EVALUATION OF EFFECTS OF ROAD MAINTENANCE ACTIONS ON APPLIED TYRE LOADS

W.J. vdM. Steyn

Department of Civil Engineering, University of Pretoria, Pretoria, South Africa
wynand.steyn@up.ac.za

Abstract
Preservation of a road network requires adequate maintenance of the road network and enforcement of the traffic load limits on the road network. The riding quality of a pavement surface is used as one of the primary parameters to evaluate the condition of the road network. When a pavement deteriorates the riding quality also deteriorates with a subsequent increase in variability in applied tire loads to the pavement. During maintenance, the causes of deterioration are typically fixed to varying degrees with the objective of reinstating the condition of the pavement. When such maintenance is not conducted to adequate standards, it may leave the pavement surfacing intact while the riding quality of the road is still inadequate. Such inadequate riding quality will affect the variability of the tire loads applied to the pavement negatively, with a higher variability and subsequent overloaded conditions applied to the pavement in the vicinity of the maintained sections. This paper evaluates the effects of the development of potholes and the maintenance of these potholes on the riding quality of a pavement section, and the effects that these deterioration and maintenance have on the applied tire loads evaluated.

1. INTRODUCTION

Real traffic applies moving dynamic tyre loads to pavements (Cebon, 1999). The cause for the dynamic nature of the tyre loads is mainly the roughness of the pavement surface (Steyn, 2001). Various vehicular and pavement parameters influence the precise values of the moving dynamic tyre load population. These include the actual pavement profile, the speed of the vehicle, the dimensions of the vehicle, the components incorporated in (mainly) the suspension of the vehicle and the load on the vehicle. Current South African pavement design and analysis techniques assume a specific equivalent load that is applied to a pavement structure through a circular area with uniform contact stresses. Although these assumptions are used internationally, attempts are currently underway to incorporate the effects of moving dynamic tyre loads on pavements during the pavement design process (Theyse et al, 2007). Normally the assumption requires four 20 kN tyres (with specific contact stress patterns and values – tyre-pavement contact stresses are excluded in the analysis for this paper) applying an 80 kN standard axle load to the pavement.

Road maintenance is required to maintain the condition of the road surface and structure adequate to ensure a smooth, safe and reliable trip for the traffic using the road, while protecting the underlying materials against undue stresses and strains and premature failure. A pavement is typically designed to carry a minimum of a specified number of standard axles, before it is accepted that rehabilitation may be required to reinstate the condition of the pavement (also depending on the effects of the environment). During this process, good road management practice requires regular maintenance of the pavement (specifically the surfacing) to keep the condition of the pavement to a specific minimum requirement (typically defined in terms of the riding quality of the pavement). If this process is well planned and managed, the development of potholes (and other defects) on the road should be minimal and should be fixed immediately. This should assist the pavement to reach its intended design life (SANRAL, 2000).

However, due to inadequate planning, maintenance and maintenance management, it often happens that many potholes develop on a road surface, causing the road to deteriorate at a more rapid pace than would have been the case if the surfacing was kept intact. This is unfortunately currently the case on many South African metropolitan and provincial roads (Paige-Green et al, 2010).

Current emergency maintenance procedures for fixing these potholes typically includes the filling of these potholes using various types of pothole fillers, and excludes evaluation of the whole pavement and subsequent maintenance of the whole pavement. Although this preserves the underlying materials, the outcome is typically an uneven surface due to either too much pothole filler (waiting for traffic to compact it) or too little filler and inadequate density. These actions thus affect the road profile and the riding quality of the pavement. This in turn affects the generation of moving dynamic loads from the traffic using the road as well as accelerations in the vehicle and transported freight. These increased tyre loads shorten the life of the pavement as many of them are higher than the acceptable tyre loads and therefore overloading the pavement (although the truck is still statically legally loaded).

Previously, the effect of potholes on a smooth road surface was evaluated (Steyn, 2010). However, this excludes the effect of the actual riding quality of the road before the potholes form, and it excludes the effect that the filled potholes have on the generated tyre loads. This paper evaluates the effect of such a pavement where potholes initially formed (on actual measured pavement profiles) and were then filled, on the generated tyre loads and excess loads on the expected pavement life in terms of the applied E80s and the actual duration to apply these E80s (and therefore the duration of life for the pavement).

