Key parameter variation effect on frost penetration and frost heave in pavement structures

FROSTDAGEN 2022

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Sensitivity analysis

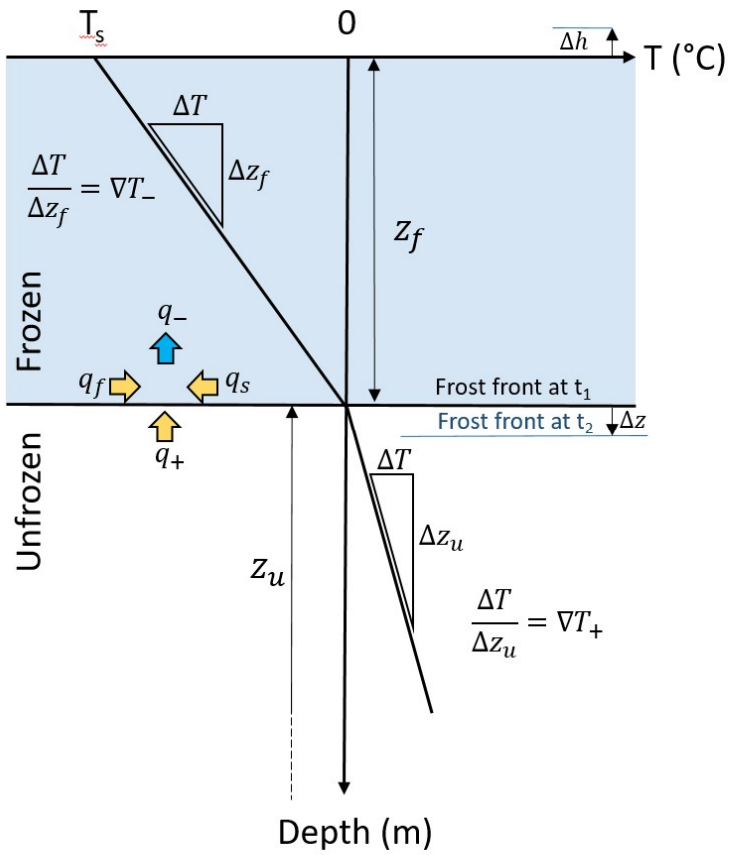
- Present work are linked to VegDIM project, specifically the ERAPave PP design software (Norwegian – Swedish collaboration)

- A (simple) sensitivity analysis was completed using the SSR model and a FEM to analyse p_d and w (or indirectly porosity and degree of saturation), and SP_0 variation effects on the frost depth and frost heave.

SSR

- Simple, and physics is good
- Have done it’s proof (Canada, Finland, lot’s of validation)
- Implemented in ERAPave PP (not ready yet).
- Several datasets were validated using both Erapave and CHAUSSEE2
- Use of CHAUSSEE2 in open mode (MTQ software Canada)

SSR Model



Energy balance at frost front

$$\boldsymbol{q_-} = \boldsymbol{q_f} + \boldsymbol{q_+} + \boldsymbol{q_s}$$

$$\lambda_f \frac{\Delta T}{\Delta z_f} = L_s \frac{\Delta z}{\Delta t} + \lambda_u \frac{\Delta T}{\Delta z_u} + SP \cdot L_w \frac{\Delta T}{\Delta z_f}$$

