NGI DIGITAL

Application of geometric and geologic information for optimization in construction projects

Focusing on parametric design and machine learning in Engineering Geology

Tom F. Hansen

Outline

- Introduction to parametric design in Rhino and Grasshopper
- Parametric model of rock support in rock slope
- Parametric model of rock support in tunnelling
- Parametric model for drilling geometry in rock grouting
- Machine learning in engineering geology – example from rockmass classification in advance

Parametric 3D modelling

Using **Rhino** and **Grasshopper**

CAD

+

PROGRAMMING

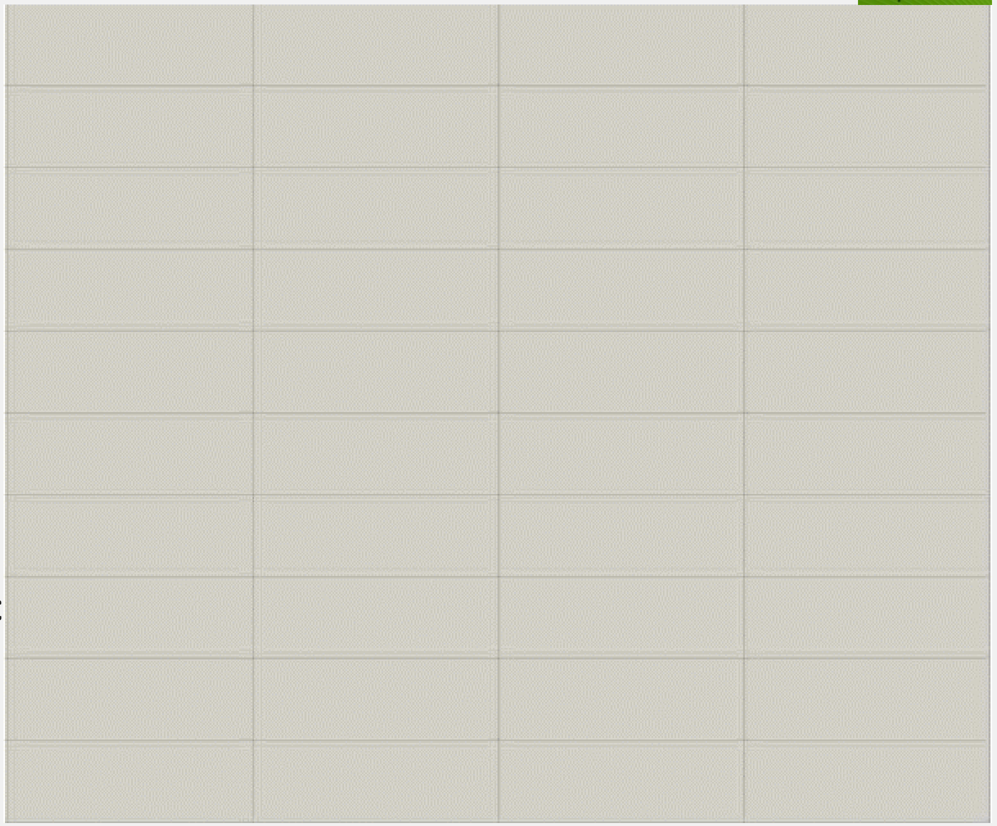
=

The what?

- A combination of **CAD software** and **programming interface** to create 3D geometries.

Rhino is used to visualize results (CAD)

Grasshopper is used to create the geometry, and muc more…



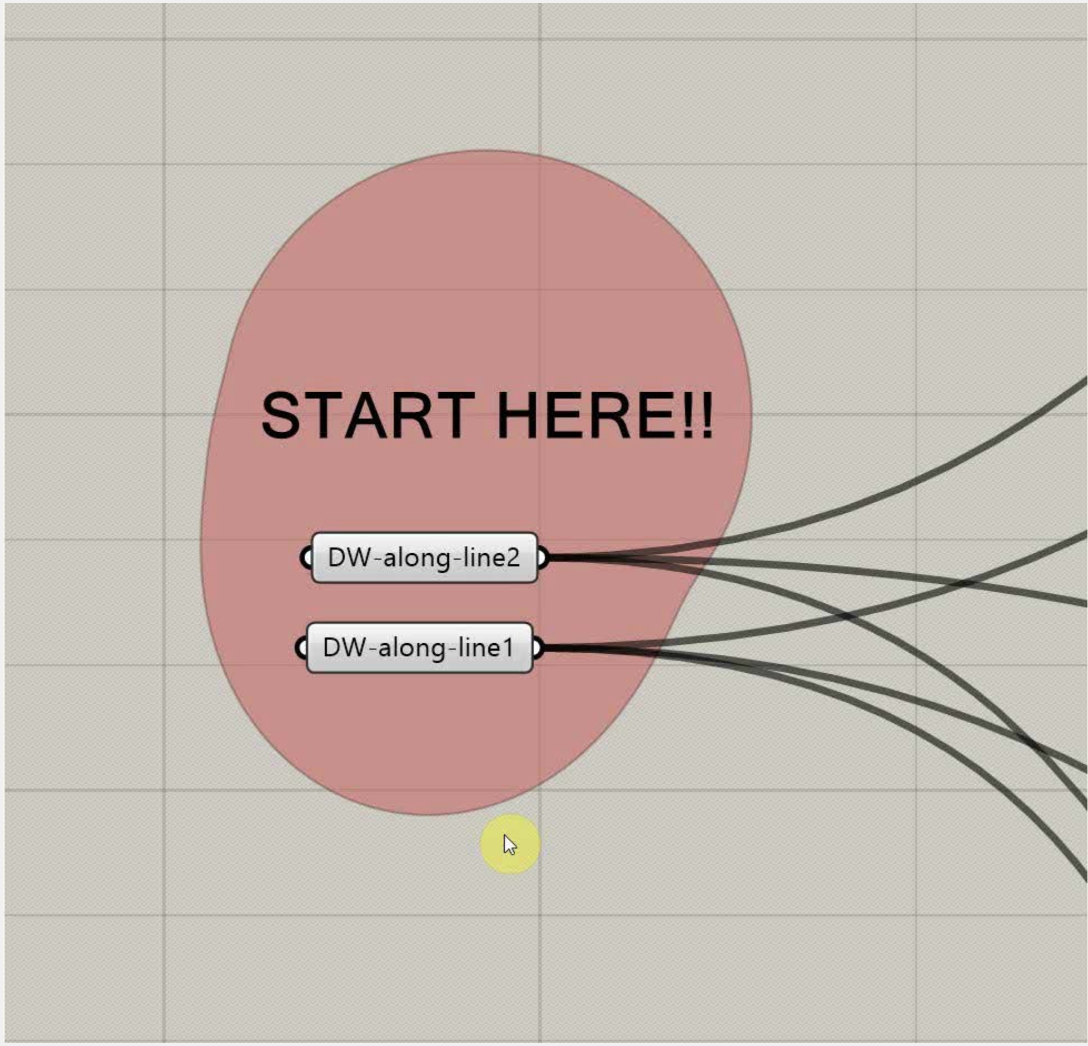
The what?

Rhinoceros

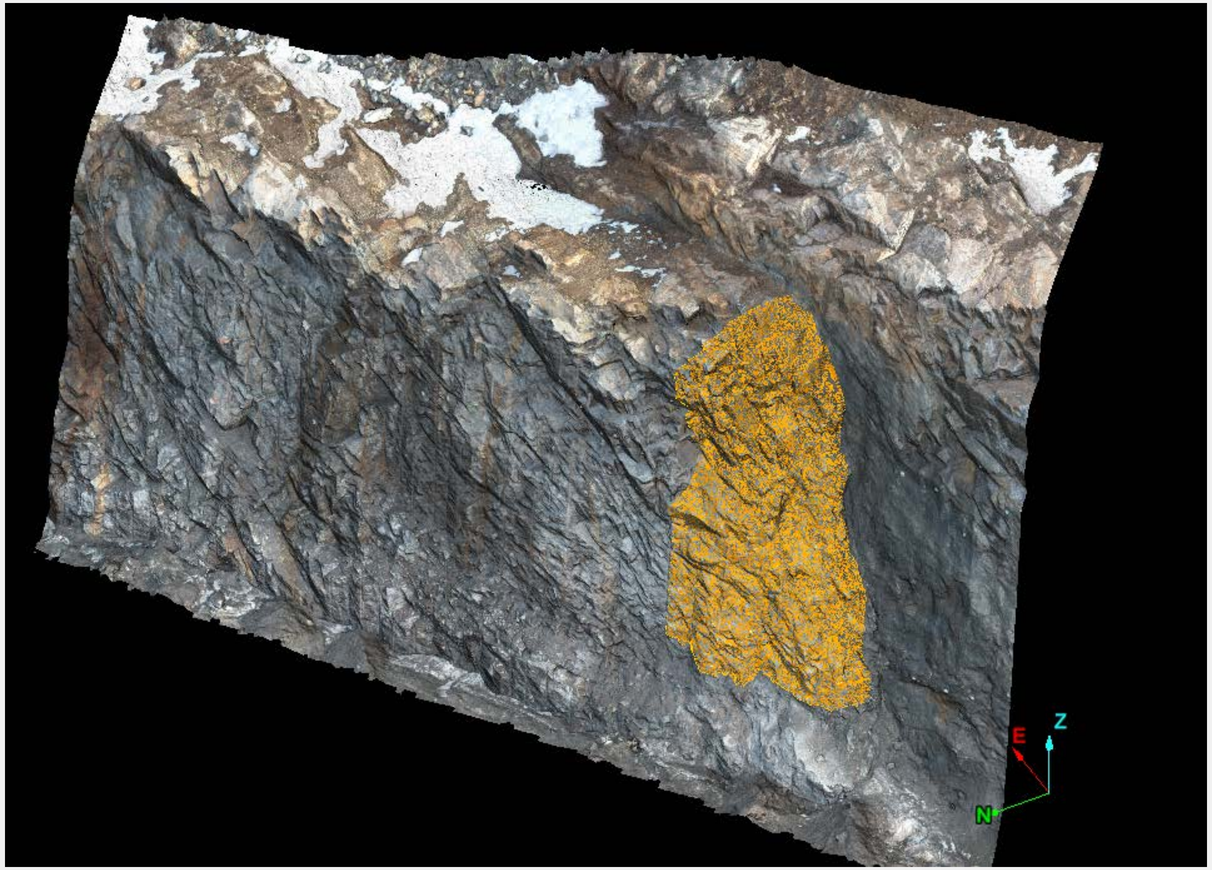
- Geometries are **parametric** – we can change the parameters to modify the model seamlessly
- Geometries are **computational** – we apply math to create the design
- Geometries can be **generative**– we can iterate the process based on goals to obtain the best solution

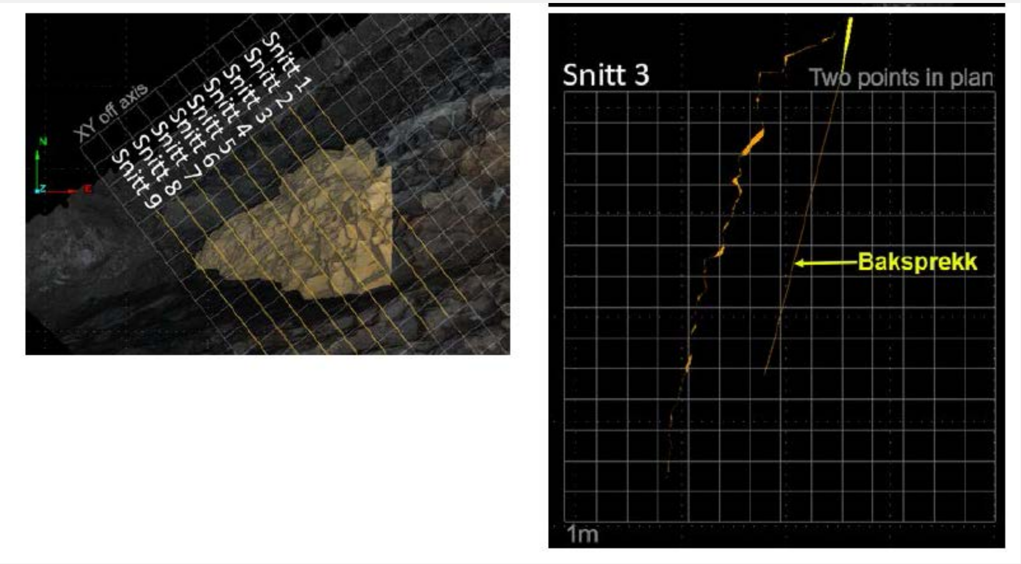
The how?

