Statens vegvesen
Norwegian Public Roads Administration

Data-Driven Estimation of Elastic Moduli for Flexible Pavements Using GPR and FWD Measurements

TRB International Partnership Meeting

Marriott Marquis Hotel

Wednesday, 14 January 2026, 15:00 – 18:00

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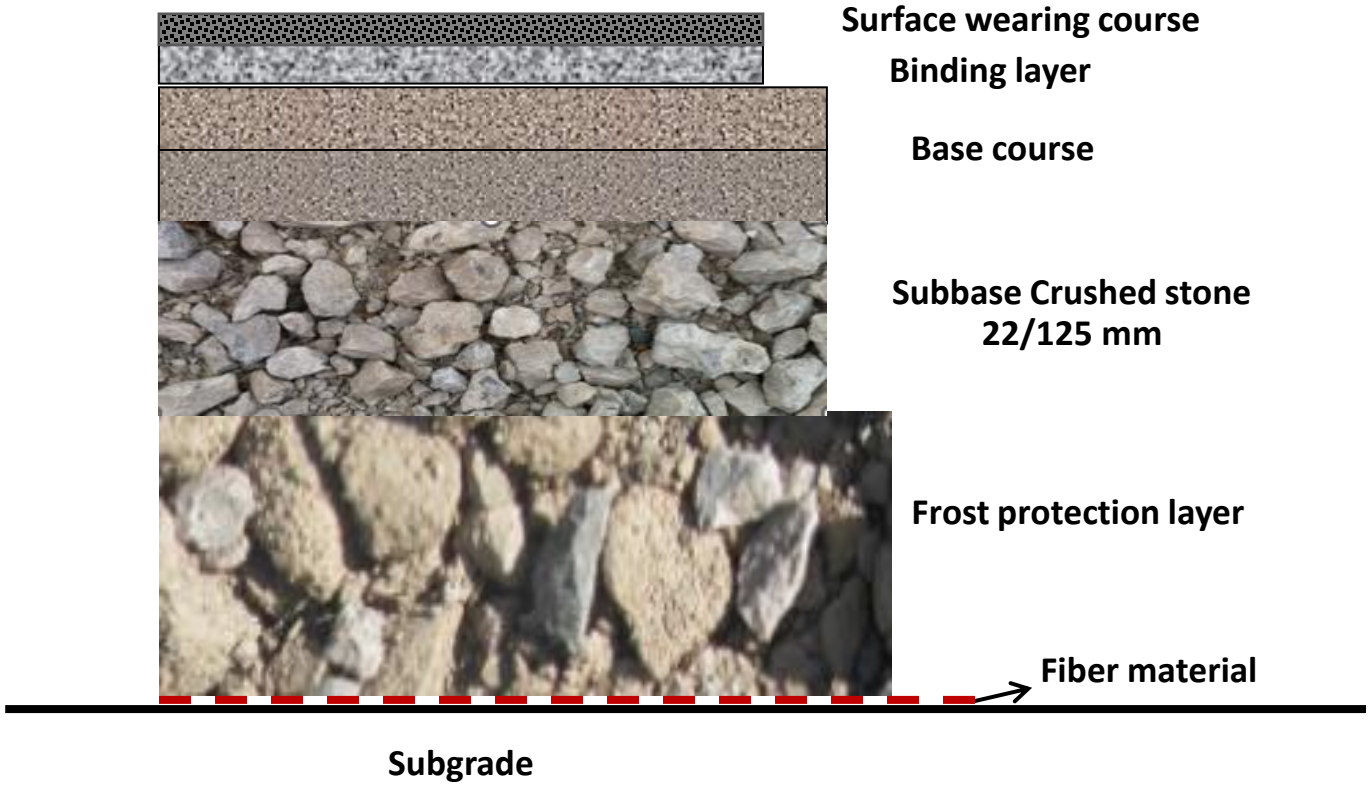
Norwegian Public Roads Administration

Road Technology Section

Contents

- Pavement layer thicknesses and their challenges
- FWD and GPR measurement
- Back-calculation of E-Modulus
- Results

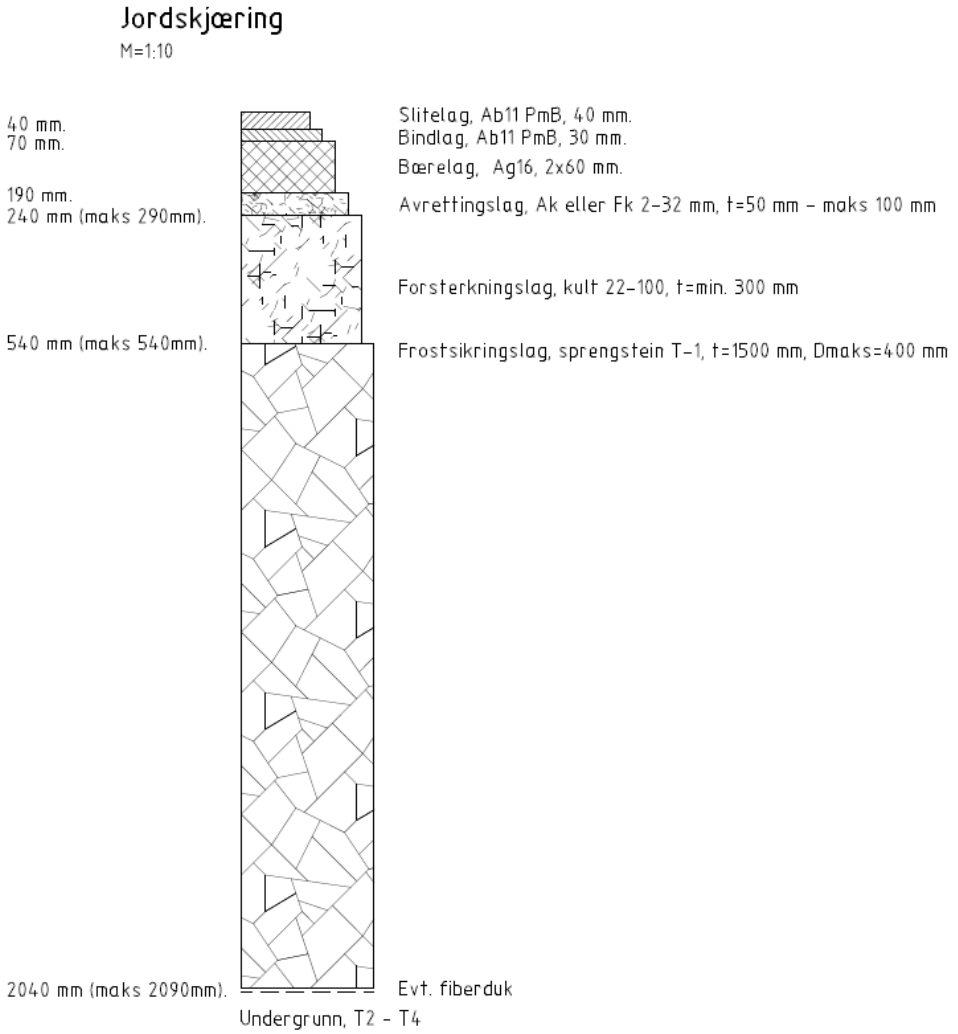
Typical Pavement Layer Thickness



- The layers thickness varies with
  - Traffic Volume – AADT
  - Quality of layer materials
  - Subgrade materials – frost susceptibility
  - Etc…

Layer thickness Determination

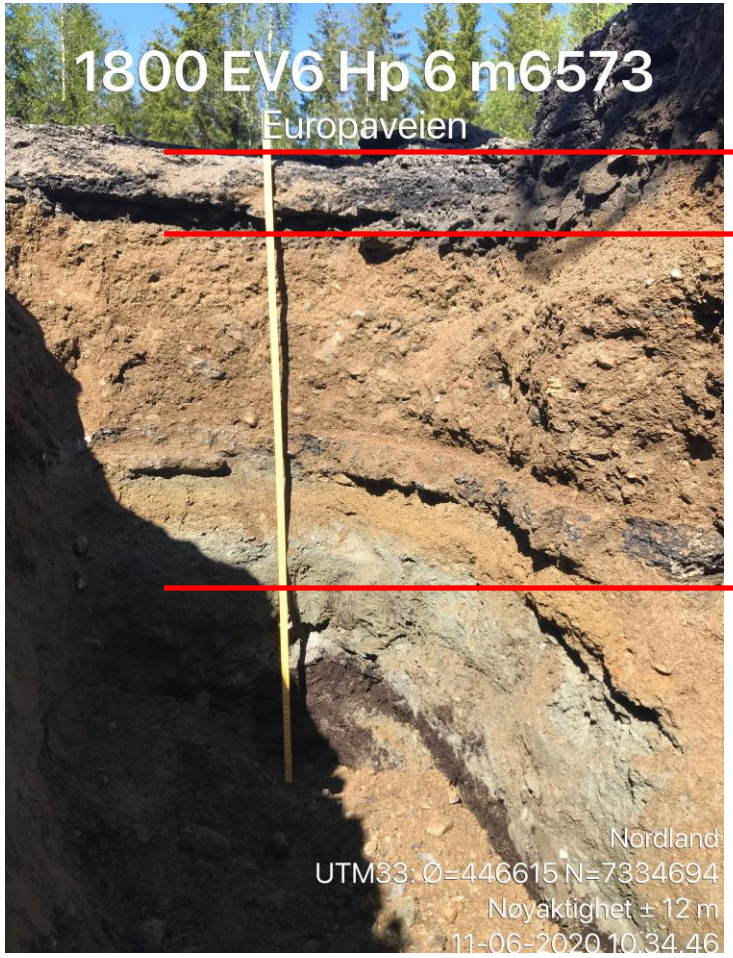
- Technical drawing from planning
- Measurement during construction
- Excavation/coring
- Non-destructive method –Ground Penetration radar

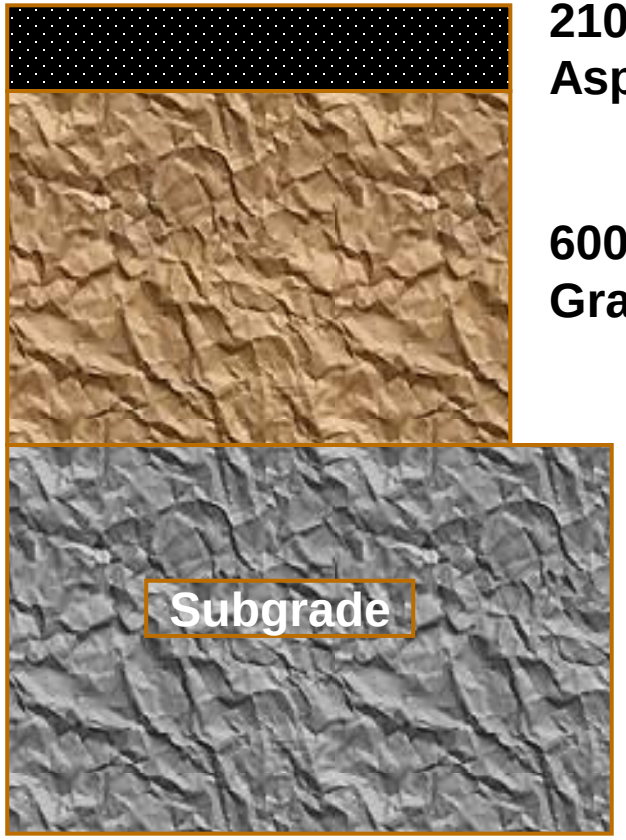


Excavation/coring layers

Fylke	Vegtype	Vegnr	Hp	Meter	H/V
18	Ev	6	6	6573	FI

Dybde cm	Lagtykk. cm	Material type	Prøve nr	Jordart	Største steinstørrelse
10				Asfalt	
20				Pr 7-10cm	
30					
40			1	Grus (dej. i hjulspor)	180
50				Natur m/stein	
60					
70				Asfalt	
80			2	Grus fin rødlig Natur	
90					
100			3	Grus grå	120
110				Knust	
120					
130				Torv	
140				Gravedybde	
150					

