



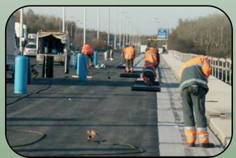


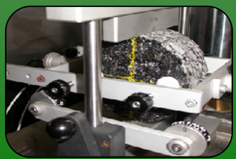

Continuous Deflection Measurements with the Curviameter for Project and Network Management.

Pavement Evaluation 2014
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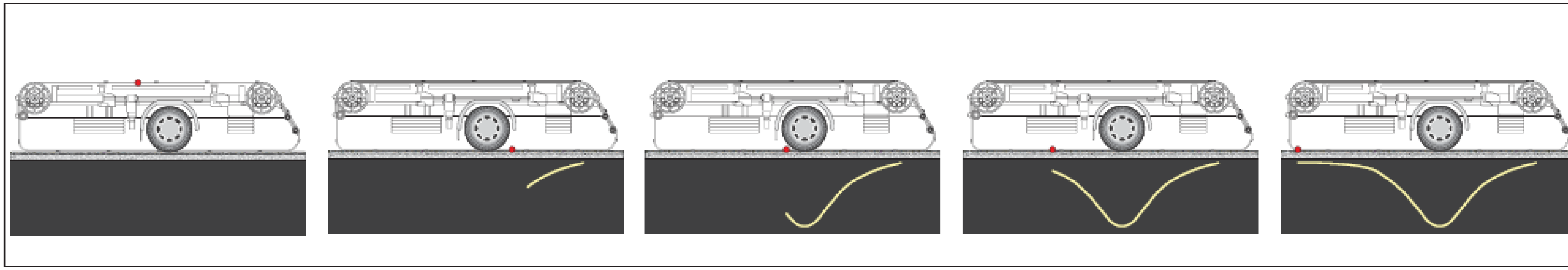
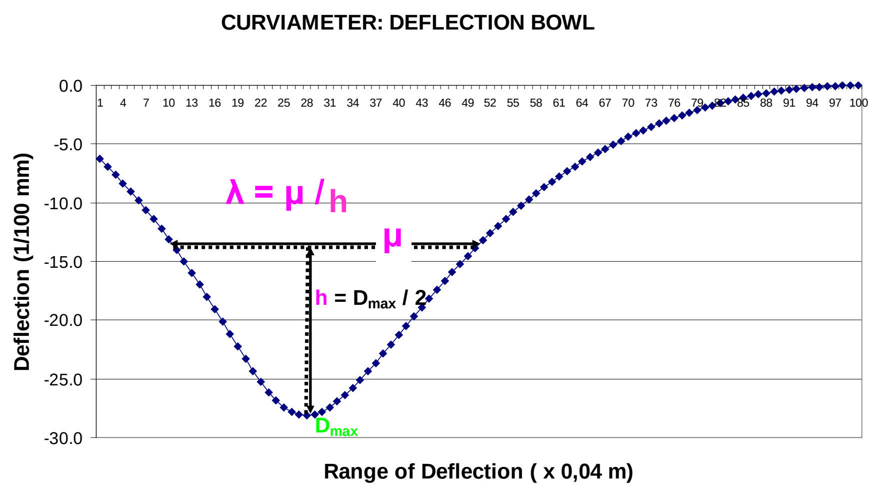
Curviameter





Raw Data and Structural Indicators

Collected data:

- Maximum deflection *Dmax*
- Radius of Curvature *Rc*
- 100 points on the deflection bowl

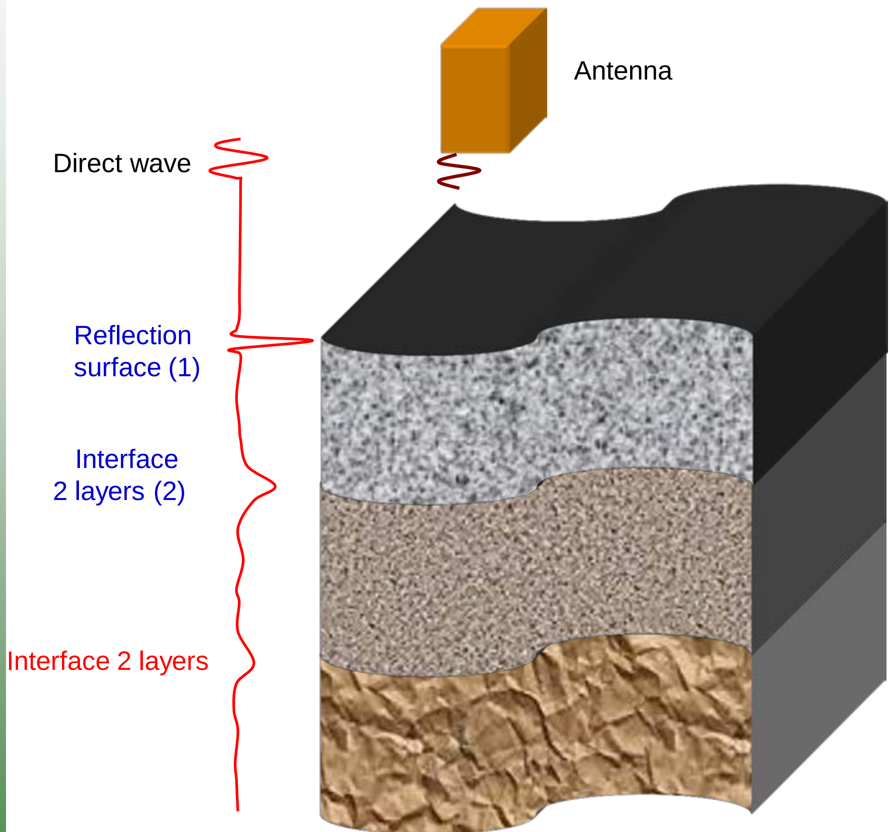
Easy to compute:

