METHODOLOGY FOR MEASURING WATER FILM DEPTH ON THE ROAD SECTIONS PRONE TO AQUAPLANING UNDER THE TRAFFIC

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Abstract

Driving on wet pavements during heavy rainfall is usually associated with increased number of traffic accidents. Inadequate pavement surface drainage conditions combined with higher driving speeds increase aquaplaning (or hydroplaning) potential, particularly in the inflection zones of motorways with shallow longitudinal grades. Previous studies clearly demonstrated that, among all the relevant parameters, such as pavement surface geometry, pavement texture and rutting, rainfall intensity and tire tread depth, the water film depth (WFD) stands out as the most important factor causing aquaplaning. This issue highlights the following key question: how to measure WFD on the existing road sections prone to aquaplaning and process obtained data to warn drivers about potentially hazardous driving conditions. The fact that WFD measurements should be performed under the traffic, without disturbing regular traffic flow, adds to the complexity of the problem. In this paper the methodology for measuring WFDs on existing road sections on national road network using Mobile Advanced Road Weather Information Sensor (MARWIS) was presented. MARWIS sensor was mounted on test vehicle and used for preliminary WFDs measurements, both on the test site (parking lot at the Faculty of Civil Engineering University of Belgrade - FCEUB) and on the selected sections of motorway E-75 through Belgrade. Collected data revealed discrepancies between WFDs measured by MARWIS sensor and real amount of stormwater running across the pavement surface on motorway sections traveled by the test vehicle. These findings prompted new laboratory tests, addressing the accuracy of WFD measurements by MARWIS sensor and determining the source of measurement errors. Results of laboratory tests provided valuable information regarding the optimal position of MARWIS sensor on the test vehicle and its mounting angle (vertical angle relative to the ground), which would improve the accuracy of WFD measurements on a network scale.

Key words: aquaplaning, WFD, MARWIS, surface drainage, road inflection zones

1 Introduction

Water-pavement interaction is considered to be one of the most challenging road safety problems. Rainfall is evacuated from the pavement surface in order to prevent aquaplaning and provide required skidding resistance. According to extensive report [1], efficiency of surface drainage depends on numerous factors: pavement surface geometry, rainfall intensity and duration, pavement hydraulic properties etc., with environmental issues adding more complexity. In order to tackle all aspects and complexity of this problem, multidisciplinary research project entitled: Road and Environmental SAFEty related to water - pavement interactions (RESAFE) is currently underway at the Faculty of Civil Engineering, University of Belgrade (FCEUB).

The primary goal of the project is to develop robust next-gen Road and Environmental Safety Toolkit (REST), tasked with thoroughly investigating WFD under the specific combinations of pavement surface geometry, hydraulic properties of the pavement structure (porous or dense graded top surface layer) and rainfall data (intensity and duration). It is expected that REST deployment would initiate revision of current road design standards and introduce new possibilities in WFD calculation. Also, REST would facilitate identification of critical sections prone to aquaplaning on existing road network. Long term goal of the project is application of REST for safety forecast in critical weather conditions, considering climate changes, and integration in the driver's information system. In order to achieve preset goals, it was necessary to verify REST accuracy in terms of predicting WFD on critical road sections prone to aquaplaning. In the previous stage of the project, REST toolkit was developed and tested in laboratory conditions, while in the next stage REST is to be applied on a set of existing road inflection zones susceptive to aquaplaning. Hence, to successfully complete and verify this task, WFD values calculated by using REST toolkit should be matched against the WFD values measured under the traffic on a national road network.

