MACROSTRUCTURE DIGITALIZATION OF THE ROADWAY SURFACE PROFILES

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This paper considers the characteristics of the device ZScanner 700, it usage and ability to process data from measurements of the roadway's geometric profile. It refers to the ability of ZScanner 700 to record surface deviations with sufficient accuracy and the possibility of processing obtained digitalized data in GOM inspect software for surface analysis and Global Mapper for watershed simulation. This analysis and simulation is directly related to the MPD measurement performed on roadways. The purpose of the MPD measurement is to detect macroscopic road surface defects to avoid water retention on the road and the origin of hydroplaning effect.

KEYWORDS

3D laser scanning, roadscan, macrotexture, surface analysis, watershed simulation.

1 INTRODUCTION

It is undisputed that the roughness of the road surface impacts on traffic safety. Road safety can be assessed in several respects (deceleration value of the vehicle in braking, accident rate, the length of the braking distance, etc.), which implies that even in the determination of the roughness criteria, the synthesis of requirements from several aspects needs to be made. One of them is also the macrotexture of the road which has a major impact on its drainage and can cause tire slipping on wet surfaces in its inappropriate condition. In the contribution we deal with one of the possibilities of diagnostics, the problematic state of the roads using the 3D scanning device, the analysis of the acquired data and the simulation of the road realized on specific place.

2 MICRO AND MACROTEXTURE DEFINITION

Roughness is the property of the road surface providing co-operation between the wheel and the road. When we talk about roughness from a geometric point of view we are talking about texture of the surface, that is morphology, the arrangement of the individual aggregate grains on the road surface (macro texture) and the arrangement of the projections on the surface of the aggregate grains (microtexture). Whether roughness is the road characteristic that characterizes its resistance to slipping the vehicle wheel on its surface it is a tangential reaction of the road that serves to provide braking and driving force on the circumference of the tire. This reaction is called shear friction and its ratio to normal wheel load defines the coefficient of shear friction. Assessing the road in terms of its shear resistance is a very challenging problem. The friction between the wheel and the road is affected by a large number of parameters, type of tire, profile and depth of tire tread, tire pressure, vehicle damping and braking system, vehicle speed, vehicle type and weight, vehicle weight distribution, temperature, season, presence and depth of water film on the road, the route of communication, the age of the road and the traffic intensity on it, the breakage of the cover, the type of the rubble layer, the type of aggregate used and the like. It would be difficult (if not impossible) to determine the influence of the individual parameters on the friction between the wheel and the road as they can't be separated and their influence by specifying specific conditions somehow eliminated. However, it must be emphasized that the greatest and most significant influence on the friction between the wheel and the road has the texture of the surface along with the type and condition of the tire, presence of water and the speed of the vehicle, with regard to the roughness of road surface as such [Kovac 2011].

It is divided by the magnitude of amplitudes and wavelengths of inequalities, micro and macrotexture. Macrotexture is an irrelevant component in the context of roughness as it affects the driving comfort and wear of the vehicle parts and in terms of wheel-to-wheel interactions, it is in principle a reduction in wheel thrust. Macrotexture plays an important role in wet roads, especially at medium and higher vehicle speeds, and in addition to hysteresis it also serves to ensure that water is drained from the surface, helping to prevent aquaplaning [Kovac 2011].

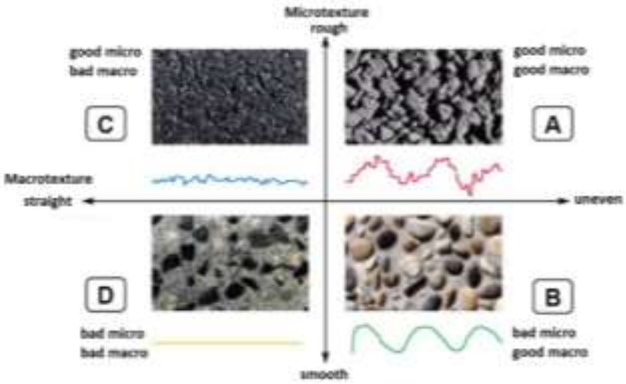

Figure 1. Example of road surfaces with different micro and macro texture values [Kovac 2011]

In general, the road surface may be divided into four categories according to the micro and macro texture values [Kovac 2011]:

A.) uneven and rough, the surface has good microtexture and macro texture,

B.) unequal and smoothed, i.e. the surface has a good macro texture, but a bad microtexture,

C.) straight and rough, i.e. the surface has a good microtexture but a bad macro texture,

D.) straight and smoothed, i.e the surface has a bad micro and macrotexture.