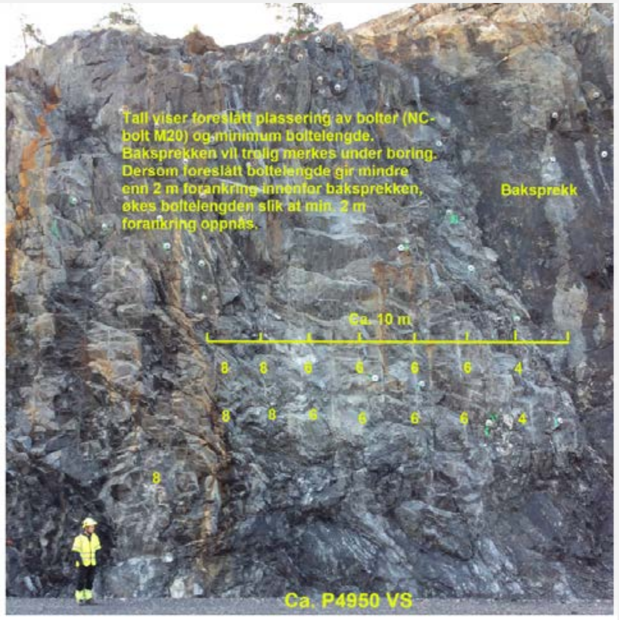
- We use **Grasshopper** – a visual programming tool
- It's like scripting – but simply more **intuitive**
- We can create **complex** geometries in 3D with little effort – fast and efficient
- On this geometry we can perform **evaluations** and **analysis**
- We can then **communicate** our design and results using BIM and VR, or export to drawings.
- Suitable for development of **dicipline models** in rock support, rock grouting and geotechnical constructions.



Parametric model of rock support in rock slope







- Example from E18 Rugtvedt-Dørdahl

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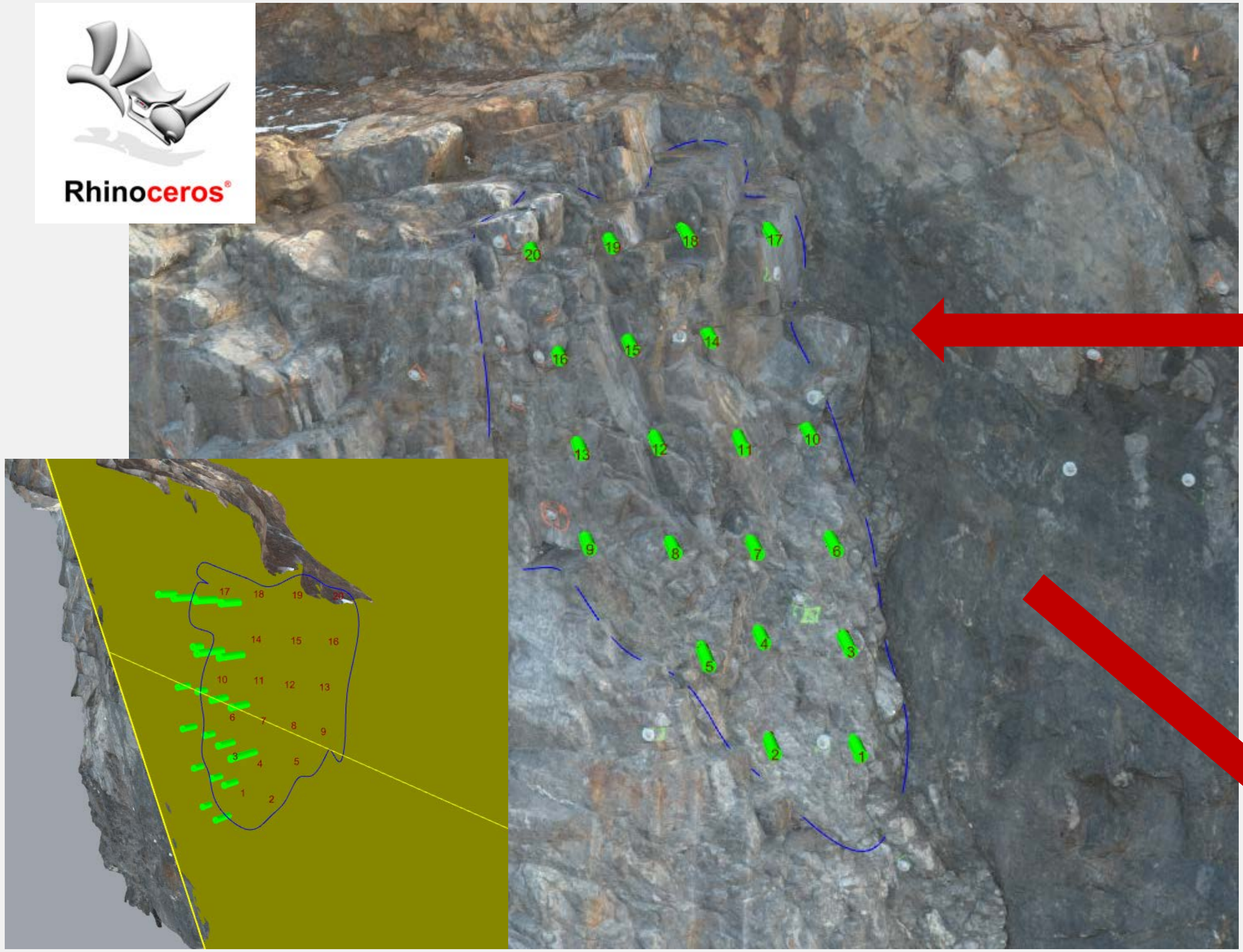
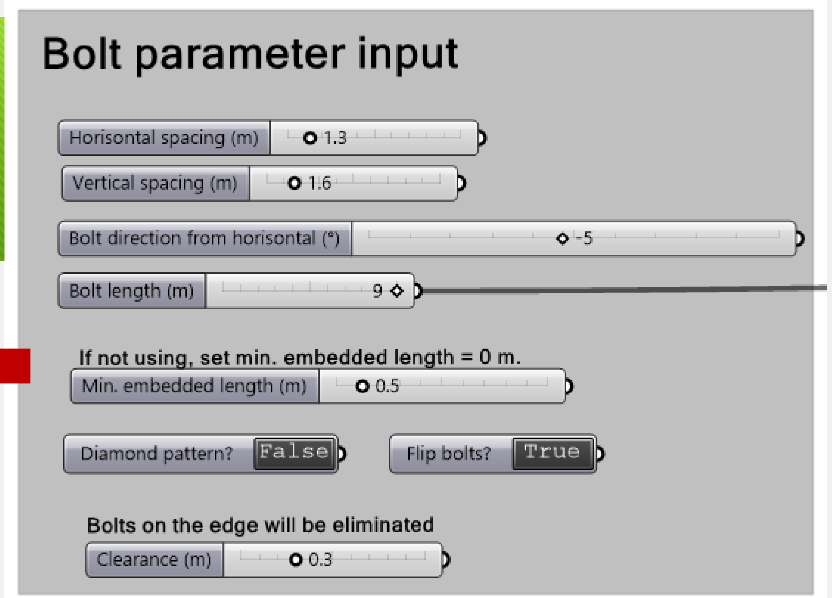
Parametric model of rock support in rock slope





A	B	C	D	E	F	G	H	I	J
Bolt length (m)	Number		Bolt Number	Bolt Length	X Coord	Y Coord	Elevation	Plunge	Azimuth
1.5	0		1	2	21.769567	-5.198002	145.587504	-5	124
2	3		2	3	22.649115	-4.275823	145.587504	-5	124
2.4	2		3	2	22.27705	-5.436059	147.040024	-5	124
3	5		4	2.4	23.325751	-4.682682	147.040024	-5	124
4	4		5	4	23.267962	-3.466384	147.040024	-5	124
5	4		6	2.4	22.715908	-5.511941	148.492543	-5	124
6	2		7	3	23.386757	-4.53564	148.492543	-5	124
8	0		8	4	24.194884	-3.633321	148.492543	-5	124
10	0		9	5	25.149276	-2.800825	148.492543	-5	124
12	0		10	2	23.577395	-5.836122	149.945063	-5	124
Total	20		11	3	23.897317	-4.709063	149.945063	-5	124
			12	4	24.729813	-3.791556	149.945063	-5	124
			13	5	25.294281	-2.762885	149.945063	-5	124
			14	3	24.708527	-4.80247	151.397583	-5	124
			15	5	25.157685	-3.610079	151.397583	-5	124
			16	6	25.504664	-2.507321	151.397583	-5	124
			17	3	24.370203	-5.708706	152.850103	-5	124
			18	4	25.128399	-4.718655	152.850103	-5	124
			19	5	25.595238	-3.601407	152.850103	-5	124
			20	6	26.031181	-2.432927	152.850103	-5	124