The paper starts with a short evaluation of the philosophy behind Vehicle-Pavement Interaction (V-PI), followed by an evaluation of the tyre loads generated as a rigid vehicle travels over three pavements with varying profiles and therefore varying riding quality. These analyses are shown for the pavement in a good (no pothole) condition, a condition with potholes (50 mm deep) at intervals of 50 m to 500 m, and the case where these potholes are filled to a height of 5 mm higher than the surrounding surface. It also provides a brief indication of the effects on expected vehicle maintenance costs and goods damage.

2. VEHICLE-PAVEMENT INTERACTION

Generically tyre loads vary in two ways. These are the variation of load between vehicles travelling on a pavement, and the varying loads applied by a vehicle along the pavement. The first type of variation is accommodated in pavement analysis through equivalent load concepts. The second type of variation is caused mainly by the pavement roughness-induced movement of the vehicle. This is traditionally termed dynamic pavement loading (DIVINE, 1997). The use of the term dynamic loading in pavement analysis refers to a load with a constant magnitude that is moving along a pavement or a load that is varying in load magnitude. Four types of vehicle loads can be defined (Steyn, 2001):

- Static Load (SL) – load magnitude is independent of time and position, and the position where it is applied is independent on time;
- Moving Constant Load (MCL) - load magnitude is constant but the position where it is applied is dependent on time;
- Dynamic Load (DL) - load magnitude is dependent on time but not on position and the position where it is applied is independent on time, and
- Moving Dynamic Load (MDL) – load magnitude is dependent on both time and position and the position where it is applied is also dependent on time.

Real traffic causes either SL or MDLs, while DL and MSL are mainly used in research to simplify the understanding of pavement response. The analyses in this paper focus on MDLs.

The riding quality of a road affects the experience of the road users significantly. The surface profile of the road translates through the tires and suspension of the vehicle to the body of the vehicle and then to the driver, occupants and cargo. In tire, suspension and vehicle engineering, a major focus area is the improvement of the vehicle's tires, suspension and the entire vehicle to respond better to changes in road surface profiles. Despite this, changes in the road surface profile still directly affect the type of vibrations that are experienced by the occupants and cargo. Therefore, the road surface profile is still a major consideration in the riding experience of road users. Various studies about the effect of the riding quality of roads on the vibrations and responses in vehicles have been conducted (Nisonger and Ervin, 1979; Singh et al, 1991; Jarimopas et al, 2005; King et al, 2010). The main conclusions from all studies are that, a decrease in the riding quality of a road is a major cause of increased vibrations, increased dynamic tyre loads and increased damage to vehicles and freight. The potential effects that worsening road conditions can have on the broader economy are depicted in Figure 1 (Steyn et al, 2009).

The effect of deteriorating riding quality on the MDL distribution of a vehicle on a road is illustrated in Figure 2. It indicates the MDL tire load distribution for a vehicle (constant load and speed) on four roads with road roughness values of 1 m/km, 2 m/km, 4 m/km and 8 m/km. As the riding quality deteriorates (IRI increases) the distribution becomes wider, indicating a higher proportion of loads higher than the average – therefore an increased proportion of overloaded conditions applied to the road by a legally loaded axle due to dynamic action.

