Non-destructive Diagnostic Methods for Smart Road Infrastructure Evaluation

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Abstract. Nowadays, high emphasis is placed on the efficient use of resources for optimum management of transport infrastructure. The use of non-destructive diagnostics is the main application for visualization and support of intelligent infrastructure models. Moreover, such models also have enormous potential to support the "smart city" concept. Disaster management, 3D cadaster, energy assessment, pavement performance, pollution monitoring and visibility analysis could benefit from regular pavement diagnostic and its surroundings. To demonstrate this potential, the authors present examples of non-destructive diagnostics on the roads in the Žilina region. As a result, the importance of using non-destructive diagnostics is highlighted, because of the potential for saving money and streamlining planning for smart city needs.

Keywords: Non-destructive diagnostic · Pavement performance · Smart City · Intelligent road infrastructure · ITS

1 Introduction

Intelligent transport processes cannot be carried out on the demanded level without being able to rely on a synergistic transport infrastructure. This means that we need to focus not only on innovation in transport technology, transport and logistics processes, but also on changing user behaviour, innovative planning and building processes. Current trends in the area of transport infrastructure for smart cities projects include e.g. development and implementation of technologies enabling the collection of selected technical, material, environmental and physical data on its current state. These are followed by technical and software solutions designed to determine the infrastructure's predictive status in order to optimize the management of traffic processes by the operator. Selected examples include solutions that work together to manage winter

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maintenance by monitoring the road temperature profile [1], the degradation status of asphalt pavement layers [2, 15] or innovations to improve the communication structure between smart application sensors [3] as well as tunnel safety enhancement features [4, 17] or overall optimization of transport processes in terms of economic context [16]. From the perspective of improving the quality of transport infrastructure elements, the trend is focused on activating the philosophy of the circular economy as a complement to the complex philosophy of Smart Cities. This is accompanied not only by the need to reuse the demolition and construction waste, but also by focusing on building parts with a longer lifespan. Emphasis is also placed on improving the quality of monitoring itself. Interesting solutions in this area include innovations in bridge object diagnostics procedures through mathematical modal analysis procedures [5], following the possibility of performing it in full operation. A concrete example of new bridge infrastructure solutions can also be found in [6] where preconditions for efficient functioning of precast concrete frames are presented.

2 Application of Approach of Non-destructive Diagnostics to Sustainable Pavement Management

The key resources for implementing the Smart City strategy are information and intelligent processing systems designed to ensure a stable link between individuals and knowledge. Smart urban construction can be supported by the benefits of new technologies that enable a stable interconnection in urban planning. One of the most reliable methods for collecting selected technical and physical road parameters is the use of non-destructive deformation diagnostics. Non-destructive diagnosis has two main advantages over destructive tests. First, destructive testing interferes with the underlying pavement or requires removal of materials, which are tested under laboratory conditions. However, in the case used to innovative technology to collect data it is indeed in-situ testing without undesirable damage to the road cover or possible modification. Another big advantage is fast road testing, in most cases without traffic restrictions or without traffic limitation and one ride can get large amounts of data to test the roadway from multiple perspectives at once [8] (Table 1).

Non-destructive diagnosis data combined with survey data, such as traffic flow composition or traffic intensity, are used to select the best alternative to maintenance and road renewal, which is a very important aspect on the way of sustainable transport and its benefits philosophy Smart City.

2.1 Data Collection with Lynx SG1

The Mobile Mapping System (MMS) enables contactless determination of spatial coordinates of points via sensors and associated evaluation software that are part of the vehicle. The mobile laser scanner is able to collect a huge number of points (point cloud) with minimal separation in a very short time. For field data collection, a mobile mapping device combines multiple technologies at the same time (LiDAR, Global Navigation Satellite System, Inertial Measurement Units and Distance Measurement Unit) [7, 11] (Fig. 1).

Table 1. Diagnostic device - Research Centre of University of Žilina

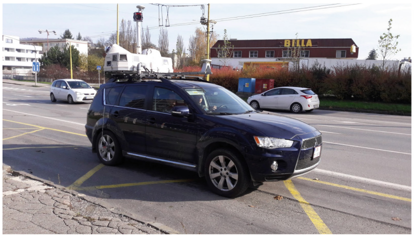
ROAD SCANNER_georadar: Is a diagnostic facility for collecting data on road and bridge faults by a non-destructive method using ground penetrating radar (GPR) technology. 	**DYNAMIC ROAD SCANNER (in developing)**: The instrument for measuring the transverse and longitudinal unevenness. 
3D scanner LYNX SG1: The Mobile Mapping System (MMS) allows contactless determination of spatial coordinates through sensors and the corresponding evaluation software that are part of the Lynx SG1. 	**Deflectometer FWD KUAB** : Impact Load Test - The goal is to simulate a truck crossing in the measured point. The resulting value is referred to as deflection. 