The term "uneven" surface is meant to have an average depth of unevenness greater than 1.0 mm within the scale defined for macrotexture. "Rough" is considered to be a surface having an average microtexture depth of 50 µm. The texture (both micro and macro) influences the anti-skid properties of the wet road at different speeds. The anti-skid properties of the road are expressed by the SN coefficient (Skid Number), the friction coefficient defined in to slip the impeded test wheel on a wet road multiplied by 100 and the effective load on the wheel at a speed of 40 km/h. It is clear from the figure that the microtexture surface of the road profile has a decisive influence at lower speeds. With an increase in speed, shear resistance is decreasing, but this decrease is not so significant if the macrotexture is on sufficient value **[Kokkalis 1998].**

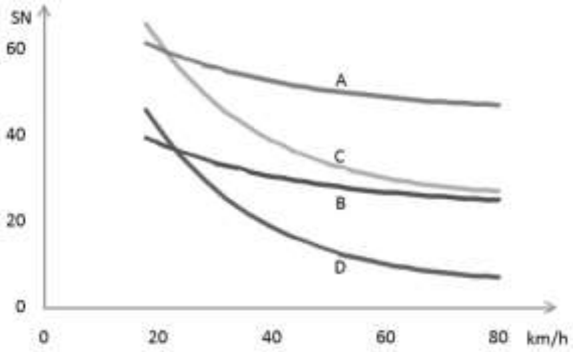

Figure 2. Anti-skid properties characterized by the SN coefficient as a function of velocity for different soil types, compared to the speed of vehicle (A: good micro and macro, B: poor micro, good macro, C: good micro, bad macro, D: bad micro and macrotexture [Kovac 2011]

2.1 *Current status of macrotexture measurements*

In practice, for the measurement of macrotexture we mainly use profile shapers that give us the average depth of the macrotexture profile (MPD). We also use the average depth of the texture by means of a measurement method which consists in spreading the glass beads of a given volume fraction to the surface of the pavement that is curved into a circle-shaped area. The bulk volume and the area covered being the number representing the average depth of the texture (MTD). There are currently over 20 kinds of known equipment for the measurement of shear friction, although some of the devices of the same type may still differ in the marginal measuring conditions (Skiddometer, Scrim, etc.). Currently Profilograph GE is used for measuring the texture which gives us the value of an average depth of profile (MPD) [Slabej 2016].

2.2 *MPD – Average depth of profile*

The method is based on the measurement of the surface profile curve with the range recorded the inequality defined for macrotexture and subsequent data processing, whereby based on the prescribed procedure we obtain the MPDs which are further calculated for the measured section as the average values for a particular operator selected step [ASTM - 01 2005].

The principle of calculation consists in dividing the profile into a base with a length of 100 ±10 mm and dividing it further into two equal parts. Once the maximum profile values have been determined from both halves of the base. The average profile value is then determined from all measured profile values over the entire base length. The principle of calculating the mean depth of profile is shown in (Fig. 3).

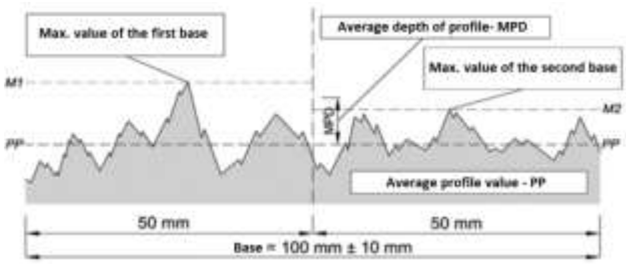

Figure 3. Calculation of the MPD profile average depth [Slabej 2016]

The average depth of the MPD profile is calculated for each measured profile as the difference in the arithmetic mean of the two highest values and the average profile value [Behrouz 2016].

$$MPD = \frac{M1+M2}{2} - PP\ [mm] \qquad (1)$$

where [STN EN 13473-1 2002]:
M1 – maximum value of the first half of the base [mm],
M2 – maximum value of the second half of the base [mm],
PP – average profile value [mm].