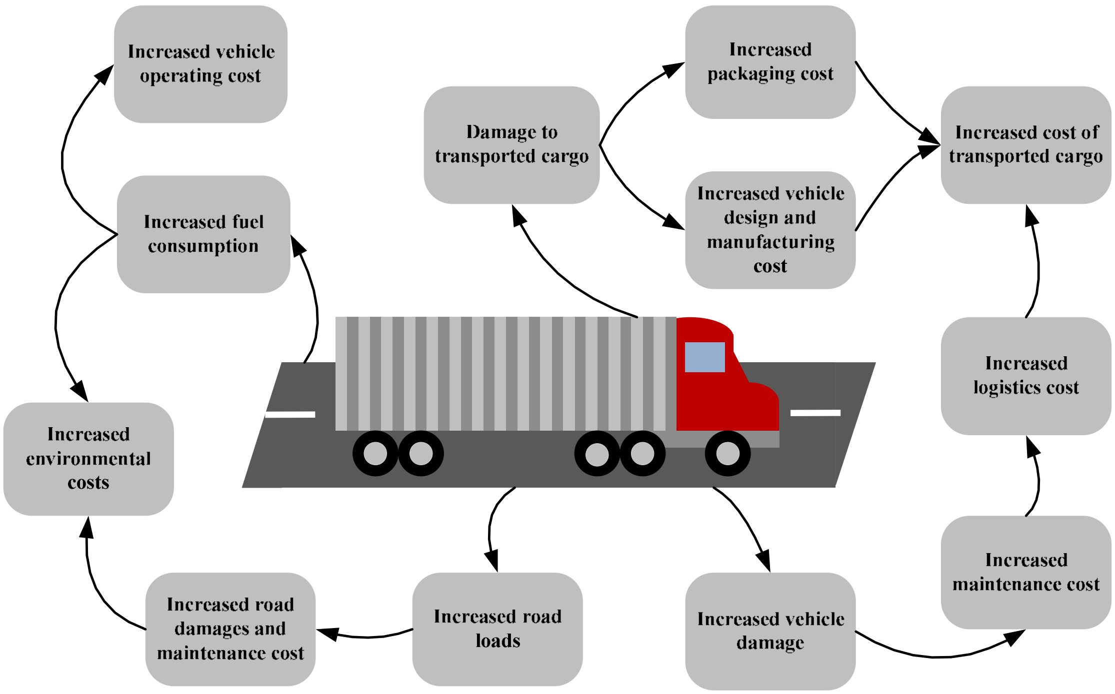

Figure 1: Conceptual indication of the effect of riding quality on truck logistics costs (Steyn et al, 2009)

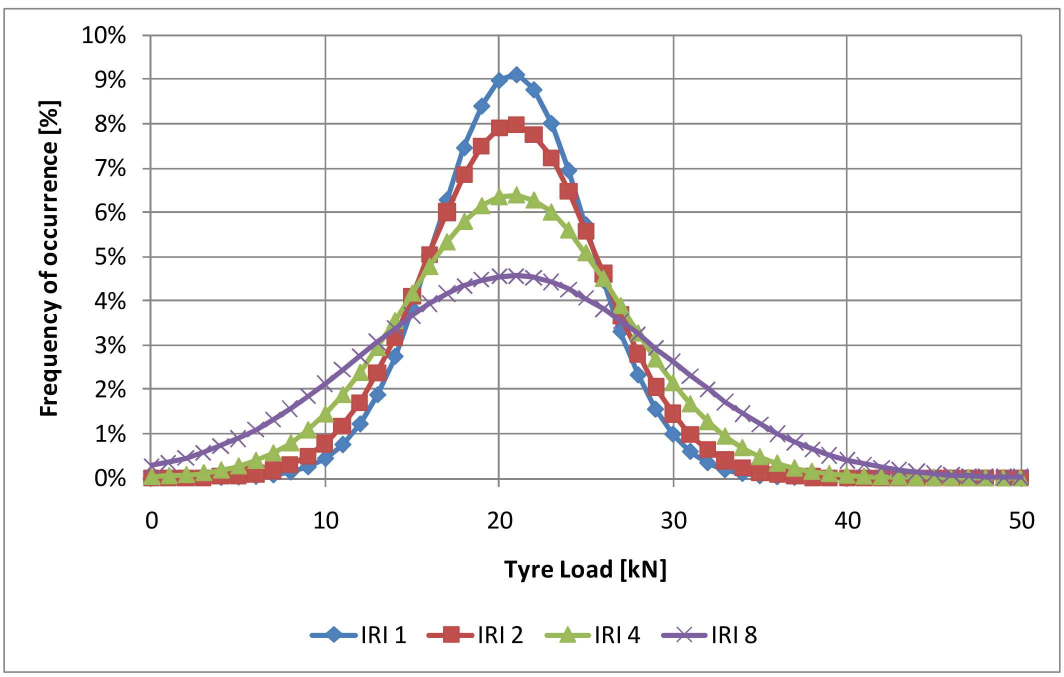

Figure 2: Conceptual indication of the effect of riding quality on truck logistics costs (Steyn et al, 2009)

3. VEHICLE-PAVEMENT INTERACTION SIMULATION AND ANALYSIS

3.1 Introduction

In this simulation and analysis the TruckSIM™ (2010) simulation package has been used to analyse the process where a rigid truck (2 axles) travels at a constant speed and load over two different road sections (1 km long) with varying riding qualities. Initially, the truck is allowed to travel over the road without any defects. This is followed by the same truck travelling over the same road, but potholes (50 mm deep in both wheeltracks) are introduced at intervals of 500 m, 250 m, 100 m and 50 m. Finally, the truck is travelling over the same road, but the potholes are filled to a height of 5 mm proud of the pavement surface. In the analysis the generated tyre loads over the different roads are compared to indicate the effect of both the neglect of road maintenance (causing potholes to develop) and the effect of localized filling of the potholes.

