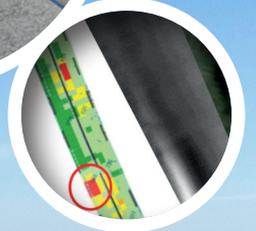




SUMMARY OF RESULTS



December 2025

**THE NATIONAL DVDC PROJECT WAS GRANTED
FINANCIAL SUPPORT FROM THE MATTE:
MINISTRIES OF TERRITORIAL DEVELOPMENT
AND ECOLOGICAL TRANSITION**

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The National DVDC (Road Lifespan) Project, a collaborative research programme implemented between 2016 and 2023, was coordinated by the Institute for Applied Research and Experimentation in Civil Engineering (IREX).

Forty (40) partners were involved in the project, representing all road infrastructure stakeholders, including network managers, government agencies, research organisations, engineering firms, road construction

companies, and manufacturers. The project was based on varied, multidisciplinary, and multi-scale approaches, which included scientific research, as well as results that can be directly applied in practice. The scientific findings of the ANR MOVEDVDC project (Modelling of Ageing and Damage for Pavement Lifetime Assessment), on specific issues relating to pavement damage mechanisms, were also incorporated into the National DVDC Project.

CHALLENGES

Road infrastructure is subject to natural ageing caused by external factors such as traffic and climate. The maintenance and upkeep of road infrastructure is therefore a major economic challenge, particularly in view of network managers' increasingly limited budgets for this work. It is therefore essential to maintain this infrastructure in a suitable condition to fulfil its required functions, while ensuring an acceptable level of safety for users.

The value of public infrastructure assets is extremely high. The road surfaces comprising this infrastructure must be valued at their construction cost, while deducting depreciation over their lifespan, as well as any maintenance costs to maintain both their asset value and their capacity to provide the required service. Underinvestment or lack of maintenance can lead to depreciation in their value, or worse, to them gradually becoming unsuitable for the services they were designed to provide, thus causing disruption to the local or national economy and posing a risk to users.

In the General Government Accounts, road infrastructure, which includes highways, civil engineering structures, ancillary works (drainage), service areas, and equipment (signs, traffic barriers, and operating systems, etc.), is valued at its "depreciated replacement cost" i.e. the cost of rebuilding this infrastructure from scratch less any maintenance costs. As a rule, this valuation is reviewed each time year-end accounts are reported.

The figure of €250 billion represents two-thirds of the government's tangible fixed assets (buildings, ports, airports, etc.). If departmental and local roads (covering 1 million kilometres) are also included, the value of this infrastructure, relative to the investment required to build it, is estimated at €2 trillion, a figure close to the country's GDP.

As a result, the stakes involved in the upkeep and maintenance of this infrastructure are high. Road network managers must know the lifespan of pavement structures (initial and residual life over time) in order to plan and budget for expenditure. This is not just a financial challenge; various studies have shown that optimising road infrastructure maintenance, by taking into account its entire life cycle, reduces its environmental impact.

To address these challenges, the national project primarily focused on assessing the residual life of pavements on three different scales:

- 1. Road networks, with macroscopic analysis of the condition of road sections.
- 2. Pavement structure, focusing on the phenomena of crack formation and interface debonding, and incorporating these factors into damage models.
- 3. Pavement materials, taking into account different types of materials. As this is a very broad topic, DVDC focused its research on better understanding the behaviour of bituminous materials and their evolution over time, Unbound Granular Materials (UGMs), the effects of freeze/thaw cycles, and the themes covered by the MOVEDVDC project. Particular focus was also given to wearing course materials, whose selection and maintenance are a major concern for road network managers.

1 - FOCUS ON ROAD NETWORKS

1.1 - Knowledge of road network condition: practices of contracting authorities

During the first stages of the project, information was collected on contracting authorities' practices for understanding road infrastructure and their data use. The surveyed group of contracting authorities was mainly made up of departmental councils. The analysis of practices was based on three surveys:

- A survey conducted during the project with eight contributing departments;
- A survey of 57 departments led by the French National Road Observatory (ONR), managed by the Institute for Roads, Streets and Infrastructures for Mobility (IDRRIM);
- Surveys conducted for the GEPUR project (2012).

In comparison to the surveys conducted for the GEPUR project in 2012, and in view of the results from the ONR and DVDC surveys, departmental councils are increasingly aware that they must better understand their road infrastructure. This is undoubtedly due to their increasing need to justify maintenance expenditure and optimise budgets.

In addition to this observation, the main findings were as follows:

- Departmental road networks are 3,500 km long on average. These networks apply a classification system and the vast majority are subject to a maintenance policy whose processes are not always clearly-defined, with a schedule that generally covers at least 3 years, depending on the hierarchy. Visual survey methods taken from the LPC testing method no. 38-2 are often used, with particular focus on operating procedures M2 and M3.
- Over 70% of the departmental road network (classes 3 and 4) consists primarily of flexible structures (UGM/asphalt mix) and older structures made of crushed stone with a surface dressing or asphalt. For the most part, only surface maintenance is carried out on these networks without reinforcement.
- Less than 6% of wearing courses are renewed annually, i.e. every 17 years or more.
- Reinforcement or resurfacing operations are carried out at least every 20 years or more, depending on the road network's classification system.
- Deterioration caused by the formation of "top-down" cracks associated with bitumen ageing appears to be increasingly common.
- Specific issues such as numerous roundabouts or mountain roads (altitude > 800 m) have been reported, highlighting that stakeholders want to share information and common issues.

Figure 1 : Breakdown of pathologies found on bituminous and semi-rigid pavements (according to the DVDC survey)

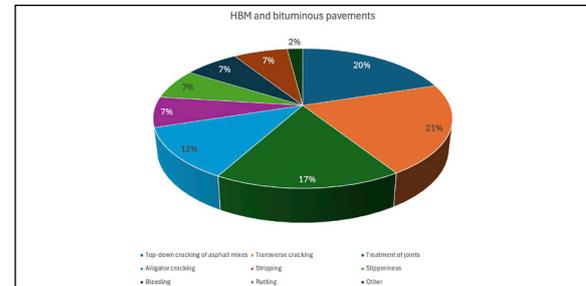
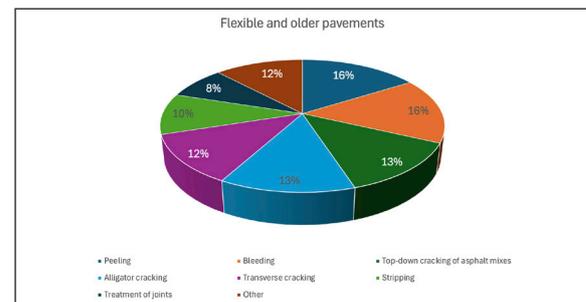


Figure 2 : Breakdown of pathologies found on flexible and older pavements (according to the DVDC survey)



The main findings of the assessment on departmental road networks were as follows:

- Information on pavement condition remains incomplete because it primarily comes from major road networks, which, among this sample group, account for only 15% of the total network length on average. Moreover, the quality and comprehensiveness of the approaches and methods used vary widely.
- Multi-year planning is not necessarily based on pavement monitoring data but rather on the knowledge of local operators.
- Tools are needed to optimise use of the data collected, as well as a recognised indicator based on transparent calculation methods. Road equipment is even less well understood than road pavements, particular in terms of infrastructure knowledge, despite the fact that maintenance of this equipment is critical to user safety.

The Departmental Council of Eure (CD27), an active partner of the project, highlighted the importance of these issues for maintaining the required service levels, assessing maintenance costs, and thus developing a multi-year plan in line with the department's maintenance strategy.

The national project also conducted research on concrete and semi-rigid pavements, including a comprehensive literature review on the mechanisms of crack formation in semi-rigid pavements and an exhaustive feedback review on concrete pavements made of "non-dowelled concrete slabs" and "continuously reinforced concrete", in order to estimate the frequency of maintenance and rehabilitation works.

Finally, knowledge of the road network also includes the many major cities across the country. The DVDC NP launched a survey of these metropolitan areas in France, in collaboration with the AITF (Association of Territorial Engineers of France), to incorporate their specific characteristics (categories of road, integration of trenches and roads with modular elements). The low response rate (5 out of 26), did not provide enough data for a detailed and reliable analysis but highlighted the lack of centralised information on the condition and monitoring of road networks.

For more information:

Report reference	Report title
DVDC/R/028	Retour d'expérience sur les mécanismes de dégradation des chaussées: Questionnaire complémentaire adressé aux conseils départementaux et projet pour les métropoles - Mise à jour (Feedback on pavement deterioration mechanisms: Supplementary questionnaire sent to departmental councils and project on metropolitan areas – Update)
DVDC/R/031	Retour d'expérience sur les mécanismes de dégradation des chaussées - Questionnaire adressé aux métropoles (Feedback on pavement deterioration mechanisms – Questionnaire sent to metropolitan areas)

1.2 - Characterisation of network condition

In view of this situation, and with the emergence of new technologies, it became essential to focus on characterising road network condition. This section is the most fully developed under Theme 2 of the national DVDC project. The main reasons for this are as follows:

- The opportunity for all project stakeholders to share their experience with the aim of developing a new common set of standards;
- The general realisation that technological advances in pavement monitoring should lead to an overhaul of standard practice, which was largely developed in the 1990s;
- The need to better inform contracting authorities about these major breakthroughs, their future potential, the added value brought about by this shift, and the impact on road infrastructure management.

1.2.1 - Surface condition monitoring

1.2.1.1 - Update of method 38-2 – Visual surveys of pavement deterioration

Initiative work in this field involved communicating the need to update the operating procedures of the LPC No. 38-2 method for surveying pavement damage. This method is based on the Pavement Deterioration Catalogue (LPC Testing Method no. 52), specifying the type and extent of the deterioration recorded.

Figure 3 : Definition of the operating procedures for the pavement deterioration survey method, according to network type and the study objectives.

Network types and study objectives	Flexible, semi-rigid, bituminous, inverted, mixed and CRC pavements;			Concrete slabs
	Rural roads and urban expressways (National and Departmental Roads, etc.)		Urban road network outside of urban expressways, municipal road network (municipalities, Federation of Municipalities)	All sites
	Major road network (in and outside urban areas)	Secondary road network		
Scheduling of operations, assessment, and monitoring	OP1	OP2	OP3	OP5
Diagnosis – reinforcement Monitoring of control sections	OP4			

The project produced a methodological paper on non-automated visual surveys, specifying the areas of application for the different operating procedures. This update meets a dual objective: to facilitate the surveying process and to make pavement condition analysis more effective by focusing on deterioration that is easy to observe without compromising on quality.

The number of operating procedures has therefore been reduced to six, and are broken down as follows:

- Three operating procedures for network assessment, which depend solely on the type of network being monitored;

For more information:

Report reference	Report title
DVDC/R/015	Actualisation de la méthode 38-2 (Update of method 38-2)

1.2.1.2 - Automated deterioration surveys

1.2.1.2.1 - Surface-based approach to pavement assessment

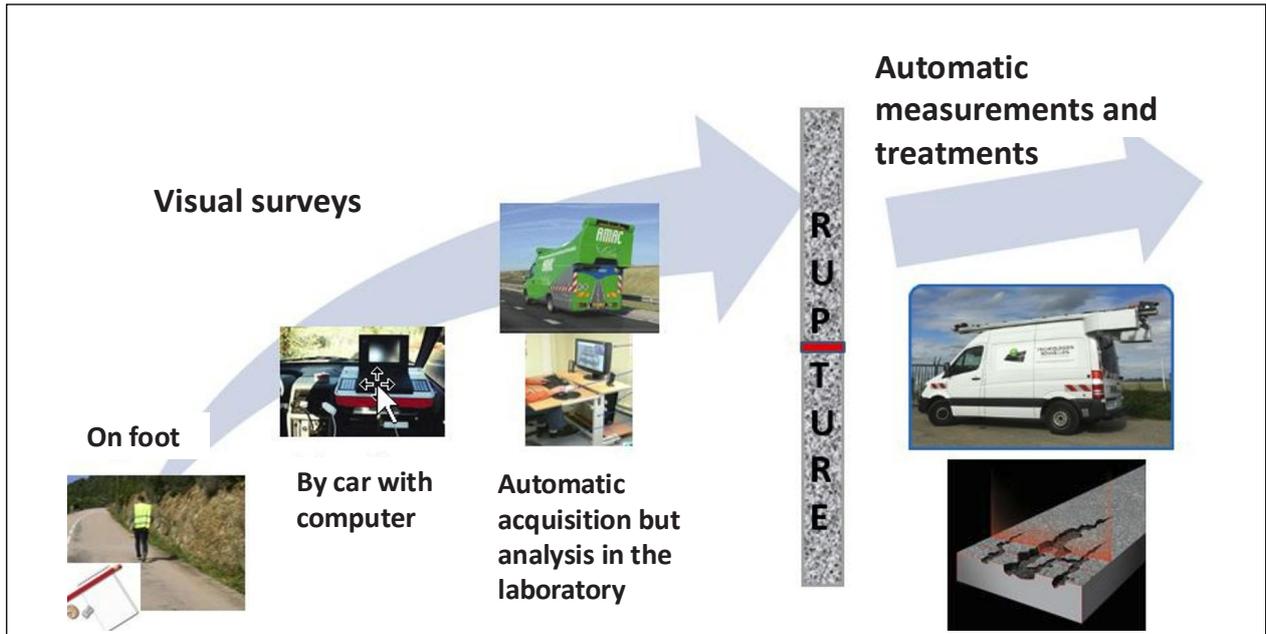
With advances in laser technology and data acquisition capacities, since 2010, new pavement monitoring solutions have been developed with huge potential for improving both the quantity and quality of information.

