SURF 2012
Norfolk, Virginia / September 19-22, 2012
7th symposium on pavement surface characteristics

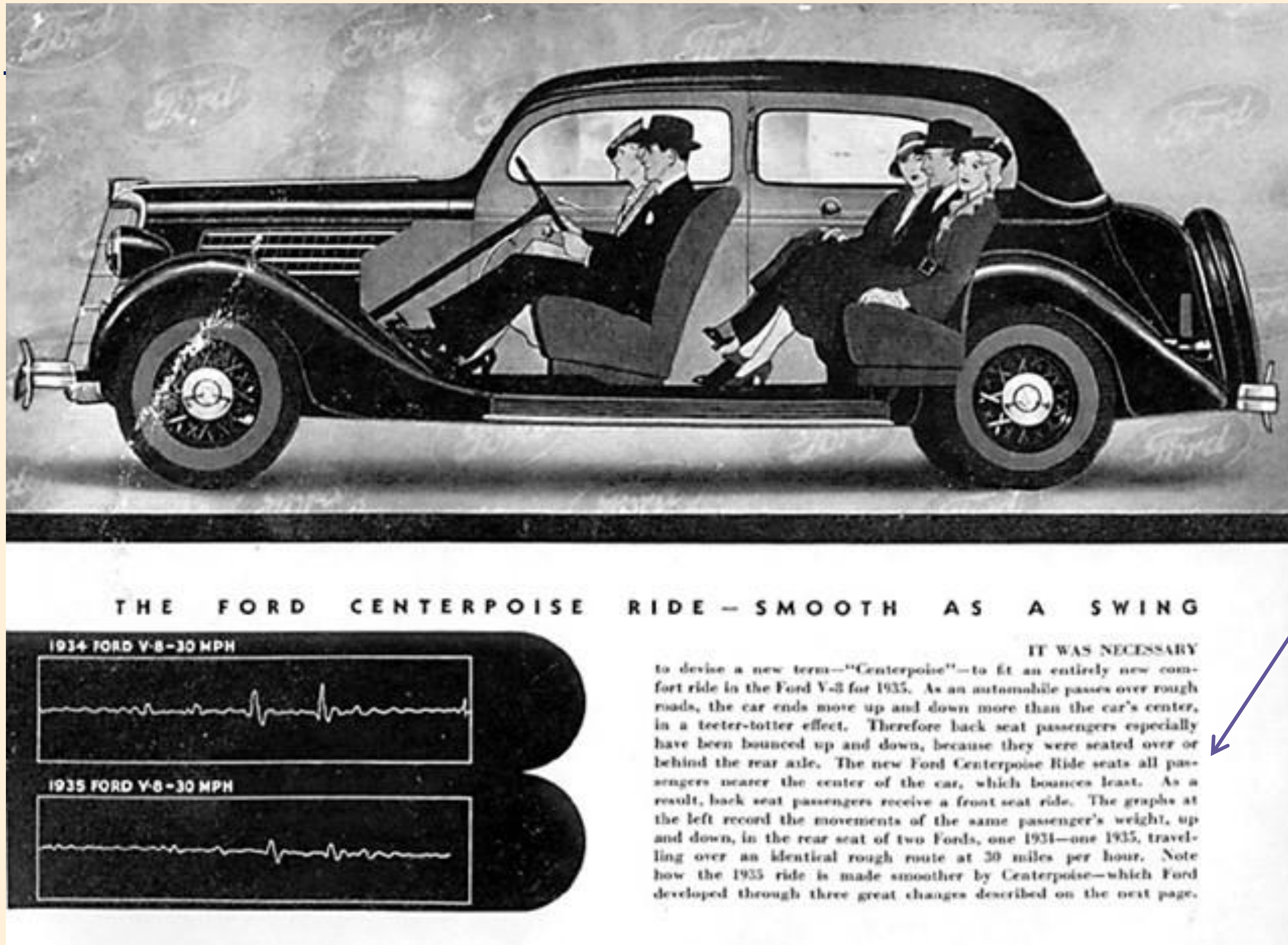
FURTHER INVESTIGATIONS ON THE WEIGHTED LONGITUDINAL PROFILE

Presenter: Roland Spielhofer
Austrian Institute of Technology, Vienna, Austria

Topics

- Introduction
- WLP calculation steps
- Deriving an evaluation scheme
- Evaluation of motorways
- Comparison with planograph for application in new work approval/acceptance test
- Conclusions

Longitudinal evenness evaluation … an ongoing problem



… movement … up and down in the rear seat … on identical rough roads

1935 Ford Ad

Longitudinal evenness evaluation ... many approaches

- Many parameters/indices have been developed over the years
  - depending on a particular measurement system (e.g. bump integrator, planograph, ...)
  - depending on a „true profile“
    - geometric indices
    - response type indices

- Arguments for/against indices
  - geometric indices are “more objective” than response-type indices
  - response-type indices reflect what drivers experience while they drive
  - response-type indices are speed dependent
  - limited wave band and variations in sensitivity due to transfer functions

Weighted longitudinal profile (WLP)

- **A recent approach for longitudinal evenness evaluation**
- **Introduced in Germany in 2004**
- **Tries to combine the strengths of geometric and response type indices**

