

# Further investigations on the Weighted Longitudinal Profile

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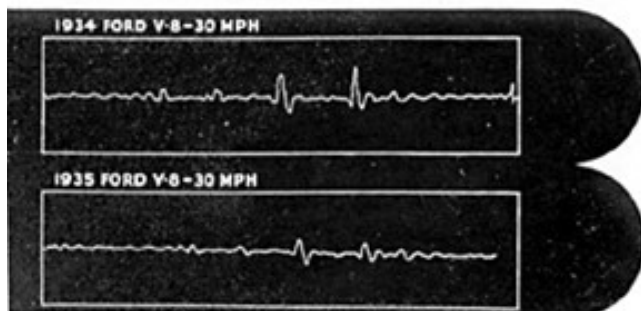
# Topics

- 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



## THE FORD CENTERPOISE RIDE — SMOOTH AS A SWING



IT WAS NECESSARY to devise a new term—"Centerpoise"—to fit an entirely new comfort ride in the Ford V-8 for 1935. As an automobile passes over rough roads, the car ends move up and down more than the car's center, in a teeter-totter effect. Therefore back seat passengers especially have been bounced up and down, because they were seated over or behind the rear axle. The new Ford Centerpoise Ride seats all passengers nearer the center of the car, which bounces least. As a result, back seat passengers receive a front seat ride. The graphs at the left record the movements of the same passenger's weight, up and down, in the rear seat of two Fords, one 1934—one 1935, travelling over an identical rough route at 30 miles per hour. Note how the 1935 ride is made smoother by Centerpoise—which Ford developed through three great changes described on the next page.

... 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

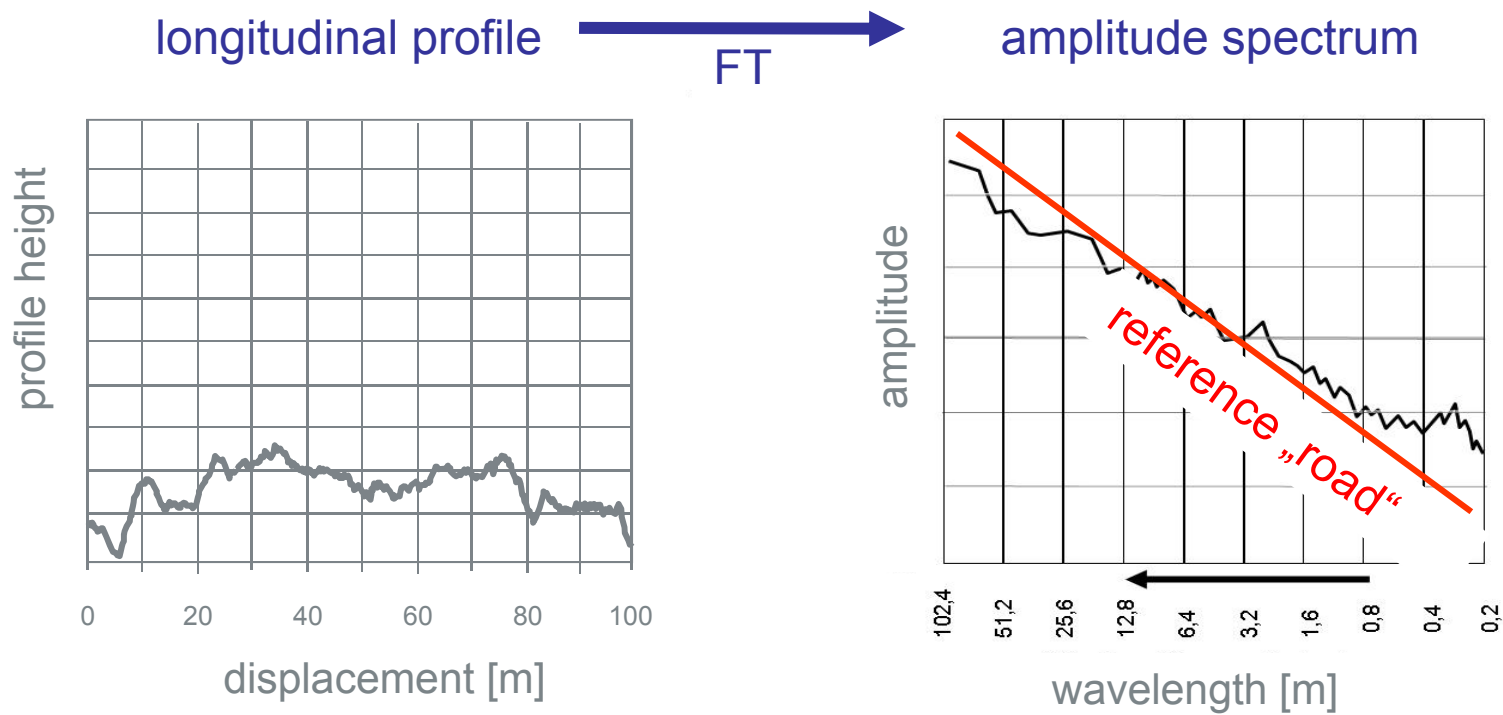
## Weighted longitudinal profile (WLP)

- 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 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)