2.3 *ZCorporation Zscanner 700*

The ZScanner device was used to measure the road because of its modifiable resolution and a maximum z-axis resolution of 0.02 mm. ZScanner is another ZCorporation scanner development board. It is a handheld, high-resolution laser scanner that allows you to move the scanned object surface and the scanner together during scanning. Scanning is done by two cameras scanning the laser red cross. The great advantage of this type of scanner is that it does not need any external fixation mechanisms or positioning that complicate digitization. The scanned surface of the object is instantly displayed on the computer monitor allowing you to monitor the consistency of the surface scan and eventually scatter locations that are not scanned in such detail [ZScanner® 700 2009].

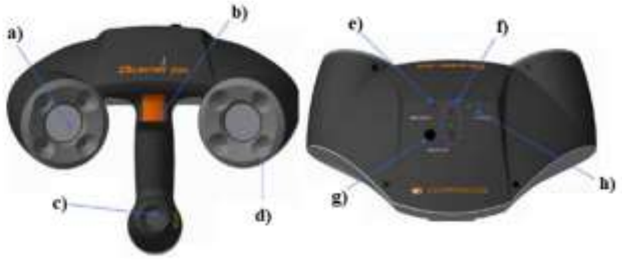

Figure 4. ZCorporation ZScanner 700 (a) Camera – searches for positional markings and position of the laser on the object, b) Startup record start, c) Surface cross-section (laser) – Ensures real-time rendering of the surface, d) LEDs illuminate the reflective part of the position markers.) LED-recording f) LED for device distance from the scanned object g) Preview button displays the laser cross and interrupts the recording h) The LED of the device [ZScanner 700 2009]

The ZScanner 700 uses positioning markers to indicate that it is moving even when sensing the surface with small deviations. If the correct positioning of the position markers or their absence is not followed the device cannot distinguish whether or not it is moving or staying with respect to the scanned surface. For the purpose of measurement, the positioning of markers on the 2550 x 260 mm section (Fig. 5) was required, size of the measured section being defined by the original intention to measure the road profile of the entire lane. When processing the measurement results scanned position marker software automatically neglects, avoiding distortion of measurement results, manipulation or editing of scanned objects.

Figure 5. Scanning the road surface (a.), setup of position markers (b.)

3 PROCESSNG OF DIGITALIZATION DATA

For processing of our data we use GOM Inspect software. It is used for the analysis of 3D measuring data for quality control, product development and production. The GOM software is used to evaluate 3D measuring data derived from GOM systems, 3D scanners, laser scanners, CTs, CMMs and other sources. Because our main goal in this measurement was not macrotexture analysis but scanning of the surface and its profile. We need to cut out our surface from the original mesh as we can see in Fig. 6. For this purpose we used NetFabb software because of its ability to cut exact values without the need of repairing surfaces.

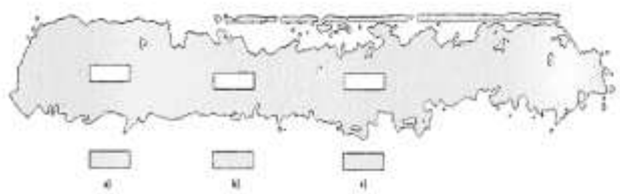

Figure 6. Cutting surfaces from original mesh, using Netfabb software

As the MPD analysis is performed on road surfaces mainly due to the retention and flow of water on unsuitable road sites. In order to prevent the occurrence of hydroplaning, i.e. the slipping of the vehicles wheels on the road. As Fig. 7 shows it is possible to create a simulation inside Global Mapper software which is showing the flow of water on the measured surface and in the individual surfaces selected for assessing the state of macro texture.

As seen in Fig. 7 it consists of three parts. The first part is a representation of the topology of the digitized surface as a whole, the second part colourants the individual unevenness found on the surface to display individual water streams on the digitized section which can be seen on the filtered third view. Values used for the simulation are responsible to average rainfall rate for year 2017. As can be seen, areas "b" and "c" are located in places with more frequent and intense surface defects than area "a" in terms of road surface condition. We deduce this fact from the higher frequency of water streams in this area.

