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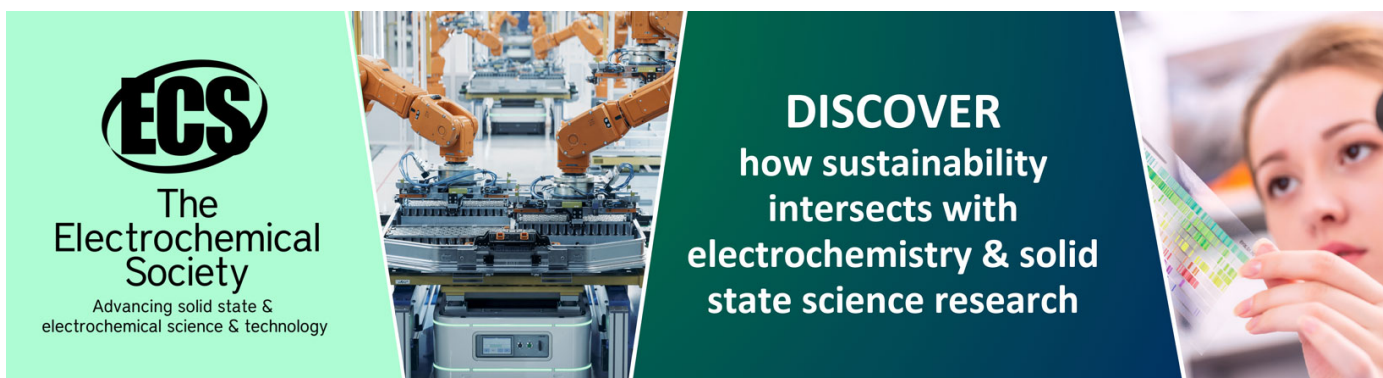
Field evaluation of rutting in concrete pavements

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Field evaluation of rutting in concrete pavements

V Ushakov¹, D Jelagin², G Dyakov¹, S Dmitriev¹ and M Goryachev¹

¹Moscow Automobile and Road State Technical University (MADI), 64, Leningradsky ave., Moscow, 125319, Russia

²Royal Institute of Technology, Department of Civil and Architectural Engineering, Division of Building Materials, Stockholm, Sweden

E-mail: madi-ushakov@mail.ru, jelagin@kth.se

Abstract. Surface wear by studded tires is a primary cause for rutting in portland cement concrete (PCC) pavements, and may, for the pavement sections with high traffic intensities, become a primary factor controlling the length of pavements maintenance intervals. In the present study, PCC pavement field performance with respect to surface wear is examined based on the transverse surface profile measurements performed yearly during first five years of pavements service life. Continuous transverse surface profile measurements have been performed yearly on a 20 km long rigid pavement section in Moscow region, Russia. Based on the measurements, quantitative parameters describing rut depth evolution are obtained and evaluated; the obtained results are discussed in context of previous research findings reported in the literature. The effect of pavement surface wear on the further rutting accumulation rate is examined. The particular attention is also given to the spatial variability of the measured pavement surface wear characteristics, i.e. rut depth and accumulation rate. The implications of the obtained results on the length of rigid pavement maintenance intervals are discussed.

1. Introduction

Rutting is one of the primary modes of pavements distress, controlling to a great extent the length of road service life. As discussed in several previous studies, a primary cause for rutting in portland cement concrete (PCC) pavements is surface wear by studded tires [5, 6]. In fact, for either PCC or asphalt concrete pavement sections with high traffic intensities, the studded tire damage may become a primary factor controlling the length of pavements maintenance intervals [6, 16]. Furthermore, pavement surface wear by studded tires generates significant amounts of dust and represents thus a significant source of air pollution [20], and may create polishing effects which may affect friction properties. Moreover, ruts are also creating serious safety risks when water cannot flow off or when vehicles suffer fishtailing when changing the traffic lanes. Accordingly, understanding the material, traffic and environment parameters controlling the rate of pavement surface wear is of profound importance for identifying pavement construction practices that are optimal from life cycle cost perspective as well as for quantifying full socio-economic effects of using studded tires. The present study aims at providing further insight into the issue through examining PCC pavement field performance with respect to surface wear.

The factors controlling the accumulation rate of studded tire wear have received considerable attention in the literature [14]. Damage of aggregates due to stud impacts with subsequent removal of material fragments by the scraping action of the stud may contribute significantly to the pavement surface wear [15]. Accordingly, ensuring adequate resistance of the aggregates to contact induced damage is crucial for ensuring adequate pavement performance with respect to surface wear [7, 12, 16].



The factors affecting the surface wear rate may be categorized as pavement, environment, traffic, vehicle and tire [13]. Regarding the pavement the most important factors were found to be the section geometry, pavement surface material and surface condition (i.e. its temperature and the presence of water, snow or ice). Generally, PCC pavements are reported to have a slower rutting rate as compared to the asphalt ones [5, 20]. It has however to be pointed out that for the case of asphalt pavements, isolating load related rutting from surface wear is a difficult task [5]. Furthermore, the rate of surface wear in PCC pavements varies significantly with time. The PCC pavements wear faster during their first 5 years of service, which may be attributed to the fact that wear is dominated by the removal of cement paste from pavements surface finishing [6]. The wear rate is reduced when the damage to underlying aggregates becomes a controlling factor.