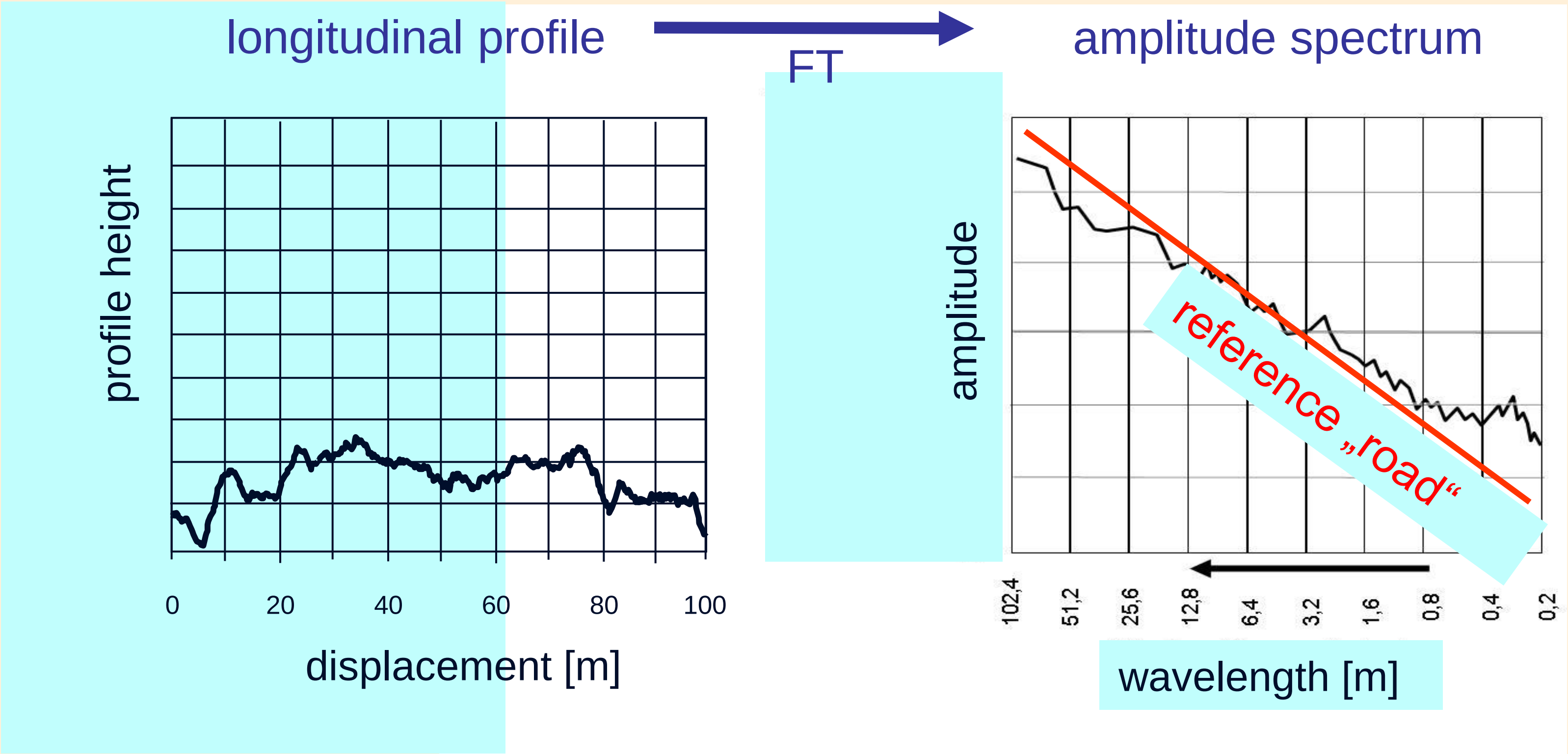
- **Currently, the calculation procedure is prepared to be integrated into prEN 13 073-5 (“Calculation of Longitudinal indices”)**

- **Several research projects in Germany and Austria**
- **In Germany already included into national regulations (“TP-Eben”)**
- **In Austria it will be integrated soon into national regulation (“RVS”)**

Weighted longitudinal profile (WLP) – computation

Step 1

- The longitudinal profile is transformed into spectral domain
- and related to a reference amplitude spectrum (characteristic)



Weighted longitudinal profile (WLP) - computation

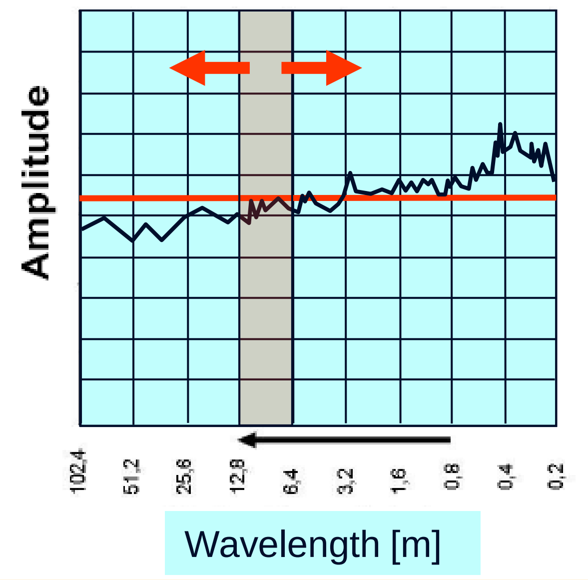
Step 2

- **The related spectrum (phase remains unchanged) is „scanned“ completely by an octave-band filter, since human perception and vehicle dynamics resemble an octave-band filtering covering certain wavelengths according to the driven speed.**

practical proceeding:

the spectrum between 0,2 and 102,4 m is divided into 9 octave bands

increase ... speed ... decrease



Weighted longitudinal profile (WLP) - computation

Step 3

- **The 9 octave-band spectra are transformed back into space domain giving 9 octave-band filtered profiles.**
- **These 9 profiles are assembled together to the Weighted Longitudinal Profile according to their respective power contribution to the total power**