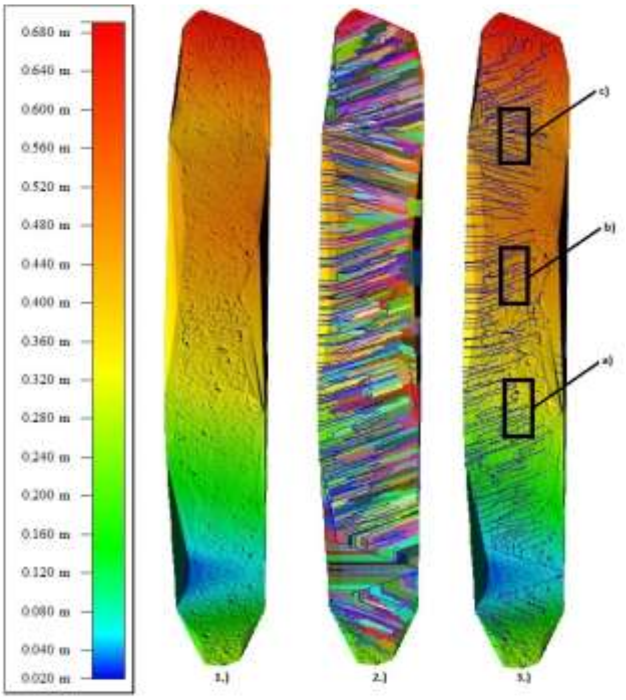

Figure 7. Simulation of Water-shedding on measured surface

As we can see in Fig. 6 after splitting the original mesh we got 3 different surfaces for our analysis. Their dimensions are 60x100 mm. Actual surface including profile curvature can be seen in Fig. 8. Where are surface data shown as surface plots after importinng the „xyz“ coordinates into MatLab software.

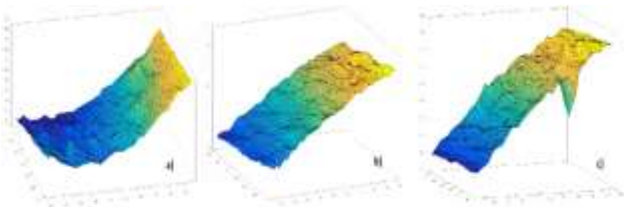

Figure 8. Actual surface on roadway's profile

Based on the MPD measurement the analysed surface should have the width of 100± 10 mm which is ours and it should be split in half for obtaining maximal deviations on each side. Fig. 9 shows an example of obtaining maximum deviation on a single section through surface „A“ whitin GOM inspect software enviroment.

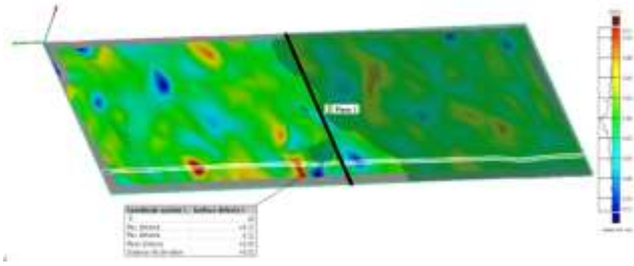

Figure 9. Surface section within GOM inspect software

Thanks to 60 mm width of messured surface, and low resolution of Zscanner which means 0.2 mm in X and Y-axis. We were able to split meassured surface in 300 similar sections which are containing surface deviation data. Fig. 10 shows an example of data obtained from one of the sections.

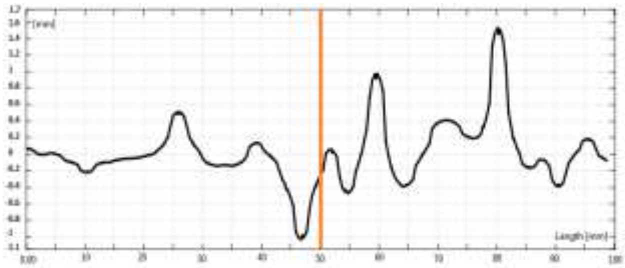

Figure 10. Surface deviations from single section on surface

3.1 Measuring principle

For measurement purposes, it is necessary to create a normal plane on which we can deduce minimum and maximum values. These are necessary to determine the values of the average depth of profile required to determine the maximum profile values in both parts of the surface and the final calculation of the MPD value for the final evaluation.

