Pavement Smoothness Affecting Riding Perception Based on Characteristic Values of Gyro Angular Velocity of Traveling Vehicles

Sufeng Zhao[1,a], Shuyun Wang[2,b*], GuoHua Fu[1,c], Ning Li[1,d]

[1]Hebei Expressway Group Engineering Consulting Co., Ltd., Shijiazhuang, China
[2]Beijing Municipal Engineering Research Institute, Beijing, China

E-mail: [a]sf_zh@163.com; [b]778419127@qq.com; [c]fghxp@163.com; [d]993863900@qq.com
*Corresponding author

Abstract. Pavement smoothness is one of the main factors affecting riding perception. There are two kinds of theories on how road surface smoothness affects riding perception: one is the widely accepted vibration acceleration (VA), and the other is gyro angular velocity (GAV) of passengers around X, Y, and Z axes. The amplitude and frequency of VA usually cause discomfort in the human skeletal, muscular, and internal organs, while GAV around X, Y, and Z axes causes neural perception discomfort in passengers. This study mainly explores the impact of GAV on riding perception, introduces inertial navigation systems to test GAV, and uses a laser road condition detection vehicle to test international roughness index (IRI). The experimental process selects four roads with significant differences in road conditions, aiming to highlight the impact of rotational movement (RM) on riding perception and to explore correlation between GAV and riding perception, especially for those related to car sickness symptoms such as dizziness and nausea in passengers. Based on three-axis GAV and IRI obtained from on-site test, characteristic value of RM represented by GAV_0 affecting riding perception is calculated. The subjects' answer to questionnaires are used as neural perception data of dizziness and stomach discomfort.Correlation between GAV_0 and riding perception data is analyzed, confirming that: for subjects with car sickness symptoms, their dizziness symptoms intensify with the increase of GAV0 values. This conclusion can provide a theoretical basis for intelligent driving and policy-making for road maintenance management.

Keywords: Riding Perception; International Roughness Index; Gyro Angular Velocity; Velocity; Characteristic Value

Y. Zhang et al. (eds.), *Proceedings of the 2024 10th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2024)*, Advances in Engineering Research 259,
https://doi.org/10.2991/978-94-6463-658-1_91

1 Introduction

Road performance evaluation began in the mid-1960s, and Pavement Serviceability Index (PSI) model was established by American Association of State Highway Officials (AASHO) through ride tests [1-2]. When the model was established, objective data on road damage, such as rutting and roughness, were first collected through experimental tests. Then, subjective scores obtained from ride tests were analyzed statistically to establish PSI model. From then, study of road performance evaluation indicators and methods has been widely carried out, and many countries have established different forms of road performance evaluation indicators for different purposes. Due to complexity of ride tests, later road performance evaluation indicators gradually separate from ride comfort evaluation, becoming a purely technical indicator that characterizes technical condition of road. The detection of road performance is usually carried out by manual or automated testing equipment, and road performance evaluation indicators are calculated according to formulas, serving as a basis for evaluation road and making decision of maintenance and repair.

In terms of road-induced vehicle vibration and ride comfort [3-9], research has been (widely conducted in the world). In these studies, comfort judgment index is vibration comfort thresholds given in ISO2631, and data collection for road-induced vehicle vibration mostly uses seat cushion accelerometers and other various vibration testing instruments. These instruments and equipment mostly measure three-axis acceleration. In recent years, with the popularization of smartphones, many studies have begun to use smartphones as simple testing equipment, using smartphone applications to obtain large data of acceleration values of vehicle suspension systems to evaluate road conditions and to improve effectiveness of road maintenance management[10].

Since IRI is most related to vehicle vibration, relationship between representative values of vehicle vibration (three-axis acceleration value or numerical value obtained from its statistical analysis) and IRI is established. Then evaluation of road based on perception of passenger riding comfort is obtained refer to vibration comfort threshold in ISO2631. The comfort response threshold for vibration environment in ISO2631 corresponds to frequency-weighted vibration acceleration composite values. When testing, human body is in a sitting position, with the Y-axis at left and right direction of body, the X-axis at front and back direction, and the Z-axis at up and down direction. GAV is usually used to describe the speed at which an object rotates around a certain fixed axis. In physics, angular velocity is the rate of change of angular displacement of an object over time, and its unit is usually radians per second (rad/s). The gyro angular velocities generated around the X, Y, and Z axes during vehicle travel are represented by GAVx, GAVy, and GAVz, respectively.

