EXTENSIONAL SMARTPHONE PROBE FOR ROAD BUMP DETECTION

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ABSTRACT

When a wide area disaster like an earthquake is occurred, an immediate monitoring and sharing of traffic situation and road condition are important for the quick rescue operation at disaster area. A road bump is one kind of conditions which is needed to an immediate monitoring and sharing. But currently, because of a road bump detection is done by human visual confirmation and a mechanical measuring of road surface shapes using profile meter, it need to use many human resources, long lead time and special equipment. In this paper, a road bump detection method is proposed that can be done more easily, which is named Bump Recorder. That is one kind of a extensional smartphone probe which is a smartphone only put on a vehicle dashboard, and the vehicle is driven as usual. At first, for a prototype Bump Recorder which is used pedometer, a bump detection principle and actual measurement result are explained which was measured at the Niigataken Chuetsu-oki Earthquake in 2007. And next, for the first generation Bump Recorder which is used three-dimensional accelerometer that is installed on a smartphone, bump detection logic and an experiment result are explained. At last, for the second generation Bump Recorder which is used three-dimensional gyro sensor is explained.

CURRENT METHOD AND PROBLEMS

Currently, road bump detection will be done by human visual confirmation and by a mechanical and optical profile meter which is measuring road surface shape. It spends many human resources, long lead time or special equipments. More convenience method is proposed which is accelerometers are installed at a vehicle shock absorber top and bottom side [(1)]. This method is more convenience than previous method, but a technical knowledge and skills are still needed to install accelerometers. For these reasons, it is difficult to research whole areas immediately after disaster.

ACTUAL MEASUREMENT AT THE NIIGATAKEN CHUETSU-OKI EARTHQUAKE IN 2007

When the Niigataken Chuetsu-oki Earthquake was occurred at 2007 July 16th which has Magnitude 6.8 strength of an earthquake, convenience method was tried for road bump detection. That is method which is used pedometer that is installed on a vehicle dashboard of vertical surface in front of a passenger seat, and counting up a number of vehicle vertical vibrations (2).

MEASUREMENT METHOD

It is assumed that vertical acceleration can be used for a road bump index, measurement method is developed which is used a pedometer. A pedometer not only can be perpetrated easy and cheap, but also respond for vertical body shake without respond other vibrations. These are good features for convenience method of road bump detection. A pendulum type digital pedometer has a pendulum switch inside. Connecting signal lines to microcomputer board, ON-OFF signals are taking out from this switch, and a time of signal ON is recording. That is the prototype of Bump Recorder. At same time, GPS is used for recording latitude and longitude at every 1[min].

MEASUREMENT RESULT

Using this prototype Bump Recorder, actual measurement was done under an actual disaster. In Fig.1, a measurement result is drawn which was measured from 2007 August 12th to 16th at around KASHIWAZAKI area which is near the epicenter or center of an earthquake. This is situation of passing one month after the disaster. In this figure, number of bump steps for each 1[km] long is calculated from recording time matching of the prototype Bump Recorder and GPS, and this number is drawn as circle diameter on a seismic intensities map. The epicenter is drawn as a cross mark. In this figure, there are many bump steps from central of KASHIWAZAKI to KARIWA and IZUMOZAKI which is located at near the epicenter. And it matches with driver's impression when the vehicle was driven on these roads.

When a vehicle speed is rising up, there is possibility to increase a number of detection. But look at the result on Route 8 around NAGAOKA in Fig.1, Route 8 is a main road and travel speed has about 60[km/h], but a number of bump detection is not so often. In addition, look at around central of KASHIWAZAKI, because there are many traffic jams, a travel speed is slow, but a number of bump detection is often. Thinking about these results, a speed influence is not so critical for bump detection. In addition, in a place of a vehicle is stopping and going repeatedly several times because there are traffic signals, a number of bump detection is not so large also. It means that the influence of acceleration of running direction is not so critical for bump detection. As a result, pedometer type of the prototype Bump Recorder is very simple method, but it can measure road damage from an earthquake. This Bump Recorder only uses standard parts, but it still not easy to done for a staff of rescue operation, because it still needed a special hardware which are modified pedometer and microcomputer board etc.

