Comparison of Asphalt and Concrete Pavement from the Aspect of Vehicle Vibration

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ABSTRACT: Since it is not possible to build perfectly smooth pavements, paving specifications usually prescribe the maximum acceptable roughness. Irregularities of road surface cause number of problems to their users, including poor ride quality, unsafe driving conditions and excitation of truck dynamics leading to further pavement deterioration as well as damage to vehicles and cargo. This fact is very interesting if we compare different types of pavement structures. This paper discusses asphalt and concrete pavement through vehicle vibrations which are the main indicator of ride comfort. Measurements of vibrations, while driving over asphalt and concrete pavement, were taken on highway Zagreb-Slavonski Brod (Croatia). Vehicle vibrations were measured with different speed from 80 to 130 km/h on both pavements. Prior to vibrations recordings, measurement of the road surface roughness (IRI index) on asphalt and concrete pavement has been performed. Based on the obtained research results, the relationship between the roughness, type of pavement, vehicle speed and vibration of vehicles has been established. These results can be very useful for road management administrative especially when facing a decision which type of road pavement should be used.

KEYWORDS: asphalt pavement, concrete pavement, vehicle vibration, measurement

1 INTRODUCTION

In the last three to four years, there has been more considering options about application of concrete pavements in Croatia. Thereby, pavements in tunnels and on road structures (bridges, viaducts, overpasses) are stated as the first sections on which these structures would be applied. The use of concrete pavements in tunnels is more favourable from the aspect of fire protection and a brighter driving surface. The application of concrete pavements on bridges is justified in the function of waterproofing of the bearing deck slab of the structure, (Vujic, 2004). However, beside the advantages mentioned above, one of the shortcomings of concrete pavements is primarily the evenness of the driving surface. That is important because the evenness of pavement is closely connected with comfort of driving, (Lakusic et al. 2008). Traveling comfort is particularly important on motorways where traffic speeds are much greater in comparison to roads in urban areas. Uncomfortable driving is the result of increased vibrations of the vehicle due to its running on an unevenly driving surface. Schematic view of vehicle movement over irregularities on the road driving surface can be seen on Figure 1.

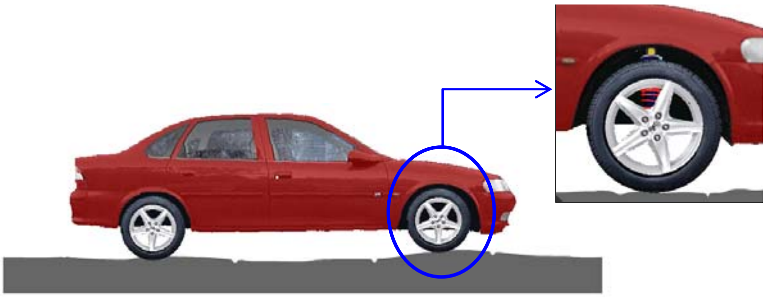

Figure 1: Movement of vehicle over irregularities on the road surface

Obtaining a satisfactory evenness of concrete pavement is realized by concrete finishers. But, in case of smaller distances, building in of concrete pavement with vibratory boards, which do not have a possibility of electronic guiding of the vertical alignment, is usually applied.

The paper researched vibrations of a passenger car on asphalt and concrete pavement on the Zagreb-Slavonski Brod motorway (Croatia), near the Bridge “ILOVA”. The mentioned bridge was reconstructed 2007 and the top layer of pavement on bridge was executed as a concrete pavement instead of an asphalt layer like on other part of motorway, (Ukrainczyk, 2003). This location of motorway was selected as test section for measuring the vibrations of vehicle.

2 DESCRIPTION OF THE TEST SECTION

Vehicle vibrations were recorded on a motorway traffic lane in 14 passages of a car at various speeds, from 80 km/h to 130 km/h. In order to ensure constant speed, not only on the bridge, but at least 60 to 70 m before and after the bridge, Croatian Motorways provided a test section with traffic signalization. Figure 2a shows the test location with the installed traffic signalization and Figure 2b shows schematic view of test section on Zagreb-Slavonski Brod Motorway.