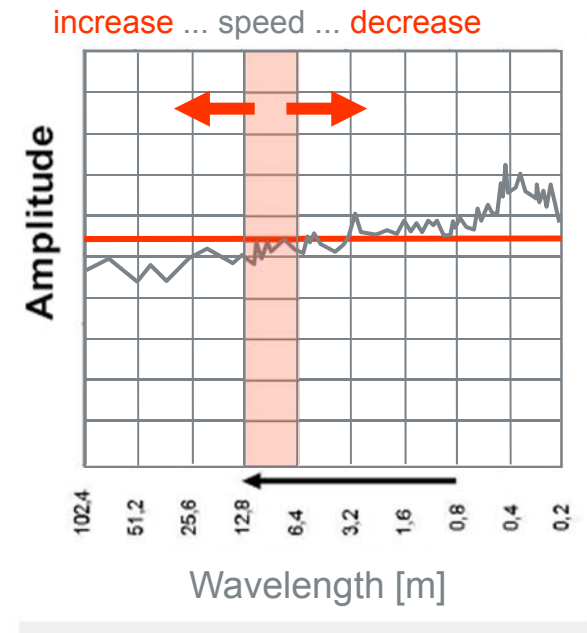
# Weighted longitudinal profile (WLP) - computation

## 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



# Weighted longitudinal profile (WLP) - computation

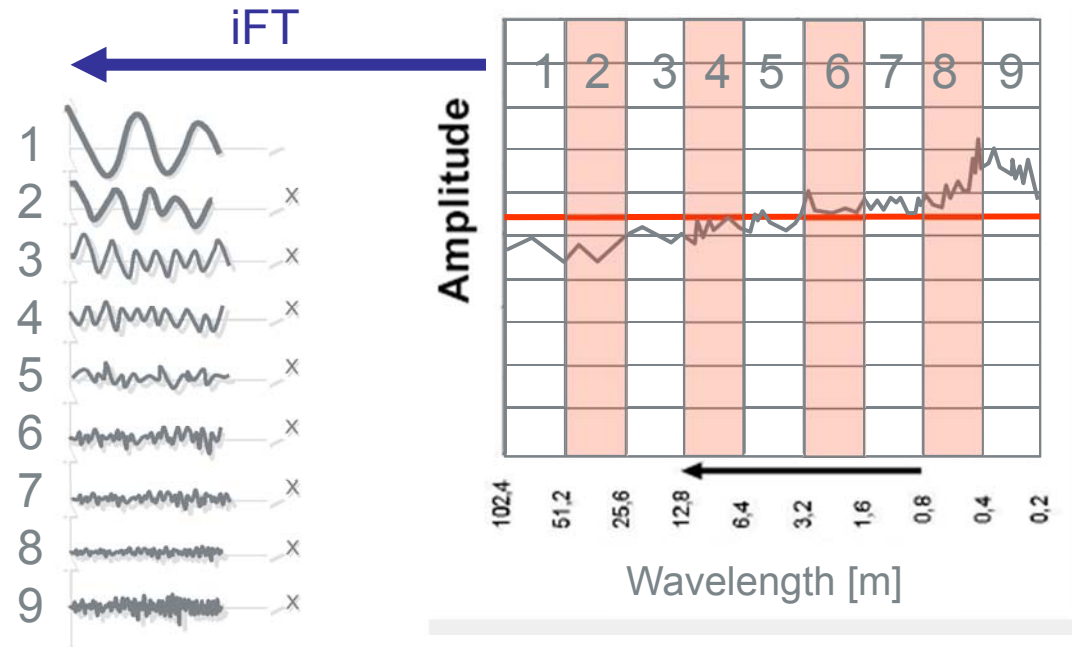
## Step 3

- 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

$$\begin{aligned}
 \text{WLP} &= \\
 &= \sigma_1 / \sigma_{\text{tot}} \cdot \text{profile 1} \\
 &\quad + \dots \\
 &\quad + \dots \\
 &+ \sigma_9 / \sigma_{\text{tot}} \cdot \text{profile 9}
 \end{aligned}$$

weighting factors

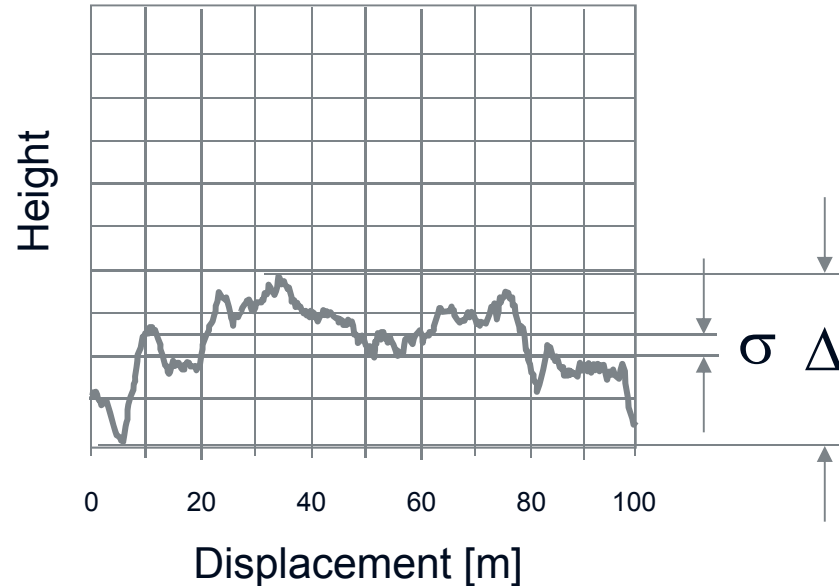




# Weighted longitudinal profile (WLP) - computation

## Step 4 (last step)

- The Weighted Longitudinal Profile is characterized by 2 indices:
  - standard deviation " $\sigma$ " (sigma)
  - range " $\Delta$ " (delta)