- An operating procedure for pavement diagnosis, maintenance, and pavement studies, as well as the monitoring of control sections;
- A specific operating procedure for concrete pavements, due to the unique and distinct nature of their pathologies compared to other pavements.

This update also highlights the importance of training and qualifications for operators performing visual surveys.

At the start of the project, the stakeholders identified these new devices, assessed the potential of these new sensors, and analysed the initial results from measurements taken on a control section provided by the CD27 (Departmental Council of Eure). The initial findings demonstrated the unparalleled potential of these devices for pavement surveys, both in terms of data accuracy and positioning, with results that remove some of the subjectivity of visual surveys. A shift is therefore currently underway from a linear visual approach (method 38-2) toward an automated surface-based approach.

Figure 4 : A revolution in pavement surface monitoring (excerpt from a presentation at the 2020 Technical Road Days)



Subsequently, the project developed a new methodology for processing and quantifying pavement deterioration, including a novel, surface-based approach to assessing deterioration.

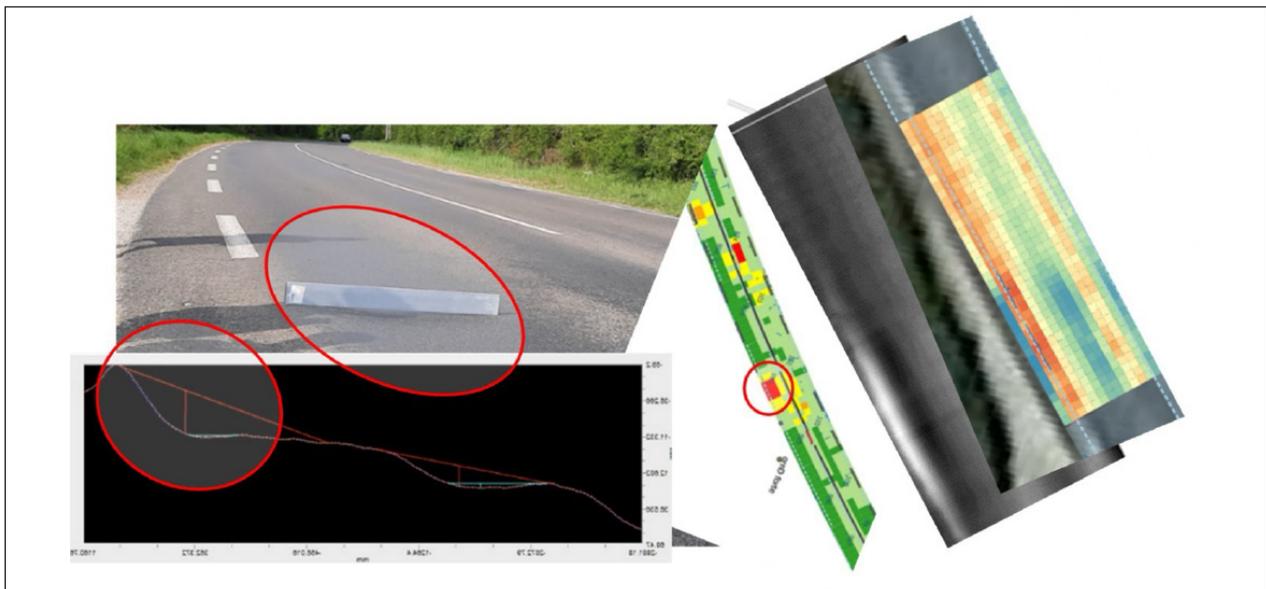
The next step was to define the minimum characteristics of all the descriptors provided by the new sensors by:

- Proposing rules for describing pavement deterioration that can be understood by everyone, easily quantified, and programmed into software;
- Specifying the location of surface deterioration so that pavement surface damage can be precisely located. This is a key factor when defining maintenance solutions.

After producing these descriptors, the project stakeholders then developed a new method for classifying pavement deterioration. This classification was required because the “standard” definitions for deterioration from the LPC test method no. 52, which are essentially based on general descriptions and images, do not apply to automated methods of data acquisition. They are not sufficiently descriptive, particularly in terms of geometry and quantification.

At the same time, deformation research was carried out because these automated devices have the capacity to take transverse and longitudinal measurements. As with pavement deterioration, the aim was to develop a surface-based assessment approach. Traditionally, significant profile variations, defined as

Figure 5 : Characterisation of the state of deformation using LCMS® sensors (credits: National DVDC Project)



deformations, are detected and characterised by taking readings from a few “traces” or “lines”. After verifying that scanner-type devices could provide more accurate “standard” indicator values than those of the reference devices, this study focused on developing and implementing several methodologies to analyse deformations using surface-based techniques.

In the final phase of the project, these approaches were validated on a section of the CD27 to determine the severity levels, while benefiting from the insight of a contracting authority.

For more information:

Report reference	Report title
DVDC/R/022	Relevés automatiques (Automated surveys)
DVDC/R/024	Connaissance du patrimoine routier départemental CD27 (Knowledge of the CD27 departmental road infrastructure)

1.2.1.2.2 - Automated surveys: What levels of performance can be expected?

Led by the French Association of Motorway Companies (AFSA) round-robin testing of automated survey equipment for pavement deterioration was carried out on a section of the APRR network to validate the accuracy of the measurements and data provided by these new technologies and to assess the impact of the processing methods used by the various operators.

This work was a crucial stage in the project, as it met the needs of contracting authorities, firstly, for the continuity of survey data in the event of a change of operator, and, secondly, for dispersion of the values measured according to the different adjustment and set-up parameters.

These round-robin tests were a first in Europe; they proved essential in defining the methodological framework for surveys carried out using LCMS® sensors, which are widely used on the French market.

This methodological framework incorporates the following aspects:

- Data acquisition procedures (installing sensors, standardising data acquisition software, taking measurements);
- Data processing methods (standardising calculation methods, versions and configuration of the LCMS_Analyser® app, etc.)
- Development of an analysis platform and definition of statistical data use (platform developed by Cerema), based on three approaches:
 - Formalised processing of raw data (Pavemetrics® descriptors),
 - Processing of data according to the surface-based deterioration assessment methodology (DVDC),
 - Processing of data in accordance with ASFA specifications.

Figure 6 : Round-robin tests conducted in March 2021 on the APRR network (photo credits: Erolf Productions)



Although the road sections were in relatively good condition, all operators identified areas of damage, regardless of the parameters used.

At a minimum, these tests should help better define the installation and operating conditions for LCMS sensors. They should also be used to define a common set of parameters.

This work still needs to be finalised.

To improve aspects of “Calibration” and “Metrology”, in the first instance, a common section could be selected and surveyed every year prior to maintenance campaigns, with the results being presented to the relevant Motorway Concession Companies (SCA), before systematically conducting round-robin tests, which could include the certification of monitoring devices.

Over the last two decades, the sensors used for pavement monitoring have come from other countries.

A certification issued by government agencies could help reassure the contracting authorities.

Given the performance levels observed in Phase 1, these tests also demonstrate the impact of the operating methods specific to each operator, as highlighted in Phase 3.

LCMS sensors represent a clear technical breakthrough but standard methodology has not been

updated accordingly. How can “significant alligator cracking in the traffic lane” be converted into a tangible mathematical formula?

The use of AI in pavement condition assessment raises the same question.

In conclusion, the feedback from these round-robin tests helped all the participants to develop their expertise in this type of testing.

The Phase 1 results have demonstrated the quality and performance level of the LCMS® technology. They have also highlighted its limitations in the case where operators are restricted to internal monitoring.

The Phase 2 results have demonstrated that the results can be interpreted differently and represent a first step toward more accurate assessment of pavement condition using surface-based techniques.

The Phase 3 results have revealed discrepancies between operators on several recorded descriptors, which may be affected by various factors including the RoadInspect settings, the parameters used for recording certain descriptors, metrology, and other external factors (e.g. weather conditions during the measurement period).

All the statistical analyses performed are included in the phase 1, 2, and 3 reports, which can be accessed via the DVDC website.

For more information:

Report reference	Report title
DVDC/R/032	Relevés automatisés : descripteurs dégradations et méthode de classification (Automated surveys: deterioration descriptors and classification method)
DVDC/R/036	Apport des appareils d’auscultation de type « scanner » pour la détection et la caractérisation en 3-D des déformations de chaussée routière (Contribution of “scanner” type monitoring devices for the detection and 3D characterisation of road pavement deformation)
DVDC/R/040	Relevés automatisés – Application in situ des descripteurs dégradations (Automated surveys – in-situ application of deterioration descriptors)
DVDC/R/048A	Essais croisés LCMS. Exploitation des relevés ASFA (Phase 1) (LCMS round-robin tests. Use of ASFA surveys (Phase 1))
DVDC/R/048B	Essais croisés LCMS. Exploitation des relevés ASFA (Phase 2) (LCMS round-robin tests. Use of ASFA surveys (Phase 2))
DVDC/R/048C	Essais croisés LCMS. Exploitation des relevés ASFA (Phase 3) (LCMS round-robin tests. Use of ASFA surveys (Phase 3))
DVDC/R/048D	Essais croisés LCMS. Exploitation des relevés ASFA (Synthèse) (LCMS round-robin tests. Use of ASFA surveys (Summary report))

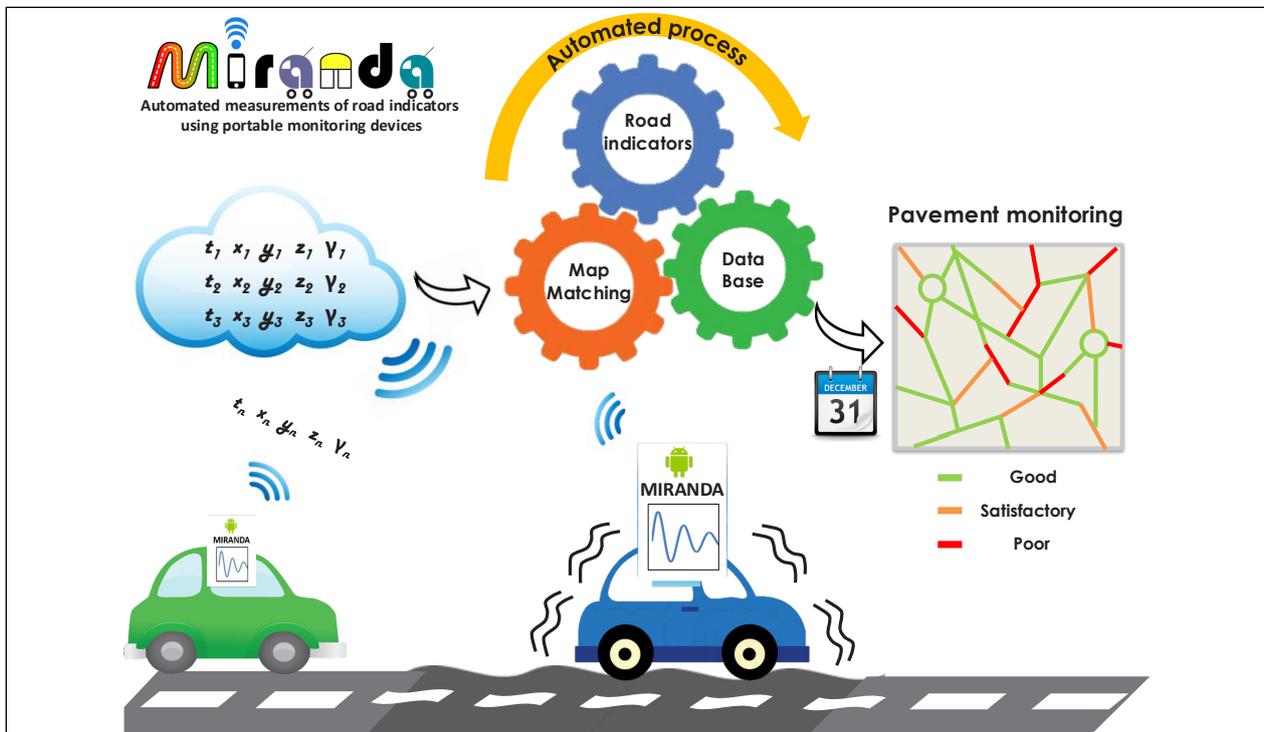
1.2.1.2.3 - Other assessment methods: the “Miranda” project

While the technologies outlined above are particularly well-suited to the monitoring of major road networks, it remains essential that network managers improve their knowledge of the condition of secondary road networks. Network managers want user-friendly and automated tools that can be installed on their fleet of vehicles (such as patrol vehicles, for example) to perform a basic assessment of the condition of their roads. The aim is, firstly, to establish a representative image of the network (particularly roads that are rarely monitored), and secondly, to use this image to prioritise maintenance schedules.

Led by Gustave Eiffel University (UGE) as part of the DVDC project, the Miranda experiment perfectly demonstrated the current data processing capabilities of in-built vehicle sensors.