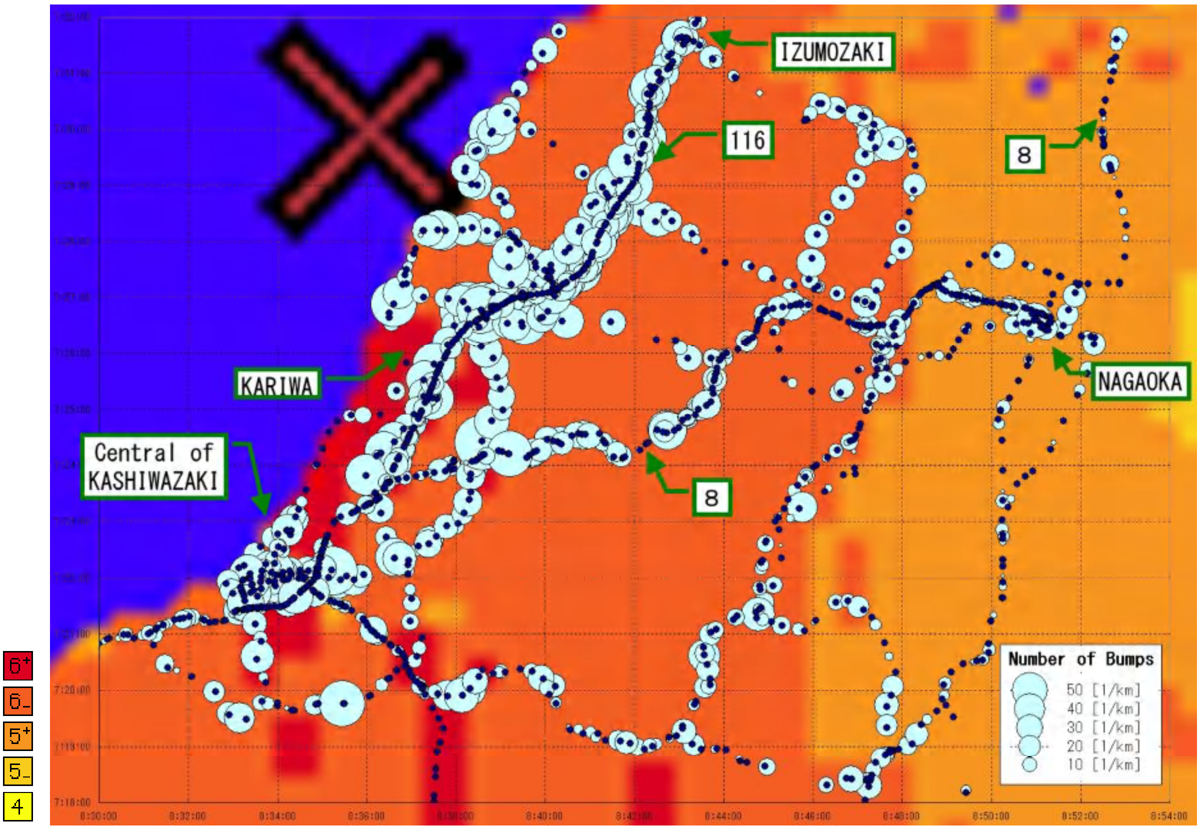


Fig.1 Measurement Result of Road Bump - Measurement Date : 2007 Aug. 12th to 16th -

PROPOSED METHOD OF USING SMARTPHONE

For more usability, road bump detection method is developed that is a smartphone only put on a vehicle dashboard. At first, for the first generation Bump Recorder which is using three-dimensional accelerometer and GPS, road bump detection logic and an experiment result are explained. Next, for the second generation Bump Recorder which is also using gyro sensor, effect of gyro sensor is explained. In this paper, iPhone is used for all development, but of course, any smartphone which has three-dimensional accelerometer, GPS and gyro sensor, it can be used for developing of a similar application.

