



Statens vegvesen

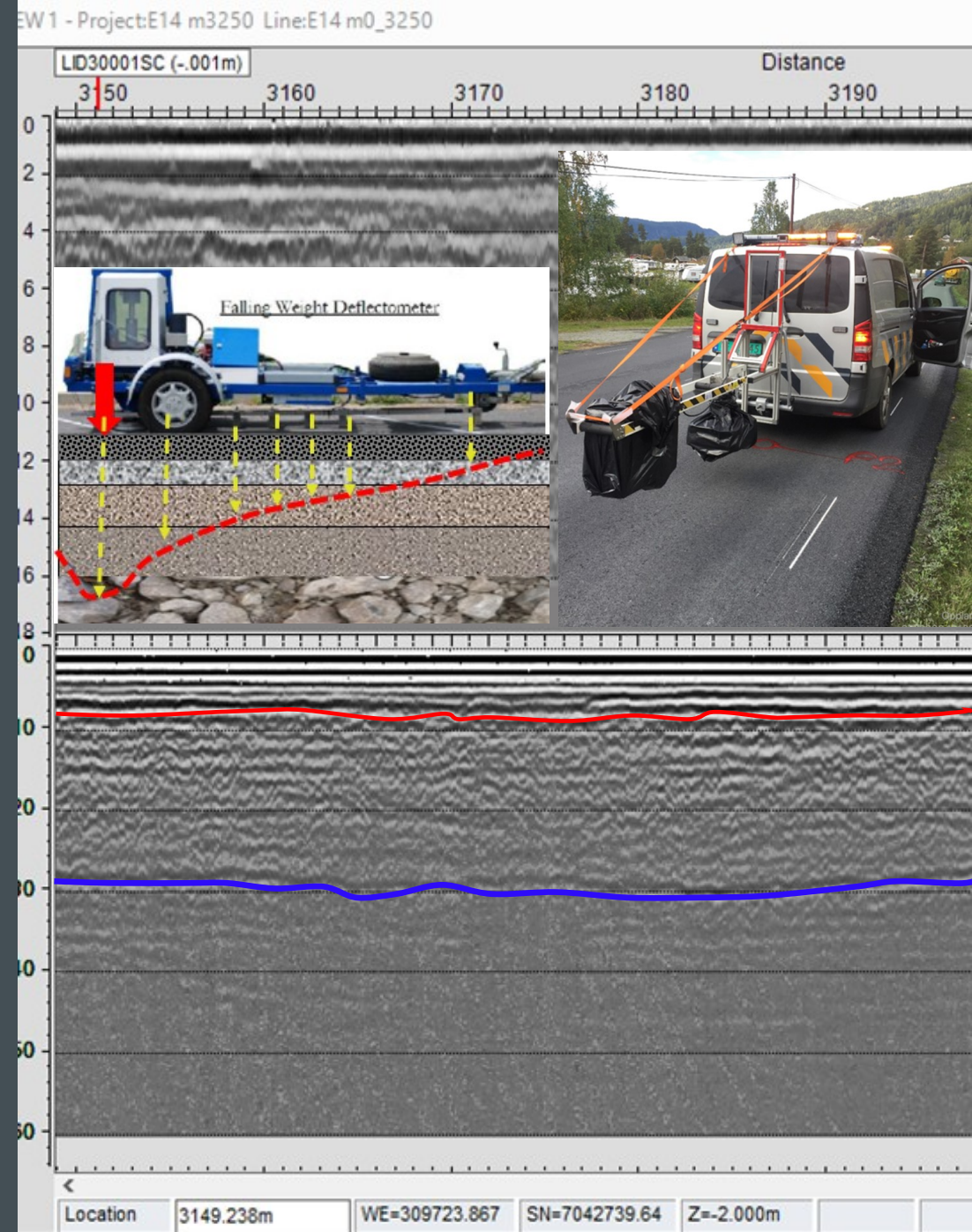
Etterregning av E-moduler for veimaterialer

- fra fallodds- og georadardata

Tatek F. Yideti

Seksjon for Vegteknologi

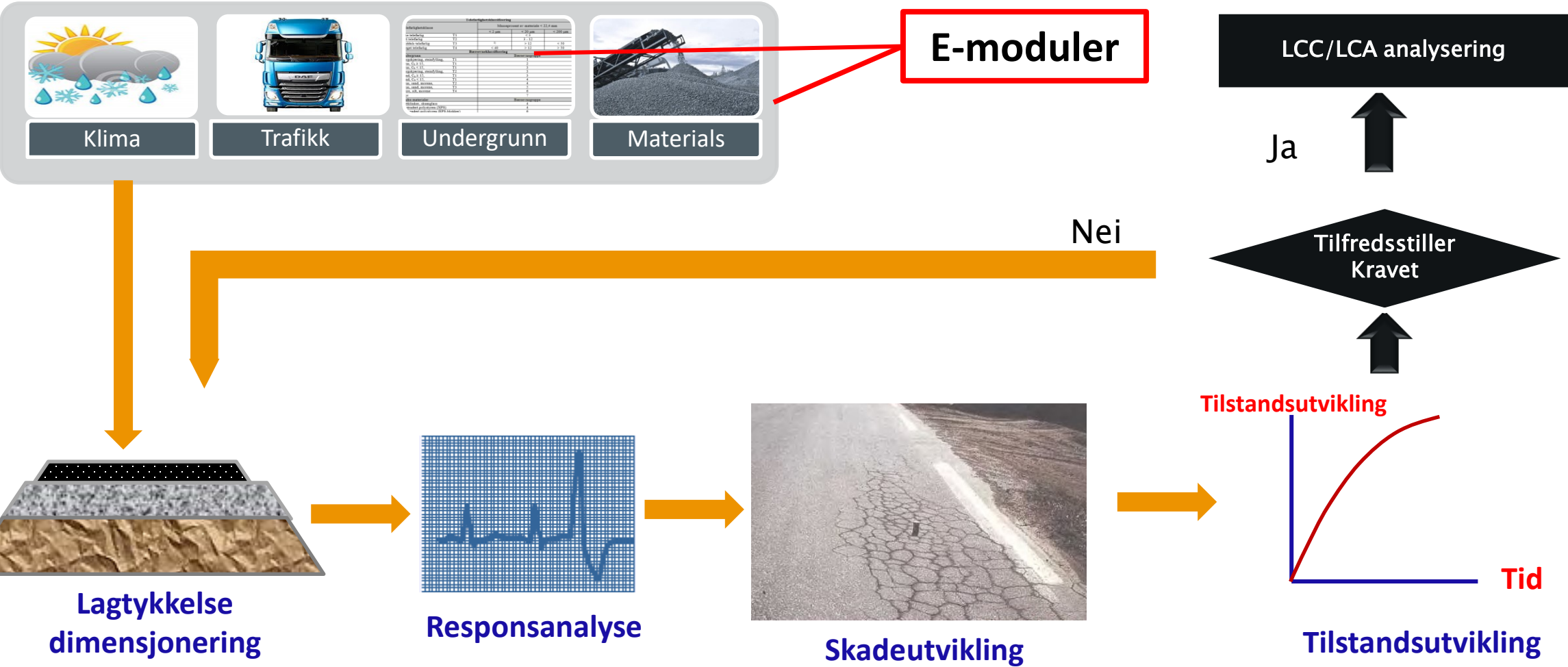
Myndighet og regelverk/Vegdirektoratet



Inneholder

- Hva, hvorfor og hvordan elastisitetsmodul (E-modul)?
- Nedbøyningsmålinger med fallodd
- Inngangsparameter – lagtykkelser
 - georadarmålinger
 - oppgravingsprøver
- RoadDoctor og ELMOD
- Resultater

E-moduler i ME- dimensjoneringsssystem



E-modul - VegDim/ERAPave PP

ERAPave PP/VegDim

File Edit Inputs Help Windows

PROJECT DESCRIPTION

Section name: Material properties

Road number: E6

Chainage: 12

☒ New Pavement ☐ Rehabilitation

DESIGN AND ANALYSIS PARAMETERS

- ☒ MATERIAL, TRAFFIC, AND CLIMATE
 - Pavement structure
 - Traffic
 - Climate
- ☒ FROST ACTION CONTROL
 - Frost heave prediction
- ☒ BEARING CAPACITY CONTROL
 - Extreme loading
- ☒ LONG TERM PERFORMANCE
 - Rutting
 - Fatigue cracking
 - Studded tyre wear

ANALYSIS AND RESULTS

Run Cancel

Results in Excel Generate Report

Structure

Pavement structure View or edit material properties

Bound layer Unbound layers and subgrade

Material properties for unbound layers

$$\log \frac{M_R}{M_{Ropt}} = a + \frac{b-a}{1 + \exp\left(\ln \frac{-b}{a} + k_m(S - S_{opt})\right)}$$

M_R = Resilient modulus (MPa)
 M_{Ropt} = Resilient modulus (MPa) at optimum degree of saturation
 S = Seasonal degree of saturation level (%)
 S_{opt} = Degree of saturation at optimum water content (%)
 a, b, k_m = Model parameters

Number of stress sensitive unbound layer: 0

☐ View more parameters ☒ Resilient modulus parameters ☐ Permanent deformation parameters ☐ Thermal and frost parameters

Layer	Mr (MPa)	Sopt (%)	a (-)	b (-)	km (-)	Poisson's ratio

undergrunn

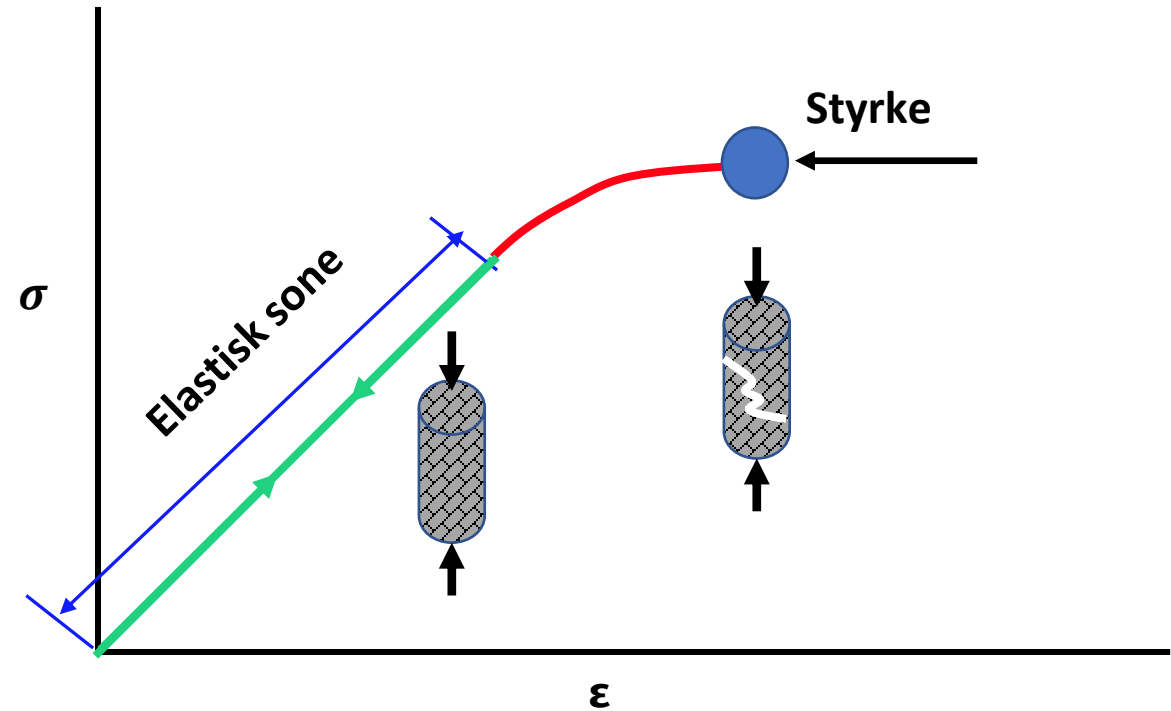
E-moduler

E-modul

- **Elastisitet** er et mål på hvor godt et materiale vender tilbake til sin opprinnelige form og størrelse.