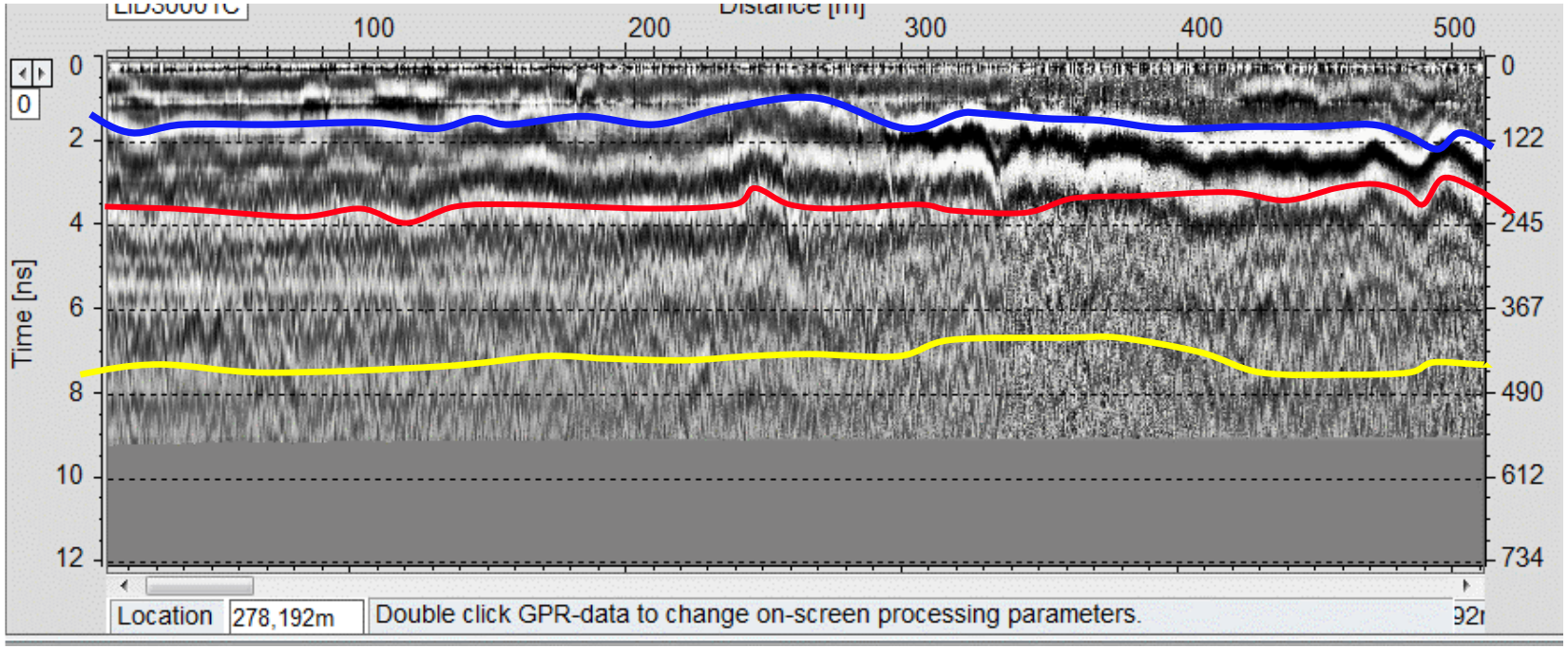




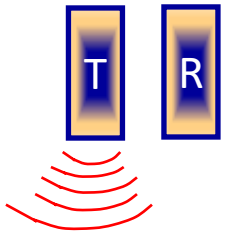
210 mm Asphalt

600 mm Gravel

Ground Penetrating Radar (GPR)

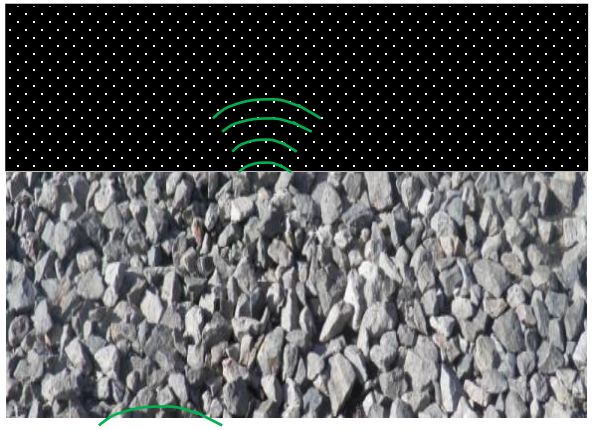


What is GPR and How it works?

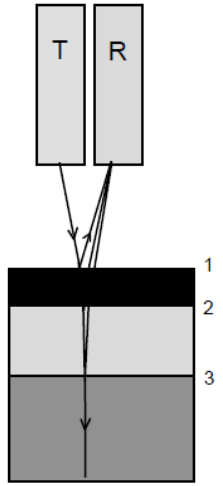


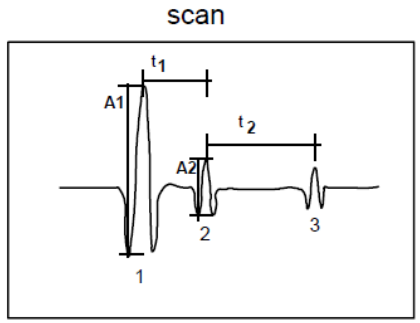
- **Transmitter (T)**
- **Receiver (M)**

- Non- destructive measurement technique
- Uses electromagnetic waves
- Depict what lies beneath the surface
- The transmitter sends the radar wave.
- The receiver antenna register the reflections and measure two-ways travel time.
- It works in soil, bedrock, gravel, asphalt, concrete , water, ice and snow.



- Bound layer materials
- Unbound layer (sub-base)



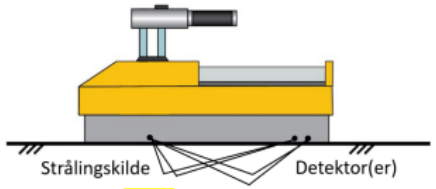


t_1 = travel time in pavement
t_2 = travel time in base
A1 = amplitude of reflection from asphalt
A2 = amplitude of reflection from base

Applications of Ground Penetrating Radar (GPR) in Road Engineering

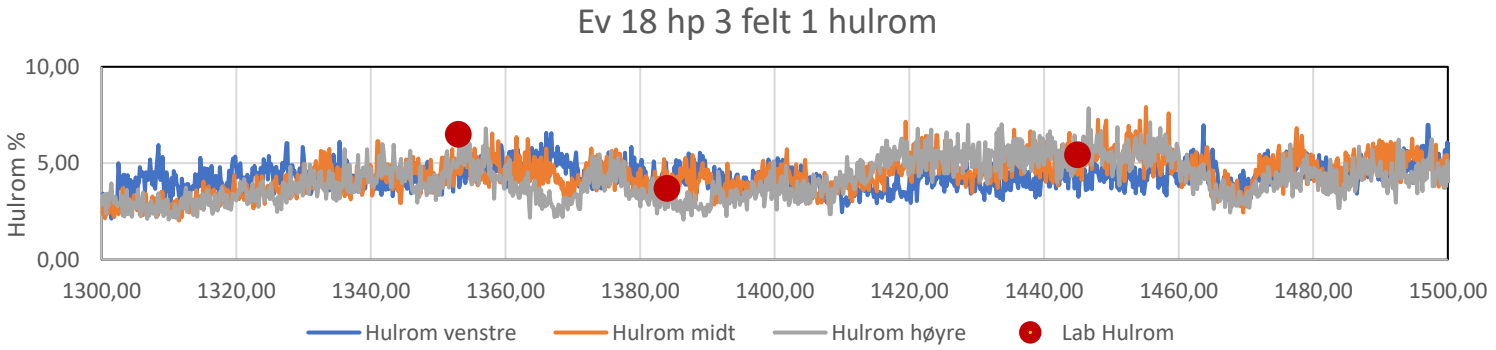
PaveScan RDM® 2.0

- Non-destructive equipment for measuring voids, density, and insufficient compaction in asphalt pavements.



Figur 2.3.4–1: Isotopmåler

R211 Feltundersøkelser



Tatek. Y. (2019) Måling av hulrom i asfalt med georadar - PaveScan RDM Rapportweb

