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VALIDATION OF STAMPER DEVICE TO MEASURE INTERNATIONAL ROUGHNESS INDEX IRI

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Abstract: Measuring International Roughness Index (IRI) is one of the tasks in the process of checking, monitoring and evaluating road surface quality. In Vietnam, the types of IRI measuring devices are still limited. There are specialized devices with high accuracy and speed, but the cost is high. Therefore, they are not commonly used for regular monitoring. To measure IRI regularly and conveniently, it is necessary to use device that is easy to use, convenient, with high speed, high accuracy, but at a reasonable cost. The STAMPER (System with Two Accelerometers for Measuring Profile, Enabling Real-time data collection) from Taisei Rotec company (Japan) has been used to measure on different types of roads in Hanoi: city road, expressway and national highway. Data will be collected many times, with speed ranges and by many types of vehicles. The results show that STAMPER can measure IRI quickly and stably. It is easy to install on many type of vehicles and gives accurate, reliable measurement results.

Keywords: International Roughness Index (IRI), STAMPER, roughness index, quality of road surface.

1. INTRODUCTION

The increasing of user's demands leading to the over-exploitation of roads creates an urgent need for rehabilitation. Thus, when it comes to a maintenance process, the pavement quality is an important indicator to evaluate. The requirements of pavement function include safety, comfort and economy [1]. The comfort is greatly influenced by the smoothness of the road. Besides, the smoothness is also related to economics such as vehicle fuel consumption and duration until the pavement needs repair. Smoothness is still satisfactory in the early stages of exploitation but will decrease over time. Therefore, the International Roughness

Index (IRI) is proposed used to evaluate smoothness. IRI was first introduced by the International Bank for Reconstruction and Development (World Bank) in 1986, then the World Bank asked the Michigan University of Transportation's technology research department to build this rating index. This new index allows the evaluation of a wide range of surfaces from rough to smooth surfaces [2]. The higher the IRI value, the greater the vertical oscillation of the vehicle and the poorer the smoothness (ride quality).

In Vietnam, the collection of road surface condition data in general and the IRI roughness index in particular has not yet received sufficient attention, so the assessment of road surface quality during the exploitation phase encounters many difficulties. Several studies have demonstrated the important influence of road surface flatness on vehicle safety. However, the assessment is only through the initial IRI index and the results of predicting the change of IRI according to foreign theoretical models, not determining the actual IRI at the time under consideration [3]. The IRI index has been measured using the direct method and has been shown to have a strong correlation with mining time [4], however, the measurements have only been conducted on a short range and not periodically.

Currently, the number of modern equipment in Vietnam to evaluate road surface quality is limited, thus, it will not be possible to conduct measurements on a large scale and regularly. That means there will not be enough data to serve the management and planning of pavement maintenance of many routes [5]. In Japan and a number of other countries around the world, the method of measuring the international roughness index IRI with mobile devices using accelerometers has been researched and practically applied at many road management units. This method not only ensures the reliability of measurement results but also ensures the economy of data collection [6-8]. Therefore, the study of applying the IRI international roughness index measurement method by mobile devices using accelerometers to evaluate the quality of road construction operations is considered to be of important significance. The STAMPER (System with Two Accelerometers for Measuring Profile, Enabling Real-time data collection) from Taisei Rotec company (Japan) is one of the measuring devices that helps collect data effectively and monitor index road roughness in real time. This study is to evaluate the validation of STAMPER device in Vietnam by conducting measurement on different types of vehicles, with different speeds on various types of roads. The result of this research will figure out the adaptable of STAMPER device in VietNam, which is significant to future road inspection and maintenance process.

2. STAMPER DEVICE USING IN MEASURING INDEX ROAD ROUGHNESS

The STAMPER from Taisei Rotec company (Japan) is one of the measuring devices that helps collect data effectively and monitor index road roughness in real time. The system consists of two small accelerations, a global positioning system (GPS) sensor, an transducer and a portable computer as show in Figure 1 [9]. A GPS sensor is put on near the window of the vehicle for measuring the vehicle traveling speed and location. STAMPER's measurement rules are based on acceleration measured from two accelerometers attached to the sprung and unsprung mass of the vehicle. The IRI simulation is quarter-car Model. A transducer converts the strain of accelerometers into the electrical signal. A computer records and displays the measurement results in real time. Simultaneously with the IRI measurement, road surface video can be obtained using a camera installed on the vehicle to capture a view of the road surface. STAMPER can directly compute the IRI arbitrary intervals based on measured profile data. The flexibility and convenience of STAMPER means it can be installed on many

types of vehicles, at a reasonable cost. In Vietnamese standard TCVN 8865:2011 [10] classifies IRI measuring method into two types: direct measuring method and indirect measuring method. Based on the article [7] and [9], STAMPER enables directly caculation of profile-based indicates based on vehicle response unlike the conventional devices that compute roughness indicates by empirical correlations between roughness profiles and vehicle motion. This device gives real-time, fast, accurate IRI results and it belongs to the group of indirect measurement methods.

To verify the accuracy of this device, a profile measurement experiment was conducted in the test course of Wacom Hokkaido Co., Ltd in Japan [7]. The test was conducted in 200m long asphalt pavement, and data surveyed by stamper at speeds of 40, 60 and 80 km/h was compared with data surveyed using the rod-and-level and low-speed profilometer method, which is a device that accurately measures profile. Arrcoding to the results, STAMPER achieves the accuracy within 10 percent as compared with the reference measures.