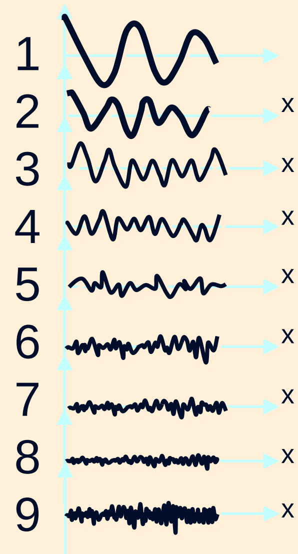
longitudinal profile

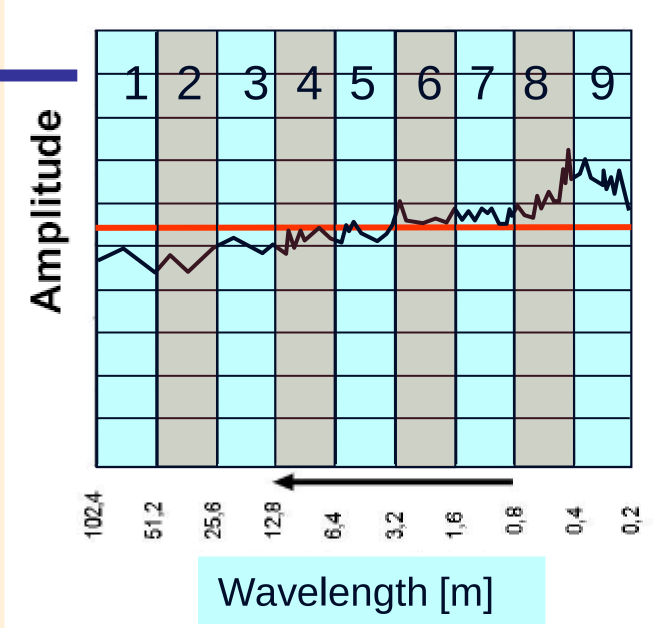
WLP =

= σ_1/σ_{tot}. profile 1
+ ....
+ ....
+ σ_9/σ_{tot}. profile 9

weighting factors

iFT

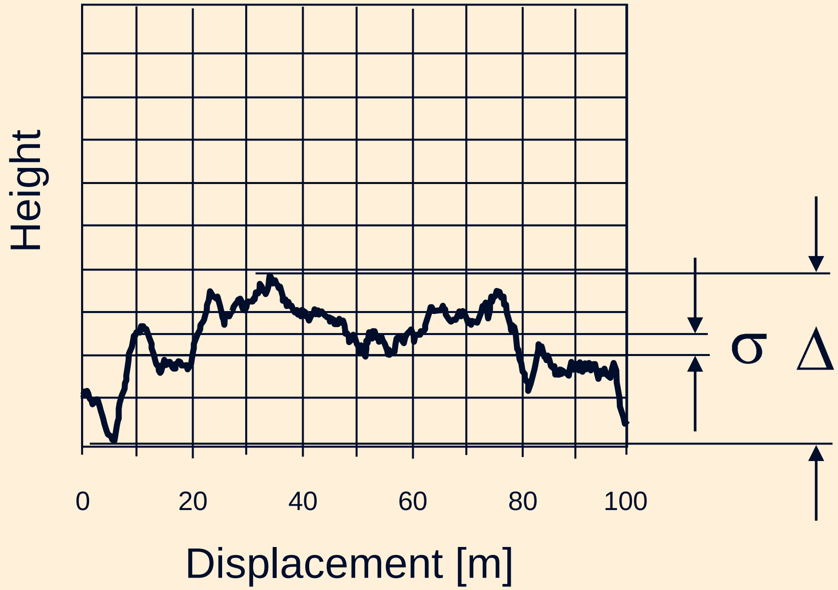




Weighted longitudinal profile (WLP) - computation

Step 4 (last step)

- **The Weighted Longitudinal Profile is characterized by 2 indices:**
  - **standard deviation “σ“ (sigma)**
  - **range “Δ“ (delta)**



2 simple indicators

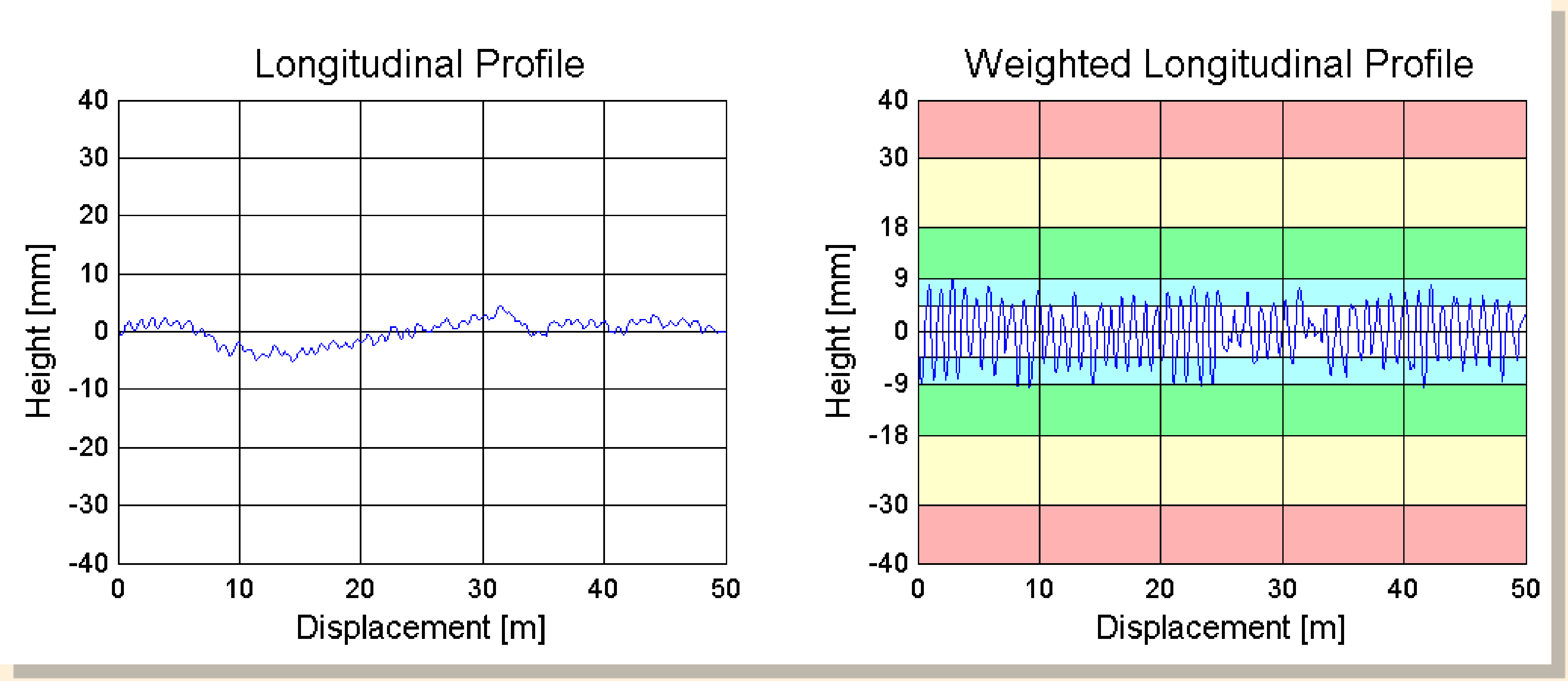
- σ for irregularities
- Δ for „local“ features

