Deltares

Memo

To
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Date	Reference	Number of pages
23 December 2015	1220111-006-BGS-0002	11
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Subject
User Manual D-Geo Stability 16.1.2.901

This memo is a user manual for the new shear strength model, called “Su-calculated with Yield Stress”, implemented in D-Geo Stability version 16.1.2.901.

Note that this new model is not yet available in combination with the Reliability Analysis Module (probabilistic analyses). This will be implemented in a future version.

1 Theory

1.1 New Su-calculated model (with yield stress)

The new undrained shear strength model is implemented as follows:

$$s_u = \sigma'_{vi} \times S \times OCR^m, \text{ with } OCR = \sigma'_{vy} / \sigma'_{vi} = (\sigma'_{vi} + POP) / \sigma'_{vi}$$

with:

s_u	Undrained shear strength [kN/m^2]
σ'_{vi}	Effective vertical stress [kN/m^2]
S	Undrained shear strength ratio (normally consolidated) = $(s_u/\sigma'_{vc})_{nc}$ [-]
OCR	Overconsolidation ratio [-]
m	Strength increase exponent [-]
σ'_{vy}	Vertical yield stress [kN/m^2]
POP	Pre overburden pressure [kN/m^2]

1.2 Procedure for the determination of the POP from a list of σ'_{vy}-measurements

When one or more yield stress values are measured at certain levels, these data must be assigned to the soils. The following procedure is used:

- First, the geometry is divided in columns, and these columns are divided in areas (see paragraph 3.2.1 called “Definition of a stress grid” of the functional design of the WTI kernel for a detailed description how to get those area’s).
- Next, all the POP-values are calculated (POP = σ'_{vy} - σ'_{vi}) by the kernel at the specified yield stress positions.
- If one or more calculated POP are present in the same soil material, all the areas with this soil material get the average value of these POP.
- Next, along a column, the following is done for the areas without a POP:
  - The areas situated above the highest area with a POP get that POP.

  - The areas situated below the lowest area with a POP get that POP.
  - The areas with a POP above and below get an interpolated value over the Z-coordinate at the middle of these areas.
- Finally, per row, the following is done for the areas without a POP:
  - If no POP is available in an area, the POP given to that area is the POP with the X-coordinate closest to the X-coordinate of the middle of the area.
- In case there are still areas without POP (meaning a column without POP), all the areas in the column get the value of the closest calculated POP.

When determining the POP of a layer, it is not taken into account that the layer changes in thickness or that the surface line above changes.

