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How to Estimate Pavement Roughness: Beyond International Roughness Index

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Abstract

The standard way to describing the road's roughness it to use a single numerical characteristics called International Roughness Index (IRI). This characteristic describes the effect of the road roughness on a vehicle of standard size. To estimate IRI, practitioners tried to use easily available vehicles (whose size may be somewhat different) and then estimate IRI based on these different-size measurements. The problem is that the resulting estimates of IRI are very inaccurate – which means that a single numerical characteristic like IRI is not sufficient to properly describe road roughness. In this paper, we show that the road roughness can be described by a fractal (power law) model. As a result, we propose to supplement IRI with another numerical characteristic: the power-law exponent that describes how the effect of roughness changes when we change the size of the vehicle.

1 Formulation of the Problem

It is important to measure pavement roughness. In the ideal world, roads must be perfectly smooth. In real life, roads can be somewhat rough. Even when we build a perfectly smooth road, eventually, it becomes rougher.

Rough pavement makes driving less comfortable, adds wear and tear to the vehicles, and may even increase the possibility of accidents. It is therefore important to make sure that roads are sufficiently smooth. For this purpose, it is important to have objective measures of pavement roughness.

How pavement roughness is estimated now: the main idea of IRI. The most commonly used roughness measure is known as the *International Roughness Index* (IRI). This model assumes a car of certain size, and estimates the pavement roughness based on the effect of this roughness on this particular type of car; see, e.g., [1, 2, 4].

The problem with IRI. Since the IRI is based on the reaction of a car to the pavement roughness, a reasonable idea is to place a sensor in an actual car, and use the sensor's recordings to estimate the IRI.

The problem is that the actual cars are all somewhat different in size, they somewhat differ from the ideal car used in the definition of IRI. As a result of this difference, recordings made in different size cars lead, in general, to values which are somewhat different from IRI.

Maybe we should go beyond IRI. Several researchers have been trying to find out how we can estimate the actual IRI (based on the ideal-size car) from the recordings made in a car of different size. This seems like a very reasonable idea:

- collect data about different size cars following the same road segment, and
- find the best-fit coefficients of the corresponding regression.

The problem is that the resulting regression formula turns out to be very crude, providing only a very rough approximation for the IRI. In plain English, this means that when you have two road segments which similarly affect a larger-size car, they may have a somewhat different effect on an IRI-standard-size car.

In other words, it means that a single number – describing the effect of pavement roughness on cars of one standard size – is not sufficient to describe the effect of roughness on cars of different size. To describe this effect, we need to supplement the IRI with another parameter that describes how this effect changes with the vehicle's size.

What we do in this paper. In this paper, we use the empirical pavement roughness data to come up with a proposed additional parameter for describing road roughness.

2 Empirical Data

In our analysis, we use the same data that was collected to motivate the IRI, namely, the data described in [4]. This data describes how the root mean square deviation d – measured in m/km – depends on the length L (in cm) of the road interval over which it is measured. This data is presented in the following table.

L	5	10	15	20	25	30	35	40	45
d	8.0	7.0	6.8	6.4	6.3	6.4	6.1	6.0	5.7
L	50	55	60	65	70	75	80	85	90
d	5.8	5.6	5.5	5.6	5.55	5.3	5.4	5.4	5.2
L	95	100	105	110	115	120	125	–	–
d	5.4	5.2	5.3	5.1	5.1	5.1	5.0	–	–

3 Our Analysis of the Available Data

General idea. In our analysis, we took into account that the in many similar practical situations when we encounter a non-smooth line – e.g., in analyzing the coastline – a good model for the corresponding non-smoothness is a *fractal* model, in which the dependence of the root mean square deviation d on the corresponding length L is described by the power law

$$d = d_0 \cdot L^\alpha; \tag{1}$$

see, e.g., [3].

How to find the parameters of the power law. In the power law, the dependence on the parameters d_0 and α is non-linear, but this dependence can be simplified if we go to log-log scale, i.e., if we consider the dependence of $\ln(d)$ of $\ln(L)$. Indeed, if we take the natural logarithm of both sides of the formula (1), we get a linear equation

$$\ln(d) = \ln(d_0) + \alpha \cdot \ln(L). \tag{2}$$

For this linear equation, we can find the coefficients $\ln(d_0)$ and α by using the usual Least Squares techniques.