RAPTOR and GPR measured roads stretches

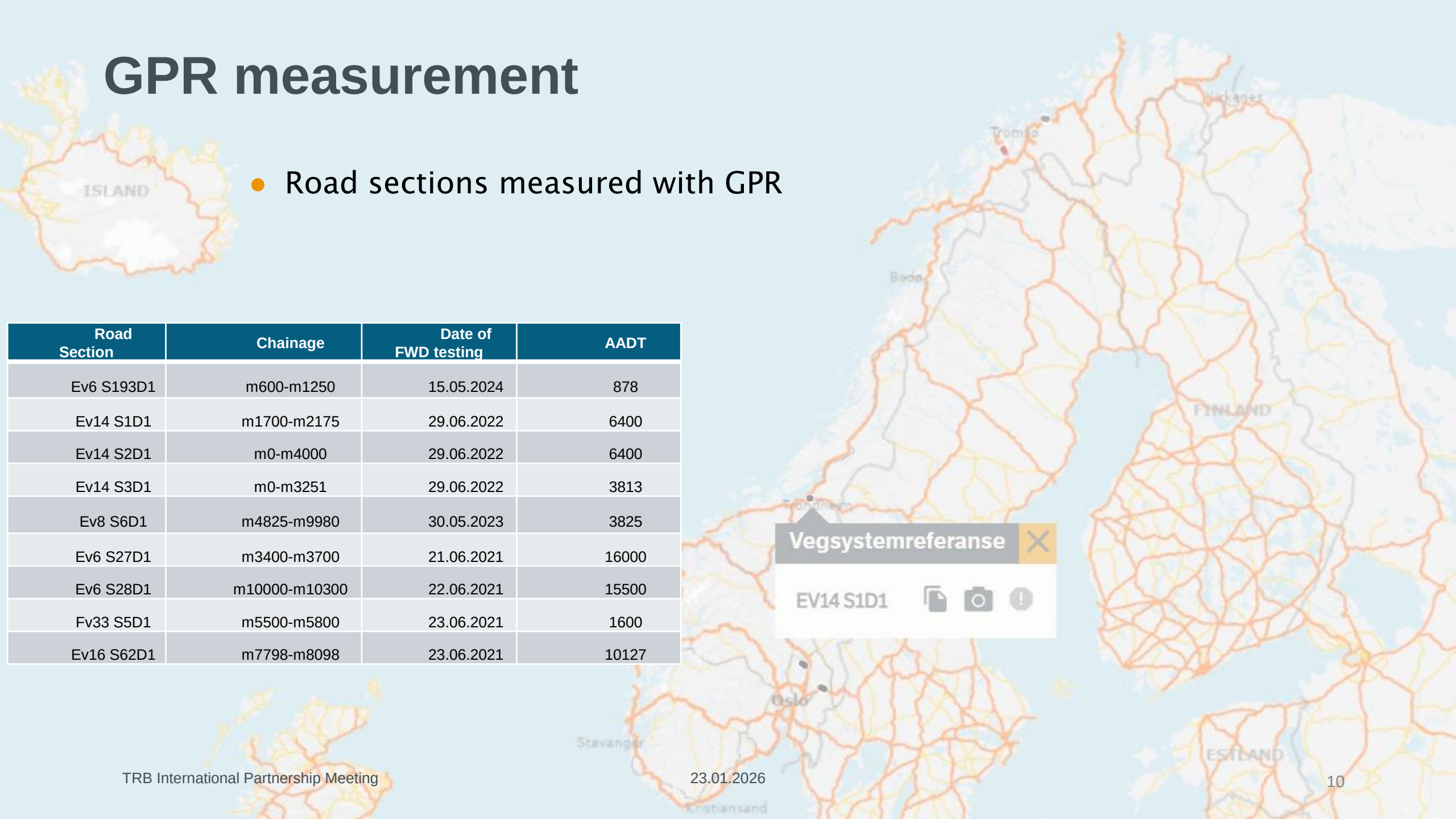
RAPTOR is a laser-based pavement deflection method. It is developed for rapid and continuously registering of the pavement deflection without traffic delay.

> 10 000 km Main highways

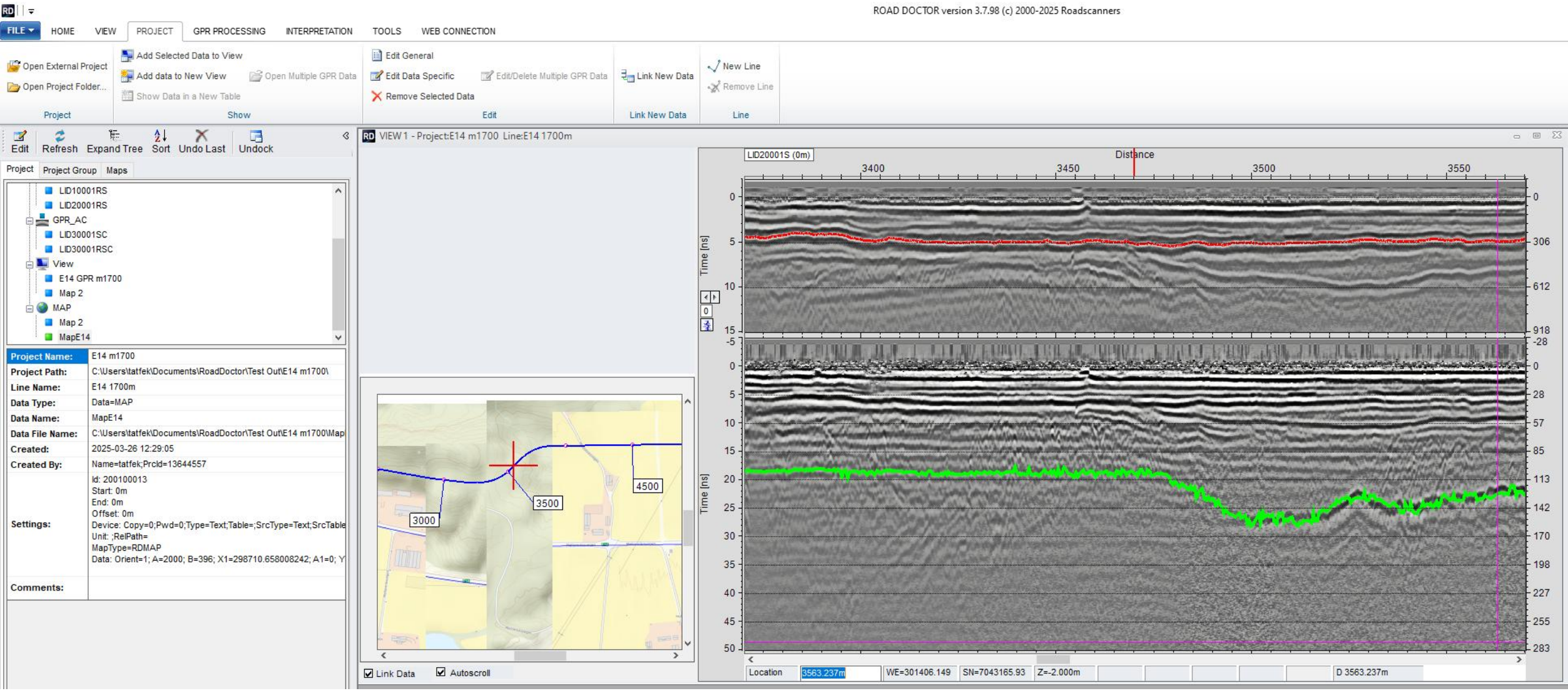
GPR measurement

- Road sections measured with GPR

Road Section	Chainage	Date of FWD testing	AADT
Ev6 S193D1	m600-m1250	15.05.2024	878
Ev14 S1D1	m1700-m2175	29.06.2022	6400
Ev14 S2D1	m0-m4000	29.06.2022	6400
Ev14 S3D1	m0-m3251	29.06.2022	3813
Ev8 S6D1	m4825-m9980	30.05.2023	3825
Ev6 S27D1	m3400-m3700	21.06.2021	16000
Ev6 S28D1	m10000-m10300	22.06.2021	15500
Fv33 S5D1	m5500-m5800	23.06.2021	1600
Ev16 S62D1	m7798-m8098	23.06.2021	10127

