DEVELOPMENT OF HALF-CAR BASED RUTTING INDEX

- Kazuya TOMIYAMA
- Kitami Institute of Technology / Japan
- Doctoral Student
- tomiyama@vortex.civil.kitami-it.ac.jp

- Akira KAWAMURA
- Tateki ISHIDA
- Shigenori NAKAJIMA
- Takashi NAKATSUJI

Contents

1.1. Motivation

- **Importance of evaluation:**

  Why evaluate the rutting?

Rutting affects the ride quality and safety of a vehicle

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Needs of the evaluation based on the vehicle vibration

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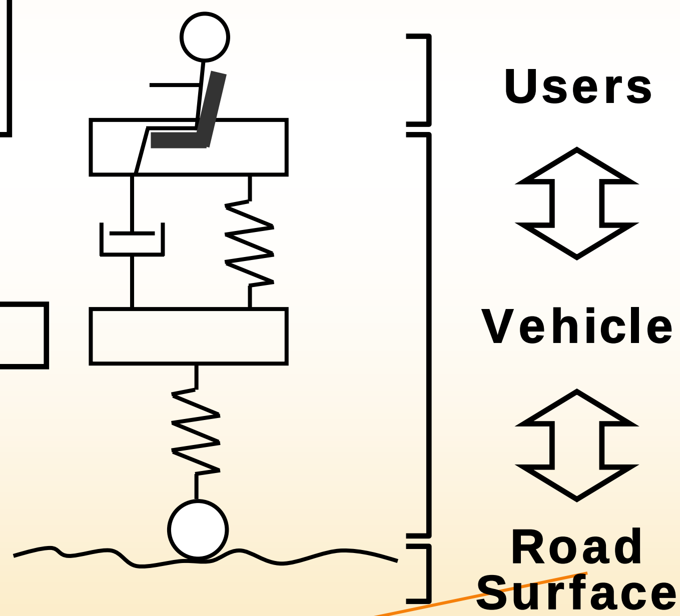
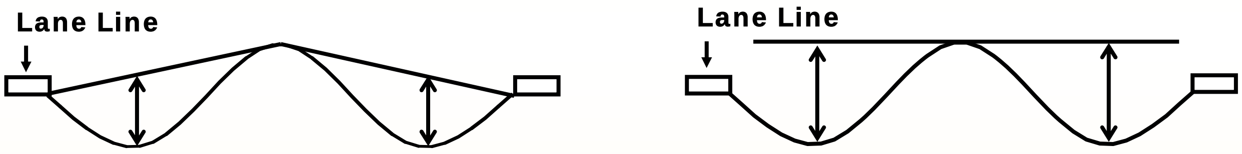
Performance specified road management



Schematic illustration of Human-Road-Vehicle system

1.1. Motivation

- **Current approach: Rut Depth (RD) is…**
  - easy to obtain an individual value of the profile
  - directly calculated from the measured profile



Definition of the rut depth

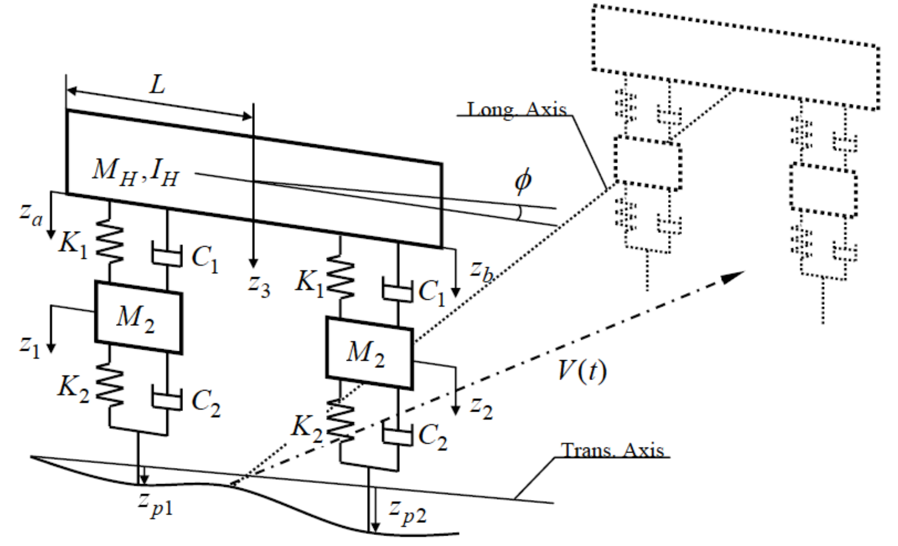
Rut Depth is difficult to evaluate

- the vehicle vibration
- the irregularities in the profile of ruts

1.2. Objective

- **The new approach:**
  based on the Human-Road-Vehicle
  - **Road-vehicle interaction**
  - **Human (user) centered evaluation**