2 Measuring of WFDs on pavement surfaces under the traffic

In current engineering practice, various methods are used to measure or estimate the thickness of the water film on a pavement. A group of researchers from France shows in their studies that an accelerometer mounted around the wheel shows very good results when evaluating the thickness of the water film by measuring the amplitudes of the impact of the water drops. Sensors mounted low and filtered in the range of frequencies 2 to 7 kHz show tight correlation, significantly dependent on vehicle speed. This kind of study was conducted both on a passenger car and on a trailer [2, 3]. Acoustic sensors can also be used for water film detection with high precision [4]: an acoustic vector sensor achieved an accuracy of 89% analyzing frequencies around 1kHz in real conditions, providing a practical and inexpensive apparatus. In their study, a team of researchers from Norway tested two optical devices for assessing the condition of the road surface in winter conditions, i.e. optical device accuracy when measuring friction, water film thickness and the temperature of the road surface. The results showed that the Teconer RCM411 and Lufft MARWIS devices gave a strong mutual correlation, as well as good match with previously performed laboratory experiments [5]. In recent study [6], optical devices are also recognized as devices with the most direct measurement and the highest precision. Therefore, for the purpose of testing the accuracy of the REST's WFD calculation, the Lufft's MARWIS sensor was selected for WFD measurements in the field.

3 Methodology of identifying sections of the road prone to aquaplaning on the existing road network

Generally, the most severe surface drainage problems might be expected at the locations where low pavement cross grades are combined with shallow longitudinal grades. This is typical for road inflection zones (central parts of reverse, or "S", curves) where the pavement cross grade changes its direction from left to right or vice versa. The water film depth (WFD) in the inflection zone is a consequence of several critical parameters: longitudinal grade, relative longitudinal grade of pavement edge (change in superelevation rate), rainfall intensity and rainfall duration. Certainly, there are also some parameters that are out of road designer's control, such as tire tread depth. Aquaplaning occurs when WFD exceeds certain critical depth. Critical depth of 2-3 mm is widely accepted by majority of relevant national standards (Swedish policies, German standards).

Methodology of identifying inflection zones prone to aquaplaning relies on the deployment of REST toolkit as displayed in algorithmic scheme in figure 1. REST toolkit that calculates WFD from geometrical pavement parameters, pavement structure characteristics (porous of impervious pavement surface) and rainfall characteristics has already been developed and tested in laboratory conditions. Also, based on geometrical design parameters applied, reasonable set of inflection zones prone to aquaplaning has been observed on Serbian national road network.

In the next stage, during exact rainfall events, MARWIS sensor will be used to measure real WFD for every inflection zone from the previously selected set. For each of these locations, WFD is also to be calculated by using REST toolkit - by using identical geometrical parameters and for the same rainfall characteristics. It is expected that measured WFDs will match WFDs calculated by using REST. Discrepancies between measured and calculated WFD values would prompt further refinements of REST toolkit.

Once thoroughly tested, both in laboratory conditions and in the field, REST toolkit will finally be used for delineating favorable from unfavorable combinations of design and rainfall parameters (longitudinal pavement grade, relative grade of the pavement edge, rainfall intensity and rainfall duration). This delineation is going to be articulated by using series of diagrams, thus facilitating identification of the locations prone to aquaplaning as early as in the design stage. Each diagram will be related to the specific longitudinal grade (i_n), with the rainfall intensity (I) labelled along the horizontal and rainfall duration (t) labelled along the vertical axis. Within each diagram, family of curves representing specific relative longitudinal grade of pavement edge (i_r) is to be incorporated as well. It is expected that, within every (i_n) diagram, there would be a certain borderline (i_r), approximately delineating favorable from unfavorable cases.

REST toolkit will also be used to verify positive effects of the application of porous asphalt and of the diagonal superelevation.