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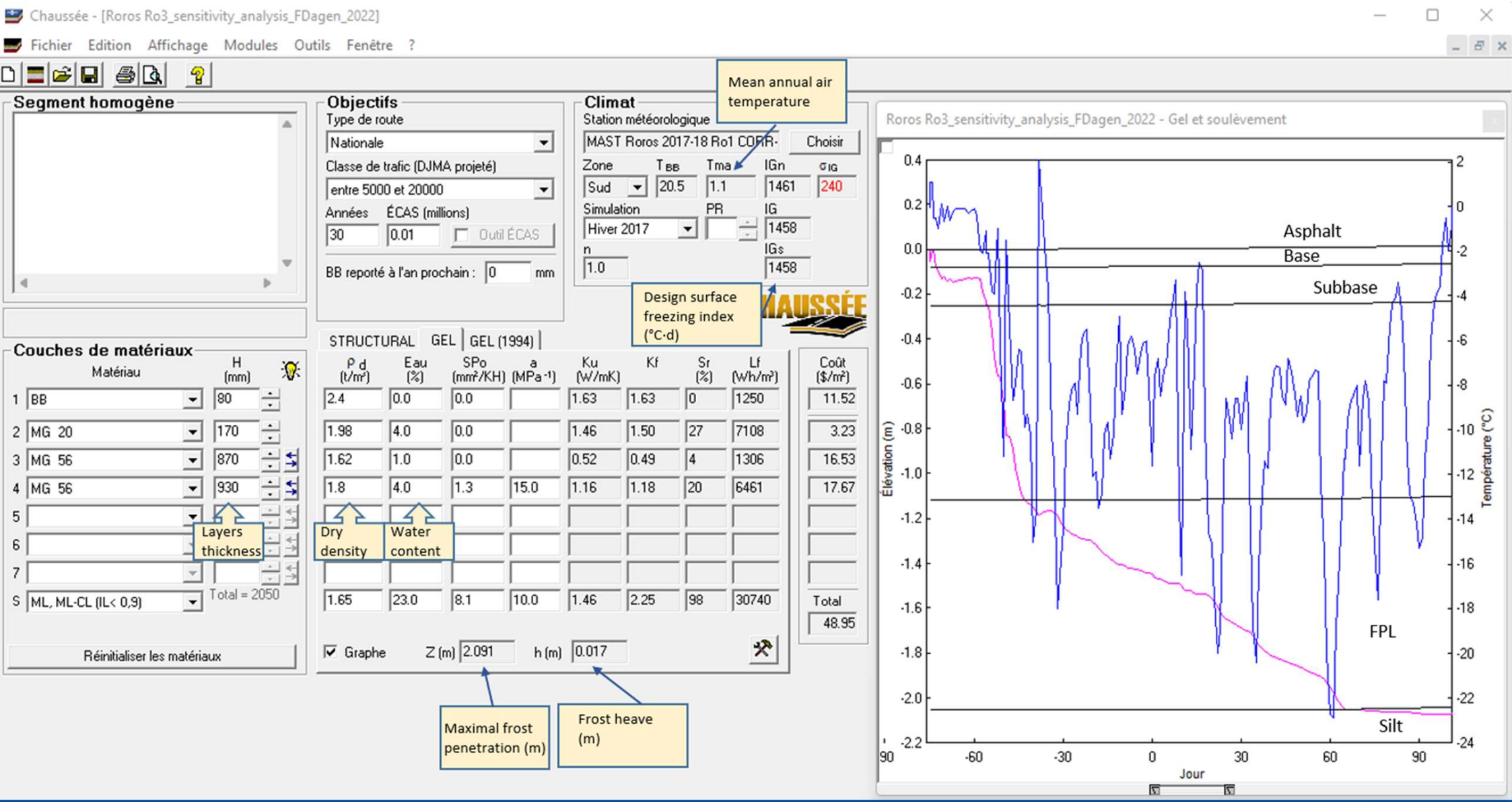
Chaussée - [Roros Ro3_sensitivity_analysis_FDagen_2022]
Fichier Edition Affichage Modules Outils Fenêtre ?
Segment homogène
Objectifs
Type de route
Nationale
Classe de trafic (DJMA projeté)
entre 5000 et 20000
Années
ÉCAS (millions)
30
0.01
Outil ÉCAS
BB reporté à l'an prochain :
0
mm
Climat
Station météorologique
MAST Roros 2017-18 Ro1 CORR-
Choisir
Zone
Sud
T BB
20.5
Tma
1.1
IGn
1461
σIG
240
Simulation
Hiver 2017
PR
IG
1458
n
1.0
IGs
1458
Mean annual air temperature
Design surface freezing index (°C·d)
Couches de matériaux
Matériau
H (mm)
1 BB 80
2 MG 20 170
3 MG 56 870
4 MG 56 930
5
6
7
S ML, ML-CL (IL< 0,9)
Total = 2050
Réinitialiser les matériaux
STRUCTURAL
GEL
GEL (1994)
ρ d (t/m³)
Eau (%)
SPo (mm²/KH)
a (MPa⁻¹)
Ku (W/mK)
Kf
Sr (%)
Lf (Wh/m³)
Coût ($/m²)
2.4 0.0 0.0 1.63 1.63 0 1250 11.52
1.98 4.0 0.0 1.46 1.50 27 7108 3.23
1.62 1.0 0.0 0.52 0.49 4 1306 16.53
1.8 4.0 1.3 15.0 1.16 1.18 20 6461 17.67
1.65 23.0 8.1 10.0 1.46 2.25 98 30740
Total
48.95
Layers thickness
Dry density
Water content
Graphe
Z (m) 2.091
h (m) 0.017
Maximal frost penetration (m)
Frost heave (m)
Roros Ro3_sensitivity_analysis_FDagen_2022 - Gel et soulèvement
Asphalt
Base
Subbase
FPL
Silt
Élévation (m)
Température (°C)
Jour