Traffic and vehicle characteristics affect pavement surface wear rates profoundly; obviously, high share of studded tire traffic on the road and long periods of winter road conditions promote surface wear. Studded tire characteristics, in particular the number of studs, their weight and geometry affect the pavement surface damage rate profoundly [17]. The pavement surface damage induced by studded tires depends also on vehicle's driving regimes and traffic speed. In areas of acceleration and braking, the pavement wear is generally found to be higher as compared to the sections with uniform traffic speeds [14]. In fact, the influence of traffic speed on the pavement wear rate may be profound; for instance, according to the data presented by Unhola [17], changing the uniform traffic speed from 80 to 120 km/h results in approximately 3.5-time increase in pavement wear.

It may be concluded from the above that pavement surface wear by studded tires is a complex multi-factor problem. Accordingly, wear rates reported in different studies vary considerably [6, 14]. Correspondingly, the influence of studded tire traffic on service life of PCC pavements has to be examined at representative traffic and environmental conditions. Several PCC pavements constructed recently in Russia have exhibited severe rutting during few years after construction [18, 19]. As argued in their study, damage from studded tires may be a primary cause for the excessive rutting observed. The pavement sections examined by Ushakov and Diakov [18] belong to major highways with a speed limit of 130 km/h. Presently, there is, however, only a very limited amount of the quantitative data on surface damage accumulation in high speed PCC pavement sections.

In the present study the implications of studded tire traffic on service life of rigid pavements are evaluated for traffic and environmental loading conditions representative for the Moscow region in Russia. In particular, transverse surface profile measurements have been performed yearly on a 20 km long rigid pavement section in Moscow region. Based on the measurements obtained during the first five years of service life, quantitative parameters describing rut depth evolution are presented. The effect of pavement surface state and traffic characteristics on the accumulation rate of the rut depth is examined. The results are discussed in context of previous research findings from literature. Particular attention is given to the spatial variability of the measured characteristics of pavement surface wear, i.e. rut depth and rutting accumulation rate. The implications of the obtained results on the length maintenance intervals for rigid pavements are discussed.

2. Field Performance Study

The examined road section is located at federal highway M4 "Don" between kilometer marks of km 52+000 and km 71+000. The reconstruction of the road section, finished in 2011, included both road widening and re-paving. During reconstruction, the width of the median strip has been reduced and an additional lane in each direction has been constructed. The plan of the reconstructed road section is shown in Figure 1 along with the pertinent dimensions (in meters) as well as lane and wheel path notation used in this report. The inner to outer lanes are designated from 1 to 3. The north- and south-bound lanes are designated with "+" and "-" signs respectively. In order to designate the measurements performed in the left and right wheel paths letters "R" and "L" are added to the lane designation.

The structural design of the road section is uniform for the whole section. As part of the reconstruction, the existing PCC pavement course has been removed and the section has been repaved. The resulting pavement cross-section is depicted in Figure 2. The section is exposed to quite intensive

traffic, with average daily vehicle count exceeding 55 thousands. During winter driving conditions, the share of studded tires on passenger cars is close to 100%. The maximum allowable speed limit along the section is set to 130 km/h for the vehicles with the gross weight below 3.5 tons. As a result, the heavy vehicle traffic is basically fully confined to the outmost road lanes (i.e. lanes ± 3).

In order to investigate the rate of rutting accumulation in the road section described above, continuous transverse profile measurements have been performed yearly between 2012 and 2016. As the pavement reconstruction has been finished in 2011, the obtained results correspond to the first 5 years of pavements life. Profile measurements have been performed with the road surface testing vehicle developed at MADI University, Russia. The surface testing vehicle, illustrated in Figure 3, combines video recording of the road surface with continuous longitudinal and transverse profile measurements. The laser profile measurement system incorporates accelerometers to compensate for vehicle movements and allows for the road transverse profile measurement with an approximately 1.2 meters step. The transverse profile measurement results are also illustrated in Figure 3. In order to calculate the rut depth, for a given measured transverse profile, a straight line, with a slope corresponding to the sections superelevation at this point, is fitted to the profile. The rut depth is obtained then as a vertical distance from the fitted line to lowest points in the left and right wheel paths.

Based on yearly transverse profile measurements, the pavement surface deterioration is examined as follows. The measurements illustrated in Figure 3 are used to calculate average rut depths at 25 meter increments for all lanes and wheel paths. Rutting accumulation rate is obtained then as difference between rut depths measured in two consecutive years. In order to examine the spatial distribution of pavement surface wear, cumulative distributions of the rut depths are calculated for all lanes examined and the results are compared with average values per lane.