EXPERIMENT CONDITION AND RESULT

The first generation Bump Recorder which is used three-dimensional accelerometer is explained. Fujino et al (2005) reported that between IRI -International Roughness Index- and RMS -Root Mean Square- of vertical acceleration at one second recording data has a correlation[(3)(4)]. In the beginning of Bump Recorder development, this principle was tried. At

first, this experiment result is explained.
Experiment condition is as follows. For GPS positioning, a smartphone should be stay under the sky. Therefore a smartphone is put on a vehicle dashboard in front of a passenger's seat. In this experiment, any mounting equipment is not used, just only used thin rubber sheet for anti slipping. iPhone is used for a smartphone. Install direction of iPhone is display side is upside and the home button is vehicle back side. It means that X-axis of accelerometer is width direction, Y-axis is running direction, Z-axis is vertical direction. Recording cycle is 100[Hz]. It means that, when the vehicle is driven at 60[km/h], travel distance is 0.17[m] at one recording cycle. GPS recording cycle is about every 1[sec]. For emulate a bump step, a round wooden rod which has 24[mm] diameter and 900[mm] long, is put on an asphalt road. And the vehicle goes over this rod, and the tire of passenger side is climbing over this rod. Vehicle speed is 30[km/h]. In this driving, a driver felt the bump step, but not felt danger. It means that this bump step is not so large. In this experiment, TOYOTA PRIUS is used. That has 2700[mm] wheelbase, 4460[mm] long, 1520[mm] tread width, 1490[mm] height, 1350[kg] weight. The vehicle is running clockwise 5 laps at square course which has 620[m] long for one lap.
In Fig.2, experiment result is drawn on the map. 1[sec] standard deviation of Z-axis acceleration which is vertical direction is drawn with circle diameter. A round wooden rod is located at arrowed position on right bottom side of Fig.1, but it is difficult to find a bump step form this figure.

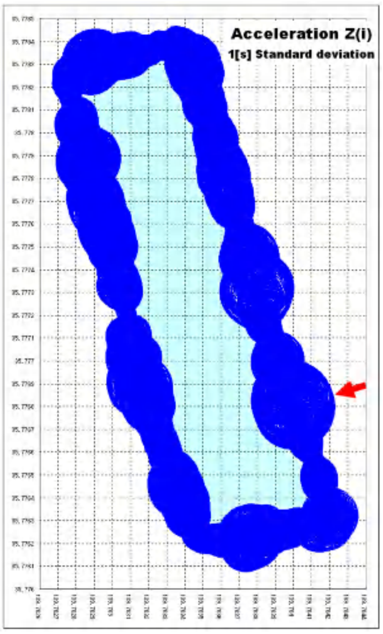


Fig.2 1[sec] Standard Deviation of Vertical Acceleration

Therefore recoding acceleration data is investigated. In Fig.3, sample data is drawn which is recorded at the vehicle goes over the round rod. In this figure, for each axis, there are two sections where vibration became intense. The interval time of these two sections is around

0.38[sec]. Vehicle speed is measured by GPS. That is 27.4[km/h] or 7.6[m/s]. Interval time of wheelbase 2.7[m] from front wheel to rear wheel is calculated 0.36[sec]. It is matched with interval time of acceleration intense sections. To pick up these features from short time period, 50[ms] or 5 cycles standard deviation is used instead of 1[sec] standard deviation. This value is drawn in Fig.4. Here, reason of 50[ms] is explained. In Japan, Legal limited speed is 100[km/h]. Interval time of wheelbase 2.7[m] is calculated 97[ms] for this speed. For bump detection, separation of features of front wheel and rear wheel is needed. Therefore a half time is used. That is 49[ms] or 5 cycles for 100[Hz].