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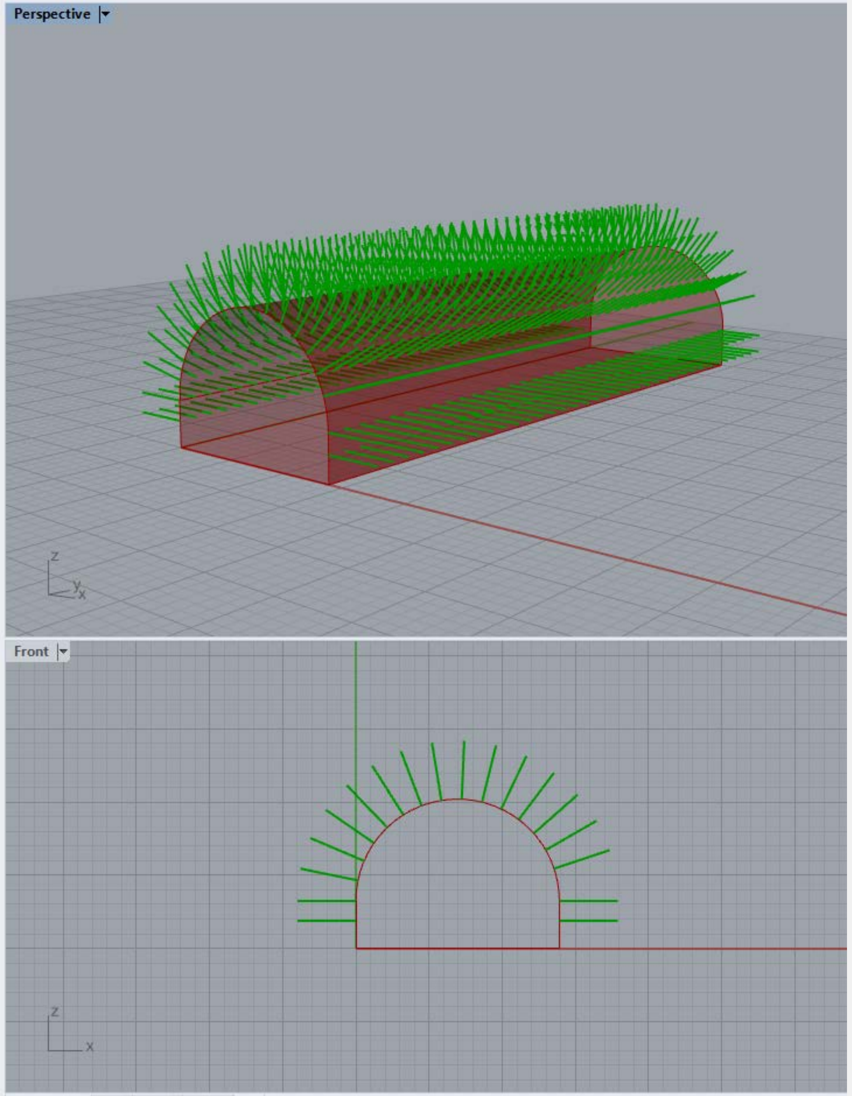
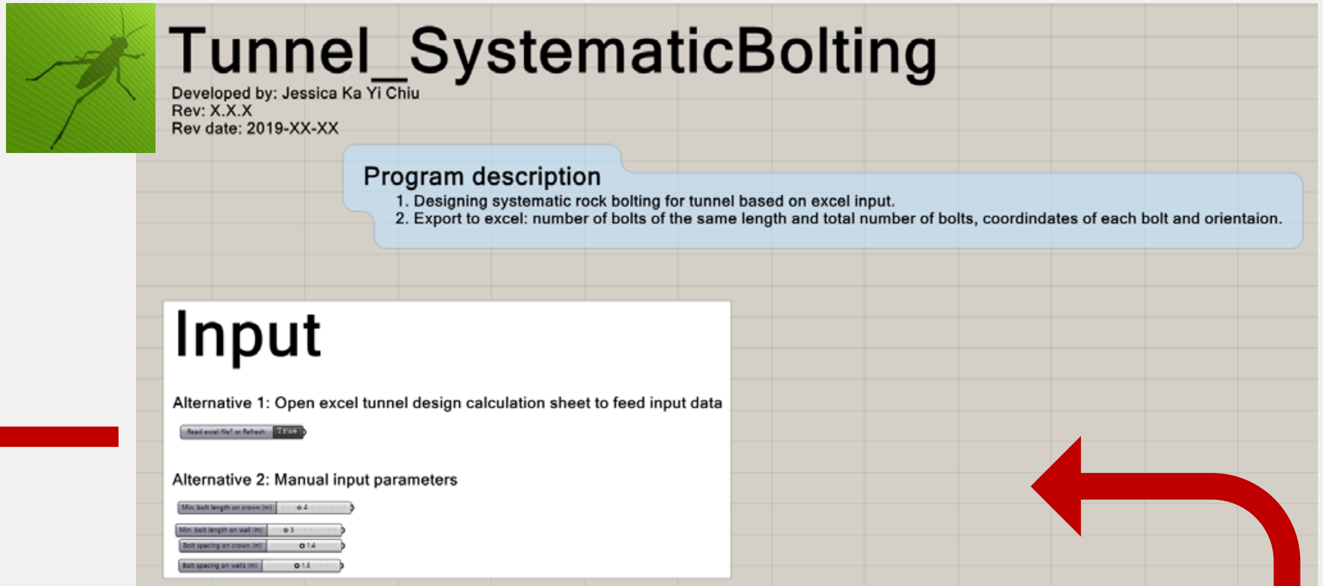
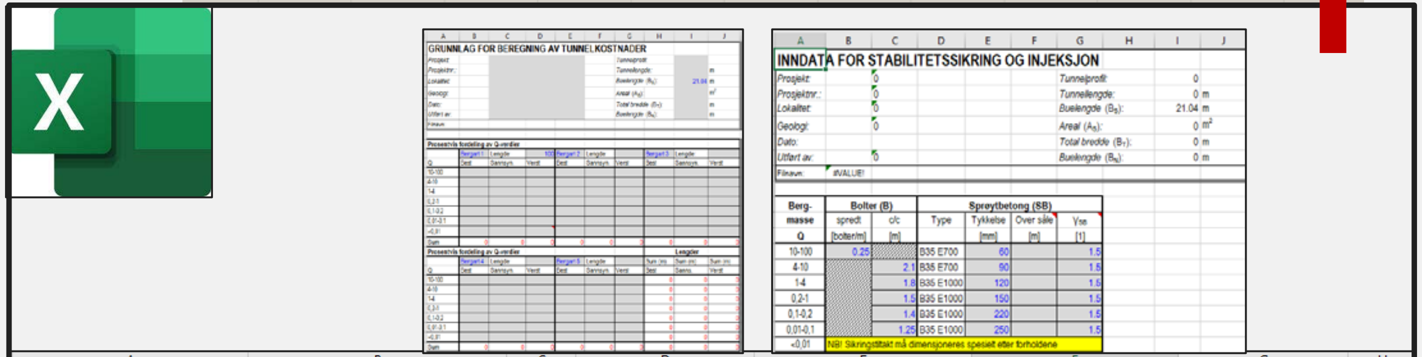
Parametric model of rock bolting in tunnel







A	B	C	D	E	F	G
Row end	11				If not specified, same as on crc	If not specified, same as on crown
			Min. bolt length on crown	Bolt spacing on crown (m)	Min. Bolt length on wall (m)	Bolt spacing on wall (m)
			4	collected from 'inndata sikring'	Same as crown	Same as crown
					8	2.5
Chainage_start	Chainage_end	Q-value				
0	10	0.2	4	1.4	4	1.4
10	20	30	4	0.25	4	0.25
20	30	50	4	0.25	4	0.25
30	55	20	4	0.25	4	0.25
55	100	50	4	0.25	4	0.25
100	200	100	4	4.938967136	4	4.938967136

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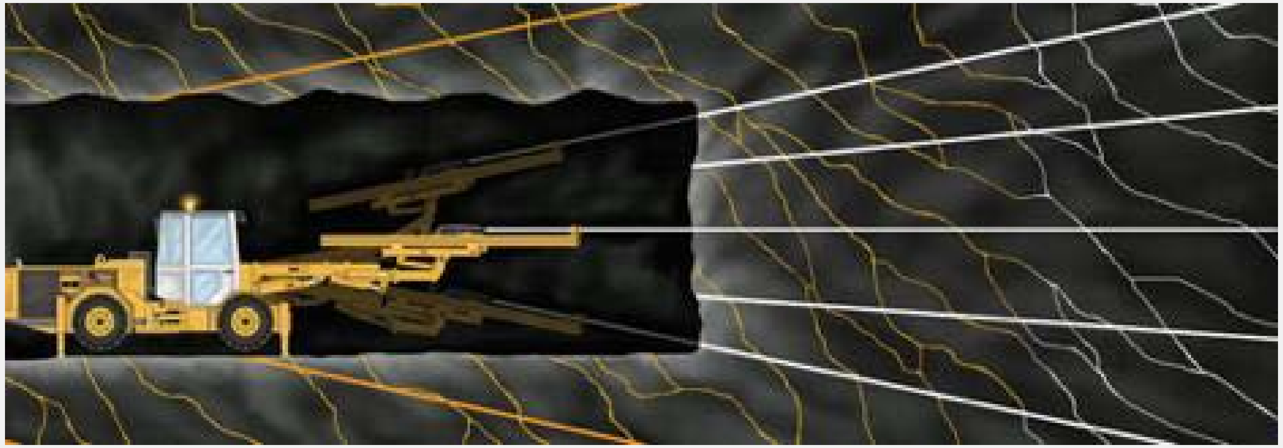
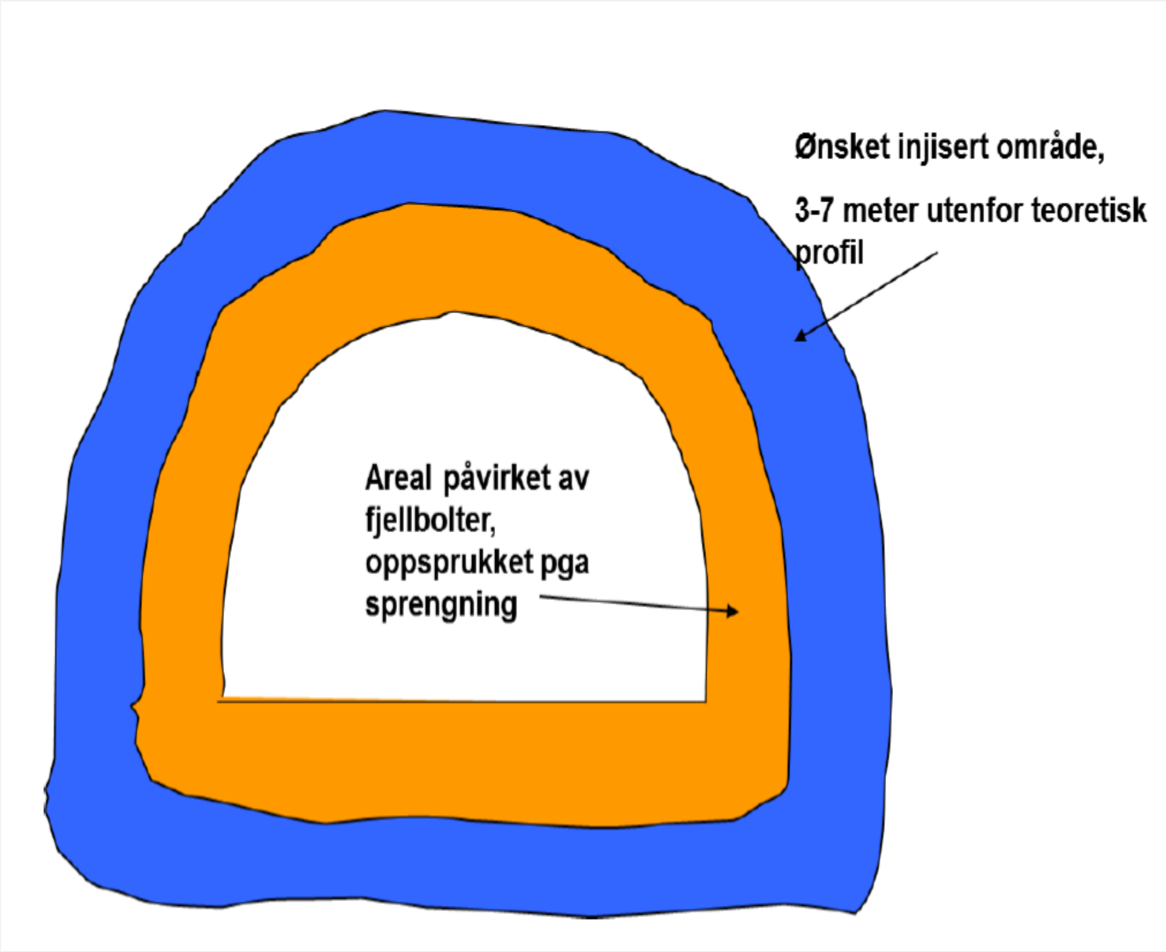
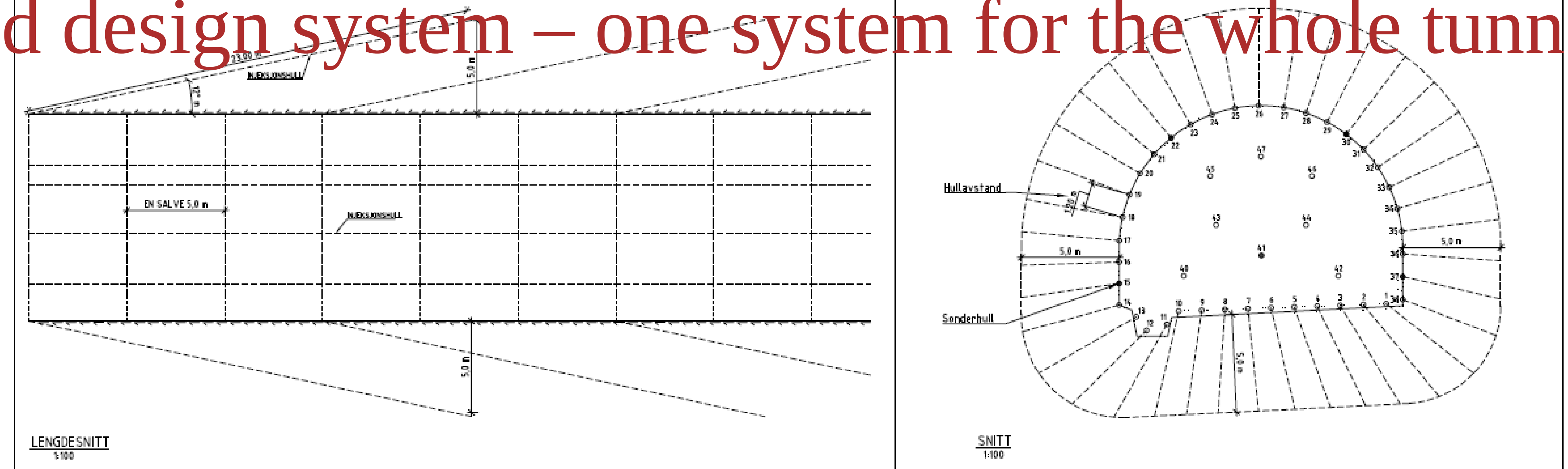
Parametric model of drilling geometry for rock grouting