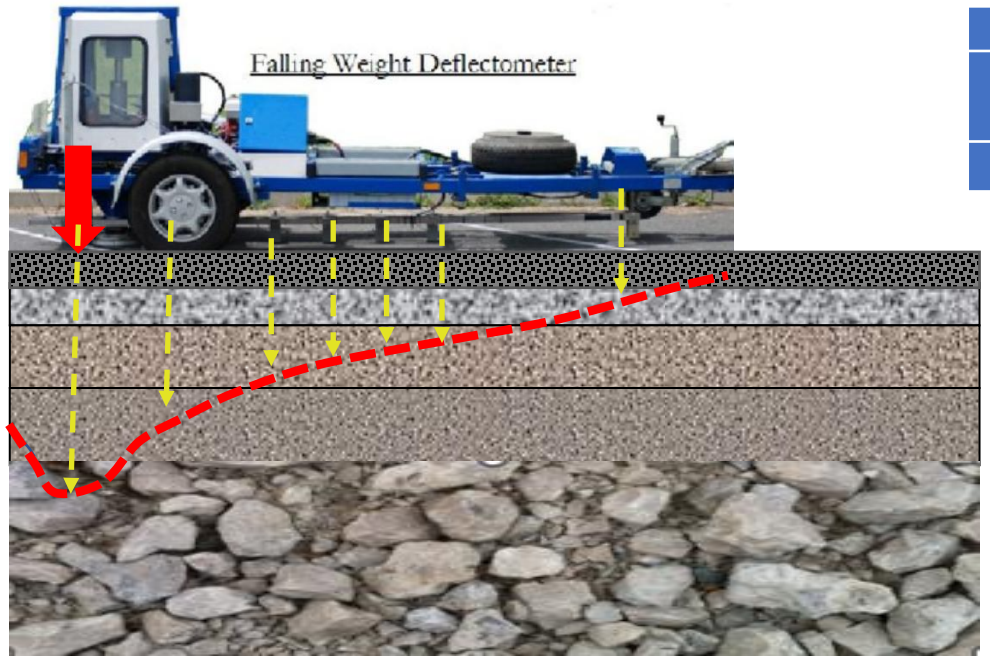


Road Doctor Software

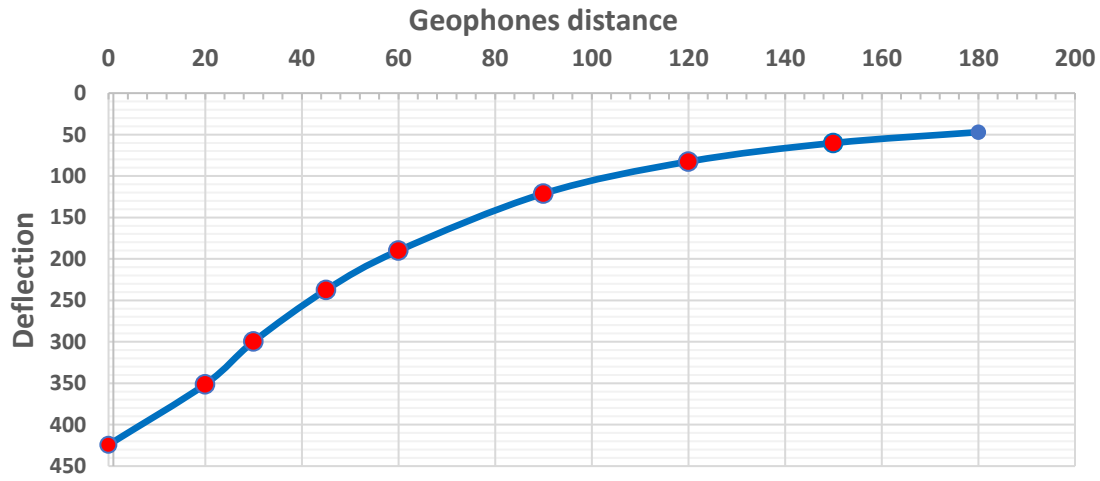


FWD-deflection measurement

50 kN

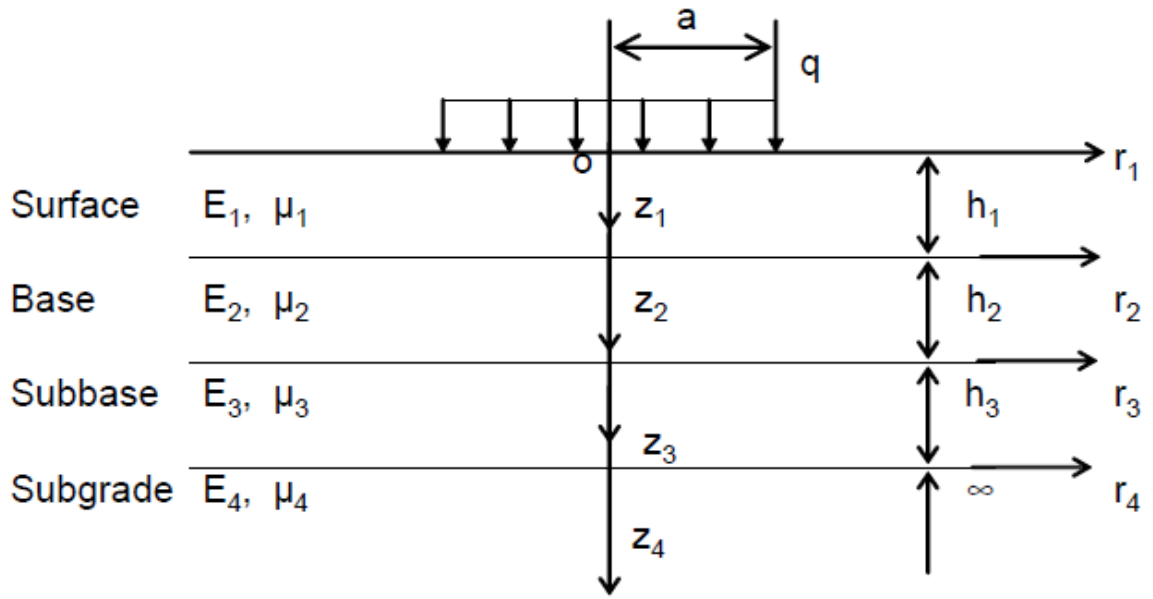


	Pos.(1), cm	Pos.(2), cm	Pos.(3), cm	Pos.(4), cm	Pos.(5), cm	Pos.(6), cm	Pos.(7), cm	Pos.(8), cm	Pos.(9), cm
	0,0	20,0	30,0	45,0	60,0	90,0	120,0	150,0	180,0
Load [kN]	Def.(1), µm	Def.(2), µm	Def.(3), µm	Def.(4), µm	Def.(5), µm	Def.(6), µm	Def.(7), µm	Def.(8), µm	Def.(9), µm
50,0	424,3	351,3	299,8	237,5	190,1	121,2	82,6	60,2	47,1



Back-Calculation Software

- ERAPave – **E**lastic **R**esponse **A**nalysis for **Pave**ment
- ELMOD – **E**lastic **L**ayers **M**oduli and **O**verlay **D**esign

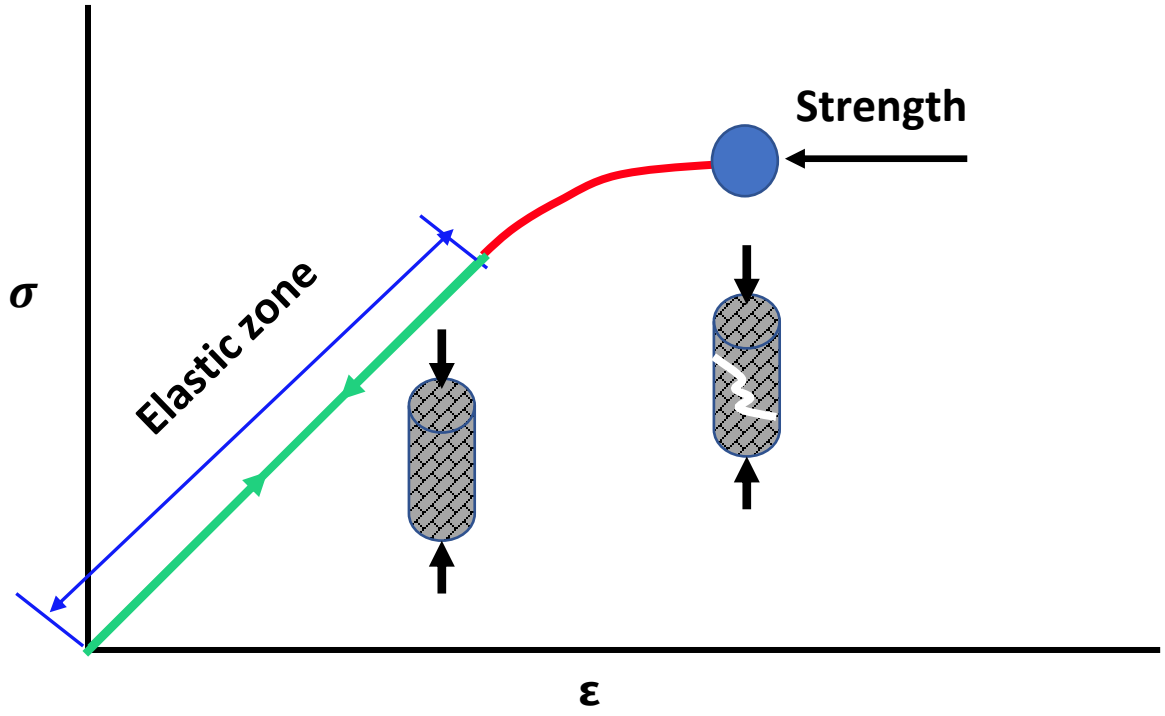


E-modulus

- **Elasticity** is a measure of how well a material returns to its original shape and size.

$$E = \frac{Stress\ (\boldsymbol{\sigma})}{Strain\ (\boldsymbol{\varepsilon})}$$

- **Strength** is the amount of stress required to break or tear a material.



E-modulus in the VegDim/ERAPave PP design system – N200

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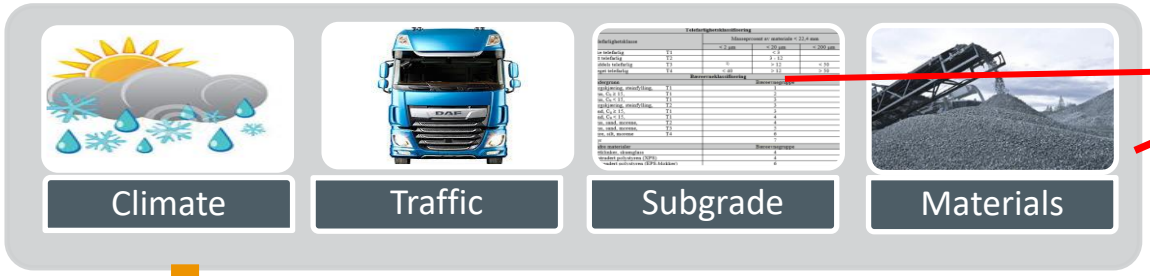