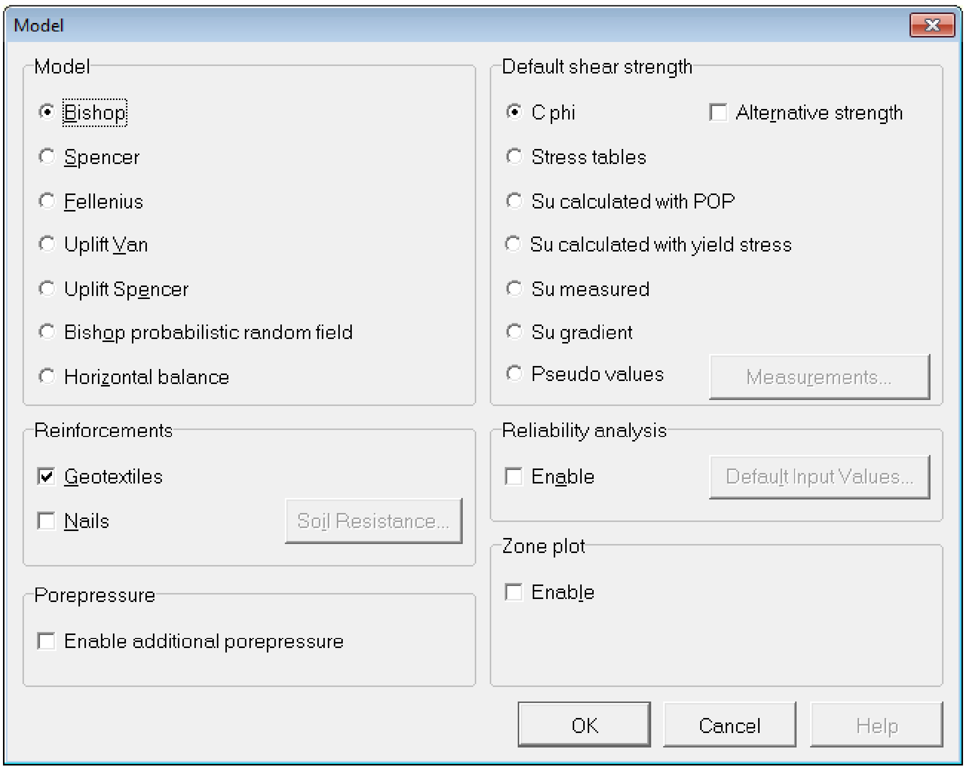
2 User Interface Input

2.1 Model window

In the Model window, the new shear strength method *Su-calculated with yield stress* can be choose as default shear strength model.

The *Su-calculated with POP* model per soil type is still available.

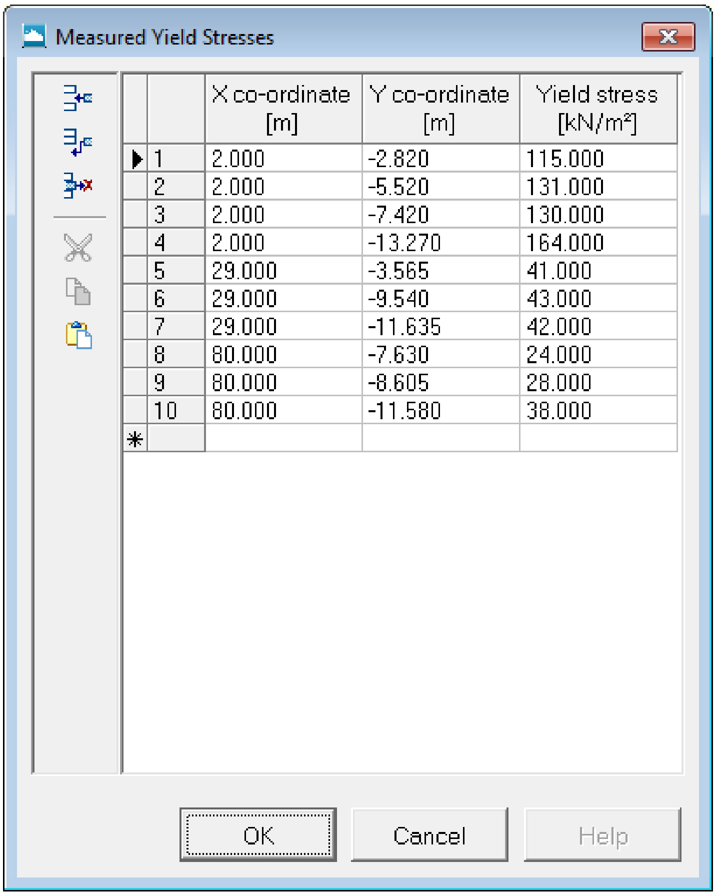
For sand layers, the *C-phi* model can be used; this has to be defined in the *Materials* window, see § 2.3.



2.2 Measured Yield Stresses window

The list of yield stress points with X- and Z-coordinates needed with the *Su-calculated with yield stress* model, can be entered by selecting *Measured Yield Stresses* under the *Soil* menu.

Note that the copy and paste buttons are available to fill the list (copy and paste from an Excel sheet or Matlab or Python output).