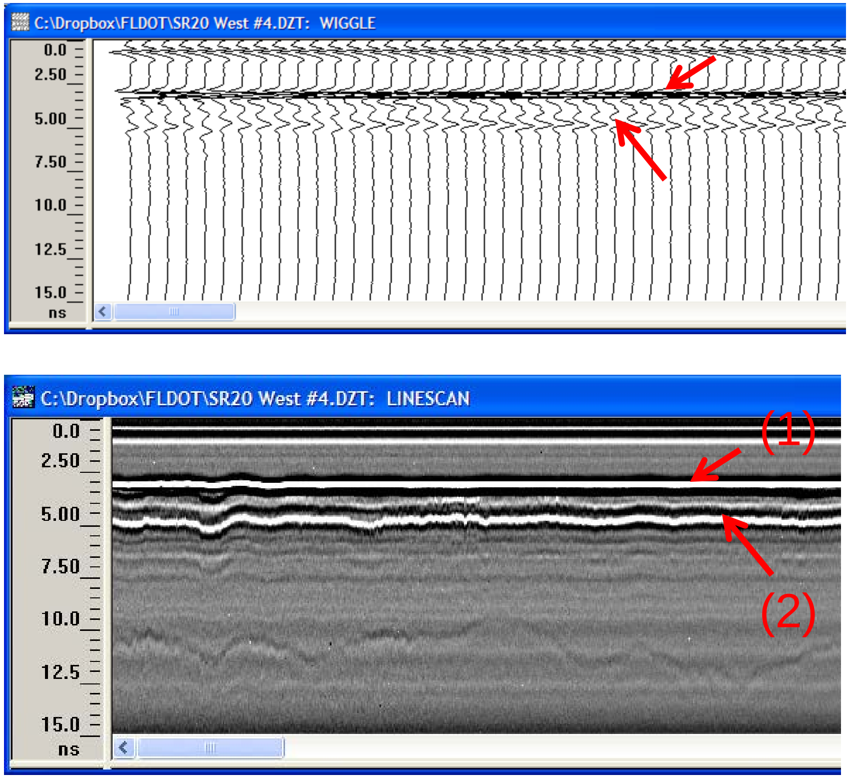
- Homogeneous zones (from *Dmax*)
- Characteristic deflection $Dc = Dmax + 2.\sigma$
- Tragfähigkeitszahl $Tz = \sqrt{Rc/Dmax}$

Indicator needed (cf. COST 354):

- Expression for residual life-time (for distribution in classes)

GPR – the principle

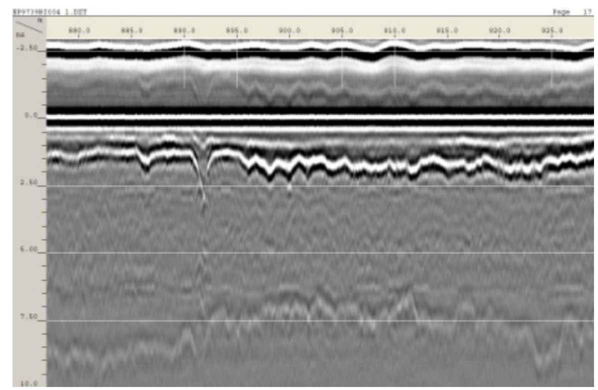




Source : Geophysical Survey Systems, Inc.

GPR – on the Curviameter

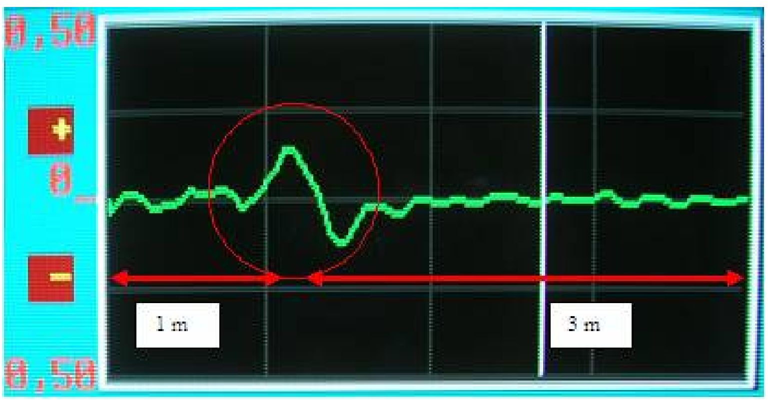
- Odometer of Curviameter triggers GPR…
- Perfect match between
  deflection bowl measurement data and radar image !



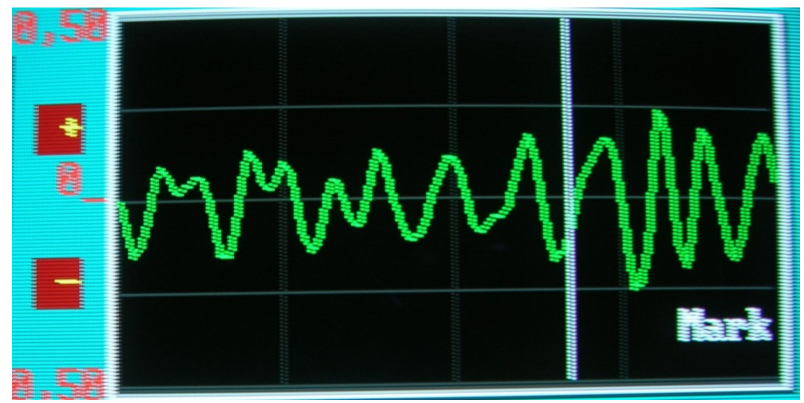
Standard post-processing

- Curviameter collects large numbers of data: 1 point per 5m.
- Curviameter runs at 18km/h => on motorways +65km/day.
- Geophone sensitivity: not on rigid road structures.