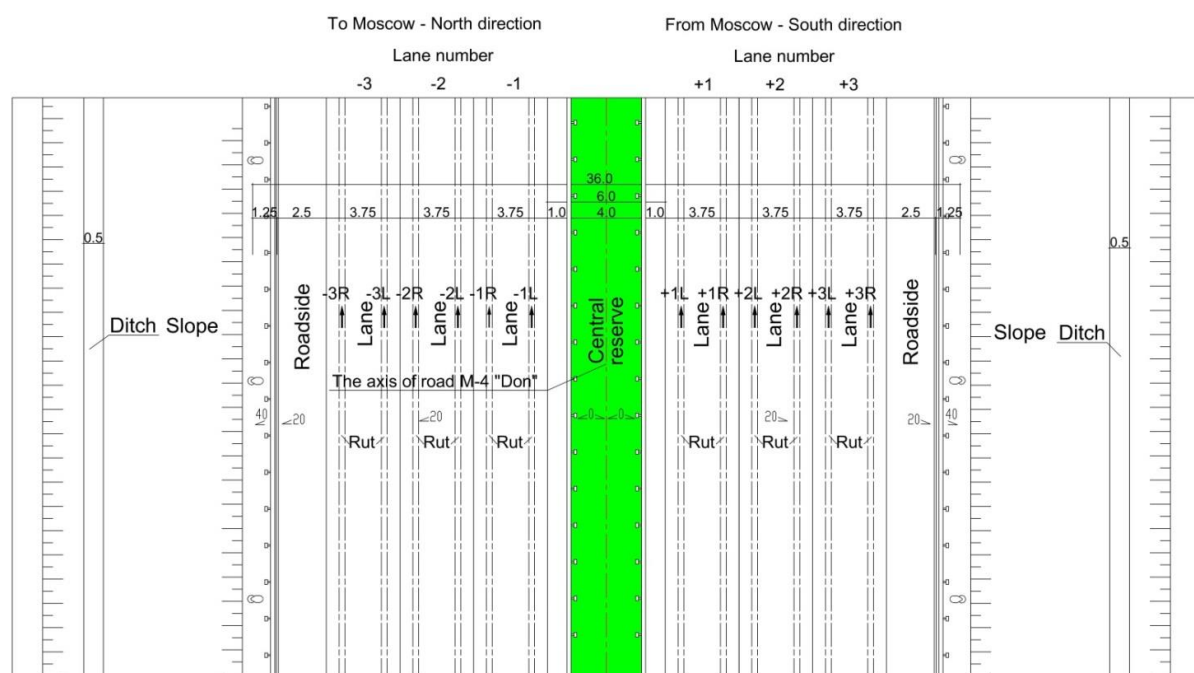


Figure 1. Plan of the reconstructed road section

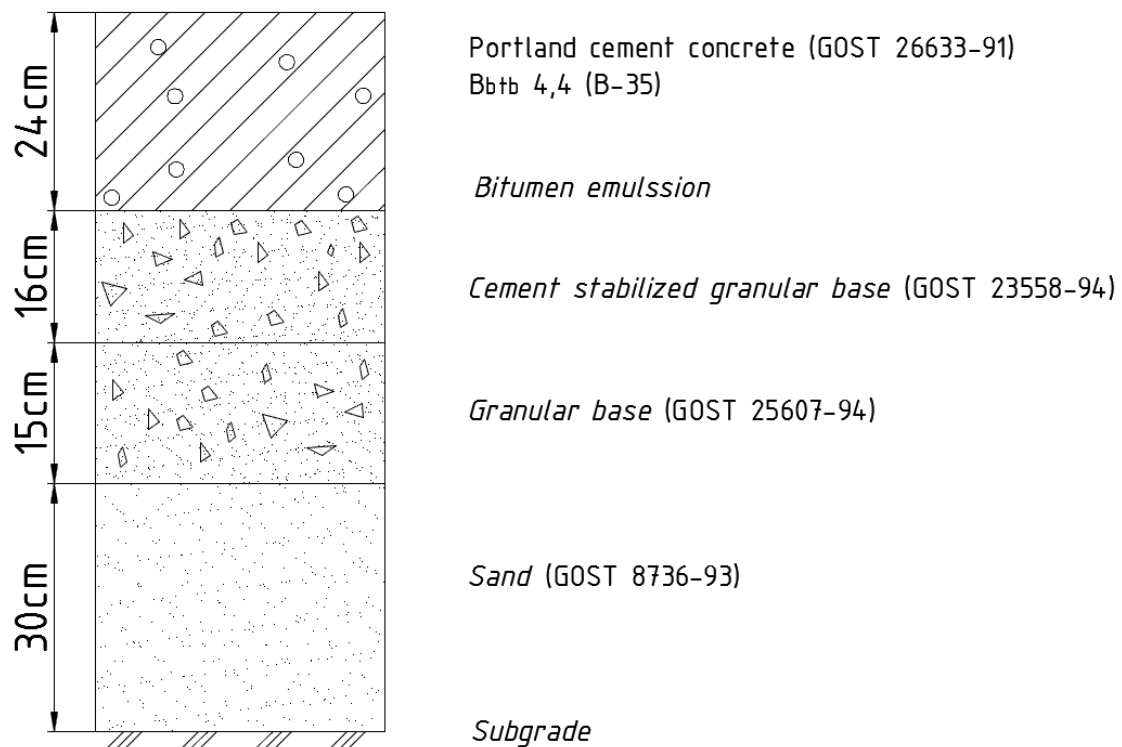


Figure 2. Structure of the rigid pavement section after reconstruction.