Fig. 1. Point cloud from experimental measurement of highway tunnel - Považský Chlmec 27. September 2017

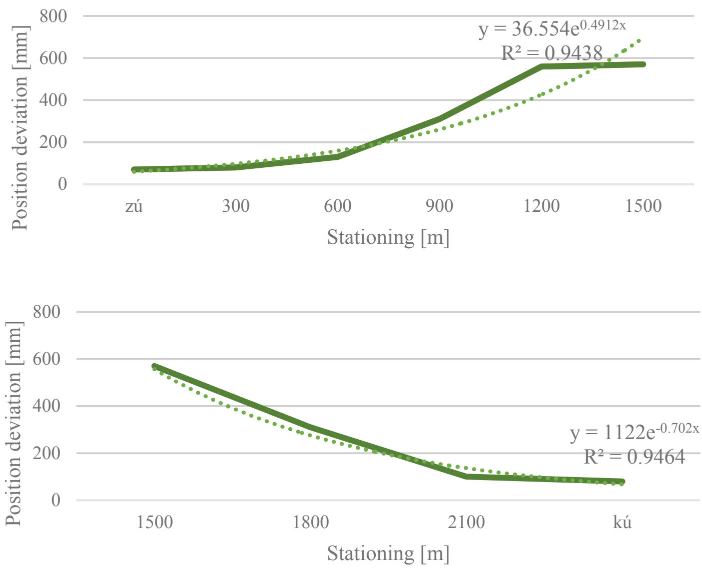


Fig. 2. Exponential accuracy of measurement at the reach of the GNNS signal – highway tunnel - Považský Chlmec 27. September 2017

Fig. 3. Example of 3D visualization with 3D Lynx SG1, which creates space for potential Smart City applications.

Terrasolid's Terrascan program has been used for *.las cloud point processing as an extension for MicroStation V8i. In order to obtain the clearest possible rendering, the first step is to classify the points, which consists of separating the individual objects (e.g. paths, sidewalks, lawns) and then removing unnecessary objects (e.g. cars, faulty objects). Points can be filtered by colour, reflected signal strength, altitude, and other criteria, and linked to groups with common attributes. Good point cloud classification is the basis for further analysis and work. After the drawing is created, the output can be exported to various standard CAD formats dgn, dwg, shp [9] (Fig. 2).

In this case, all data including vectorization is processed in the ETRS89 coordinate system. Finally, a.dgn drawing is created, which is transformed into the SJTSK system (Unified Trigonometric Network System) using a transformation service. This transformation allows the measured data to be located in the territory of the Slovak Republic and subsequently it is possible to work with such data also in the area of the real estate cadastre for support more sophistic urban planning [9] (Fig. 3).

Fig. 4. Location of mapped setting into cadastral map SR for support more sophistic urban planning.

2.2 Data Collection with Dynamic Road Scanner

Mobile high-capacity contactless measuring device for road surface profiles with the precision needed to determine the IRI index (Fig. 4).

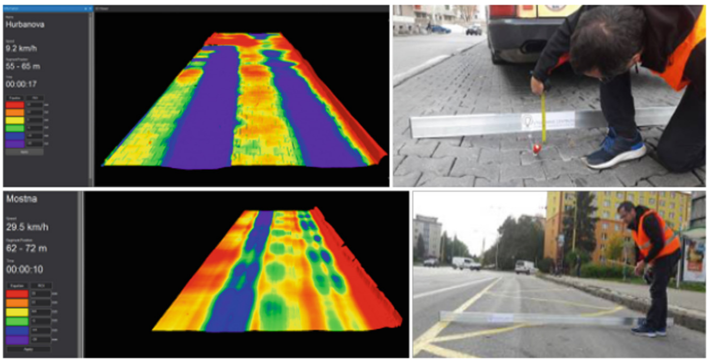


Fig. 5. Results of Dynamic Road Scanner measurements of Bus stop Hurbanova and Mostná in Žilina 17.10.2017 and standardized measurements according to STN EN 13036-7.

