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PAPER TITLE	Preliminary report for IRI changes after KUMAMOTO earthquake Japan, by using Smartphone roughness measurement		
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KEYWORDS:

IRI, response type measurement, pavement maintenance management, smartphone, accelerometer

ABSTRACT:

The Kumamoto earthquake was occurred in Japan on April 14th 2016. After this earthquake, road damage investigation was done that is roughness condition IRI measurement over 3,000km roads. This preliminary report is written for this investigation results.

As for this IRI measurement, response type measurement was done by using a smartphone built-in an accelerometer / GPS and a commercially available car, instead of the inertial profiler. This method is simple, easy and low-cost. So it can immediately measure IRI of whole disaster areas under the damaged rougher road. Measurement results are drawn on online maps. It includes roughness current status and comparison with past status before an earthquake.

Preliminary report for IRI changes after KUMAMOTO earthquake Japan, by using Smartphone roughness measurement

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1 INTRODUCTION

In Japan, Kumamoto earthquake was occurred on April 14 and 16, 2016, at the west end side of Japan. It was the quite large twin earthquake. In Figure 1 shows the location of Kumamoto prefecture. And Figure 2 shows its seismic intensity map. The first shock occurred at 21:26, April 14 and it recorded moment magnitude Mw6.2. The second main shock was occurred at 01:25, April 16, whose magnitude was Mw7.0 bigger than first one. Of course, there were several aftershocks followed the initial quake. In a series of seismic activities, the first shock is usually the biggest one, but at this earthquake, the second main shock was the biggest, which was quite unusual. In the first main shock, many houses, buildings, bridges and roads were damaged. As you know there are many earthquakes in Japan, for example Kobe Earthquake 1995, Chuetu Earthquake 2004, and the Grate East Japan earthquake 2011. So in Japan, buildings etc. have seismic performance. For this reason, at the first main shock in Kumamoto, many of them have damages to some extent but it was not serious for residents' safe. At that time, I thought it was a large earthquake, but it could be under control. However, after the second shock, many structures had already lost enough seismic performance. Many structures were completely destroyed. As the result, 49 peoples died in Kumamoto earthquake. A at the Grate East Japan earthquake 2011, more than 20,000 people died because of the tsunami attack at some pacific coastal areas, not because the quake. Its wave was higher than 35m. At Kumamoto earthquake, more peoples died by quake damages. That was a large quake. Over 137 thousand houses were destroyed by the quake. Of cause it was affected not only to houses, but also to roads and pavements.

Previously, as for pavement inspection, only the human visual inspection used to be applied. In this case, the result is not quantitative, which is difficult to compare with other inspections. Also the use of an inertial profiler is difficult, because of its high costs and the possibility of the breakdown caused by bad road conditions after an earthquake. On the other hand, the response type roughness measurement by using smartphone is one of the solutions to these problems. It can measure quantitative data by using a car that is tougher than an inertial profiler. After two weeks from the main shock of Kumamoto prefecture roughness measurement was done the whole prefecture. Driving distance was up to 3,100km.