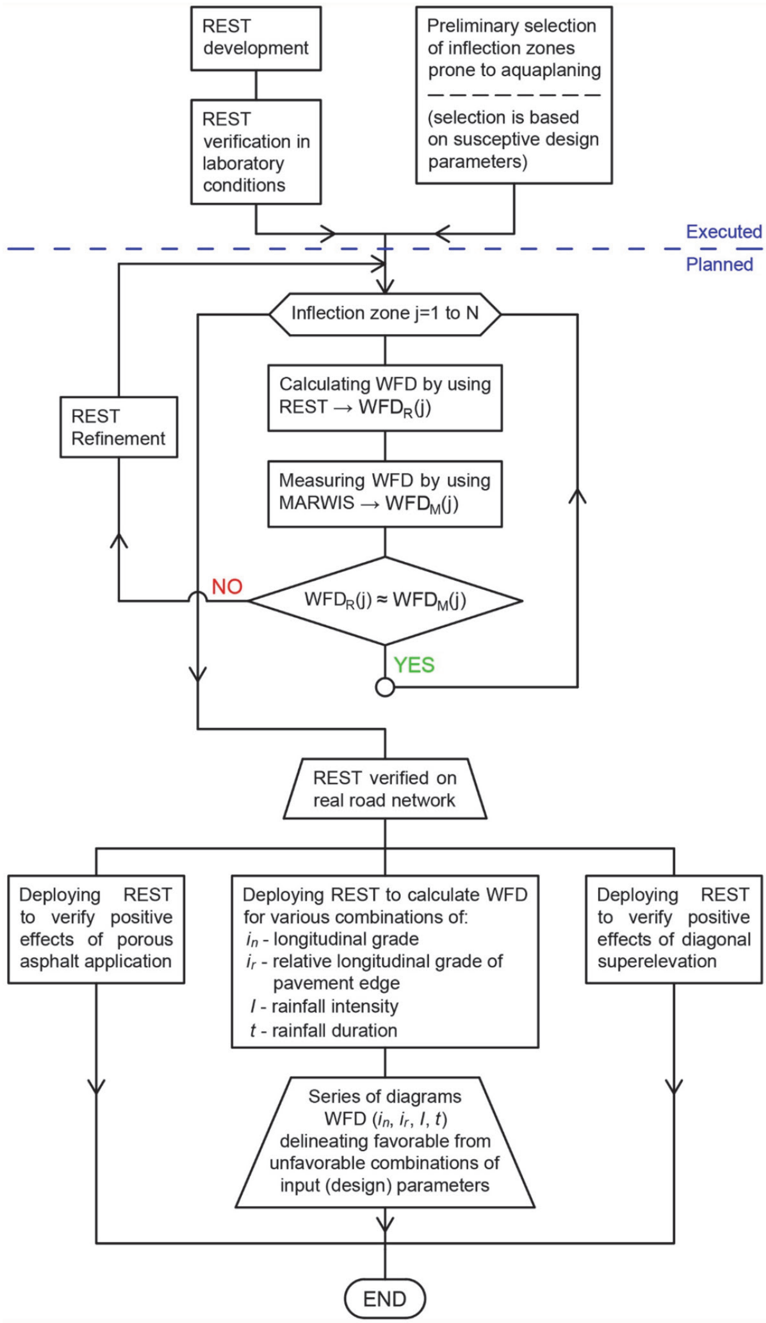

Figure 1 Algorithmic scheme graphically representing described methodology

4 Trial measurements of WFDs using MARWIS sensor

In cooperation with Public enterprise (PE) Roads of Serbia, test measurements of WFDs by MARWIS sensor were conducted. These trial measurements served as preparation phase for the future experimental verification of previously developed REST toolkit. As shown in figure 2a, MARWIS sensor was mounted sideways on the PE "Roads of Serbia" test vehicle and connected to the tablet computer installed inside the vehicle. Since MARWIS device is equipped with GPS locator, the tablet recorded georeferenced measurement data using specially developed Lufft's MARWIS Android App.

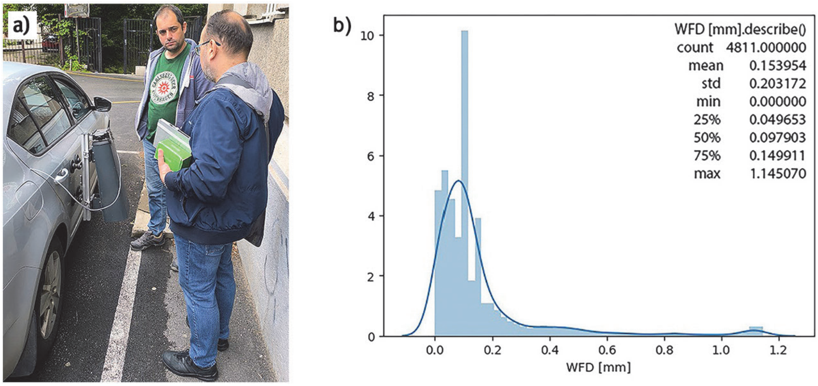

Figure 2 a) MARWIS position on test vehicle; b) Distribution of measured WFDs during pilot testing of MARWIS sensor

