual wheels (Figure 2a), is established centered on a radius of 16 m. The lateral positions of the dual wheels are 11, spaced 10.5 cm apart for a footprint of 1.65 m large. The frequency of passage to these different positions follows the curve presented in Figure 2b to simulate real traffic.

a)



b)

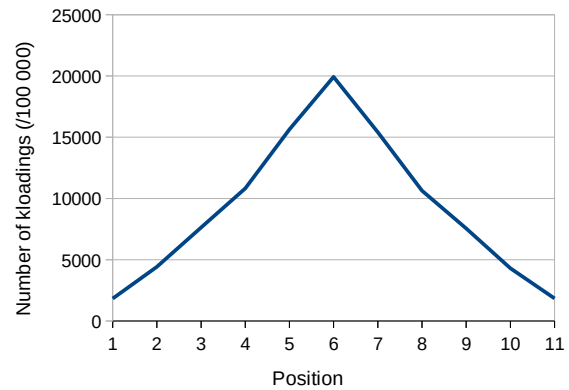


Fig. 2 a) Dual wheels of the carousel, b) Traffic density as a function of the lateral positions of the dual wheels axis per 100 000 loadings

1.2. GPR TECHNIQUES

Five GPR systems were used during two series of experiments in 2012 and 2019 (see further section).

In 2012, the GPR systems used are as follows:

- A SIR3000 GPR system, manufactured by GSSI, associated with an impulse ground-coupled 2.6 GHz antenna,
- An experimental Stepped-Frequency Radar (SFR), which is composed of a Keysight E8362A vector network analyzer (45MHz-20GHz), associated with two air-coupled Ultra Wide-Band (UWB) Vivaldi antennas, which reflection coefficient is less than -10 dB from 800MHz to 12.8GHz (Dérobert et al., 2001). The two antennas are fixed on a 1,60 long horizontal bench at 18 cm above the pavement surface (from the bottom of the antenna to the pavement), and with a lateral offset of 20 cm. The selected frequency samples are recorded within the [0.8-10.8] GHz frequency bandwidth in S21 mode. Fourier-based transform is used to compute the radar data (B-scans) in time domain. The antennas are moved over the pavement surface by a robotic antenna-carrier system controlling the horizontal movements to provide B-scan data.

In 2019, GPR systems were:

- A SIR4000 GPR system, manufactured by GSSI, associated with an impulse ground-coupled 1.5 GHz antenna,
- A 2.6 GHz StructureScan, an impulse ground-coupled system, manufactured by GSSI,
- The experimental Stepped-Frequency Radar described above,
- A stepped-frequency array system, from 3D-radar manufacturer, composed of 21 ground-coupled antennas, arranged to acquire 20 B-scans, spaced by 7.5 cm. The frequency band is ranging from 40 to 3 000 MHz, working with the highest range of frequency, leading after an inverse Fourier transform, to radar data comparable to a 1.5 GHz impulse radar. Data collection is done with a sampling of 1 cm and the width monitoring of each swath is about 1.40 m. For this database, only B-scans centred on the defects are available.

1.3. EXPERIMENTATIONS

The experiment started in the spring 2012. Loads of 65 kN were applied on the debonded area. The fatigue machine was regularly stopped to test the pavement with the different GPR systems. Thus 300 000 loads were globally applied to the road before the end of July.

Survey of the debonded zone was possible at different loading times:

- After the construction and before loading (initial state),
- At 10 000 loadings, corresponding to the consolidation of the structure,
- At around 50 000, 100 000, 200 00, 250 000 and 300 000 loadings.

As the global loading did not reveal clear evolution for road specialists, a second series was programmed. The fatigue carrousel planning, combined to external financing requirements, led to a second series of 500 000 loadings in 2019-2020. This second part has been supported by the French Research Agency (ANR), the FEREC foundation, and the French Ministry of Ecological and Solidarity Transition (MTES). Survey of the debonded zone were performed at the following loading times:

- At 310 000 loadings, corresponding to a new consolidation of the structure,
- At 396 000, 420 000, 500 000, 550 000, 600 000, 720 000 and 800 000 loadings.

Data were collected longitudinally and transversely through the centre of defects. Location of the beginning of the profiles in relation with the traffic path, described in section §1.1, is summarized in Table 2. One have to take into account the width (center to front) of the antenna systems and add 9 cm for the StructureScan radar and 15 cm for the 1.5 and 2.6 GHz antennas to the values given in Table 2. Moreover, transversal sawn trenches along the profiles, at the end of the experiment, enable to localize the limit of the defect.

Table 2 Location of the beginning of the GPR profiles to the internal traffic limit

Name	Profile orientation	Distance antenna front to the internal traffic limit (cm)	Distance antenna front to the defect limit (cm)
I11	T	53	39
I12	T	37	24
I13	T	38	~28

The reader can find the dates of experiments and the weather information, such as sunshine, precipitation, temperature and daily weather, in a specific folder /Weather_Conditions/ or at the Internet site www.infoclimat.fr/stations-meteo/analyses-mensuelles.php.

2. DATA PRESENTATION

2.1. DATA FILES AND STRUCTURE OF DATA

Database gathers the B-scan data which have been collected on the fatigue carrousel over the largest debonded defects I11 to I13 by the four different radar techniques. Database is organized in folder trees; folders at the first level being dedicated to each defect. They are named I11, I12 and I13 respectively.