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- Variation of w and p_d; SP and FI constant

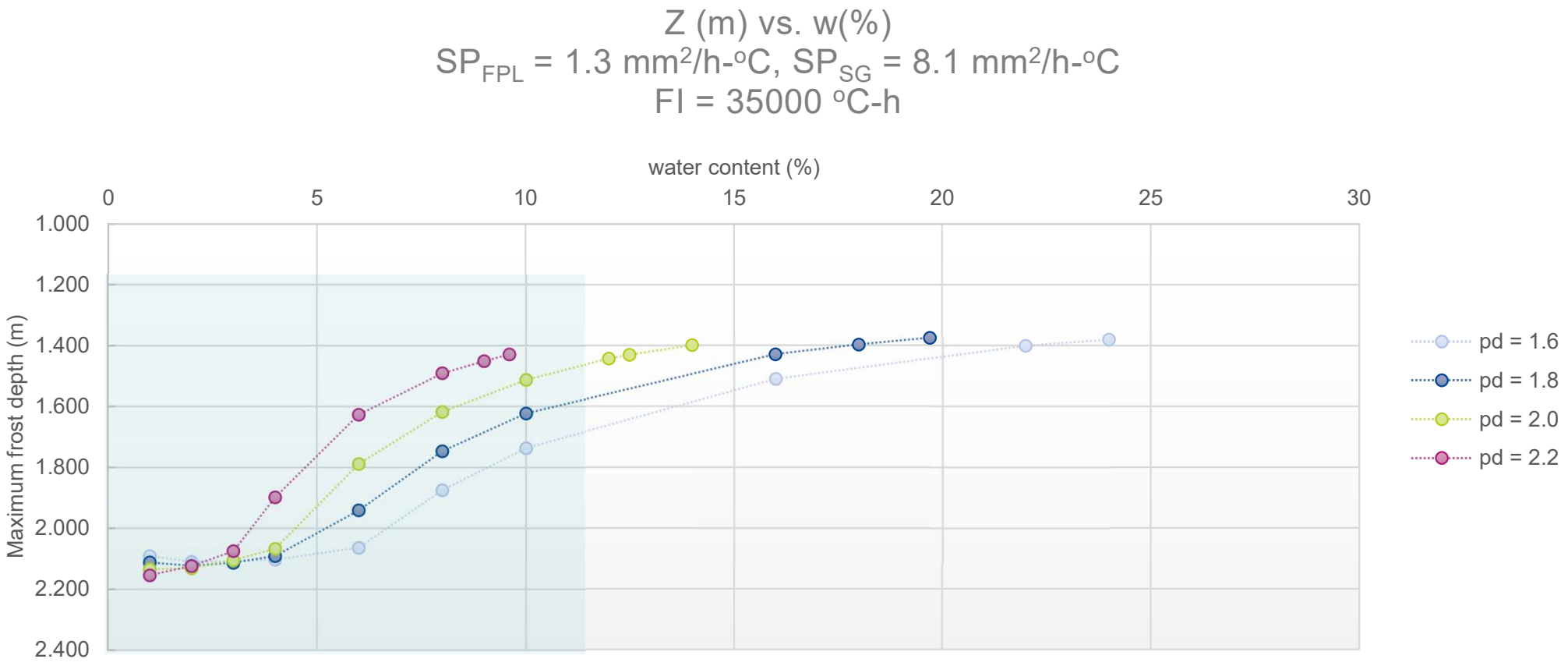
pd = 1.6	Tma=1.1		
w (%)	Z (m)	h (m)	Sr (%)
1	2.091	0.023	4
2	2.110	0.024	8
3	2.108	0.023	11
4	2.103	0.020	15
6	2.064	0.012	23
8	1.875	0.011	30
10	1.737	0.010	38
16	1.510	0.008	60
22	1.401	0.007	83
24	1.381	0.011	90