Prem et al (2001) did a comparison between simulations from computer-based models of heavy vehicles and real truck data and concluded that good response simulations can be expected from these vehicle-pavement interaction simulations. Local evaluations as part of the SANRAL update to the SA Pavement Design Method confirmed this (Steyn, 2010), and therefore the software is currently used in South Africa for V-PI simulations.

3.2 Analysis data and discussion

The two road sections used for the simulations are shown in Figure 3 (only right-hand wheeltrack shown for clarity). The riding quality of the sections was 1.8 m/km and 3.7 m/km (in terms of International Roughness Index). The IRI scale is indicative of the unevenness of the road profile, ranging from 0 mm/m as a perfect even road to 16 mm/m as an impassable road. Typical good road profiles will have an IRI of around 2 mm/m, while the South African National Roads Agency (SANRAL) report the percentage of travel undertaken on national roads with roughnesses less than 4.2 mm/m as at least 95 per cent over the last 5 years (SANRAL, 2009).

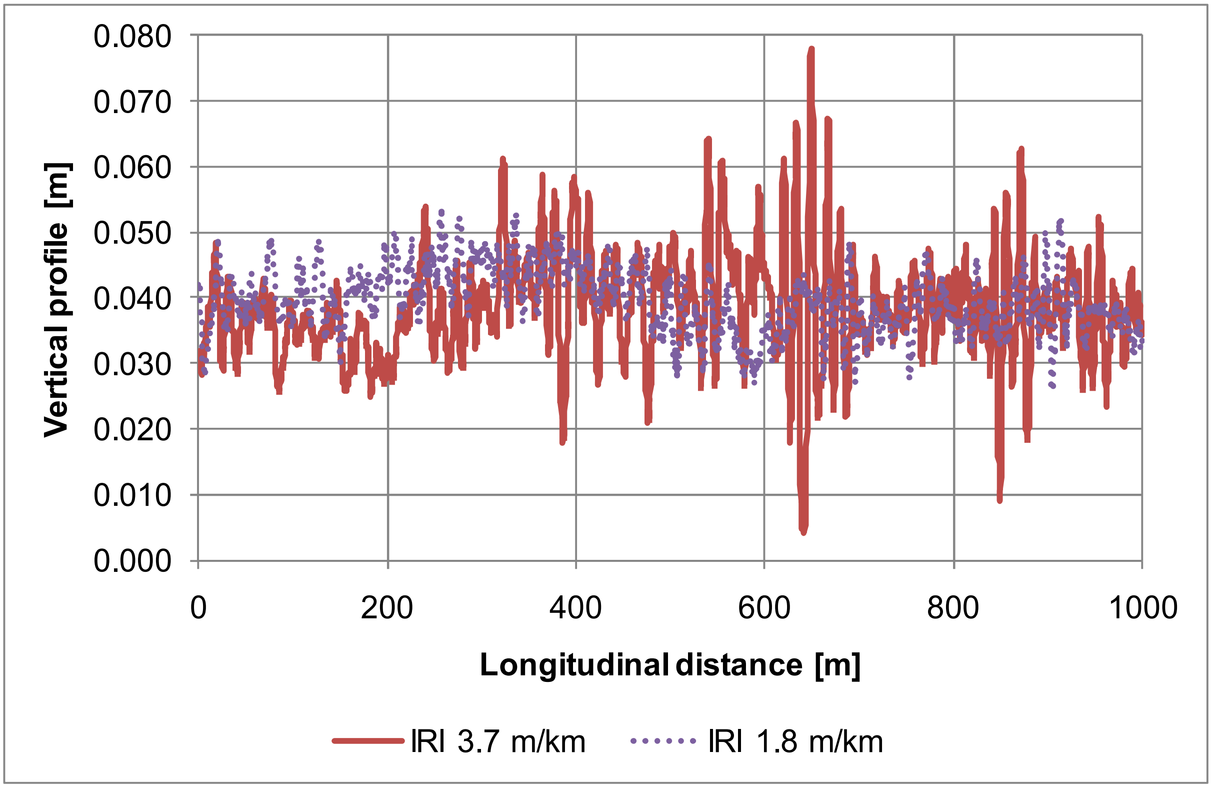

Figure 3: Road profiles for two road sections used in the simulations

Simulation of the Rigid vehicle travelling over these two road sections at a constant speed of 80 km/h at a legally loaded condition generated tyre loads for each of the six tyres (two on the steer axle and four on the drive axle) of the rigid vehicle at 560 mm intervals. As indicated, the simulations were conducted with the road in a condition without any potholes, with potholes at different intervals (between 50 m and 500 m), and with the same potholes in a filled condition.

Typical output for the tyre loads (indicated as a histogram of steer axle loads for the IRI 1.8 m/km road section, flat, 500 m interval potholes and filled and 50 m potholes and filled) is shown in Figure 4. Only axle loads between 35 kN and 60 kN are shown to enhance clarity of the graph. The effect of the spacing of the potholes is visible in the flatter and wider distribution of axle loads for the 50 m interval potholes. Although the 500 m interval open and filled potholes generated quite similar distributions, the 50 m interval filled potholes generated higher dynamic loads than the no pothole and 500 m interval pothole cases, as well as the 50 m interval open pothole case. This generally illustrates the trends found for all the tyre loads in the analyses.

The focus of the paper is on the effect of road maintenance on applied tyre loads and the effect that the maintenance or lack thereof has on the standard axles applied to the pavement, and therefore the duration of time before the pavement will require rehabilitation due to it reaching its design traffic load. In order to conduct this analysis, the axle loads for the vehicle were converted to standard axles (E80s) through a damage exponent of 4, and the resultant E80s compared to each other. The assumption was made that 50 of these vehicles travel on a road per day for 250 days per year.