The use of the “Miranda” demonstrator in the CD27 has shown that longitudinal deformations of a local service network can be assessed by measuring vertical acceleration with a smartphone from the passenger compartment of a vehicle. An additional accelerometer sensor positioned near a wheel (called “UniWheel”) produced more accurate evenness readings than the smartphone, and were similar to those obtained using reference devices such as the Longitudinal Profile Analyser (LPA).

Figure 7 : Miranda project - Automated measurements of road indicators using portable monitoring devices (Gustave Eiffel University - Mast - Lames)



Monitoring this type of indicator over time can be extremely useful for tracking changes in pavement condition.

For more information:

Report reference	Report title
DVDC/R/008	MIRANDA : mesure d'indicateurs routiers automatisée par appareils nomades d'auscultation : Expérimentation dans l'Eure (CD27) (MIRANDA: automated measurement of road indicators using portable monitoring devices: Experimentation in the Eure (CD27))
DVDC/R/023	MIRANDA: Evaluation d'un capteur de roue (UniWheel) / Expérimentation dans l'Eure (CD27) (MIRANDA: Evaluation of a wheel sensor (UniWheel)/ Experimentation in the Eure (CD27))

1.2.2 - Structural health monitoring

1.2.2.1 - High-accuracy deflection measurements

In addition to these major developments in the characterisation of pavement surface condition, another technological breakthrough has emerged over the last ten years: the capacity to take high-accuracy deflection measurements in flowing traffic. Over the past 50 years, numerous devices have been developed to measure pavement surface deflection, ranging from slow-speed rolling devices to dynamic loads. These devices include the Benkelman beam, the dynaflect, the Lacroix deflectograph (and other deflectographs of similar design), the curviameter, and the Falling Weight Deflectometer (FWD). All of these devices can take measurements either while stationary on the pavement or while moving at slow speeds.

The high-speed deflectometer (HSD) is the first deflection measuring device in regular production that takes measurements at speeds comparable to other road users. As this device measures the pavement's response to an actual dynamic load, HSD measurements are likely to be more accurate than FWD measurements, for example.

Since the development of the first prototype in the early 1990s, the Danish company Greenwood Engineering has produced more than ten Traffic Speed Deflectometers (TSDs), which are now being used in the following countries: Denmark, the United Kingdom, Italy, Poland, South Africa, Australia, China, the United States, and Germany. Dynatest has since developed a device using the same measurement technology, marketed under the trade name RAPTOR. In 2019, this device was acquired by the Swedish company Ramboll, and was subsequently acquired by Cerema in 2023.

For this reason, the DVDC project assessed the potential of this type of equipment by analysing international feedback, despite the differences in standards, and by conducting round-robin tests.

The DVDC project therefore performed comparative tests on two high-speed road deflection measurement systems: the TSD and the Raptor. These innovative systems can be used to take measurements under normal road conditions, without slowing down traffic. During these tests, conducted on a 168 km stretch of road, including a section for repeatability tests, discrepancies were found in the maximum deflection values measured.

These deviations appear to be linked to pavement stiffness as the measurements for flexible structures were more consistent. Three analysis methods were used to compare the results: decile classification, cumulative sum analysis (FWD approach), and data harmonisation.

The cumulative sum method identified similar homogeneous areas for both devices, despite different raw values. Data harmonisation based on standardisation demonstrated similar results for signal shapes, highlighting the capacity of both systems to characterise deflection variations.

However, the decile analysis revealed more significant classification differences with rigid pavements. This highlights the issue of instrument sensitivity and the need to precisely calibrate the classification thresholds.

The report concludes that overall performance is good despite the disparities. It suggests that further testing be conducted on more flexible structures, and that information on the shape of deflection basins be used for more detailed analysis.

In addition to maximum deflection measurements, other values were assessed during these tests, with the two devices producing a more detailed range of data, including:

- Information on the deflection basin, over at least 1.5 metres;
- Information on the asymmetry of the basin around the load, which becomes more pronounced with speed when a viscous material is tested;
- Data to help better understand the impact of the load speed on the pavement structure's response;
- Data on other international indicators, taken from the FWD, at higher speeds and with greater accuracy (SCI, BCI, BDI, for example);
- When combined with an accurate mechanical model of the pavement (based on RADAR measurements or historical data, for example), these devices can be used to perform a highly accurate assessment of road pavement condition, by applying the principles of the guide "Diagnostic et conception des renforcements de chaussée" (Diagnosis and Design of Pavement Reinforcement) on a large scale.

Further research should be conducted to compare materials using the afore-mentioned indicators, with the most useful being the deflection basin measurements.

Using a viscoelastic calculation model, combined with data on each measurement point of the measured basin, should produce a more precise and accurate model of the actual behaviour of the existing pavement. The dispersion of pavement conditions could then be assessed and, ideally, linked to their lifespan, which could then inform research on pavement "survival laws". This research could then be used to inform decisions on public policy.

At the time of publication of this summary, additional tests had also been carried out on the 168-kilometer stretch of road, using the Raptor acquired by Cerema (Raptor No. 3) and the MESAS system by BAST. The same sections were measured using the two devices in 2023-2024 and 2024 respectively. This data will be analysed as part of another project with the aim of developing new, more comprehensive uses for the measurements taken with these promising devices.

Figure 8 : Round-robin testing of deflection (excerpt from a presentation at the 2023 Technical Road Days



For more information:

Report reference	Report title
DVDC/R/033	Mesures de Déflexions à grand rendement (High-speed deflection measurements)
DVDC/R/050	Essais croisés des matériels de déflexion à grande vitesse (Round-robin tests on high-speed deflection equipment)

1.2.2.2 - Radar approach

Understanding pavement structures, and more specifically, the condition of interfaces, is crucial for defining technical solutions to reinforce pavements. However, it is difficult to obtain this information on different road sections, except through targeted destructive tests such as pavement coring. Therefore, a review was conducted to identify the potential means available to network managers for better characterisation of their pavement structures, with the aim of making road diagnostics more reliable.

The aim of this work was to improve, use, and analyse radar measurements, in particular, to characterise the integrity of pavement interfaces, and more specifically, to analyse potential defects in pavement layer interfaces.

As part of this study, a detailed signal analysis was performed using data from an ultra-wideband frequency-hopping radar. Various methodologies were tested on data from an experiment conducted on a road in the Eure department. The results obtained demonstrate the potential of this technology. However, before it is rolled out across an entire network, the processing methods still need to be improved using automated techniques, and particularly artificial intelligence.

For more information:

Report reference	Report title
DVDC/R/021	Méthodologie d'exploitation des mesures radar pour la caractérisation des interfaces de chaussées : approche expérimentale (Methodology for using radar measurements to characterise pavement interfaces: an experimental approach)

1.3 - Structural indicators

Ultimately, the technological advances outlined above highlight the considerable benefits of these tools for characterising the surface and structural condition of a road network. Network managers can now obtain an accurate description of the state of deterioration

of their network. However, this description is too detailed for the assessment of an entire network spanning several thousand kilometres. Pavement condition indicators must therefore be defined to evaluate the level of pavement damage by section.

1.3.1 - Analysis of existing indicators

One of the DVDC project's primary objectives is to define relevant indicators on the methods for monitoring road networks and interpreting data.

The first phase of this work involved a review of the current indicators for pavement structural condition. While this analysis was not exhaustive, various approaches within the scope defined above were evaluated: French national road networks (non-concessionary roads within the national network and concessionary motorways), local networks (departments, metropolitan areas, municipalities), and comparable international networks (Germany). Studies and research conducted on the same topic from European (notably the COST 354 project) and international sources (PIARC, American indicators) were also reviewed.

These approaches, and the methods used to calculate structural condition indicators, vary considerably. Despite these differences, several common denominators can be identified:

- All structural indicators are primarily based on the treatment of relevant surface damage: fatigue cracking and cross-sectional profile deformation;
- Some indicators incorporate longitudinal evenness;
- Some indicators take into account surface deformability (deflection);
- The most commonly-used methods combine these indicators to calculate a weighted sum; there are variations, such as penalty methods;
- Technical and financial methods involve analysing deterioration to determine what repairs are required and then quantifying these repairs to assign a score (for example, the second version of the IQRN (National Network Quality Image) is used in France).

1.3.2 - Proposal for a structural indicator

The development of monitoring technologies that provide surface readings of deterioration and deformation is changing traditional approaches to defining indicators. In recent years, Cerema has been working on a surface-based assessment approach for the national network, called IQRN 3D, based on a surface evenness approach in particular. The advantage of this method is that structural weaknesses can be identified in highly localised areas, thus producing a map of the extent of pavement damage.

The DVDC project working group highlighted a processing method using the results obtained with a grid composed of 25 cm squares, which determines the precise location and density of deterioration and deformation. This approach makes it easier to apply this data to maintenance techniques, thus meeting the needs of contracting authorities.

Figure 9 : Deterioration descriptor proposed by the DVDC project (photo credits: National DVDC Project)



In response to demand from contracting authorities, service providers with these new technologies can now process data and meet specifications based on conventional M2- and M3-type methods. However, this approach is counterproductive because lower-quality data is provided upstream in the process.

As a result, the national DVDC research project proposes an automated structural indicator (ISa) based on data from LCMS-type acquisition systems. This indicator provides objective and reproducible data for assessing pavement condition.

The ISa is based on the combined analysis of cracking and deformation. A basic grid with sides of 25 cm is used to quantify and locate these pathologies. Image processing algorithms extract precise information about cracking, while deformation is analysed using specific methods, including volume measurements per cell.

The severity of deterioration for each cell is then classified using decision tables. A structural index per cell (ISm) is then calculated, taking into account the combined severity of cracking and deformation. The aggregated ISm values for a given section provide the ISa indicator, categorised according to four levels: good, fairly good, fairly poor, and poor.

This automated approach offers an effective alternative to traditional assessment methods. However, a structural indicator calculation based on the same methodology, combining degradation and deformation data estimated using these traditional methods (visual surveys and deflection measurements, for example), is provided in Appendix 5.1 of the research report.

The ISa is part of a broader approach developed by the DVDC project, which includes a more flexible and adaptable standard structural indicator (IS) for different contexts. Further work will be carried out after the DVDC project to validate and calibrate the ISa using a larger dataset, and assess its potential for integration into infrastructure management systems.

Follow-up work to the DVDC should establish a point of convergence and the development of an effective operational method for processing automated readings in line with these new possibilities.

In addition to ageing mechanism models, “naturalistic observation” remains essential to the maintenance strategy of network managers. Moreover, pavements are exposed to changing climatic and geotechnical conditions (such as shrinkage and swelling of clay soils) that are difficult to model and are likely to occur more frequently.

Infrastructure management also requires indicators that document changes in deterioration, rather than simply providing a snapshot of the pavement condition at a given time.

To this end, the Universities of Limoges and Gustave Eiffel have proposed methodological principles for modelling the evolution of deterioration on different sections of a road network. The benefit of this approach is that it is “open source” and therefore any type of deterioration could theoretically be incorporated based on a geostatistical approach that could be combined with AI in the future.

For more information:

Report reference	Report title
DVDC/R/012	Etude sur les indices structurels (Study on structural indices)
DVDC/R/0047	Relevés automatisés : contribution à l’élaboration d’un indicateur structurel (Automated surveys: development of a structural indicator)

1.4 - Conclusion - Taking this research further

New measuring and surveying devices provide a better understanding of pavement condition but actually make it more complicated to develop a common indicator for aggregating this data and obtaining the most objective possible overview of a pavement's general condition. Deterioration surveys are a prime example of how technology has progressed. They can be carried out manually through visual inspection based on method 38.2, updated during the national project, but they can also be conducted "automatically" using more powerful tools, although expert supervision remains essential. The descriptors obtained using "manual" and "automated" methods are not exactly the same and will therefore provide different information about the pavement's condition.

With regard to "automated" deterioration surveys, the technology of certain devices, such as the aforementioned laser imaging sensors commonly known as LCMSs (Laser Crack Measurement Systems), was already mature but had not been assessed through round-robin testing, as with the study on motorway sections conducted in partnership with ASFA (French Association of Motorway Companies).

There have been rapid advances in pavement monitoring technology in recent years. The national DVDC project, the work carried out by Cerema as part of the IQRN3D and the Departmental Network Management – GRD project (conducted with ten Departments), as well as the work on "pavement audit and diagnosis" by Routes de France, have helped optimise use of these devices. Looking ahead to the future, particularly with the benefits brought by AI, the research from these various projects will no doubt be applied to new contexts.

2 - FOCUS ON PAVEMENT STRUCTURE

Under the national DVDC project, pavement structure and pavement design are closely linked. The project's major contributions in this field include the following:

- Detailed state-of-the-art analyses focusing on two specific themes in pavement design and dimensioning: i) wearing course specifications according to substrate deflection, and ii) the inclusion of roadbed bearing capacities and granular materials in the design of flexible pavements and unpaved roads.
- Tools for road engineering available to the road community: i) the development of a new methodology for characterising the degree of layer bonding in situ (including the development of a test and review of performance thresholds) and ii) the development of a finite element model for the various structural defects that affect (cracks, bonding defects) deflection basins.
- Research work to develop advanced design tools that combine pavement mechanics with: i) a probabilistic approach, ii) fracture mechanics (crack formation and propagation), and iii) contact mechanics (tribology).

2.1 - State-of-the-art analyses

2.1.1 - Roadbeds and granular materials in the design of flexible pavements and unpaved roads

Flexible pavements constitute an essential part of French and international road infrastructure. Their lifespan is closely linked to that of granular layers making up the base course.