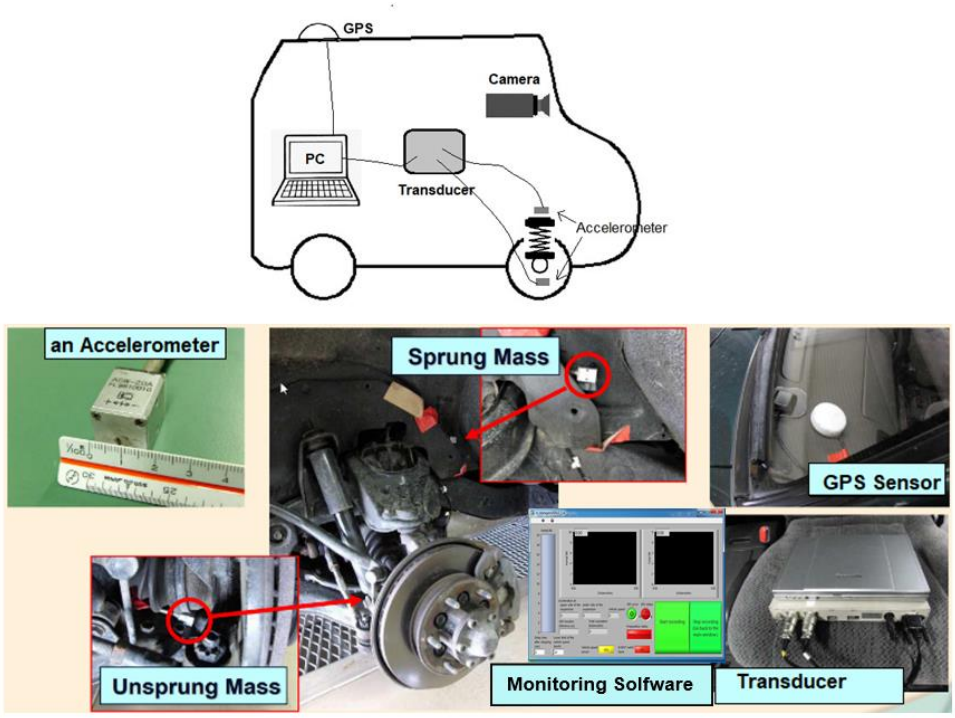

Figure 1. System instrumentation.

With these characteristics, the STAMPER has been researched in a joint contract between Taisei Rotec Joint Stock Company and Hanoi University of Transport. The research has achieved some initial results in terms of measurement capabilities IRI in Vietnam [9] [11]. Studies have shown that the use of STAMPER in Vietnam is appropriate and applicable, so to further evaluate the ability to use STAMPER equipment with many types of roads, on many types of measuring vehicles, with different velocity ranges are included in this study. This study helps management agency evaluate and have a basis to use STAMPER equipment for inspection, monitoring and management of roads.

3. USING STAMPER TO MEASURE IRI IN HA NOI

The research team of the University of Transport and Communications conducted IRI measurements with the STAMPER device on several roads in Hanoi in October 2022. The

measurements were carried out on the designated roads in Hanoi, on a national highway, residential road and expressway. The STAMPER is installed on 2 different types of measuring vehicles, with 3 measuring speed ranges. The IRI roughness measuring step is determined to be 10m. Detailed parameters are as Table 1_IRI measurement information in Ha Noi

Table 1. IRI meaurement information in Ha Noi.

Type of vehicle	Roads are measured IRI	Speed Range
• Kia Carens • Toyota Innova	• Residential road: Lang Hoa Lac residental road from the suburbs to the city center. • Expressway: Lang Hoa Lac expressway from the city center to the suburbs. • National highway: the road connecting National highway No.5 from Nhat Tan bridge to Dong Tru bridge (in both directions).	• 30 *km/h* • 40 *km/h* • 60 *km/h*

3.1. Measurement conditions

STAMPER device of Taisei Rotec company is installed on two vehicles to measure data according to the manufacturer's instructions, also including a GPS receiver, and a video camera [8]. Before measuring, the devices are installed, and parameters are determined.

Figure 2. Install the devices: remove the wheel to install the accelerometers.

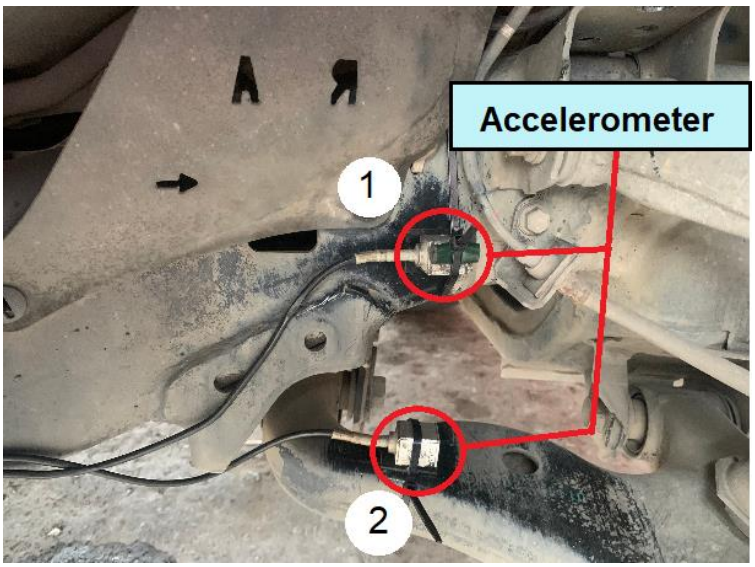

Figure 3. Install the accelerometers: 1-accelerometer on the sprung mass, 2-accelerometer on the unsprung mass.