Our data fit the power model perfectly. The Least Squares analysis has shown that the above data fit the power model perfectly well, see Fig. 1.

Doublechecking. To doublecheck that we indeed have a power law model, we tried to match the above data with the linear dependence $d = a \cdot L + b$, and we got a much worse fit, see Fig. 2.

4 Conclusion

We believe that an adequate description of road roughness should include a dependence on the length L – the contact length describing the contact between the tire and the road. The larger the vehicle, the larger this contact length.

In general, according to our findings, we expect that any characteristics C of roughness – including IRI – should follow the power law dependence $C(L) = C(L_0) \cdot (L/L_0)^\alpha$, for an appropriate coefficient α. Thus, to properly characterize the road segment, we recommend to supplement the standard value $C(L_0)$ with the parameter α that describes how this value changes when we consider vehicles of different size.

Acknowledgments

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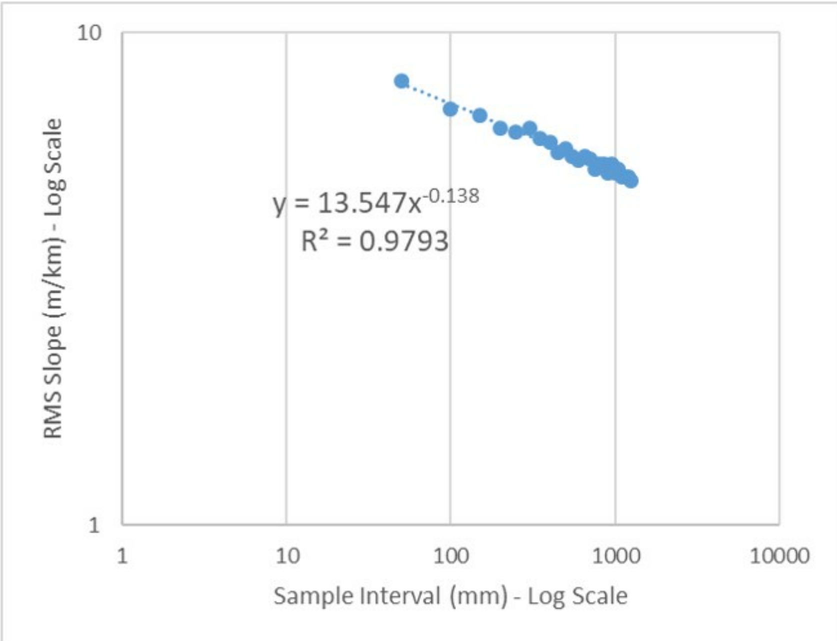

Figure 1: Confirmation of power law

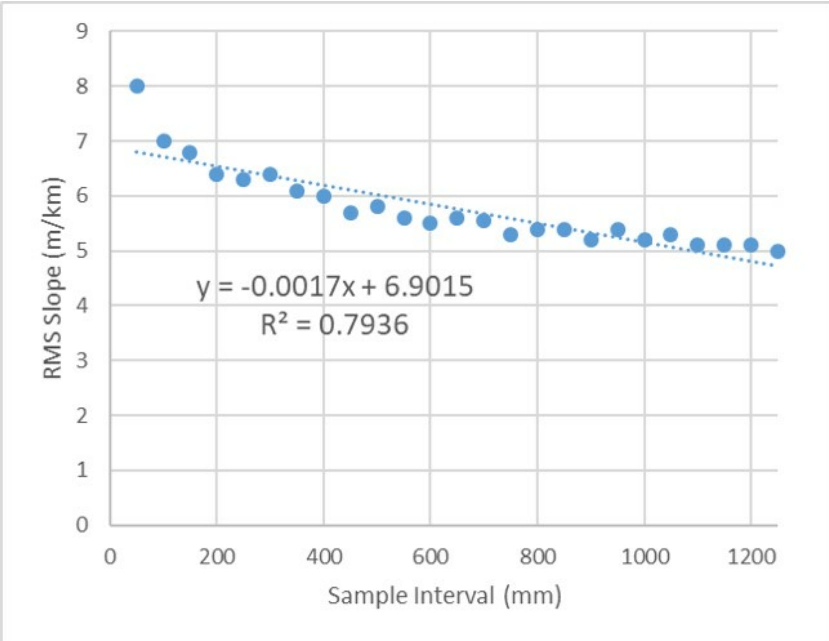

Figure 2: Testing a simple linear dependence