The report of around one hundred pages includes a literature review of the various design methods for flexible pavements and unpaved roads used internationally, based on 22 design guides and catalogues. The analysis aims to describe roadbed bearing capacities and the incorporation of granular materials (pavement sub-layers) in the design process.

In particular, this work provides a summary of the major assumptions of the different methods reviewed (an excerpt of this summary is provided in Figure 10 for methods and Figure 11 for catalogues).

Figure 10 : Excerpt of method design assumptions

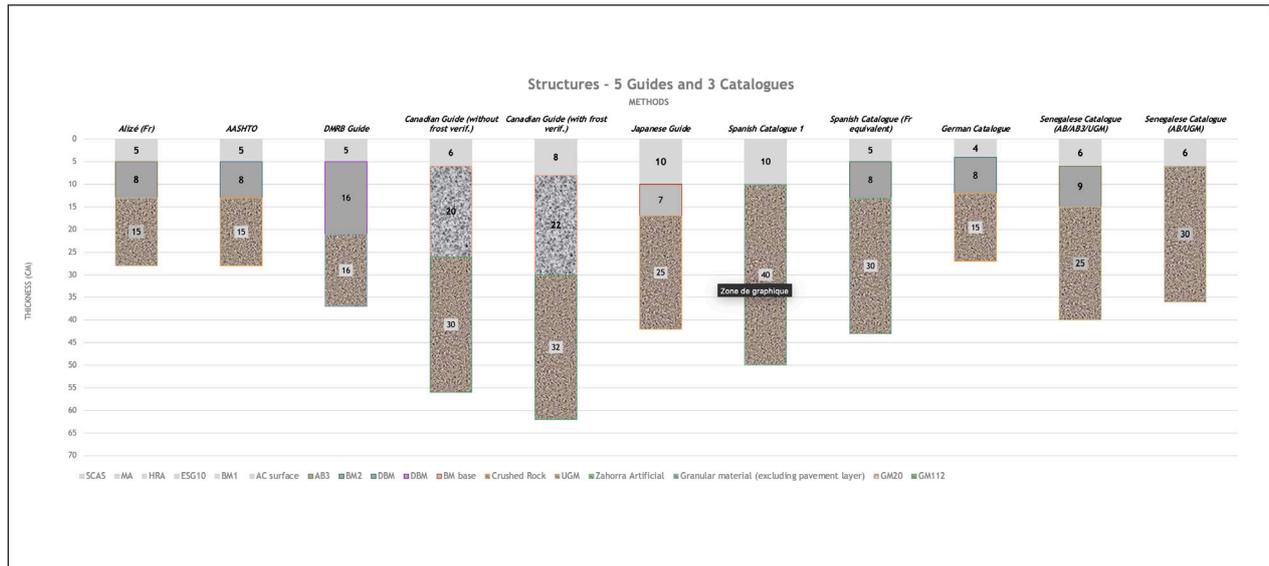
Parameter	Guide/Manual							
	American (AASHTO 1993)	English (DMRB 2006)	Belgian (CRR - R 49/83)	Canadian (AASHTO 1993)	Australian (AUSTRROADS Part 2 - 2012)	Brazilian (Manual de Pavimentação DNIT 2006)	Japanese (Handbook of Asphalt Pavement 2019)	CEBTP (1984)
Method type	Empirical	Empirical	Analytical	Empirical	Analytical	Empirical	Empirical	
Axle/reference load	8.16t	8.16t	13t	8.16t	8.16t	8.16t	Reference axle 10t (but for the traffic class the reference load is 5t)	13t
Soil bearing capacity/CBR (criteria)	Modulus calculation for CBR subgrade soil	Modulus calculation for CBR subgrade soil	Modulus calculation for CBR subgrade soil/soil type and drainage conditions	Modulus calculation for CBR subgrade soil	Modulus calculation for CBR subgrade soil	CBR subgrade soil	Modulus calculation for CBR subgrade soil	Modulus calculation for CBR subgrade soil (95% OPM)
Classes	RM (psi) = 750 to 3,000 x CBR; RM (psi) = 1,500 x CBR if CBR < 10%, i.e. RM (MPa) = 10.3 x CBR; RM (psi) = 2,555 x CBR ^{0.86} if fine materials, i.e. RM (MPa) = 17.6 x CBR ^{0.86} ; RM (psi) = 3,000 x CBR ^{0.85} , i.e., RM (MPa) = 20.7 x CBR ^{0.86} [AASHTO 1993]	Class 1 - E= 50 MPa Class 2 - E= 100 MPa Class 3 - E= 200 MPa Class 4 - E= 400 MPa	E= 10 x CBR The soil modulus is determined based on the soil type and drainage conditions. There are no clearly-defined classes for roadbeds, although EV2 ranges are defined (10 MPa, 20 MPa, 30 MPa, 40 MPa, 60 MPa and 80 MPa)	RM (MPa) = 17.6 x CBR 0.647/Consideration of seasonal effects	E= 10 x CBR, with max = 150 MPa (special attention paid to the density and test w)	CBR soil lines in the N _x Total Thickness chart: 2, 3, 4, 5, 6, 7, 8, 10, 12, 15 and 20	There are no classes but rather ranges of CBR values (the lower limit of the range is selected) 2 to 3 3 to 4 4 to 6 6 to 8 8 to 12 12 to 20 >20	S1 - E= 25 MPa S2 - E= 50 MPa S3 - E= 75 MPa S4 - E= 150 MPa S5 - E= 300 MPa S1 < 5% S2 < 10% S3 < 15% S4 < 30% S5 > 30% If CBR < 5, replace by 50 cm wherever possible
UGM Base course								
Thickness	150 cm (single layer)	of 15 to 60 cm	Min. 15 cm	GM112 = 50mm - 100mm and + GM20 = 50mm - 200mm and +	Min. 10 cm	10 to 20 cm	Min. 7cm et max. 3xD	Min. 15 cm
Mechanical requirement	Base course - generally the a2 coefficient used for the dimensions is equal to 0.14, a CBR value of 100% and a modulus of 30,000 psi (210 MPa) Subbase course - generally the a3 coefficient used for the dimensions is equal to 0.11, a CBR value of 30% and a modulus of 20,000 psi (100 MPa) These values should be adapted according to the materials available and in accordance with the graph presented in	Function of the roadbed class	Ebase = 400 to 600 Mpa Esubbase = 200 to 300 Mpa	E _{GM112} = 90 to 110 MPa E _{GM20} = 125 to 290 MPa	E measured with triaxial test: E UGM under AC low thickness = 250 MPa (subbase), 300, 350 or 500 MPa (base: depends on the quality of UGM). E UGM under bound materials = 150 to 350 MPa (standard quality), depending on the thickness and equivalent modulus of the bound materials on top of it	Granular base course - CBRmin = 60% Subbase course - CBRmin = 20%	Granular base course - Modified CBR min = 80% Subbase course - Modified CBR min = 20%, 30%	E= 5 CBR (coarse aggregate materials) E= 3 CBR (high fine fraction aggregate materials) E= 300 MPa (UGM) E= 500 MPa (crushed UGM base course)
Particle size characteristics	0/37.5, 0/25, 0/19	0/45, 0/63, 0/80	0/16; 0/32; 0/40	GM20 0/20 GM112 0/112	0/20; 0/40	UGM base - % pass 0.075mm < 2/3 pass 0.425mm / LA ≤ 50	M (crushed stone) 40; M30; M25; C (Crusher-run) 20; C30; C40	0/40; 0/31.5

Figure 11 : Excerpt of catalogue design assumptions

Parameter	Catalogue					
	Road Note 31 (1993)	South Africa (SATCC 2001 Catalogue)	Algeria (2000 Catalogue)	Spain (Catalogue Norma 6.1IC Seccionnes de formes)	Senegal	Germany (RstO 12 2015 Catalogue)
Axle/reference load	8.16t	8.16t	13t	13t	13t	10t
Soil bearing capacity/CBR (criteria)	Modulus calculation for CBR subgrade soil (see CBR)	Modulus calculation for CBR subgrade soil	Roadbed bearing capacity and CBR (95% OPM)	Modulus calculation for CBR subgrade soil	Roadbed bearing capacity and CBR	Roadbed bearing capacity
Classes	S1 = 2% 3% ≤ S2 ≤ 4% 5% ≤ S3 ≤ 7% 8% ≤ S4 ≤ 14% 15% < S5 ≤ 29% S6 = 30%.	S1 = 2% 3% ≤ S2 ≤ 4% 5% ≤ S3 ≤ 7% 8% ≤ S4 ≤ 14% 15% < S5 ≤ 29% S6 = 30%.	E= 5x CBR S4 - E= 14 MPa S3 - E= 25 MPa S2 - E= 50 MPa S1 - E= 125 Mpa S0 - E= 200 MPa	S1 < 5% S2 < 10% S3 < 25% S4 < 40% S5 > 40% E1 - EV2>60MPa/d ≤ 250MPa E2 - EV2>120MPa/d ≤ 200 MPa E3 - EV2>300MPa/d ≤ 150 MPa	E= 5 x CBR PF1 - Emin 20 MPa/EV2 > 30 MPa/d ≤ 300 MPa/CBR min 5% PF2 - Emin 50 MPa/EV2 > 80 MPa/d ≤ 200 MPa (80 MPa bound)/CBR min 10% PF2qs - Emin 80 MPa/EV2 > 100 MPa/d ≤ 120 MPa (70 MPa bound)/CBR min 15% PF3 - Emin 120 MPa/EV2 > 120 MPa/d ≤ 90 MPa (60 MPa bound)/CBR min 25% PF4 - Emin MPa/EV2 > 200 MPa/d ≤ 50 MPa (bound)/CBR min 40%	In the German catalogue all structures are sized based on an EV2 ≥ 45 MPa. Therefore, there is not really a classification. The classification focuses more on the sensitivity of the soils to frost (F1, F2 and F3).
UGM Base course						
Thickness	Min. 15 cm	Min. 15 cm	Min. 15 cm	20 to 30 cm	UGM 0/14 = 10 cm UGM 0/20 = 15 cm UGM 0/31.5 = 20 cm	Modulus function: 15 to 35 cm
Mechanical requirement	Characterisation based on the PI and CBR: PI < 6 and CBR > 30	CBR > 30 - subbase CBR > 80 - base	E= 500 MPa (UGMbase), E= 2.5 x E Lower layer (UGMsubbase)	Not specified in the catalogue	E= 500 MPa (UGMbase), E= 3 x E lower layer (UGMsubbase) per layer of 25 cm maximum, capped at 600 MPa in UGM structure/UGM, 360 MPa in UGM/GB structure	80 to 180 Mpa
Particle size characteristics	0/37.5 0/28 0/20	0/50 0/37.5	0/20 0/31.5	Not specified in the catalogue	UGM 0/14 UGM 0/20 UGM 0/31.5	0/45
Calculation risk	Not specified in the catalogue	Not specified in the catalogue	Not specified in the catalogue	Not specified in the catalogue	5% and 25%	Not specified in the catalogue
Additional criteria (drainage/maintenance frequency)	Incorporation of groundwater level depending on the season (rainfall levels)	Coefficient according to the climate zone	First maintenance operation at 8 to 10 years	The catalogue suggests taking into account 3 climatic zones based on rainfall levels, but only for porous asphalt.	Maintenance frequency is not specified in the catalogue, but a three-year plan is recommended to compare economic parameters and monitoring of Senegalese road networks.	Coefficient according to the climate zone (increase or decrease in total thickness)
Reference temperature	30°C	Not specified, but the structure information sheets are divided into dry and humid regions	Not specified, but 4 climate zones are defined in the catalogue	Not specified, but 3 climate zones are defined in the catalogue	34°C	Not specified, but the climate zone is taken into account when defining the total pavement thickness.

A comparative analysis of eight methods (for all guides and catalogues), applied to the same reference case where possible, is also provided. This comparison is shown in Figure 12.

Figure 12 : Summary of examples of application: Eight methods/guides/catalogues - Structure 5BB/8AB3/15GNT/PF2



This literature review highlights recommendations that emphasise the importance of understanding the actual behaviour of road materials to extend the lifespan of road structures. Regardless of the design method, local experience remains essential, as does

the regular revision of these models to incorporate observations from the field and the behaviour of new materials (modified binders, reclaimed asphalt pavement, warm-mix asphalt, cold-mix asphalt, etc.).