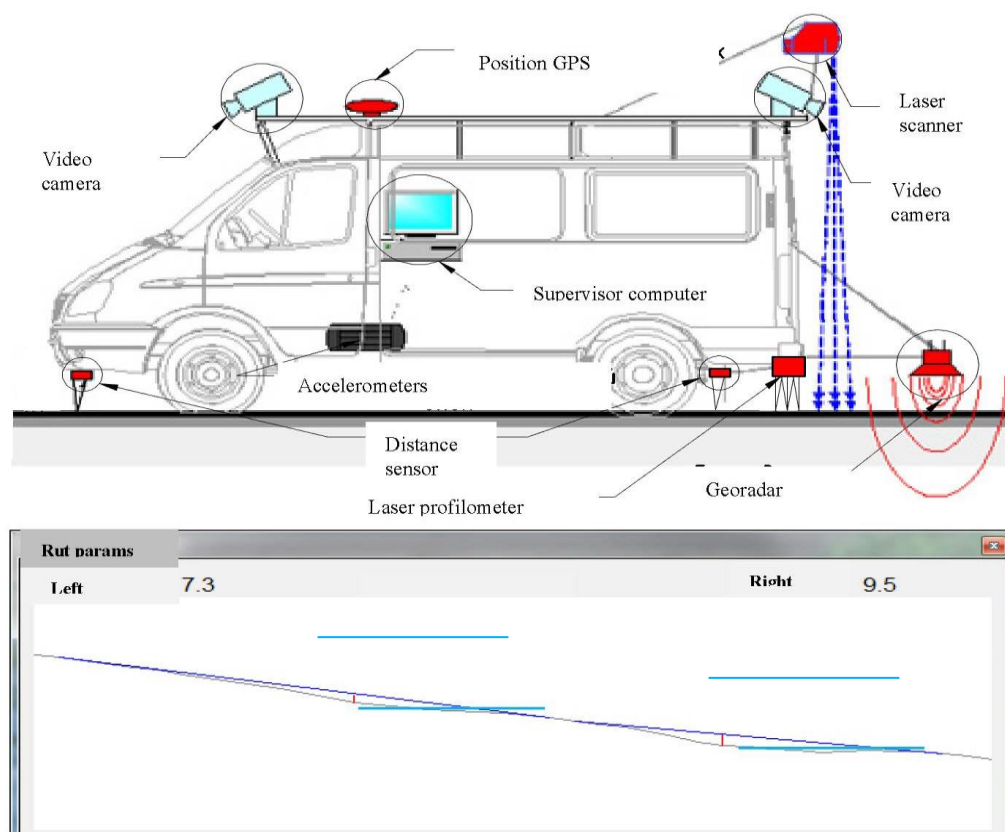


Figure 3. Measurement vehicle and measurement data illustration (the data point shown corresponds to lane -1, km 66+500)

3. Results and Discussion

3.1. Rutting evolution with time

Attention was focused first on the evolution of the transverse pavement profiles; results are presented using lane and wheel path notations of Figure 1. Figures 4 and 5 show the evolution of average rut depth in each wheel path over time as obtained from transverse profile measurements for North and South bound lanes. As may be seen in Figures 4–5, the measurements for the left and right wheel paths are fairly consistent for all the lanes. In most cases the difference in rut depth measurements is less than 1 mm and the maximum difference between the measurements obtained in the left and right wheel path is approximately 2 mm. Obviously, the observed surface wear is highly dependent on the lane. According to Figures 4–5, the inner lanes accumulate rutting at least twice as fast as than the outmost lanes. This was expected, as the outmost lanes are primarily used by heavy traffic and accordingly both traffic speed and proportion of studded tire traffic is higher for the lanes 1 and 2.

As it may also be noticed in Figures 4–5, the rut depth accumulation rate varies significantly with time. A particularly high rutting rate is observed during the first year of service for all the lanes examined. This observation may be associated with the faster wear of cement paste from the pavements surface finishing [6]. The average rutting accumulation rates per lane are also reported in Table 1. As may be seen in Table 1, after the first service year, the rutting accumulation rate drops significantly and starts to increase again during service years 3–5.

It has to be pointed out that for all the cases examined the observed rutting rates are quite high, being above 0.5 mm/year for virtually all the cases examined. At average wear rates above 0.5 mm/year the surface wear will become a primary factor controlling service life of rigid pavements [6]. The average wear rates measured during first five years of pavements service are above 2mm/year for lanes 1 and 2, cf. Table 1. Also, in contrast to observations reported by Cotter and Muench [6], rutting rate does not reduce with years of service. Rutting rate reduction was attributed in their study to change of rutting mechanism from wear of the cement paste to aggregate damage. This qualitative discrepancy between the results in Table 1 and the ones reported by Cotter and Muench [6] may be explained by the differences in traffic speed, material properties and winter maintenance approaches. In order to evaluate whether material related factors are responsible for the excessive wear observed, the intention is, as part of the future studies, to conduct an experimental study for quantifying the resistance of both cement concrete and aggregates to abrasive wear.

3.2. Spatial distribution of rutting

In order to investigate spatial distribution of surface wear, maximum rut depth values for each 25 meter interval of the pavement section have been calculated based on the transverse profiles measured after 5th years of the roads service life. The rut depth distribution obtained is presented in Figure 6 for the North- and South-bound lanes 1, having their average rut depth values of 10.5 and 12 mm respectively. As may be seen, there is considerable spatial variation in the pavements surface wear, with rut depths varying between approximately 5 and 20 mm for both lanes examined. Regions with extremely high rutting (with rut depth of approximately 20 mm) are not concentrated to any given location, but rather more or less uniformly distributed along the section. These regions, representing severe driving safety concern with respect to hydroplaning, are not captured adequately with the average rut depth measures. Accordingly, the results presented in Figure 6 emphasize the importance of examining the spatial distribution of rutting for supporting pavement maintenance decisions.