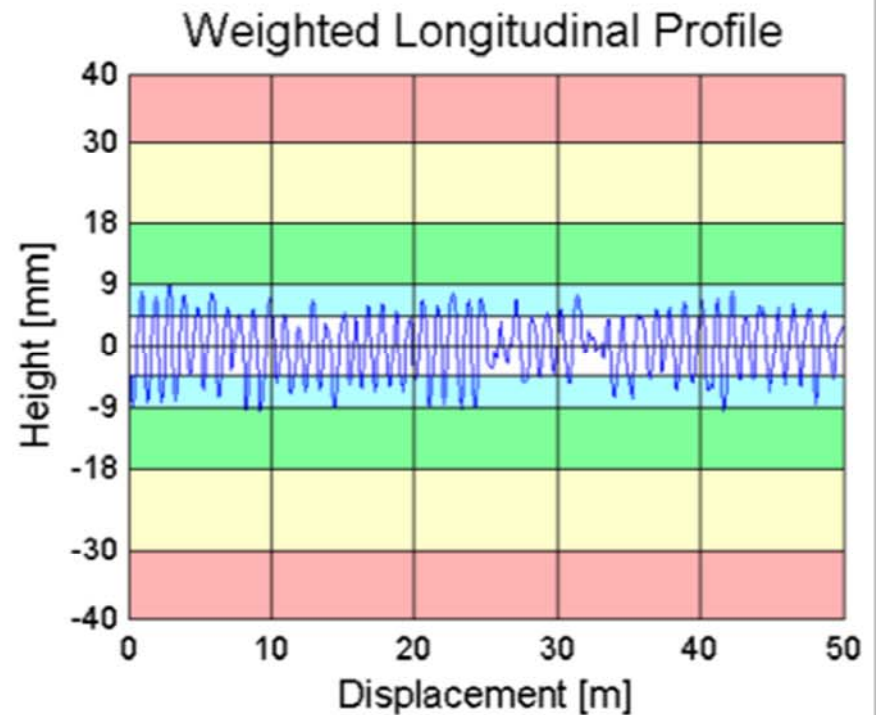
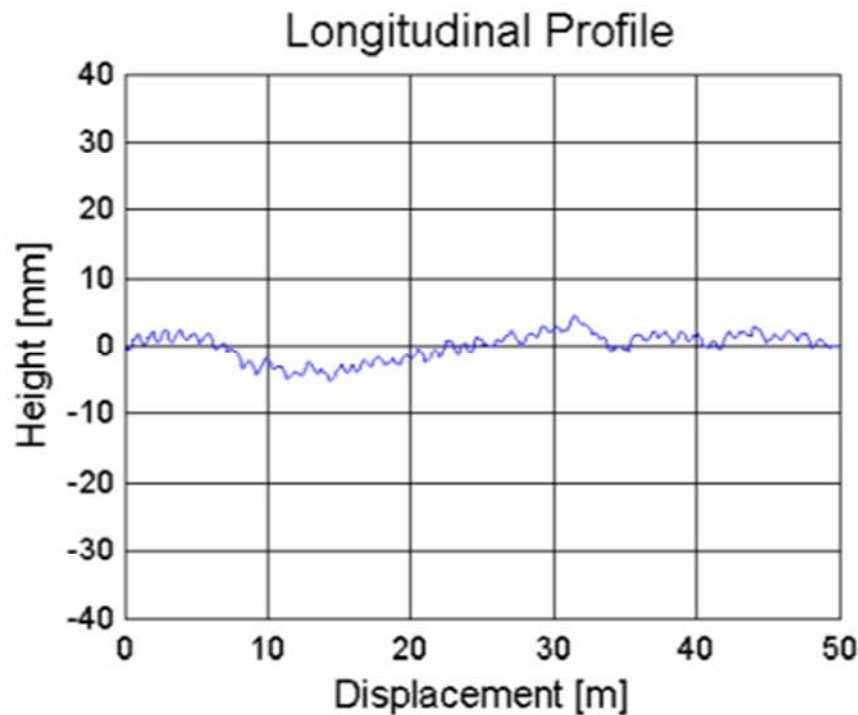


## 2 simple indicators

- $\sigma$  for irregularities
- $\Delta$  for „local“ features
- $\Delta/\sigma = 3 \dots\dots 6 \dots\dots >10$   
„wavy“ ... irregular ... impulsive