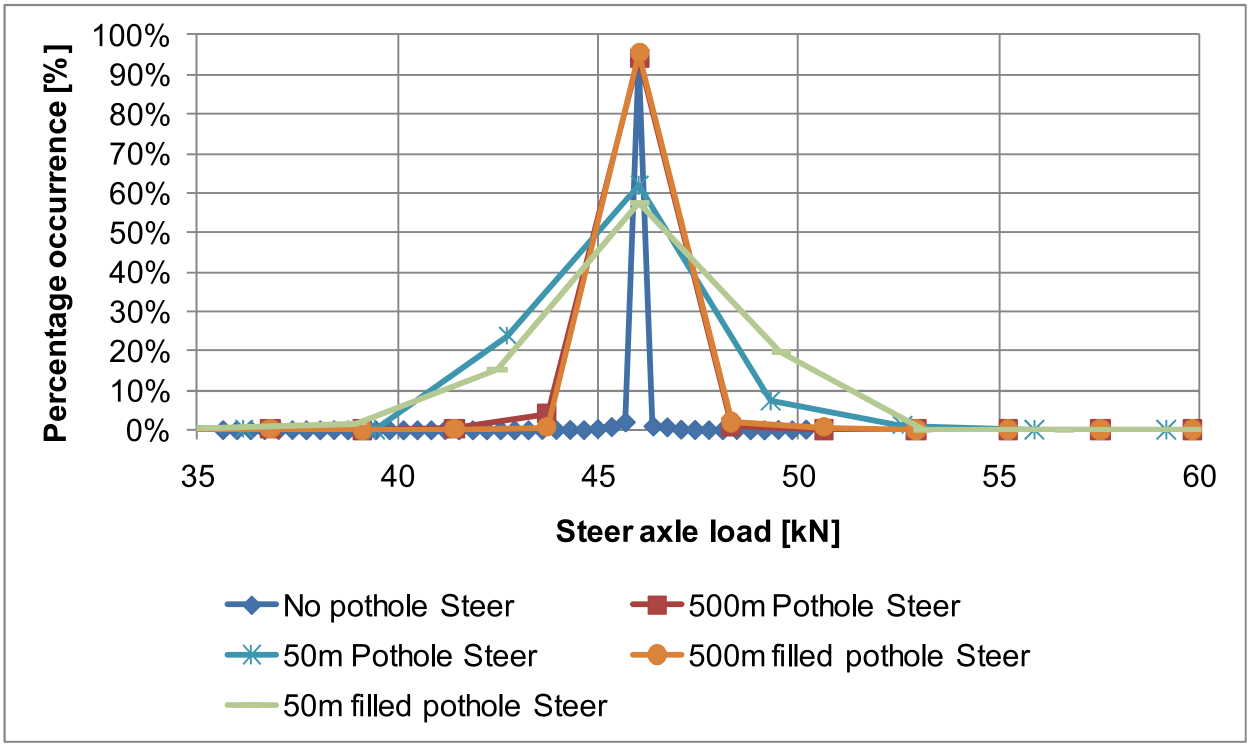

Figure 4: Steer axle load distribution for IRI 1.8 m/km road section (only data between 35 kN and 60 kN shown for clarity)

In Figure 5 the percentage increase in E80s between the no pothole scenario and both the pothole and the filled pothole scenarios are shown. Initial analysis of the graph appears to be counterintuitive, as it indicates that the presence of potholes on the IRI 1.8 m/km road cause a higher increase in E80s than the rougher IRI 3.7 m/km road. However, the data should be seen in conjunction with the actual number of E80s, where this number is 13 674 E80s for the no pothole scenario on the IRI 1.8 m/km road while it is 14 705 E80s for the same scenario on the IRI 3.7 m/km road. The higher increase due to potholes for the