- Δ/σ = 3 .... 6 ....>10

  „wavy“ ... irregular ... impulsive

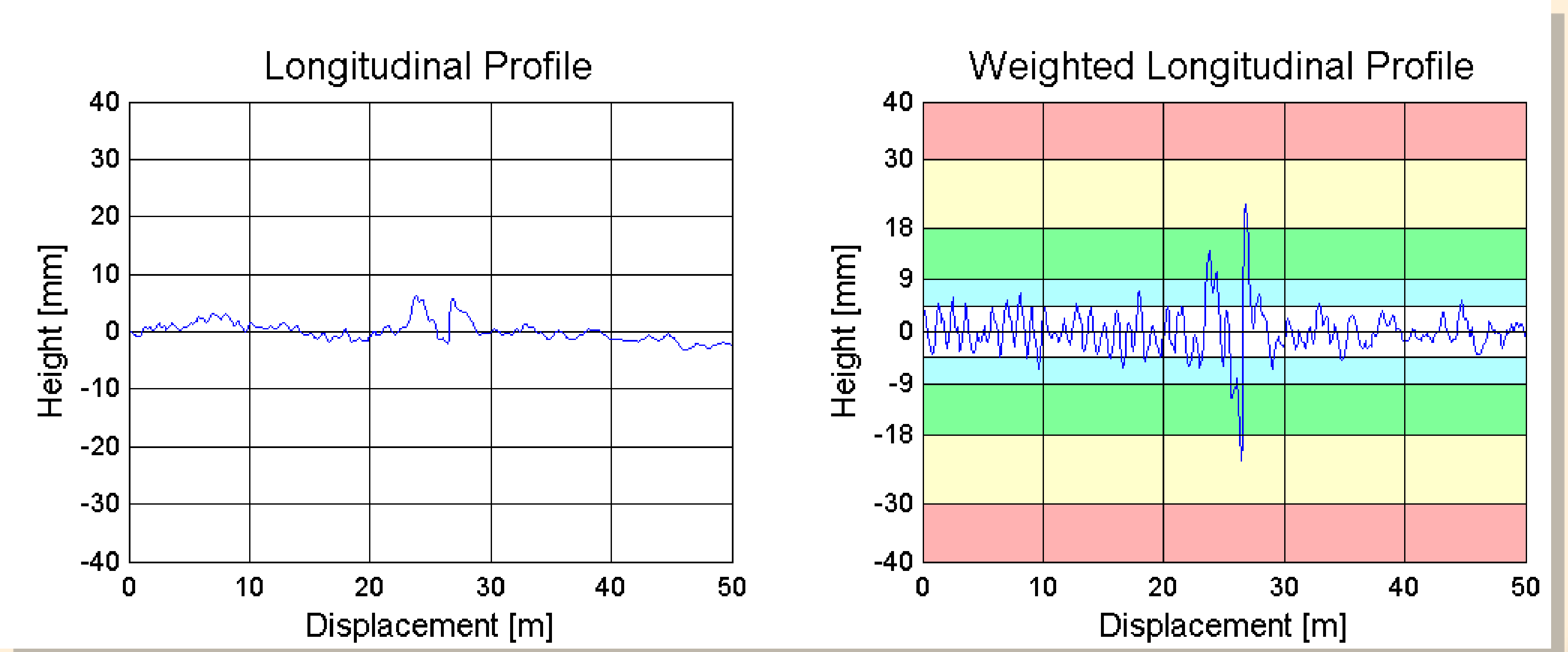
Weighted longitudinal profile (WLP) – examples

Periodical unevenness



Weighted longitudinal profile (WLP) – examples

Single obstacle

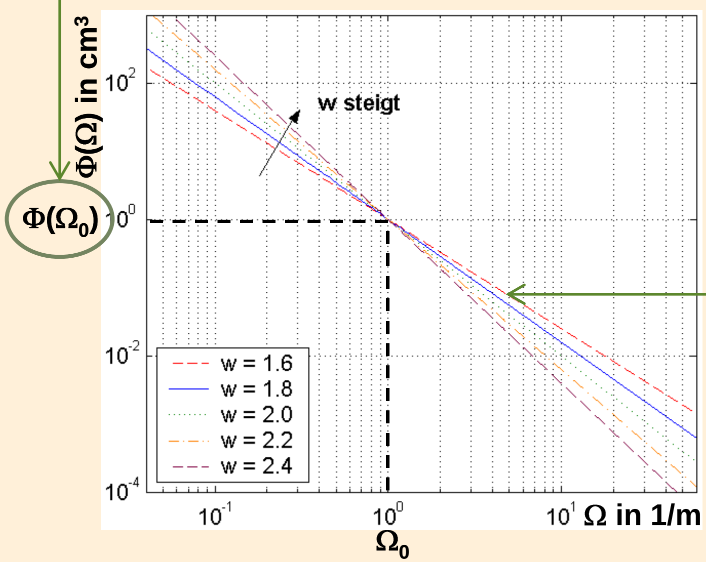


Deriving an evaluation scheme

- Mathematical relationship between WLP and PSD
  - $G(\Omega_0)$
  - w* - waviness – slope of the reference PSD in loglog scale

$$\sigma^2 = \frac{G(\Omega_0)\cdot\Omega_0^{w*}}{(w*-1)(2\pi)^{w^*-1}}\cdot\underbrace{(L_{\max}^{w^*-1} - L_{\min}^{w^*-1})}$$