3.2. Measurement routes

As shown in Figure 4. Measurement location of Lang - Hoa (Residential and Expressway), Figure 5. Measurement location of National Highway 5 (from Nhat Tan bridge to Dong Tru bridge), three types of roads around Ha Noi are measured, which are Expressway, Residential and National Highway. On these routes, there are many lanes, measurements are taken on the appropriate lane that the measuring vehicle can pass through, ensuring the vehicle maintains the required speed and runs in the selected lane. There are 3 measurement routes with a total of 4 lanes, and information about the measurement sections is shown in Table 2. Information on IRI measurement routes.

Figure 4. Measurement taken on Lang – Hoa Lac (Residential and Expressway): the map on GPSVisualizer with measurement data.

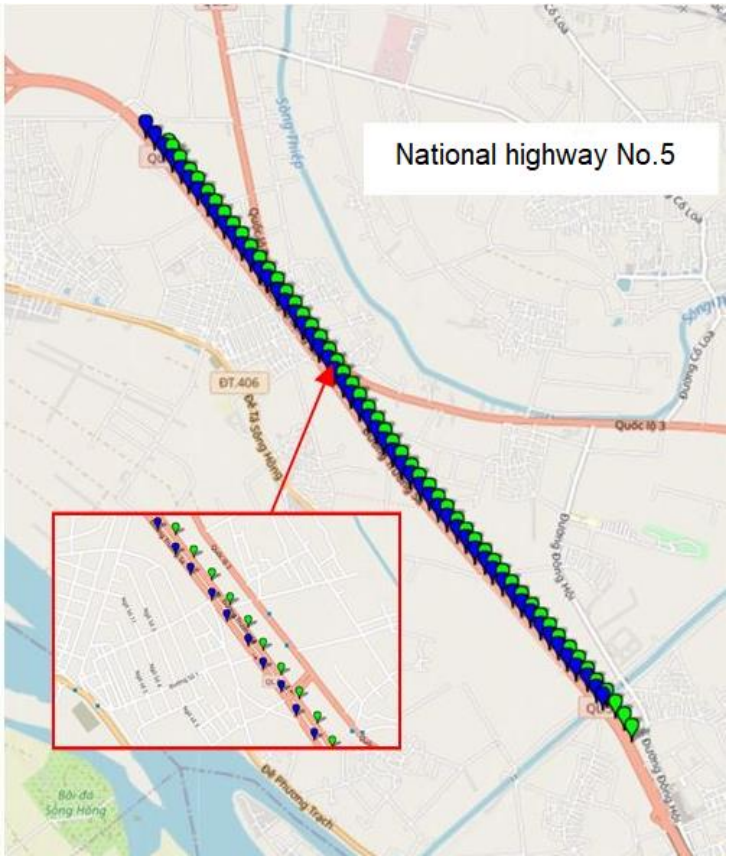

Figure 5. Measurement taken on National highway No.5 from Nhat Tan bridge to Dong Tru bridge (in both directions): the map on GPSVisualizer with measurement data.

Table 2. Information of IRI measurement routes.

Lang Hoa Lac route **Vehicle: Kia Carens**					
Time	***Direction***	***Road type***	***Lane***	***Distance***	***Speed***
1	From the city to the suburbs	Expressway	Right Outside	10km	40km/h
	From the suburbs to the city	Residential road	Left Inside	6km	40km/h
2	From the city to the suburbs	Expressway	Right Outside	10km	40km/h
	From the suburbs to the city	Residential road	Left Inside	6km	40km/h
3	From the city to the suburbs	Expressway	Right Outside	10km	40km/h
	From the suburbs to the city	Residential road	Left Inside	6km	40km/h
4	From the city to the suburbs	Expressway	Right Outside	10km	60km/h
	From the suburbs to the city	Residential road	Left Inside	6km	30km/h
5	From the city to the suburbs	Expressway	Right Outside	10km	60km/h
	From the suburbs to the city	Residential road	Left Inside	6km	30km/h
National Highway from Nhat Tan bridge to Dong Tru bridge **Vehicle: Kia Carens**					
Time	***Direction***	***Road type***	***Lane***	***Distance***	***Speed***

1	From the city to the suburbs	National Highway	Right Outside	5.1km	40
	From the suburbs to the city	National Highway	Right Outside	5.2km	40
2	From the city to the suburbs	National Highway	Right Outside	5.1km	60
	From the suburbs to the city	National Highway	Right Outside	5.2km	60
Lang Hoa Lac route Vehicle: Toyota Innova car					
Time	***Direction***	***Road type***	***Lane***	***Distance***	***Speed***
1	From the city to the suburbs	Expressway	Right Outside	8km	40km/h
2	From the city to the suburbs	Expressway	Right Outside	8km	40km/h
3	From the city to the suburbs	Expressway	Right Outside	8km	40km/h

4. Results and Discussion

In this section, these are the results of measuring road roughness that the research team conducted on 3 roads in Hanoi with comparative contents:

- Same type of vehicle, same speed, same location, different time.