- **Some** data are of “poor” quality:



“Perfect signal”



“Rejected: too much noise”

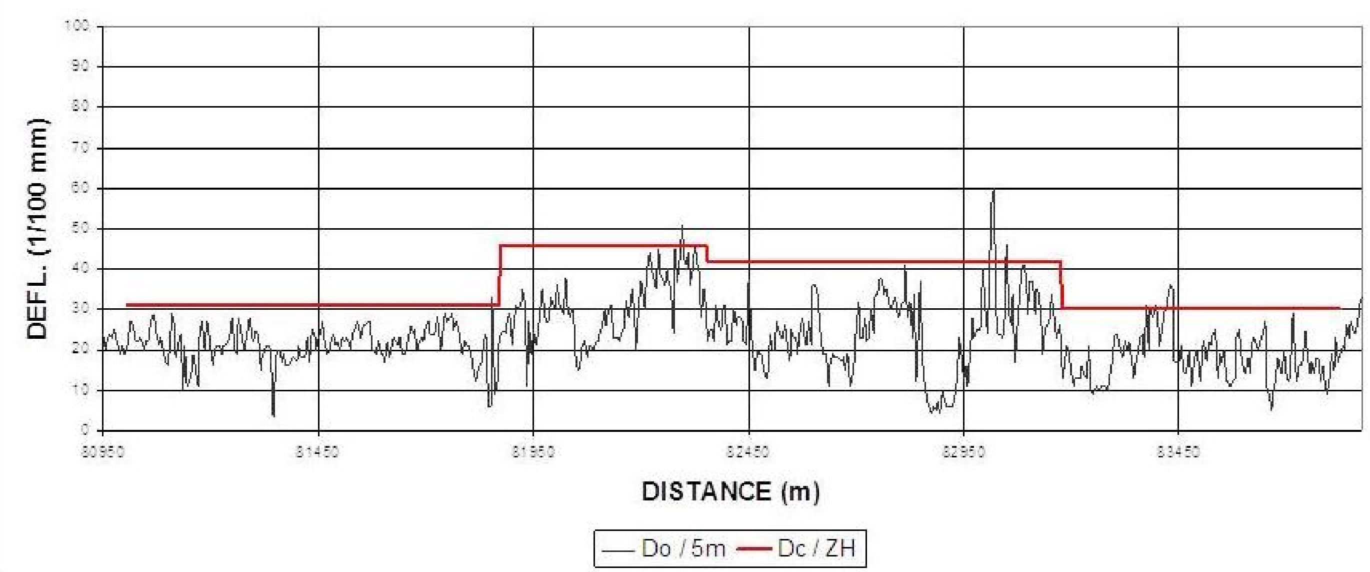
  - markings are set automatically
  - first post-processing: visual verification of automatic markings

- **Large data set: clean up and do statistical analysis!**

"Homogeneous Zones" (HZ)

- Using the ***maximal deflection***, cut the road in "zones" with "homogeneous structural behavior".

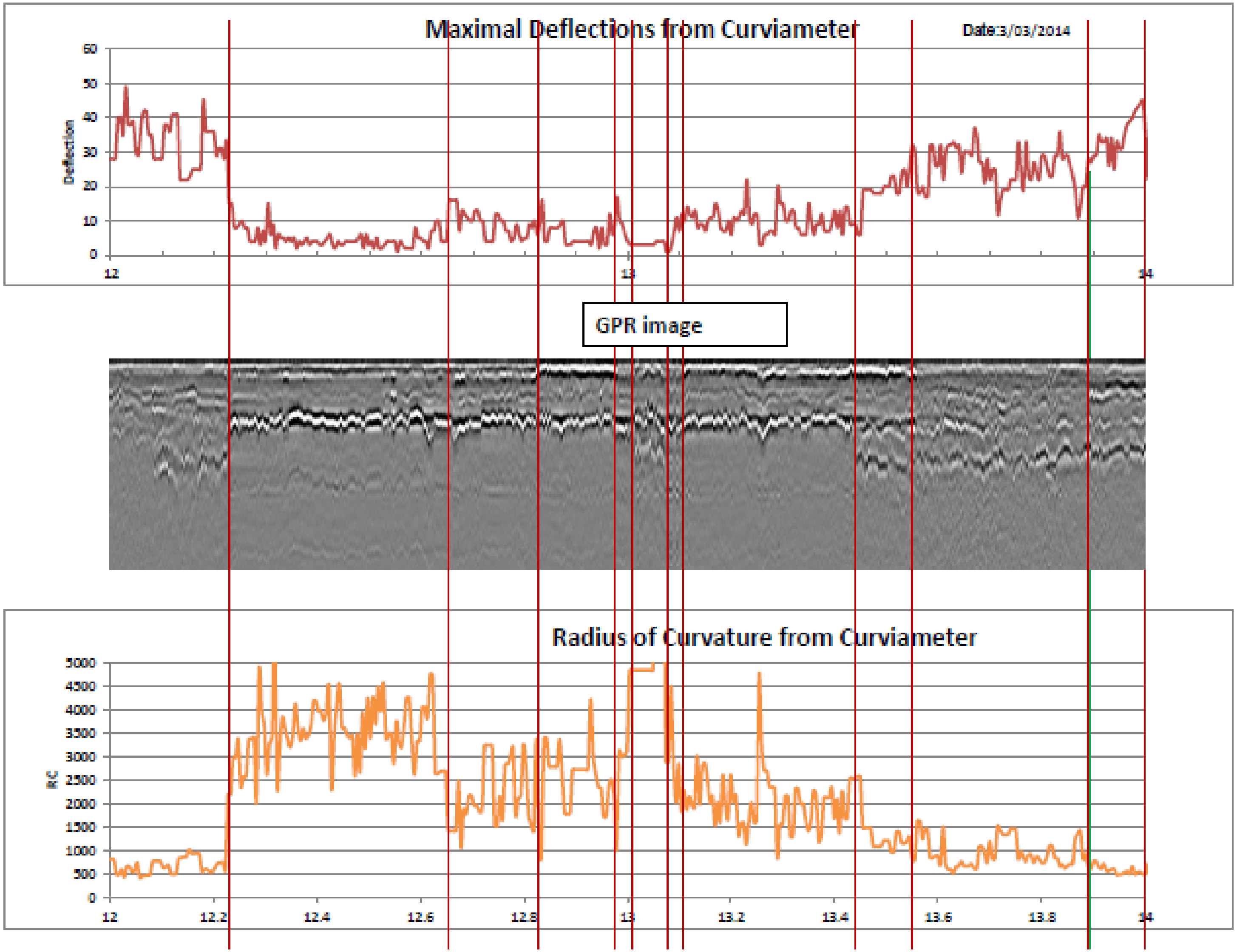
- Example : section divided in 4 zones :