smoother road is the fact that the rougher road already contains a higher level of unevenness than the smoother road, and therefore the effect of the addition of both the potholes and the filled potholes on the smoother road will appear to be more severe.

When comparing the actual E80s on each of the scenarios (Figure 6) it is clear that on the IRI 1.8 m/km road, open potholes with an interval of between 50 m and 100 m can be allowed before the same number of E80s will be generated on this road than on the IRI 3.7 m/km road. The benefit of ensuring that the road is as smooth as possible during its life is thus clear.

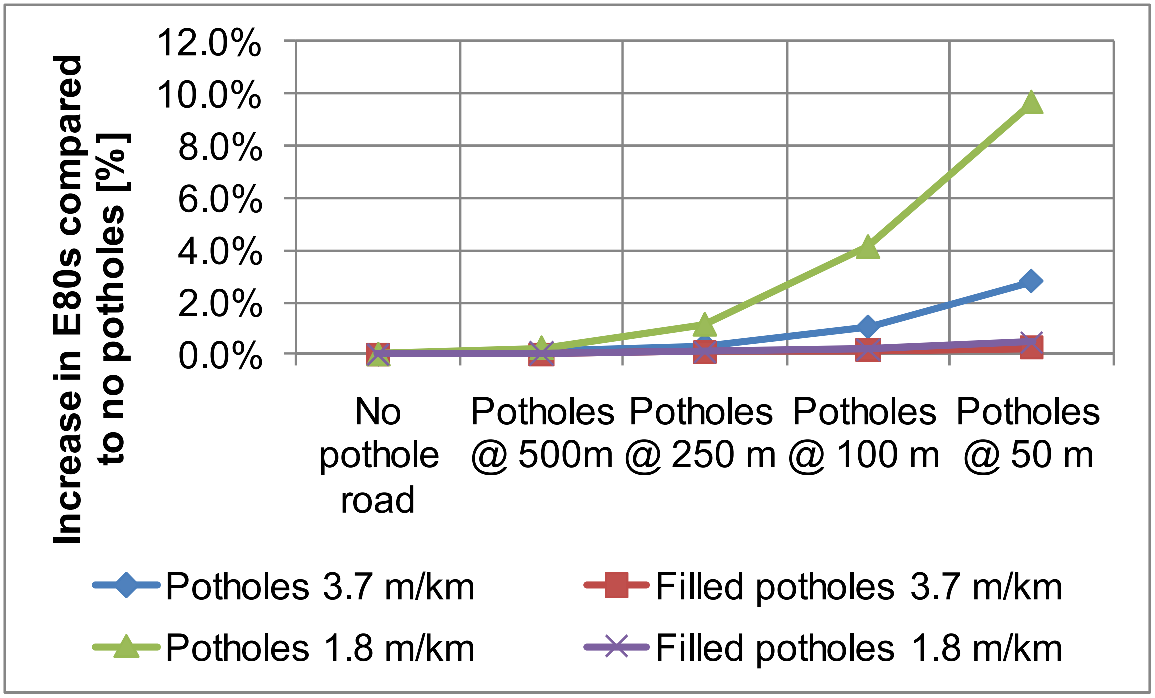

Figure 5: Percentage increase in E80s generated on IRI 1.8 m/km and IRI 3.7 m/km roads with open and filled potholes