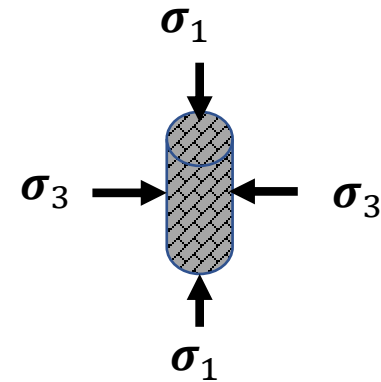
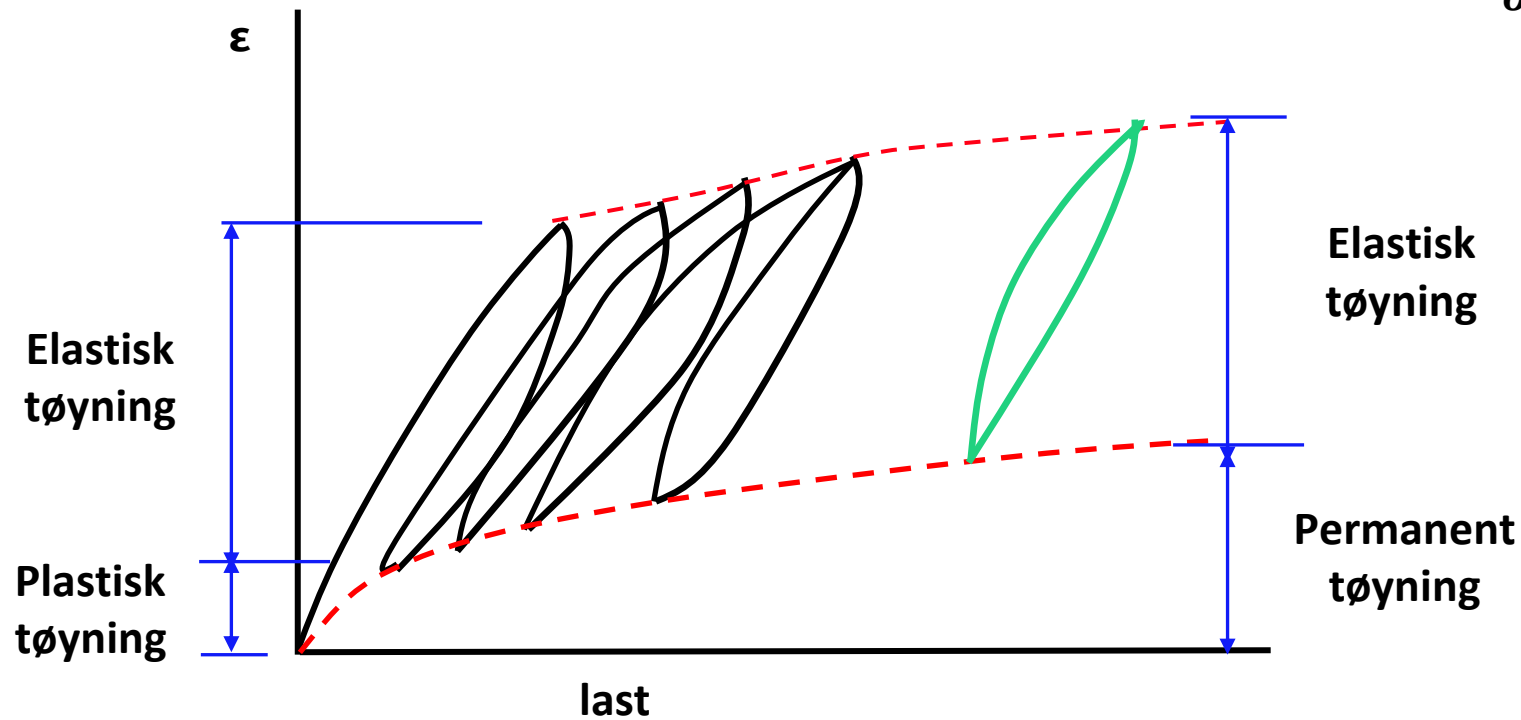
$$E = \frac{\text{spenning } (\sigma)}{\text{Tøyning } (\epsilon)}$$

- **Styrke** er den spenningen som trengs for å bryte eller rive et materiale.



E-modul for elastoplastiske materialer?

Syklisk treaksialtesting



$$Mr = \frac{\sigma_d}{(\epsilon_r)}$$

$$\sigma_d = \sigma_1 - \sigma_3$$

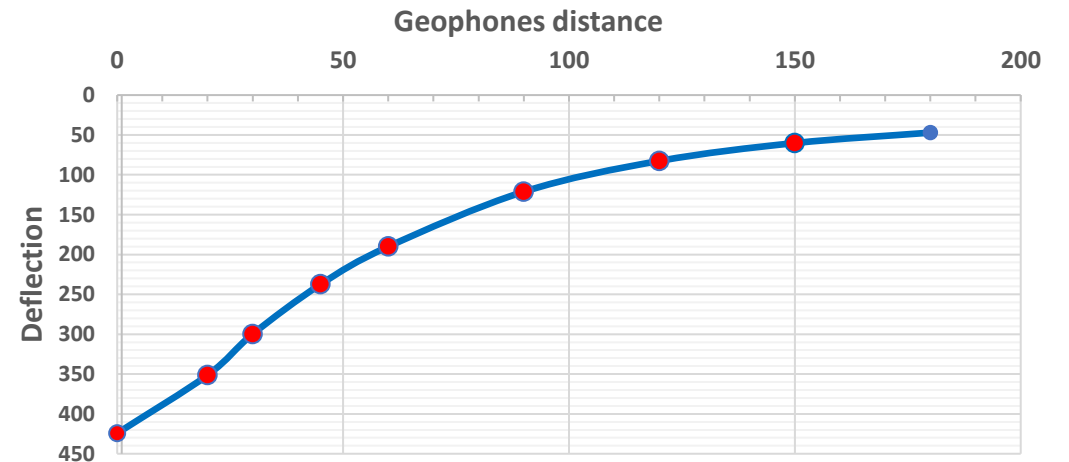
Etterregning E-modul

► Inngangsparameter

- Nedbøyningsmålinger med fallodd
- Last 50 kN
- **Lagtykkelser fra oppgravingsprøver eller fra georadarmålinger**
- Startmoduler

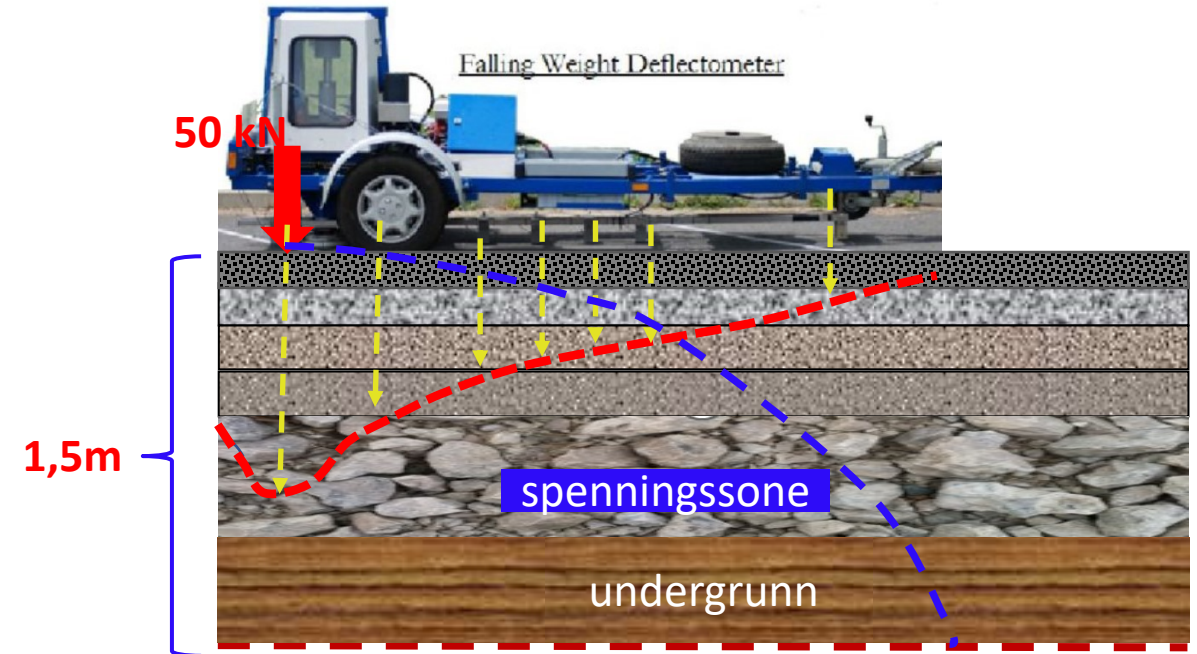
► Utdata

- E-moduler for hvert lag
- Beregnet defleksjon



Nedbøyningsmålinger med fallodd

- Forutsetninger med etterregningen
 - Nederste lagskille bør ikke være mer enn 1,5 m fra dekkeoverflaten.
 - Antall lag i beregningen bør ikke overstige 5 lag inkl. undergrunnen
 - Geofonene som registrerer nedbøyninger, har en nøyaktighet i størrelsesorden $\pm 2 \mu\text{m}$.
 - Måleverdiene for geofonen lengst fra belastningsplaten bør minst være 20 μm . Dvs. at 10 % feil på geofonsregistrering.