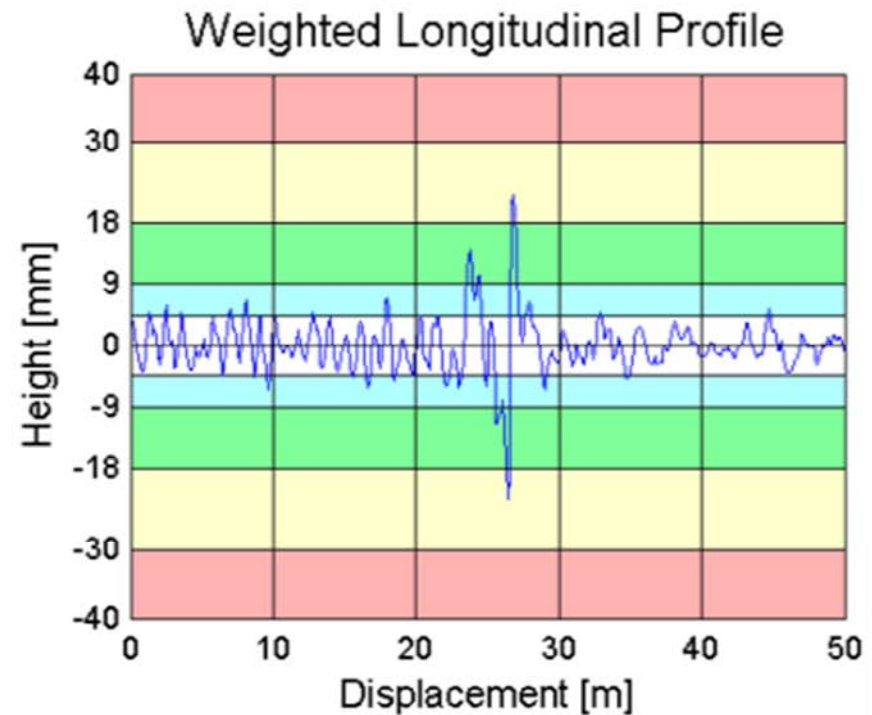
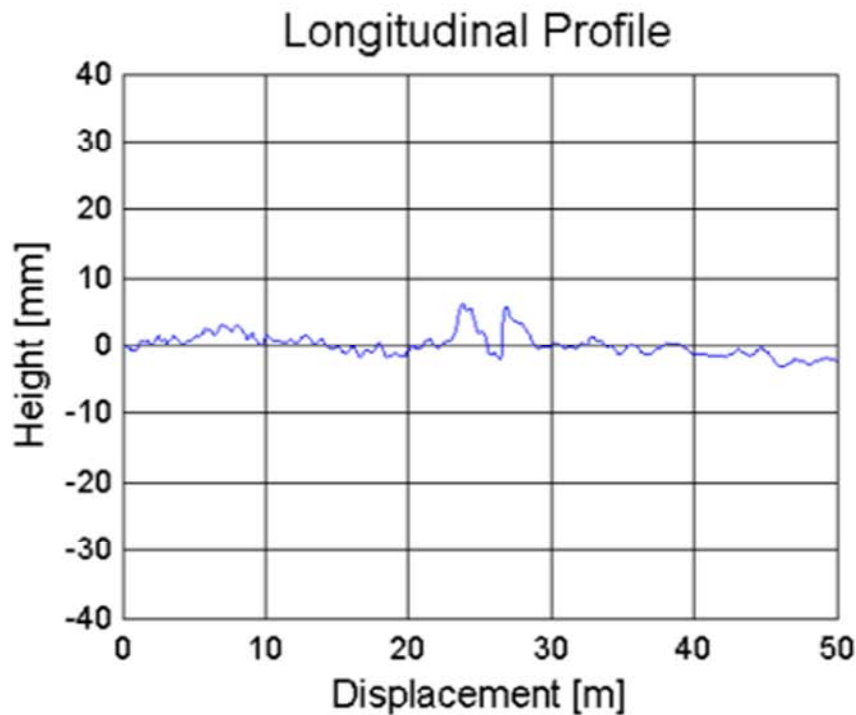
# Weighted longitudinal profile (WLP) – examples