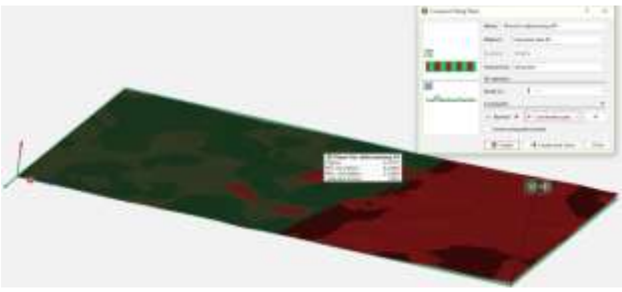

Figure 11. Setting normal plane for determining average profile value

After applying the normal planes to the measured surfaces a, b, c we are able to obtain maximum and minimum surface values. After averaging these values, we get a PP value for each surface as seen in Tab 1.

Table 1. Example of max/min values on surface “a, b, c”

	Max. distance [*mm*]	Min. distance [*mm*]	PP
Surface "a"	*1.04*	*-0.28*	0.38
Surface "b"	*1.06*	*-0.14*	0.46
Surface "c"	*-3.08*	*0.26*	-1.41

Based on positive and negative profile heights we were able to calculate exact PP values. These values are approximate or equal to zero, unless there are relatively large deviations in profile depth, such as holes caused by mechanical damage on the road or erosive activity such as seen on surface “c”.

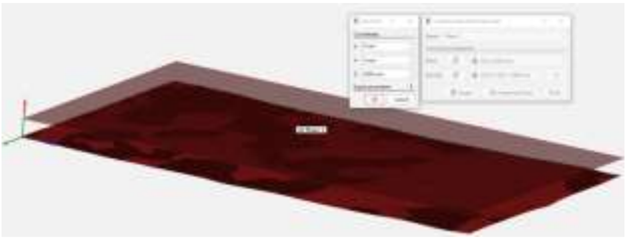

Figure 12. Fitting plane that determines average profile height—PP

After applying these steps to each measured surface, we can profile the sections with a resolution equal to that of the ZScanner 700, which is 0.2 mm. This way, we get the 300 profiles mentioned above through the measured surface and we can read the values needed to calculate the average MPD value in individual sections. In detailed view we can see individual sections with arrows expressing the orientation and magnitude of each deformation.

Figure 13. Detail of surface sections and elevation in various points on surface

3.2 Measurement results

Table 2. Selected profile cross-sections on surface “a”

Surface defect's in individual on sample "a"			MPD value in each section
No. Section	**Max. deviation on A1**	**Max. deviation on A2**	
1.	*0.22*	*0.33*	*-0.11*
30.	*0.3*	*0.3*	*-0.16*
60.	*0.33*	*0.45*	*1.8*
90.	*0.61*	*0.32*	*0.47*
120.	*0.5*	*0.3*	*0.4*
150.	*0.72*	*0.55*	*0.64*
180.	*0.41*	*0.4*	*0.41*
210.	*0.53*	*0.51*	*0.52*
240.	*0.54*	*0.31*	*0.43*
270.	*0.22*	*0.4*	*0.31*
300.	*0.21*	*0.36*	*0.29*

Due to the large amount of data, we do not show the data from the overall measurement in the following tables, but only examples from the selected profile cross-sections. For this sample, we chose every thirtieth section. In each section, every 0.2 mm is the control point capturing the profile deformation value at the given coordinate. From these data, 2 maximum values are selected for each half of the measured section (A1, A2, B1, B2, C1, C2).

Based on MPD measurements and surface diagnostics of the digitized part of the road, we can say that the average MPD is 0.41 mm. This value is based on STN EN ISO 13473-1, which determines the equation for the estimate texture depth – ETD. Below we can see graphical representation of all values from 300 sections [STN EN 13473-1 2002].

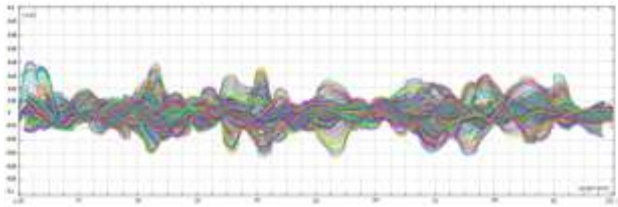

Figure 14. Graphical view of surface defect’s in individual on sample "a", including all surface sections

As already mentioned, we can notice the fact that the areas "b" and "c" in terms of topography of the measured section are located in places with increased flow of water, when simulating the flow of water on the road. From this we assumed that the depth of the profile would be higher in these locations and deformations more often than in the "a" area. Regions "b" and "c" are very similar in terms of MPD evaluation. Their average values are 0.64 mm for b and 0.57 mm for c. Both of these obtained values are unsuitable.