- For each "homogeneous zone": compute indicators.
- Statistics: characteristic deflection in a zone:

$$D_{char} = D_{max,average} + 2.\sigma$$

HZ: Comparison GPR image and Curviameter data



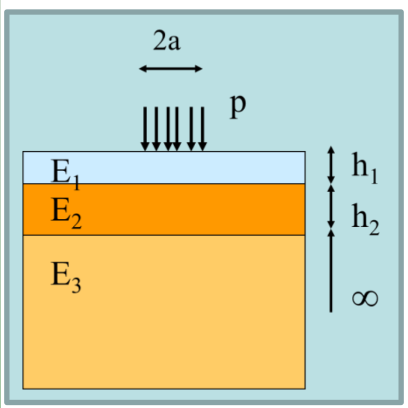
Project Level

Settings:

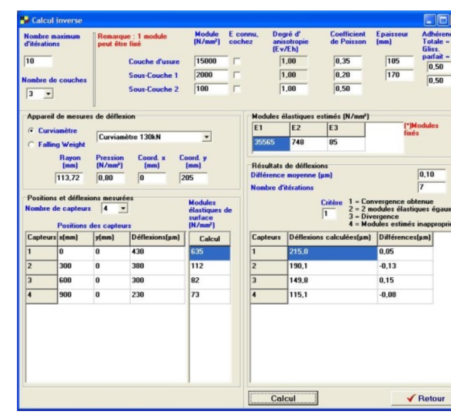
- Maintenance of an existing road.
- Over “limited length”: investigate 1road section.
- Need for “detailed analysis”.
- Most important decision to take:
  “can we leave the base course in place?”

Approach:

- Model of the road structure, deflections, GPR, coring.
- Back-calculation and if information about traffic: residual life.



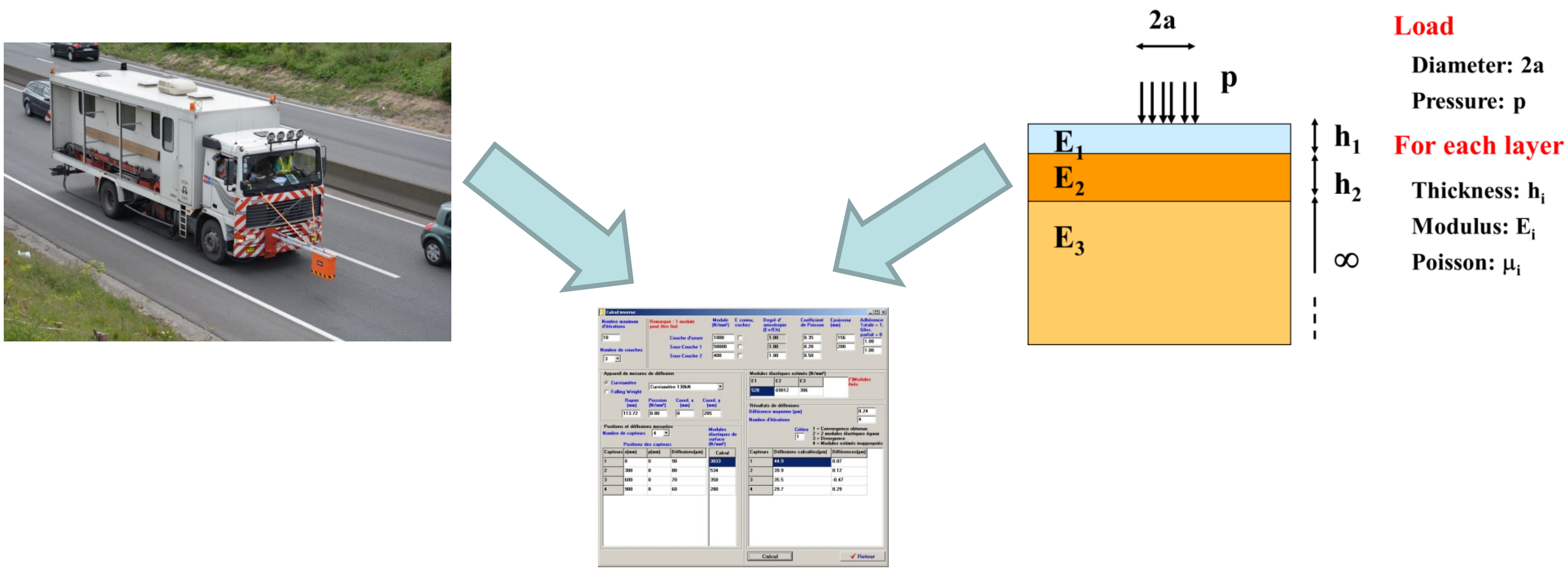




Hence: a lot of work on a rather small amount of data...

Theory: back calculation approach

- Objective: determine E-modules of all layers
  - compute deflection bowl from a multi-layer model
  - compare computed deflection bowl with measured deflection bowl
  - if deflection bowls not "identical" then modify E-modules and iterate…

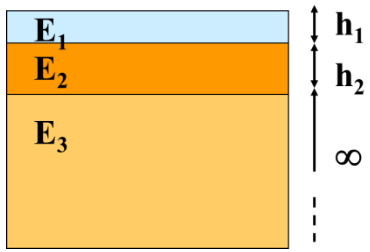


- then **redesign** "current structure + overlay" (similar to a new built) with **a design software** and estimate life-time.
- if poor then change more in deeper part in the road structure.

Instead of design software: Equivalent single layer model

- Replace each layer of the multi-layer road structure by a 1-layer model with "equivalent" thickness (thicker than the sum of thicknesses):

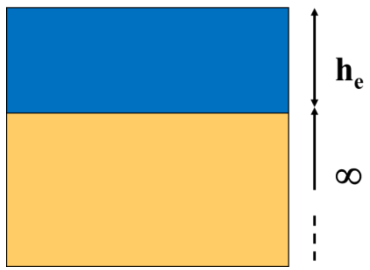
- Multi-layer model: thicknesses h_1, h_2, h_3,...



- Equivalence factors: a_1, a_2, a_3,...

$a_i = \sqrt[3]{(E_i/500)}$ with E_i the elasticity modulus of the layer or from a table based on the "type of the layer material".