## Periodical unevenness



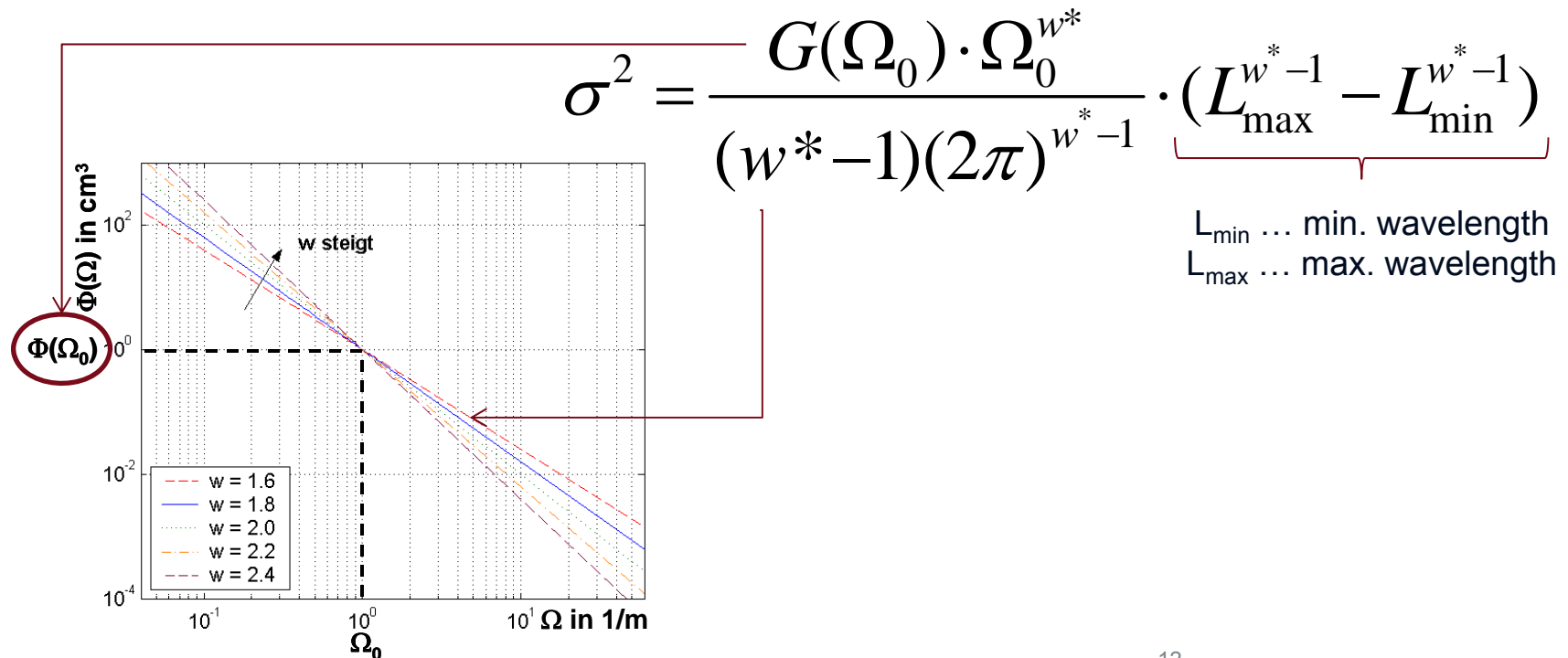
# Weighted longitudinal profile (WLP) – examples

## 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



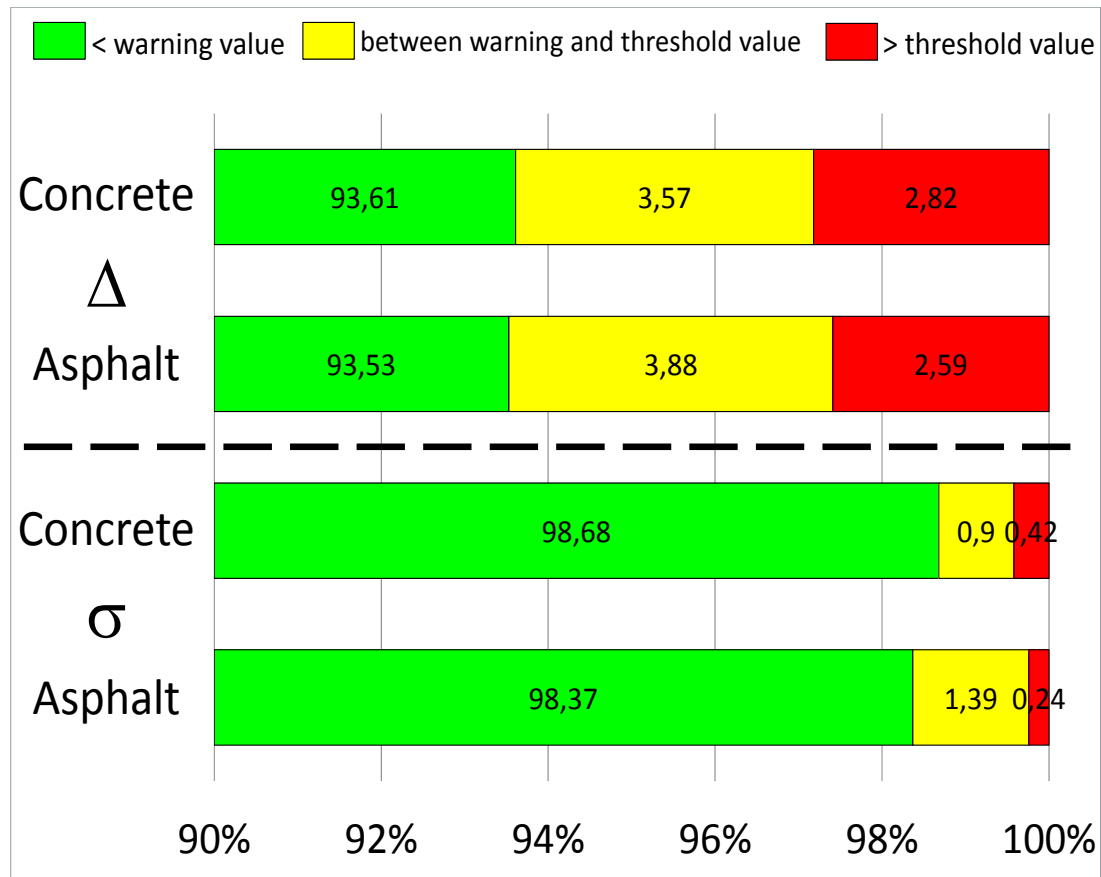
# Deriving an evaluation scheme

- for  $G(\Omega_0)$  there are already evaluation values in Germany (for motorways)
- $w$  is set to  $w = 2.6$ 
  - lower values ( $w \sim 2.2$ ) would emphasize on longer wavelengths
  - higher values ( $w > 2.5$ ) emphasize shorter wavelengths
- $L_{\min} = 0.5 \text{ m}$
- $L_{\max} = 50 \text{ m}$
  