Table 3. Selected profile cross-sections on surface “b”

Surface defect's in individual on sample "b"			MPD value in each section
No. Section	**Max. deviation on A1**	**Max. deviation on B2**	
1.	*0.77*	*0.84*	*0.345*
30.	*0.59*	*0.59*	*2*
60.	*0.84*	*0.99*	*0.92*
90.	*0.91*	*0.12*	*0.52*
120.	*0.83*	*0.11*	*0.47*
150.	*0.38*	*0.57*	*0.48*
180.	*0.81*	*0.1*	*0.46*
210.	*0.12*	*0.56*	*0.34*
240.	*0.34*	*0.12*	*0.23*
270.	*0.125*	*0.14*	*0.13*
300.	*0.11*	*0.12*	*0.12*

The road macro-texture according to STN EN ISO 13473-1, should not exceed the tolerated limit, which is MPD = 0.4 mm. Below we see the results of the individual measurements for areas "b", "c" and the real representation of the values of the individual cross-sections in the graphs.

We can see that the diversity is not so wide when it comes to "b" and "c", but the magnitude compared to surface "a" is much greater.

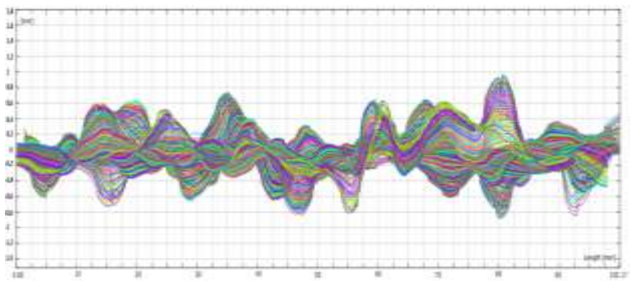

Figure 15. Graphical view of surface defect's in individual on sample "b", including all surface sections

Table 4. Selected profile cross-sections on surface "c"

Surface defect's in individual on sample "c"			MPD value in each section
No. Section	Max. deviation on C1	Max. deviation on C2	
1.	*0.14*	*0.2*	*1.58*
30.	*0.55*	*0.55*	*0.55*
60.	*0.82*	*0.4*	*0.61*
90.	*0.73*	*0.85*	*0.79*
120.	*0.67*	*0.12*	*0.4*
150.	*0.77*	*0.63*	*0.7*
180.	*0.69*	*0.81*	*0.75*
210.	*0.59*	*0.14*	*0.37*
240.	*0.61*	*0.12*	*0.37*
270.	*0.96*	*0.12*	*0.54*
300.	*0.1*	*0.55*	*0.33*

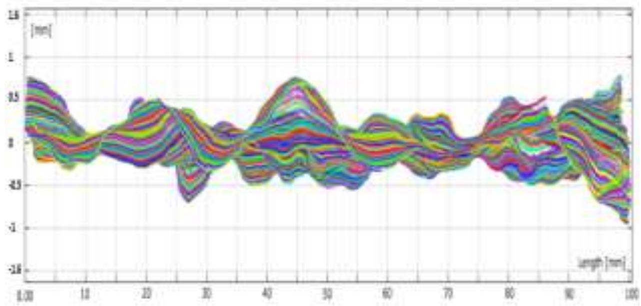

Figure 16. Graphical view ofsurface defect's in individual on sample "c", including all surface sections

Based on the results of the accident and texture relationship research it is suggested that the minimum value for the average depth of the profile is MPD = 0.4 mm. This value was designed based on the MTD data obtained from the measurement method using the relationship from STN EN ISO 13473-1 to determine the estimated depth of the ETD texture. [STN EN 13036-4 2012]

The upper boundary of the average depth of the texture profile does not need to be determined because the high value of the macro texture still does not have to be compliant with the anti-skid properties (weak micro- texture, smudged stones) which implies the need to combine this method with the shear resistance evaluation method (PTV, Mu) [Behrouz 2016].