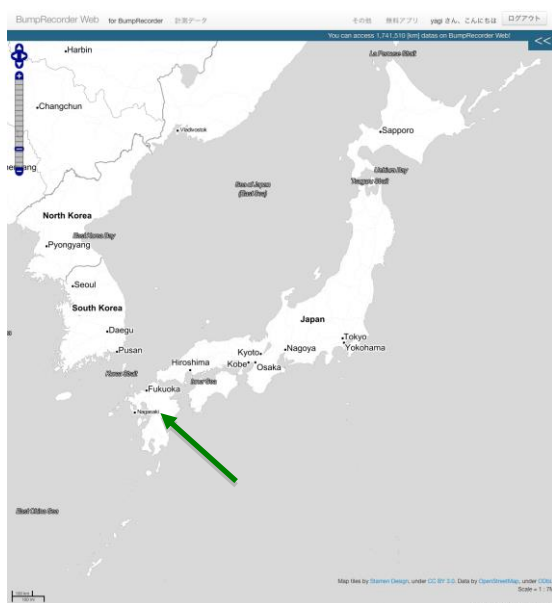


Figure 1. Location of Kumamoto prefecture

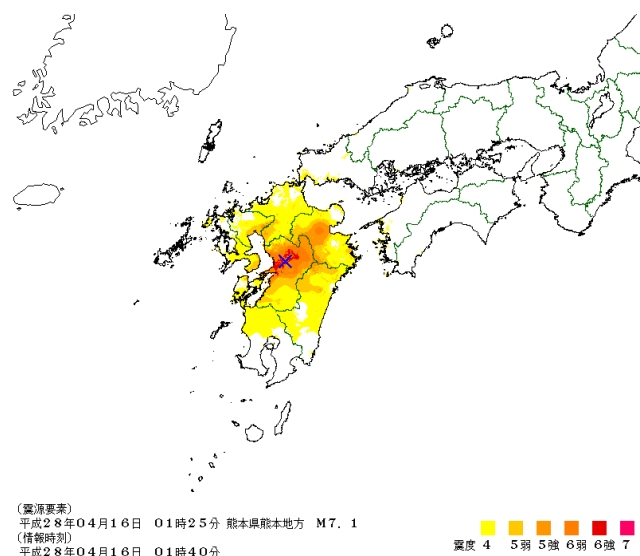


Figure 2. Seismic intensity map

2 SMARTPHONE TYPE ROUGHNESS MEASUREMENT

A smartphone application named BumpRecorder was used for IRI roughness measurement of the road damage inspection from Kumamoto earthquake. The measurement principle was reported at 1st IRF Asia Regional Congress. An essence of this method is as follows.

Smartphone is on the vehicle dashboard. It is located over the vehicle suspension. So a recording acceleration is easily influenced by vehicle model and driving speed. As the result, measurement results are not stable. To increase measurement stability, vibration frequency analysis is applied. Figure 3 is drawing calculation steps.

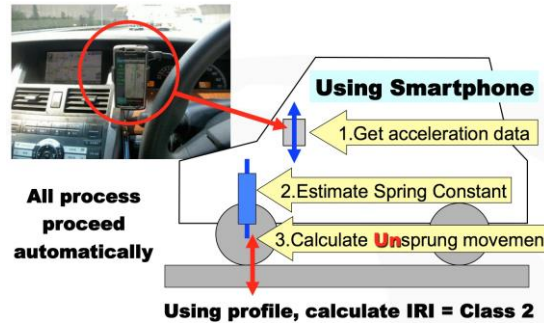


Figure 3. Roughness measurement method

At first, using FFT, vehicle suspensions resonant frequency and damping ratio are estimated. Even if recorded acceleration is including several resonant frequencies, suspensions movement is a main vibration, so it's resonant frequency can be found around 1.5[Hz] easily.

Next, using this spring parameters, the equation of motion of one mass spring model is calculated. This model appears in Figure 4. An equation (1) is an equation of motion for this model. In this equation, Lz is a sprung vertical movement, " u " is an unsprung vertical movement, " ω " is an angular frequency, " h " is a damping ratio. " ω " is defined by equation (2). In this equation, " f " is a resonant frequency. Here, " h " and " f " are used for previous FFT result.

And finally, an unsprung movement " u " is assumed that it is equal to road longitudinal profile, and it is calculating the Quarter Car simulation, then IRI will be calculated.

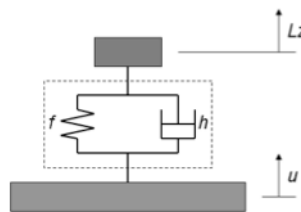


Figure 4. One mass spring model

$$\ddot{Lz} + 2h\omega(\dot{Lz} - \dot{u}) + \omega^2(Lz - u) = 0 \quad (1)$$

$$\omega = 2\pi f \quad (2)$$

Previously, the response type roughness measurement uses correlation equation between IRI and sprung acceleration. That is IRI class 3. And correlation equation is calculated by a test drive result of each vehicle model before measurement drive. On the other hand, BumpRecorder calculates longitudinal profile first, and then QC simulation is applied. That is IRI class 2. And it is not required a previous test drive. That is because calculation parameters of spring constant and damping ratio are estimated form acceleration data of measurement drive.