Old design system – one system for the whole tunnel



TABELL OVER HULLANSETT, RETNING I FORHOLD TIL TUNNELAKSEN OG LENGDER

HULL NR.		
PRIMÆRSKJERM	TUNNELAKSE	LENGDE
SÅLE: 1 – 13	12°	23m
VEGG/HENG: 14 - 38	12°	23 m
STUFF: 40 – 47	0°	23 m
SONDERBORHULL		
TETTHETSKLASSE 1: INGEN SYSTEMATISK SONDERBORING TETTHETSKLASSE 2: BORES SYSTEMATISK SOM HULL NR. 15, 22, 30, 37, 41		

TABELL OVER TETTHETSKLASSER OG INJEKSJON I ULIKE DELSTREKNINGER I HOVEDTUNNELEN

Tetthetsklasse	Krav til lekkasje inn i tunnelen	Prognoser for tetthetsklasser og injeksjon i hovedtunnelen			Tettestrategi
Tetthetsklasse 1	maks. 10 l/min	Skillingsmyr tunnel pelnr. 171,200 – pelnr. 171,350	150 m	380 m	Systematisk injeksjon
		Skillingsmyr tunnel pelnr. 172,100 – pelnr. 172,150	50 m		
		Skillingsmyr tunnel pelnr. 172,210 – pelnr. 172,390	180 m		
Tetthetsklasse 2	maks. 20 l/min	Skillingsmyr tunnel pelnr. 169,300 – pelnr. 171,200	1900 m	4010 m	Sporadisk (behovsprøvd) forinjeksjon
		Skillingsmyr tunnel pelnr. 171,350 – pelnr. 172,100	750 m		
		Skillingsmyr tunnel pelnr. 172,150 – pelnr. 172,210	60 m		
		Skillingsmyr tunnel pelnr. 172,390 – pelnr. 173,080	415 m		
		Ørnsåsen tunnel pelnr. 173,500 – pelnr. 174,090	590 m		
		Storberget tunnel pelnr. 174,455 – pelnr. 174,750	295 m		

FORKLARINGER

- ○ Injeksjonshull
- – – – Injeksjonshull
- ● Systematiske sonderborhull ved sporadisk forinjeksjon. Inngår som del av eventuell injeksjonsskjerm. Ellers som injeksjonshull.

BESTEMMELSER

1. Injeksjonshullene bores 23 meter lange og med en vinkel 12 grader med tunnelaksen slik at hullendene er lokalisert 5 meter radielt utenfor teoretisk sprengningsprofil. Hullavstand ved ansett er 1,2 meter.
2. I hovedtunnelen og ved andre sprengningsprofiler må skjermgeometri tilpasses etter avtale med byggherren. Videre vil plassering, antall, retning og lengder av injeksjonshull og sonderborhull tilpasses fortløpende etter geologi og lokale lekkasjeforhold. Dette er forhold som vurderes av byggherrens geolog. Injeksjonsopplegg er generelt et fleksibelt system. Endringer må forventes.
3. Injeksjonsopplegget for hver enkelt injeksjonsskjerm er i utgangspunktet likt for tetthetsklasse 1 og 2. Men ved systematisk forinjeksjon og tetthetsklasse 1 sonderbores det ikke systematisk, men kun etter avtale med byggherre. Ved sporadisk forinjeksjon og tetthetsklasse 2 skal byggherren ta beslutning om injeksjon på bakgrunn av innlekkasje av vann på stuff-flaten eller fra sonderborhull. Disse bores da systematisk og vil inngå som en del av injeksjonsskjermen dersom den blir etablert.
4. Injeksjon for delstrekninger gitt ovenfor er antagelser og kan bli endret.

BYGGEPLAN
UNDERBYGNING – GEOLOGI
SONDERBORING OG INJEKSJON, HOVEDTUNNEL
PRINSIPPTEGNING

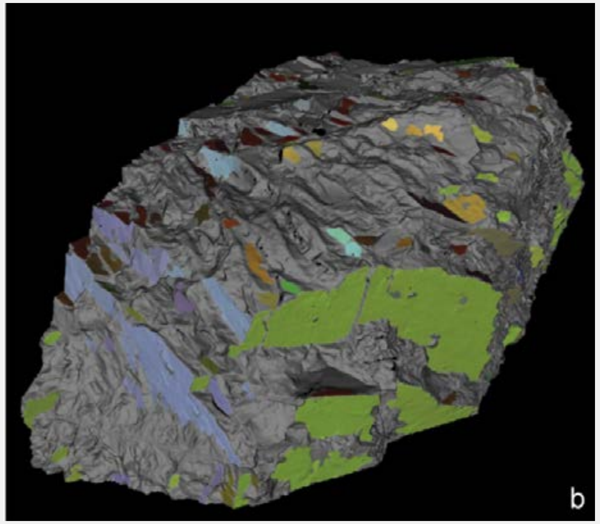
MODERNISERING AV VESTFOLDBANEN
12.2 TELEMARK GRENSE – PORSGRUNN

UVB-22-V-31050 02C

Jernbaneverket

Goals with scripts

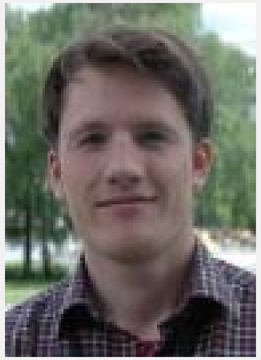
1. Design grouting geometry in a parametric 3D way «on the fly»
   - New design process: tailormade grouting geometry for each unique rock face (use data from engineering geology mapping on face + automated mapping with plane detect etc, MWD) >>> reduce drilling to achieve the leakage requirement
   - Reduce quantities in grouting (drilling time, grouting time, grouting materials).
   - Ensure optimal covering of the tunnel profile
2. Dicipline model for grouting in a parametric and quick way
3. Tool for estimation of quantities for grouting



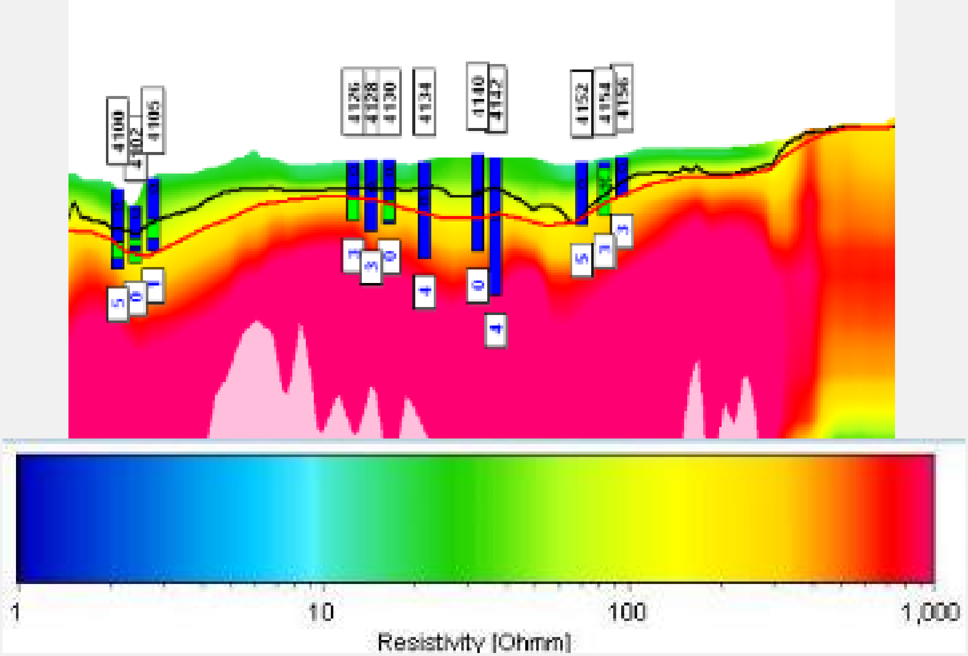
Model

Machine learning in applied geosciences

Emerald - construction of bedrock topography



- Geotechnical drillings:
  - Expensive site investigation
  - Time consuming
  - Accurate, but very local
- Geophysics:
  - Less expensive
  - Very fast
  - Covers large volume
  - Greater uncertainty