As mentioned, assessing the roughness of the road with a parameter that characterizes the average depth of the road texture profile (MPD) addresses the problem of resolution between positive and negative texture. This problem arises because according to the definition given in STN EN ISO 13473-1 the average depth of profile (MPD) is calculated as the difference of the average of the two maximum profile values and the average profile value [STN EN 13473-1 2002].

4 CONCLUSIONS

The safety and fluency of road transport are some of the most important aspects of traffic. For this reason several types of surface and road profiles measurements are realized in relation to trafic. One of them is the MPD measurement. Which is performed on individual sections of the road. The MPD measurement results mainly tell us about the water flow and retention on the roads surface. Values obtained in this measurement tell about the roads condition and the possibility of hydroplaning, i.e. risk of wheel slipping on the water retained or flowing on the roads surface. This measurement is mostly realized at high speed by the Profilograph GE vehicle. Measurement in this article describes one of the options for evaluating the macrotexture with manual ZScanner 700 device. Processing data from the measurement and reproducing the standardized MPD measurement according to valid STN. The result of this article is a conclusion based on a comparison of the data obtained and simulation created within specialized software.

Based on the MPD profile's average depth we can deduce that the areas "b" and "c" are inappropriate for the assessment of the macro-texture. This finding also corresponds to the result of the simulation of the retention and flow of water on the road which was applied to the same data from the digitization of the road surface on which the MPD itself was measured.

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REFERENCES

[ASTM - 01 2005] Standard Test Method for Determination of Silica in Manganese Ores, Iron Ores, and Related Materials by Gravimetry. ASTM - 01 (2005).

[Behrouz 2016] Behrouz, M., et al. Pavement Friction and Skid Resistance Measurement Methods. Open Journal of Civil Engineering, 2016, Vol. 6, pp. 537-565.

[Cizikova 2016] Cizikova, A., et al. Numerical and experimental modal analysis of gear wheel. MM Science Journal, 2016, pp. 1232-1236, ISSN 1803-1269.

[Kokkalis 1998] Kokkalis, A.G. and Panagouli, O.K. Fractal Evaluation of Pavement Skid Resistance. Chaos, Solitons & Fractals, 1998, Vol. 9, No. 11, pp. 1875-1890.

[Kovac 2011] Kovac, M., Remiasova, E., Komacka, J. Update of the evaluation criteria for the anti-sensitive characteristics of the vehicles in the context of European norms. 2011, pp. 1-36.

[Kumar 2016] Kumar, R., et al. Wear Characteristics and Defects analysis of Friction Stir Welded joint of Aluminium alloy 6061-T6. Eksploatacja i Niezawodnosc – Maintenance and Reliability, 2016, Vol. 18, No. 1, pp. 128-135.

[Olejarova 2017] Olejarova, S., et al. Measurements and evaluation of measurements of vibrations in steel milling process. Measurement, 2016, 106, pp. 18-25, ISSN 0263-2241.

[Panda 2014] Panda, A., Prislupcak, M., Pandova, I. Progressive technology diagnostic and factors affecting to machinability. Applied Mechanics and Materials, 2014, Vol. 616, pp. 183-190, ISSN 1660-9336.

[Slabej 2016] Slabej, M., Grinc, M. Model for Monitoring of Transfers Unevenness and Skid Resistance. 2016, pp. 537-565, ISBN 978-86-916153-1-4.

[STN EN 13036-1 2010] STN EN 13036-1 (73 6171) Surface features of roads and airport areas. Test methods. Part 1: Measurement of depth of road surface macro-texture by a modest method, 2010.

[STN EN 13036-4 2012] STN EN 13036-4 (73 6171) Surface properties of roads. Test methods. Part 4: Surface anti-skid resistance measurement method. Pendulum test, 2012.

[STN EN 13473-1 2002] STN EN ISO 13473-1 (73 6177) Characterization of road surface texture using surface profiles. Part 1: Determination of the mean depth of the profile, 2002.

[ZScanner 700 2009] ZScanner 700, ZCorporation, 2009, Burlington MA 01803 USA [online]. Available from <www.bibuschina.cn/fileadmin/product_data/3DSystems/documents/zcorp_zscanner_catalog_en_2010.pdf>.3DS-BRO3-2009.

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