L_{min} … min. wavelength
L_{max} … max. wavelength



Deriving an evaluation scheme

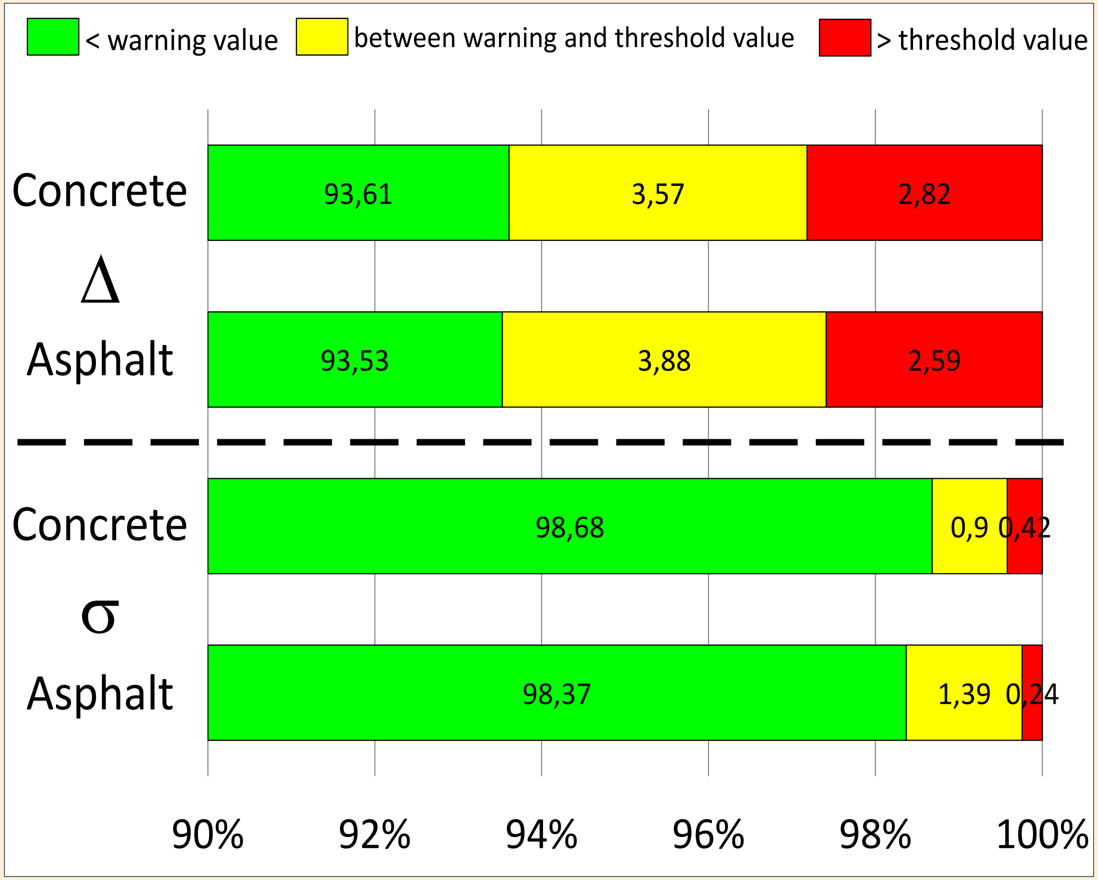
- for $G(\Omega_0)$ there are already evaluation values in Germany (for motorways)
- w is set to w = 2.6
  - lower values (w ~ 2.2) would emphasize on longer wavelengths
  - higher values (w > 2.5) emphasize shorter wavelengths
- L_{min} = 0.5 m
- L_{max} = 50 m

- $G(\Omega_0)$ = 1 cm³ .... target value (current limits in Germany)
- $G(\Omega_0)$ = 9 cm³ .... threshold value

	target value	acceptance value	warranty value	warning value	threshold value
σ_{WLP} [mm]	4	6	7	9	13
Δ_{WLP} [mm]	26	36	42	54	78