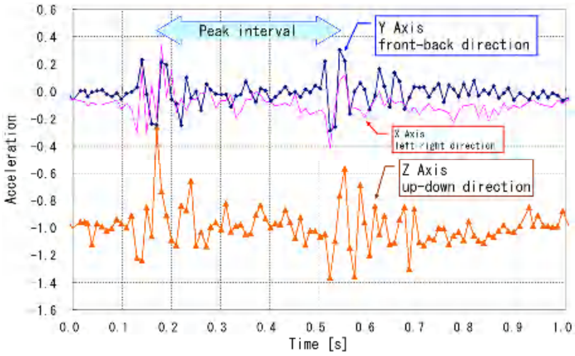


Fig.3 Recoding Value of Acceleration

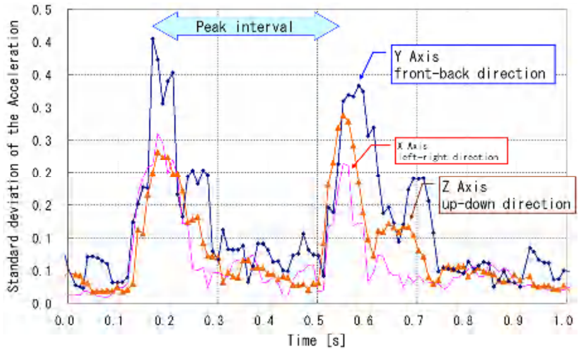


Fig.4 50[ms] Standard Deviation

Not only on Z-axis of vertical direction, but also on other axis, there is an acceleration intense section. A consideration is applied. Fig.5 is schematic view when the wheel climb over the round rod, reaction force is occurred that direction is from the contact point of the round rod to the center of wheel. As a result, not only on Z-axis of vertical direction, but also on Y-axis of running direction, acceleration will be occurred. This is the reason of Y-axis data intense. This experiment was done under the condition of only the wheel of passenger side climbs over the round rod. Therefore, rolling force is applied, that is reason of X-axis data intense. As a conclusion, features of bump step are appeared on Y-axis of running direction and Z-axis of vertical direction.

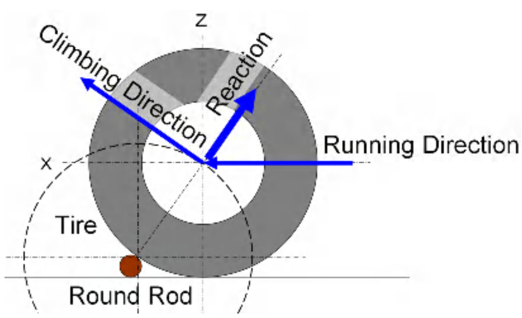


Fig.5 Schematic View when the Wheel climb over the Round Rod

ROAD BUMP DETECTION LOGIC

Based on the experiment result, road bump detection logic is designed as follows.

Condition 1 : Both of Y-axis or running direction and Z-axis or vertical direction, 50[ms] standard deviation is large.

Condition 2 : These sections are appeared with wheelbase time.

Here, each variable is defined as follows. A recording order number is defined i. Acceleration data are defined *X(i), Y(i), Z(i)* for each axis. For Y-axis or running direction and Z-axis or vertical direction, 50[ms] standard deviation is defined *SDy(i), SDz(i)*. For condition 1, simultaneity index is defined *SDyz(i)*, and it is calculated by equation 1.

$$SDyz(i) = SDy(i) \times SDz(i) \qquad \text{--- (equation 1)}$$

A cycle number of wheelbase time is defined *Nw*. For condition 2, Bump Index is defined *Byz(i)*, and it is calculated by equation 2.

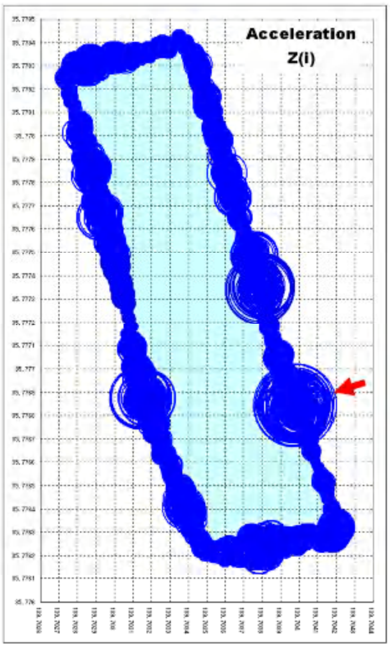
$$Byz(i) = SDyz(i) \times SDyz(i + Nw) \qquad \text{--- (equation 2)}$$

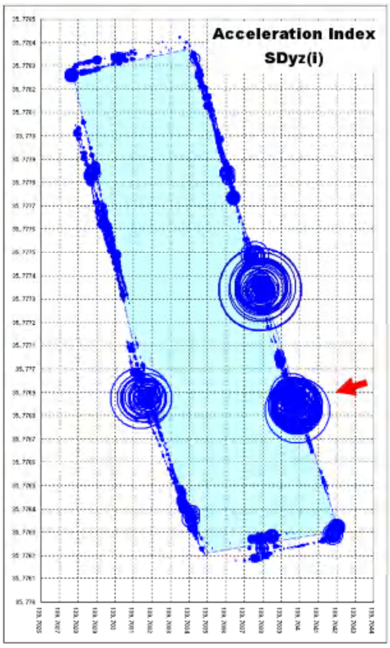
Nw is related with vehicle speed. Vehicle speed is defined *V*[m/s]. Wheelbase is defined *Lw*[m]. Recording cycle is defined *H*[Hz]. *Nw* is calculated by equation 3.