- **Development of**
  Half-Car based index
  - **Vehicle vibration**
  - **User's ride sensation**



2. Mathematical Derivations

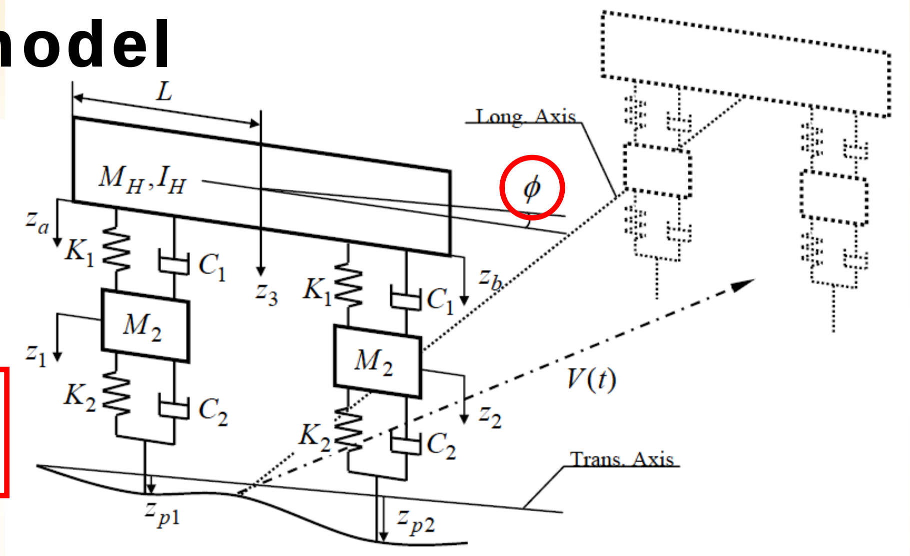
❖ Half-Car simulation model

$$M_2\ddot{z}_1 = K_2(z_{p1} - z_1) - C_1(\dot{z}_1 - \dot{z}_a) - K_1(z_1 - z_a)$$

$$M_2\ddot{z}_2 = K_2(z_{p2} - z_2) - C_1(\dot{z}_2 - \dot{z}_b) - K_1(z_2 - z_b)$$

$$M_H\ddot{z}_3 = C_1(\dot{z}_1 - \dot{z}_a) + K_1(z_1 - z_a) + C_1(\dot{z}_2 - \dot{z}_b) + K_1(z_2 - z_b)$$

$$I_H\ddot{\phi} = \{C_1(\dot{z}_1 - \dot{z}_a) + K_1(z_1 - z_a)\}L - \{C_1(\dot{z}_2 - \dot{z}_b) + K_1(z_2 - z_b)\}L$$



I_H : roll moment of inertia,
K_1 : vehicle spring constant,
K_2 : tire stiffness,
L : half of tread width,
M_H spring mass,
M_2 : unsprung mass,

z_a, z_b : sprung mass displacement,
z_{p1}, z_{p2} : transverse profile as inputs,
z_1, z_2 : unsprung mass displacement,
z_3 : vehicle cg. displacement,
ϕ : roll rotation of sprung mass,
(cg. = center of gravity)