The comfort evaluation index based on human physiological perception is greatly influenced by subjective factors of the subjects. The vibration comfort threshold of passengers in moving vehicles differs from that of simulated environment in ISO2631. The vibration simulation in ISO2631 mainly considers physiological responses caused by vibration acceleration. When people are sitting in a moving car, the discomfort is more often due to the physiological responses indirectly caused by poor road conditions. The road conditions are transmitted to human body through vehicle's motion, which, in addition to vibration acceleration, also includes significant rotational movements. With development of economy and improvement of road conditions, discomfort caused by VA is not obvious. Carsickness is a specific riding perception based on a small group of people who are prone to motion sickness. This group feels a significant reduction or even disappearance of dizziness in cars with good road conditions, smooth alignment, and uniform driving speed. In contrast, dizziness is enhanced under poor road conditions, peculiar alignment, and sudden changes in driving speed. Based on this, this study investigates the relationship between this specific riding perception of carsickness and road condition.

2 Methodology

The methodology is shown in Fig.1. To investigate the impact of GAV on riding perception, it is necessary to test road IRI, GAV of vehicle, and subjective perception of passengers simultaneously. In ISO2631, it is mentioned that RM around the X, Y, and Z axes are auxiliary factors affecting comfort perception, but it does not list testing instruments, testing methods, or testing indicators for RM. In this study, a laser road condition detection vehicle is selected to measure IRI and speed during testing process. An inertial navigation system is used to test GAV. During experiment, inertial navigation system is fixed on the platform in front of co-driver's seat (as shown in Fig. 5), and the testing time of inertial navigation system is adjusted to the same time of laser road condition vehicle in order to acquire synchronous data from the two instruments. The subjects sit in back seat, and the subjects' perceptions are asked and recorded immediately after each test section is completed.

Selection of test roads is very important. To highlight the impact of road surface smoothness, this study selected four roads with significantly different conditions: one undulating tourist road in a scenic area, one rural cement concrete road, one urban arterial road nearing medium repair, and one urban branch road close to major maintenance. The IRI, vehicle speed V, three-axis GAVs and riding perception are tested synchronously. Through data analysis, correlations between GAV0, IRI, and V can be established. In this study, 10 subjects were selected to score riding perception, and a initially correlation between GAV0 and riding perception was established.

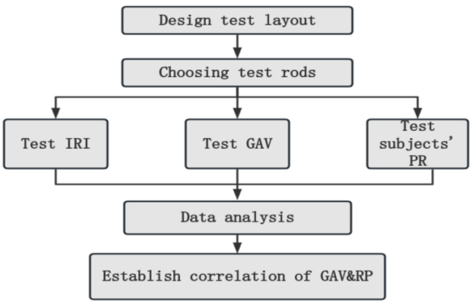

Fig. 1. Methodology

3 Wavy Road Test

3.1 Wavy Road Profile

As is shown in Fig.2, the wavy road is a scenic road in an amusement park located in Shanting District, Zaozhuang City, Shandong Province. It is paved with colored asphalt, with a unique undulating shape. This road is a newly paved one with good road conditions, free from diseases such as rutting and potholes etc. Fig. 3 shows a laser road condition detection vehicle, and Fig. 4 shows a small inertial navigation system placed on the platform in front of the co-pilot seat, with its X, Y, and Z axes aligned with the directions in Fig. 1. The direction of vehicle advancement is the X-axis, the left and right directions perpendicular to the X-axis are the Y-axis, and the vertical direction is the Z-axis.

Fig. 2. Wavy road

Fig. 3. IRI test

Fig. 4. Inertial navigation system test

3.2 IRI data of Wave Road

The experiment was conducted by synchronizing testing of IRI and GAV at speeds of 30km/h and 50km/h separately. In each speed, IRI and GAV were tested 3 times, and the average of these three test results was calculated as the final data,which is shown in Fig. 5.