WFDs were measured on FCEUB parking lot and on motorway sections nearby Belgrade. In figure 2b, distribution of measured WFDs and basic statistical parameters of collected data (min, max, mean, standard deviation) are shown. In figure 3, spatial distribution of measured WFDs on selected trial motorway sections around Belgrade is presented.

Spatial distribution of measured WFD data showed that there were only several locations on local motorway network where MARWIS sensor detected WFDs greater than 0.5 mm. Measurements results raised suspicions, given that there was intense rainfall at the time of testing. Moreover, it was obvious that, all the time during the measurement, large amount of water was accumulated on the pavement surface. Therefore, research team decided to compare WFDs measured by MARWIS to WFDs registered at the same time by Lufft's passive road sensors IRS31Pro-UMB installed in pavement near the interchanges ''Dobanovci'' and ''Bubanj Potok''. Compared measurement results revealed significant discrepancies between WFDs measured by MARWIS and WFDs measured by using fixed road sensors (fixed road sensors are part of integrated Road Weather Information System - RWIS and continuously monitored by PE Roads of Serbia). These findings prompted additional assessment of the validity of WFDs measured by MARWIS sensor in order to reconsider the decision on its application for future WFDs measurement under the traffic on a network scale. Accordingly, research team decided to additionally test MARWIS reliability in laboratory conditions.

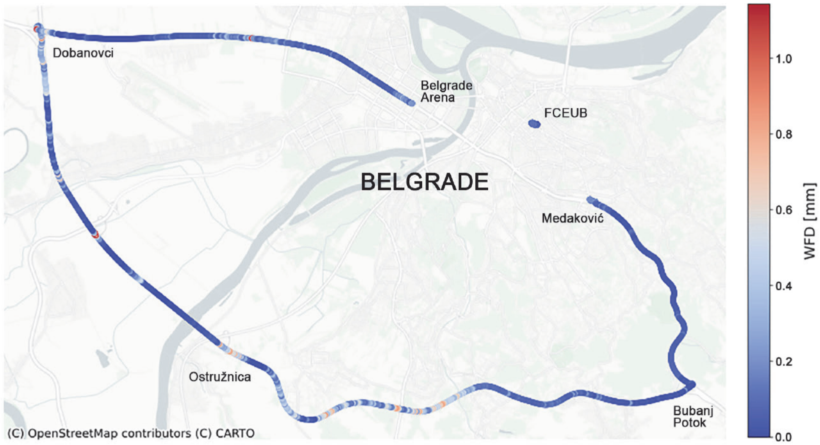

Figure 3 Spatial distribution of measured WFDs along selected motorway sections near Belgrade

5 Accuracy of MARWIS WFD measurements - laboratory tests

MARWIS sensor (provided by PE Roads of Serbia) was mounted on a vertical steel support inside the Laboratory for pavement structures at FCEUB. Strong magnets were used to attach MARWIS sensor to the steel support, enabling at the same time simple variation in clearance between the sensor and the round plastic pan placed on a horizontal concrete floor beneath. Also, the angle between the MARWIS camera direction and the floor was varying to examine its influence on WFDs measuring results. Tests were carried out by using plastic pans with three different diameters - 190 mm, 236 mm and 300mm. Since accurate dimension of the plastic pan beneath the MARWIS sensor is known, exact WFD in the pan is precisely derived from the volume of the water inside the pan. Test preparation and basic testing procedure are shown in figure 4. For every position of MARWIS sensor mounted on the steel support, WFDs in plastic pans were varying from 1.00 to 6.00 mm, which means that 66 measurements were conducted in total for 11 various MARWIS positions. Then, known WFDs in plastic pans were compared to the ones measured by MARWIS and the results were presented in table 1. The most important findings of conducted laboratory tests are:

- with the distance between the floor and MARWIS sensor increased, the measurement accuracy decreases
- the angle between the MARWIS camera direction and the floor does not significantly affect the accuracy of the measurement
- generally, with the diameter of the plastic pan increased, the measurement accuracy also increases.