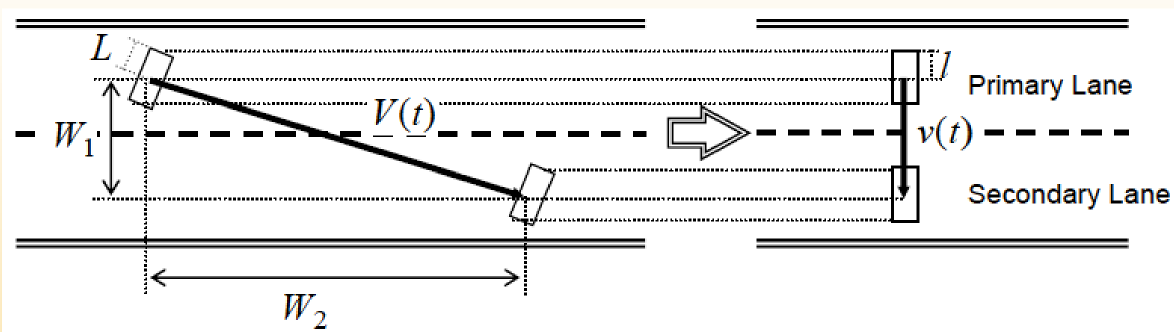
Parameter: Roll Rate

2. Mathematical Derivations

❖ Simulation Procedure

- The measurement data for input to the simulation is given as a single cross-section profile
- The simulation process requires successive cross-sections toward forward direction

Transition Speed enables the simulation for a single profile, and simulate lane-change maneuver



$$v(t) = V(t) * W_1 \Big/ \sqrt{W_1^2 + W_2^2}$$

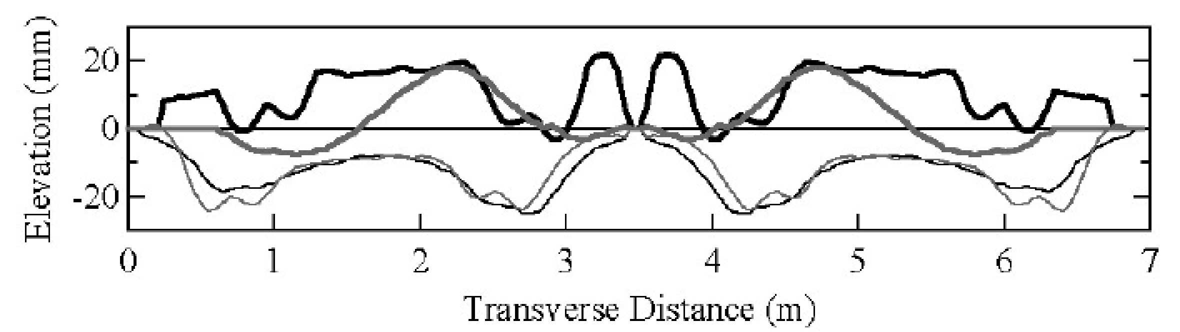
$$l = L * W_1 \Big/ \sqrt{W_1^2 + W_2^2}$$

Definition of the transition speed

3. Definitions

Input Profile Data

- The input data is expanded by the combination with symmetrical itself
- The sample interval is no longer than 150mm
- The profile is assumed to have a constant slope between sampled elevation points



Examples of input profile data

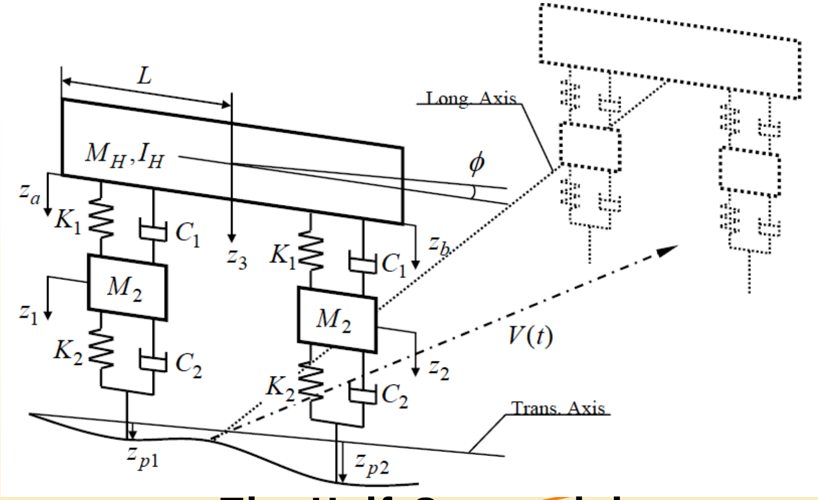
3. Definitions

❖ Specifications of the Half-Car

- The set of specific parameter values that is often called Golden Car (by ASTM No. E1170)