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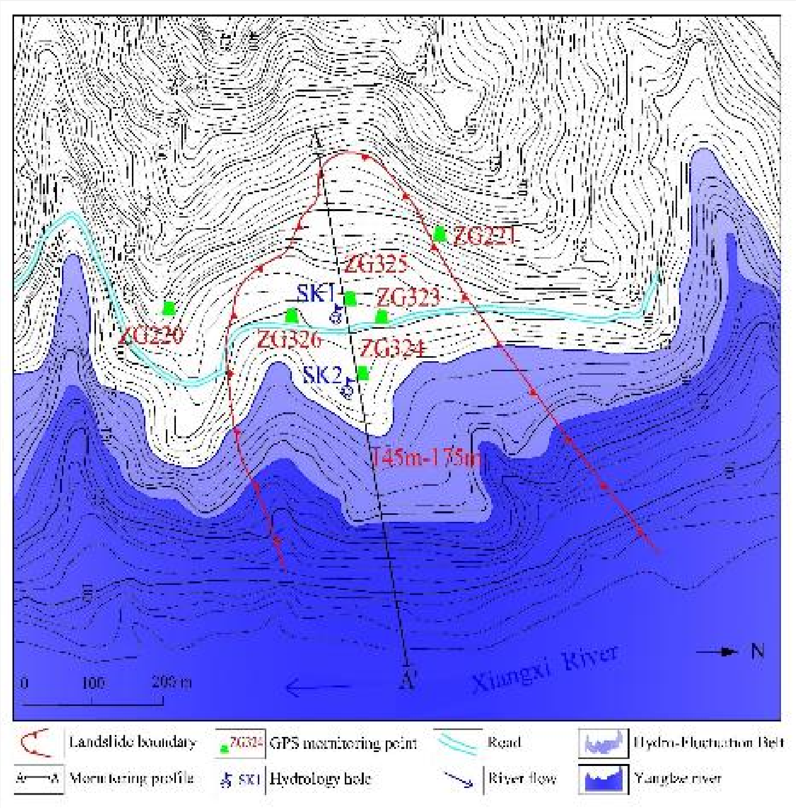
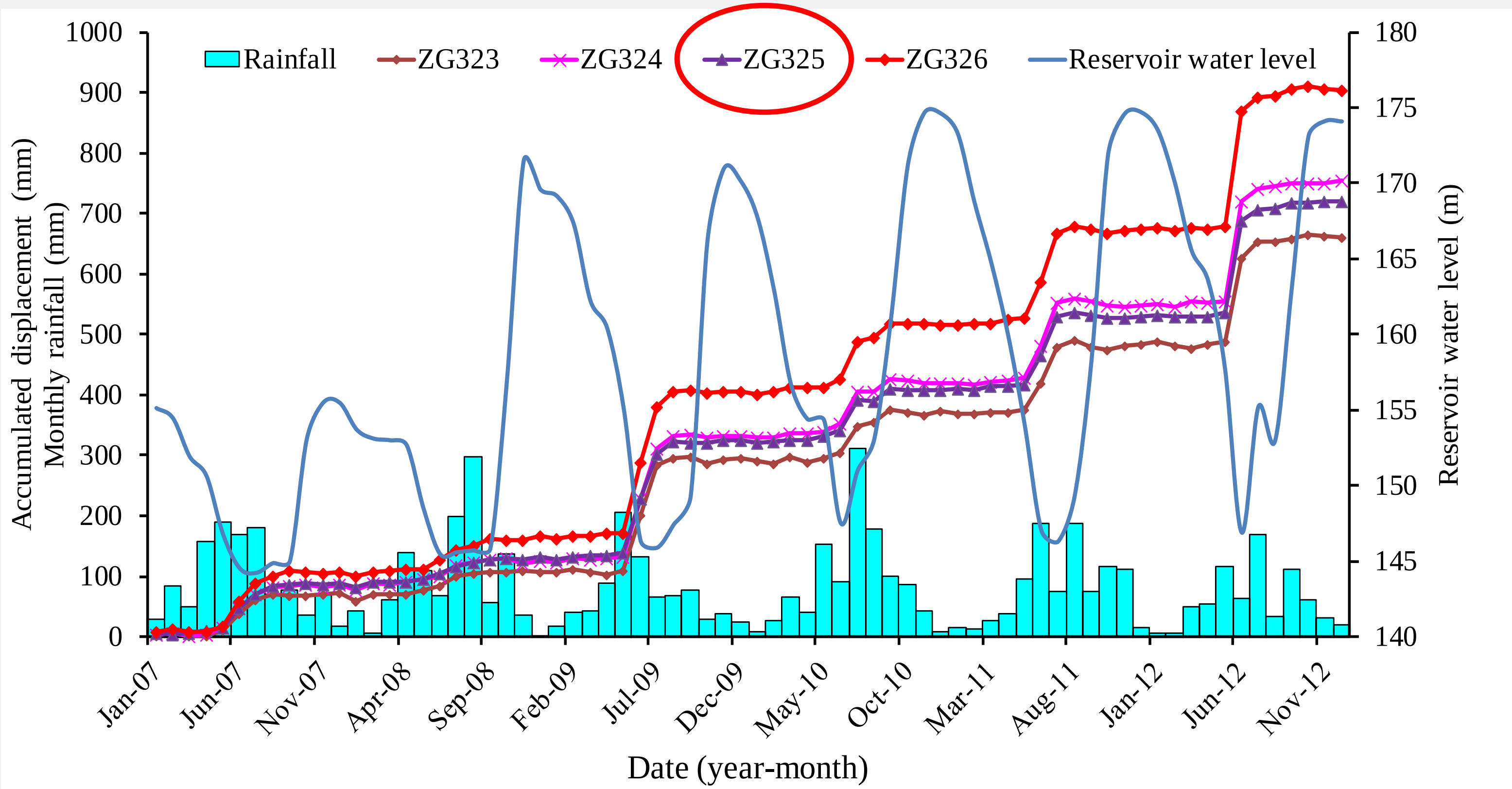
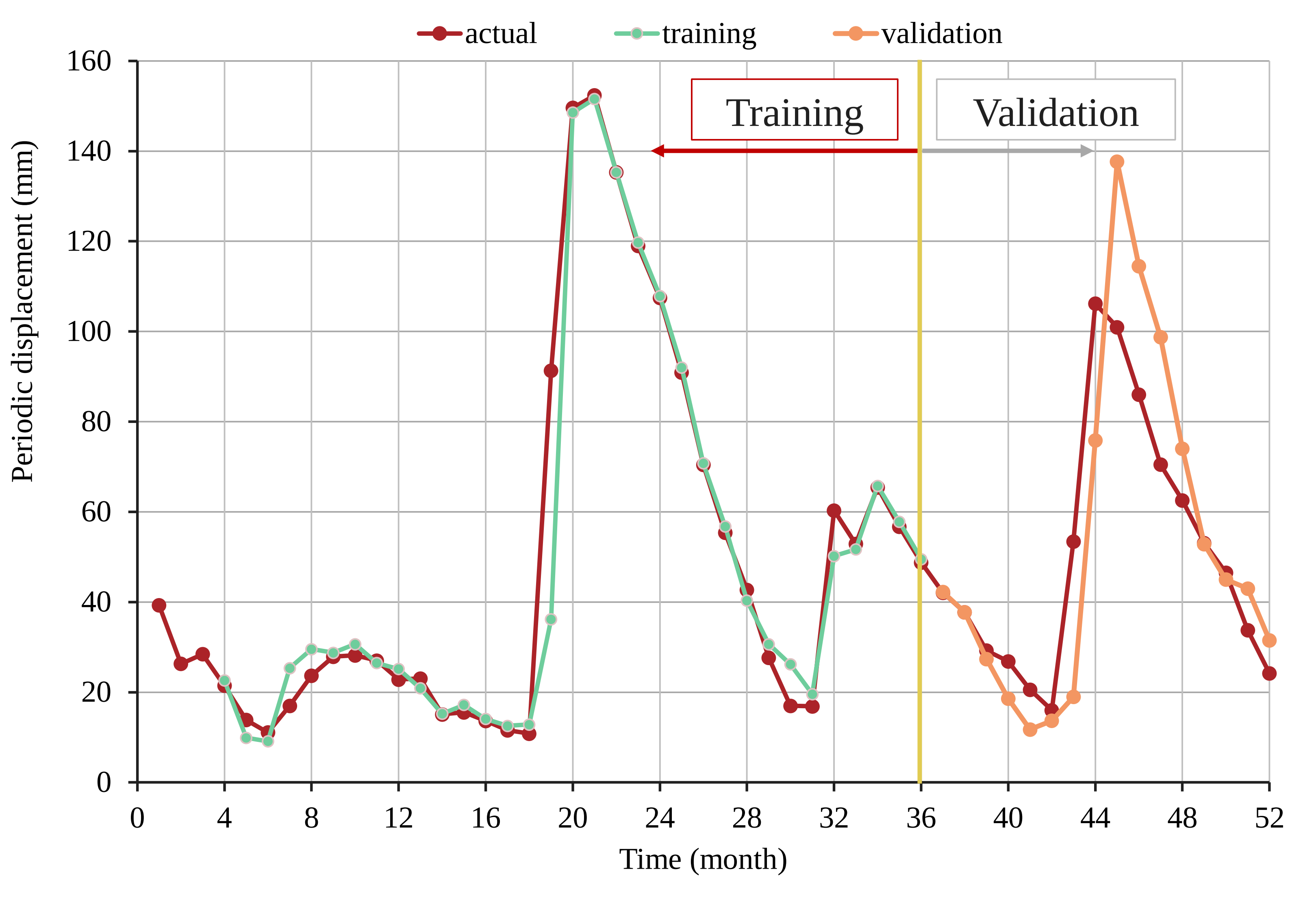
Monitoring system of the Baijiabao landslide