pd = 1.8			
w (%)	Z (m)	h (m)	Sr (%)
1	2.112	0.025	5
2	2.123	0.024	10
3	2.113	0.021	15
4	2.091	0.017	20
6	1.941	0.010	30
8	1.747	0.009	41
10	1.623	0.008	51
16	1.429	0.007	81
18	1.397	0.012	91
19.7	1.375	0.014	100

pd = 2.0	Tma=1.1		
w (%)	Z (m)	h (m)	Sr (%)
1	2.134	0.026	7
2	2.131	0.023	14
3	2.105	0.017	21
4	2.067	0.010	28
6	1.789	0.008	42
8	1.618	0.007	57
10	1.513	0.007	71
12	1.443	0.006	85
12.5	1.431	0.009	88
14	1.399	0.012	99

pd = 2.2			
w (%)	Z (m)	h (m)	Sr (%)
1	2.154	0.026	10
2	2.124	0.019	21
3	2.075	0.011	31
4	1.898	0.007	42
6	1.627	0.007	62
8	1.491	0.006	83
9	1.451	0.011	94
9.6	1.429	0.011	98

Variation of w and p_d; SP and FI constant



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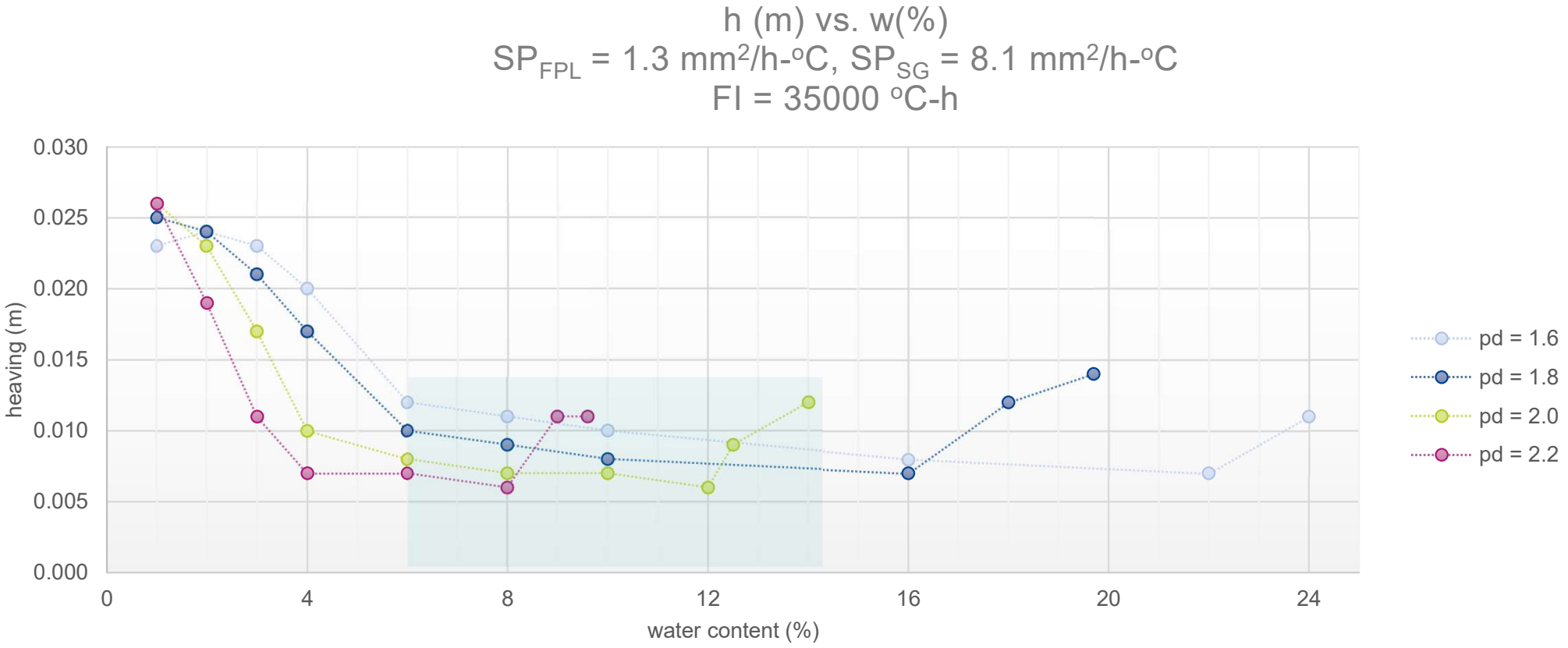
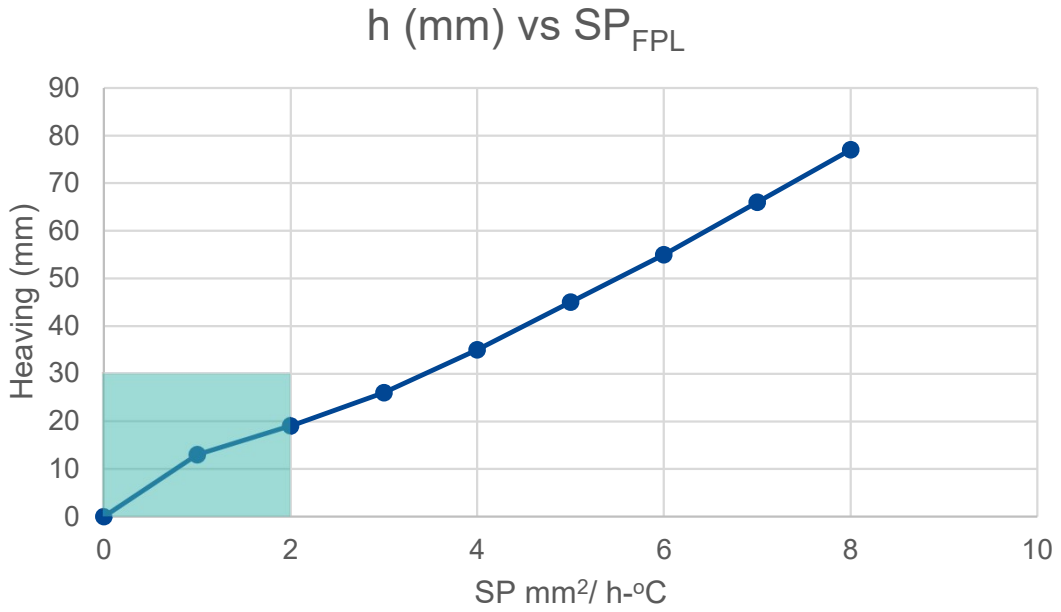
Variation of w and p_d; SP and FI constant