- $G(\Omega_0) = 1 \text{ cm}^3$  .... target value (current limits in Germany)
- $G(\Omega_0) = 9 \text{ cm}^3$  .... threshold value

	target value	acceptance value	warranty value	warning value	threshold value
$\sigma_{\text{WLP}} [\text{mm}]$	4	6	7	9	13
$\Delta_{\text{WLP}} [\text{mm}]$	26	36	42	54	78

# Verification of evaluation scheme

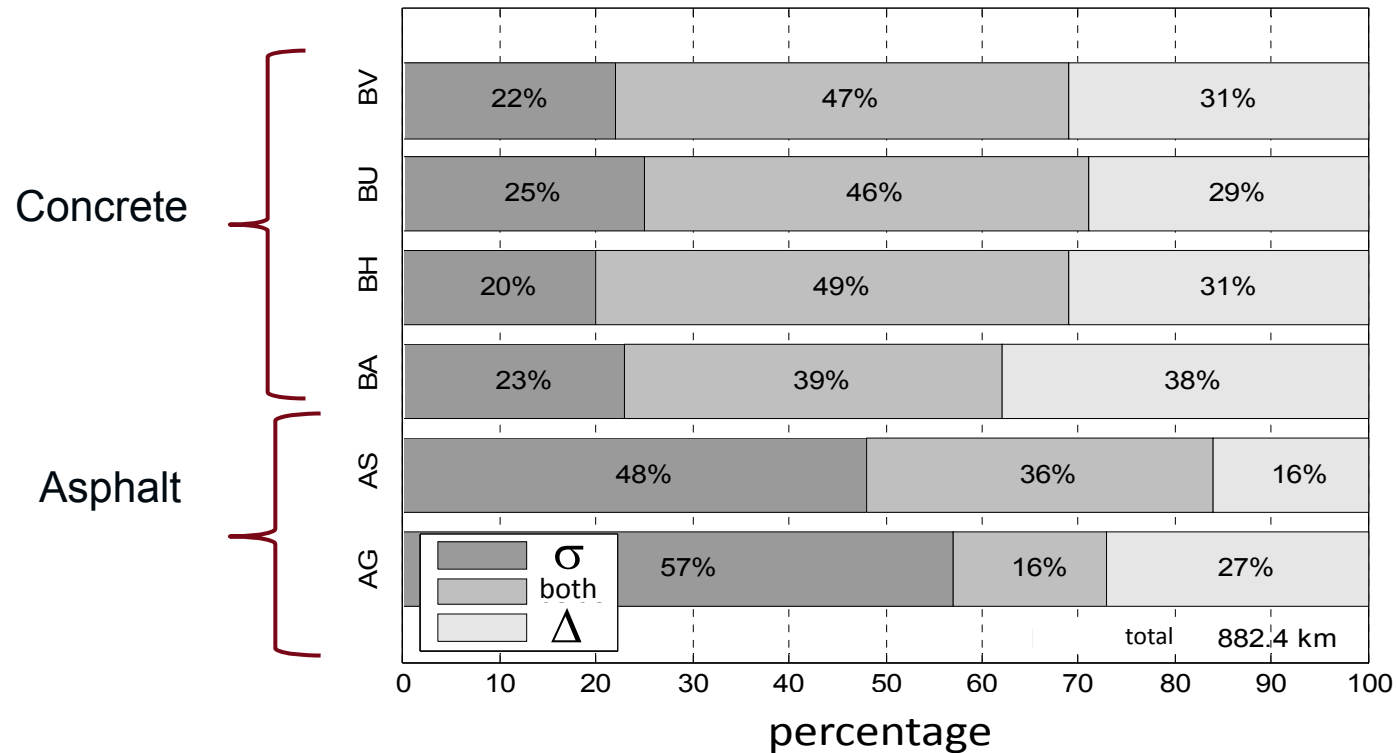
- German motorways (data from 2005/2006)