For more information:

Report reference	Report title
DVDC/R/010	Etude expérimentale sur le comportement élastoplastique du matériau granulaire de Bréfauchet à différents états hydriques initiaux (Experimental study on the elastoplastic behaviour of Bréfauchet granular material in different initial moisture conditions)
DVDC/R/016	Synthèse des méthodes de dimensionnement de chaussées souples / routes non revêtues à l'international (Summary of international design methods for flexible pavements/unpaved roads)
DVDC/R/045	Etude de l'incidence du comportement réel de matériaux non liés (GNT et sols) sur le dimensionnement des chaussées à faible trafic (Study of the impact of the actual behaviour of granular materials (UGM and soils) on the design of low-traffic pavements)

2.2 - Tools for road engineering

2.2.1 - New methodology for characterising the degree of layer bonding in situ

The bonding of layer interfaces has long been incorporated, in a simplified form, into widely-used design models; layer debonding is a recognised and frequently cited mechanism of damage but can be very difficult to assess physically using a representative test. A European testing standard, EN 12697-48,

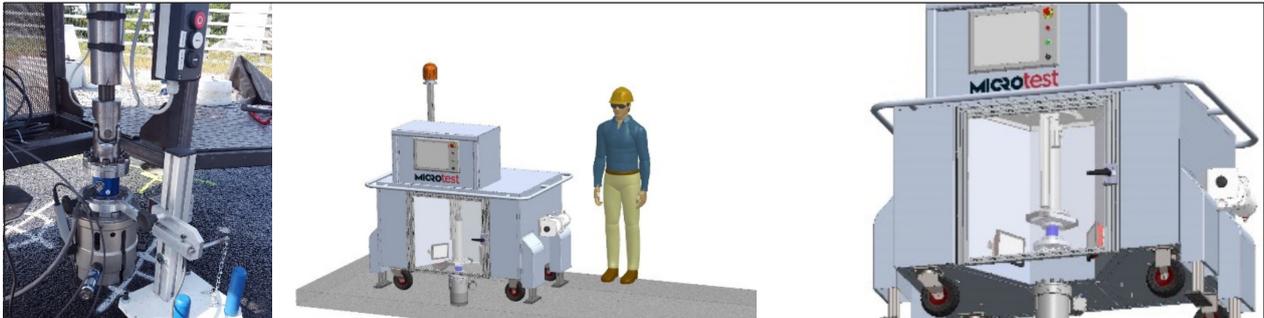
under consideration from 2011 and validated in 2021, has proposed various tests (mainly laboratory-based), but, as yet, none have achieved widespread consensus.

The national project focused on developing a new in-situ test to determine different degrees of layer bonding. This work began with an initial prototype developed by Pérennise Chaussée, which assesses the interface between two asphalt mixes using a controlled torsion test (torque control in N.m/s), which is more reliable than a screwdriver or torque wrench. Improvements were made to this initial tool through laboratory experiments on known and controlled structures (SCAS 010 on AB0/10 with pure or modified bitumen emulsion), at set temperatures (10, 20, and 30°C), and reliable test conditions were defined. Tests conducted on various work sites, under varied climatic conditions, also informed and enhanced this analysis. Controlling the temperature during tests in the field remains crucial, and a procedure has been proposed to achieve this control, while not completely resolving the issue.

It should be noted that the test is not necessarily destructive and can determine whether the degree of bonding is satisfactory, without causing fracture. Based on the first prototype (Figure 13) and the promising experiments carried out, specifications were drafted, and the initial results were presented at a seminar open to industry professionals (RGRA article).

At the same time, a survey was conducted among Laboroute-accredited laboratories on this measurement device. In both cases, there was genuine interest in this type of field test, given the moderate cost of the equipment, its ergonomic design, and the speed of execution on work sites with heavy traffic. Following consultation with various equipment design companies, a solution was validated in line with the specifications. While the definition of threshold specifications for layer bonding is still in its early stages, this work has led to progress and clarifies the position in France on interface assessment. It also marks a major step forward that requires further development.

Figure 13 : Details of the DVDC GT1.3 torsion prototype on the fatigue testing carousel in Nantes (Source: Colas) and model of the finished device proposed by Proviteq/Microtest.



Alongside these tests, a theoretical approach was adopted to estimate fatigue resistance of the interface bonded in situ, based on its shear strength via a monotonic torsional shear test. The complexity of

these phenomena and the need for numerous assumptions mean that sufficiently reliable values cannot be obtained and data from many additional tests is required.

For more information:

Report reference	Report title
DVDC/R/014	Vers une caractérisation performantielle in situ des interfaces des couches de surface (Developing in-situ performance characterisation of surface course interfaces)
DVDC/R/017	Evaluation du dispositif de mesure de collage des couches d'enrobés in situ par torsion (Evaluation of a device for the in-situ torsional measurement of the bonding of asphalt layers)
DVDC/R/030	Vers une caractérisation performantielle, in situ, des interfaces des couches de surface - Evaluation du dispositif de mesure de collage des couches d'enrobés in situ par torsion (Developing in-situ performance characterisation of surface course interfaces - Evaluation of a device for in situ torsional measurement of the bonding of asphalt layers)
DVDC/R/034	Collage des couches d'enrobés - Elaboration d'un seuil de rupture pour essai in situ en cisaillement (Bonding of asphalt layers - Development of a fracture threshold for in-situ shear testing)
DVDC/R/042	Vers une caractérisation performantielle, in situ, des interfaces des couches de surface (Developing in-situ performance characterisation of surface course interfaces)

2.2.2 - Finite element model of the various defects in a structure that affect deflection basins

Pavement monitoring plays a crucial role in effective infrastructure management. However, field observations must still be linked to the actual condition of the structure.

To achieve this, the researchers decided to develop a finite element model, shown in Figure 14, incorporating the various structural defects that could affect deflection basins: debonding between layers; vertical cracking; and variations in thickness.

Figure 14 : Illustration of the finite element model's response to a road load.

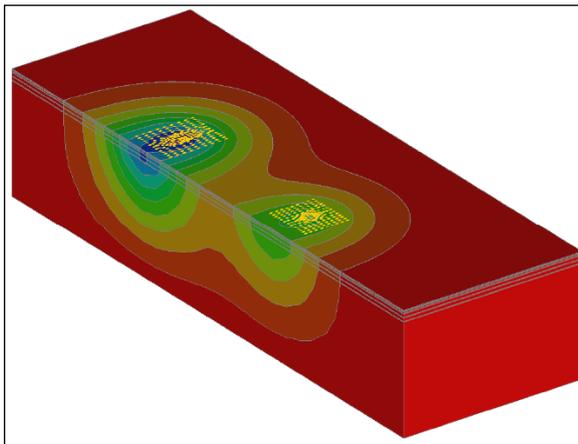
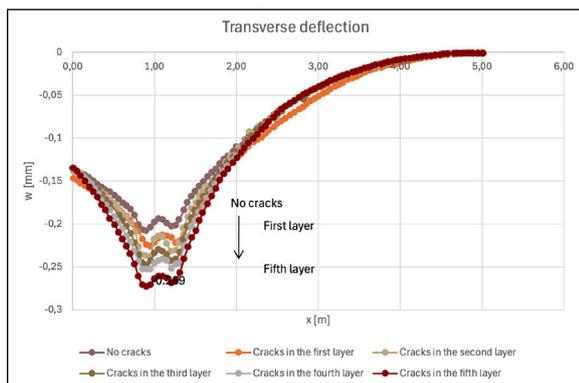


Figure 15 shows an elementary result of the model applied to a case of vertical cracking at different depths within the structure.

Figure 15 : Example of the impact on transverse deflection of a vertical crack at different depths



The main findings of this study were as follows:

- With vertical longitudinal cracks, the deeper the cracked layer, the greater the impact on the deflection basin. The longitudinal deflection measured using a curviameter-type calculation follows this trend. The impact of these trends is significantly greater with long longitudinal cracks.
- The maximum relative deflection (comparison of cracked/non-cracked) obtained from a theoretical longitudinal measurement (finite element analysis) or estimated using a curviameter-type calculation is identical for flexible pavements (CS1 or CS2), with little relative difference (less than 10%), confirming that this device is not particularly suitable for this type of structure and measurement. If the slope of the deflection basin is calculated with measurement intervals of 0.1 m, these discontinuities can be detected due to the contrast in stiffness. With this type of pavement, the maximum relative deflections tend to be consistently similar across the thickness of these structures. The highest maximum relative deflection levels are approximately 3.5/100 mm, at the limit of detectability.
- The maximum relative deflection for the thick bituminous pavement assessed fluctuates in the same way for both finite element simulation and curviameter calculations. The variation in the maximum relative deflection is greater when estimated using the curviameter calculation. The maximum relative deflection levels reach a maximum of 4.4/100 mm for the deepest layers, and thus a detectable value.
- The comparison carried out shows a curviameter calculation is sensitive enough to produce an absolute deflection basin value with a relative difference of 33% compared to the uncracked structure.

This study aims to support diagnosis after monitoring operations have been carried out. It could be used by engineering firms or contracting authorities. In the longer term, this research could inform the "structure" part of a pavement structure's digital twin, as well as the material aspects.

This work can also be used for reference cases within the industry.

For more information:

Report reference	Report title
DVDC/R/005	Evaluation de la durée de vie résiduelle des chaussées. Modèles de dégradation des structures (Assessment of the residual life of pavements. Structural deterioration models)

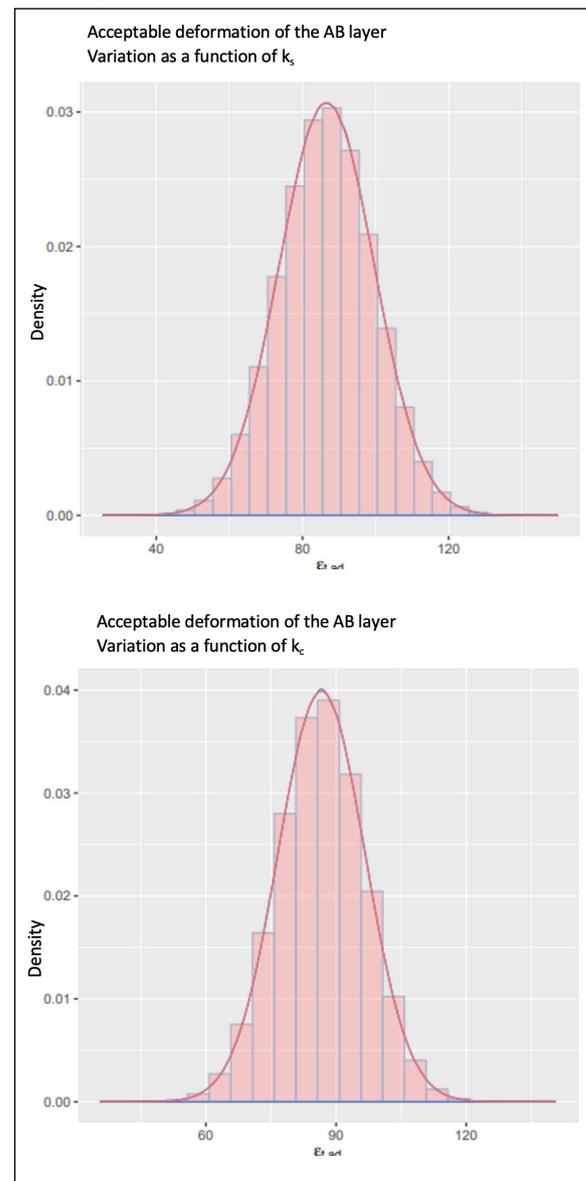
2.3 - Developing enhanced mechanical models

2.3.1 - Statistical modelling combining the physical mechanisms of pavement deterioration

This preliminary work has laid the groundwork for applying statistical approaches to current design methods. This scientific work takes into account:

- Variability in road maintenance data, using two different approaches in particular: mixed non-linear regression and machine learning models.
- Variability in pavement structure design (illustrated with a design parameter – Figure 16)
 - This study highlights the varying impact of three design model parameters: dispersion over the thickness of a layer and the k_s and k_c coefficients selected by the researcher.
 - It also demonstrates the variability observed in stress values when probability distributions are assigned to certain input parameters of the model. The final question to be addressed is the impact of variability on layer thickness, as recommended by the French Design Guide.

Figure 16 : Illustration of a coupled probabilistic mechanical model applied to the description of AB (Asphalt Base) deformation as a function of the variation in design parameters (k_c and k_s)



While this work is not yet complete, it provides the source codes needed for further research, combining the capabilities of probabilistic analysis with mechanical tools such as the Alizé model's computational core.