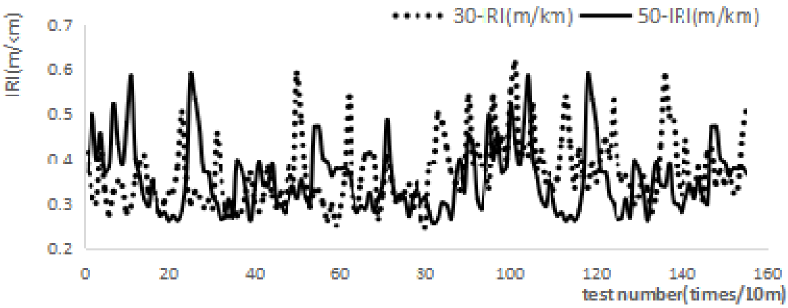

Fig. 5. IRI test results of wavy road

Fig.5 shows that IRI acquisition frequency is a number per 10 meters, with the dashed line representing IRI at 30km/h, and the solid line representing IRI at 50km/h. Due to inconsistency in wheel trajectory during two tests, IRI values could not match precisely. However, by taking the average of IRI over a 1600m section at these two different speeds, the values are 0.351m/km and 0.356m/km respectively, indicating that speed has little influence on IRI.

3.3 Analysis of GAV Data of Wavy Road

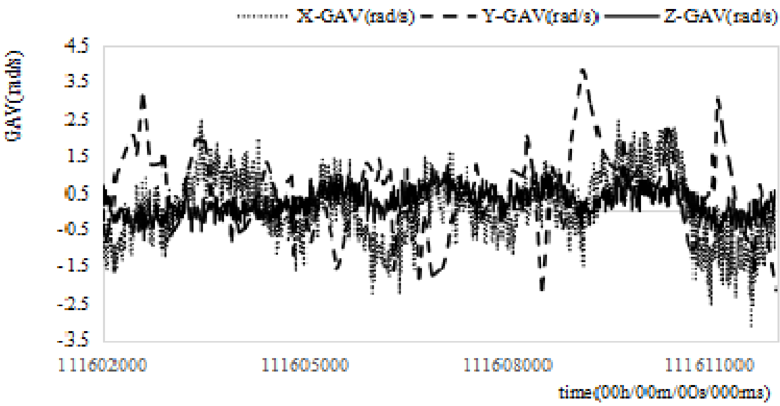

Fig. 6. Three-axis GAV of wavy road at 30km/h

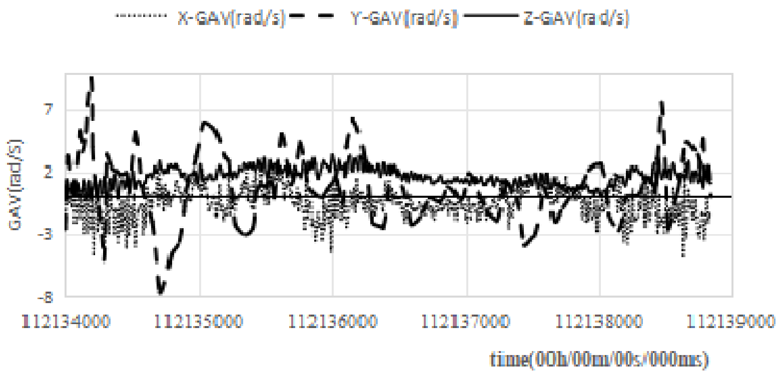

Fig. 7. Three-axis GAVs of wavy road at 50km/h

Fig.6 and Fig.7 show time sequence curve of three-axis GAV values on the wavy road at driving speeds of 30km/h and 50km/h, respectively. The GAVS at two different speeds varies significantly, especially in Y-axis direction. The maximum value approaches 10rad/s at 50km/h, while it is about 4rad/s at 30km/h. Although speed has a subtle effect on IRI, fusion of speed and IRI together influence GAV greatly.