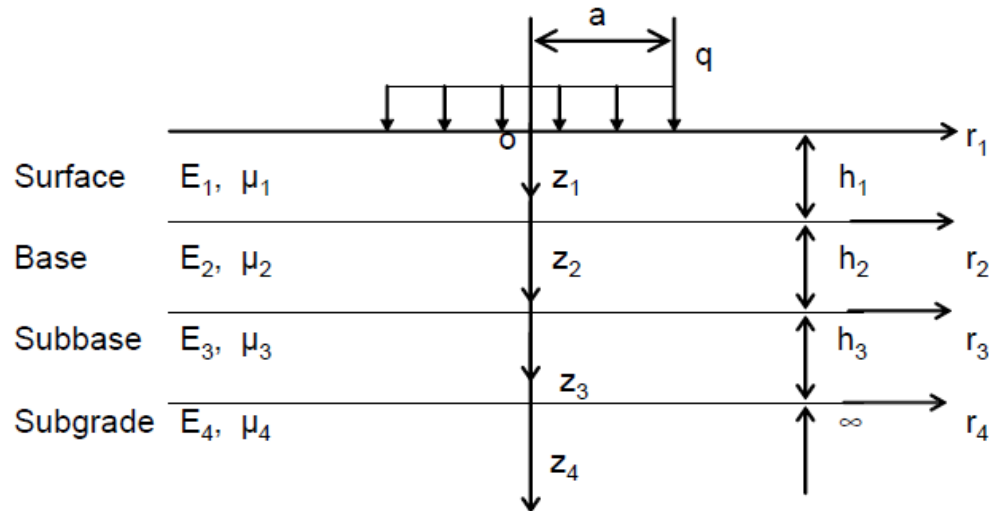


	Pos.(1), cm	Pos.(2), cm	Pos.(3), cm	Pos.(4), cm	Pos.(5), cm	Pos.(6), cm	Pos.(7), cm	Pos.(8), cm	Pos.(9), cm
	0,0	20,0	30,0	45,0	60,0	90,0	120,0	150,0	180,0
Load [kN]	Def.(1), μm	Def.(2), μm	Def.(3), μm	Def.(4), μm	Def.(5), μm	Def.(6), μm	Def.(7), μm	Def.(8), μm	Def.(9), μm
50,0	424,3	351,3	299,8	237,5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

Teori av etterregning

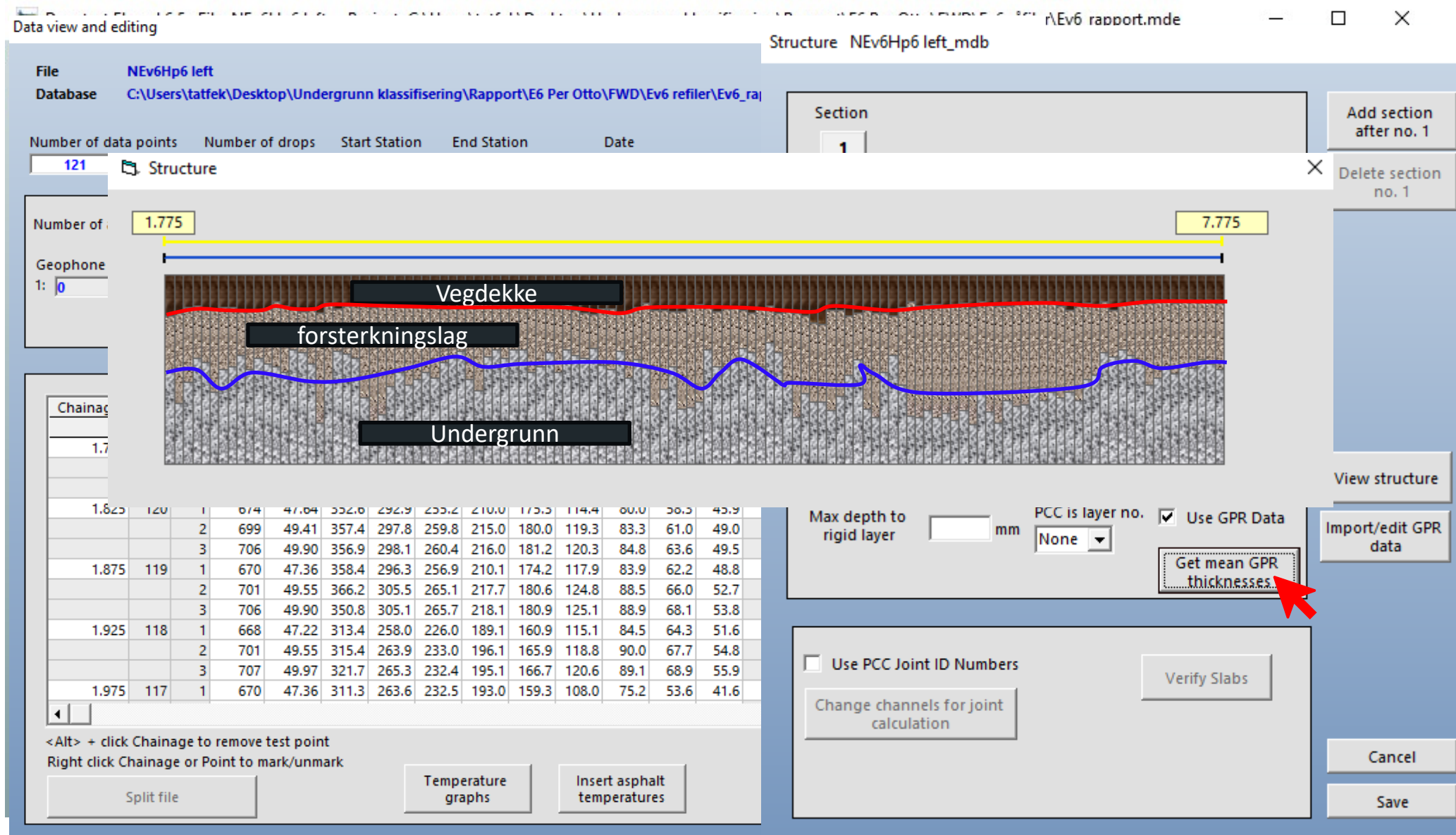
Burmister (1958)

- Two-layers system
- Multi-layer linear elastic system

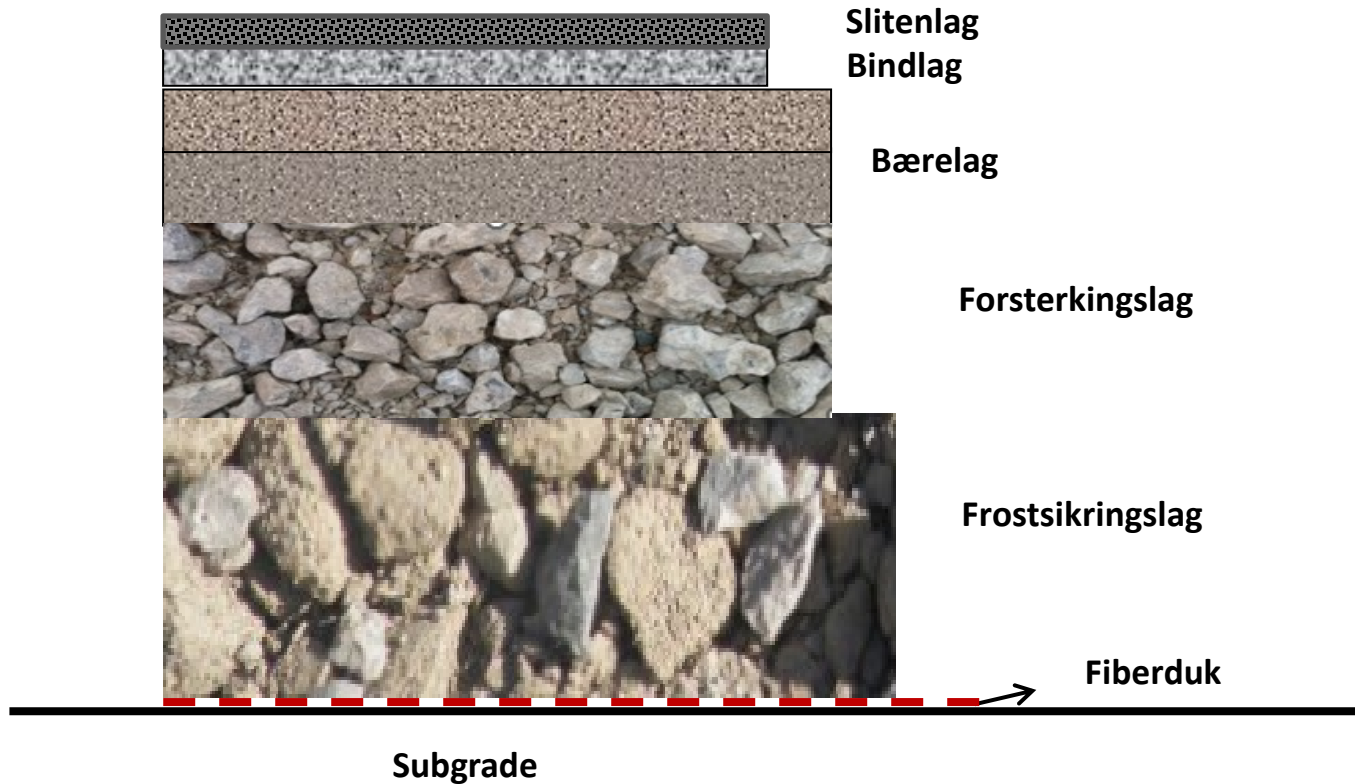


$$u_i = \frac{1 + \mu_i}{E_i} \int_0^\infty \left(\begin{aligned} &A_i(m) m e^{mz} + B_i(m) m e^{-mz} \\ &+ C_i(m) (1 + mz) e^{mz} \\ &- D_i(m) (1 - mz) e^{-mz} \end{aligned} \right) J_1(mr) m dm$$

$$w_i = \frac{1 + \mu_i}{E_i} \int_0^\infty \left(\begin{aligned} &-A_i(m) m e^{mz} + B_i(m) m e^{-mz} \\ &+ C_i(m) (2 - 4\mu_i - mz) e^{mz} \\ &+ D_i(m) (2 - 4\mu_i + mz) e^{-mz} \end{aligned} \right) J_0(mr) m dm$$