- Same type of vehicle, different speed, same location.

- Different type of vehicle, same speed, same location.

4.1. Measurement results using STAMPER on the same type of vehicle, at the same speed, with several times of measurement at the same location.

STAMPER device, which is used to measure IRI, was installed on a Kia Carens car.

4.1.1. Lang Hoa Lac expressway

The measurement was taken place at Lang Hoa Lac expressway, at the speed of 40km/h, on the outer right lane as shown below. Average IRI results measured at three times is 3.55mm/m, 3.63mm/m and 3.61mm/m respectively. The ratio of the average value of the difference of IRI values between two measurements to the average IRI value can be used to consider the difference between two series of measured values of IRI, and is called the relative average Denta. This value of measurements 1-2 is 1.14%, between measurements 1-3 is 1.71%, between measurements is 2-3 is 0.56%. Thus, the deviation between repeated measurements with the same type of vehicle and the same speed is quite small and insignificant.

Lang Hoa Lac residential road

Measurement results at Lang Hoa Lac residential road, at the speed of 40km/h, in the inner left lane as shown below. Average IRI results measured at three times is 4.88mm/m, 4.78mm/m and 5.01mm/m respectively. The relative average Denta of measurements 1-2 is 1.54%, between measurements 1-3 is 1.86%, between measurements 2-3 is 3.45%. Thus, the deviation between repeated measurements with the same type of vehicle and the same speed is minor.

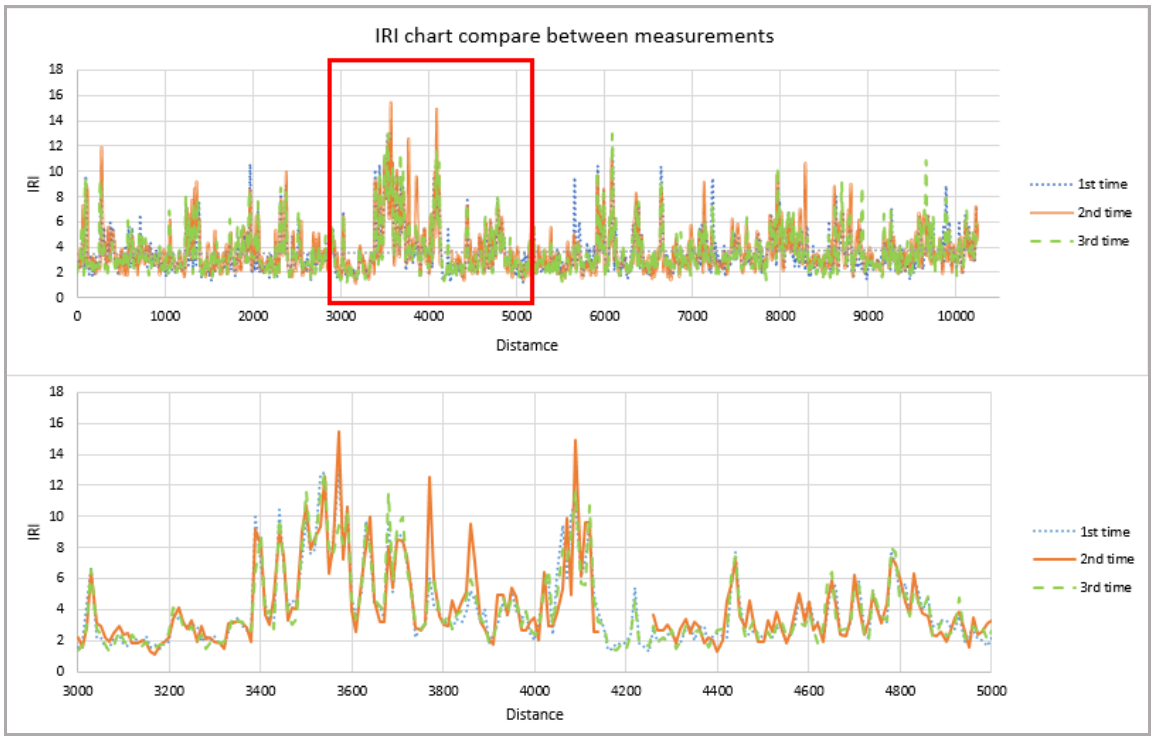

Figure 6. Comparison of IRI_{10m} value between 3 times on the Lang Hoa Lac Expressway.