As during trial measurement MARWIS sensor was mounted sideways on test vehicle, the influence of ''side splash effect'', caused by the front right wheel of the test vehicle, on WFD measuring accuracy was significant. To mitigate this effect, MARWIS sensor should be mounted in front of the test vehicle, right in the middle of its front bumper. On the other hand, bearing in mind the results of laboratory tests, the optimal distance between the MARWIS sensor and pavement surface is 0.80 m, or slightly lower as shown in figure 5. The mounting angle between the MARWIS camera direction and the pavement surface should be close to 90 deg.

Figure 4 Laboratory tests of MARWIS sensor accuracy for WFDs measurements

Table 1 The results of laboratory tests of WFD measurement accuracy using MARWIS sensor (WFDs were ranging from 1.0 to 6.0 mm)

Distance from the floor [cm]	Angle between MARWIS camera direction and floor [deg]	Diameter of plastic pan [mm]	Mean measurement discrepancy [%]	Standard deviation of measurement discrepancy [mm]
80	70	190	15.0	0.51
80	90	190	10.9	0.27
80	70	236	15.3	0.51
80	90	236	9.8	0.30
80	90	300	7.2	0.17
100	90	190	17.5	0.50
100	90	236	12.5	0.43
100	90	300	11.9	0.41
120	90	190	25.6	0.75
120	90	236	15.1	0.52
120	90	300	13.3	0.44

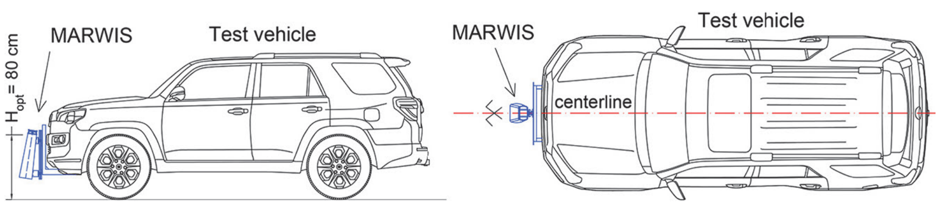

Figure 5 The optimal position of MARWIS sensor on the test vehicle

6 Conclusion

RESAFE research project addresses complex mechanism of water-pavement interaction, particularly the stormwater surface drainage on road sections prone to aquaplaning. The key project goal is to develop robust next-gen REST toolkit which will be used to calculate WFDs for various input parameters (longitudinal grade, relative longitudinal grade of pavement edge, rainfall intensity and rainfall duration) in order to identify critical road sections prone to aquaplaning.

Up to know, REST toolkit was developed and tested in laboratory conditions, but its accuracy in terms of WFD calculation on real road sections is yet to be examined. To complete this task, WFD values calculated by REST toolkit should be matched against the WFD values measured under the traffic on national road network. Lufft's MARWIS sensor was used for WFD measurements in the field. Trial measurements of WFDs by using MARWIS sensor were conducted on the test site on FCEUB parking lot and on the selected sections of motorway E-75 around Belgrade. Since collected data revealed discrepances between WFDs measured by MARWIS sensor on a motorway network and WFDs observed by a naked eye, new laboratory testing of MARWIS was prompted. Based on the results of laboratory tests, the optimal position of MARWIS sensor on the test vehicle is determined. In order to get accurate WFDs measurement, MARWIS sensor should be mounted in front of the test vehicle, right in the middle of its front bumper, at the distance of 0.80 m from the pavement surface. In addition, the mounting angle between the MARWIS camera direction and the pavement surface should be close to 90 deg.

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