Based on the high gradients of rutting presented in Figure 6 (rut depth often changes more than 5 mm over 250 meters intervals), it may be argued that the observed variability is due to traffic characteristics, i.e. it's speed, density and driving conditions. This conclusion is indirectly supported by the consistently lower rut depths observed at the ends of the monitored section, as the toll stations located there results in both lower traffic speed and more uniform distribution of traffic over the lanes. However, a detailed investigation of the factors affecting variability of rut depth lies beyond the framework of the present study.

The spatial variability of rutting measured in lanes 1 after 5 years of service is further examined in Figure 7, where cumulative distribution of rut depth along the lanes is presented. As discussed above, the average rut depths for the north- and south-bound lanes 1 differ by approximately 15 %, and, as seen in Figure 7, cumulative distribution of rut depths in the North-bound lane is somewhat lower than for the South-bound lane. At the same time, the tails of the cumulative distributions presented basically coincide, with basically 100 % of the section having a rut depth of at least 5 mm and 10 % of the section stretches having a rut of at least 17 mm. Accordingly, results presented in Figure 7, indicate that the average rut depth does not provide a fully adequate measure of pavements surface wear. In particular, the difference in the length of the repairs for the north- and south-bound lanes 1 may vary between 0 and 30 %, depending on the threshold rut depth (i.e. rut depth requiring maintenance). This again emphasizes the importance of incorporating spatial characteristics of rutting into pavement management decisions.

In order to examine the influence of rut depth on accumulation rate of rutting, average yearly rutting rates are presented in Figure 8 as function of the rut depth measured in the previous year. The average rutting rates reported in Figure 8 for the south-bound lane 1, were obtained as differences between the profiles measured in two consecutive years. Based on the rutting rates calculated for each 25-meter stretch of the lane, average rutting rates have been determined for the rut depth intervals presented in Figure 8. As may be noticed in Figure 8, rutting rates are significantly higher at the points where accumulated rut depth exceeds 6 mm. Primary factors responsible for this increase in the pavement surface degradation rate may be speculated to be as follows. As discussed, presence of water at the pavement surface increases the pavement wear from studded tires [14, 20]. Obviously, presence of significant amount of rut depth will hinder water removal from the road surface and thus increase further rutting accumulation rate. Deep ruts may furthermore increase dynamic tire road interaction forces as well as reduce lateral traffic wander, thus concentrating wear of pavement surface to narrower regions.