$$K_1 / M_H = 32(s^{-2}); \; K_2 / M_H = 326(s^{-2}); \; M_2 / M_H = 0.075;$$

$$C_1 / M_H = 3(s^{-2}); \; I_H / (M_H b^2) = 0.42; \; b = 2 * L = 1.8(m);$$



The Half-Car model

3. Definitions

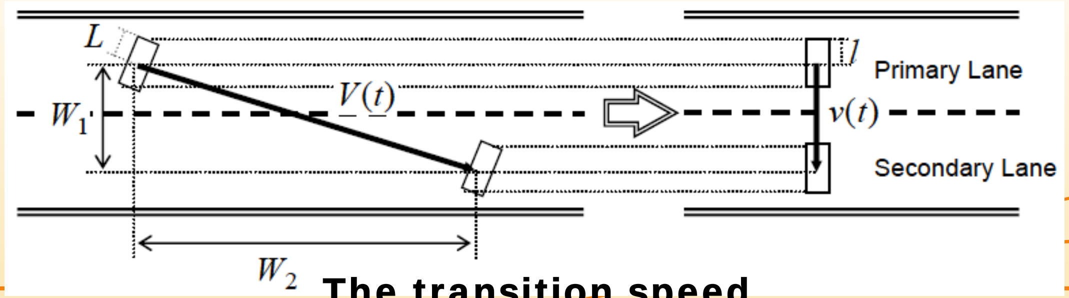
Driving Condition

- The transition width W_1 and distance W_2 are decided on the basis of ISO 3888-1

$$W_1 = 3.5(m); \quad W_2 = 30(m)$$

- The simulated forward speed, $V(t)$, is defined as 80km / h, then transition speed $v(t)$ and l are

$$v(t) = 2.58(m/s); \quad l = 0.89(m)$$



The transition speed

Definition of HRD

HRD: Half-Car based index for Rutting Distress

- The HRD is the root mean square (RMS) value of the roll rate from the Half-Car simulation
- The HRD has unit of angular velocity such as rad / s

$$HRD = AVx_{RMS}$$

where

AVx_{RMS} : RMS of roll rate of sprung mass (rad/s)

3. Definitions

Stationary HRD

- **For pavement monitoring applications, the HRD can be reported as a summarized value in some longitudinal segments**

$$HRD_{stat} = \frac{\sum HRD_j}{N} \quad (j = 1,2,3,\cdots,N)$$

$$N = seg/\Delta$$

where

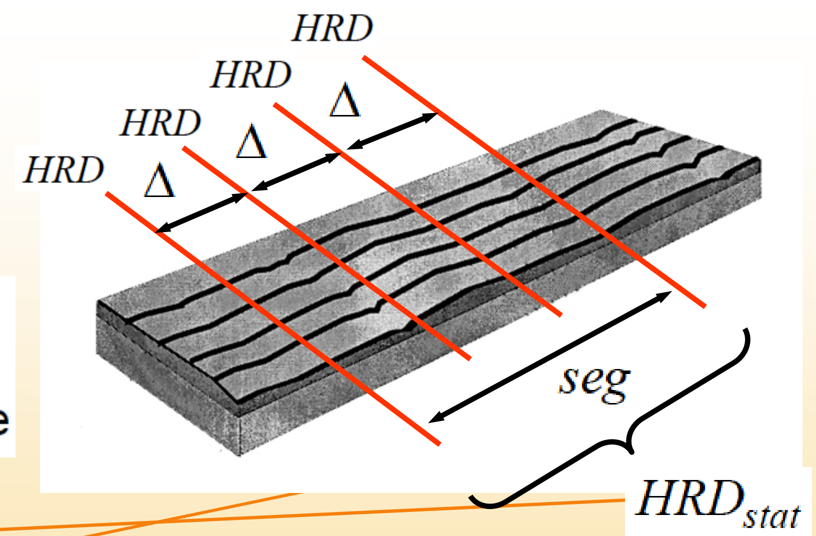
HRD_{stat} : stationary HRD (rad/s)

N : number of segments (-)

j : measurement point of cross-section profile

seg : segmentation length (m)

Δ : sample interval of cross-sections (m)



4. Applicability

- Which is the best estimator of rideability
  - Rut Depth is geometrically and directly calculated form the measured profile
  - HRD is computed from the measured profile based on the vehicle vibration response

- Subjective survey by a driving simulator
  - Comparison between Rut Depth and HRD
  - Applicability of HRD for the rutting evaluation

4.1. Driving Simulator

❖ KITDS:

Kitami Institute of Technology Driving Simulator

Conventional simulator

- Safety of subjects
- Easy setting of test conditions
- Repeatability of test conditions
- Economical testing