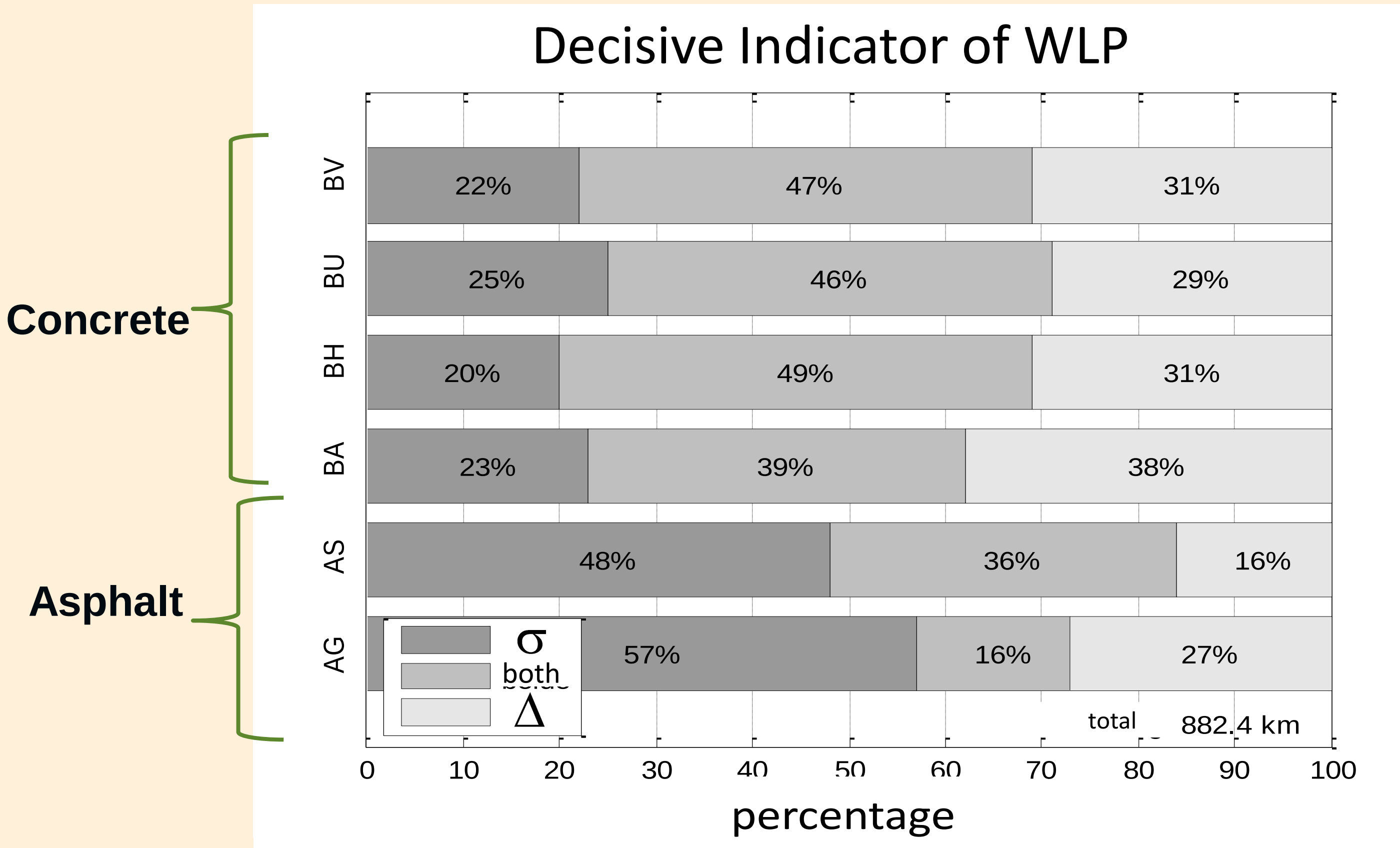
Verification of evaluation scheme

- German motorways (data from 2005/2006)