Figure 2a: Presentation of the location for vehicle vibrations test

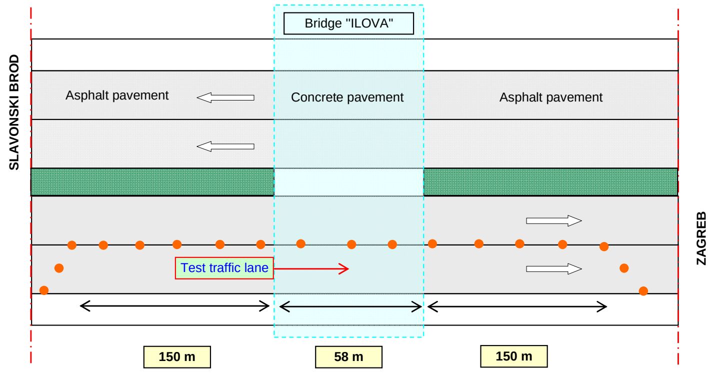

Figure 2b: Schematic view of test section on Zagreb-Slavonski Brod Motorway

The Bridge “Ilova” is 58 meters long, with the area of 625 m2. The project of renovation of the bridge required strengthening of the existing bearing concrete structure of pavement with the thickness of 8-10 cm. Since the vertical alignment of the driving surface of pavement could not be raised, execution of concrete pavement was anticipated, which would meet the bearing capacity of the structure, waterproofness and roughness of the driving surface. The evenness of pavement surface was not checked separately, but, since a motorway is in question, it was expected to be at the level of the driving surface before, i.e. after the structure.

Figure 3: Pavement renovation procedure on Bridge “Ilova”

The renovation of pavement was executed so that machine removal (milling) of the existing asphalt and waterproofing was done first (Figure 3a), then hydrodynamic removal of degraded reinforced concrete of the pavement slab, under high pressure up to 2500 bars, Figure 3b. By hydrodemolition, a variable thickness of the slab was achieved, and, in the area of drains, the concrete slab was removed in its full thickness. On the clean surface of hydrodemolished pavement, the fabric reinforcement Q 283 was laid, and special polymer-modified micro-reinforced concrete C 35/45 was installed, with the thickness of 10-16 cm, Figure 3c. Installation of the concrete layer was carried out by the vibratory board which does not have the performances of the device for installation of concrete pavement, so that the evenness of the driving surface was of unacceptable IRI index values. Therefore, leveling of the driving surface of pavement was approached, by grinding and granulating to the acceptable evenness from the aspect of safety. The executed concrete layer was cured by application of the curing coating against dewatering of fresh concrete based on latex in the duration of 24 hours. Final treatment of the concrete surface was executed by water under high pressure of 400 bars (Figure 3d), for the purpose of achieving the prescribed roughness and adhesion of the driving surface of pavement. In the end, surface impregnation was carried out, with two coatings of the styrene-butadiene latex solution with 15 % of the dry substance of polymer, (Mostprojekt, 2004).

3 VIBRATION MEASUREMENT SYSTEM

For the investigation of vehicle vibrations, personal car OPEL Vectra 1.8 1.6V comfort, equipped with summer tires 'Michelin Energy, 195/65 R15', regularly maintained (serviced at every 15000 km), having passed totally 130000 km, was used. OPEL is the German subsidiary of General Motors. In the United Kingdom, it is known as a Vauxhall and as a Holden in Australasia. Figure 4 shows the vehicle ‘Opel Vectra’ on the test section during the measurement of vibration. Vibrations were measured immediately next to the vehicle wheel, i.e. on the wheel holder), on the vehicle chassis, and on the vehicle steering wheel. The installed accelerometers for all the three measurement points are presented in Figure 5. Vibrations of the wheel and the chassis of the car were measured in the vertical "z" direction, while vibrations of the steering wheel were measured, beside in the "z" direction, also in the "x" direction, i.e. in the direction of driving of the car. Vibrations of the vehicle's wheel are important for considering the effects of unevenness of pavement on the vehicle's suspensions (shock-absorbers). Vibrations of the chassis are directly connected with comfort of driving and they show to what extent is the vehicle elastic. Vibrations of the steering wheel of the vehicle are important due to the fact that they are transferred directly to the driver's hands. That is particularly important in case of vehicles which are also the work posts of drivers (buses, trucks, delivery vehicles), and this phenomenon can be considered a direct exposure of a person to vibrations.