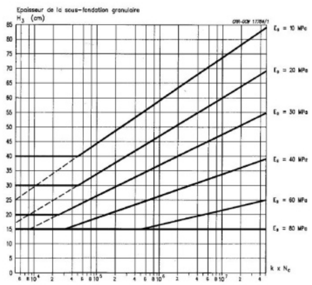
- Thickness of equivalent layer: $h_e = \Sigma a_i \cdot h_i$

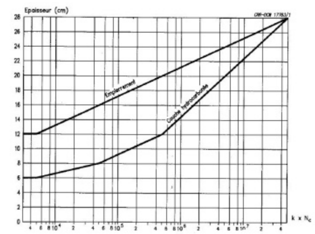


Equivalent single layer model: thickness of overlay…

- Determine traffic (kN_c): past, present and future traffic.

- Graphs established in 1991 (BRRC report R56/85):





traffic maps to thicknesses H_1,H_2,H_3 of the ideal multi-layer road

- The ideal equivalent thickness: $H_e = \Sigma\, a_i \,.\, H_i$
  (for the equivalent 1-layer model)

- Do overlay: $W = (H_e - h_e) \,/\, 2.7$ (with a_i =2.7 for a bituminous layer)
  is **the needed thickness of the bituminous overlay** in order to get the equivalence of the ideal multi-layer road structure

Deflections at network level by others: France

- Cf.: Ph. Gaborit, H. Di Benedetto, C. Sauzéat, S. Pouget, F. Olard, S. Quivet, *Analyse d'une structure de chaussée autoroutière par auscultation in situ et essais en laboratoire,* Actes des 30[ième] Rencontres Universitaires de Génie Civil (AUGC et IBPSA 2012), Chambéry, 6-8/6/2012.

- Curviameter measured motorway section of 15km in 1999 and 2010.
- Comparison Dmax 1999 / 2010 and Rc 1999 / 2010.
- Laboratory tests on monsters taken in 2010.
- Back-calculation and residual life-time expectance.

Directly with measurement data

The hard way…
But only 15km…

Structural indicator expresses life-time

- Conclusions:
  - Non-destructive test allowed estimating E-modules.
  - Estimated E-modules correspond to laboratory tests for then bituminous layers, not for the subgrade though.
  - Measurements and laboratory tests confirm both that residual life-time expectance is still high for this section.

Deflections at network level by others: Italy

- *Cf.: M. Crispino, G. Olivari, M. Poggiolo, I. Scazziga, Including Bearing Capacity into a Pavement Management System, International Conference on Bearing Capacity of Road Pavements, Trondheim, Norway, 2005.*

- Deflections by FWD on network of motorways, points at 100m intervals.
- T…
- Tra… Benkelman beam deflections
- Residual pavement life from Swiss standa… reinforcement thickness versus Benkelman deflection and traffic.
- Map … 3 classes:
  - Reha… when residual life < 5 years,
  - Allow every treatment when residual life between 5 and 12 years,
  - Only maintenance when residual life > 12 years.

- This as an extra rule in exi…ing PMS.

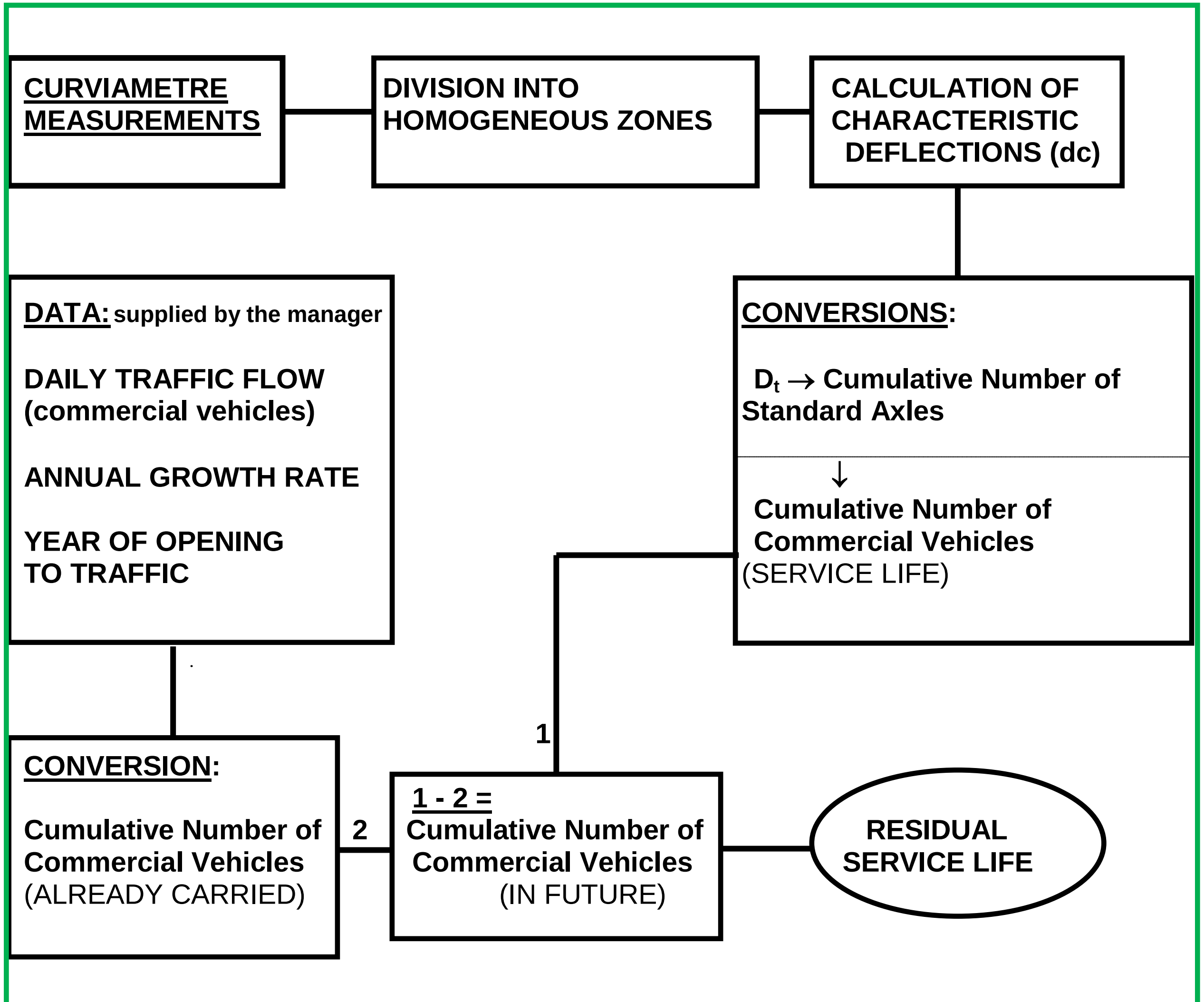
Directly with measurement data

Structural indicator expresses life-time

Network evaluation = rough classification

Characteristic deflection ~ residual life (BRRC)

Cf. M. Gorski, *Residual Service Life of Flexible Pavements and its Impact on Planning and Selecting Priorities for the Structural Strengthening of Road Networks*, PIARC XXI World Road Congress, Kuala Lumpur, Malaysia, October 3-9, 1999.