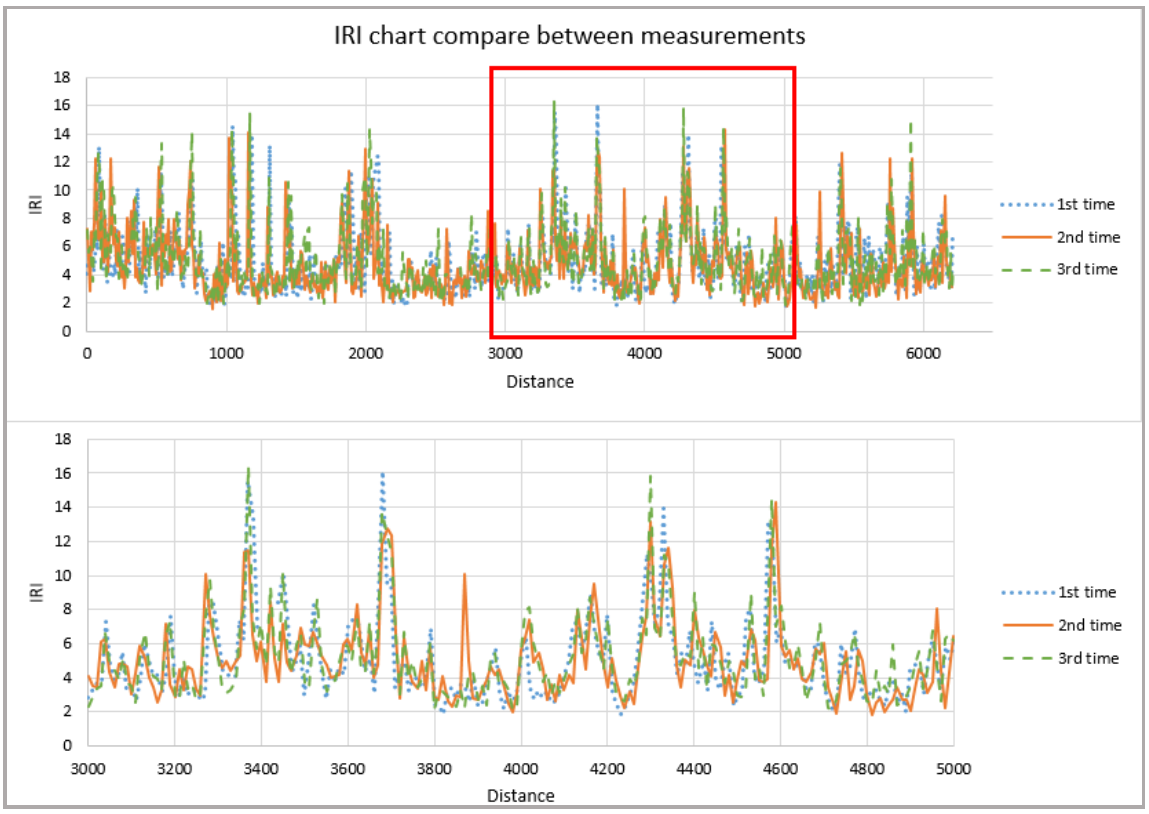

Figure 7. Comparison of IRI_{10m} value between 3 times on the Lang Hoa Lac residential route.

At Lang Hoa Lac expressway and Lang Hoa Lac residential road, the IRI data obtained of these two routes are in two different ranges. But it can be seen that with same speed and vehicle, the measurements by STAMPER device have low relative averange Denta. At Lang Hoa Lac expressway the results of Delta respectively are 1.14%, 1.17%, 0.56%, at Lang Hoa Lac residential route the results of Delta are 1.54%, 1.86%, 3.45%. This proves that the reliability level of the STAMPER device when repeatedly measuring is quite high with many types of roads and different IRI values.

4.2. Measurement results using STAMPER on the same type of vehicle, at 2 different speeds, at the same location.

4.2.1. Lang Hoa Lac express way

The measurement was carried at Lang Hoa Lac express way. The research team executed the experiment at two speeds of 40 km/h and 60 km/h on the same Kia Carens. The resulted charts of IRI were obtained as shown in the figure below. With the outcome of IRI at the speed of 40 km/h and 60 km/h are 3.61 mm/m and 3.69 mm/m respectively, the relative average Denta equals to 1.76%. According to this chart and obtained values, the IRI value measured at a speed of 60km/h is greater than that at a speed of 40km/h, however, the difference between these two measurements is insignificant on the Lang Hoa Lac expressway, where the average IRI is 3.60 mm/m.