Figure 4: Test vehicle during the measurement of vibration on asphalt and concrete pavements

Figure 5: Positions of accelerometers: a) on the wheel holder, b) on the chassis, c) on the steering wheel

4 MEASUREMENT PROCEDURE AND RESULTS ANALYSIS

As it was already mentioned in Item 2, vehicle vibrations were recorded at speeds from 80 km/h to 130 km/h. Figure 6 shows the results of measuring the vibrations of the wheel, of the chassis and of the steering wheel of the vehicle at the speed of 130 km/h.

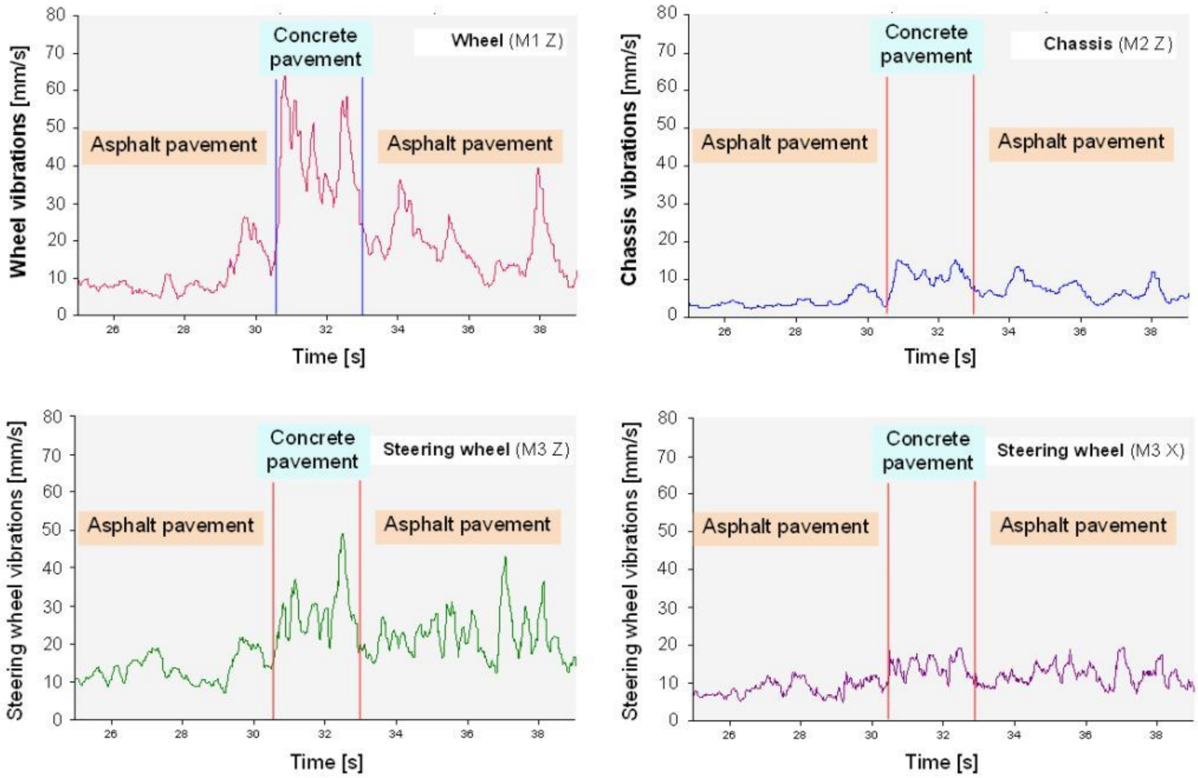

Figure 6: Vehicle vibrations at the speed of 130 km/h

In the time interval of 14 seconds, it is evident that greatest vibrations appear on the wheel of the vehicle and on the steering wheel of the vehicle in the vertical z direction. The maximum values of vibrations were obtained at the moment when the vehicle drives over the expansion joint of the bridge. The zone of movement of the vehicle along concrete pavement is specially marked in the diagram. The duration of movement of the vehicle along the test section at the speed of 130 km/h amounted to 1.7 s. However, in order to compare vibrations on concrete pavement with vibrations on asphalt pavement more precisely, average vibrations