In each of them, folders are organized in type of measurements and named by their central frequency and type of impulsions, as presented below:

/Defect_Central frequency_Type of impulsions/,

where:

- Defect: namely I11, I12 or I13,
- Central frequency: 1.5, 2.6 or 5.5 GHz,
- Type of impulsions: impulse or stepped-frequency type (namely Imp or SF)

For each B-scan data file, filename nomenclature has been defined as:

Freq_Emission_Defect_Orientation_Loading,

where:

- Freq corresponds to the nominal central frequency (*100 MHz),
- Emission, to the impulse or stepped-frequency radar type (Imp or SF),
- Defect, to the name of the defect,
- Orientation, specifying if transversal or longitudinal B-scan (T or L). Directions of the transversal B-scans are towards outdoors, for the longitudinal ones noted L, from I13 to I11, and for the ones noted L₁, from I11 to I13.
- Loading, the loading stage (in kloading) at which the GPR data were collected.

The 5.5 GHz SFR data being limited to a length of 1.60 m, due to the size of the antenna-carrier system, two successive profiles were performed, namely L1 and L2 (in the direction from I13 to I1), to collect the data over each defect. The two profiles are slightly overlapping two each other by a few A-scans. Both L1 and L2 B-scan profiles then include a part over the healthy zone and a part over the debonded zone.

At last, data are in a binary format for GSSI ones (extension .dzt, and coupled with a parametric file of the same name and extension .dxt for the SIR4000 system), in an ascii format for the experimental SFR (extension .txt) and classical sgy format for the 3D-Radar B-scans.

All the B-scan data can be visualized and processed using software, like the commercial one Reflexw (from Sandmeier Geophysical Research). Data under ascii format, from the 5.5 GHz SFR system, are ordered as follows: every row of data corresponds to the sampling of a time signal (A-scan) measurement. Table 3 gives the required information (number of samples per scan, duration, scans per meter) to reconstruct the B-scans.

2.2. DATA PRE-PROCESSING

Moreover, the list of data types is gathered in Table 3 with the associated setting parameters.

Data collected by impulse radar system, namely, SIR-family and StructScan, are raw data but the SIR3000 ones, which get the following setting parameter: a [0.5 GHz–5 GHz] bandpass filter and a constant time gain.

By contrast, data collected by the SFR systems require some pre-processing to get B-scan data after a proper transform from frequency to time domain.

The SFR data from the 3D Radar had been acquired by sequential frequency steps of 40 MHz within the full available bandwidth of 40-2980 MHz with a dwell time of 3 μ s leading to an integration time of 220.5 μ s. Data had been recorder within 25 ns double time range but only the first 4.25 ns (27 cm)

had been kept for this study. On this bandwidth, the IFFT uses a Kaiser window with a shape factor beta of 4 in order to return the B-scan.

Concerning the data from 5.5 GHz SFR system, setting parameters were the followings: S21, 801 frequencies from 0.8 to 10.8 GHz, IF bandwidth = 1 kHz, power transmission = -5 dBm, one internal calibration at least for each daily measuring session.

Fourier-based transform is performed to get B-scan data. The chirp Z-transform (czt in short) is computed to allow flexible transformation from frequency domain to the time domain. Eventually, appropriate frequency apodization and/or time gating is performed.

The transient signal within the Vivaldi antenna last a long time and overlaps with the useful radar echoes. Data preprocessing then include the subtraction of the transient signal from each raw SFR data file. Then, the recorded time range retained is 4 ns as a zoom of the zone of interest. This roughly corresponds to 20 cm probing depth within the pavement subsurface. Nevertheless, frequency data can be provided on request, for non-commercial use.

CONCLUSION

The data base is available to the GPR community and may serve as a reference benchmark for both developing and testing the performance of various processing techniques for either interface detection, characterization, or monitoring purposes of debonded areas of pavement structures under scale-1 controlled traffic.

Table 3 Information about the data collected on the fatigue carrousel defects I11, I12 and I13.

GPR system	Central Freq (GHz)	Type impulse	Coupling (AC / GC)	Orien-tation	File Name	Scan/m	Data format	Sampl.	Range (ns)	LP / HP (MHz)	Loading (k)	Nb Files
SIR4000	1.5	Imp	GC	L / T	15_Imp_I11_L/T_kload	100	dzt	1024	7	3000/250	300 / 310 / 396 / 420 / 500 / 550 / 600 / 720 / 800	3*18
3D-radar	1.5	SF	GC	L	15_SF_I11_L_kload	100	seggy	62*	4.25	2980/40	396 / 500 / 600 / 720 / 800	3*5
SIR3000	2.6	Imp	GC	L	26_Imp_I11_L_kload	100	dzt	1024	8	5000/500	0 / 10 / 50 / 100 / 200 / 250 / 300	3*7
StructScan	2.6	Imp	GC	L / T	26_Imp_I11_L/T_kload	800	dzt	256	6	5000/500	310 / 396 / 420 / 500 / 550 / 600 / 720 / 800	3*16
SFR	5.5	SF	AC	L / T	55_SF_I11_L/T_kload	50	Segy	2868**	7	10800/800	0 / 10 / 50 / 100 / 200 / 250 / 300	3*14
						50		1433	7	10800/800	310 / 420 / 500 / 600 / 720 / 800	3*18

*: File 15_SF_I11/I13_L_600.sgy propose 45 samples per scans

** for 0 and 10kloadings, sampling is 1751

Imp / SF: impulse / Stepped-frequency

AC / GC: air-coupled / ground-coupled

L/L/T: longitudinal (direction I13 to I1) / longitudinal (direction I1 to I13) / transversal

Sampl.: sampling of A-scans

LP/HP: low pass/ high pass – or Freq(Max) & Freq(Min) for the SFR systems

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