$$Nw = \frac{Lw}{V} \times H \qquad \text{--- (equation 3)}$$

EXPERIMENT RESULT

This logic is applied to Fig.2 data. 50[ms] standard deviation of Z-axis acceleration or vertical direction *SDz(i)* is drawn in Fig.6. Simultaneity index *SDyz(i)* is drawn in Fig.7. Bump index *Byz(i)* is drawn in Fig.8.





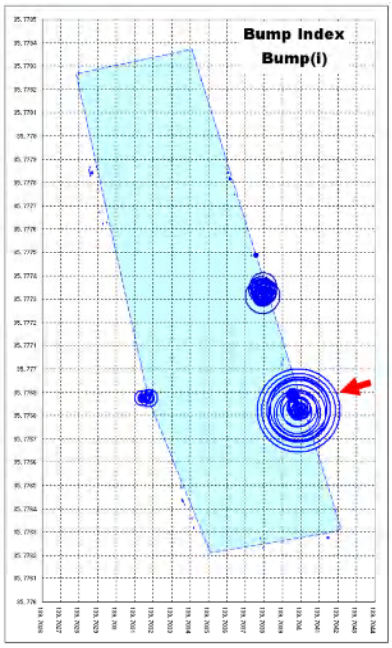


Fig.6 50[ms] Standard Deviation *SDz(i)* **Fig.7 Simultaneity Index *SDyz(i)*** **Fig.8 Bump Index *Byz(i)***

Compare with Fig.6 of 50[ms] standard deviation and Fig.2 of 1[sec] standard deviation, 50[ms] standard deviation is better than 1[sec] standard deviation. But bump step position still not clear. In Fig.7 of simultaneity index, noise is reduced. In Fig.8 of bump index, large circle is concentrated in the right bottom side. This position is same as emulated bump position. In other place, for example a left and top side has small circles. Therefore, after this experiment, road surface of these positions are checked. As a result, a small crack was found on the border of asphalt construction. This result said road bump detection logic has good capability which is using relationship of two axis acceleration and wheelbase time.

EFFECT OF GYRO SENSOR

Gyro sensor is installed on latest iPhone4. Effect of gyro sensor is examined. Experiment conditions are same as above. When the vehicle is climb up the bump step, it is expected that pitching will be generated. It is equivalent to rotation of X-axis or width direction acceleration. Fig.9 and Fig.10 are drawn which is applied pitching data on Fig.3 recording data and Fig.4 50[ms] standard deviation. Here, because of the recording value of pitching data is small, 10 times value is used on these graphs.