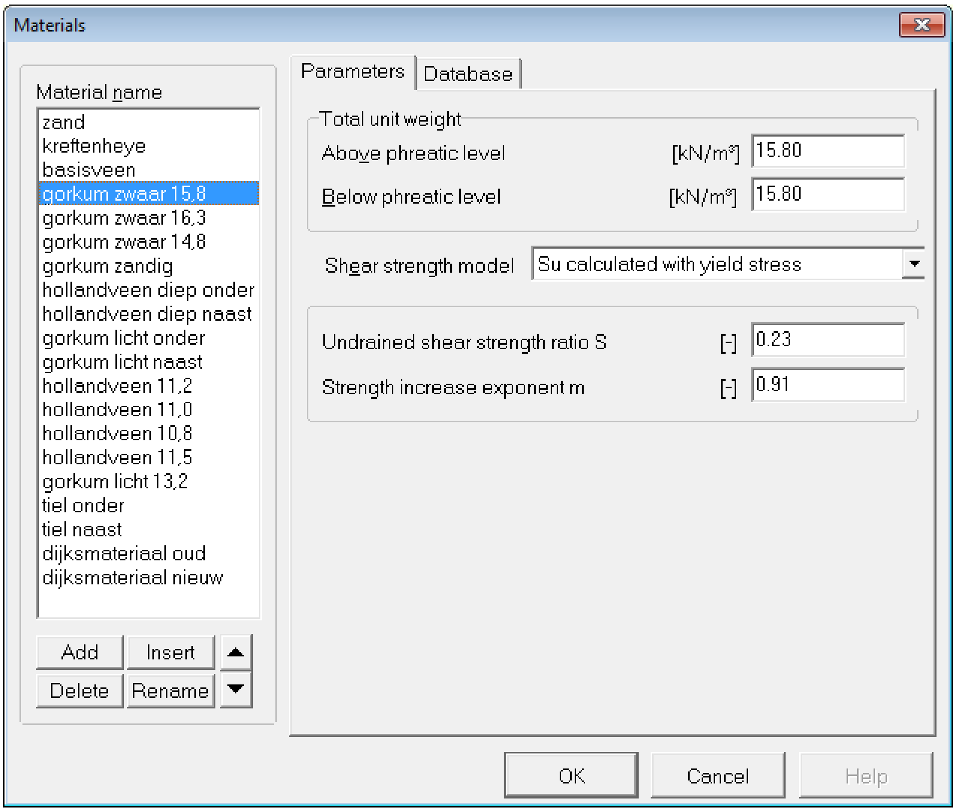
	X co-ordinate [m]	Y co-ordinate [m]	Yield stress [kN/m²]
1	2.000	-2.820	115.000
2	2.000	-5.520	131.000
3	2.000	-7.420	130.000
4	2.000	-13.270	164.000
5	29.000	-3.565	41.000
6	29.000	-9.540	43.000
7	29.000	-11.635	42.000
8	80.000	-7.630	24.000
9	80.000	-8.605	28.000
10	80.000	-11.580	38.000
*			

2.3 Materials window

The shear strength model (and the needed parameters) can be defined by selecting *Materials* under the *Soil* menu. For *Su-calculated with yield stress* model, two parameters need to be defined:

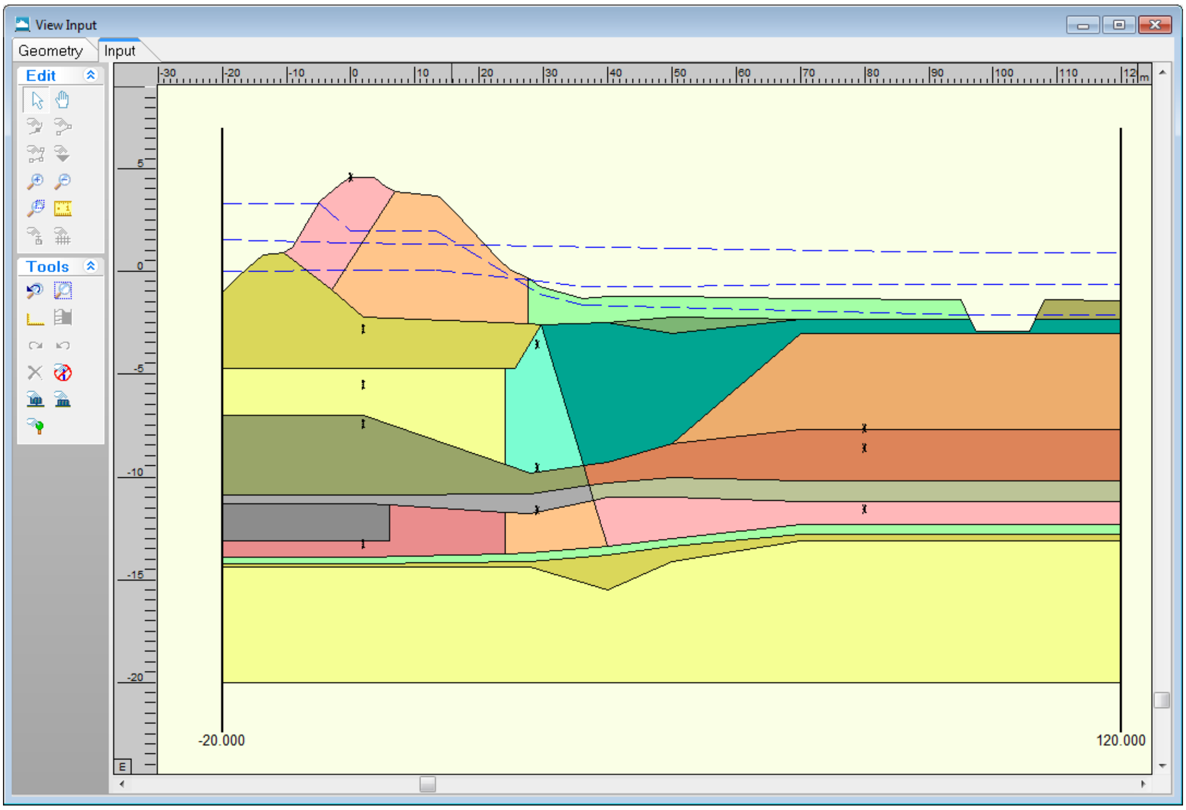
S Undrained shear strength ratio (normally consolidated) = $(s_u/\sigma'_{vc})_{nc}$ [-]