Overbygningstykkelse



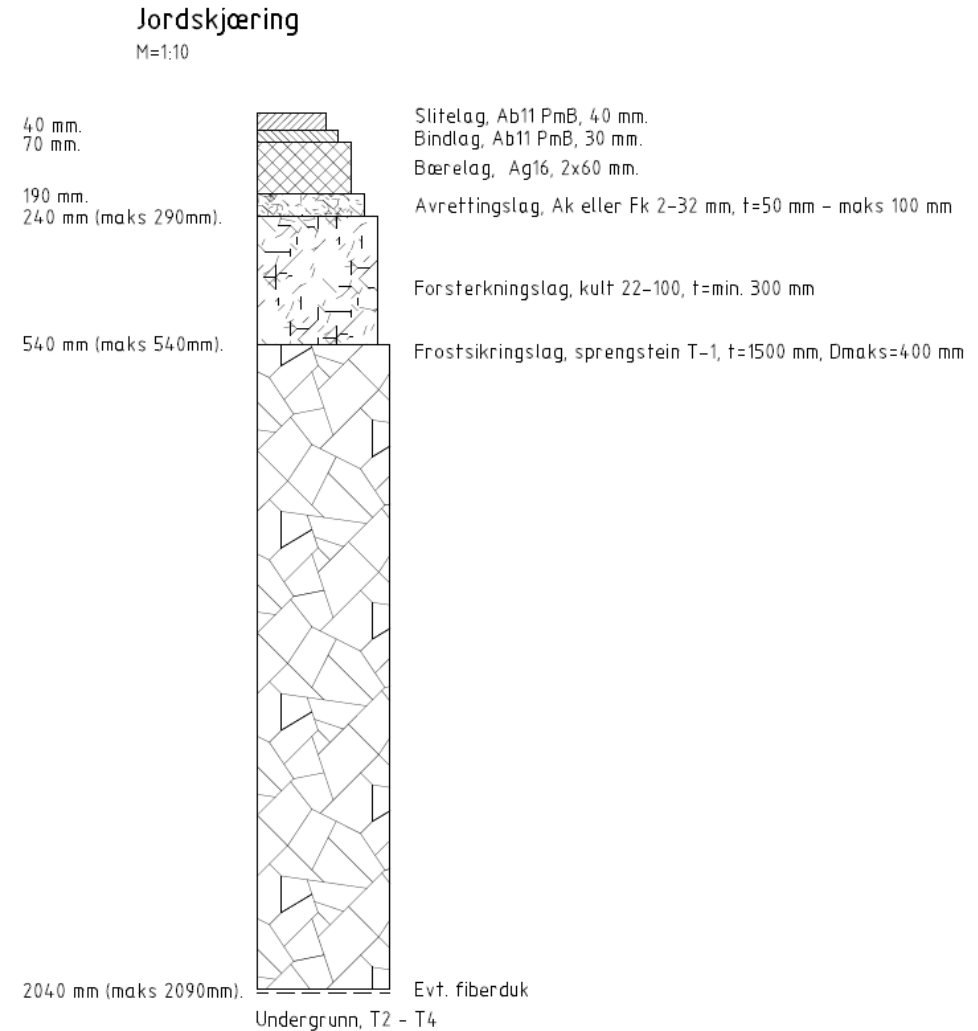
- Overbygningstykkelse varierer med
 - Trafikkmengde – ÅDT
 - Materialkvalitet
 - Undergrunns type – telefarlighetsgrad
 - Osv...

Lagtykkelse bestemmelse

Etterregningene krever relativt nøyaktige data for lagtykkelsene i overbygningen.

► Teknisktegninger (F-tegning)

► Måling under bygging

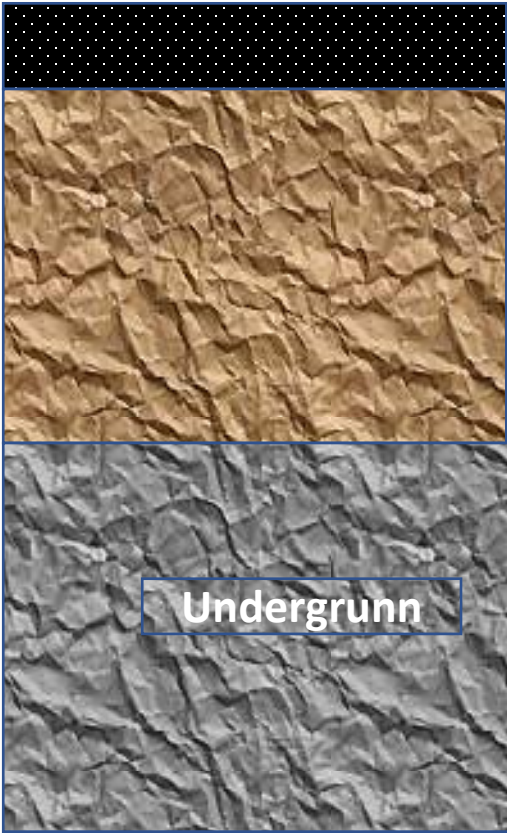
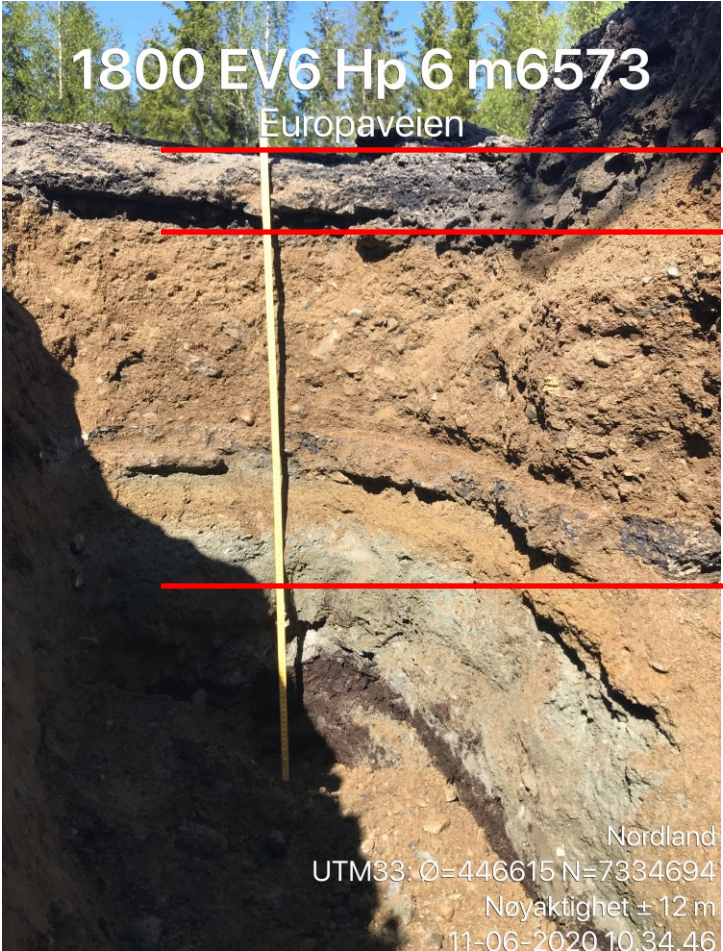