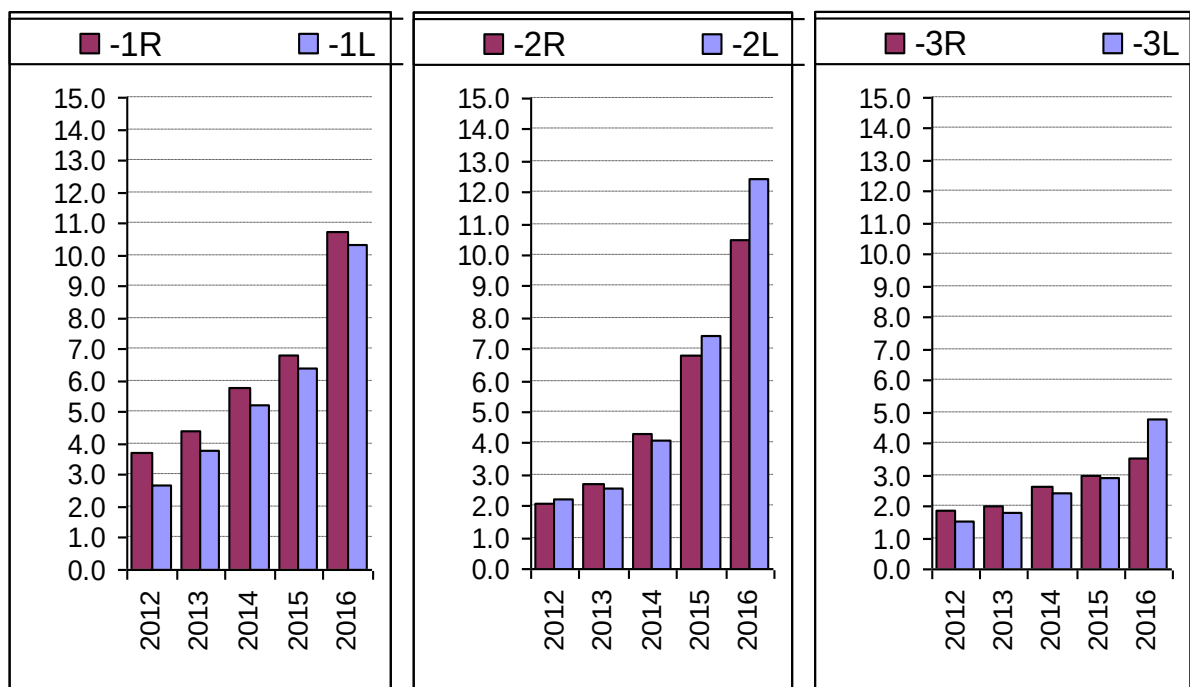


Figure 4. Rut depth accumulation in North-bound lanes

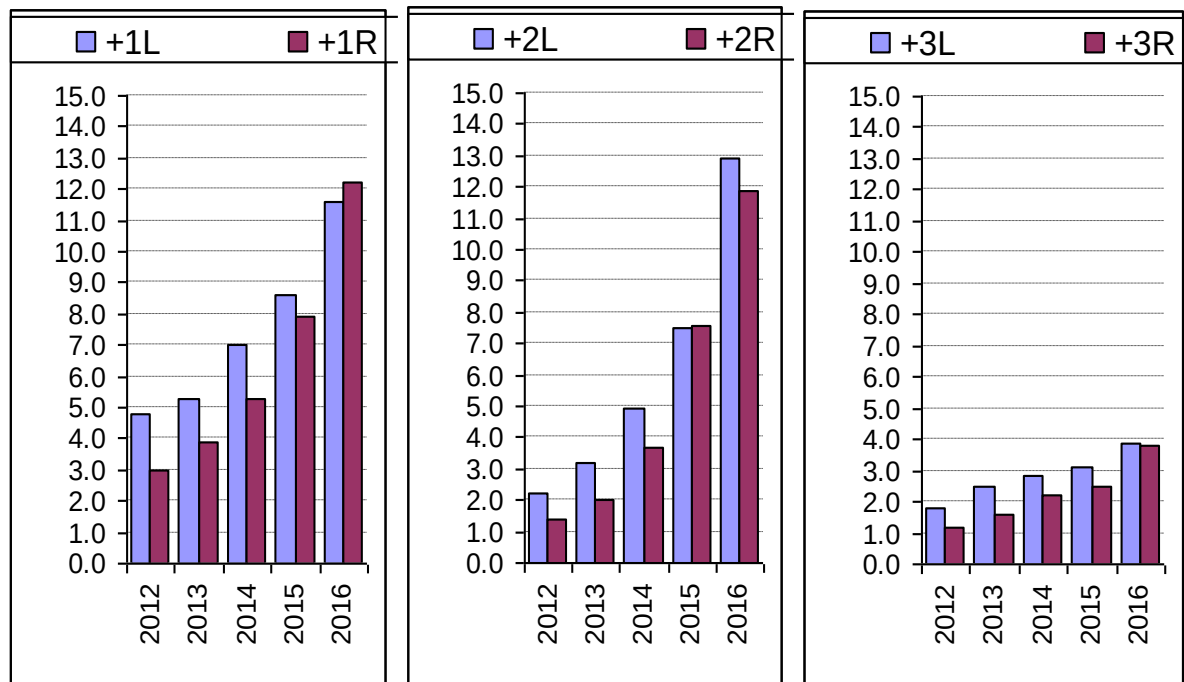


Figure 5. Rut depth accumulation in South-bound lanes.

Table 1. Average rutting rate (in mm).

Years of service	Lane					
	-3	-2	-1	+1	+2	+3
1	1.7	2.2	3.2	3.9	1.8	1.5
2	0.2	0.5	0.9	0.7	0.8	0.6
3	0.6	1.6	1.4	1.6	1.7	0.5
4	0.5	2.9	1.1	2.1	3.3	0.3
5	0.8	4.4	3.9	3.7	4.9	1.1
<i>Average</i>	<i>0.8</i>	<i>2.3</i>	<i>2.1</i>	<i>2.4</i>	<i>2.5</i>	<i>0.8</i>

3.3. Discussion

From the results presented in Figures 4-8 and in Table 1, it may be concluded that rutting controls the service life of the rigid pavement section examined. The rut formation is fully attributed to the surface wear by the studded tire traffic as underlined by significantly lower rutting rate in the outer lanes where traffic is predominantly composed of heavy vehicles equipped with stud-less winter tires.

Major corrective maintenance techniques for restoring smoothness of rigid pavements include surface grinding and construction of either asphalt or PCC wearing courses. by However, while diamond grinding is the most economical solution with respect to restoring pavement smoothness it does not address the underlying structural and/or material defects of the pavement [6]. Accordingly, given the severity of rutting observed within the first 5 years of pavement life, construction of wearing course overlay is a most feasible maintenance method.

Hard and coarse aggregates tend to slow (but not prevent) studded tire wear for both asphalt and cement concrete overlays [6, 16]. Accordingly, it is crucial that aggregates with the best performance in durability and soundness tests such as Los Angeles (LA), micro-Deval abrasion and aggregate soundness tests [1–3] are used in the wearing courses. As pointed out above in connection to Table 1, rutting rates measured in this study are not decreasing with years of service, in contrast to the results reported in Cotter and Muench [6]. In fact, as illustrated in Figure 8, rutting rate rather tends to increase with the accumulated rut depth. These observations provide an indication of inadequate abrasion

resistance of the aggregates. With respect to cement concrete wearing courses, several concrete additives with the potential to improve concrete's resistance to abrasive wear have been proposed and evaluated [4, 19]. The evidence with respect to the effect of those additives on the material wear performance in the field is still lacking and needs to be investigated further [4].