3 SQUARE MESH SECTION FOR IRI SECTION

To calculate IRI, calculating the section is important. Usually, this section is defined by a road location markers e.g. kilo-post data. But it is not convenience. Because kilo-post data is prepared for a main road, but not for many roads. When not using kilo-post data, the measurement GPS data is separated in a certain distance for example each 100m, which is easy in calculation. But unfortunately, GPS data has an error, when it wants to compare current IRI with previous IRI, it is expected that each IRI section is not same, and a comparison check is difficult.

To improve the situation, "Square Mesh Section" is proposed. It can pick up the same section for same location, anytime, anywhere, only by using GPS data. Square shape mesh is defined by the longitude and the latitude on the earth. When it is driving to cross over one mesh, a section between an entry point and an exit point is used in IRI calculation section. It is drawing in Figure 5.

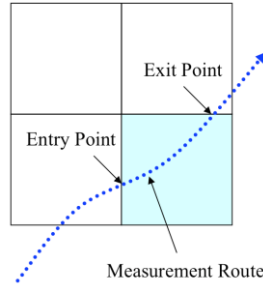


Figure 5. IRI calculation section

In detail, East West length of Square Mesh is defined by $1/8192=2^{-13}$ length for each 1 degree of the longitude. It is about 10m around Japan located around latitude 35 degrees. And North South length is the same width as East West width. For each square shape mesh, Square Mesh Code is a pair code for the longitude and the latitude. An equation (3) defines longitude code of LonCode, and an equation (4) define latitude code of LatCode. LonCode and LatCode are integer.

$$LonCode = \text{int}\left(\frac{longitude}{2^{13}}\right) \quad (3)$$

$$LatCode = \text{int}\left(\left(\frac{1}{\cos(latitude)}\right)^a\right) = \text{int}\left(\log \frac{1 + \sin(latitude)}{1 - \sin(latitude)} \cdot \frac{a}{2}\right) \quad (4)$$

Here, “ a ” is defined for LatCode is 1 when LonCode is 1. That is as follows equation (5).

$$a = 469,367.1234 \quad (5)$$

In Addition, an expand mesh is defined, because it usually wants to use longer section to calculate IRI. An expanding mesh is defined by 2 times, 4 times, 8 times, 16 times width of original mesh one. Square Mesh code is defined by array of (MeshSize, LatCode, LonCode). It shows in Figure 6.