Lagtykkelse bestemmelse

► Oppgraving/kjerneboring

Fylke	Vegtype	Vegnr	Hp	Meter	H/V
18	EV	6	6	6570	FI

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

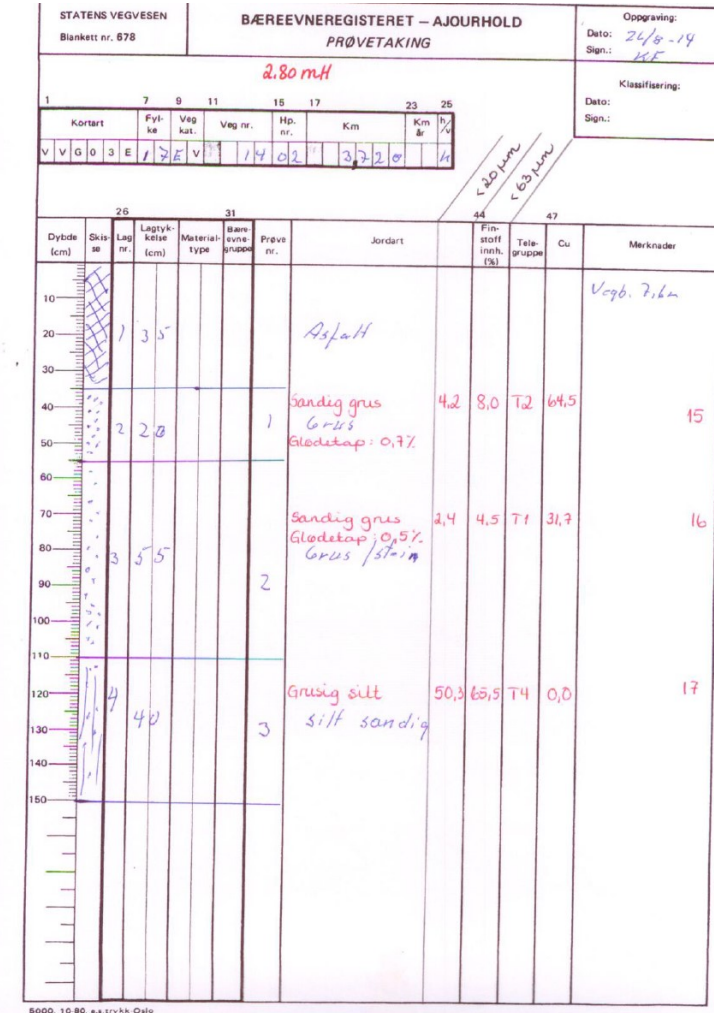


210 mm
asfalt

600 mm
grus, T2

Undergrunn

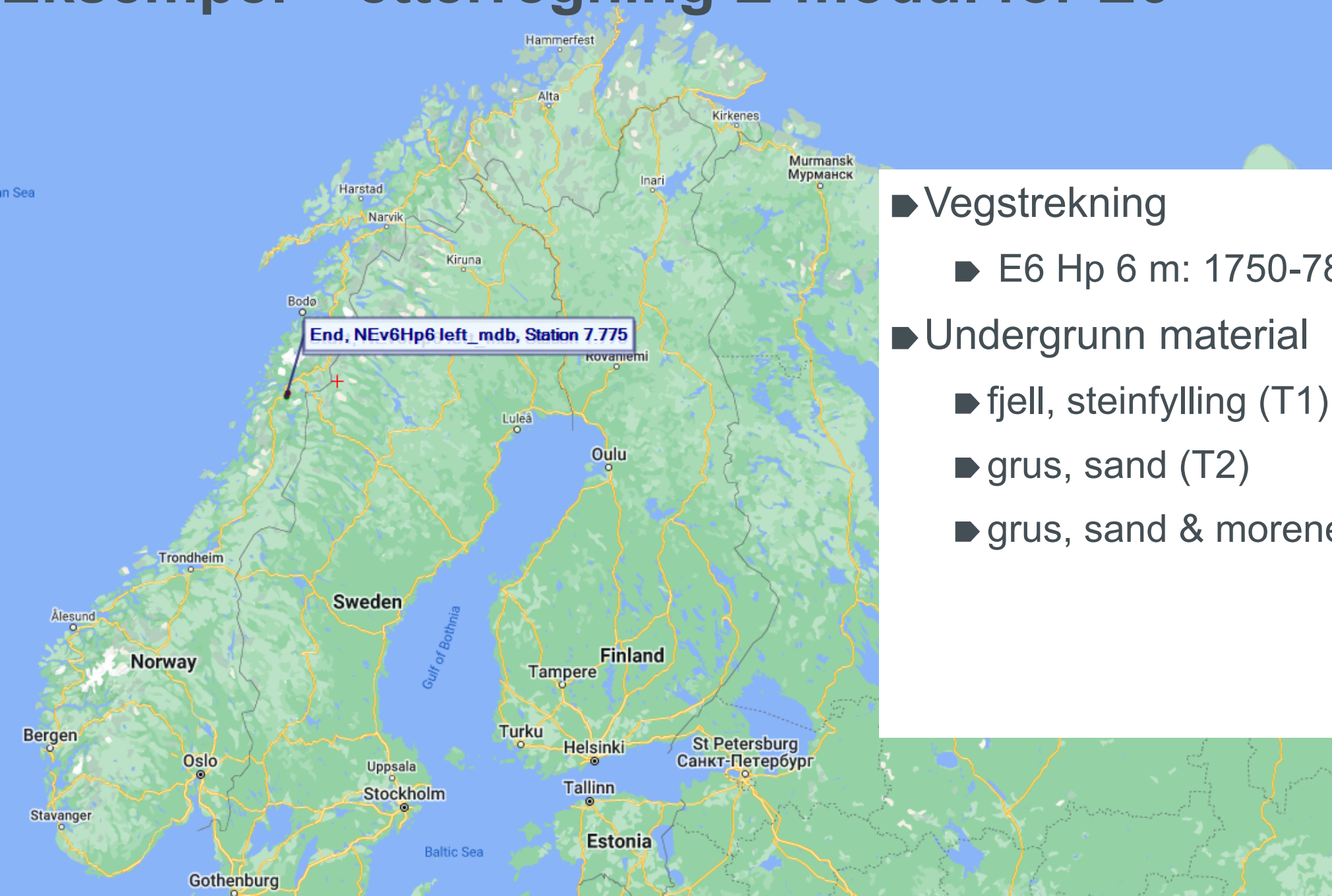
► Ev14 – Stjørdal - Leirfall



Eksempel – etterregning E-modul for E6



Statens vegvesen



► Vegstrekning

- E6 Hp 6 m: 1750-7800 (~ 7 km)

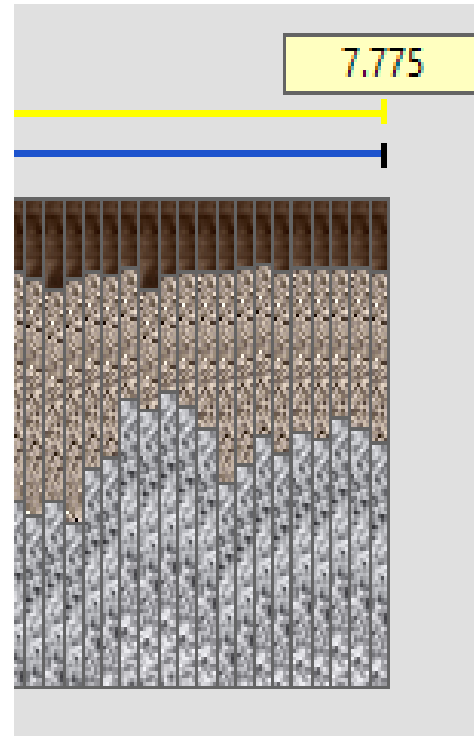
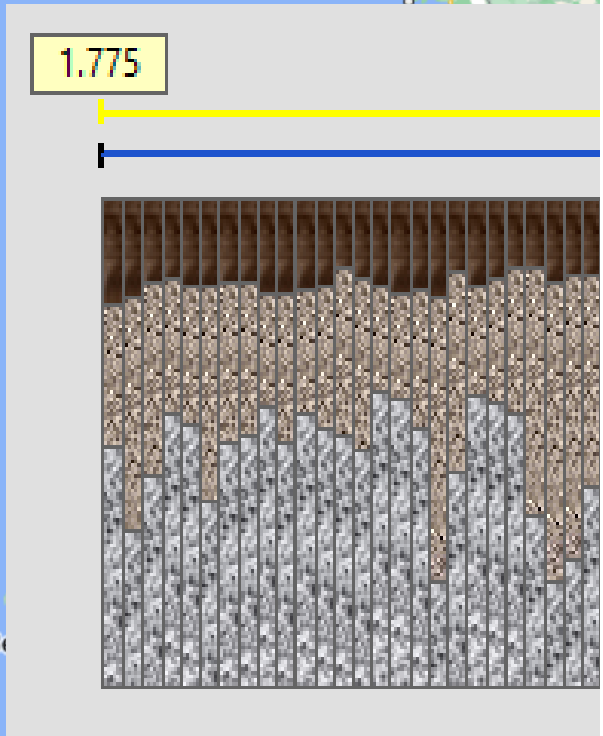
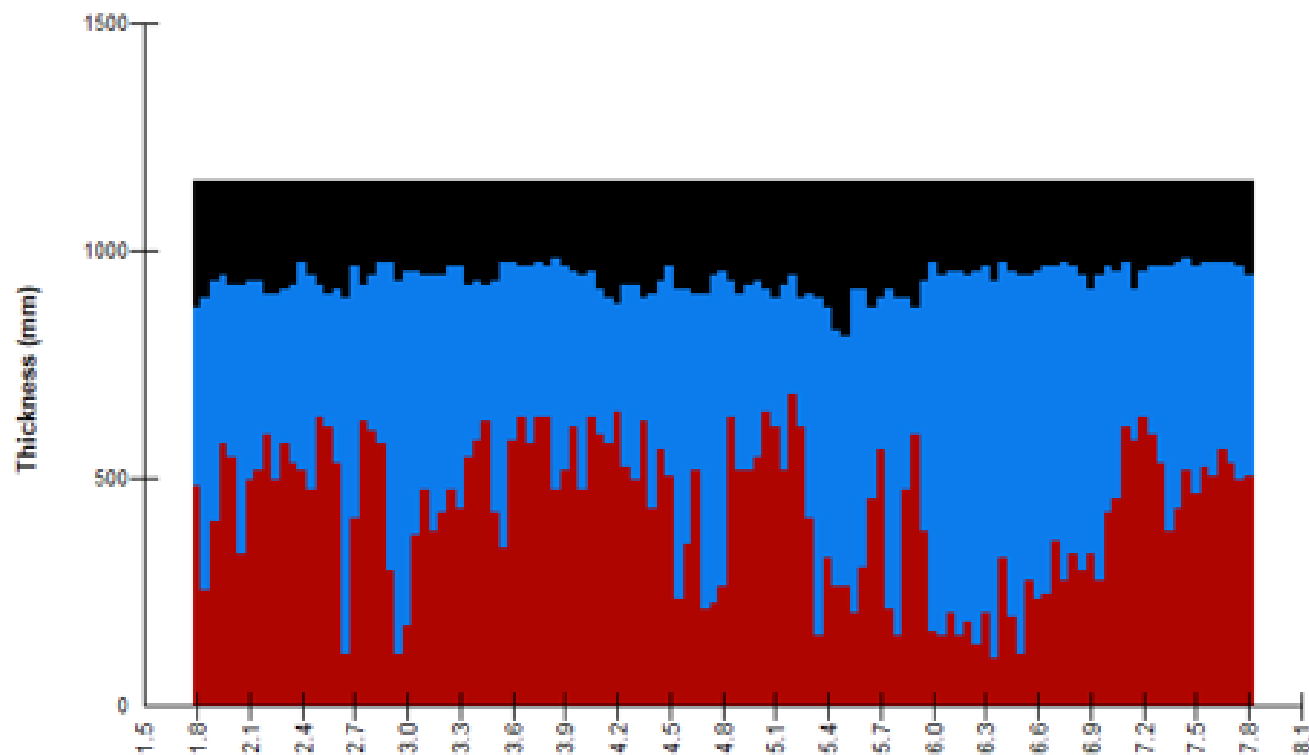
► Undergrunn material

- fjell, steinfylling (T1)
- grus, sand (T2)
- grus, sand & morene (T4)