m Strength increase exponent [-]



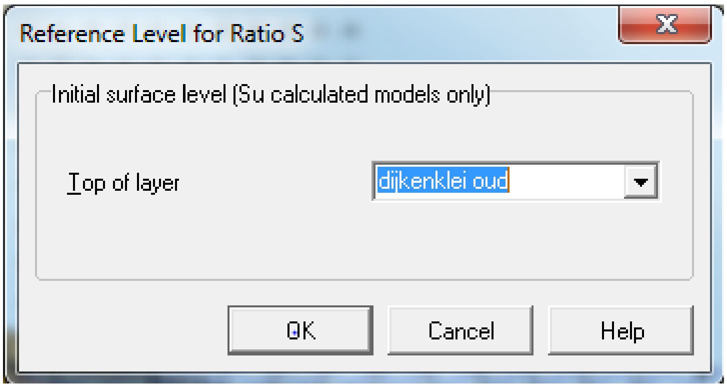
2.4 View Input window

The positions of the yield stress measurements inputted in the *Measured Yield Stresses* window (see § 2.2) are displayed in the *View Input* window (*Input* tab) with the marker ✳, see figure below.



2.5 Reference Level for Ratio S

In this window, it is possible to define a reference surface level. This option applies only to the calculated undrained strength models. It is appropriate to use the reference level, if an embankment has been added to initially over-consolidated soil.



Top of layer: Select the top of the layer that will be used as the reference level.

D-GEO STABILITY uses the reference level to calculate the yield stress:
$\sigma'_{vy} = \max(\sigma'_{vi,ref} + POP; \sigma'_{vi})$

$\sigma'_{vi,ref}$ The reference value of the vertical effective stress is determined from a reference level of the historic ground surface.

σ'_{vi} The vertical effective stress is determined from the top of a new embankment.

3 User Interface Output

3.1 Report window

In the *Report*, the yield stress, POP and OCR per slice are reported.
Note that results per slices are available in the *Report* only if option *Long report* was selected in the *Calculation >> Start* window.