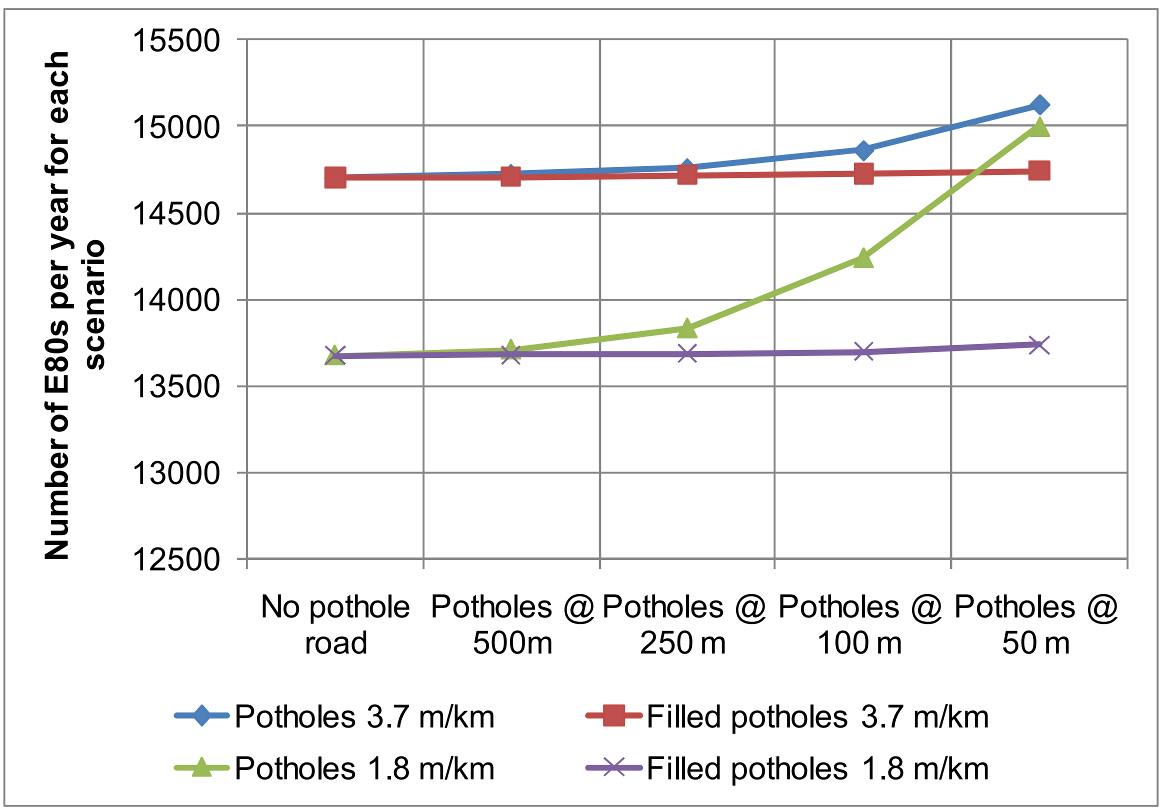

Figure 6: Comparison between actual E80s generated per year on IRI 1.8 m/km and IRI 3.7 m/km roads with filled potholes

Finally, the difference between a road without any potholes and a road where the potholes have been filled to the 5 mm high level discussed earlier is evaluated. Figures 5 and 6 indicates that the additional E80s generated by this increase in pavement roughness cause a much smaller increase in E80s over the life of the pavement, between 0.3 per cent and 0.5 per cent. However, Figure 4 indicates that (for the 50 m pothole intervals) there are a number of additional higher than average loads caused by the additional unevenness of the filled potholes. Although these differences are relatively small, the increase in pavement roughness is between 0.3 per cent and 8.9 per cent (Figure 7), and this should lead the practitioner to realise that a road without any localized unevenness is still the best option (therefore adequate maintenance to prevent the initial formation of potholes that need to be filled).