LSTM model for prediction of displacement



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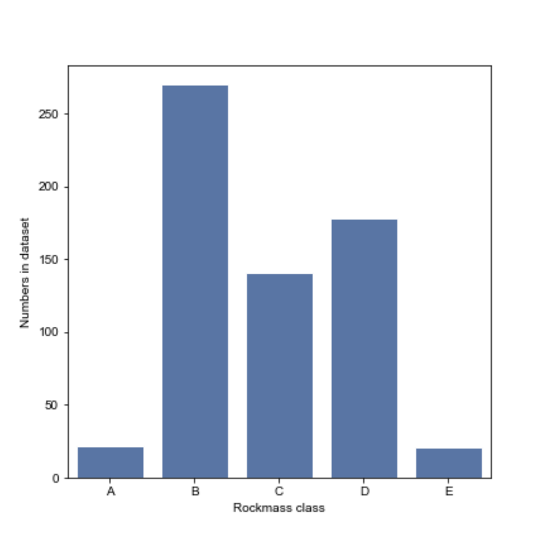
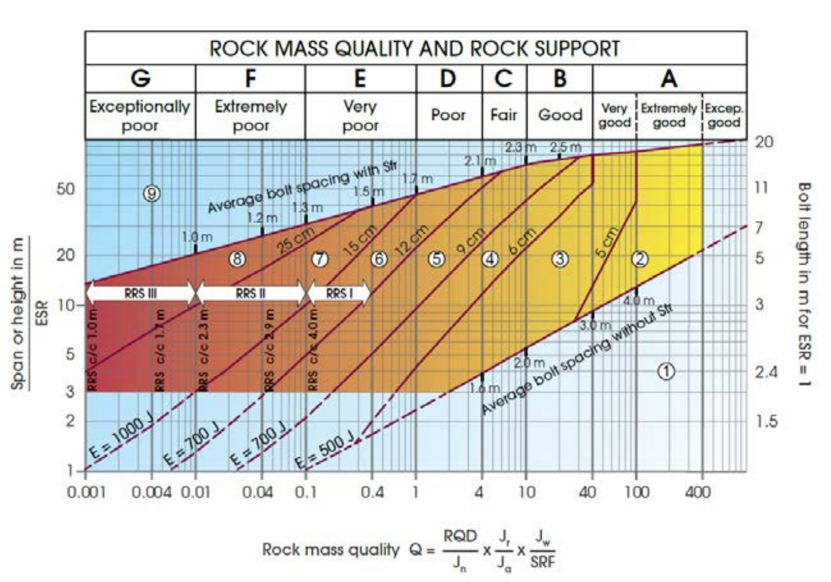
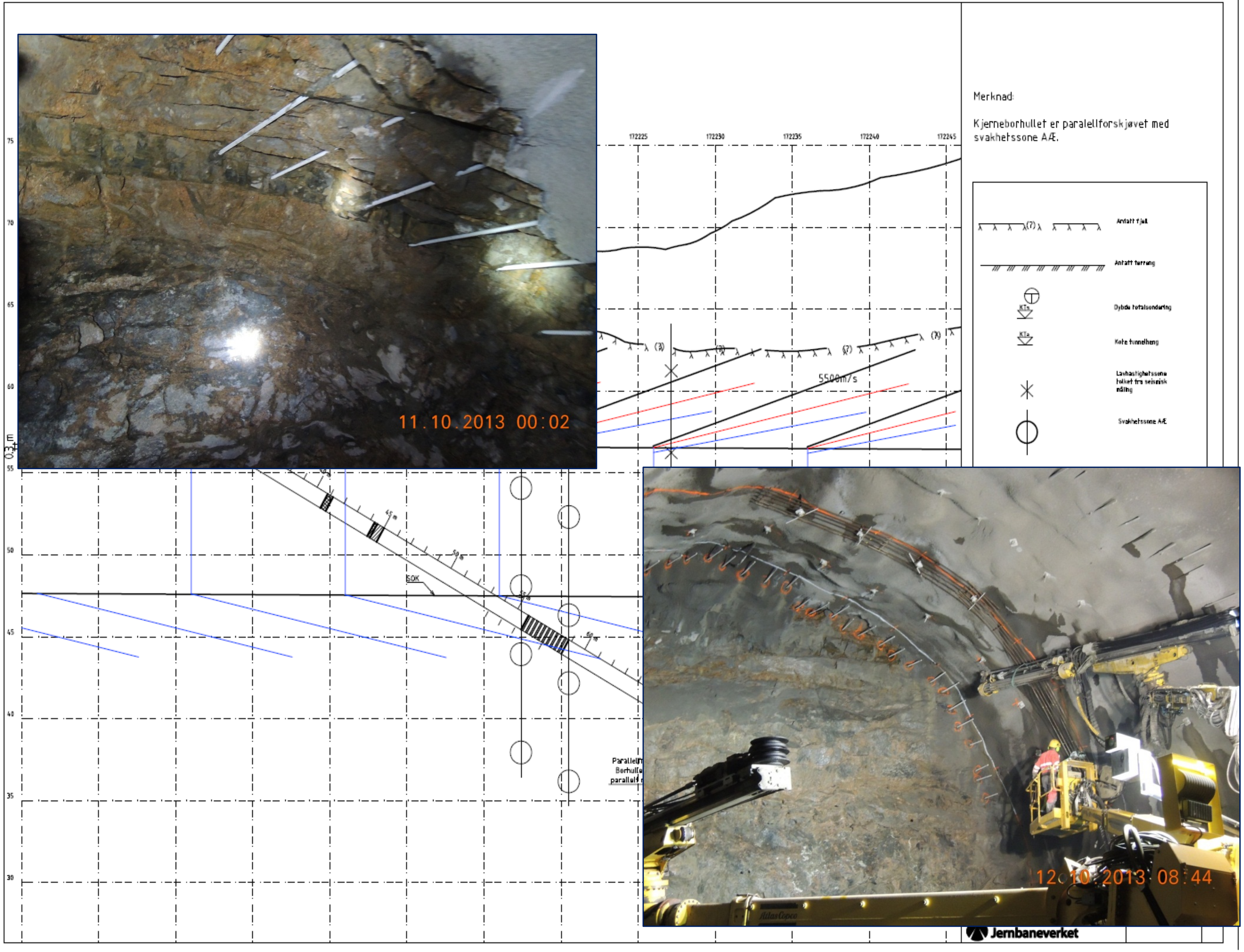
Rockmass classification from MWD-data

- Holmestrandstunnelen:
  - 4 km of MWD-data – blasting holes
  - Mapped Q-value and rockmass class
- Goal: Predict rockmass class in front of the face, in order to plan in advance:
  - Wider profile for heavy rock support
  - Spiling bolts
  - Other operational planning






Merknad:
Kjerneborhullet er paralellforskjøvet med svakhetssone AÆ.
Antatt fjell
Antatt terreng
Dybde totalsondering
Kote tunnelheng
Lavhastighetssone tolket fra seismisk måling
Svakhetssone AÆ
172225
172230
172235
172240
172245
5500m/s
11.10.2013 00:02
12.10.2013 08:44
Jernbaneverket

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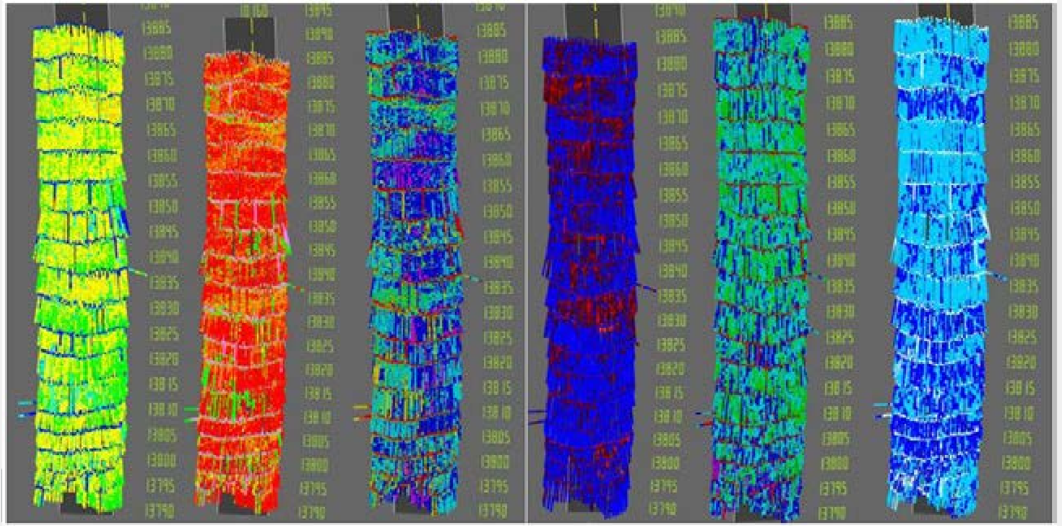
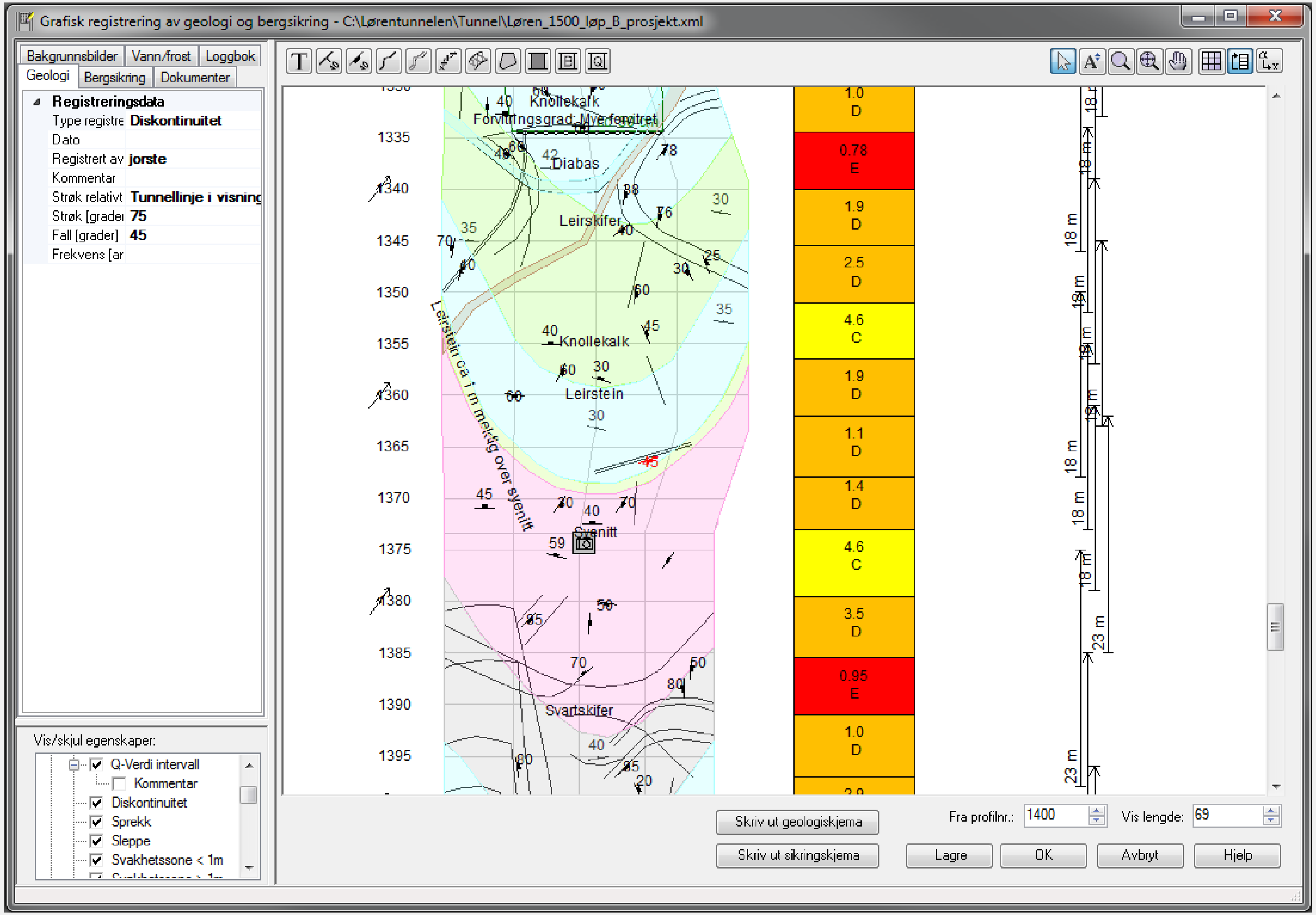
Measure while drilling (MWD)

Depth (m)	Penetration (m/min)	Rotation pressure (bar)	Feeder pressure (bar)	Hammer pressure (bar)	Rotation speed (rpm)	Water pressure (bar)	Water flow (l/min)
0,351	1,9	89	53	111	268	25	120
0,401	1,8	95	54	111	271	25	119
0,454	2,0	94	58	121	271	25	120
0,505	2,5	89	64	149	272	25	120
0,556	2,9	90	68	168	272	25	118
0,609	3,6	90	71	176	272	25	116
0,66	3,5	99	77	180	272	25	116
0,71	3,4	108	79	182	268	25	117
0,761	3,4	109	79	180	266	25	116
0,813	3,5	111	78	184	266	25	116
0,866	3,4	108	78	182	266	25	116
0,918	3,3	107	78	183	267	25	116