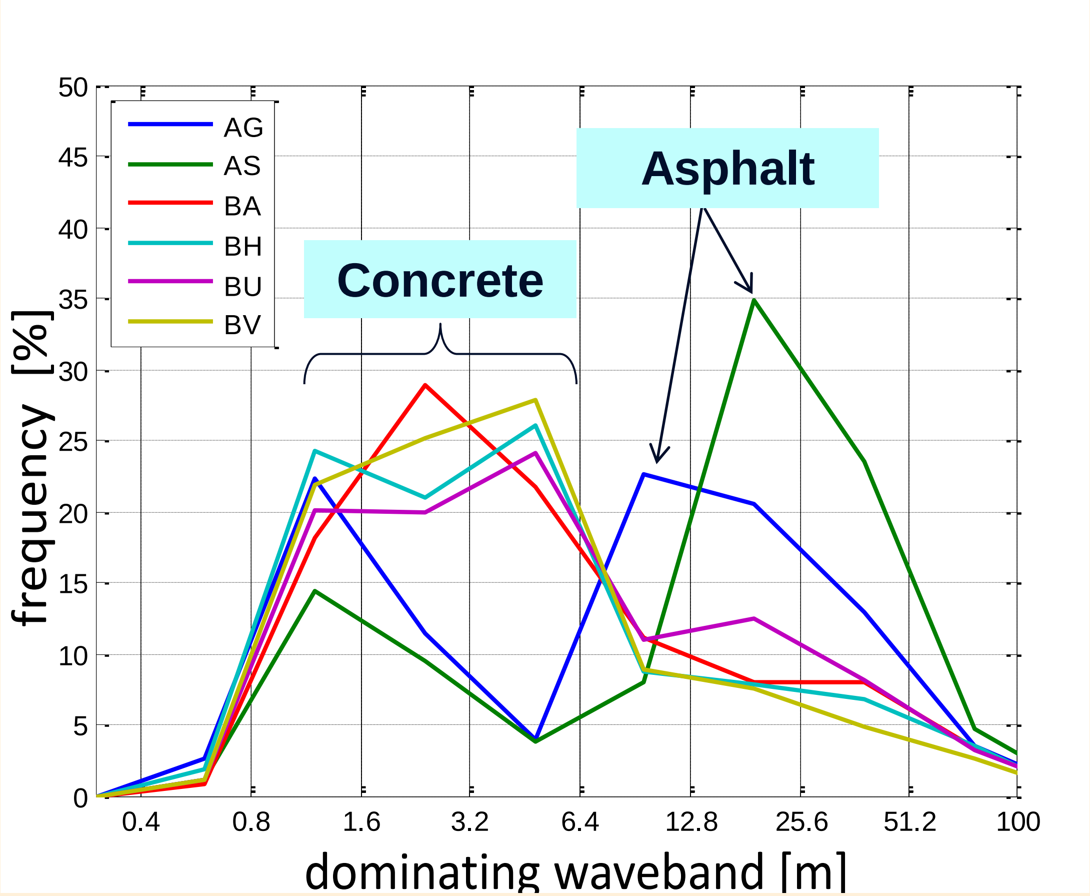
37,785 km Asphalt
13,856 km Concrete

Rating of asphalt and concrete



- BA, BH, BU, BV .... Concrete
- AG, AS .... Asphalt

Rating of asphalt and concrete

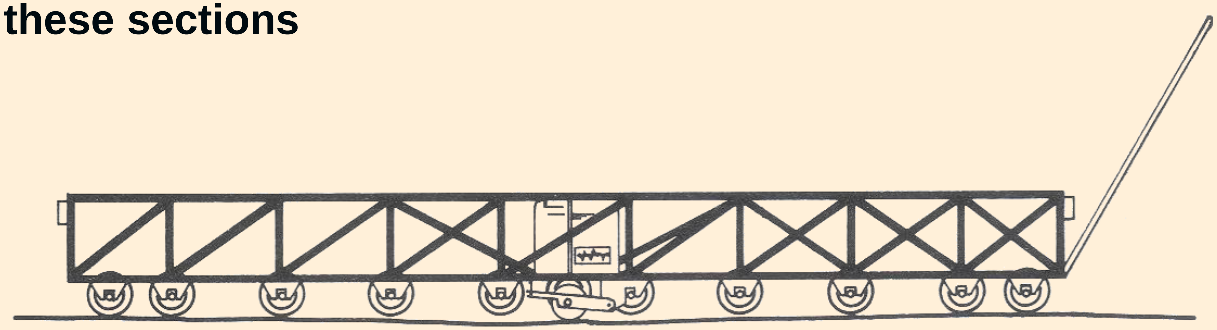


- **BA, BH, BU, BV .... Concrete**
- **AG, AS .... Asphalt**

WLP for new work approval?

- Currently, on Austrian motorways a criterion for planograph/4 m straight edge exists
- Planograph cannot rate certain evenness problems
- What would happen if the criterion is changed to WLP?

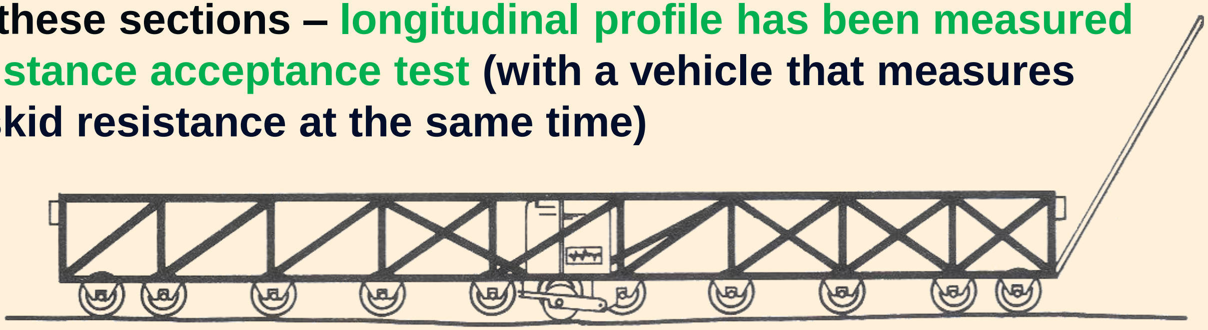
- Prerequisites for a comparison
  - location of newly built sections
  - planograph results of these sections
  - WLP results of these sections



WLP for new work approval?

- Currently, on Austrian motorways a criterion for planograph/4 m straight edge exists
- Planograph cannot rate certain evenness problems
- What would happen if the criterion is changed to WLP?

- Prerequisites for a comparison
  - location of newly built sections – well known
  - planograph results of these sections - not centrally available
  - WLP results of these sections – longitudinal profile has been measured during skid resistance acceptance test (with a vehicle that measures evenness and skid resistance at the same time)

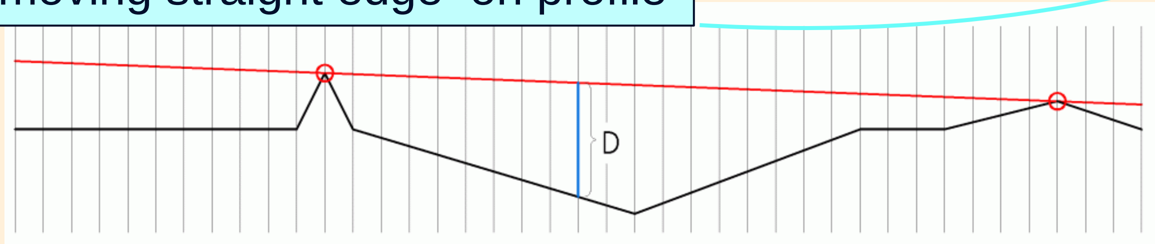


WLP for new work approval?

- Currently, on Austrian motorways a criterion for planograph/4 m straight edge exists
- Planograph cannot rate certain evenness problems
- What would happen if the criterion is changed to WLP?