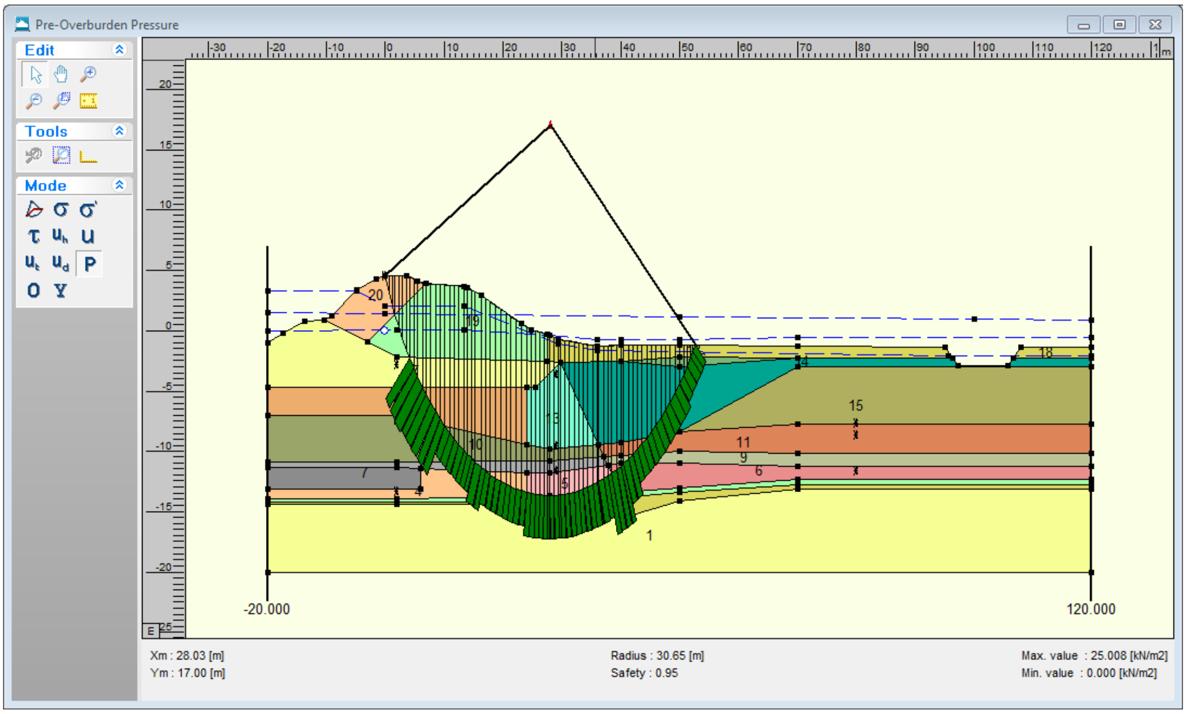
Report

Slice	SPreLoad [kN/m2]	S-eff. [kN/m2]	Yield [kN/m2]	POP [-]	OCR [-]	S [-]	m [-]	Su [kN/m2]
1	0.00	12.60	0.00	0.00	1.00	0.00	0.00	0.00
2	0.00	36.39	0.00	0.00	1.00	0.00	0.00	0.00
3	0.00	50.28	0.00	0.00	1.00	0.00	0.00	0.00
4	0.00	57.88	0.00	0.00	1.00	0.00	0.00	0.00
5	0.00	67.29	0.00	0.00	1.00	0.00	0.00	0.00
6	0.00	76.34	0.00	0.00	1.00	0.00	0.00	0.00
7	0.00	82.45	0.00	0.00	1.00	0.00	0.00	0.00
8	85.35	85.35	110.36	25.01	1.29	0.21	0.89	22.53
9	87.81	87.81	112.82	25.01	1.28	0.21	0.89	23.05
10	91.29	91.29	116.29	25.01	1.27	0.21	0.89	23.78
11	94.13	94.13	117.83	23.70	1.25	0.33	0.86	37.68
12	96.06	96.06	119.76	23.70	1.25	0.33	0.86	38.32
13	98.77	98.77	122.46	23.70	1.24	0.33	0.86	39.21
14	101.26	101.26	124.96	23.70	1.23	0.33	0.86	40.04
15	103.56	103.56	127.26	23.70	1.23	0.33	0.86	40.80
16	106.16	106.16	119.58	13.42	1.13	0.23	0.89	27.15
17	109.05	109.05	122.47	13.42	1.12	0.23	0.89	27.81
18	111.70	111.70	125.12	13.42	1.12	0.23	0.89	28.42
19	114.14	114.14	127.56	13.42	1.12	0.23	0.89	28.98
20	115.71	115.71	129.13	13.42	1.12	0.23	0.89	29.34
21	115.38	115.38	128.80	13.42	1.12	0.23	0.89	29.27
22	113.85	113.85	127.27	13.42	1.12	0.23	0.89	28.92
23	109.29	109.29	126.20	16.91	1.15	0.33	0.86	40.81
24	102.81	102.81	119.72	16.91	1.16	0.33	0.86	38.67
25	97.63	97.63	111.06	13.44	1.14	0.23	0.91	25.25
26	92.66	92.66	106.10	13.44	1.15	0.23	0.91	24.11
27	87.60	87.60	101.04	13.44	1.15	0.23	0.91	22.94
28	82.44	82.44	95.88	13.44	1.16	0.23	0.91	21.75
29	77.19	77.19	90.63	13.44	1.17	0.23	0.91	20.55
30	71.87	71.87	85.30	13.44	1.19	0.23	0.91	19.32
31	66.46	66.46	79.90	13.44	1.20	0.23	0.91	18.08
32	61.27	61.27	74.71	13.44	1.22	0.23	0.91	16.88
33	56.48	56.48	73.39	16.91	1.30	0.23	0.91	16.49
34	53.22	53.22	70.13	16.91	1.32	0.23	0.91	15.73
35	50.19	50.19	67.10	16.91	1.34	0.23	0.91	15.03
36	46.26	46.26	63.17	16.91	1.37	0.23	0.91	14.13
37	42.29	42.29	59.20	16.91	1.40	0.23	0.91	13.21
38	36.38	36.38	53.29	16.91	1.46	0.23	0.91	11.84
39	32.71	32.71	49.62	16.91	1.52	0.23	0.91	10.99