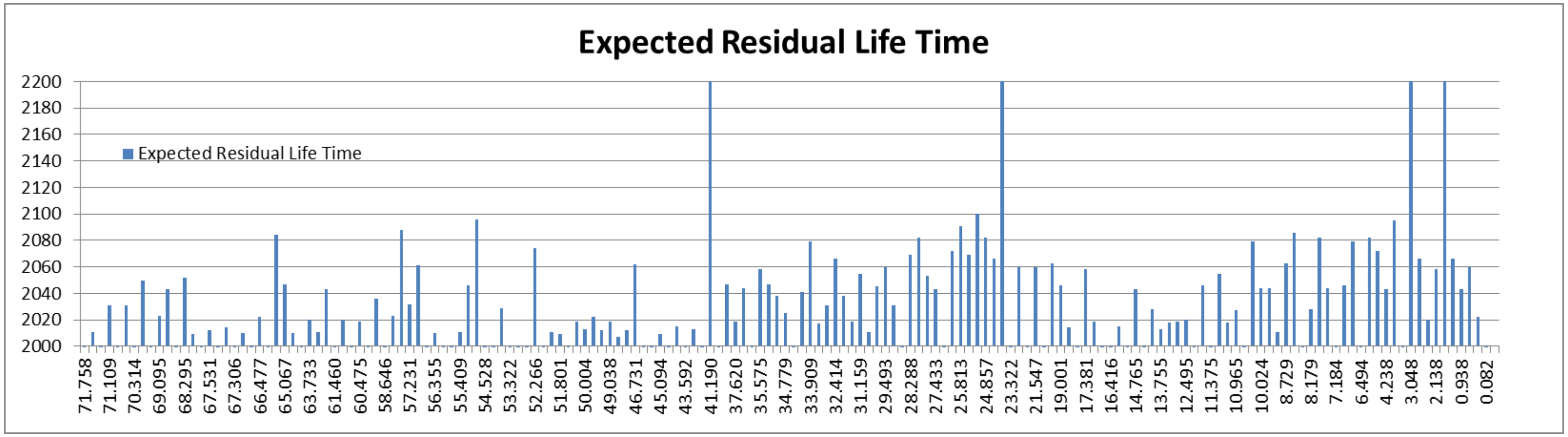
$$DB = 1.38 \, . \, DC$$

$$Nst = \frac{2.46 \, . \, 10^{12}}{d_c^{\,3}}$$

Database of a motorway network *BRRC/SINECO*

Cf. M. Gorski, R.Benetti, M.Garozzo, M.Mori, *Investigating long life pavements. A case study*, in Advanced Characterisation of Pavement and Soil Engineering Materials, Loizos, Scarpas & Al-Quadi (eds), 2007.

- BRRC Curviameter measurements on SINECO network in Italy (≤ 2003);
- SINECO data about structure (GPR) and traffic data (counted);
- Formation modulus obtained from D(900);
- Back-calculation of E-moduli with 3-layer Odemark model;
- With traffic data: expected residual life-time (cf. previous slide).



Expected residual life time for each homogeneous zone.

Rc x Dmax α E2 / E3

Cf.: P. Autret, *Utilisation du produit Rd pour l'auscultation des chausses à couche de base traitée*, Bulletin de liaison des Laboratoires des Ponts et Chaussées N° 42, Déc. 1969, Réf. 740, pp.67-80.

For fully flexible bituminous roads,
if the structure of the road is in a good condition then:

- R.d is constant
- R.d α E2/E3
  - E2 elasticity module of the sub-base layer,
  - E3 elasticity module of the formation,
  - As long as the thickness of the sub-base layer is constant.

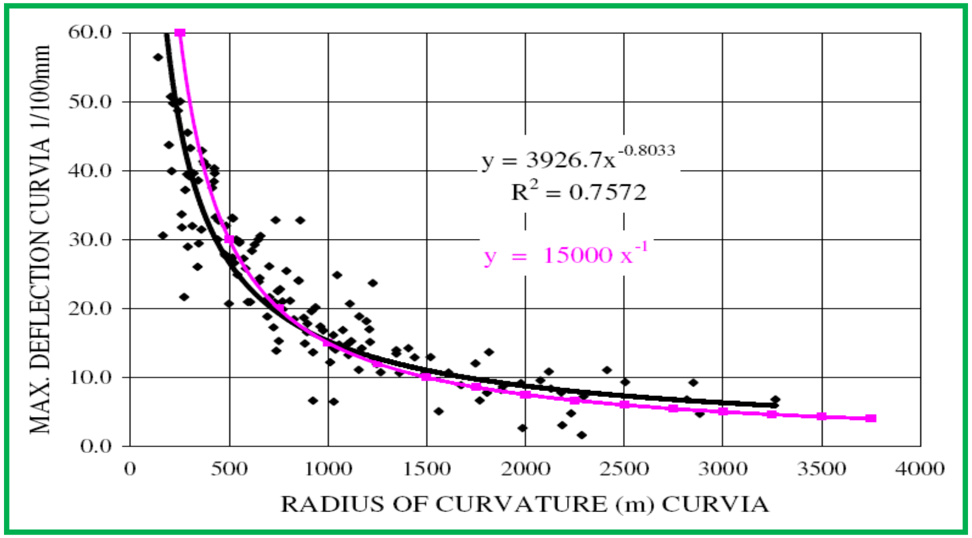


Illustration from BRRC measurements on different road structures.