The device is able to measure road profiles while driving and is able to filter out the measuring beam oscillation based on gyroscopes and accelerometers. The data processing software provides both the raw height data of the measured profile x, y (*.txt) as well as the determination of IRI values based on the determined algorithm (Fig. 5).

2.3 Data Collection with Georadar

The principle of the georadar method consists of the repeated transmission of radio frequency electromagnetic pulse through transmitting antenna into the examined environment. In locations where the electromagnetic pulse change occurs, the reflection that receives the antenna takes place. It, therefore, shows different types of layers, material continuity disorders. The laser scan method is based on the laser beam time transmitted from the scanner to the measured surface and back from which the distance is calculated. Using a laser beam can be determined, for example, depth of the ruts [10].

Fig. 6. Evaluation of experimental measurement - depth of track depth.

In the Fig. 6, the authors present the results of experimental measurements that determine the depth of rutted tracks. Results from experimental measurements form the basis for assessing roadworthiness to optimize traffic infrastructure management.

2.4 Data Collection with FWD KUAB

Diagnostic devices - deflectometers work on the principle of in-situ impact loading test. The impact load test is one of the dynamic impulse methods, the aim of the method is to simulate the truck's passage at the measured point. When tested, a roadblock is applied to the road that is damped by a rubber pad and the change in impact load and deformation at the point and outside of the vertical direction, known as deflection [12].

The paper presents the results of the authors from the diagnostics of the newly built transport infrastructure, but also from the analysis of the long-term monitored sections in the Žilina region - road section Poluvsie - Porúbka Road 1/64, where the technical parameters were analysed and evaluated diagnostics (Fig. 7).

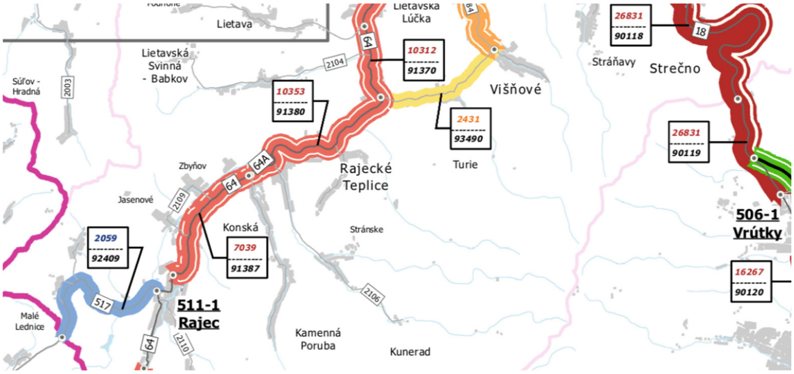


Fig. 7. Road section 91380 - Polúvsie – Porúbka 1/64

The assessment based on the equivalent resilient modulus is based on the greatest (maximum) time deflection amplitude on the road surface in the centre of the y_0 loading plate. The equivalent resilient modulus E_{ekv} is calculated from the general relationship [14]:

$$E_{ekv} = 2.\left(1 - \mu^2\right).\frac{\alpha.\sigma}{y_{0(50,T20)}} \tag{1}$$

Eekv	Equivalent resilient modulus [MPa]
$Y_{0(50,\ T\ 20)}$	deflection in the centre of the load plate calculated at 50 kN comparative force and 20 °C comparative temperature [m]
α	loading plate radius [m]
σ	contact load stress [MPa]
μ	Poisson's number

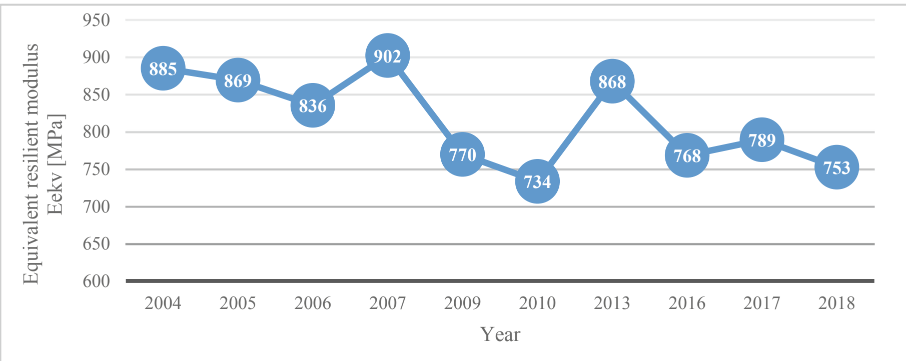


Fig. 8. Development of equivalent resilient modulus - Long term monitored road section Poluvsie – Porúbka - Diagnostics with Deflectometer FWD KUAB