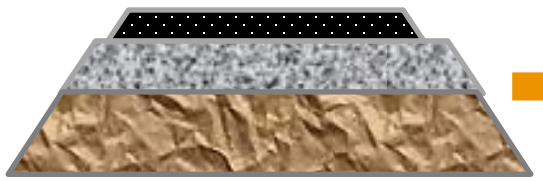
E-modulus

LCC/LCA analysis

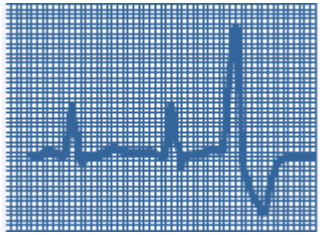
Ja

Nei

Satisfy the requirement

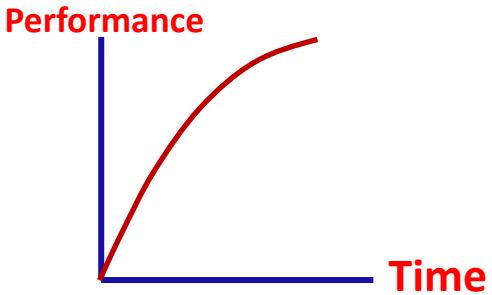


Layer thickness design



Response analysis

Distress



Condition deterioration

E-modulus in the VegDim/ERAPave PP design system – N200

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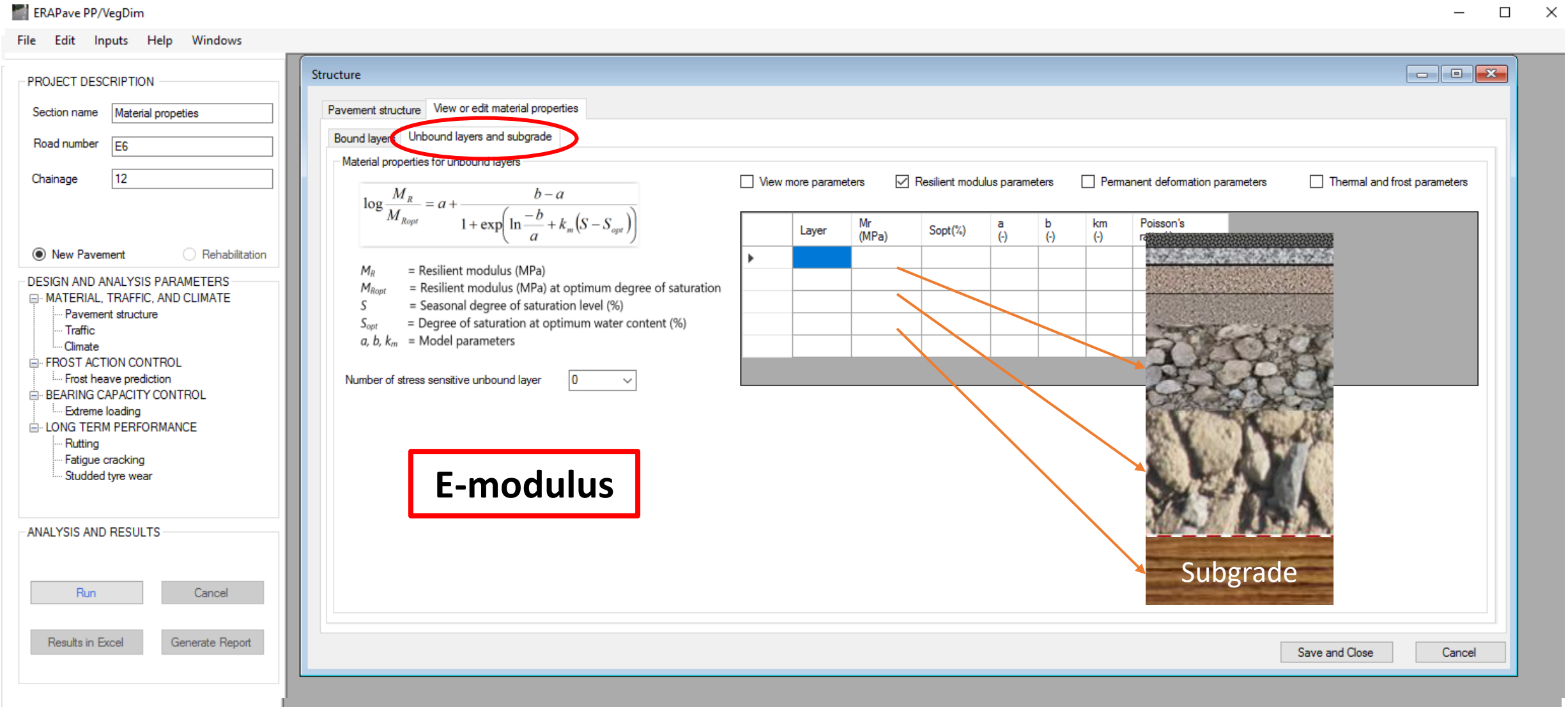
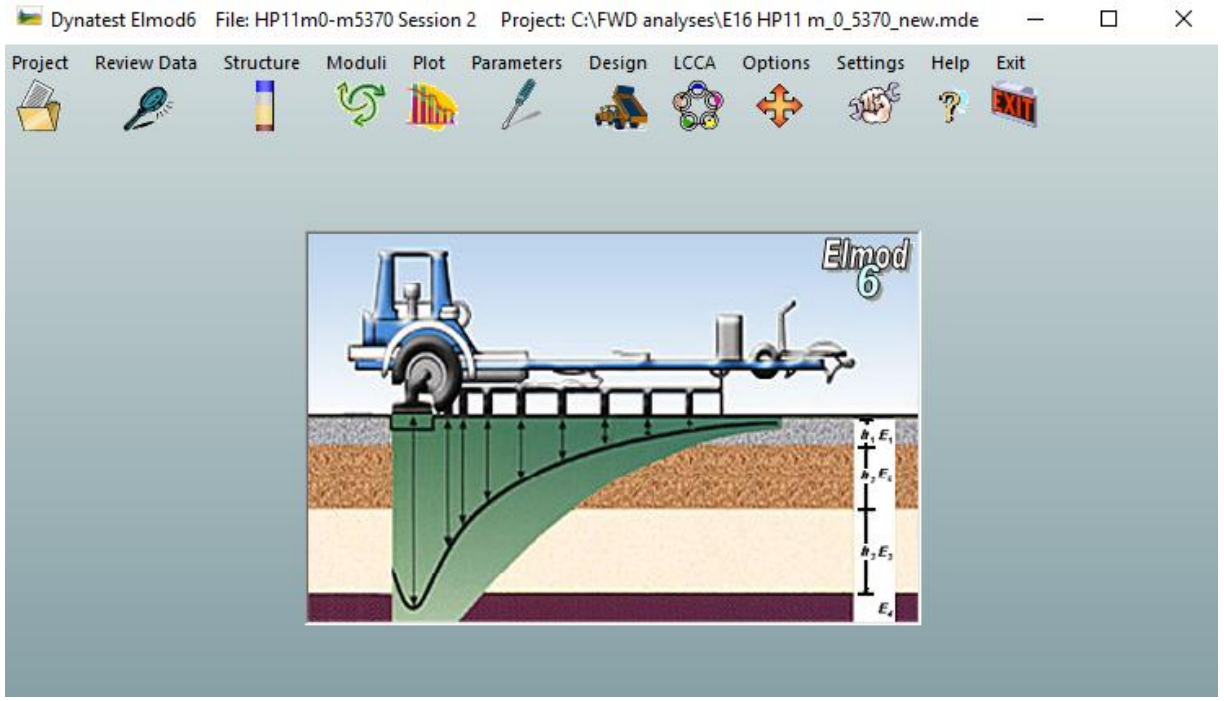
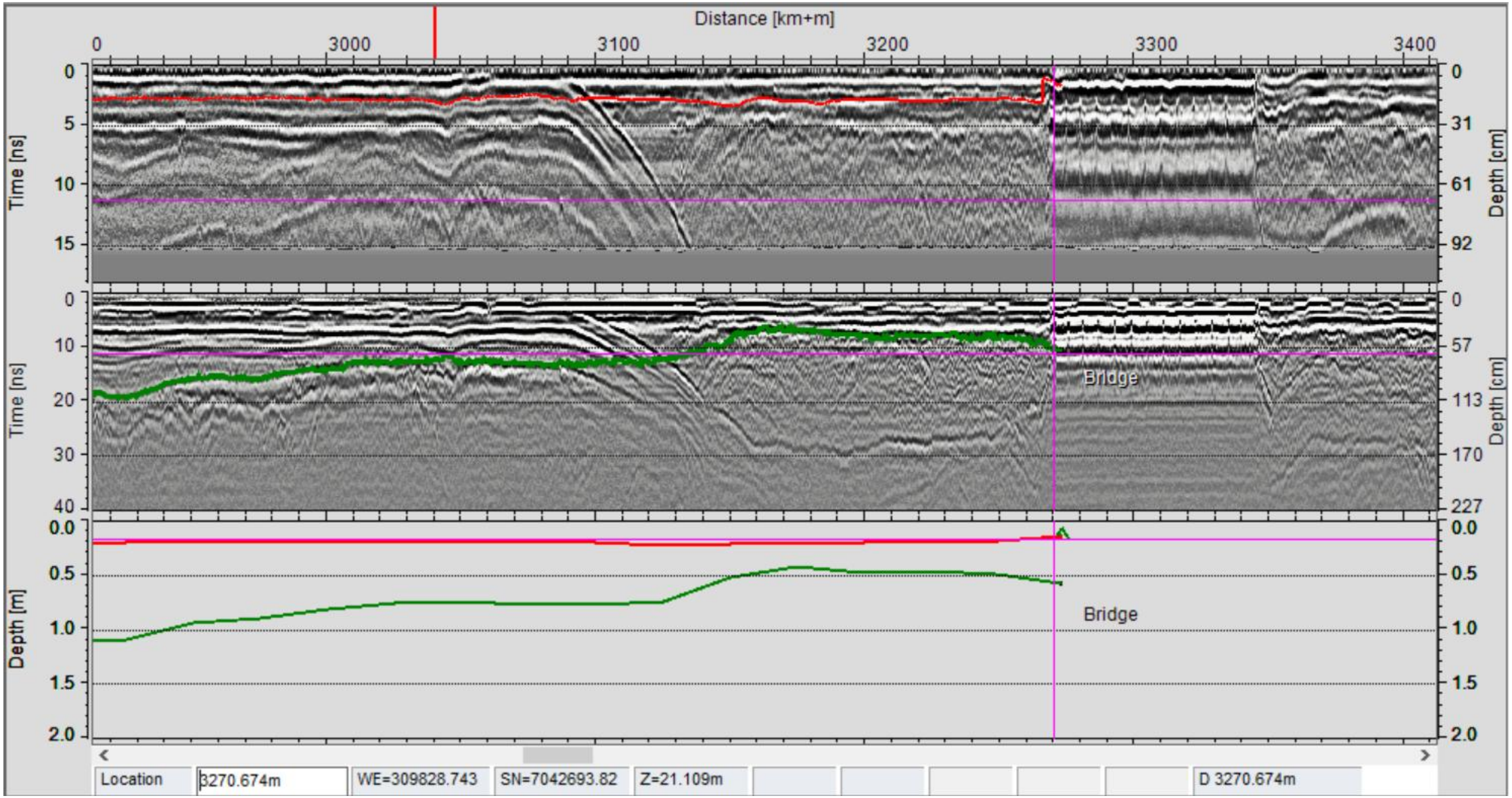


ELMOD

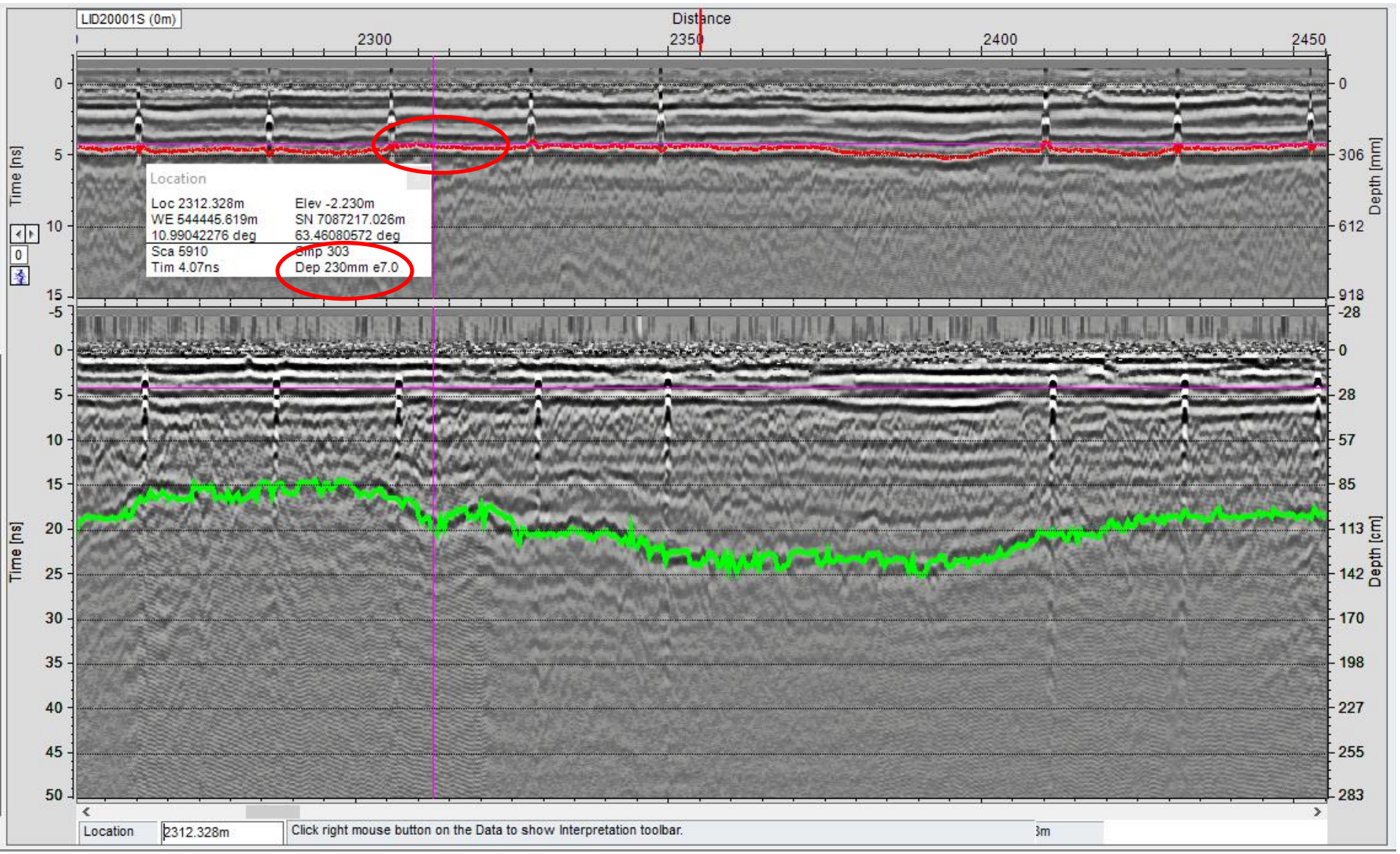
- ELMOD – **E**valuation of **L**ayer **M**oduli and **O**verlay **D**esign
- ELMOD – determines the elastic moduli, stresses and strains and deflections for each modelled layers