37,785 km Asphalt  
13,856 km Concrete

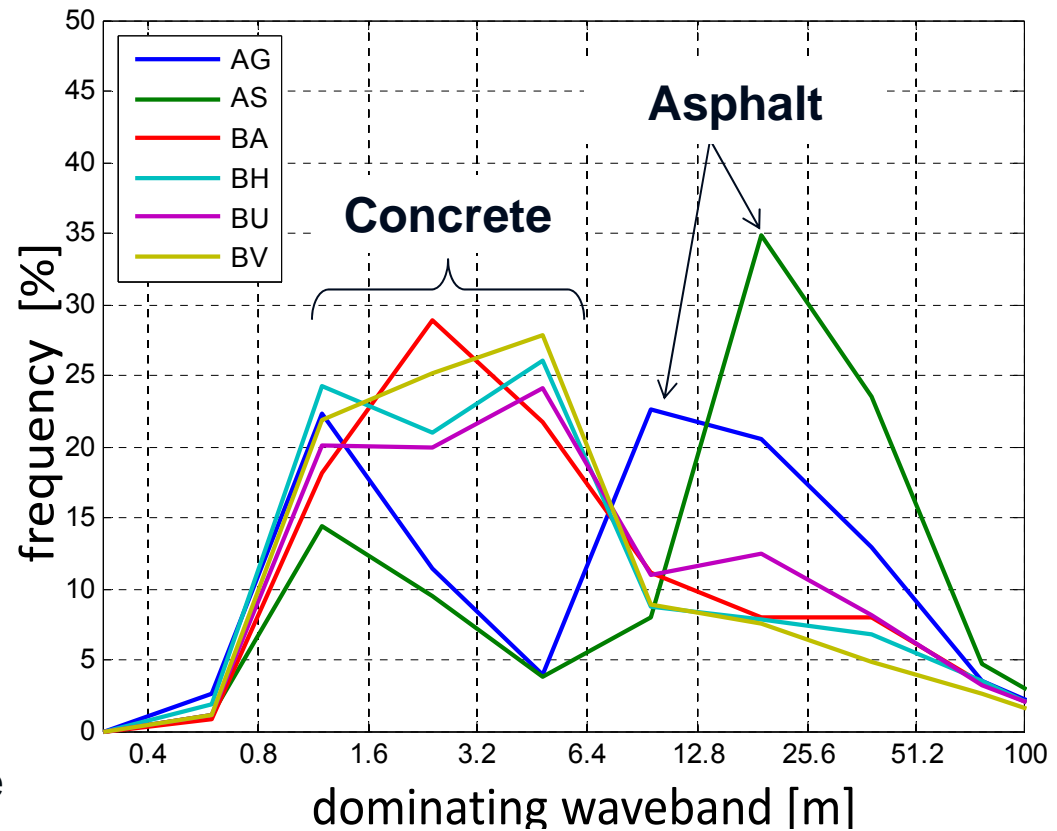
# Rating of asphalt and concrete

Decisive Indicator of WLP



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

# Rating of asphalt and concrete

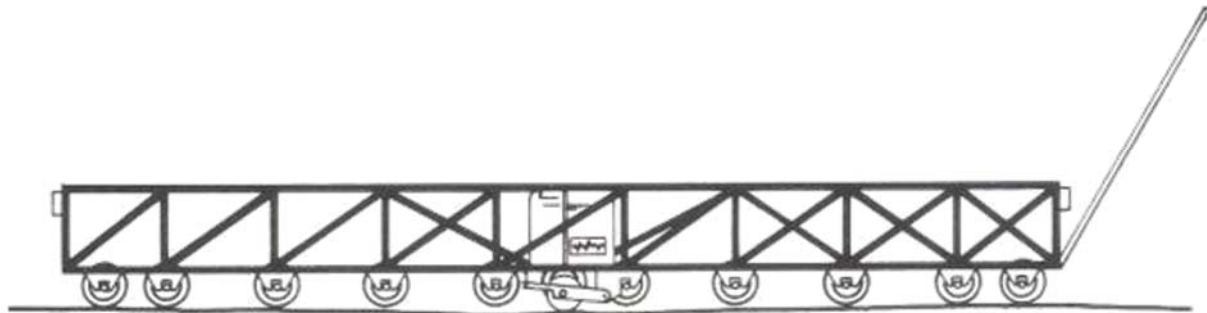


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## WLP for new work approval?

- 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



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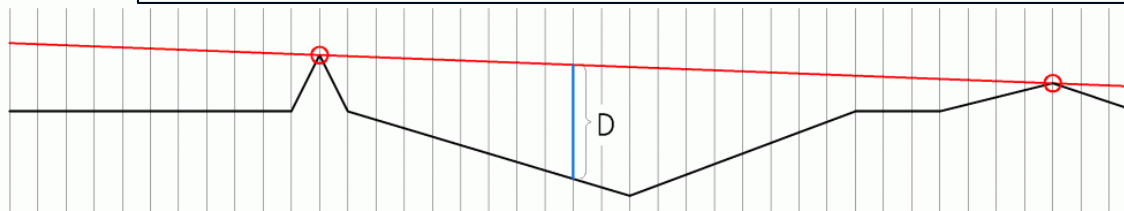
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  - planograph results of these sections - **not centrally available**
  - WLP results of these sections – **longitudinal profile has been measured during skid resistance acceptance test** (with a vehicle that measures evenness and skid resistance at the same time)