- Variation of SP

FI = 35000		
pd = 1.8	w=4%	Tma=1.1
SP	Z (m)	h (m)
0	2.086	0.000
1	2.084	0.013
2	2.080	0.019
3	2.077	0.026
4	2.033	0.035
5	1.951	0.045
6	1.865	0.055
7	1.774	0.066
8	1.678	0.077

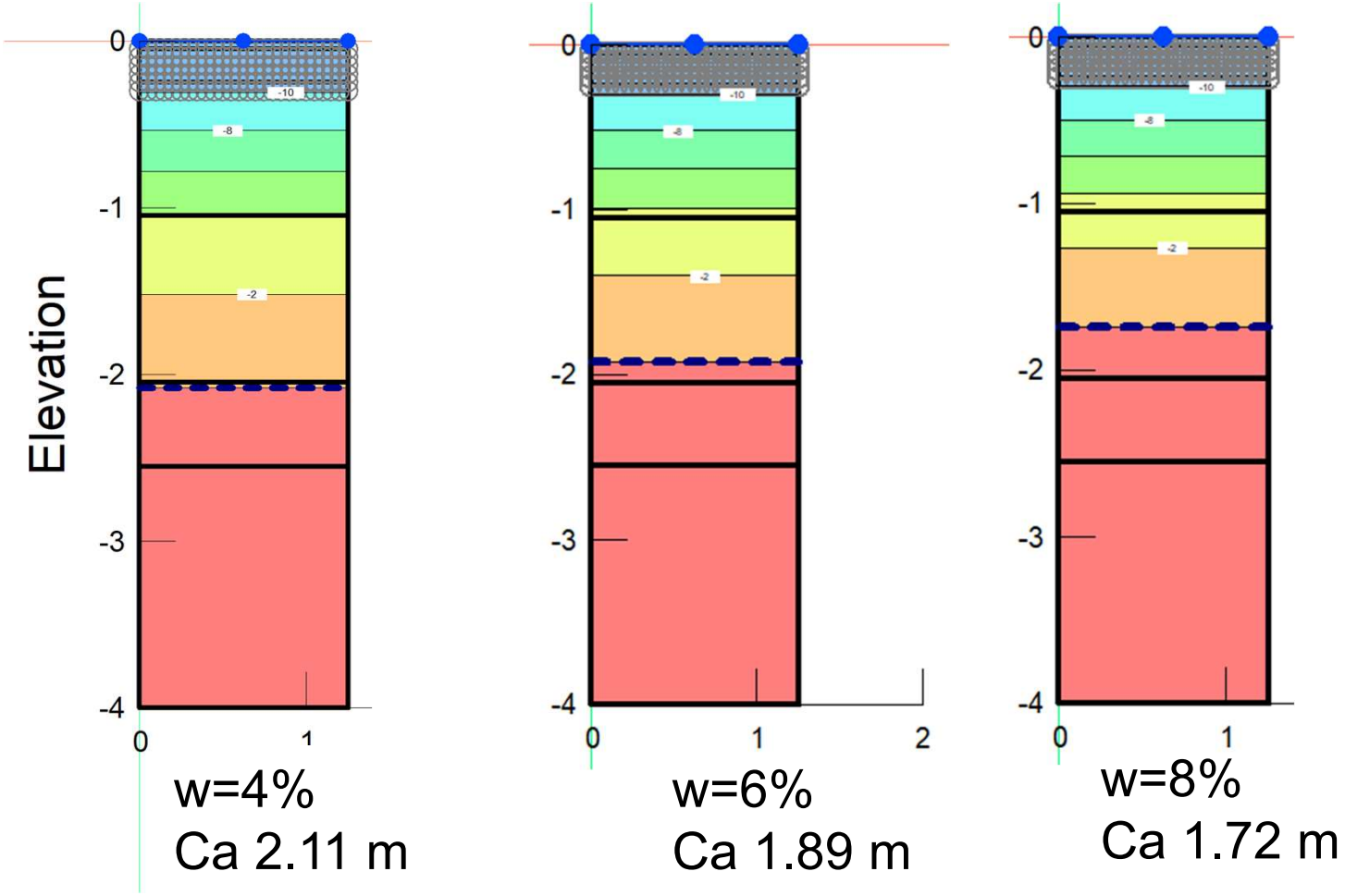


In Chaussee2 (approximately): Silty sands are 2-4, Clayey sands are 2, low fine content sands are 0.5, clays are 2-6 and silt 6-12