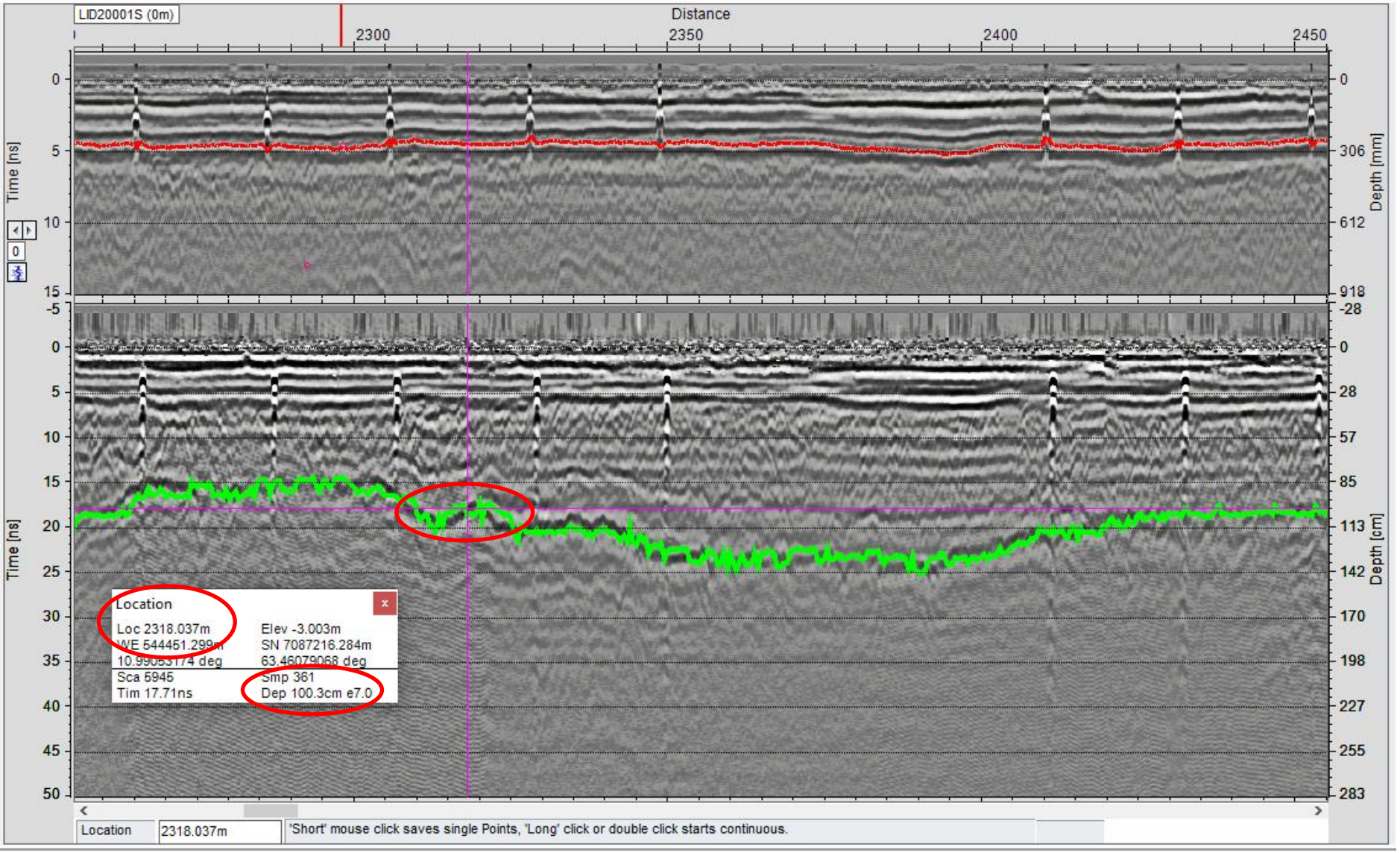
RESULTS – GPR image at E14



RESULTS – layer thickness – E14



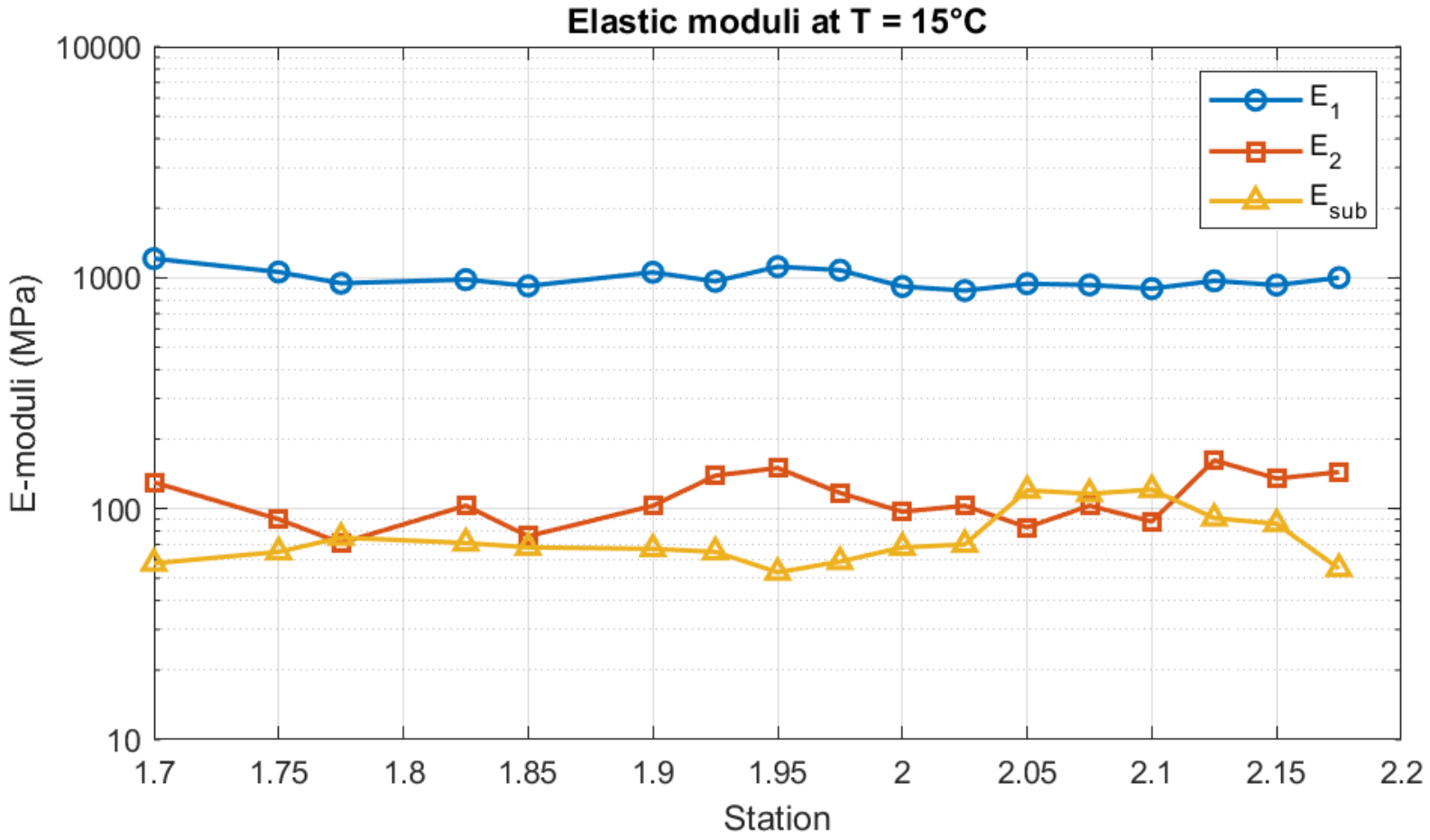
RESULTS – layer thickness



Back-calculation

- E14 S1D1

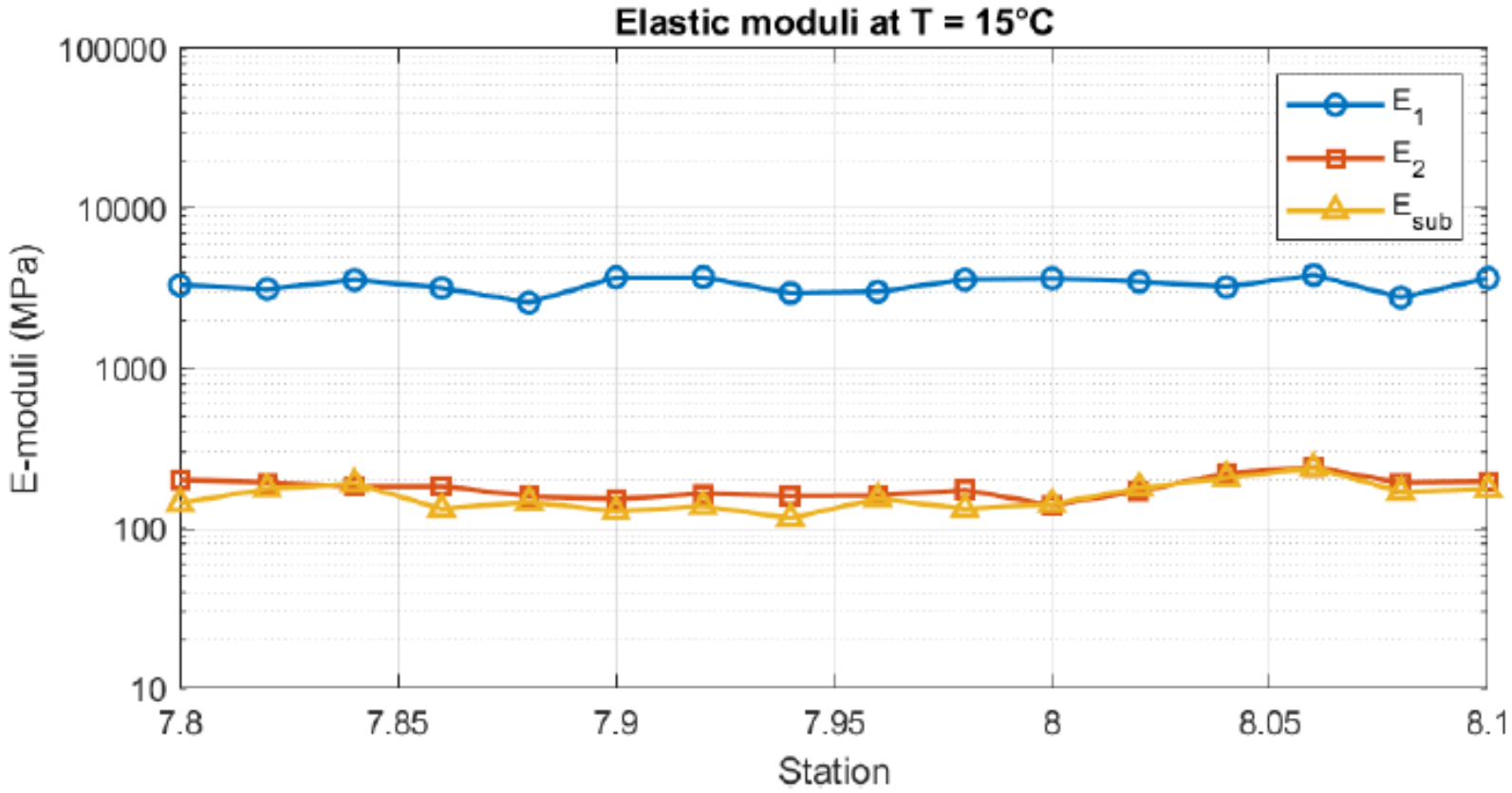
Measurement interval (km)	Layer	Material type	Avg. layer Thickness (mm)	Avg. E-moduli at ref. temp (MPa)
1.7-2.175	Pavement	Asphalt	330	988
	Subbase	Crushed gravel	650	111
	Subgrade	sand	-	77