Since three-axis GAVs have both positive and negative values. In order to highlight data differences of different roads, a characteristic value is obtained by formula (1)in this study. The characteristic value GAV0 can reflect road conditions impacting on human physiological indicators induced by vehicle GAV.

$$\mathrm{G}AV_0 = \frac{\sqrt{\sum_{i=1}^{n}(GAV_{xi}^2 + GAV_{yi}^2 + GAV_{zi}^2)}}{n} \tag{1}$$

GAVXi, GAVYi, GAVZi——rad/s, respectively representing the X-axis gyroscopic angular velocity, Y-axis gyroscopic angular velocity, and Z-axis gyroscopic angular velocity accompanying with acquisition frequency.

According to formula (1), GAV0 values of the wavy road at speeds of 30km/h and 50km/h are 3.78rad/s and 6.13rad/s, respectively.

4 Conventional Road Testing

This study selected three public roads, R1, R2, and R3, with significantly different IRI to highlight the impact of pavement condition. IRI and GAV are tested separately. Photos of three roads are shown in Fig.8 to Fig.10. Among them, R1 is a rural road with a cement concrete surface, which has a very poor surface condition, with an IRI of 6.75m/km. The surface damage is not severe. Fig. 9 shows road R2, which is a branch road on the verge of major repairs, with an asphalt concrete surface and very poor smoothness, having an IRI of 12.34m/km. The road surface is severely damaged, and the elevation undulates in waves. Fig. 10 displays road R3, which is a main arterial road nearing medium repair, with an asphalt concrete surface and relatively poor smoothness, having an IRI of 2.98m/km. The road surface exhibits severer damage, with noticeable loose and cracked areas, as well as pronounced rutting.

Fig. 8. R1 road

Fig. 9. R2 road

Fig. 10. R3 road

Table 1 presents on-site test data of theses three public roads and their calculated GAV0 values. R1 is tested for IRI and GAV at speeds of 30km/h, 50km/h, and 70km/h. Using formula (1), the GAV0 are calculated to be 2.69rad/s, 3.96rad/s, and 6.05rad/s, respectively. R2, a branch road with severe damage, has an IRI value of 12.34m/km and is not suitable for high-speed travel. It was tested at two speeds of 30km/h and 50km/h, with corresponding GAV0 values of 6.97rad/s and 8.83rad/s, respectively. R3, a main arterial road, has an IRI value of 2.984m/km, and the GAV0 values at speeds of 30km/h, 50km/h, and 80km/h are 1.61rad/s, 2.63rad/s, and 3.35rad/s, respectively.

Table 1. On-site test results and calculated GAV0 of three public roads

Road		R1		R2			R3	
Speed(km/h)	30	50	70	30	50	30	50	80
GAV0(rad/s)	2.69	3.96	5.05	6.97	8.83	1.61	2.63	3.35
IRI(m/km)		6.75		12.34			2.98	

5 Subjective Perception Test

These ten participants in this experiment include five women and five men, among whom three female test personnel have motion sickness. Table 2 categorizes all the participants into three groups, T1, T2, and T3, based on gender and the presence or absence of motion sickness symptoms; all group members are in good health. During the tests on the aforementioned wavy road and roads R1, R2, and R3, the ten participants are simultaneously seated in the back seat. After the road tests, the participants immediately are asked about their perception of road conditions, with options including: normal, comfort (mild, moderate, normal, extreme), discomfort (mild, moderate, normal, severe), dizziness & stomach discomfort (mild, moderate, normal, severe). Table 3 presents the subjective perceptions of the three test groups under different roads and speeds.

Table 2. Subjects' profile

Team	Subjects	Profile
T1	Five males	Age 22-40 years old, good health, no carsickness
T2	Three females	Age 22-40 years old, good health, carsickness
T3	Two females	Age 22-40 years old, good health, no carsickness

From Table 3, it is well known that females predominate most with motion sickness symptoms. Men and women who do not experience motion sickness have a consistent perception of road conditions. Motion sickness is a major factor leading to poor riding perception. The riding perception of people prone to motion sickness is positively correlated with GAV0 values, and their feelings of dizziness and stomach discomfort intensify with the increase of GAV0. Non-motion-sick participants do not have significant dizziness and stomach discomfort during the ride, but they may express discomfort, which also intensifies with the increase of road GAV0. However, psychological factors greatly influence riding perception of non-motion-sick individuals. When driving on a specific scenic wavy road at 30km/h and 50km/h, the GAV0 values are 3.78rad/s and 6.13rad/s, respectively, and the corresponding perceptions of non-motion-sick individuals are "comfort" and "mild discomfort". Concrete pavements have a higher stiffness, and the discomfort is more noticeable compared to asphalt concrete pavements under the same GAV0.