TEMP W – model analysis

- Finite element software
- Solve heat transfer in porous media
- Easy to use, but not free…

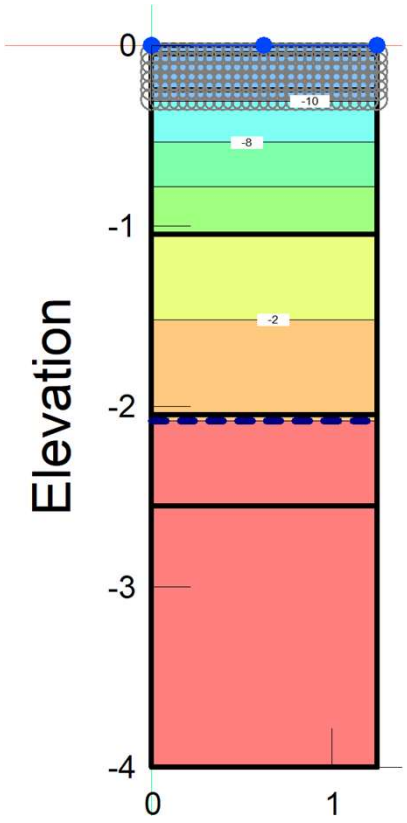
TEMP W – model analysis - Ro-3



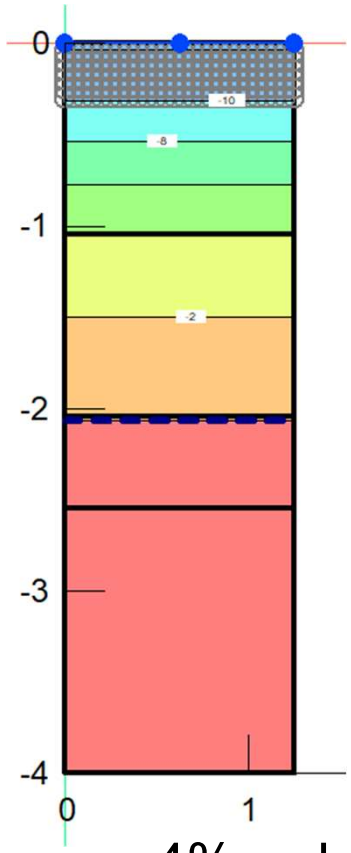
ssr

pd = 1.8		
w (%)	Z (m)	h (m)
1	2.112	0.025
2	2.123	0.024
3	2.113	0.021
4	2.091	0.017
6	1.941	0.010
8	1.747	0.009