Back-calculation

- E16 S62D1

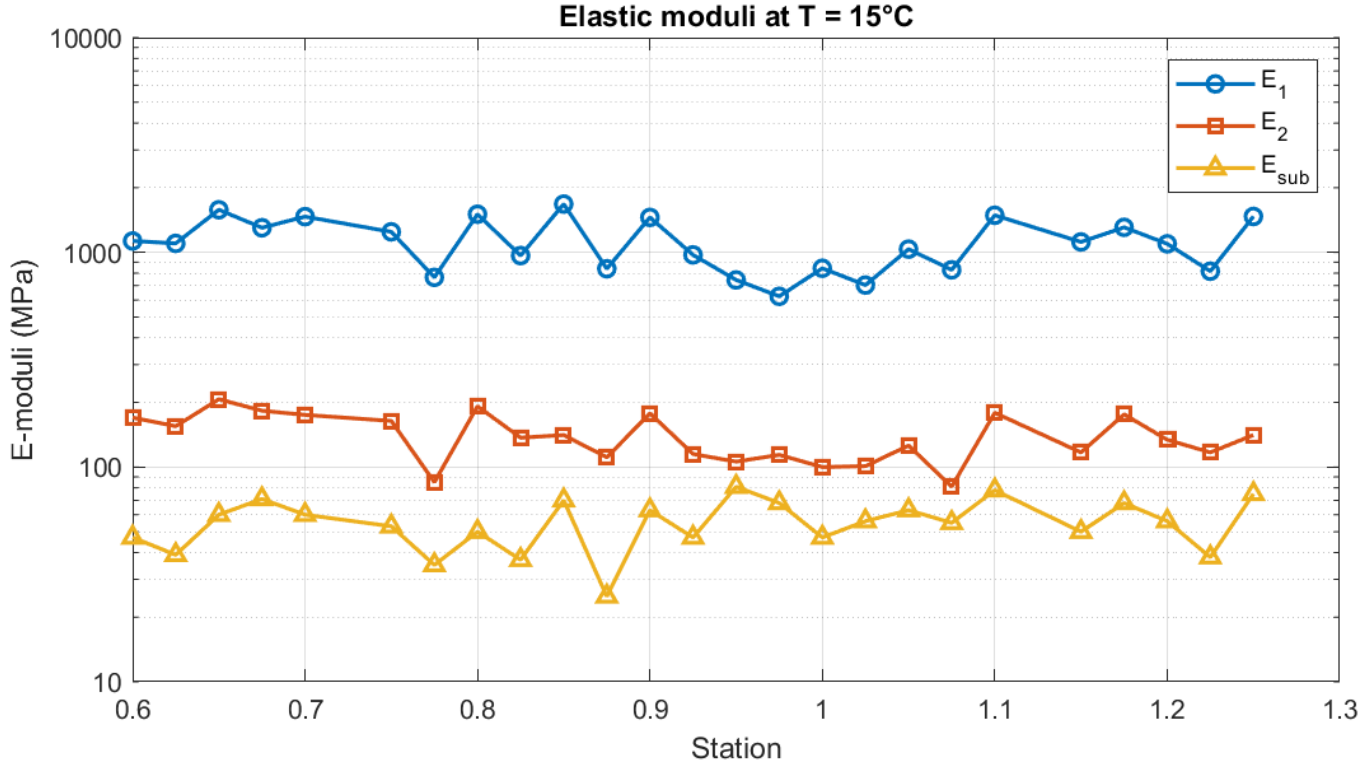
Measurement interval (km)	Layer	Material type	Avg. layer Thickness (mm)	Avg. E-moduli at ref. temp (MPa)
7.8-8.1	Pavement	Asphalt	215	3344
	Subbase	Crushed blasted rock	923	181
	Subgrade	Foam glass gravel 10/50	-	161



Back-calculation

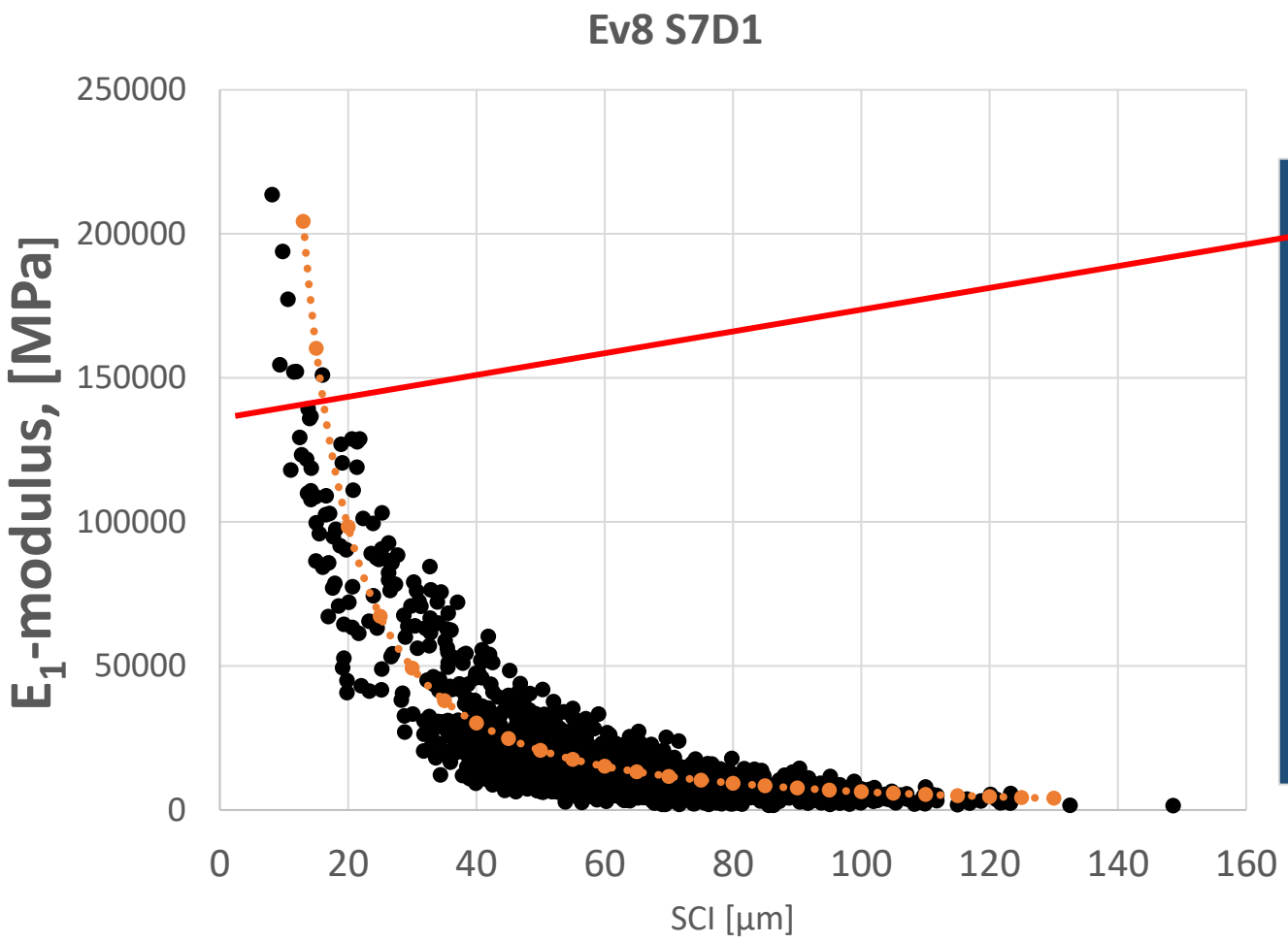
- Ev6S193D1

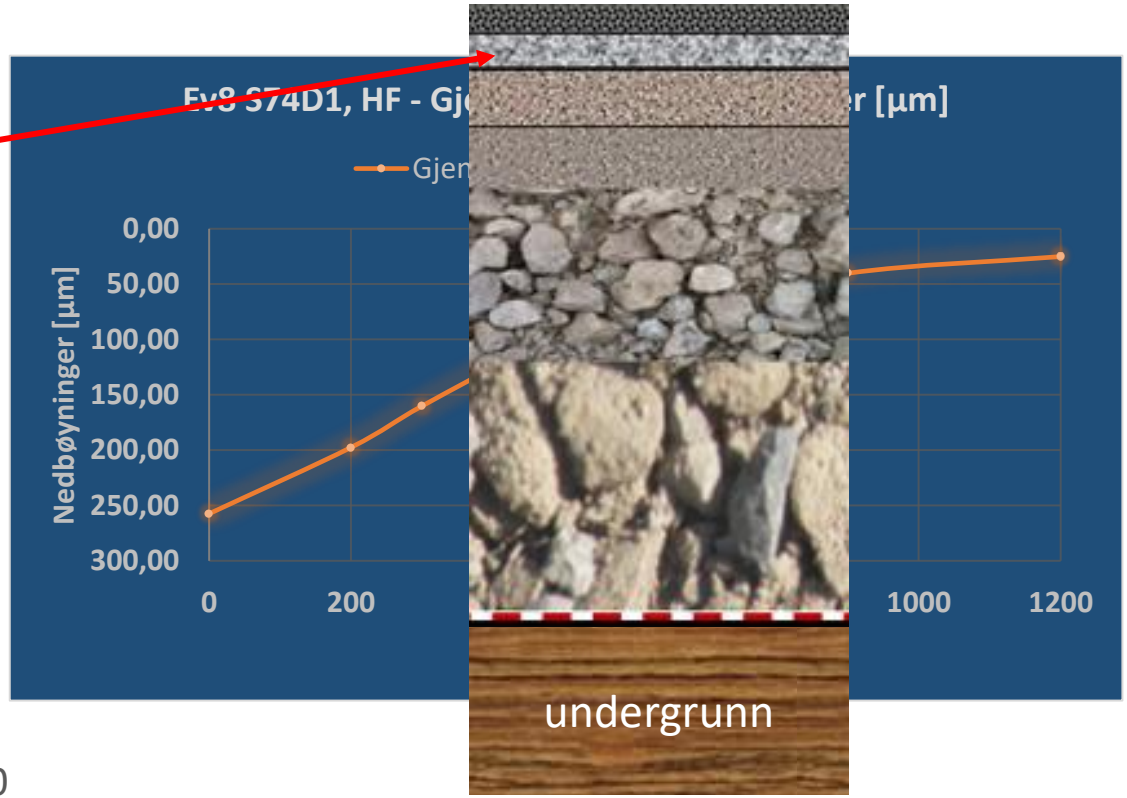
Measurement interval (km)	Layer	Material type	Avg. layer Thickness (mm)	Avg. E-moduli at ref. temp (MPa)
0.6-0.95	Pavement	Asphalt	142	1197
	Subbase	Gravel	496	151
	Subgrade	clay	-	53
0.975-1.25	Pavement	Asphalt	147	1030
	Subbase	Gravel	646	126
	Subgrade	silt	-	59