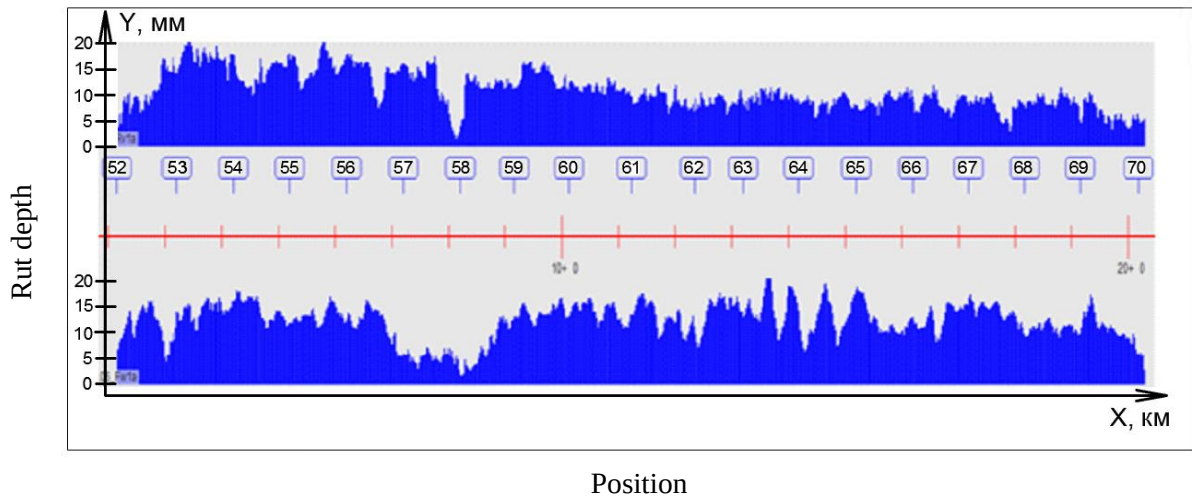


Figure 6. Spatial variation of the measured rut depth for lanes 1; a) North bound; b) South bound.

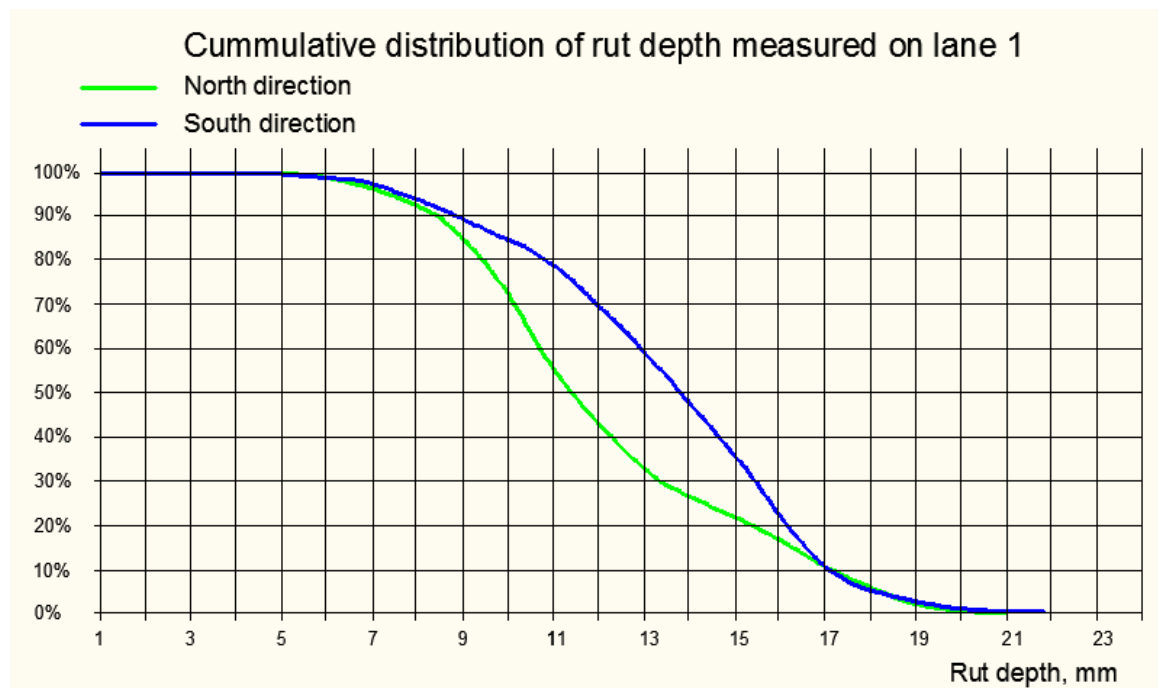


Figure 7. Cumulative distribution of rut depth measured on lanes 1, north and south bound after 5 years of service life.

In addition to material related factors, extremely high rutting rate observed in this study may be attributed to traffic parameters, and in particular, traffic speed may have a profound influence on the pavement surface wear [17]. The section examined belongs to the primary highway network with the maximum allowable speed limit of 130 km/h, being above the speed ranges commonly accounted for in the literature. It is thus essential to investigate the resistance of wearing courses to studded tires at speeds

representative for the intended application. In this context, accelerated pavement testing under representative vehicle-road interaction conditions (i.e. speed, tire type, temperature and humidity), may provide a useful link between material properties and expected performance in the field. Hence, it is the intention of future studies, to identify the optimal wearing courses by combining extensive material characterization, with particular focus on aggregates durability and soundness, and the evaluation of road surface wear, based on the road simulator tests at representative climate conditions and at speeds ≥ 130 km/h.