Table 3. Subject's perception questionnaire

GAV0 (rad/s)	Subjects judging			Notes
	T1	T2	T3	
1.61	Normal	Normal	Normal	
2.63	Normal	Normal	Normal	
2.69	Normal	mild dizziness & stomach discomfort	Normal	
3.35	Normal	Moderate dizziness & stomach discomfort	Normal	
3.78	Comfort	Dizziness& stomach discomfort	Comfort	Wavy road, with beautiful scenery
3.96	Mild discomfort	dizziness and stomach discomfort	Mild discomfort	
5.05	Discomfort	Severe dizziness and stomach discomfort	Discomfort	cement concrete pavement
6.13	Mild discomfort	Severe dizziness and stomach discomfort	Mild discomfort	wavy road, with beautiful scenery
6.97	Moderate discomfort	Dizziness and stomach discomfort	Moderate discomfort	
8.83	Severe discomfort	Dizziness and stomach discomfort	Severe discomfort	

6 Conclusions

This study propose a testing method based on human perception for road evaluation, and initially verifies that there is a positive correlation between GAV of riding vehicles induced by road conditions and subjects' perception of discomfort, especially perception of dizziness.The process and conclusions can provide theoretical support for intelligent driving and road maintenance decision making. It is recommended to expand the samples of test roads and participants, and by using machine learning methods, obtain a highly correlated relationship between GAV0 and perception of riding dizziness.

References

1. Shi Y., Ling T. Q., Cui L.L., et al. Study on evaluation standard for asphalt pavement preventive maintenance and decision-making optimization [J].Journal of Highway and Transportation Research and Development, 2020, 10 (7): 25-56.
2. Dong S., Xu Z.L., Wang J.W., et al. Comparison and Conversion Study on Asphalt Pavement Technical Status Assessment Standards between China, Japan, America, and Canada.Chongqing Traffic University, 2023, 02 (42): 44 - 51.
3. ISO 2631-1:Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration, Part 1: General requirements. National Digital Library Standards. 1997.
4. Zhang J.X., Cao D.D., Ding Y.J. Pavement Roughness Detection Method Based on Smartphone and PSO-BP Neural Network. 13Th International Conference On Road And Airfield Pavement Technology 2023: 883-893.
5. Guo W.D.,Zhang J.X., Cao D.D., et al. A monitoring framework for urban road ride quality using smartphone sensing technology. Measurement 235, 2024, 114957. https://doi.org/10.1016/j.measurement.
6. Ufuk Kırbaş, Mustafa Karaşahin. Investigation of ride comfort limits on urban asphalt concrete pavements, International Journal of Pavement Engineering, 2016, DOI: 10.1080/10298436.2016.1224413.
7. Fatjon Seraj, Berend Janvander Zwaag, Arta Dilo et al. RoADS: A Road Pavement Monitoring System for Anomaly Detection Using Smart Phones. 2016, 128-146. DOI: 10.1007/978-3-319-29009-67.
8. Wang S.Y., Zhang J.X., et al. Bridge Head Secondary Bump Disease Testing Method and Device [P]. ZL:2021102277165, 2022.03.29, China.
9. Wang S.Y., Zhang J.X., et al. Method and Device for Judging Vehicle Ride Comfort on Pavement [P].ZL:202110227714.6, 2023.07.18, China.
10. Ye Sang, Qiqin Yu, Yihai Fanget al. Smartphone-Based IRI Estimation for Pavement Roughness Monitoring: A Data-Driven Approach. 2024, 7(11):19708 - 19720, DOI: 10.1109/JIOT.2024.3369109.