Photos and figures: NFF Publication 28

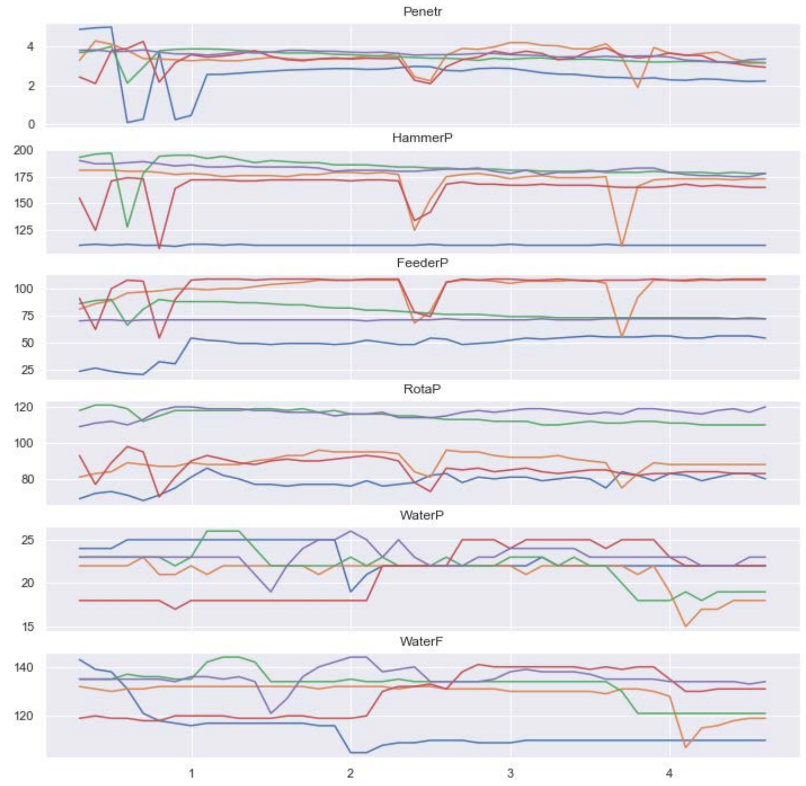
Geology and rockmass classes



Modelling process

- Built on experience from:
  - Eldert et. al (2019), Application of MWD technology to predict rock mass quality and rock support for tunneling
  - Galende et. al (2018), MWD-based estimation of rock mass rating with computational intelligence. The case of tunnel excavation front.
  - Hayashi et. al (2019), Prediction of forward tunnel face score of rock mass classification for stability by applying machine learning to drilling data.
- Combined 290 sections of blasting rounds
- Preprocess, clean and scale data
- Downscale 150-170 blast holes in each section to 3 summary-parameter (mean, median, variance) for each MWD-parameter, in total 18 parameters + blasting length and mapped rockmass-class from last section

Challenge – downscaling (dimention reduction)



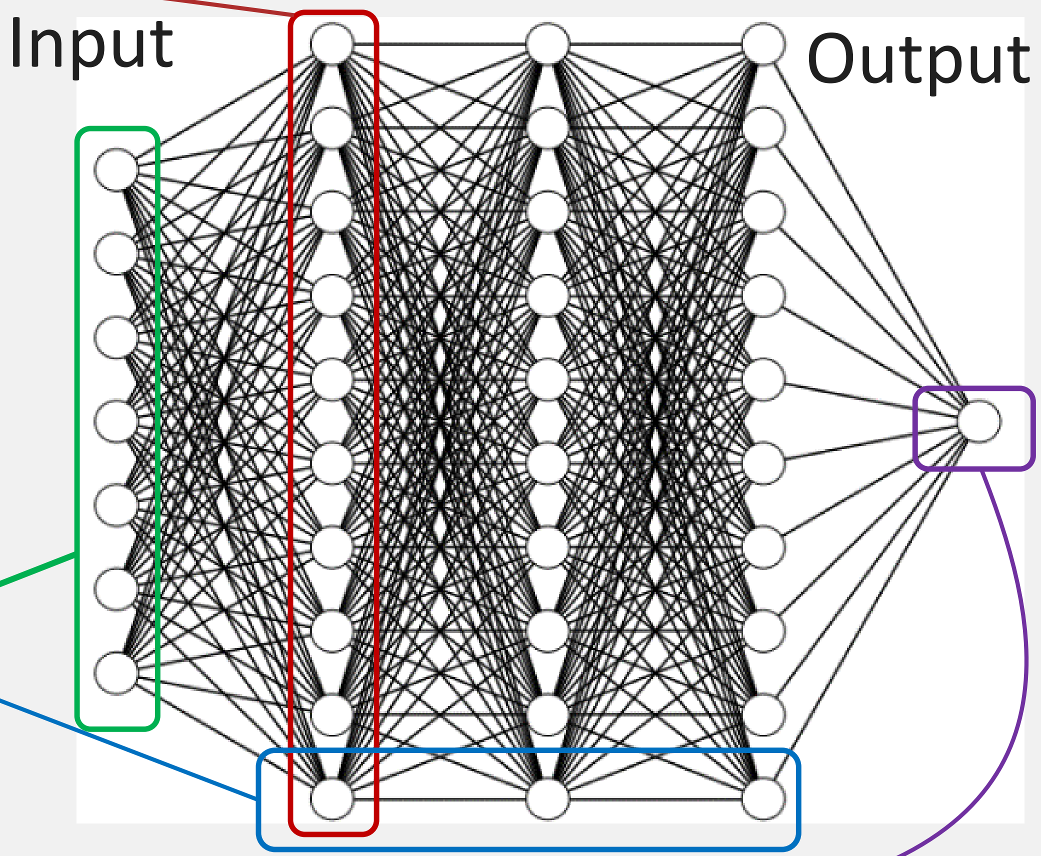
Bergklasse	last_Bergklasse	FeederP_mean	FeederP_med	FeederP_var	HammerP_mean	HammerP_med	HammerP_var	Penetr_mean	Penetr_med	Penetr_var	RotaP_mean	RotaP_med	RotaP_var	WaterF_mean	WaterF_med	WaterF_var	WaterP_mean	WaterP_med	WaterP_var	salvelengde
D	D	78,46	80,68	195,54	149,46	156,41	413,55	3,77	3,62	1,88	95,77	97,52	102,43	118,63	120,39	215,35	20,02	19,75	2,93	3,3
D	D	74,89	77,51	179,98	144,45	152,26	503,44	3,53	3,54	1,07	93,32	94,91	115,22	120,41	124,29	250,07	20,77	20,53	2,96	3,3
D	D	70,77	74	217,94	140,66	149,66	658,37	3,36	3,19	1,06	92,88	92,38	171,14	123,63	127,49	277,77	21,2	21	2,63	6,1
C	D	82,82	81,78	183,37	156,93	161,32	270,66	3,37	3,37	0,45	96,1	99,55	131,37	118,31	123,03	185,78	20,64	20,51	2,75	4,7
C	C	91,85	93,73	156,37	157,44	161,1	237,38	3,19	3,05	1,34	100,71	101,24	45,82	117,66	123	165,08	20,7	20,6	1,45	6,2
D	D	87,01	87,89	177,73	155,55	159,4	294,13	2,77	2,79	0,27	99,38	100,41	65,88	120,87	124,14	215,89	21,38	21,17	4	5,3
C	C	88,76	90,6	133,42	157,79	161,71	258,8	3,28	3,15	1,7	100,01	101,09	52,47	118,06	125,76	293,25	21,31	21,23	1,61	3,4
C	C	86,27	87,4	156,02	161,68	163,28	203,92	3,33	3,1	1,43	101,65	102,31	62,47	119,93	124,58	169,81	21,68	21,35	2,27	5,9
D	C	86,27	87,4	156,02	161,68	163,28	203,92	3,33	3,1	1,43	101,65	102,31	62,47	119,93	124,58	169,81	21,68	21,35	2,27	5,9
C	D	87,11	85,81	138,55	161,83	163,19	172,17	2,98	2,96	0,33	89,97	97,16	328,15	123,18	125,38	133,75	20,43	20,09	3,09	5,6
D	D	88,72	88,92	174,18	162,96	164,43	252,56	3,49	3,52	0,4	97,55	98,12	66,9	114,39	115,05	181,34	21,71	21,52	2,1	5
D	D	90,77	93,59	258,52	150,43	156,15	356,35	3,07	3,09	0,55	93,02	95,85	110,24	114,63	118,06	124,14	20,97	20,97	1,1	5,8
D	D	96,48	102,59	217,04	161,52	160,57	133,11	3,33	3,26	0,37	95,28	96,29	85,69	122,76	125,88	129,93	21,8	21,65	2,02	5,6
C	D	97,48	100,5	142,01	157,81	157,29	156,16	3,46	3,33	0,79	93,41	94,02	75,2	115,69	119,25	105,88	20,77	20,72	2,11	5,7
C	C	97,54	99,78	164,14	161,74	158,86	110,47	3,6	3,53	0,27	98,07	97,67	58,63	117,94	123,59	149,39	21,08	20,75	1,31	5,4
B	C	92,88	93,18	126,4	156,24	156,58	149,77	3,49	3,47	0,3	96,43	97,65	44,53	117,56	120,73	103,47	20,57	20,47	1,34	5,7
B	B	91,95	92,5	138,91	157	158,28	161,53	3,34	3,33	0,46	98,58	99,58	49,42	120,92	125,77	152,14	20,98	20,79	1,65	5,6
C	B	91,59	90,6	133,85	161,01	160,66	150,24	3,5	3,52	0,21	100,61	100,86	41,3	120,09	127,4	157,41	21,27	21,19	0,95	5,7
C	C	86,97	84,16	173,19	158,59	159,36	261,92	3,28	3,28	0,45	90,1	94,74	233,15	119,09	124,57	161,14	20,79	20,79	2,53	5,8
D	C	91,98	89,76	150,37	163,47	161,75	209,07	3,36	3,37	0,15	100,58	101,68	88,16	117,34	122,95	151,72	20,83	20,71	1,23	6,2
C	D	89	87,77	140,4	164,59	163,38	112,6	3,39	3,44	0,34	100,9	101,79	112,01	121,93	124,96	156,85	21,82	21,73	2,9	5,4
C	C	86,69	85,05	145,68	160,13	160,63	166,8	3,51	3,57	0,45	102,79	102	90,84	118,27	122,9	186,11	21,46	21,32	1,62	5,5
C	C	85,76	83,82	118,76	162,92	161,47	63,06	3,57	3,61	0,27	103,39	102,91	77,14	120,48	124,3	154,31	21,76	21,66	1,87	5,3
C	C	88,38	88,76	88,11	155,43	156,33	143,03	3,41	3,39	0,71	99,09	99,38	42,11	114,54	119,62	201,17	21,18	20,97	1,98	5,9
C	C	84,44	83,71	99,85	159,5	159,34	156,83	3,59	3,62	0,26	101,34	100,69	79,07	118,1	123,28	146,97	20,88	20,72	1,08	5,7
C	C	82,71	82,75	101,13	156,29	158,57	195,23	3,54	3,62	0,45	97,66	98,32	92,03	115,77	123,29	223,07	21,25	21,12	1,39	5,9
C	C	89,01	86,47	177,69	162,85	162,93	222,96	3,39	3,52	0,32	101,09	101,41	53,92	112,52	122,19	341,28	21,63	21,48	1,61	5,8
D	C	87,77	85,47	150,68	160,22	160,79	187,33	3,84	3,87	0,49	97,82	98,1	50,64	113,99	119,47	183,71	21,26	21,17	1,2	3,5
D	D	82,06	82,08	116,91	152,7	154,96	219	3,91	3,86	1,48	93,2	94,07	75,21	122,85	128,08	160,57	22,15	22,02	1,89	3,6
D	D	78,83	78,74	70,93	153,94	156,25	160,48	4,24	3,98	3,09	96,47	96,74	96,31	120,88	127,24	212,27	21,75	21,58	1,5	3,7
D	D	85,44	83,45	178,82	154,74	156,87	271,86	3,93	3,72	3,21	95,41	96,35	60,82	121,43	128,56	298,54	21,89	22,01	2,08	3,5
D	D	83,9	82,34	130,68	152,22	154,11	188,96	4,08	3,82	2,7	94,1	94,71	51,88	121,47	126,73	170,84	21,37	21,36	1,92	3,6
D	D	82,85	83,2	127,65	153,27	156,09	240,78	3,94	3,81	1,83	93,35	94,76	100,02	120,56	126,81	237,28	21,49	21,26	1,85	3,6
D	D	76,15	78,14	126,31	164,84	166,54	156,78	3,83	3,58	4,02	74,36	73,44	37,69	121,88	127,2	169,18	21,89	21,61	1,74	3,5
D	D	73,85	74,53	72,34	164,92	165,92	117,36	3,91	3,79	1,84	73,31	73,01	46,64	121,03	128,81	219,24	21,86	21,71	1,35	3,3
D	D	72,75	72,23	172,76	169,01	173,23	159,89	4,18	3,91	3,16	77,41	76,32	126,85	121,64	126,71	202,69	22,22	22,32	3,17	3,2
D	D	71,46	74,55	99,08	159,66	162,17	287,36	3,29	3,34	1,78	76,44	76,07	63,74	129,84	130,93	461,28	22,08	22,15	3,85	5,6
D	D	66,24	66,62	37,75	163,37	166,62	220,85	3,73	3,85	0,42	71,6	69,65	67,76	119,22	126,48	218,38	21,83	21,67	1,48	6,2
C	D	72,05	74,98	87,6	163,67	164,85	167,31	3,5	3,55	0,71	71,63	69,39	55,13	117,74	122,89	195,78	21,1	20,8	2,65	5,1
C	C	75,53	76,97	72,7	163,94	166,29	215,71	3,62	3,6	0,91	77,15	74,93	118,24	121,92	125,01	174,26	22,36	22,05	3,1	5,6