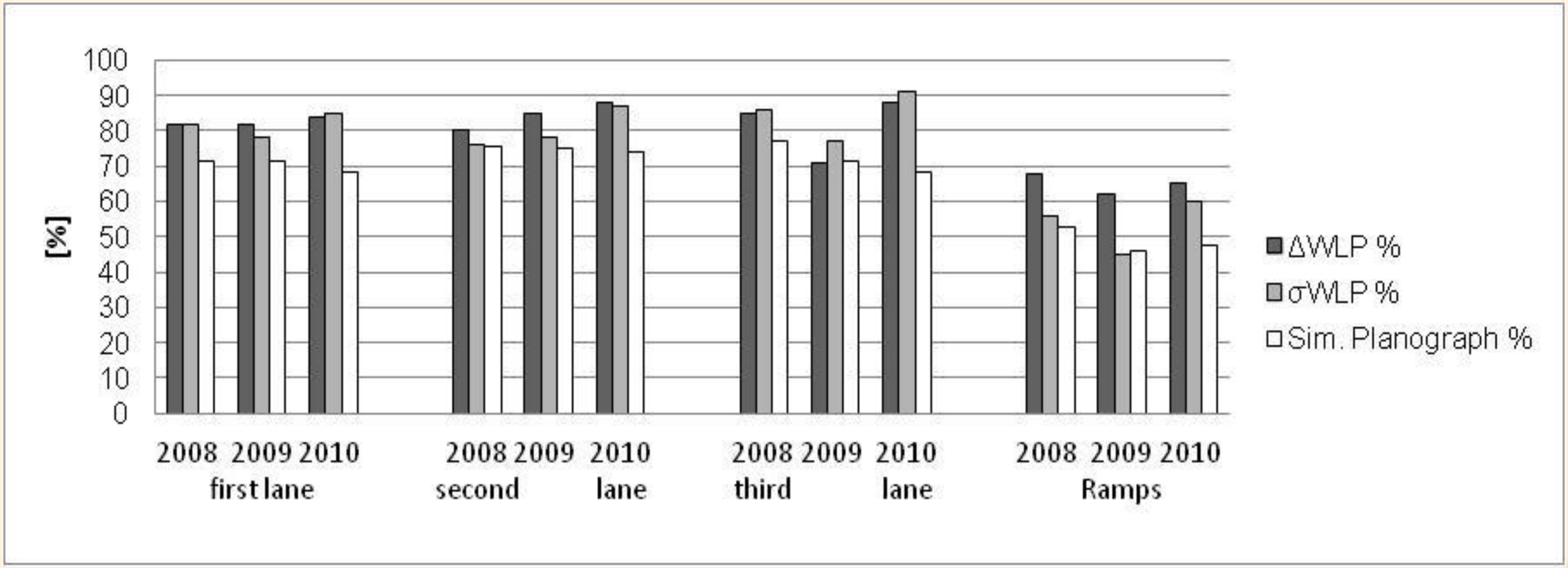
- Prerequisites for a comparison
  - location of newly built sections – well known
  - planograph results of these sections – not centrally available
  - WLP results of these sections – longitudinal profile has been measured during skid resistance acceptance test (with a vehicle that measures evenness and skid resistance at the same time)

simulation of moving straight edge on profile



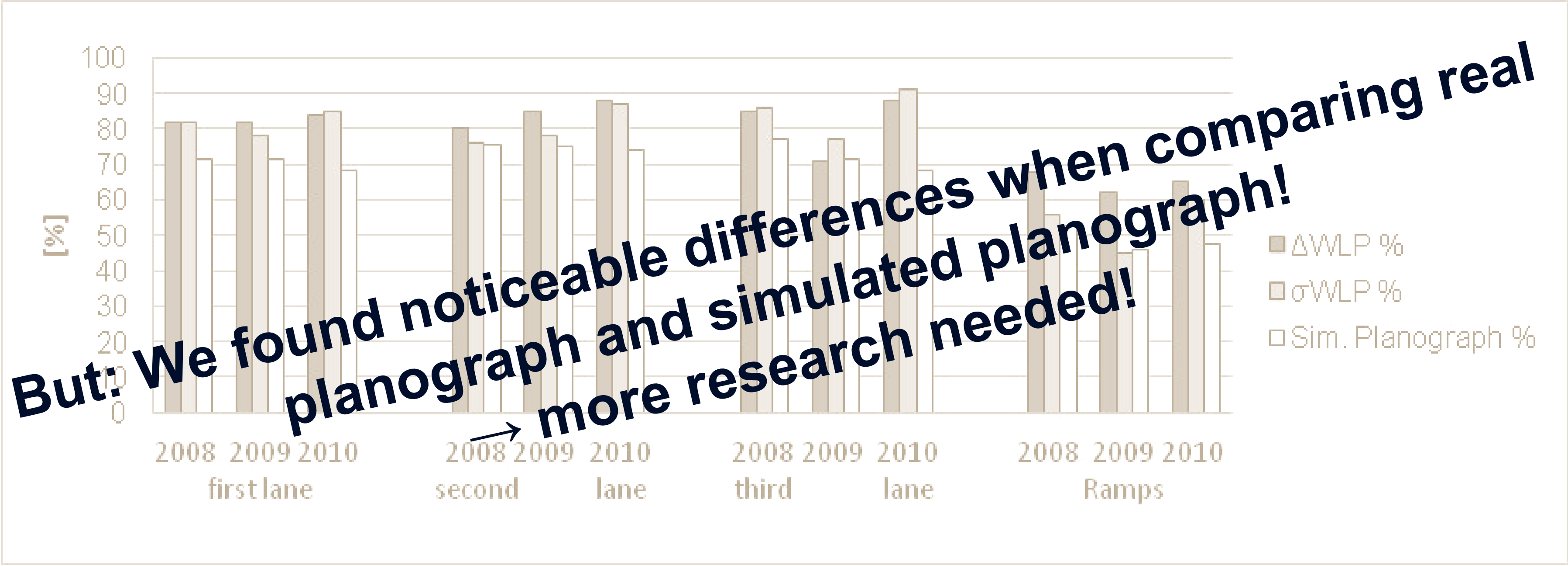
WLP for new work approval?

- Comparison of WLP and simulated planograph for 50 m sections
  - Percentage of "positive" sections
    - Δ_{WLP}, σ_{WLP} better than acceptance value
    - simulated planograph: no deviation > 4 mm in section



WLP for new work approval?

- Comparison of WLP and simulated planograph for 50 m sections
  - Percentage of "positive" sections
    - Δ_{WLP}, σ_{WLP} better than acceptance value
    - simulated planograph: no deviation > 4 mm in section



Conclusions

- **Weighted longitudinal profile is a versatile index for evenness evaluation**
- **Evaluation scheme is derived from a linearized PSD and is easily adaptable.**
- **No bias was observed when for the evaluation of different surface types**
- **WLP clearly differentiates the characteristics of asphalt and concrete pavements.**
- **Possible change to WLP as acceptance criteria needs more research (real vs. simulated planograph)**

- **WLP seems to be ready to be of use in Pavement Management Systems**

Acknowledgements to

- **Andreas Ueckermann**

for co-writing the paper

- **Austrian Federal Ministry of Transport, Innovation and Technology**
- **German Federal Ministry of Transport, Building and Urban Development**

for funding our research projects

Thank you for your attention!

Roland Spielhofer – roland.spielhofer@ait.ac.at
Andreas Ueckermann - ueckermann@isac.rwth-aachen.de