It has also to be pointed out, that the dependency of the rutting rate from accumulated rut depth emphasizes the importance of taking into account spatial variation in the pavement surface wear as well as variation of pavement surface wear rate evolution with time for accurate estimation of the remaining pavement service life. In fact, taking a rut depth of 20 mm as a maximum allowable rutting, the remaining service life of a PCC pavement under studded tire traffic can be estimated to be approximately 4 years, based on the data in Figures 4–5 and Table 1. At the same time, as seen in Figure 7, more than 70 % of lane 1 have accumulated rut depths exceeding 10 mm during the first 5 years of service. Accordingly, based on the results in Figure 8, rutting rate may be expected to exceed 5 mm/year, resulting in less than 2 years of remaining life. Furthermore, according to Figure 8, sections with rutting above 14 mm (25 to 50 % of lanes 1, as illustrated in Figure 7), may, be expected to accumulate a maximum allowable rut depth of 20 mm within a year. It may be concluded thus that yearly transverse profile measurements improve estimation of the remaining service life and are therefore very useful tools in pavement maintenance and rehabilitation planning.

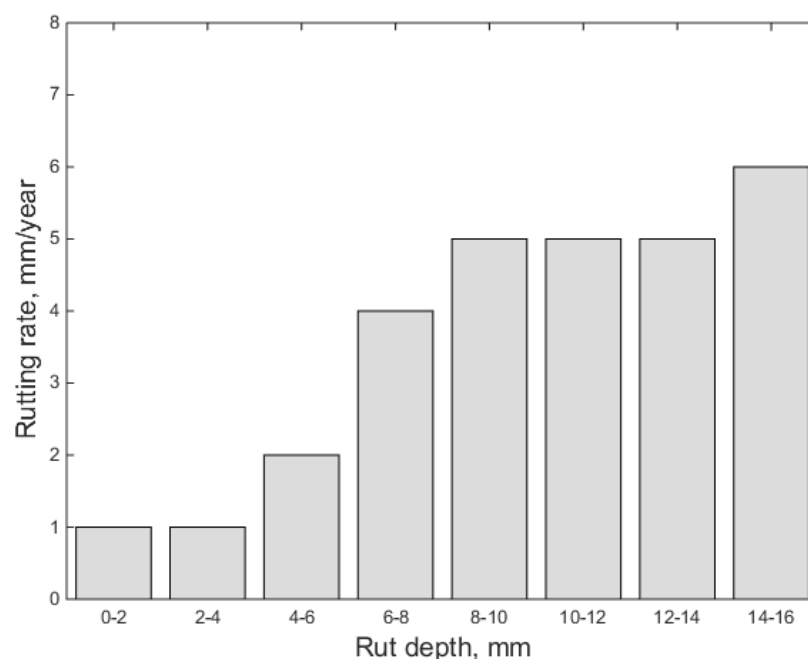


Figure 8. Rutting rate as function of rutting depth measured in previous year.

4. Conclusions

A field study of surface deterioration of a rigid pavement has been performed in order to evaluate the influence of surface wear on the service life at traffic and climate conditions representative for the highway network in the Moscow region, Russia. For the road section examined, yearly transverse profile measurements have been performed for the first 5 years of pavements service. Based on the profile measurements, average rut depths and yearly rutting accumulation rates have been calculated at 25 meter increments for all pavement lanes. The main findings of the study may be summarized as follows:

- The surface wear of the road is significantly higher for the inner lanes as compared to the outmost lanes. In particular, rutting accumulated during first five years of pavements service life has been found

to be at least 2 times higher for the inner lanes as compared to the outmost lanes. Furthermore, rutting accumulation rates measured at 5th service year were approximately 4 times higher for the inner lanes. These differences are attributed to traffic composition, as the outmost lanes are primarily used by slow heavy traffic with stud-less tires whereas the inner lanes 1 and 2 were subject to high speed traffic with a high share of studded tire vehicles

- The rut depths and rates measured for lanes 1 and 2 indicate that pavement wear by studded tire traffic is quite significant. Indeed, assuming 20 mm maximum allowable rut depth shows that wear by studded tires becomes a dominant mode of failure controlling the length of maintenance intervals. Supported by results from literature, severe rutting of the section may be attributed to high traffic speed and inadequate aggregate durability. The detailed experimental investigation of the influence of material parameters on pavement wearing rate was beyond the scope of this study and will be performed as a part of future work.

- Measured rut depths and rutting accumulation rates were found to exhibit significant spatial variability, where regions with excessive rutting were in general uniformly distributed throughout the section. Furthermore, rutting rates were found to be dependent on the accumulated rut depths. In particular the sections with rutting exceeding 6 mm were found to have at least twice as high rutting rate as compared to those with less rutting. This may be attributed to the fact that presence of significant amount of rutting may hinder water removal from the road surface, increase dynamic forces applied to the pavement surface and reduce lateral wander of the traffic.

- Based on observed variability of measured rut depths and rates it was shown that yearly continuous transverse profile measurements allow more accurate predictions of the remaining pavement service life as compared to those based on the average rut depths and rates. Accordingly, taking into account spatial variability of rutting and rutting rate evolution with time may improve pavement maintenance and rehabilitation planning.

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