on the mentioned sections (before the bridge, on the bridge and after the bridge) were calculated. The values at the moment of crossing of the vehicle over the expansion joint were not taken in consideration for calculation of the average vehicle vibrations. For the purpose of determining the average values of vibrations, the following time intervals were selected:
a) before the bridge: interval of 5 s (constant driving speed)
b) on the bridge: the length of the interval depending on the driving speed (1.6 to 2.6 s)
c) after the bridge: interval 1 – 2 s (due to intense breaking after the bridge)

Vehicle vibrations are closely connected with the evenness of the driving surface of pavement. By measuring the evenness by inertial profilometer of the LaserProf type, the following values were obtained:
a) before the bridge: asphalt pavement – the average value IRI10 = 0.91 [m/km]
b) on the bridge: concrete pavement – the average value IRI10 = 4.36 [m/km]
c) after the bridge: asphalt pavement – the average value IRI10 = 1.03 [m/km]

The measured evenness values were presented by the International Roughness Index (IRI), specifically, processed for the 10 meter segment, because a small length of the structure is in question, and that way the evenness values over the expansion device in the driving surface were processed separately. The IRI values indicate large differences in driving comfort over the asphalt part of pavement and the concrete part of pavement on the Bridge ILOVA. The ascertained evenness of the driving surface of concrete pavement is not acceptable according to the applicable technical conditions for motorways executed with asphalt pavement. Since concrete pavements are scarcely present in Croatia, with only 0.3%, there are no conditions for evenness for this type of pavement. That is the reason why measuring of vehicle vibrations was made within this paper in the first place.

The reasons for execution of concrete pavement exist on parts of roads with large dynamic load on the driving surface from slowing down, stopping and moving of the vehicle, such as, for example, crossroads. This type of pavement is almost always executed in the area of motorway toll collection because degradation of asphalt pavement by leaking oil products and exhaust gases from vehicles in the slow regime of traffic is thereby avoided. The mentioned examples of application of concrete pavement do not have great demand regarding the evenness of the driving surface because of small driving speeds, while the unevenness directly influences the increase of vehicle vibrations with the increase of the speed. The average vehicle vibration is increased with the increase of the IRI evenness index, i.e. dynamic effects of driving are increased, the consequences of which are an uncomfortable ride, degradation of the vehicle and the structure of pavement.

The average vehicle vibrations (of the wheel, chassis and steering wheel) were calculated for all the speeds at which testing was carried out for sections with asphalt pavement (before and after the bridge), and for the section with concrete pavement (on the bridge). The results are shown in Figure 7 as four diagrams of average vibrations depending to the driving speed. At all the measuring points, the greatest vibrations are on the bridge, and the smallest before the bridge. With the increase of the driving speed, the average values of vibrations are increased. Vibrations of the wheel of the vehicle are three to four times greater on the bridge with concrete pavement than before the bridge where there is asphalt pavement.