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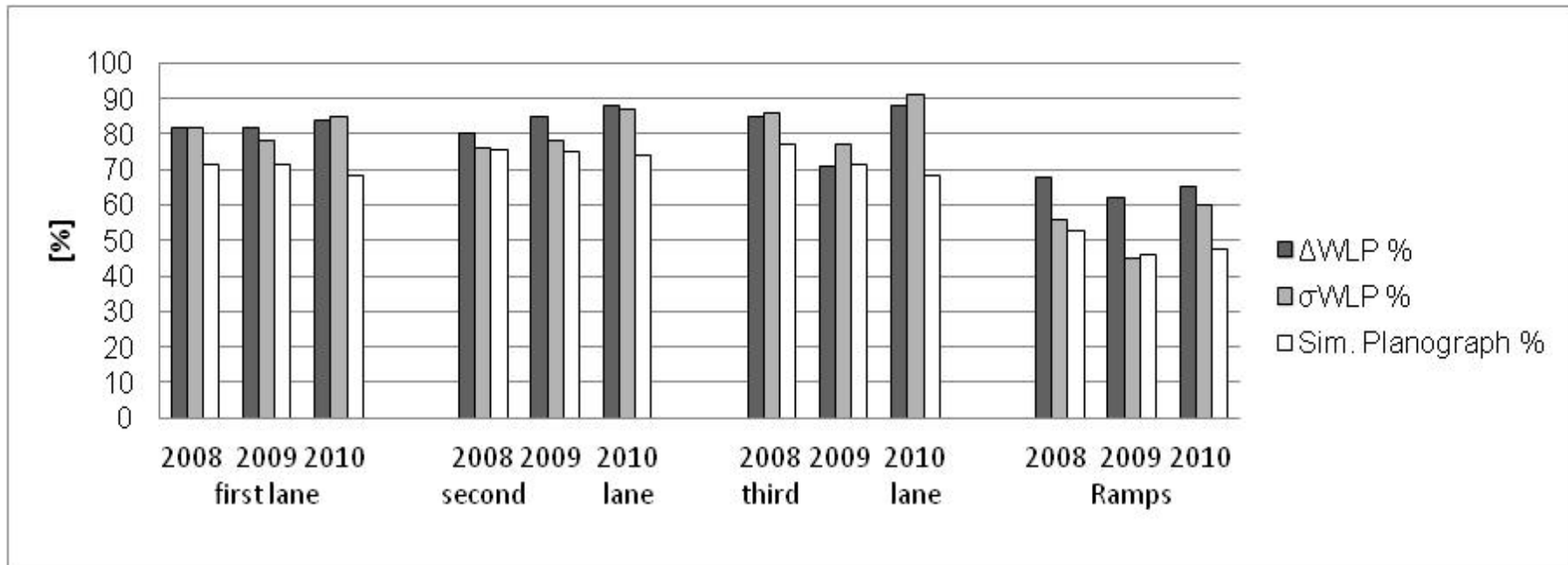
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simulation of moving straight edge on profile



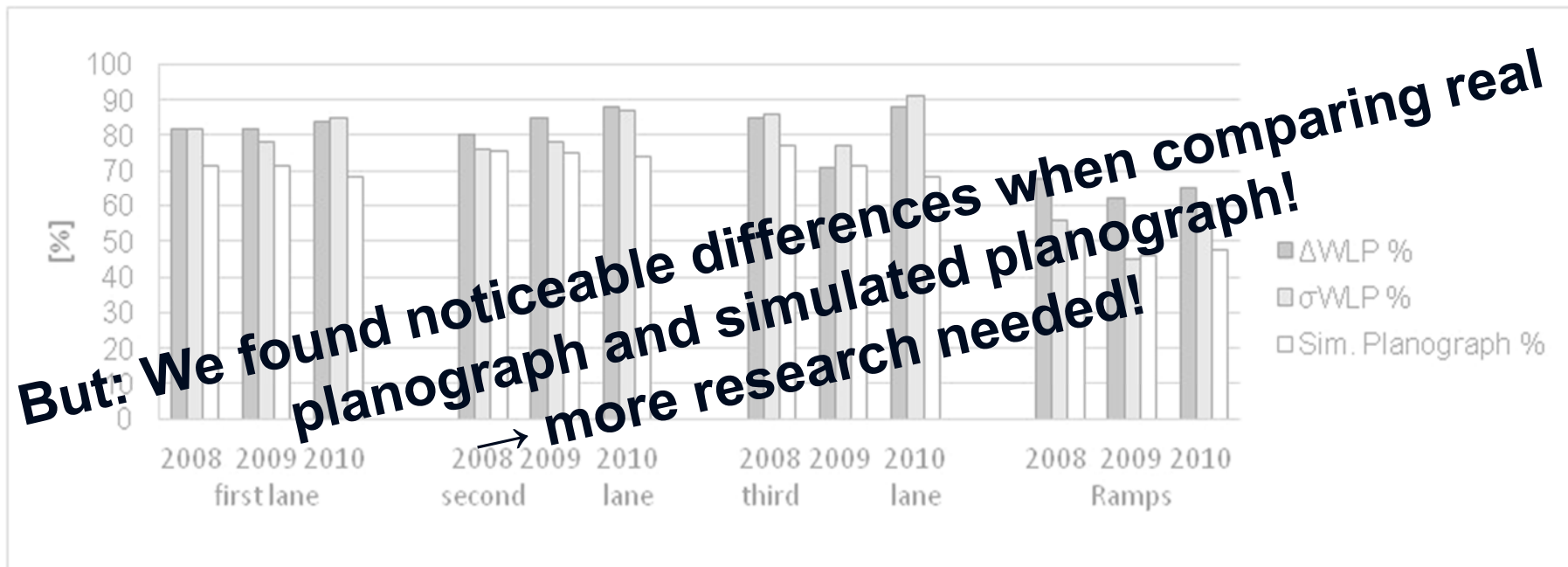
# WLP for new work approval?

- Comparison of WLP and simulated planograph for 50 m sections
  - Percentage of “positive” sections
    - $\Delta_{WLP}$ ,  $\sigma_{WLP}$  better than proposed approval value
    - simulated planograph: no deviation > 4 mm in section



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## 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

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# Thank you for your attention!

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