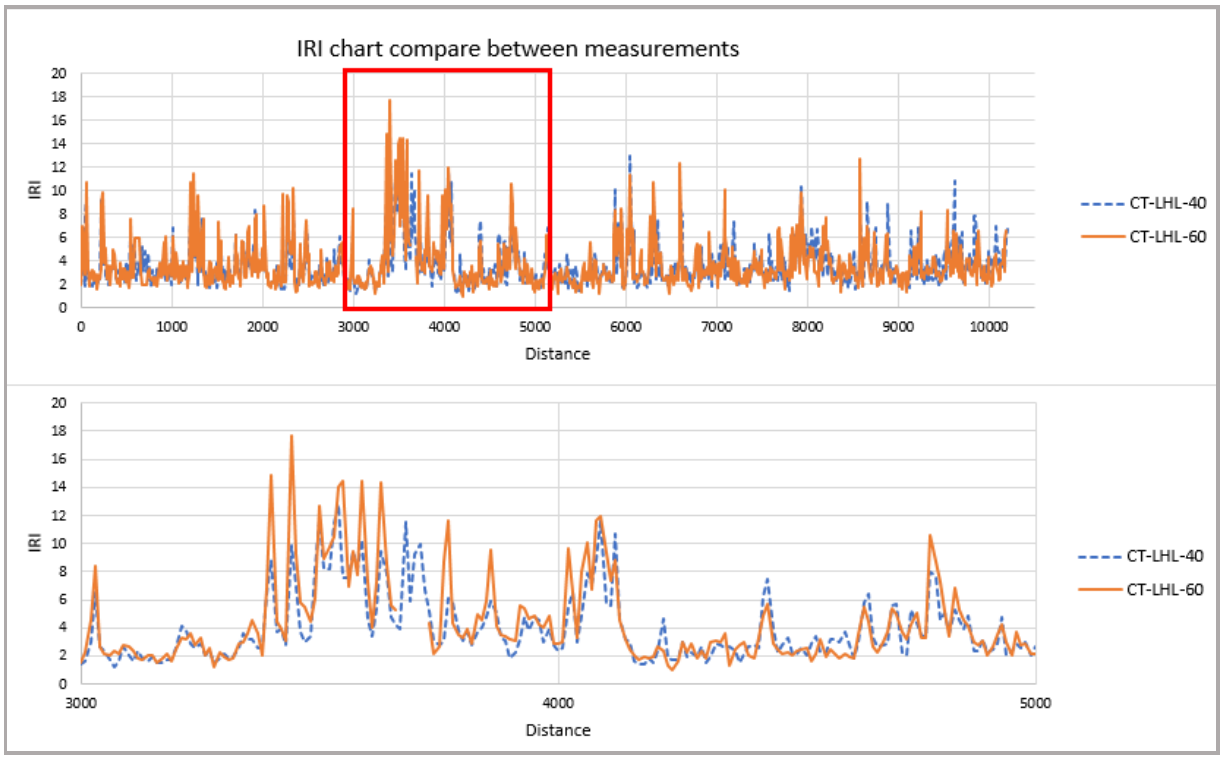

Figure 8. Comparison of IRI_{10m} value when measured at speeds of 40km/h and 60km/h on Lang Hoa Lac expressway.

4.2.2. Lang Hoa Lac residential road

The measurement was taken place on Lang Hoa Lac residential road, using Kia Carens with two different speeds of 30km/h and 40km/h, the results are in the chart below. With IRI measured at a speed of 30km/h is 4.49mm/m and a speed of 40km/h is 4.77mm/m, the relative average Denta is equal to 5.8%. With this result, the value obtained of IRI when measured at a speed of 40km/h is higher than the value of IRI when measured at a speed of 30km/h. The relative average Denta value on the Lang Hoa Lac residential road (IRI = 4.88mm/m) is larger than that on the Lang Hoa Lac expressway (IRI = 3.60mm/m).

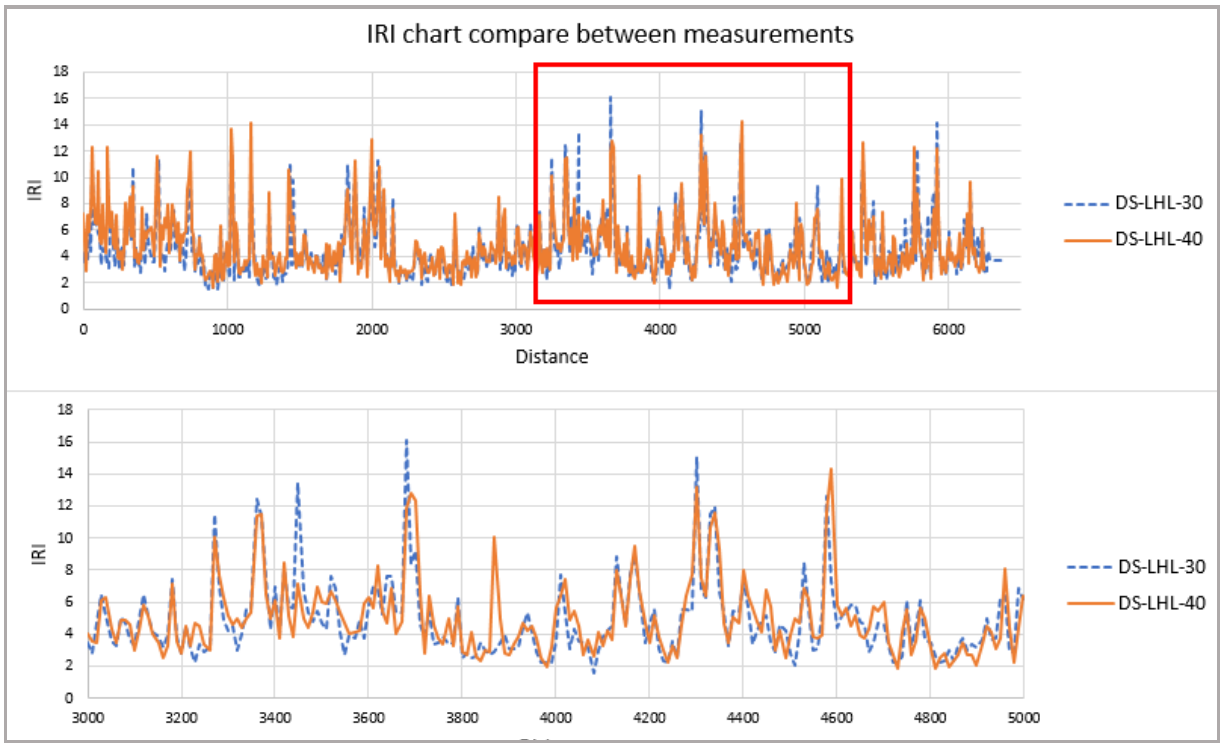

Figure 9. Comparison of IRI_{10m} value when measured at speeds of 30km/h and 40km/h on Lang Hoa Lac residential road.