For more information:

Report reference	Report title
DVDC/R/006	<p>Evaluation de la durée de vie résiduelle des chaussées. Aspects probabilistes - Etat de l'art</p> <p>(Assessment of the residual life of pavements. Probabilistic aspects - State-of-the-art techniques)</p>

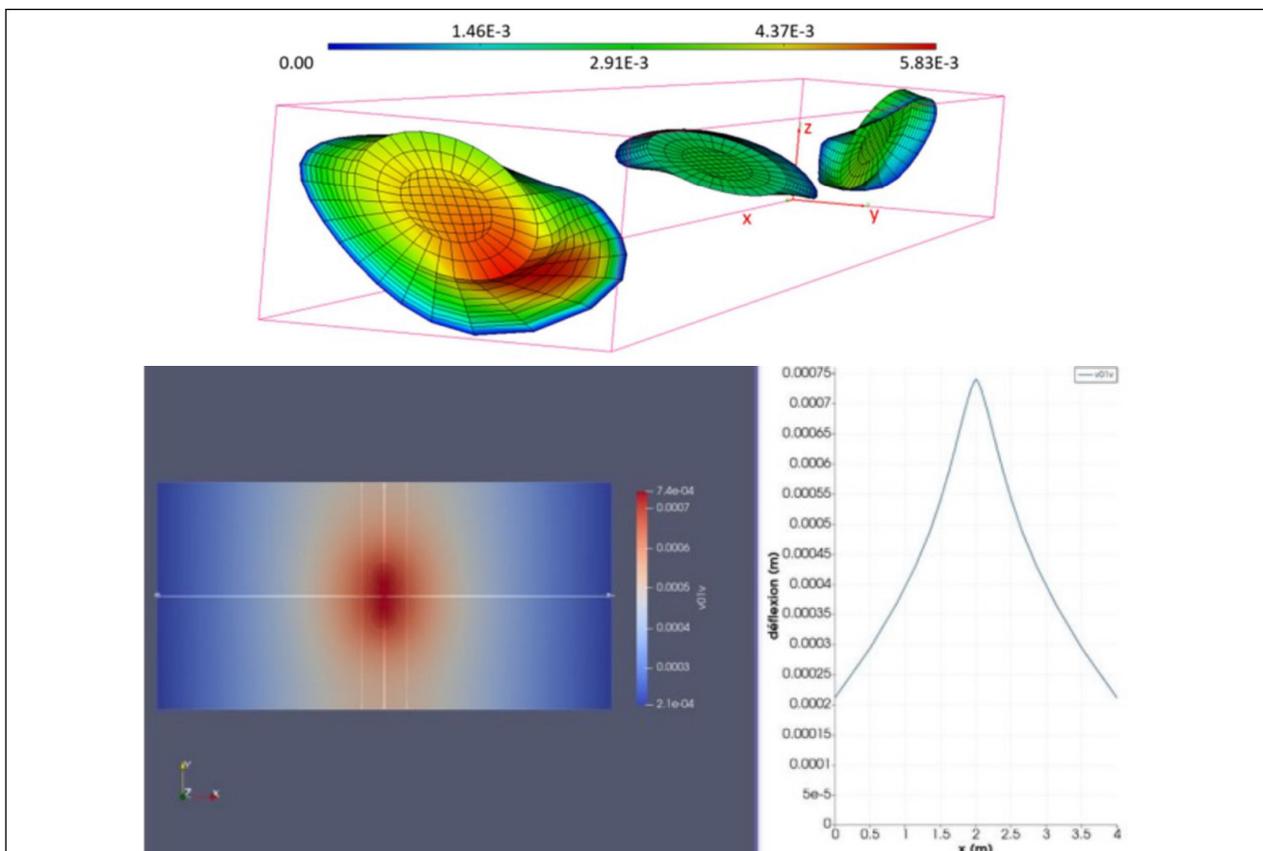
2.3.2 - Mechanical modelling incorporating the mechanisms of crack formation and propagation

A pavement structure deteriorates over time, with cracks and interface debonding among the most common defects.

To account for these flaws in pavement design tools, engineers use penalty methods (flat-rate reductions) to assess the performance of damaged layers. The aim is to adopt realistic assumptions with the resources available to prescribe the best maintenance solutions.

Two research teams have been working to develop digital tools that use physical, rather than flat-rate methods, to assess cracks in the pavement structure (illustrations shown in Figure 17). The research carried out by INSA Strasbourg was also based on the SOL-DUGRI project.

Figure 17 : Illustration of two mechanical models incorporating crack formation and propagation mechanisms – top: automated propagation of a crack in a pavement structure – bottom: comparison of a model incorporating deflection using a FABAC accelerated traffic simulator.



For more information :

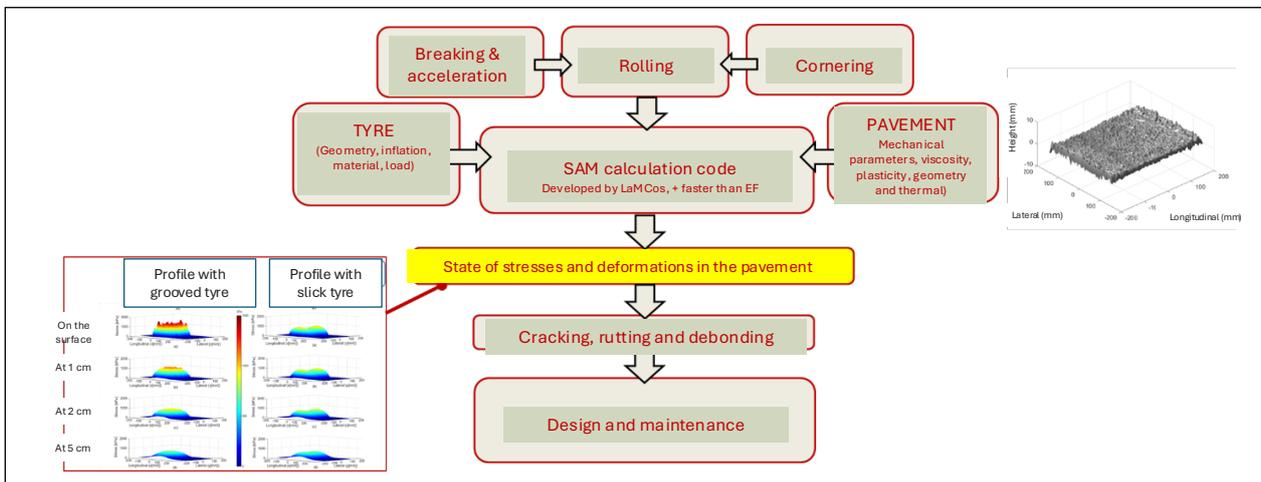
Report reference	Report title
DVDC/R/020	Modèles probabilistes de dimensionnement des chaussées (Probabilistic models for pavement design)
DVDC/R/026	Evaluation de la durée de vie résiduelle des chaussées - Modèles de dégradation des structures (Assessment of the residual life of pavements - Structural deterioration models)
DVDC/R/029	Modélisation numérique 3D de l'endommagement des chaussées par modèle M4-5n : fissuration & décollements d'interface (Digital 3D modelling of pavement damage using the M4-5n model: cracking and interface debonding)
DVDC/R/035	Evaluation de la durée de vie résiduelle des chaussées - Modèles de dégradation des structures (compléments) (Assessment of the residual life of pavements - Structural deterioration models (supplements))

2.3.3 - Mechanical modelling incorporating tyre-pavement contact (tribology)

Among the pathologies seen on pavement structures, in addition to the well-documented issues of bottom-up cracking and rutting, downward or “top-down” cracking is now being observed.

Researchers at the University of Limoges have proposed a mechanical approach based on models from contact science (tribology) to study this pathology. This original approach is based on an ANR (MA-CADAM) project that predates the DVDC project. Its development was primarily based on combining the various techniques shown in Figure 18.

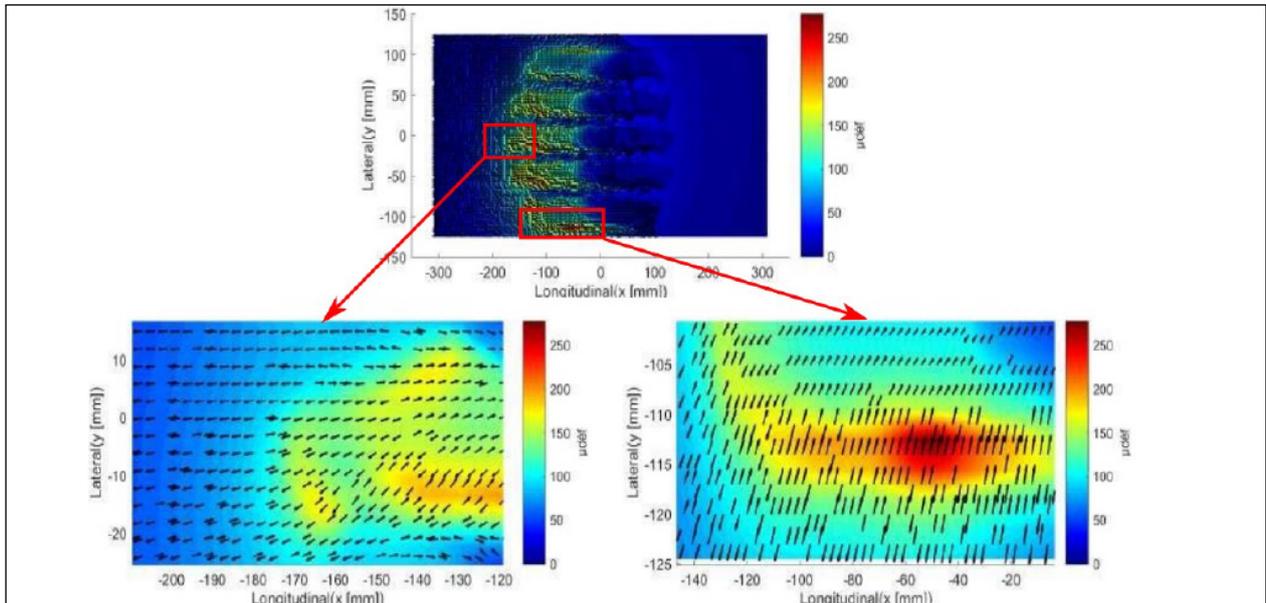
Figure 18 : Tribological approach applied to pavement surface deterioration: an overview of the experimental and digital techniques used.



This approach incorporates surface description (texture) and is used to create local and heterogeneous stress maps that could be linked to surface course deterioration mechanisms in the future, by also integrating horizontal forces related to vehicle acceleration and braking (Figure 19) – factors that are completely overlooked by current tools.

This work has demonstrated that this highly-accurate methodology identifies more significant stresses and deformation than those assessed through conventional methods (particularly Alize). This could explain the premature deterioration observed, especially in areas of frequent acceleration, braking, and cornering. This research will likely inform future work, leading to the development of a rational method for designing surface courses.

Figure 19 : Principal surface extension directions ($z = 0$) for a wheel in a turn (drive wheel condition in a turn, $F_x = 15$ kN; $F_y = 5$ kN)



For more information:

Report reference	Report title
DVDC/R/007	Approche tribologique du contact pneu-chaussée (Tribological approach to tyre-pavement contact)
DVDC/R/037	Approche tribologique du contact pneu-chaussée (complément) (Tribological approach to tyre-pavement contact (supplement))

3 - FOCUS ON PAVEMENT MATERIALS

In terms of “materials”, the study conducted at INSA Strasbourg on the elastoplastic behaviour of a type of UGM with different moisture contents has laid the groundwork for greater emphasis on “humidity” in flexible structures. Experiments, based on the repeated load triaxial test (RLT) in particular, have demonstrated that permanent deformation is highly dependent on water content.

Various field observations have highlighted that water and freeze-thaw cycles in winter cause significant damage to certain types of asphalt mix. These obser-

vations have been documented by the administration for the national road network and summarised in an IDRRIM report outlining recommendations on formulation and application.

A doctoral thesis supported by the ENTPE (Graduate School of Civil, Environmental and Urban Engineering) demonstrated the impact of water saturation of asphalt mixes during freeze-thaw cycles on the complex modulus, fatigue, and restrained-shrinkage testing.

3.1 - MOVEDVDC Project

Assessing road lifespan also requires knowledge of the residual mechanical performance of bituminous materials in base courses and their evolution over time. This subject was addressed by the MOVEDVDC (Modelling of Ageing and Damage for Pavement Lifetime Assessment) project, an initiative linked to the national DVDC project and supported by the ANR (French National Research Agency).

The maintenance of road infrastructure presents a major socio-economic challenge, particularly at a time when network managers’ budgets are increasingly tight. To optimise maintenance of this infrastructure, monitoring and diagnosis methods must provide the most reliable estimations possible of the extent of pavement ageing and its residual life.

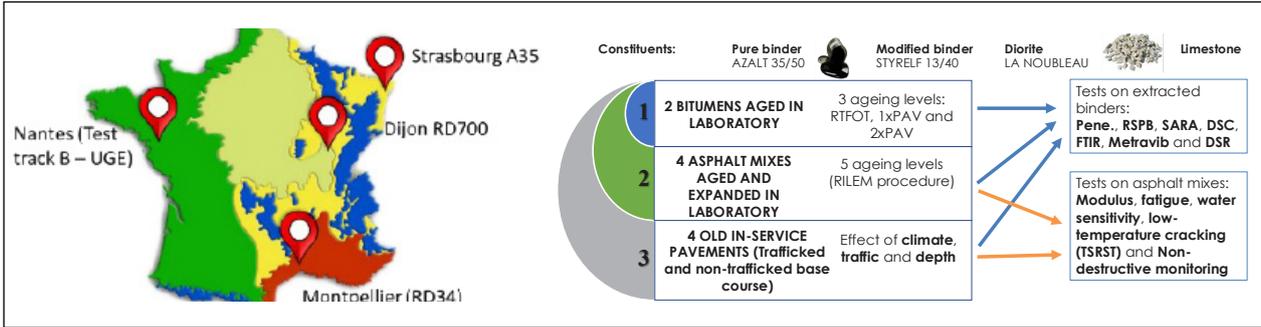
The MOVEDVDC project aimed to meet this objective, by studying the residual mechanical performance of bituminous materials in base courses and their evolution over time—two essential factors for estimating the residual life of pavements and defining maintenance solutions. Its objectives included the following:

- propose a method for evaluating the ageing and damage of materials sampled on-site, based on the mechanical characterisation of asphalt mixes and the mechanical and physicochemical characterisation of extracted binders.
- define practical ageing indicators for assessing the residual life of materials.
- propose models for predicting the behaviour of older materials (moduli, fatigue strength) and then calculating road lifespan.

The MOVEDVDC project’s approach to studying the extent of ageing in bituminous materials involved a combination of:

- Tests on materials sampled from older pavements. To this end, four pavement sites were selected of approximately 20 years old with signs of moderate damage.
- Tests conducted on binders and asphalt mixes that were artificially aged in the laboratory (with various levels of ageing).