TEMP W – model analysis - Ro-3



w=4%, pd =1.8
Ca 2.11 m



w=4%, pd = 2.2
Ca 1.89 m

ssr

pd = 1.8		
w (%)	Z (m)	h (m)
1	2.112	0.025
2	2.123	0.024
3	2.113	0.021
4	2.091	0.017
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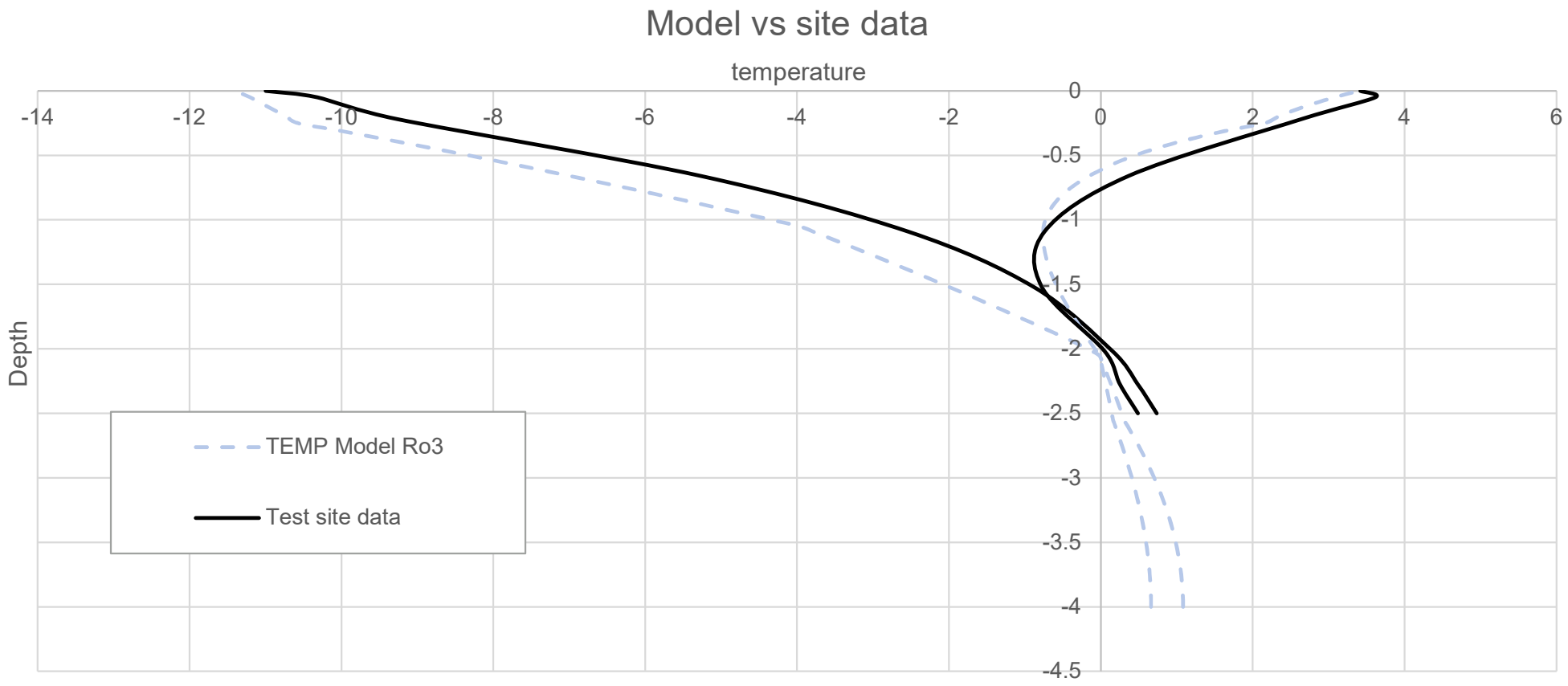
TEMP W vs Test site



Conclusion

- w and p_d are very important in modelling FD and FH
- The SSR and FEM gives similar results
- SP have an important effect in frost depth
  - release of latent heat from segregationnal ice lenses
- TEMP uses full unfrozen water content function and uses heat capacity.

Takk! Thanks!