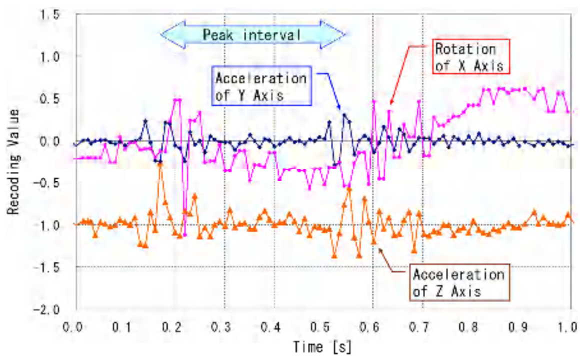


Fig.9 Acceleration and Rotation Data

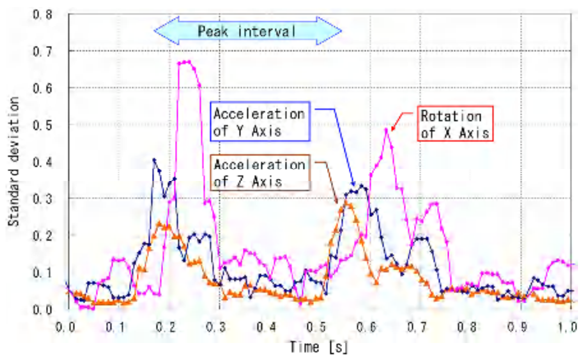
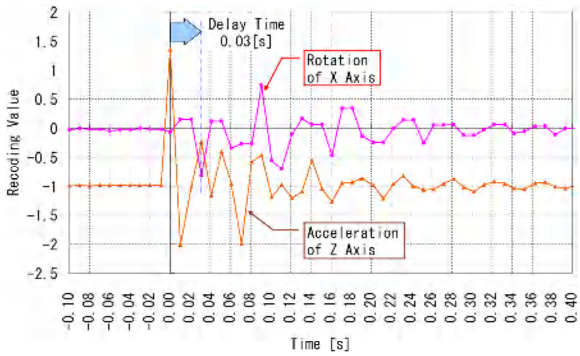


Fig.10 50[ms] Standard Deviation

In Fig.9, because of pitching data has a long cycle wave, feature of bump step is not so clear. But in Fig.10, there are two data intense sections with wheelbase time. And pitching data is delayed form acceleration data of Y-axis or running direction and Z-axis or vertical direction. A confirmation experiment was done to clear the feature form a vehicle or gyro sensor.

iPhone4 is put on a test table, impact force is applied for vertical direction at the table edge of one side. The result is as follows. In Fig.11, acceleration data of Z-axis or vertical direction and pitching data are drawn. In Fig.12, 50[ms] standard deviation is drawn. For convenience, in these graphs, 10 times value is used for pitching data. In Fig.11, the feature is not so clear, but in Fig.12, there is about 30[ms] delay from acceleration data to pitching data. This result said delay of pitching data is a feature of gyro sensor on iPhone4. It should be reflected to bump detection logic.



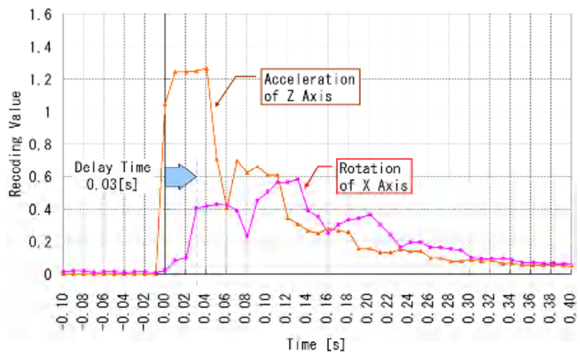


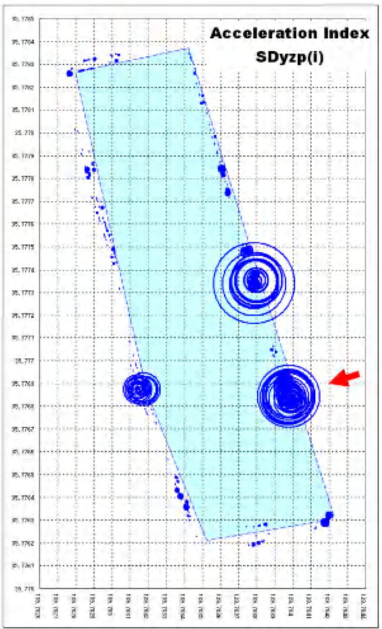
Fig.11 Data Delay on Recording Data **Fig.12 Data Delay on 50[ms] Standard Deviation**

Here, pitching data is defined *P(i)*. 50[ms] standard deviation of *P(i)* is defined *SDp(i)*. Cycle number of delay from accelerometer data to gyro sensor data is defined *Nd*. Simultaneity index *SDyzp(i)* and bump index *Byzp(i)* are applied pitching data as follows.

$$SDyzp(i) = SDy(i) \times SDz(i) \times SDp(i + Nd) \quad \text{--- (equation 4)}$$

$$Byzp(i) = SDyzp(i) \times SDyzp(i + Nw) \quad \text{--- (equation 5)}$$

This logic is applied to experiment data which is used Fig.7 and Fig.8. Simultaneity index *SDyzp(i)* is drawn in Fig.13. Bump index *Byzp(i)* is drawn in Fig.14. Compare with the result of only using acceleration data, the result of using gyro sensor data, noise of simultaneity index is reduced, and bump index is also stabilized.