Figure 20 : Material sampling sites and experimental program



A comprehensive testing program was performed on the extracted asphalt mixes and binders:

- The binders were characterised via physicochemical tests (infrared spectroscopy, SARA fractions, simulated distillation) and rheological tests (complex modulus)
- The asphalt mixes were characterised via mechanical tests: Complex modulus, fatigue, low-temperature cracking, and water sensitivity tests.

Based on these tests, laws on the evolution of physicochemical and mechanical properties in relation to ageing levels were established. Binder ageing indicators were also proposed. In particular, an indicator based on the rheological behaviour of binders, which defines an apparent molecular mass distribution of a binder (Molecular Agglomeration Index, or MAI), was proposed. This indicator can be used to better assess the risk of binder cracking.

Original testing methods, combining mechanical tests (fatigue, low-temperature cracking) and acoustic emission measurements, were also proposed to better assess damage of asphalt mixes during testing.

Finally, an original behavioural model for bituminous mixtures has been developed, which takes into account viscoelastic behaviour and fatigue damage, as well as biasing effects (self-heating, non-linearity, thixotropy), and ageing effects.

Main results:

- A database of experimental results on binders and asphalt mixes aged in the laboratory, and binders and asphalt mixes sampled from road sites. This database includes 58 binder variants, characterised by physicochemical and rheological tests, and 18 asphalt mix variants, characterised via modulus, fatigue, resistance to low-temperature cracking, and water sensitivity tests. These results are unique because they relate to base course materials (all AB3 mixes), whose ageing process is poorly understood, and because they enable a comparison between materials with similar formulations aged in the laboratory (with at least four ageing levels) and those sampled from road surfaces. This database provides very comprehensive information on the ageing of these AB3 mixes and also has other applications.
- Various indicators proposed for characterising binder ageing. This study demonstrated the relevance of conventional indicators based on physicochemical properties (carbonyl and sulfoxide indices) and rheology (Glower-Rowe parameter). More importantly, it highlighted the value of the delta method, used to characterise the molecular distribution of asphalt mix, which is highly sensitive to ageing, through rheological data. The Molecular Agglomeration Index (MAI) indicator, which is based on this molecular distribution, was proposed.

Figure 21 : Calculation principle for the “Molecular Agglomeration Index (MAI)” and changes in the MAI according to the level of ageing (number of days aged at 85 °C)

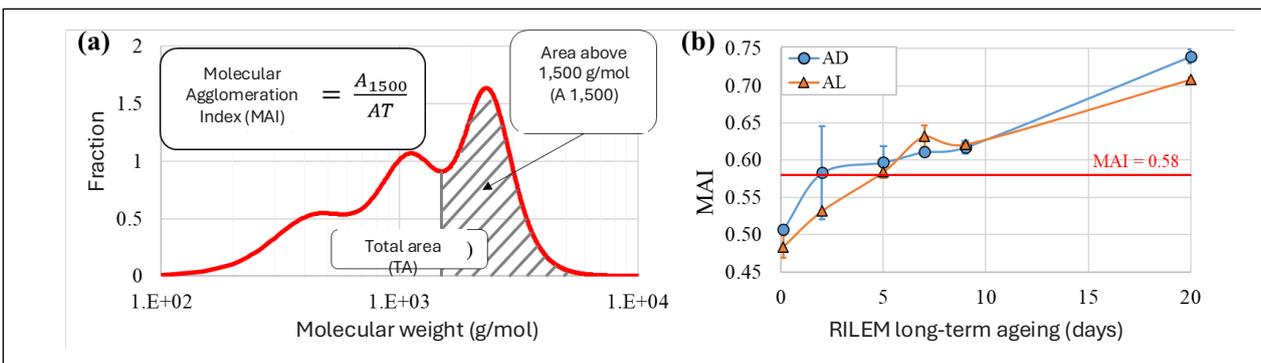
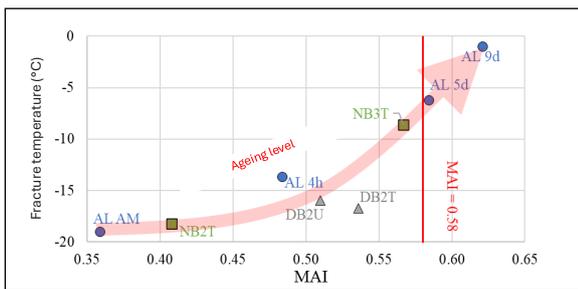


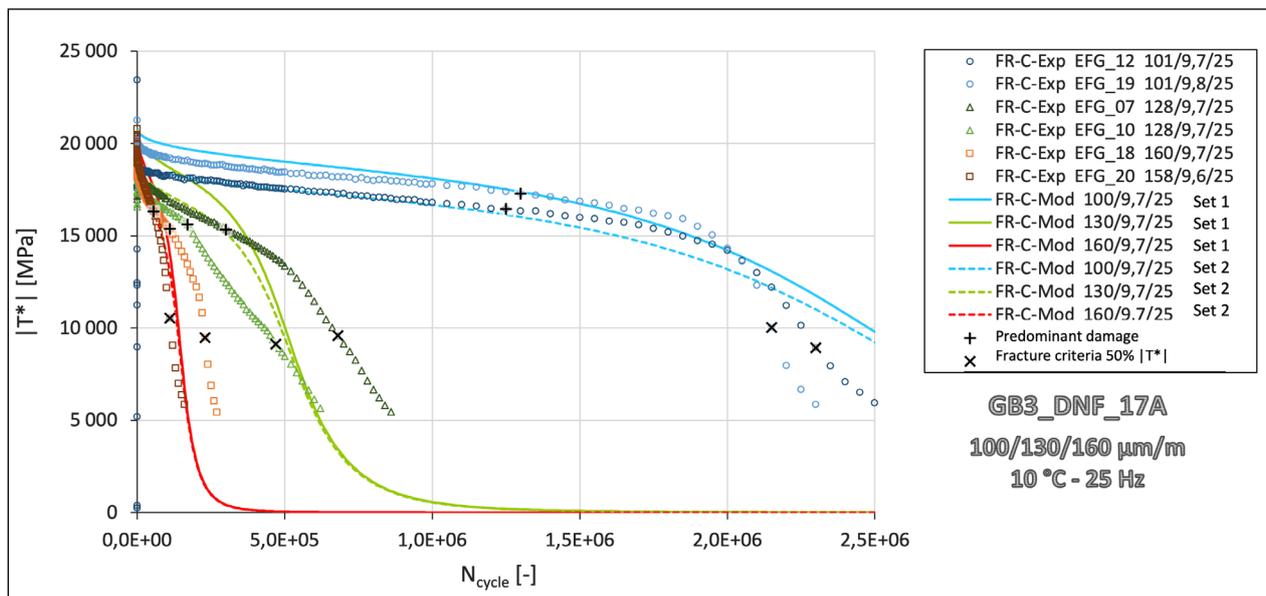
Figure 22 : Relationship between the fraction temperature of the TSRST test and the MAI index of the binder



- The calculation based on the delta method and the determination of the MAI were integrated into the Viscoanalyse software, initially designed for determining and modelling master curves for bitumen and asphalt mixes. A free, online version of Viscoanalyse has been developed (<https://viscoanalyse-database.ifsttar.fr/>).
- For asphalt mixes, the effect of ageing on the various mechanical parameters has been clearly demonstrated: showing an increase in modulus and a decrease in phase angle with ageing; a relatively minor impact of ageing on the fatigue strength of ABs with a pure binder, but a much greater drop in performance with the modified binder. However, the effect of ageing was particularly evident in the TSRST tests, which showed a significant loss of resistance to low-temperature cracking (increased brittleness) with ageing.

- The sites used for sampling in the field were all high-traffic roads, of approximately 20 years old, with few signs of damage, except for the Montpellier site, where the pavement was heavily cracked. The base course materials sampled on-site (and the binders extracted from these materials) mostly showed signs of moderate ageing, which, for the binders, ranged between RTFOT and RTFOT +1 PAV. Only the materials from the Montpellier site showed much higher levels of ageing (similar to RTFOT + 2 PAV for the binder), associated with severe cracking.
- The Glover-Rowe criterion was adapted for asphalt mixes (G-Rm) to highlight changes in the rheological parameters of the asphalt mixes (modulus, phase angle) with ageing. For the ABs tested (aged in the lab or on-site), with the same 35/50 bitumen grades, ageing was shown to cause very similar changes in the rheological characteristics, except for certain materials sampled on-site that also showed signs of significant damage caused by traffic (as in the case of the Montpellier site). Provide the E-fatigue results for the samples.
- For asphalt mixes, methods of acoustic emission measurement could be useful for improving the analysis of damage progression during testing and defining more relevant fatigue fracture criteria.
- For modelling the behaviour of aged asphalt mixes, Leo Coulon's thesis proposes an original VENOL model, which takes into account both the viscoelastic behaviour and fatigue damage of asphalt mixes, as well as their evolution with ageing. Based on a discrete element analysis code, it can be applied to various types of laboratory tests and could potentially be used in structural calculations.

Figure 23 : Calibration of the VENOL model for fatigue tests performed on the AB subbase course of the Dijon site – the curve legend 101/9.7/25 corresponds to 128 $\mu\text{m}/\text{m}$ 9.7°C/25 Hs.



MOVE DVDC project summary:

The MOVEDVDC project achieved its objectives in terms of experimental studies. It defined a methodology for material ageing and characterisation tests for aged materials, both in the laboratory and on-site. In particular, it demonstrated the value of the phase angle master curve and the delta method for analysing aged binders. For analysing older asphalt mixes, it demonstrated the effectiveness of restrained shrinkage tests, and acoustic emission measurements coupled with fatigue tests. These test methods clearly have potential for characterising aged asphalt mixes and binders, as well as recycled asphalt mixes that comprise these aged materials. For example, including low-temperature cracking tests in asphalt mix design methods appears particularly useful. Another potential use could be for improving the fatigue life criteria for asphalt mixes.

The project also led to a better understanding of how the characteristics of binders and asphalt mixes in base courses evolve with age, particularly by testing the laboratory-aged materials at various stages. A detailed analysis of the binders was used to define relevant indicators for characterising ageing, such as the MAI (Maximum Ageing Index), as well as the Glover-Rowe criterion, which was not previously used in France. One limitation of these studies was that, due to the complexity of the experimental program, they only involved a limited number of materials (2 binders and 4 asphalt mixes aged in the laboratory, and 4 pavement sites). As a relevant methodology is available, it would be useful to expand these studies to include a greater number of materials (with both base course and wearing course materials). A database could therefore be created and feedback compiled on the ageing of different types of materials used in French pavements, with the definition of relevant performance thresholds for assessing the condition and residual life of older materials.

The development of a new, open-access, online version of the Viscoanalyse software for modelling complex modulus tests on binders and asphalt mixes, based on the delta method, and calculating the MAI index for binders, is a major deliverable of the project. It will facilitate the dissemination of these indicators and broaden their application (recycled materials, evaluation of the effectiveness of regenerative products for recycled asphalt mixes, etc.).

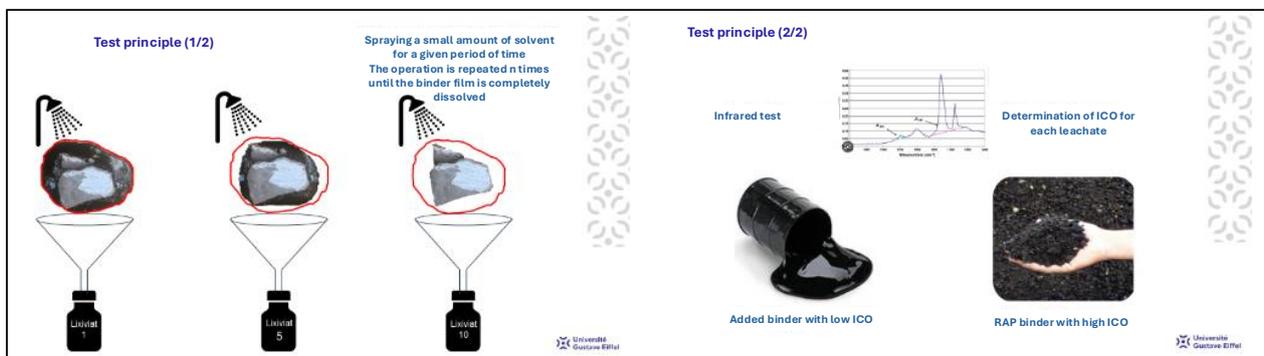
In terms of modelling, the VENOL model, which incorporates viscoelastic behaviour and fatigue, as well as accounting for biasing effects, is a valuable tool for characterising behaviour relating to fatigue. The potential future applications of this work include pavement structure calculations.

However, with regard to modelling, the project did not fully achieve its objective to develop a practical method for calculating the residual life of pavements. The experimental phase was significantly delayed by the COVID-19 pandemic, and the test programs could only be completed towards the end of the project. The potential of these results for calculating pavement lifespans could not be fully explored, and further work needs to be carried out in this field. Developing such a method for calculating residual life also requires expanding the experimental study to include a larger number of materials, as previously stated.