By evaluating and thoroughly analysing the given parameters, we obtain detailed information on the status of the transport infrastructure as part of the Smart Cities philosophy, for the need of urban engineers and planners to benefit from such created models as much as possible, especially with regard to rapid urbanization, which requires obtaining the most accurate information about the environment in the most effective time so that it can be reached soon with the lowest possible financial costs [13].

It is clear from the evaluation of the equivalent modulus of elasticity that all grading stages (5) are located on the entire monitored road section Poluvsie - Porúbka, with the highest percentage of grades 1–3 (excellent, very good, good), namely the 1st grading grade 31.37%, 2nd classification 27.45% and 3rd classification level again 31.37% of which we can conclude that based on the assessment of the road according to the equivalent resilient modulus in good to excellent. Graphically, the evaluation is shown in Fig. 9 is the percentage of all 5 grades. The remaining grading grades have the following percentages: 4. grading grade 3.92% (sufficient) and 5. grading grade 5.88% (insufficient). Figure 8 shows the development of the equivalent modulus of elasticity from 2004 to 2018.

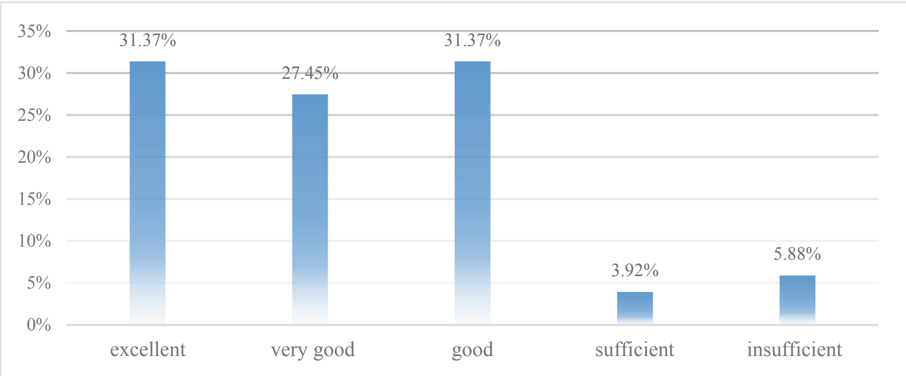


Fig. 9. Percentage of classification grades by module E_{ekv}

3 Conclusion

The technologies for non-destructive diagnostic and technologies for capturing and processing 3D geodata are rapidly advancing. As a result of these developments in geodata acquisition technology, the availability of 3D geodata is steadily increasing.

The current use of diagnostic of pavement and its ambient is mainly used to the visualization of damage, which leaves many other potential applications for the approach to the smart city. This is a chance for change, since urban managers and planners have benefited tremendously from road infrastructure models. This is especially true in light of the rapid urbanization worldwide, which requires continuous monitoring of energy consumption, noise pollution and many other 'smart city' applications. This paper presents the results of several experimental measurements, which are the basis for optimal management of roads and present sustainable approach for intelligent urban construction for smart mobility.

The development of transport means and their characteristics requires a corresponding adjustment of the technical parameters of the transport infrastructure and its gradual modernization. This problem must also be resolved due to the increasing transport performance and the number of means of transport on the roads. The current state of the infrastructure is not able to provide sufficient traffic stream throughput. Additional infrastructure expansion is not possible especially in urbanized areas and the construction of new infrastructure is very demanding. The solution is to use non-destructive diagnostics to quickly determine and predict roadway development almost without any traffic restrictions - without limiting the transport infrastructure logistics processes. The basic goal is to reduce the financial costs involved and to determine the optimal time for repair, maintenance or reconstruction while maintaining the longest possible road life. The cost of repairing roads by using non-destructive diagnostics can be effectively reduced and added value to urban modelling with 3D mobile mapping tools. By optimizing the cost of repair, road maintenance contributes to reducing user costs, improving service delivery and reducing pollution. Last but not least, the aim is to increase road traffic safety, increase the efficiency of transport, expressed by saving time for transport, as well as increasing the quality of the environment and improving the productivity of the company's commercial activity.

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