4.2.3. National Highway No.5 (from Dong Tru bridge to Nhat Tan bridge)

The procedure was similarly carried out on extended National Highway 5 using Kia Carens, with two different speeds of 40km/h and 60km/h, resulting in the chart as shown below. The IRI Highway surface roughness at a speed of 40km/h is 3.03mm/m, smaller than the IRI measured at a speed of 60km/h which is 3.13mm/m, the relative average Denta is 1.68%. This result shows that the difference between measurements at different speeds on this extended National Highway (IRI = 3.08mm/m) is insignificant.

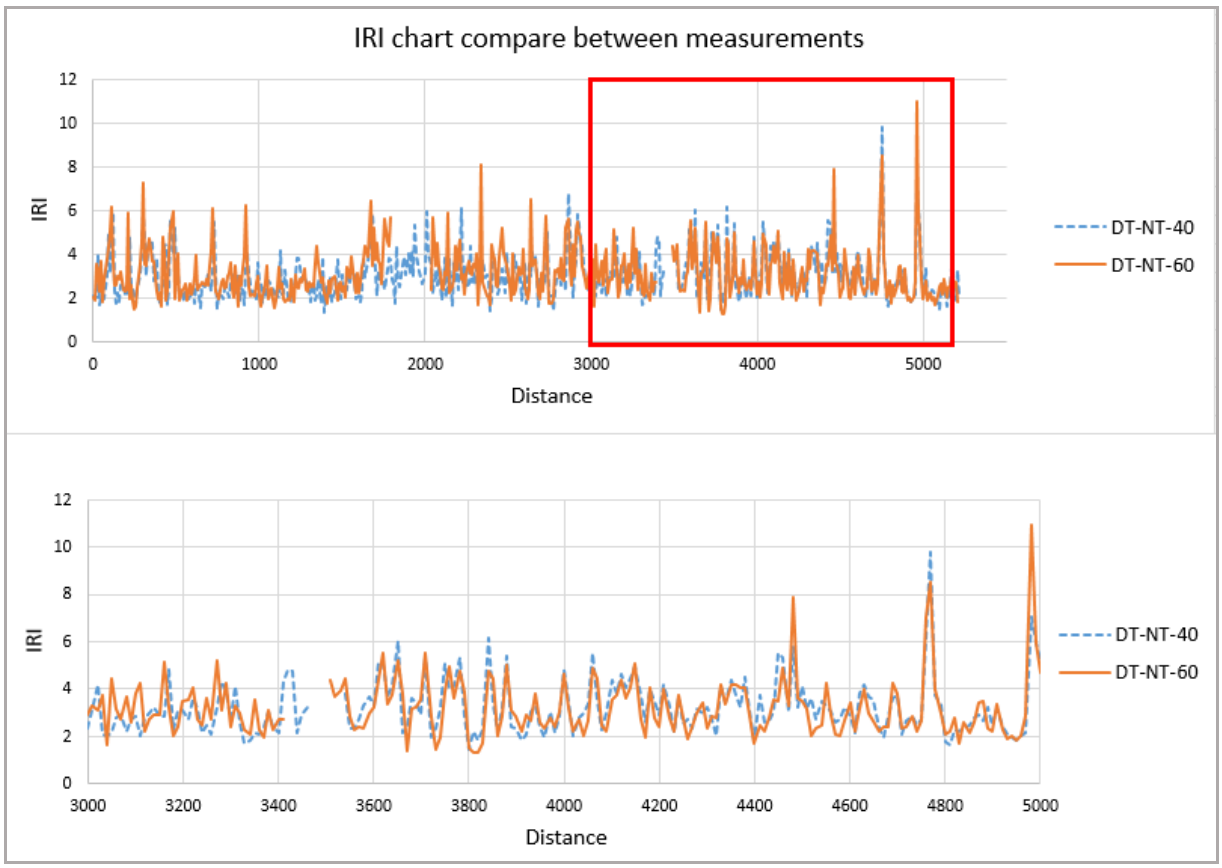

Figure 10. Comparison of IRI_{10m} value when measured at speeds of 40km/h and 60km/h on Extended National Highway No.5.

Based on the measurement results of using the same vehicle, at different speeds and the same location on the Lang Hoa Lac expressway, Lang Hoa Lac residential road, and National Highway No.5, the measured IRI values are the same. The relative average Denta of expressway is 1.76%, residential roads is 5.8% and national highways is 1.68%. The IRI values are similar between measurements at different speeds on many types of roads, meaning that different speeds have a negligible effect on the IRI measurement results when using STAMPER.

4.3. Measurement results using STAMPER on 2 different types of vehicles, at the same speed, at the same location.

The STAMPER device in this measurement was attached on two different vehicles, Kia Carens and Toyota Innova. These two vehicles were used by the research team to survey IRI at the Lang Hoa Lac Expressway, in the same location, the route length was 8km and the driving speed was 40km/h for both vehicles including Kia Carens and Toyota Innova.

With two different vehicles, determining the parameters before measuring: tire diameter, k1/m1, c/m1 will yield different values between the two vehicles. The results obtained after measuring with these two means at the same location, with 1 speed are obtained as shown below.