3.2 Stresses window

On the menu bar, click *Results* and then select the *Stresses* option to open a window which gives access to various graphical representations of the calculated results.

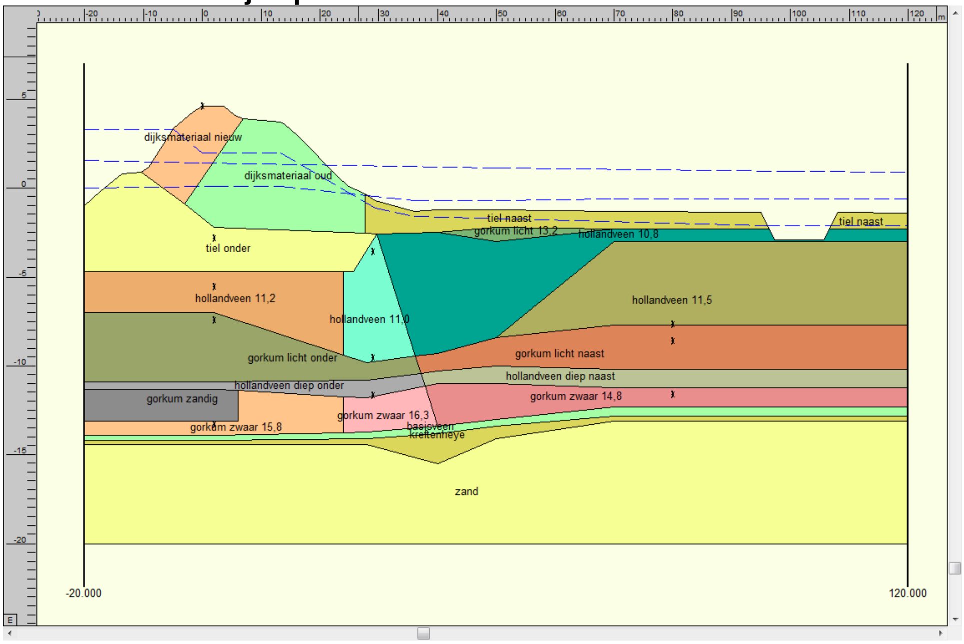
Clicking on the buttons P O Y gives access respectively to the POP, OCR and yield stress per slice along the calculated slip plane.



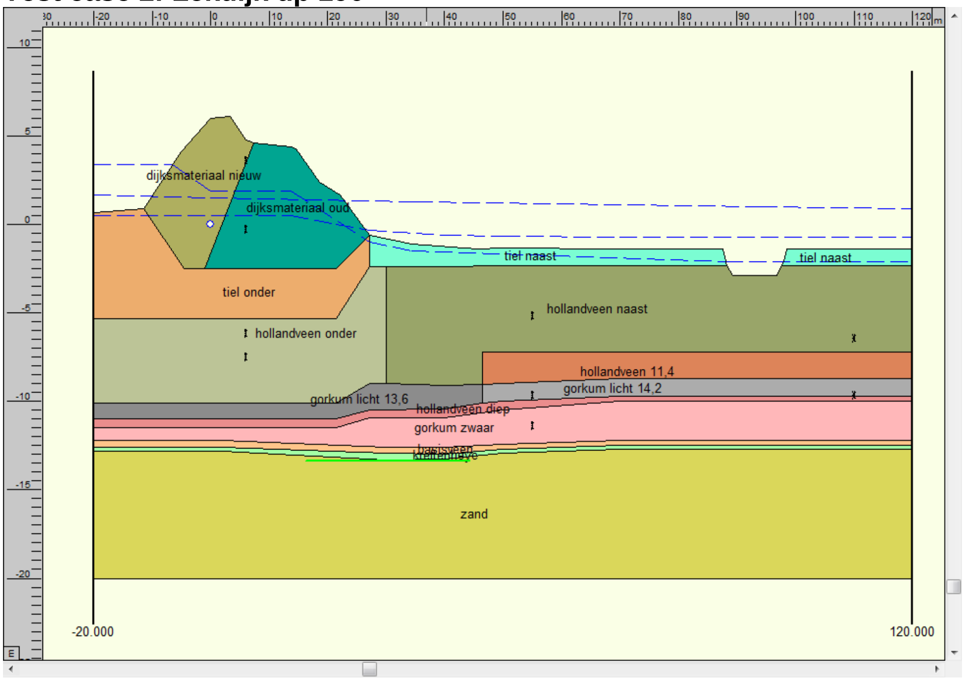
4 Testing the *Su-calculated with yield stress* model