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KITDS

- Road surface evaluation
  - Roughness
  - Rutting
  - Skid resistance

Overview of the KITDS

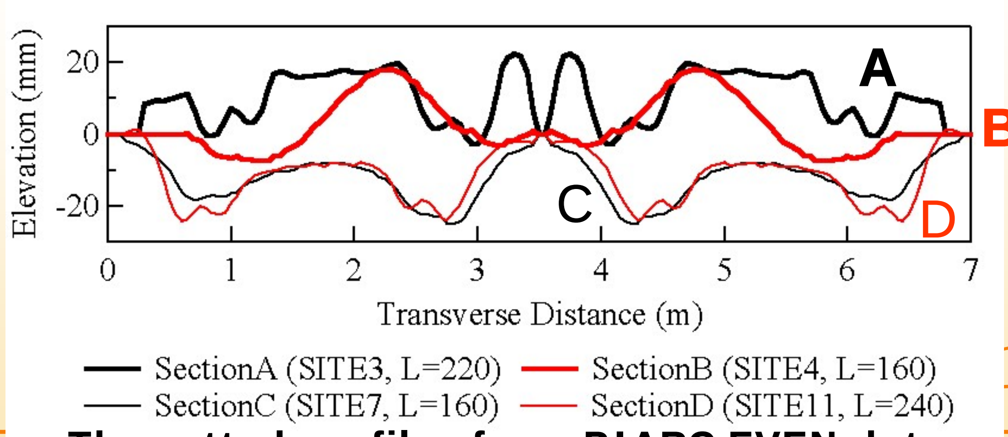

Virtual proving ground

4.2. Road Surface Characteristics 1 2 3 4 5

❖ **Four rutted profiles were obtained form the PIARC EVEN data**

Characteristics of the rutted profiles

Section	SITE in EVEN Project	Wearing/Flowing	Dual/Single
A	SITE3, Long. Dist.=220m	Flowing	Dual
B	SITE4, Long. Dist.=160m	Flowing	Single
C	SITE7, Long. Dist.=160m	Wearing	Single
D	SITE11, Long. Dist.=240m	Wearing	Dual