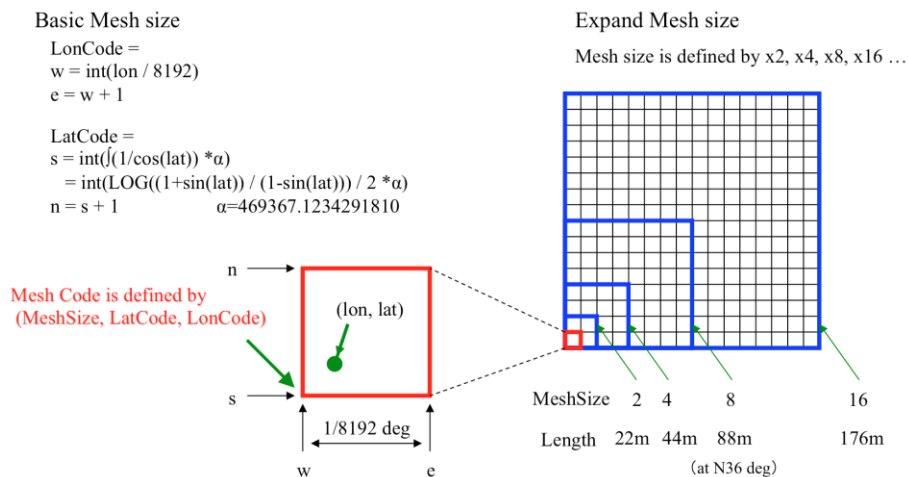


Figure 6. Definition of the Square Mesh Code

4 MEASUREMENT CONDITIONS AND RESULTS

Figure 7 shows roughness measurement roads. It is around Kumamoto prefecture, collected after Kumamoto earthquake. This map has 200km long for south to north, and 260km width for the west to the east. The brown line indicates measurement roads which have over 3,100km long. Measurement roads are located around the epicenter, referred to Figure 2.

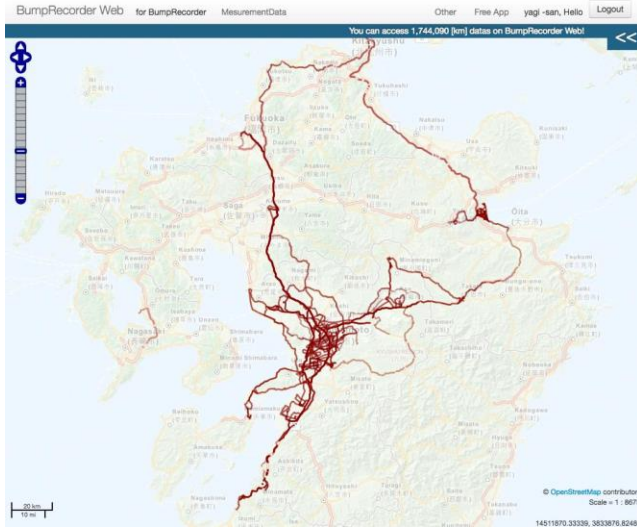


Figure 7. Roughness measurement road around Kumamoto prefecture

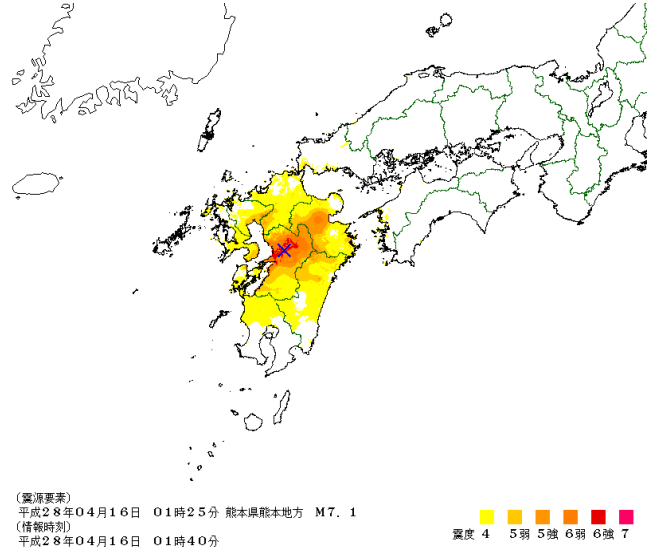


Figure 2. Seismic intensity map (reshown)

Figure 8 and Figure 9 were taken in Mashiki Town during roughness measurement driving. Mashiki Town is located at the Kumamoto earthquake epicenter, and it had biggest damages. Figure 8 indicates a left house originally with two floors, but its ground floor is collapsed down. Figure 9 shows a left house also damaged, its ground floor and wall. that is dangerous to pass its side, so, the left turn lane was closed.

Figure 10 and Figure 11 shows the then Mashiki Town too. Here, pavements are peeled. In Figure 11, on the right hand side of the road, the water drain is floating up, as the result there are bump steps on this intersection.

Figure 12 and Figure 13 shows the then Aso City. It is located at the north east of the epicenter. As for the big bum step of Figure 12, in order to it, the pavement is peeled and graveled. Figure 13 shows a temporally bump step sign for drivers safety, which is continued about 7km long. Driving speed is slowed down.