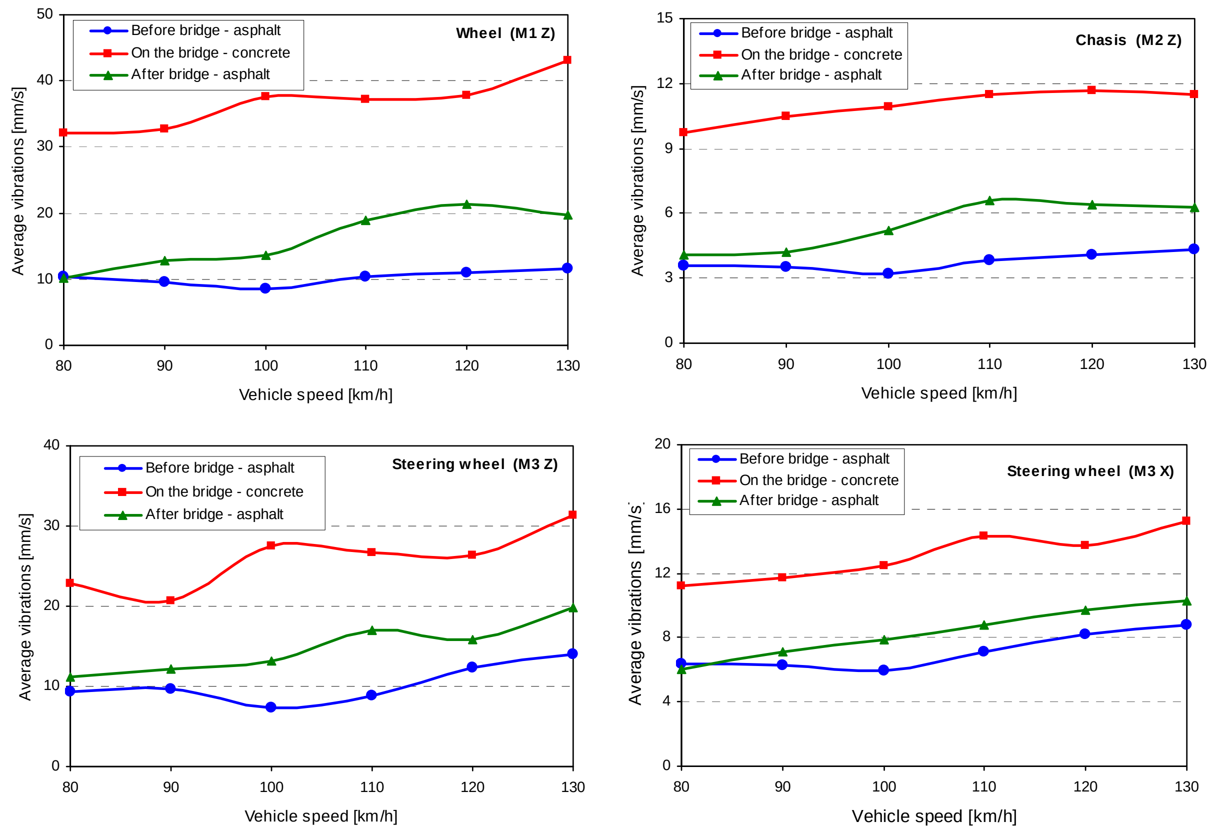

Figure 7: Average vibrations before the bridge, on the bridge and after the bridge relative to the driving speed

Vibrations on concrete pavement (on the bridge) and vibrations on asphalt pavements (before and after the bridge) are presented separately in Fig. 8. It can be seen that vibrations of the chassis are the smallest, and vibrations of the steering wheel on the z axis are only a little smaller than vibrations of the wheel. With the increase of speed from 80 to 130 km/h, vibrations of the wheel are two times larger after the bridge than before the bridge because of different irregularity of the driving surface. Detail view of wheel, chassis and steering wheel vibrations in vertical direction on asphalt and concrete pavement can be seen in Figure 9.

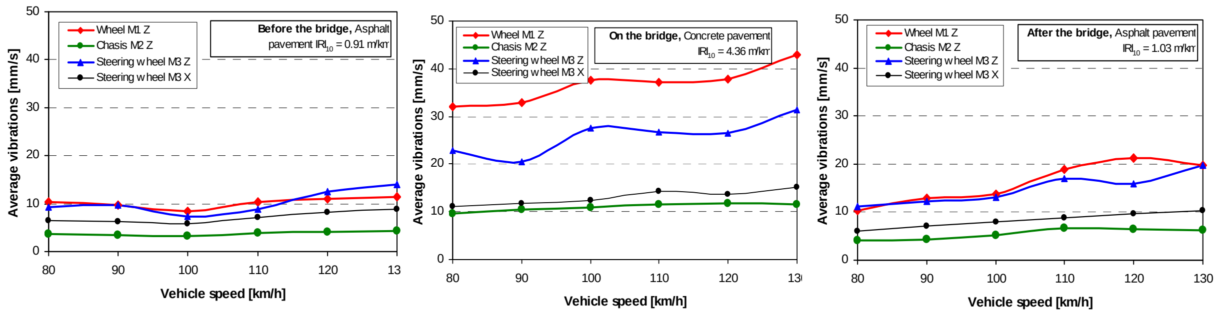

Figure 8: Vibrations relative to the driving speed, type of pavement and irregularity of the running surface