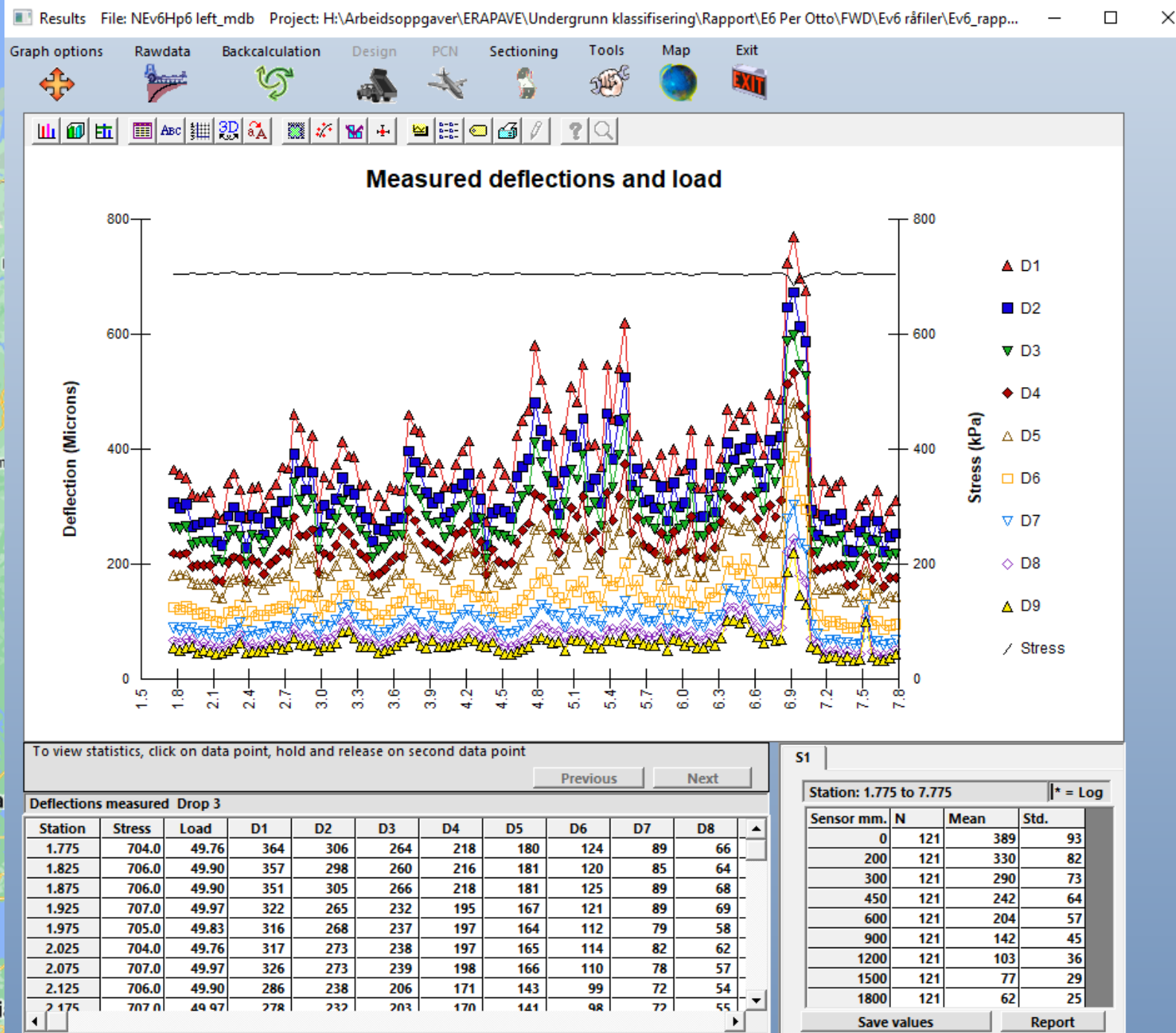
Eksempel – lagtykkelse fra georadar for E6