E_1 Vs. SCI

$$SCI = d_0 - d_{20}$$

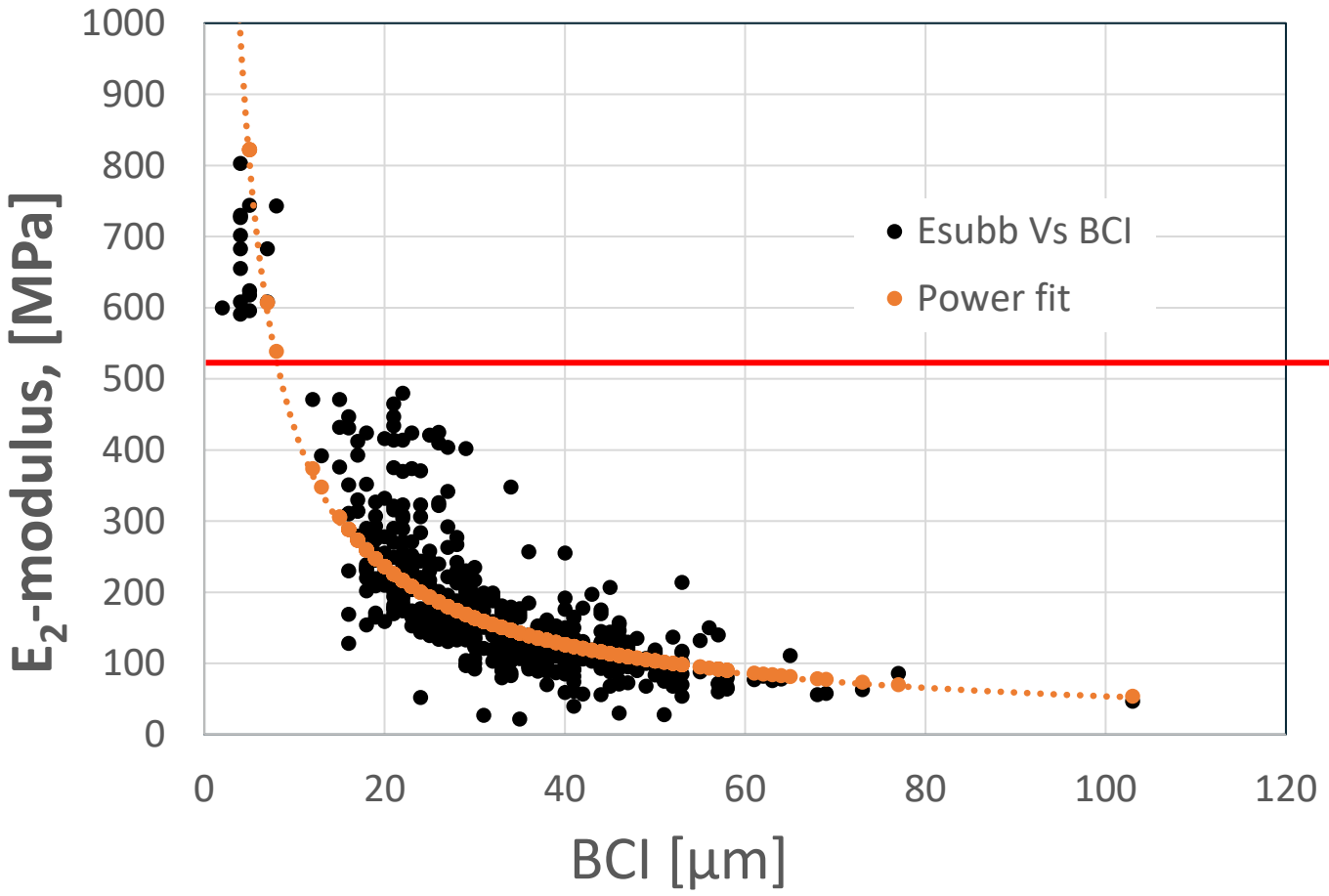




E_2 Vs. BCI

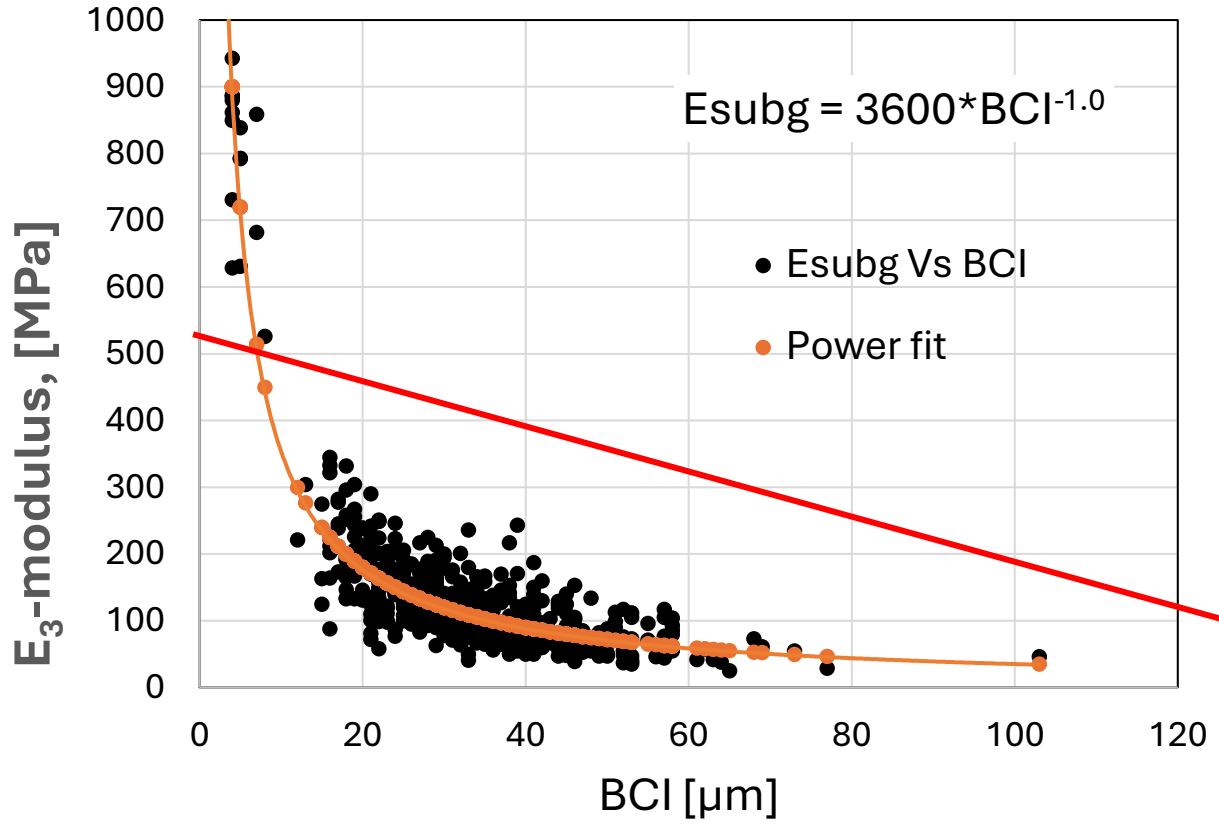
$$E_{asfalt} = 3500 * BCI^{-0.9}$$

$$\mathrm{BCI} = \mathrm{d}_{90} - \mathrm{d}_{120}$$



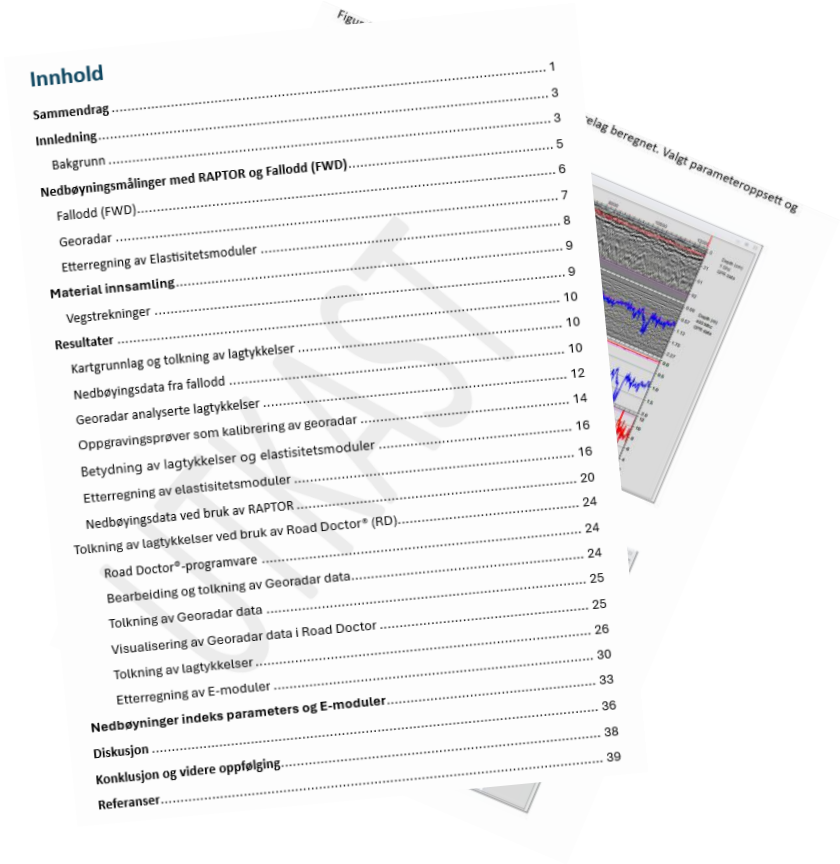
E_3 Vs. BCI

$$BCI = d_{90} - d_{120}$$



Further works

- The R&D project has developed a method for interpretation and back-calculation based on Falling Weight Deflectometer (FWD), RAPTOR, and ground-penetrating radar (GPR).
- The method will be implemented in connection with strengthening works.
- Two students from Oslo Metropolitan University have started their master's theses this month. They will work extensively with RAPTOR and GPR measurements on the national road network.



Thank you for your attention