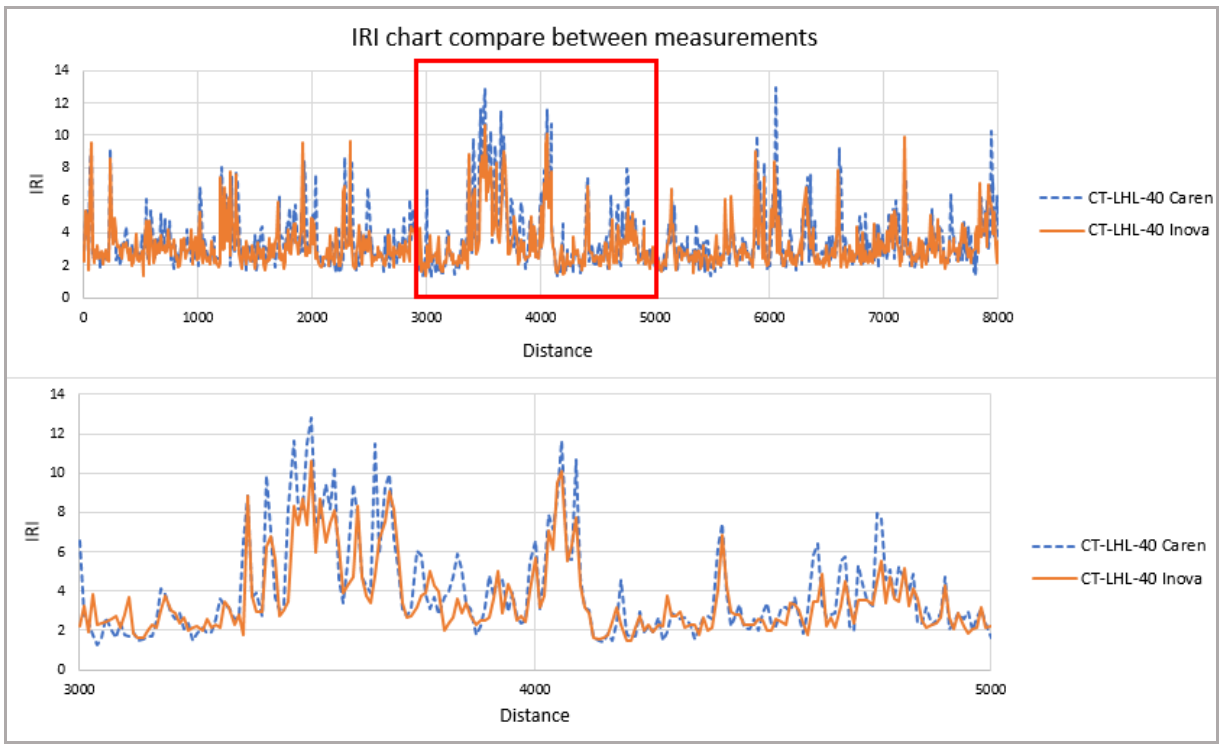

Figure 11. Comparison of IRI_{10m} value when measured with 2 types of vehicles on Lang Hoa Lac expressway.

Measurement results show that, on the Lang Hoa Lac expressway: at the same speed of 40km/h, when measured by Carens vehicle, IRI=3.55 mm/m is obtained, when measured by Innova vehicle, IRI=3.28 mm/m is obtained. Relative average delta is equal to 8.01%.

By the ability to be installed on many vehicles, in this case the research team used Kia Carens and Toyota Innova. IRI measurements using different cars show similar results in both trend and value. This result is very meaningful to evaluate the flexibility of the device. Being able to setup and use on many different types of vehicles helps improve the flexibility and convenience of use of STAMPER. This allows management agencies to survey road surface condition more easily by their existing vehicles with high speed and accuracy when they cannot use other high-cost specialized device.

5. Conclusions

Measurements using STAMPER device were conducted on 3 types of roads: Expressway, Residential Road, and National Highway. The vehicle speeds are 30, 40 and 60km/h depending on each route. Two types of vehicles for taking measurements are Kia Carens and Toyota Innova. The obtained results are IRI data with measuring steps of 10m, accompanied by video data for each route.

With measured routes, when comparing repeated measurements with the same type of vehicle, at the same speed, the IRI values tend to be similar, and the difference between

measurements is very small. IRI results when measured at different speeds on many types of roads also vary slightly, reflecting the ability of STAMPER to be used with a wide range of speeds from low to high. In case of measurements with different types of vehicles, the IRI values measured by Carens and Innova vehicles tend to be similar, and the difference between these two values is not too large. These measurement results show that the STAMPER device can be used repeatedly on many different types of roads, with wide speed range, on different vehicles. The values of the measurements are equivalent, in other words, the device is used flexible with a stable outcome.

Through analysis of IRI data of the surveyed road sections, it shows that a specific and comprehensive measurement of the road surface roughness is necessary for a precisely assessment of the road surface condition. The IRI results obtained with the STAMPER and road surface images obtained with the camera are the basis for visual and detailed assessment of road surface condition. STAMPER device has been developed and applied in Japan, with the high accuracy and the convenient installation of the STAMPER device on many vehicles lead to a reduction in price and ease in technology transfer in comparison to other specialized IRI measuring devices.

The results of the study show that this device can be installed on different types of vehicles, measured several times at different speeds with high precision, and can investigate many types of roads. The reference values of the device are similar in compare to the trusted device which has high accuracy [7], these studies confirm the reliability of the STAMPER device. As a result, it can be seen that the practical applicability of the device is very flexible and suitable for road management agencies in Vietnam with the characteristics of accuracy, low cost, and convenience in the inspection and maintenance of roads.

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