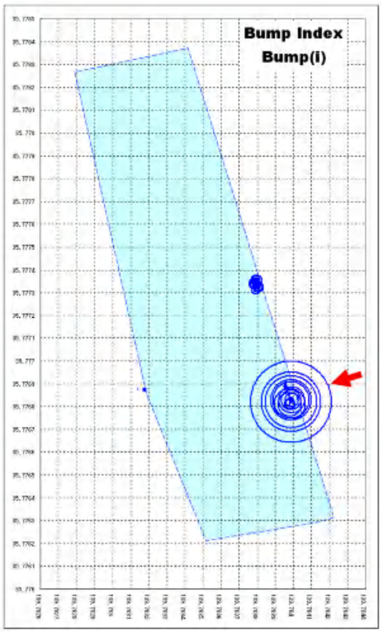


Fig.13 Simultaneity Index *SDyzp(i)* **Fig.14 Bump Index *Byzp(i)***

Measurement experiment was done on a public road. In Fig.15, bump index is drawn, that is a result of 3 laps driving at SHIKAHAMA bridge which has about 500[m] long, located at SHIKAHAMA, ADACHI-ku, TOKYO Japan. In this figure, upper data is recorded at driving from west to east, and bottom data is recorded at driving from east to west. Bump index value is drawn as circle diameter. Driving distance is drawn as horizontal axis, and position of bridge joint is drawn as vertical dot line. All of the bump steps are detected at near bridge joint. This result said bump index has good reproducibility of bump location.

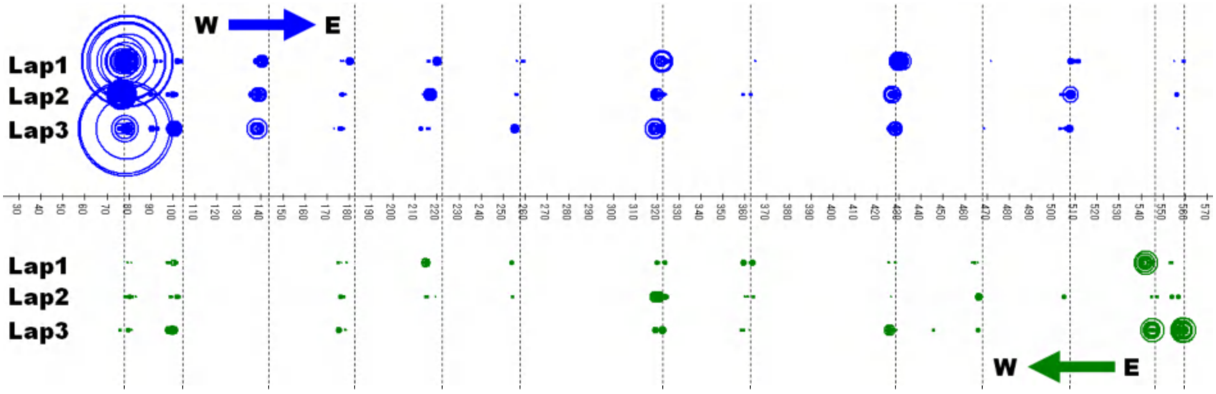


Fig.15 Bump Index of SHIKAHAMA bridge - measuring date : 2010 July 6th -

CONCLUSION

At the Niigataken Chuetsu-oki Earthquake 2007, prototype Bump Recorder is developed, which is used pedometer, and road bump detection was done under the actual disaster. As a result, road bump detection can be done at whole disaster area with low human resources and short lead time. And it is confirmed that the measurement result is matched well with the distribution of seismic intensities.

Using a smartphone, first generation and second generation Bump Recorder is developed. A road bump can be detected, only a smartphone is put on a vehicle dashboard and the vehicle is driven as usual. It is confirmed that this method is very simple, but reproducibility of measurement bump location is well.

Using this method, when an earthquake will be occurred, road bump detection can be done immediately at whole disaster area. But, if it is not clear that road bump is occurred by the earthquake or there are here before, right decision is difficult for rescue operation. Road bump measurement is needed, not only after disaster but also usual time. Therefore, it hopes that this method is used under many situations like road management, and will bring quick rescue operation when the disaster will be occurred.

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