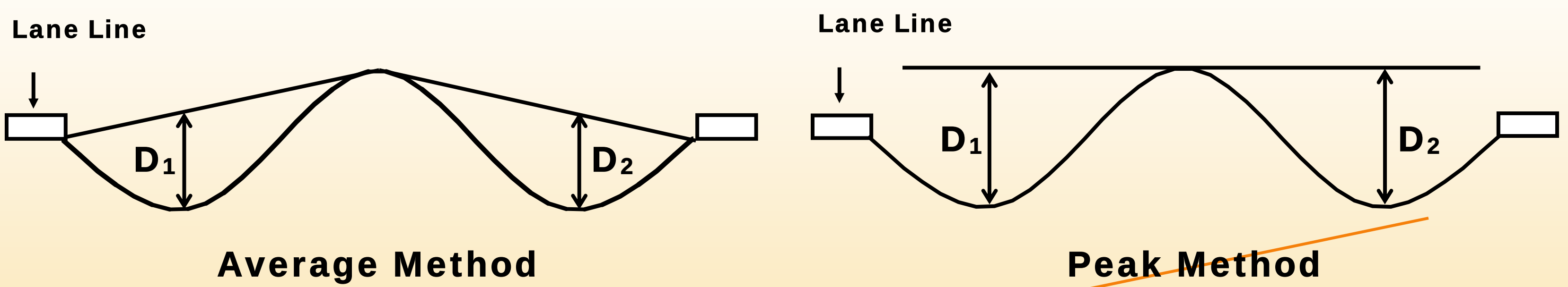


The rutted profiles from PIARC EVEN data

❖ Evaluation Result of Analyzed Profiles

Calculation results of the indices

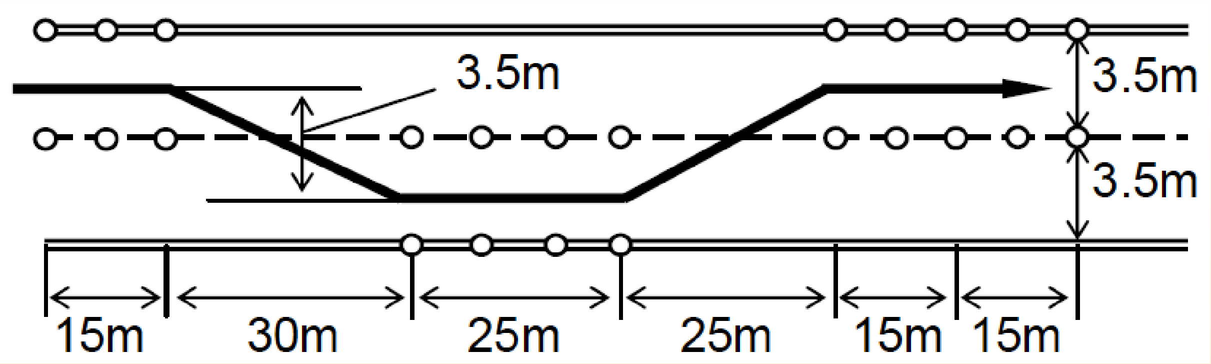
Section	Location in the EVEN Project	HRD: x 10^2 rad/s	Rut Depth - Average Method: mm	Rut Depth - Peak Method: mm
A	SITE3, Dist.=220m	15.5	24	25
B	SITE4, Dist.=160m	5.5	14	25
C	SITE7, Dist.=160m	4.4	25	25
D	SITE11, Dist.=240m	6.3	25	25
Perfect Smooth	-	0	0	0



Definition of the rut depth

4.3. Driving Scenario

- **8 drivers** were required to drive at one time on each analyzed profile
  - Double lane-change maneuver defined by the ISO
  - Keeping a constant driving speed of 60km/h



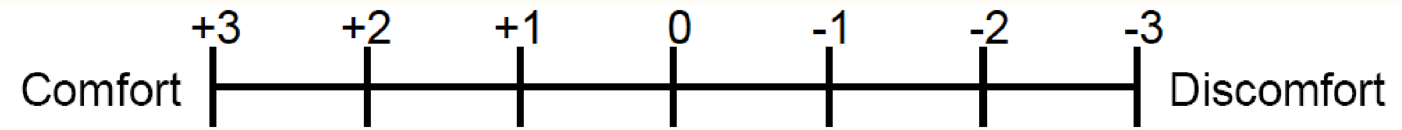
ISO Double Lane-Change test
Ex. ISO3888-1

4.3. Driving Scenario

- **8 drivers** were required to drive at one time on each analyzed profile
  - Double lane-change maneuver defined by the ISO
  - Keeping a constant driving speed of 60km/h