- Under such conditions Rc.Dmax is independent from the actual E-values.

Rc and bad bond between layers

Small radius of curvature can be the consequence of:

- top layer in bad shape, or
- bad bonding between upper layers, or
- bad quality of unbound base layer.

Top layer in bad shape can often be seen at the road surface… Road administrator should know about existence of an unbound base layer…

Example: bad bond at 50mm

Homogeneous zones		Maximum deflection			Radius of curvature			
Begin	End	average	Standard dev.	characteristic	average	Standard dev.	2nd decile	5th decile
(km)		(1/100 mm)			(m)			
17.505	18.395	9	3	16	3187	1273	2110	3034
18.400	19.085	13	4	21	2205	1033	1419	1980

- Homogeneous zones are determined with Dmax only, hence Rc may vary within a zone.
- 2nd decile vs. 5th decile : many "small" Rc values in both zones.
- Higher Dc and lower Rc in second zone than in first zone and evidence of bad bond found in second zone by coring…
- Also: many "bad quality" signals…

In zone 2: BK 18.705

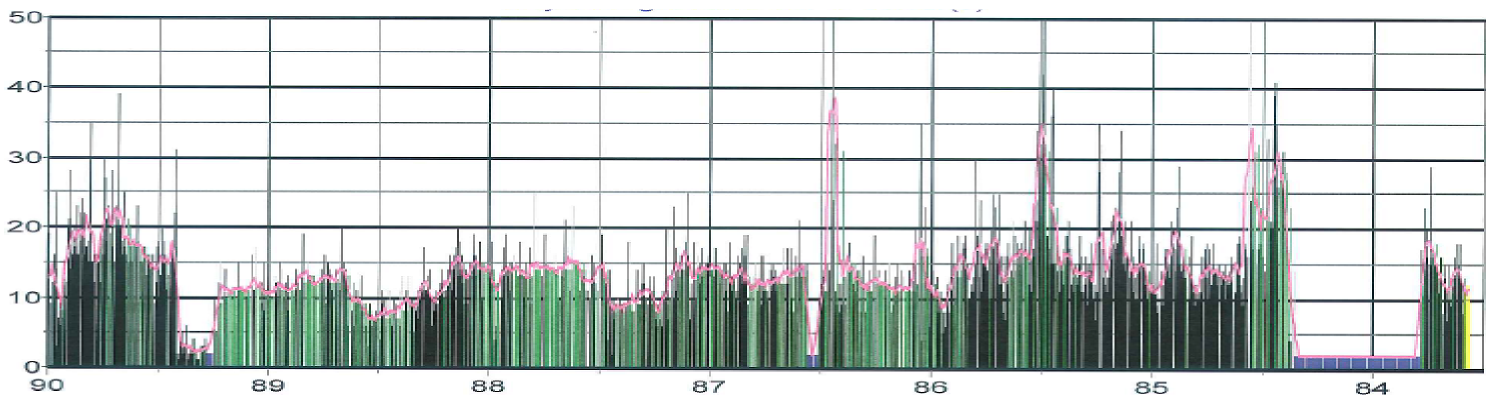
Tragfähigkeitszahl ~ bearing capacity

Cf. Shafik Jendia, Bewertung der Tragfähigkeit von bituminösen Straßenbefestigungen, Veröffentlichungen des Institutes für Straßen- und Eisenbahnwesen der Universität Karlsruhe, Heft 45, 1995.

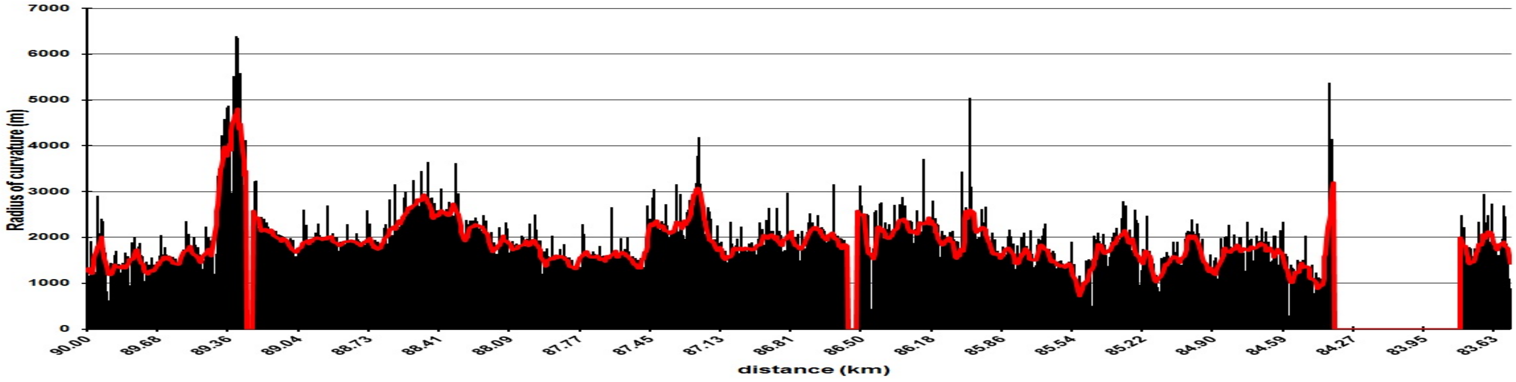
- Theory of Boussinesq: $E = 1.061 \cdot p \cdot (R/Y)^{0.5}$
  - E: E-module of halfspace,
  - p: contact pressure,
  - R: radius,
  - Y: deflection.
- Definition: $Tz = (Rc / Dmax)^{0.5}$
- S.Jendia proposes radius computation from FWD and Tz as indicator of bearing capacity of the whole road structure. (low Tz means weak bearing capacity)
- Why not computing it from Curviameter data…

Example : Motorway measured with Curviameter

- First lane and middle lane, both directions, 5km
- Maximum deflections:

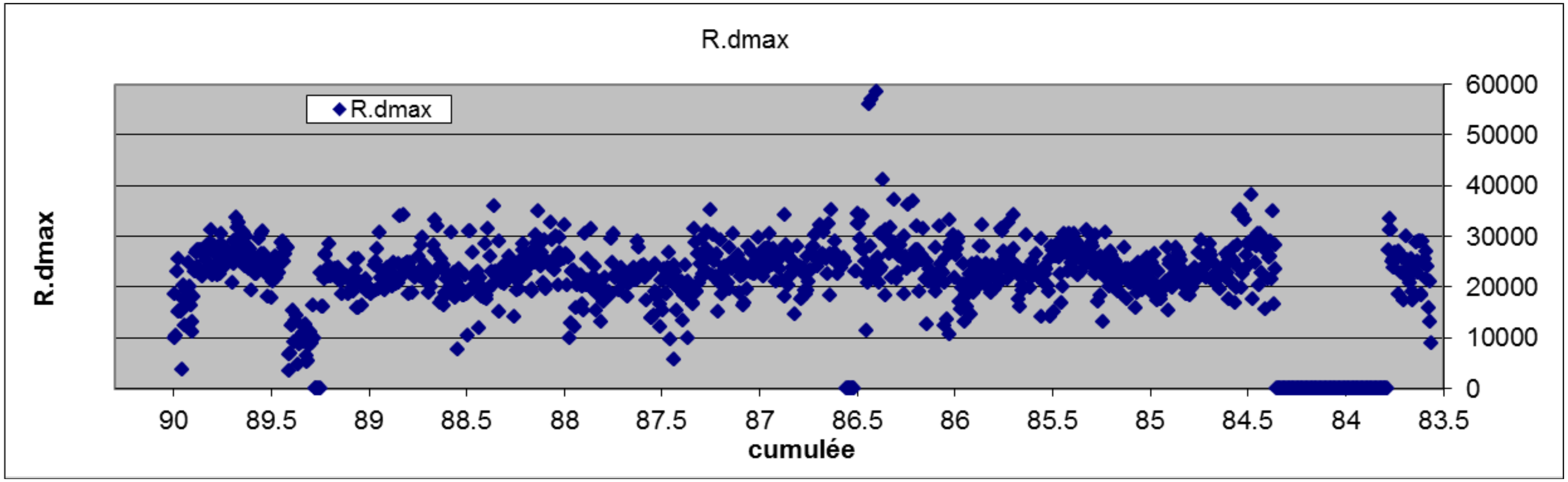


- Radius of curvature:



Easy input…

Homogeneous zones			lane	Deflections (µm) (averages in zone)				Dc	Rc	Tz	Rc.Dmax
	start	end									
N°	(km)			D(0) = Dmax	D(300)	D(600)	D(900)				
1	88.629	88.265	1	90	80	70	50	15	2472	5.1	233142
2	87.178	86.557	1	140	120	100	80	21	1872	3.7	256493
3	85.435	84.570	1	150	130	110	80	17	1662	3.3	247317
4	84.565	84.373	1	270	240	190	140	20	1300	2.2	347308



Back-calculation (the difficult way...)

- Structure of the motorway:
  - 3 layers: bituminous layer, lean concrete, subgrade and soil
  - Thickness of bituminous layer = 225mm or 240mm (different in different directions) .
  - Thickness of base course not well-known (180mm - 220mm?).
  - Traffic : ?

- Input per homogeneous zone:
  - Curviameter deflections (D(0),D(300),D(600),D(900))
  - 3 layer model of road structure (thickness, Poisson coefficient)

zone	point	Deflections (µm) – (representative point)				Hypotheses on layers				
						L1		L2		L3
		D(0)	D(300)	D(600)	D(900)	Thickness (mm)	Poisson	Thickness (mm)	Poisson	Poisson
1	88.315	110.2	99.3	81.2	62.2	225	0.35	220	0.20	0.50
2	86.900	132.0	122.5	102.8	81.4	225	0.35	220	0.20	0.50
3	85.051	149.0	133.7	107.2	81.3	225	0.35	220	0.20	0.50
4	84.459	205.2	185.3	152.2	118.2	225	0.35	220	0.20	0.50

Results of back-calculation

- E-modules estimated with software Qualidim:

"most realistic" point	Elasticity modules of existing layers (MPa)		
	E1	**E2**	**E3**
88.315 (zone 1)	22675	1029	300*
86.900 (zone 2)	28015	429	230*
85.051 (zone 3)	14516	847	230*
84.459 (zone 4)	16276	112	180*

"best convergence" point	Elasticity modules of existing layers (MPa)		
	E1	**E2**	**E3**
88.315 (zone 1)	34982	51	601
86.900 (zone 2)	36886	34	450*
85.051 (zone 3)	22832	50	394
84.459 (zone 4)	18451	42	234

- E2 extremely low, probably E1 overestimated
- E2 low

(*) : E-module fixed by user of back-calculation software (Qualidim)

Comparison easy indicators and back-calculation

"most realistic" point	Elasticity modules of existing layers (Mpa)			
	E1	E2	E3	E2/E3
88.315 (zone 1)	22675	1029	300*	3.43
86.900 (zone 2)	28015	429	230*	1.87
85.051 (zone 3)	14516	847	230*	3.68
84.459 (zone 4)	16276	112	180*	0.62

Homogeneous zones			lane	Deflections (µm) (averages in zone)				Dc	Rc	Tz	Rc.Dmax
	start	end									
N°	(km)			D(0) = Dmax	D(300)	D(600)	D(900)				
1	88.629	88.265	1	90	80	70	50	15	2472	5.1	233142
2	87.178	86.557	1	140	120	100	80	21	1872	3.7	256493
3	85.435	84.570	1	150	130	110	80	17	1662	3.3	247317
4	84.565	84.373	1	270	240	190	140	20	1300	2.2	347308

Dc ~ life-time, Tz low ~ bad bearing capacity, Rc.Dmax α E2/E3

Conclusion

- Curviameter is useful on project and network level.

- Network ≠ Project

- Project level:
  - Question is: must we also replace base course?
  - Back-calculation from Curviameter data is often done.
  - Best: “easy to determine indicators” and “sofisticated modeling” to be completed by more field evidence.

- Network level:
  - Need for indicator on “residual life-time expectance”,
  - Back-calculation: not impossible but time-consuming and need for a lot of detailed information on road structures in place,
  - “easy to determine indicators” can already give a first idea.

- Same raw data, other analysis!