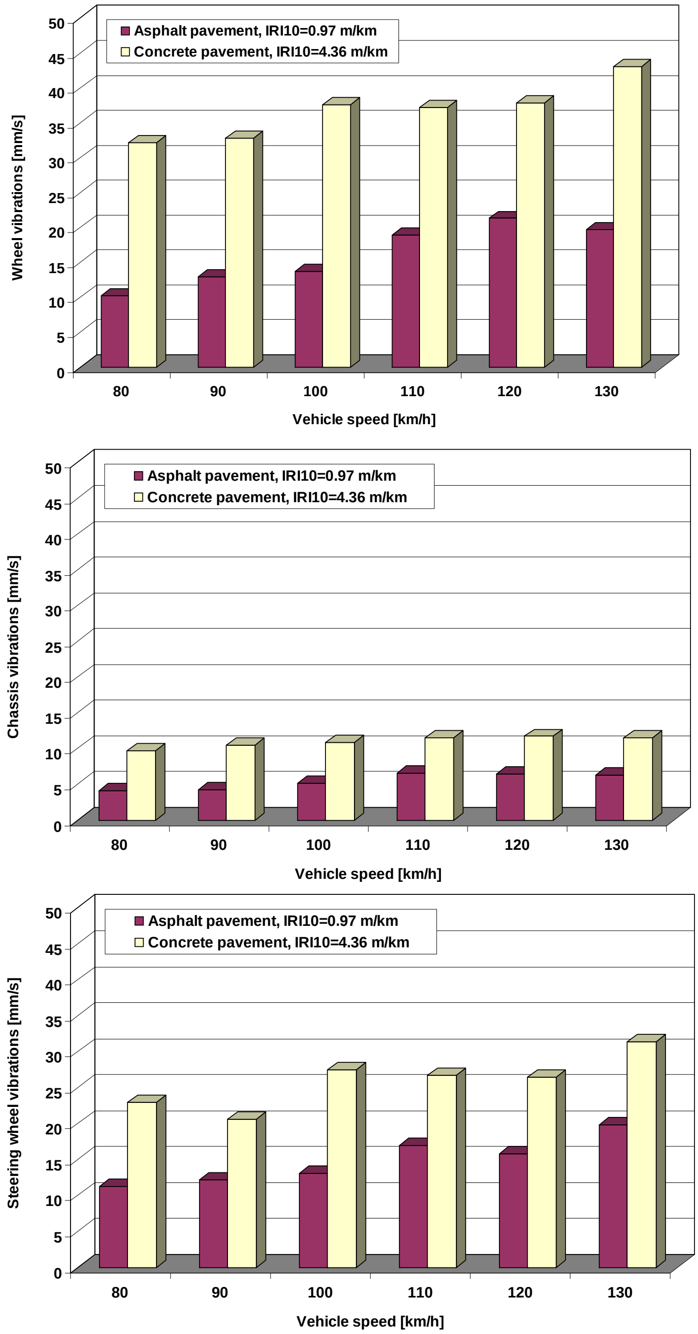

Figure 9: Wheel, chassis and steering wheel vibrations on asphalt and concrete pavement depending of vehicle speed

5 CONCLUSIONS

Measurements for researching the effects of pavement driving surface evenness on vibrations of the car were made on asphalt pavement and on concrete pavement. The measured evenness values of driving surfaces indicate large differences in driving comfort, and the average values of vibrations of the wheel of the vehicle are three to four times larger on the concrete pavement than on asphalt pavement. The problem of unevenness and poor driving comfort over constructed concrete pavement indicates that construction of concrete pavement of a motorway requires the use of adequate machinery (concrete finisher). There is another technical detail, which is putting of constructed concrete pavement into use from the moment of its installation; the condition is seven days of intense curing until the strength of the stipulated class is achieved. For a more precise comparison of these two types of pavements it is necessary to conduct such measurements on long sections of asphalt and concrete pavement. On longer sections, concrete pavements are being constructed with concrete finisher and the evenness of the driving surface is favorable and therefore less vibration and better ride quality.

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