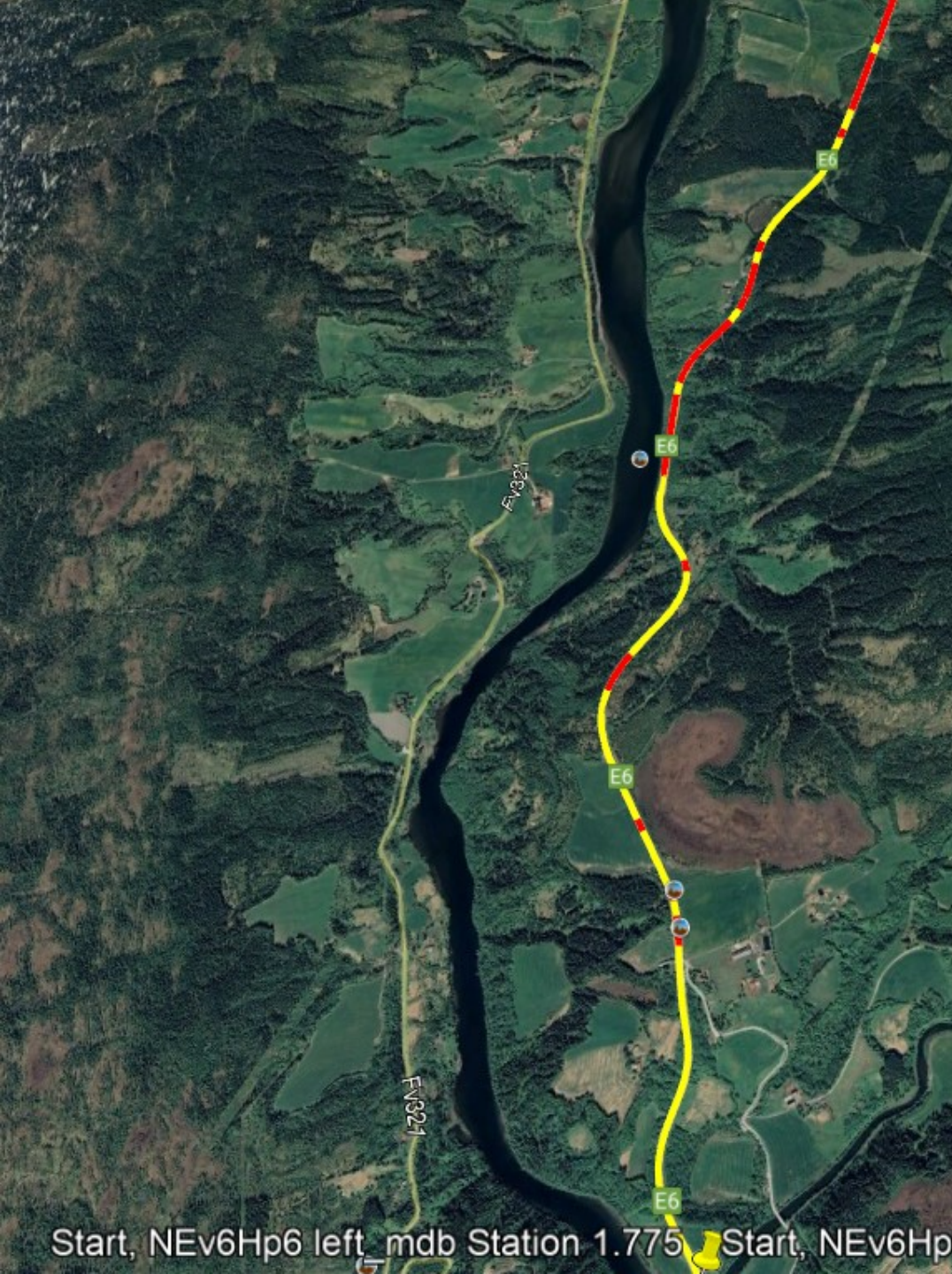
Layer Thicknesses



Nedbøyning - fallodd



E6 Hp 6 m: 1750-7800 fallodd – defleksjon



Open profile Default View Manual Hide

Sessions and Data Types Thresholds and Colors Calculation General Options

Deflections μ

Number of intervals 3

Thresholds

250

400

Colors

$x < 250$ Green

$250 \leq x < 400$ Yellow

$x \geq 400$ Red

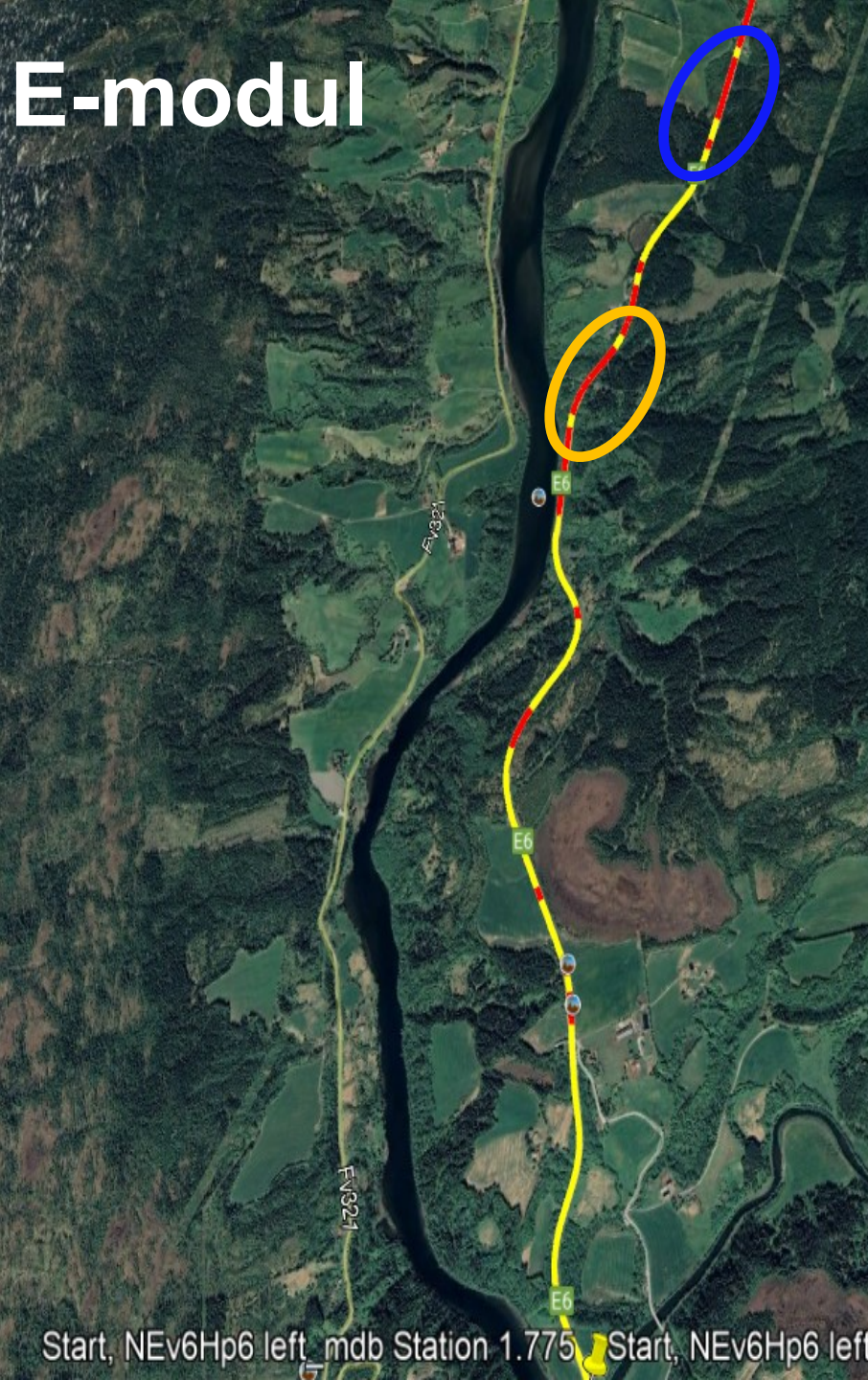
Click color box to change

Save profile Save as new profile... Refresh Map

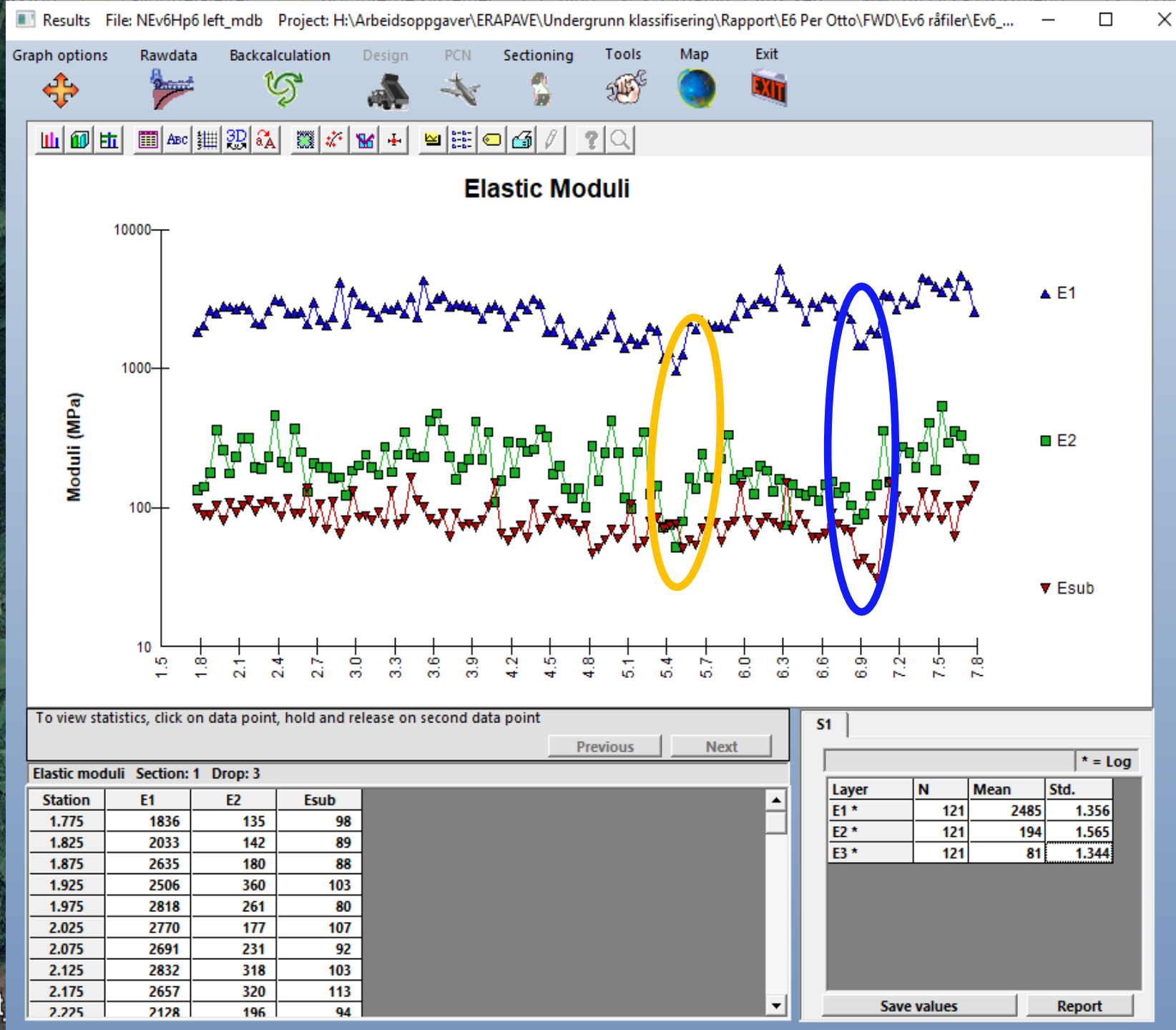
Delete Profile Export map... Fit Zoom

Start, NEv6Hp6 left_mdb Station 1.775 Start, NEv6Hp

E-modul

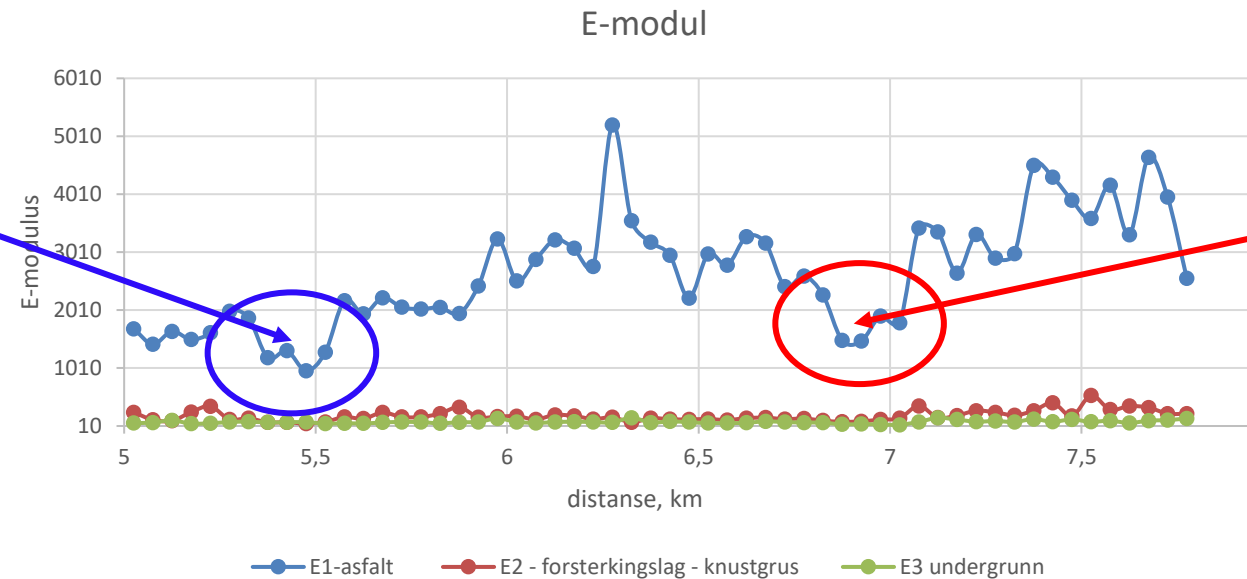


Start, NEv6Hp6 left_mdb Station 1.775 Start, NEv6Hp6 left



Etterregning av E-moduler

► E-modulverdien varier med undergrunnstype

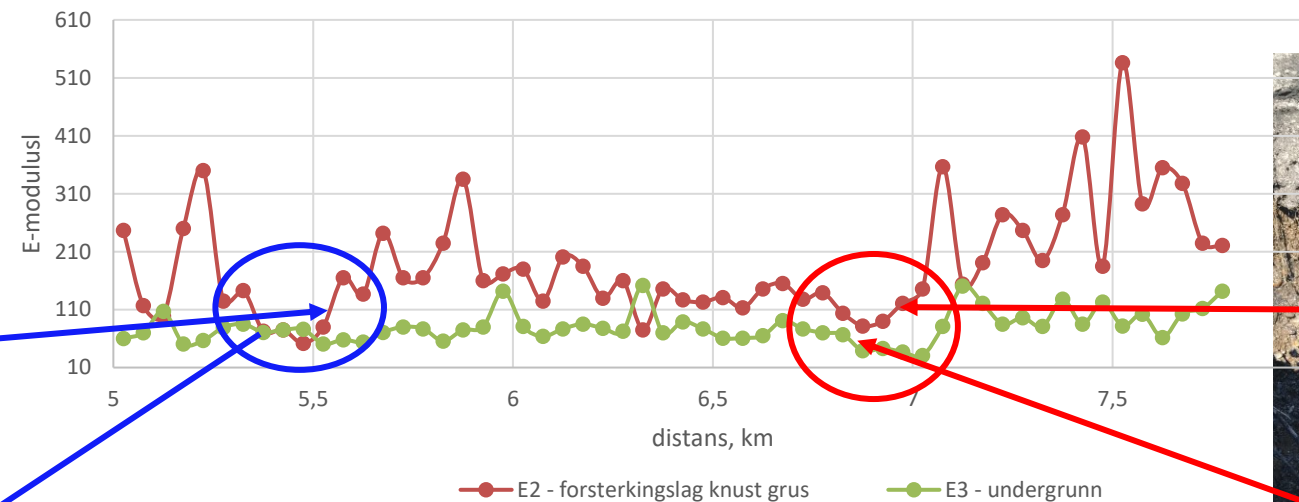


Distance, [km]	E1 [MPa] Vegdekke	E2 [MPa] forsterkingslag	E3 [MPa] undergrunn	Do, µm
5.475	965	52	76	542
5.525	1280	80	51	619
6.875	1489	82	39	725
6.925	1474	90	43	771
6.975	1906	121	37	698
7.025	1793	146	31	676