Figure 8. House collapse at Mashiki Town



Figure 9. House collapse at Mashiki Town



Figure 10. Pavement peeling at Mashiki Town



Figure 11. Pavement peeling at Mashiki Town



Figure 12. Bump step and pavement peeling at Aso City



Figure 13. A bump step sign at Aso City

Figure 14 indicates the roughness measurement result around Mashiki Town, located near the epicenter. On this map, the line color indicates road roughness, which is the Japanese roughness standard index "Flatness Index" like IRI. light blue lines means most flat conditions, blue, green, brown lines do rougher roads, and red lines mean the most rough roads. In addition, triangular shapes indicate bump steps. Large triangular means large bump steps. This map indicates current roughness situations. However, according to this map, it is a little bit difficult to understand which roughness and/or bump step is affected by the earthquake. That is because some roads have been rough before the earthquake, for example around manholes, or bridges, etc.

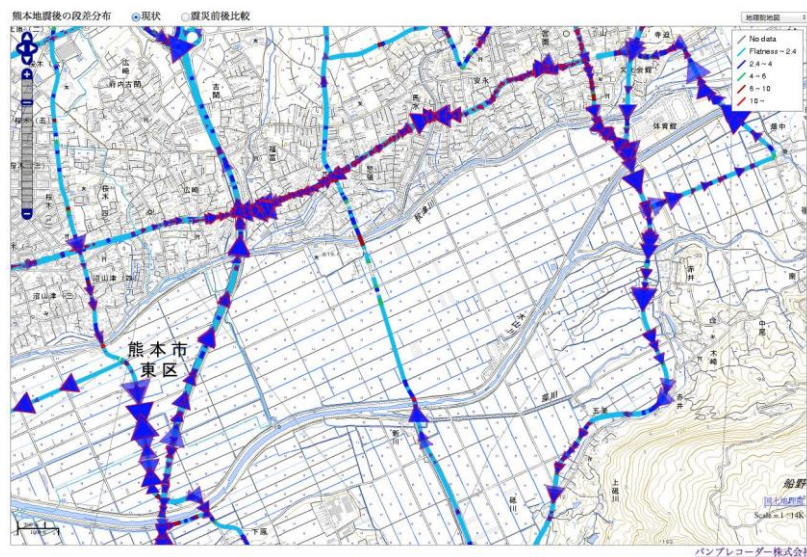


Figure 14. Current roughness and bump step distribution map

BumpRecorder Co., Ltd is measuring road roughness with the global IRI and the Japanese standard "Flatness" from 2011. Figure 15 indicates the measured roads by BumpRecorder application that has already spread all over Japan. So the roughness data before the Kumamoto earthquake happened was already acquired. Using this data, roughness comparison is done between before and after the Kumamoto earthquake.



Compared with Figure 14, current roughness drawing, Figure 16 of the before and the after comparison is easily understood where the quake has damaged. For example, the green arrow point has a bump step, but it is not the quake affect, which is recognized by Figure 16, but difficult to see by Figure 14.

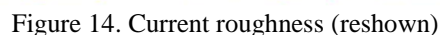
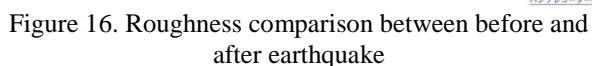


Figure 17 and Figure 18, show the roughness comparison result of wider areas around Mashiki Town. Figure 17 has 20km width for the west to the east, and Figure 18 shows 40km width. Look at this figure, road damages are spreading out the south west direction.