3.2 - Durability of wearing courses

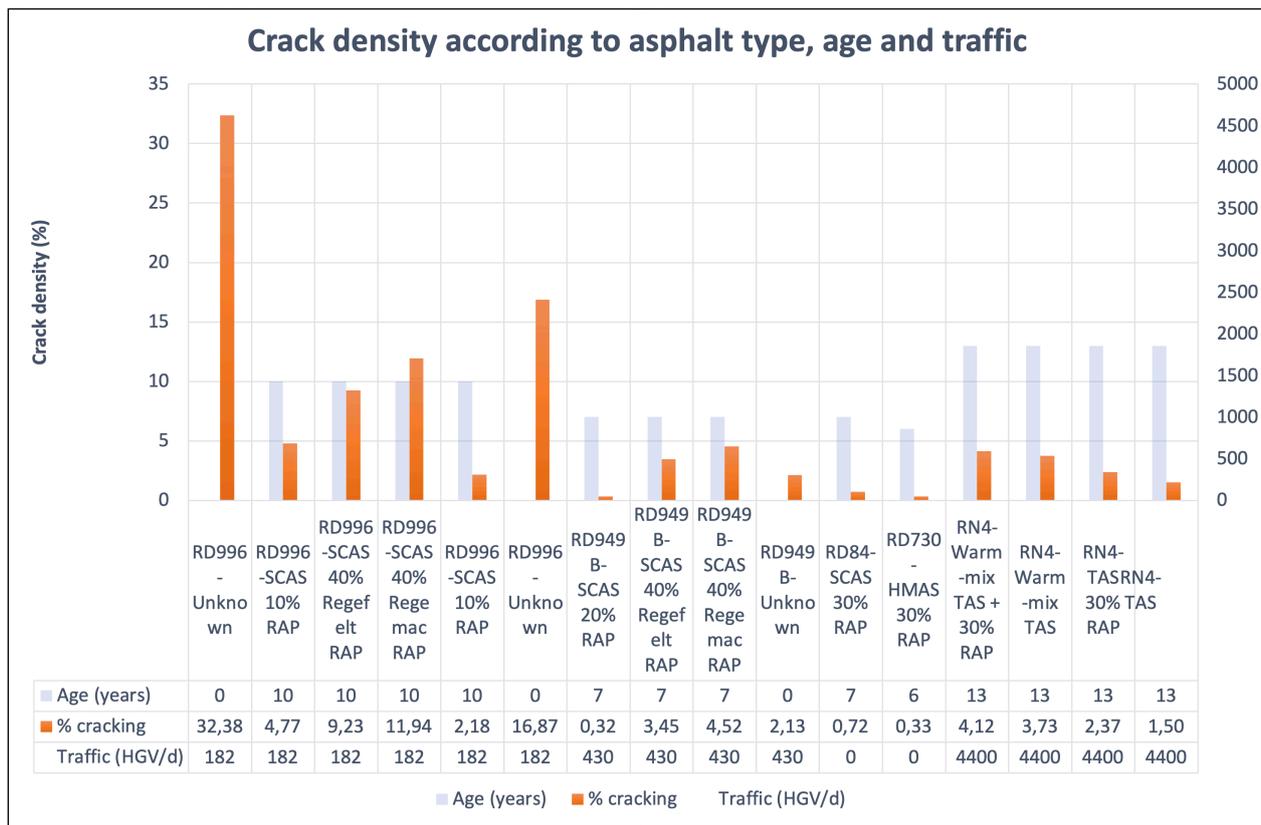
A working group of the national DVDC project focused more specifically on asphalt wearing courses with and without Reclaimed Asphalt Pavement (RAP). The approach used field diagnosis techniques including laser imaging and sequential stripping to assess the mixture of original and added bitumen.

Figure 24 : Illustration of the sequential stripping test



This research builds on the work produced by the national MURE project and demonstrates that the RAP bitumen and the added bitumen are highly compatible. In addition, very few cracks were found on the sections analysed.

Figure 25 : Summary graph of crack densities observed on the project sections



Network managers and road companies are aware of the following principles regarding the durability of asphalt mixes: not to use bitumen from the mix that is too hard, and not to overheat the asphalt mix, as both of these actions can cause top-down cracking.

For more information:

Report reference	Report title
DVDC/R/039	Elaboration d'une méthodologie de traitement de données dans le cadre de l'étude de la durabilité des couches de surface (Development of a data processing methodology for assessing the durability of surface courses)
DVDC/R/046	Application méthodologie de traitement de données dans le cadre de l'étude de la durabilité des couches de surface (Application of a data processing methodology for assessing the durability of surface courses)

GENERAL CONCLUSION

In conclusion, the national DVDC project, which involved a large number of industry stakeholders, has been a success. Through this collaborative work, it has drawn on a wealth of expertise and resources to help achieve the ambitious goal of extending pavement lifespan by gaining a better understanding of its condition and ageing process, in short: by performing maintenance operations in the right place at the right time.

This offers many advantages for the industry, both in terms of the high-quality and innovative studies conducted, and the tangible results produced. These

exchanges have also helped forge ties between the various stakeholders, and build a shared vision for the future. We hope that everyone who reads this summary, divided into three focus areas (road networks, pavement structure, and pavement materials), will find these various subjects of interest.

This project has contributed to the development of a sustainable and expert framework for the management of road infrastructure.

LIST OF DVDC REPORTS

Report reference	Report title
DVDC/R/001	Lorino T. Modèles d'évolution des chaussées (Modelling the evolution of pavement surface characteristics), p. 32, 2017.
DVDC/R/002	Bolot B., Brandely F., Espinasse B., Grin L., Kobisch R., Marchand J.-P., Odéon H., Périssé L. Retour d'expérience sur les mécanismes de dégradation des chaussées : Questionnaire (Feedback on pavement deterioration mechanisms: Questionnaire), p. 27, 2017.
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DVDC/R/004	Abdo J., Marchand J.-L., Pero F. Durée de vie résiduelle des chaussées semirigides, mixtes et en béton de ciment (Residual life of semi-rigid, composite, and cement concrete pavements), p. 24, 2017.
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DVDC/R/007	Manyo E., Petit C., Picoux B., Reynaud P. Approche tribologique du contact pneu-chaussée (Tribological approach to tyre-road contact), p. 28, 2018.
DVDC/R/008	Martin J.-M., Théret S. MIRANDA : mesure d'indicateurs routiers automatisée par appareils nomades d'auscultation : Expérimentation dans l'Eure (CD27) (MIRANDA: Automated Measurement of road indicators using mobile monitoring devices: Experimentation in the Eure (CD27)), p. 25, 2018.
DVDC/R/009	Tran D.-T., Sauzéat C., Di Benedetto H. Étude bibliographique sur l'endommagement des enrobés bitumineux à l'eau et au gel (Literature review on the damage to bituminous mixtures caused by water and frost), p. 40, 2018.
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DVDC/R/012	Varga A.-M., Lepert P. Etude sur les indices structurels (Study on structural indices), p. 22, 2018.
DVDC/R/013	George L.-A., Maignol J., Wasner S. Retours d'expérience sur la connaissance de l'état d'un réseau routier (Feedback on knowledge of the condition of a road network), p. 15, 2018.
DVDC/R/014	Dony A., Koutiri I, Godard E., Pouteau B., Millien A., Ollier S. Vers une caractérisation performantielle in situ des interfaces des couches de surface (Developing in-situ performance characterisation of surface course interfaces), p. 39, 2018.

Report reference	Report title
DVDC/R/015	Maignol J., George L.-A., Wasner S., Sagnier F., Péjouan H. Actualisation de la méthode (Update of method 38-2), p. 24, 2018.
DVDC/R/016	Varga A., Maillard-Nunes P. Synthèse des méthodes de dimensionnement de chaussées souples / routes non revêtues à l'international (Summary of international design methods for flexible pavements/unpaved roads), p. 93 , + Appendices, 2020.
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DVDC/R/018A	Tran D.-T., Sauzéat C., Di Benedetto H. Endommagement des enrobés bitumineux à l'eau et au gel. Présentation de la campagne expérimentale et premiers résultats (Damage to bituminous mixtures caused by water and frost. Presentation of the experimental campaign and initial results), p. 67, 2019.
DVDC/R/018B	Tran D.-T., Sauzeat C., Di Benedetto H. Endommagement des enrobés bitumineux à l'eau et au gel. Présentation de la campagne expérimentale et premiers résultats. ANNEXES (Damage to bituminous mixtures caused by water and frost. Presentation of the experimental campaign and initial results. APPENDICES), p. 82, 2019.
DVDC/R/019	Bolot B., Brandely F., Espinasse B., Grin L., Kobisch R., Marchand J-P., Odéon H., Périssé L. Retour d'expérience sur les mécanismes de dégradation des chaussées : Questionnaire complémentaire adressé aux conseils départementaux et projet pour les métropoles (Feedback on pavement deterioration mechanisms: Supplementary questionnaire sent to departmental councils and project on metropolitan areas), p. 25, 2019.
DVDC/R/020	Lorino T. Modèles probabilistes de dimensionnement des chaussées (Probabilistic models for pavement design), p. 32, 2020.
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DVDC/R/027	Abdo J., Marchand J.-P., Pero F. Durée de vie des chaussées en béton de ciment (Residual life of semi-rigid, composite, and cement concrete pavements), p. 44, 2020.

Report reference	Report title
DVDC/R/028	Bolot B., Brandely F., Espinasse B., Grin L., Kobisch R., Marchand J-P., Odéon H., Périsset L. Retour d'expérience sur les mécanismes de dégradation des chaussées : Questionnaire complémentaire adressé aux conseils départementaux et projet pour les métropoles - Mise à jour (Feedback on pavement deterioration mechanisms: Supplementary questionnaire sent to departmental councils and project on metropolitan areas – Update), p. 35, 2019.
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DVDC/R/030	Dony A., Barrière P., Ollier S., Brissaud L., Godard E. Vers une caractérisation performantielle, in situ, des interfaces des couches de surface - Evaluation du dispositif de mesure de collage des couches d'enrobés in situ par torsion (Developing in-situ performance characterisation of surface course interfaces - Evaluation of a device for in situ torsional measurement of the bonding of asphalt layers), p. 27, 2020.
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DVDC/R/033	Trottier P., Joly B., Maignol J., Martin J.M., Pilet D., Degrange R., Loison E., Hebling A., Theret S. Mesures de Déflexions à grand rendement (High-accuracy deflection measurements), p. 19, 2022.
DVDC/R/034	Masdan M., Pouteau B. Collage des couches d'enrobés - Elaboration d'un seuil de rupture pour essai in situ en cisaillement (Bonding of asphalt layers - Development of a fracture threshold for in-situ shear testing), p. 15, 2022.
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DVDC/R/039	Barras M., Druet J. Elaboration d'une méthodologie de traitement de données dans le cadre de l'étude de la durabilité des couches de surface (Development of a data processing methodology for assessing the durability of surface courses), p. 40 + Appendices, 2019.

Report reference	Report title
DVDC/R/040	Radde B., Joluy B., Ménand F., Guiraud H., Martin JM., Wasner S. Relevés automatisés – Application in situ des descripteurs dégradations (Automated surveys – in-situ application of deterioration descriptors), p. 24, 2023.
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DVDC/R/042	Barrière P., Leroy-Malloi F., Van Rompu J., Attias T., Pouteau B., Ollier S. (Vers une caractérisation performantielle, in situ, des interfaces des couches de surface) Developing in-situ performance characterisation of surface course interfaces, p. 20, 2023.
DVDC/R/043	Decamps J.-A., Dony A., Faucon-Dumont S., Mouillet V., Nicolai A., Quigniot S., Van Rompu J. Exploitation complémentaire des données de laboratoire du PN MURE (Additional use of laboratory data from the MURE National Project), p. 39, 2023.
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DVDC/R/045	Maillard Nunes P., Duca L. Étude de l'incidence du comportement réel des matériaux non liés (GNT et sols) sur le dimensionnement des chaussées à faible trafic (Study of the impact of the actual behaviour of unbound materials (UGM and soils) on the design of low-traffic pavements), p. 41, 2023.
DVDC/R/046	Druet J. Application d'une méthodologie de traitement de données dans le cadre de l'étude de la durabilité des couches de surface (Application of a data processing methodology for assessing the durability of surface courses), p. 97 + Appendices, 2024.
DVDC/R/047	Degrange R., Guiraud H., Joly B., Loison E., Maignol J., Pilet D., Wasner S. Relevés Automatisés. Contribution à l'élaboration d'un indicateur structurel (Automated surveys. Contribution to the development of a structural indicator), p. 26, 2024.
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DVDC/R/048B	Kempf Y., Feeser A., Lesbats D., Grignard N., Wasner S., Joly B., Radde B., Sagnier F., Maignol J., Pilet D., Degrange R. Essais croisés LCMS. Exploitation des relevés ASFA (Phase 2) (LCMS round-robin tests. Use of ASFA surveys (Phase 2)), p. 190, 2024.
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Report reference	Report title
DVDC/R/048D	Kempf Y., Feeser A., Lesbats A., Grignard. N, Wasner S., Joly B., Radde B., Sagnier F., Pilet D., N’guyen T.-S., Georges S. Essais croisés ASFA : livrable de synthèse (ASFA round-robin tests: summary report deliverable), p. 28, 2025.
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Specific information on the different versions of the summary report

The French version includes a compilation of the aforementioned deliverables.

The English and Spanish versions do not include a compilation of the deliverables.

All the deliverables listed are available on the National DVDC Project website: dvdc.fr