ANN model

- We use KERAS running on top of TensorFlow in Python to perform a supervised non-linear regression analysis.
- The Artificial Neural Network (ANN) is a Multilayer Perceptron (MLP) model and consists of three layers with a width of 250 neurons each.
- We have 20 Input parameters
- 1 Output per depth
  - Rockmass class

Deep neural network

3 hidden layers



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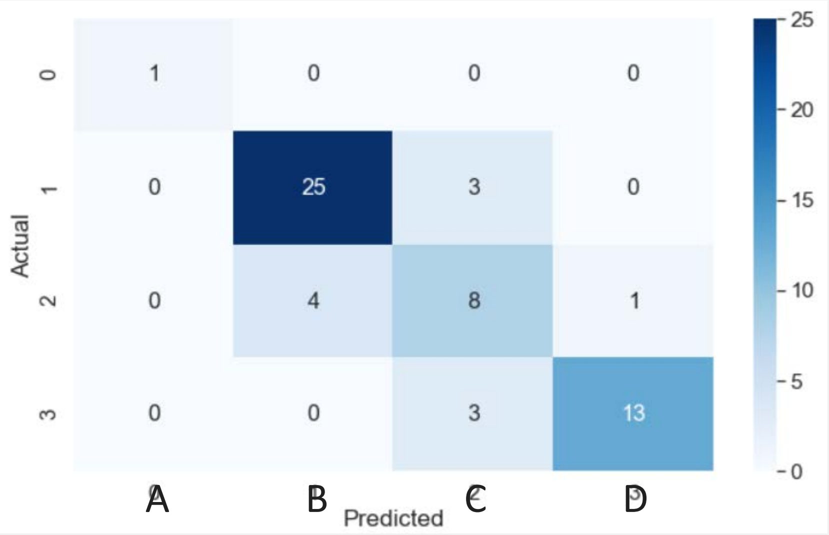
Results

- 75/25 Train and Testset (unseen data for the model)
- Algorithms tested out:
  - Logistic regression: 59%
  - KNN:48%
  - Random Forest: 72%
  - Gradient Boosting: 81%
- 83+/- 8% accuracy on test set with neural network
- Further development:
  - Increase accuracy close to 100% based on clustering and principal component analysis (PCA) – before neural network.
  - Build a more general model based on data from many tunnel projects. Need more data ☺
  - Predict from drilling for grouting 10-15-20 m in advance

```
Epoch 1/20
230/230 [==============================] - 12s 54ms/step - loss: 1.0467 - acc: 0.6696
Epoch 2/20
230/230 [==============================] - 0s 913us/step - loss: 0.5620 - acc: 0.8217
Epoch 3/20
230/230 [==============================] - 0s 875us/step - loss: 0.3977 - acc: 0.8609
Epoch 4/20
230/230 [==============================] - 0s 1ms/step - loss: 0.3371 - acc: 0.8739
Epoch 5/20
230/230 [==============================] - 0s 649us/step - loss: 0.2810 - acc: 0.8870
Epoch 6/20
230/230 [==============================] - 0s 954us/step - loss: 0.2566 - acc: 0.8957
Epoch 7/20
230/230 [==============================] - 0s 865us/step - loss: 0.2125 - acc: 0.9304
Epoch 8/20
230/230 [==============================] - 0s 873us/step - loss: 0.1851 - acc: 0.9304
Epoch 9/20
230/230 [==============================] - 0s 856us/step - loss: 0.1603 - acc: 0.9435
Epoch 10/20
230/230 [==============================] - 0s 824us/step - loss: 0.1412 - acc: 0.9522
Epoch 11/20
230/230 [==============================] - 0s 724us/step - loss: 0.1462 - acc: 0.9304
Epoch 12/20
230/230 [==============================] - 0s 878us/step - loss: 0.1283 - acc: 0.9435
Epoch 13/20
230/230 [==============================] - 0s 1ms/step - loss: 0.1001 - acc: 0.9652
Epoch 14/20
230/230 [==============================] - 0s 719us/step - loss: 0.0845 - acc: 0.9783
Epoch 15/20
230/230 [==============================] - 0s 1ms/step - loss: 0.0706 - acc: 0.9826
Epoch 16/20
230/230 [==============================] - 0s 994us/step - loss: 0.0713 - acc: 0.9783
Epoch 17/20
230/230 [==============================] - 0s 866us/step - loss: 0.0639 - acc: 0.9783
Epoch 18/20
230/230 [==============================] - 0s 770us/step - loss: 0.0510 - acc: 0.9826
Epoch 19/20
230/230 [==============================] - 0s 908us/step - loss: 0.0412 - acc: 0.9957
Epoch 20/20
230/230 [==============================] - 0s 850us/step - loss: 0.0387 - acc: 0.9870
<keras.callbacks.History at 0x17b16290908>
```




```
acc: 80.00%
acc: 83.33%
acc: 75.86%
acc: 93.10%
acc: 82.76%
acc: 89.66%
acc: 82.76%
acc: 93.10%
acc: 64.29%
acc: 84.62%
82.95% (+/- 8.13%)
```

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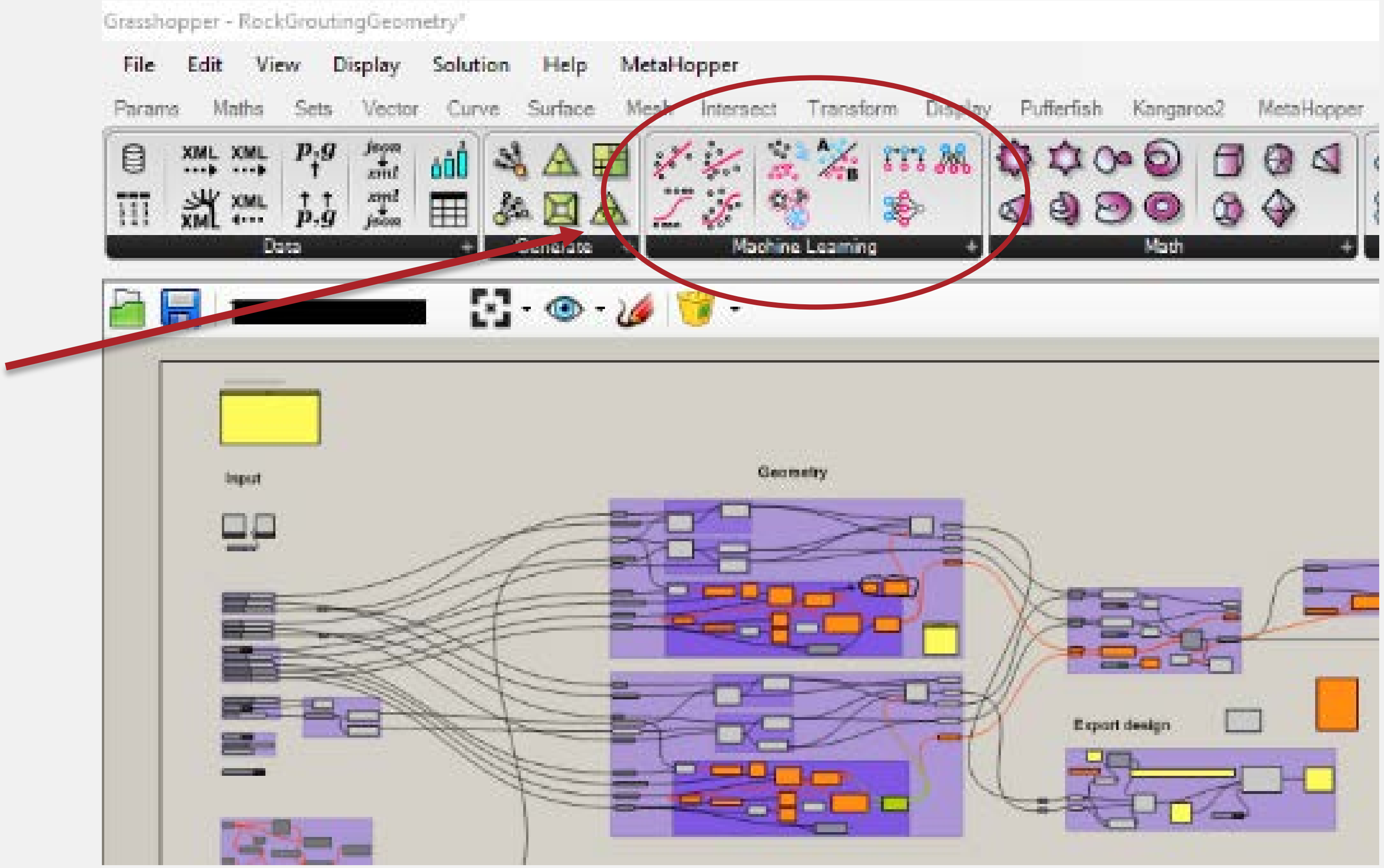
Closing the circle - 3D/BIM in parametric design and tools for machine learning

Modules for machine learning in Grasshopper



#påsikkergrunn

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