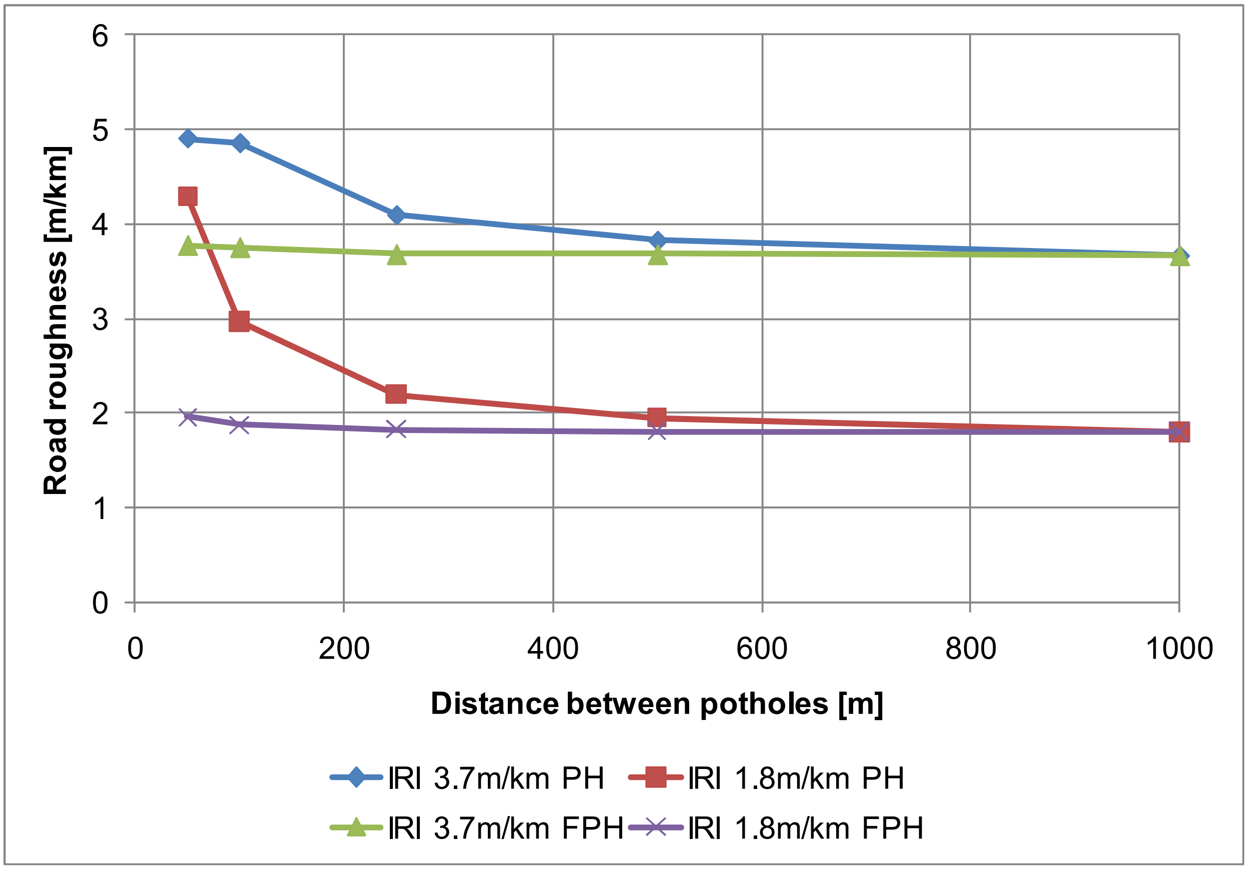

Figure 7: Effect of presence of potholes on road roughness (IRI)

4. CONCLUSIONS

The following conclusions are drawn based on the information contained in this paper:

- The presence of potholes in a road causes a deterioration in road roughness as well as an increase in the dynamic loads and excessive overloads applied by a vehicle travelling on the road;
- Maintenance of these potholes through filling them assists in improving the road roughness and decreasing these excessive overloads, and

- Although a road with filled potholes generate less excessive overloads than a road with open potholes, the effect of good maintenance practices is beneficial in that the best riding quality and lowest excessive overloads are experienced on a road without any additional unevenness caused by filled potholes.

5. RECOMMENDATION

It is recommended that the basic information provided in this paper be used and expanded to other vehicles on the road as well as actual road riding quality conditions before and after maintenance actions to evaluate the effect and potential success of the maintenance on the road.

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KEY WORDS

Vehicle-pavement interaction, Moving dynamic loads, road riding quality