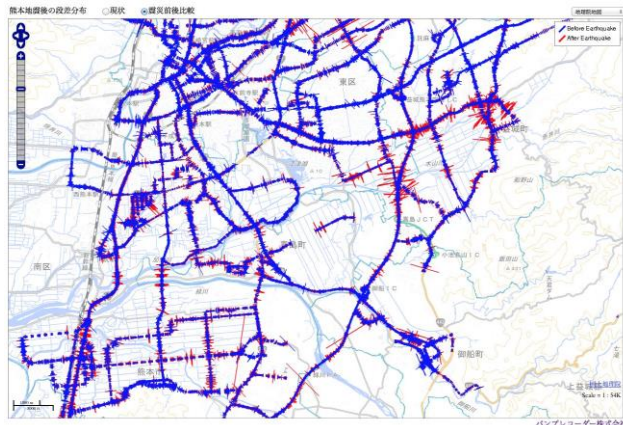


Figure 17. Roughness comparison around Mashiki Town and neighbouring cities and town

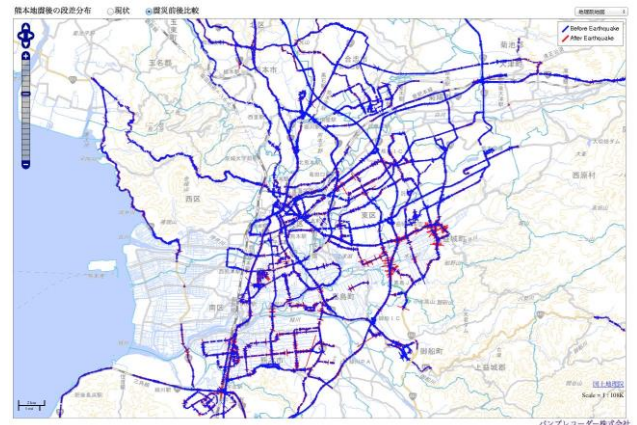


Figure 18. Roughness comparison around central Kumamoto

Figure 19 shows the current roughness distribution map of Aso City located at the north east from the epicenter. In this city, after the earthquake, there is measurement data on many main roads. But there is only few data for before the earthquake. For this reason, Figure 20 shows the fact that two roads can only be made roughness comparison map. According to this result, the regular and frequent measurement is very important to understand pavement situations.

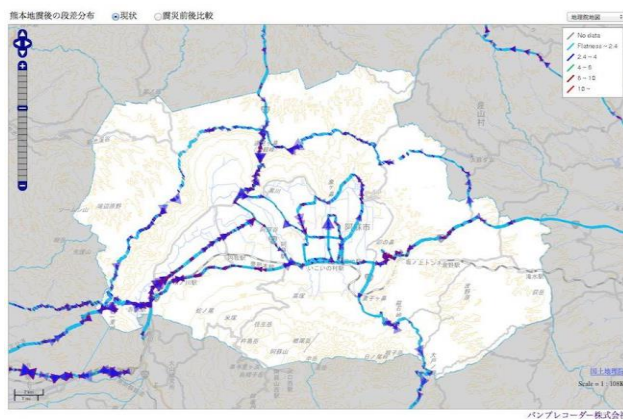


Figure 19. Current roughness distribution at Aso City



Figure 20. Roughness comparison at Aso City

7 CONCLUSIONS

Kumamoto earthquake occurred on April 14 and 16, 2016. The epicenter was in Mashiki Town, and the area strongly damaged by the quake was spreading south west and the north east area from the epicenter. After the earthquake, IRI data was collected from over 3,100km roads in a week. During the inspection, smartphone type roughness measurement application was used. It is easy and low cost to collect roughness data, so it is possible to collect long distance in a short period.

Current roughness data is useful for the pavement maintenance management. However, because the road structure is not sometimes flat, for example manholes and/or abuts of bridge etc., roughness becomes large. That is not damaged by the earthquake. To understand the affect by the earthquake clearly, roughness comparison has been done by using previous measurement data, which enabled us easily to understand where has been damaged. Unfortunately, in some places, for example in Aso City, creating roughness comparison distribution map was impossible because of lacking previous data, which clearly indicates the importance of frequent measurement. It is very important to understand current road conditions. The existing method of inertial profiler is difficult to use because of the high operation cost.

Smartphone type roughness measurement is a powerful tool to collect roughness data. It is easy and low cost. At Kumamoto earthquake, smartphone roughness measurement clearly indicates the possibility to collect roughness data immediately in a short period.

8 REFERENCES

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