Etterregning av E-moduler

► E-modulverdien varier med undergrunnstype

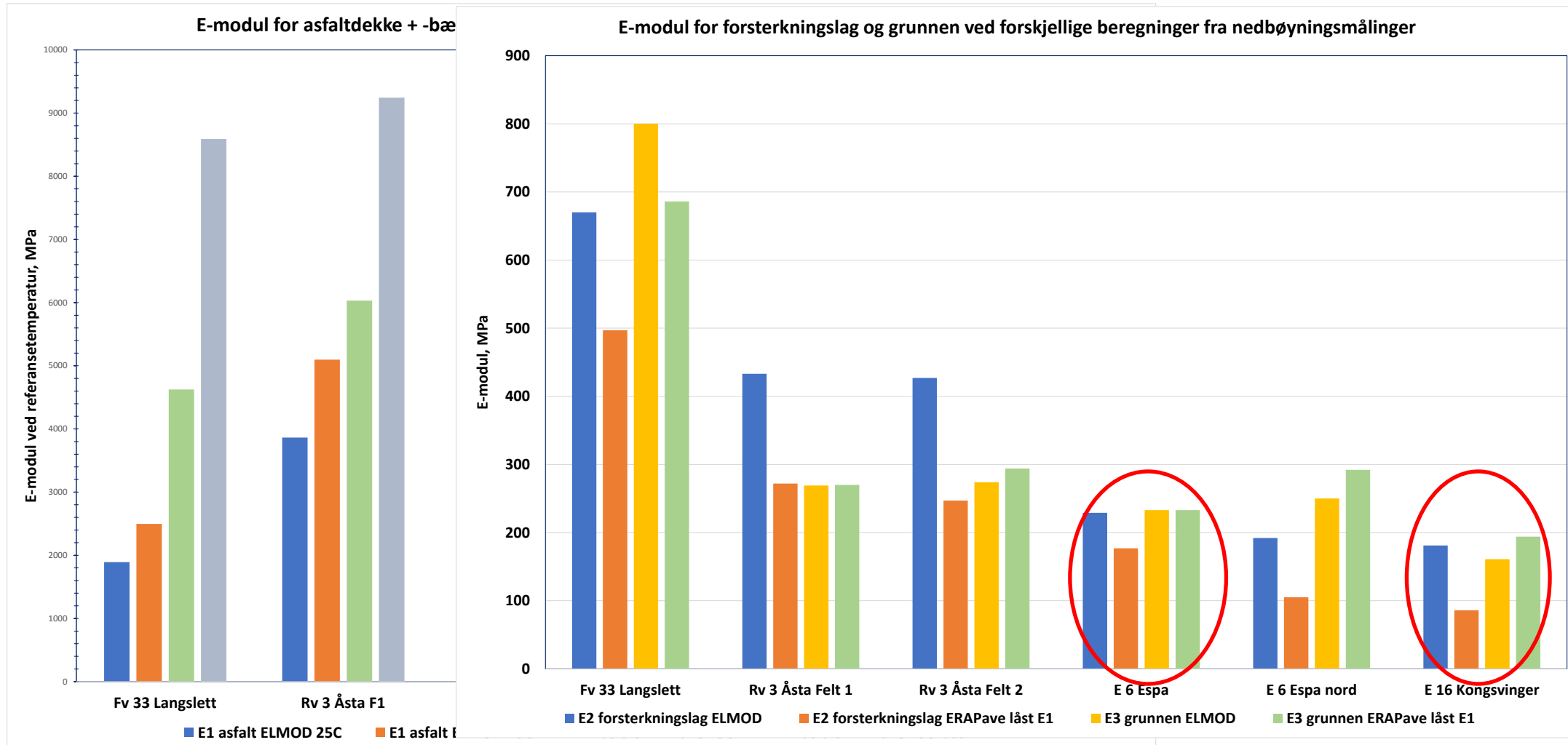
E-modul for forsterkningslag og undergrunnen



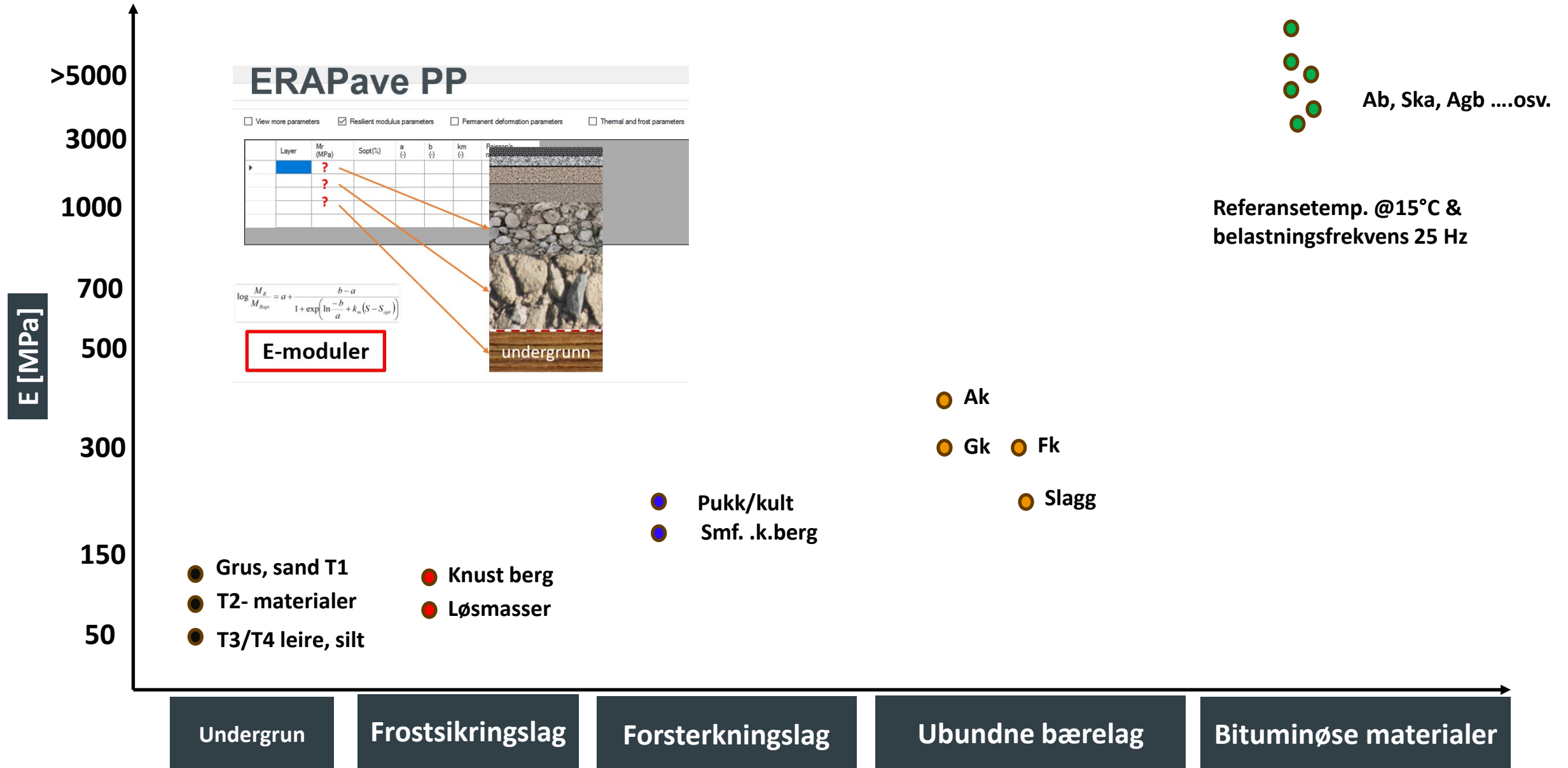
Distanse, [km]	E1 [MPa] Vegdekke	E2 [MPa] forsterkningslag	E3 [MPa] undergrunn	Do, µm
5.475	965	52	76	542
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6.875	1489	82	39	725
6.925	1474	90	43	771
6.975	1906	121	37	698
7.025	1793	146	31	676

Referansestreknings fra VegDim prosjektet

► Fem referansestreknings i Innlandet og fem referansestreknings i Nordland.

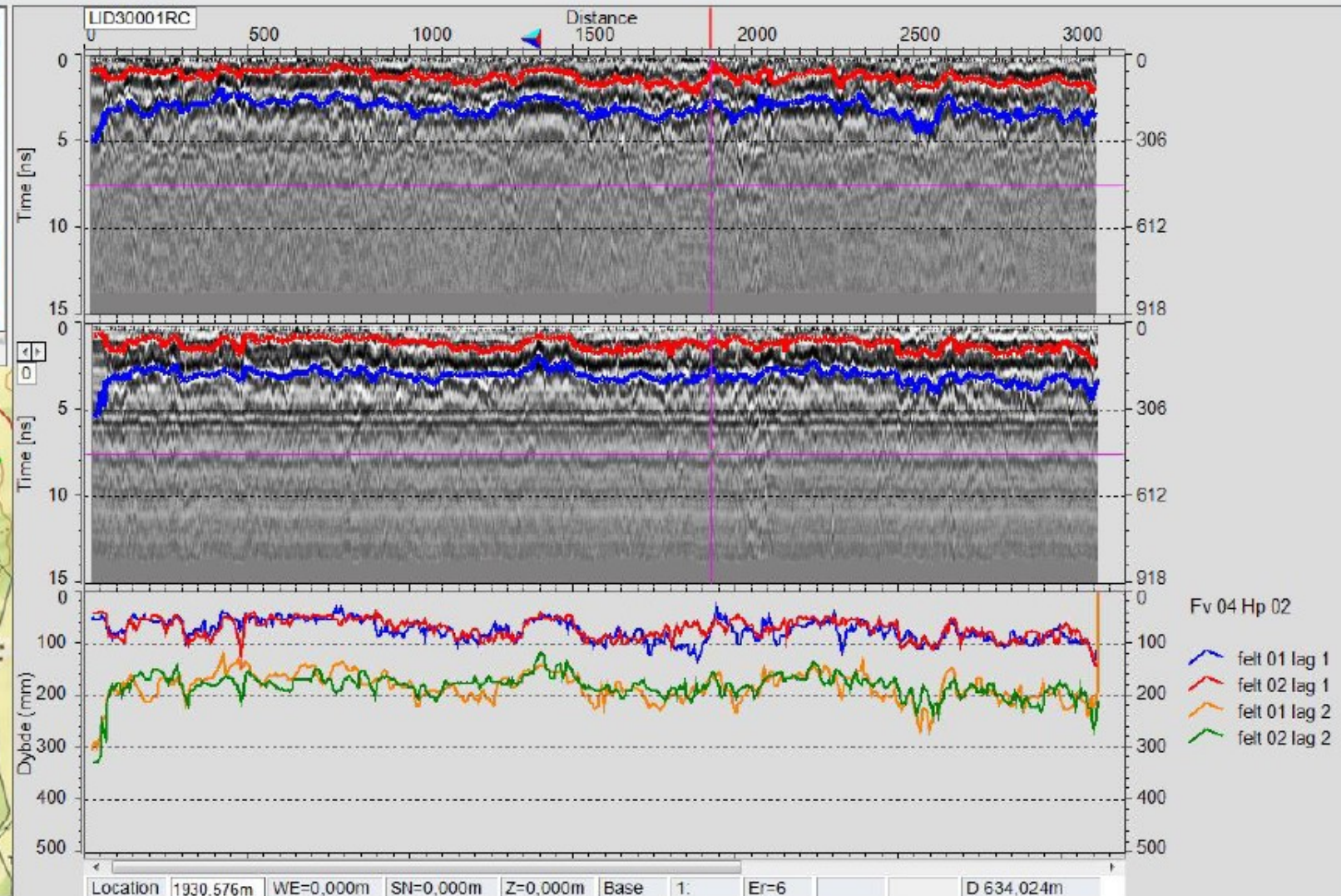


E-moduler datainnsamling fra flere vegstrekinger



Pågående FoU georadar prosjekt 2024-2025

RD VIEW 1 - Project:Fv4 Hp02 Line:fv04 hp02_felt01



A scenic landscape featuring a paved road with yellow lane markings that curves through a lush green field. To the left of the road is a narrow dirt path. In the background, there are rolling green hills and mountains under a clear blue sky with a few wispy clouds. A few small buildings, including a red barn and a white house, are visible in the distance. The overall atmosphere is peaceful and rural.

Takk for
oppmerksomheten

SPM?