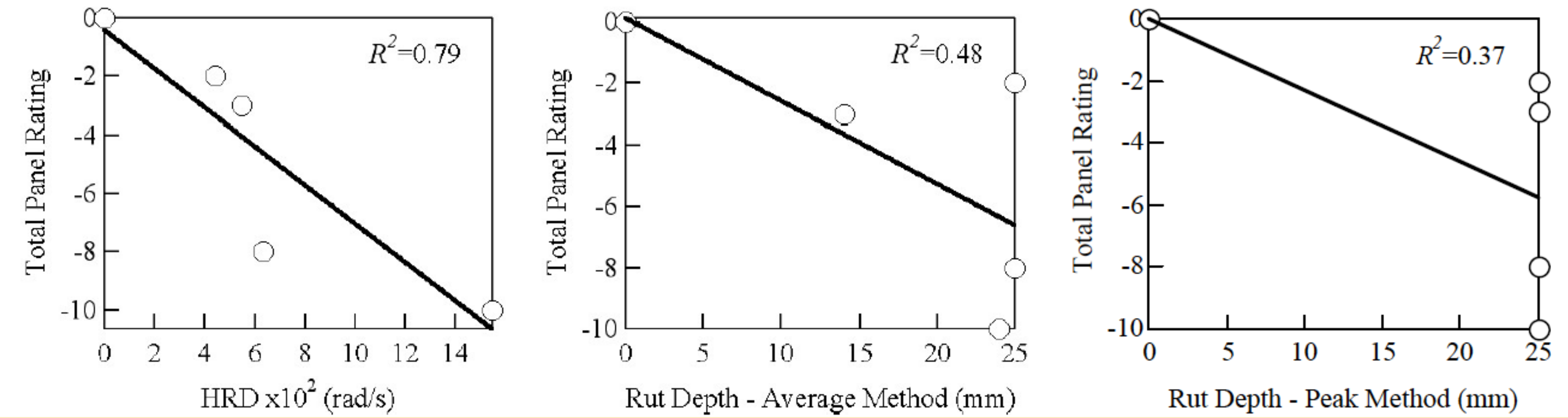
4.4. Result of Applicability

- Drivers were asked to answer the questionnaire about the ride quality

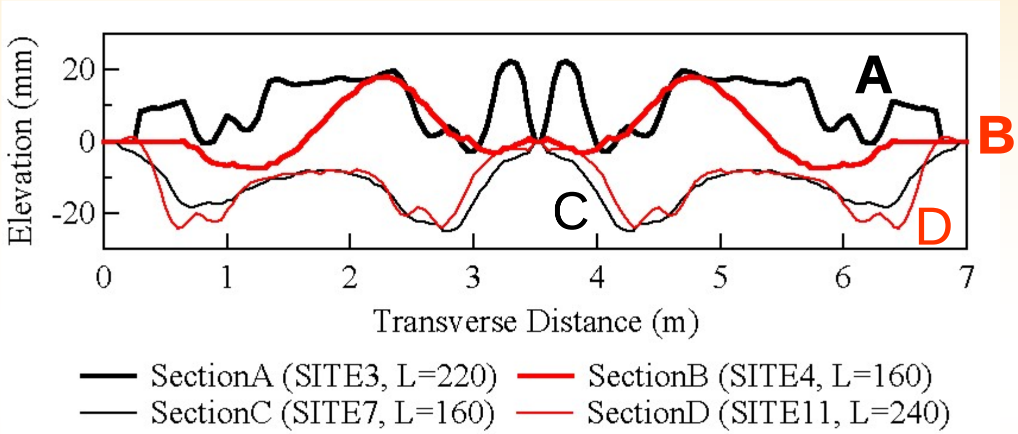


Questionnaire of the Subjective Survey

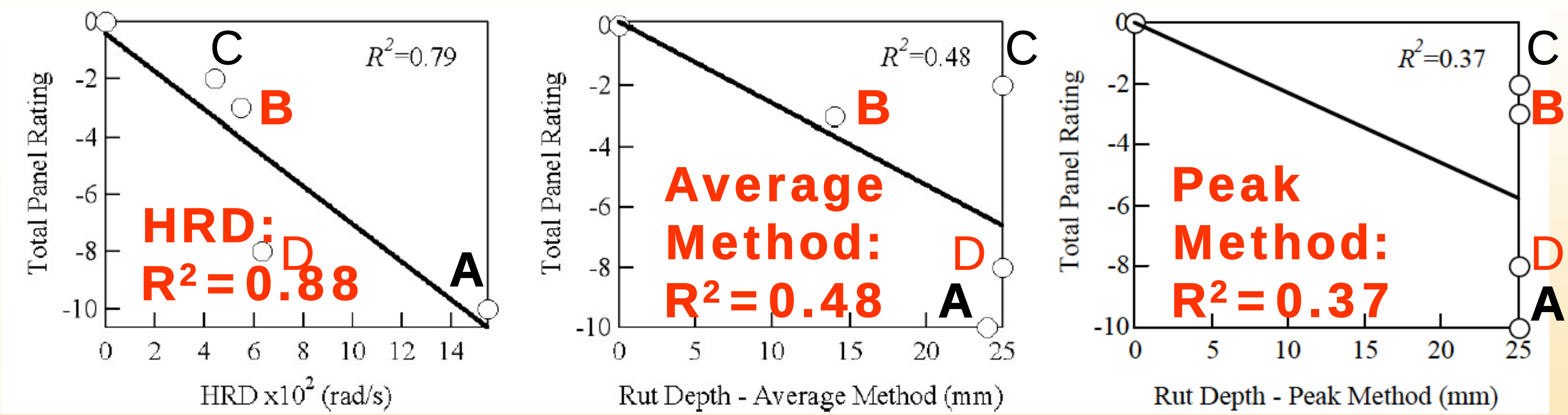
- **Result:** Correlation between total panel rating and each index



4.4. Result of Applicability



The rutted profiles from PIARC EVEN data



5. Conclusions

- This study developed a new index of rutting based on the vehicle vibration response
  - The HRD can be suitable for predicting the severity levels of rutting distress in terms of the drive's perception of ride quality.
  - Any definitions of rut depth cannot be applicable in the case of which profiles are indicated to the same depth with including the irregularities in their shapes

Thank you for your kind attention !!

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Kazuya TOMIYAMA
tomiyama@vortex.civil.kitami-it.ac.jp

Traffic Engineering Laboratory
Dept. of Civil & Environmental Engineering
Kitami Institute of Technology
Japan