A comparison with the results given by the WTI kernel Macro-Stability has been performed as the *Su-calculated with yield stress* model is also implemented in this kernel.
Four test cases have been used, for the three methods Bishop, Spencer and Uplift-Van and for a single slip plane.

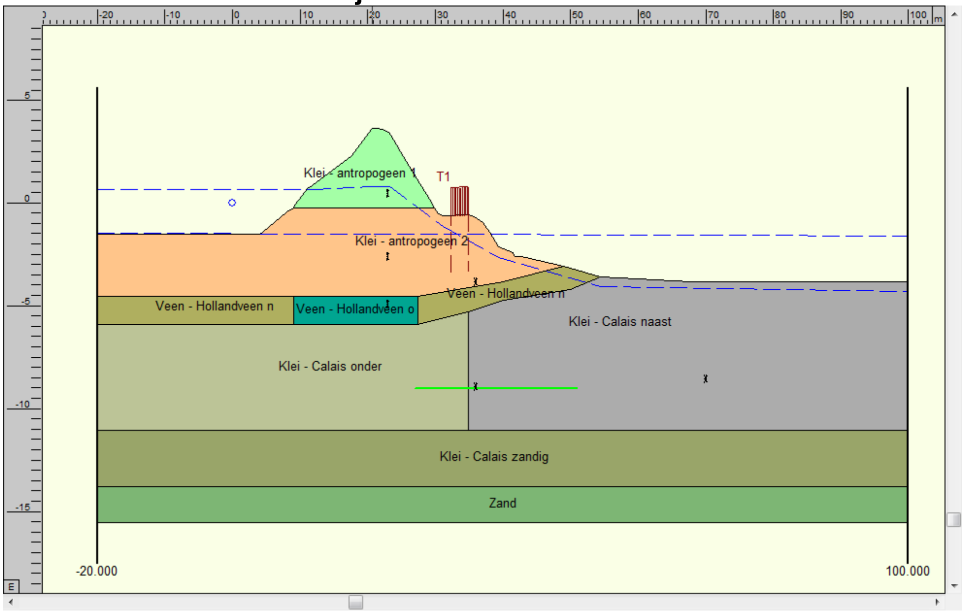
4.1 Test case 1: Lekdijk dp 183



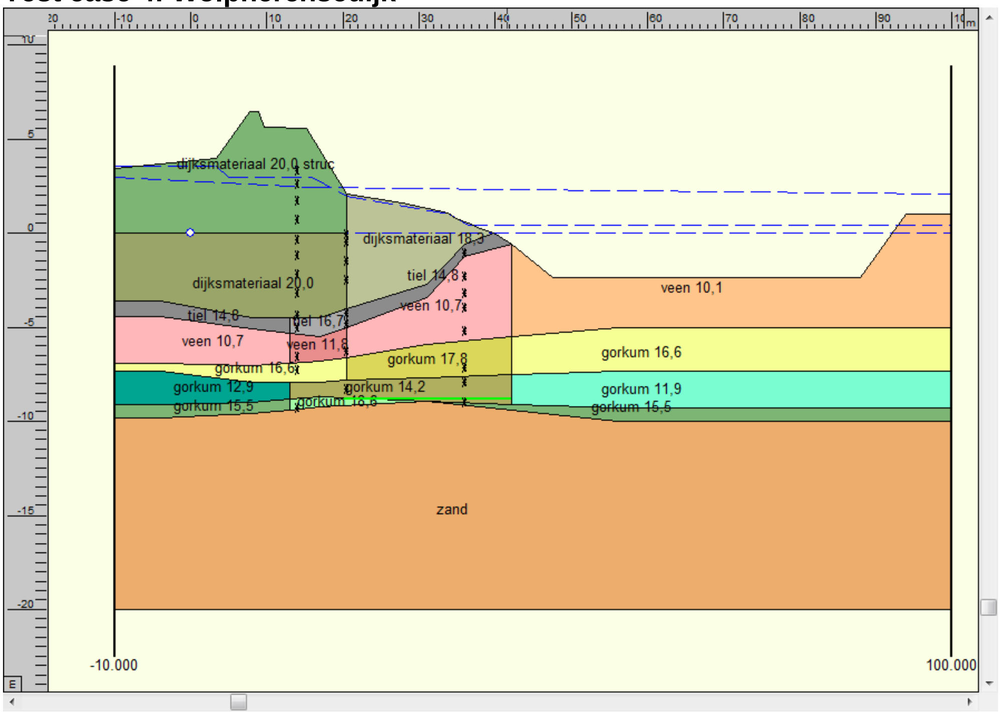
4.2 Test case 2: Lekdijk dp 190



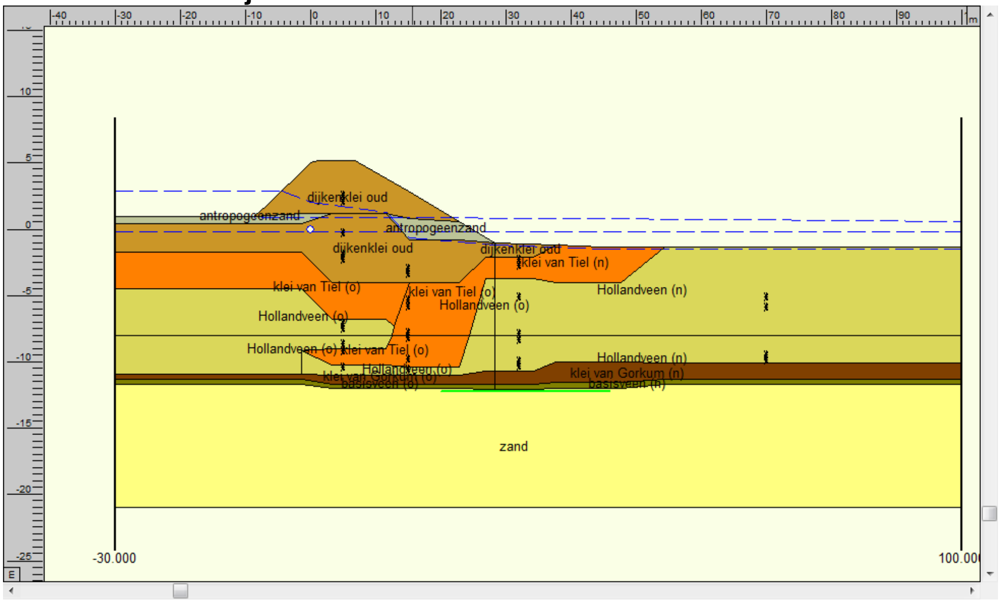
4.3 Test case 3: Markermeerdijk



4.4 Test case 4: Wolpherensedijk



4.5 Test case 5: Lekdijk west 10a ultimate A



4.6 Results of the comparison between D-Geo Stability and WTI MacroStability kernel

The results of the comparison are given in the table below.

The calculated safety factors are very close (and sometimes exactly the same) for the first test case, but not for the other ones because in those test cases the same material is used in different layers and/or contains several yield stress measurements: D-Geo Stability uses an average value of all the POP values available for the material whereas WTI MacroStability uses also an average value of the POP values but per column (of the pre-process calculation) not for the complete section.

		Lekdijk op 183			Lekdijk op 190 (zonder verkeer			Markermeerdijk			Wolpherensedijk			Lekdijk west 10a ultimate A		
Benchmark name		bm5-06a			bm5-06d			bm5-06g			bm5-06j			bm5-06m		
Model		Bishop			Bishop			Bishop			Bishop			Bishop		
		WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]
Safety factor	[-]	0.954	0.954	0.00	0.848	0.838	1.19	0.718	0.729	1.51	1.071	1.061	0.94	0.958	0.926	3.46
Driving moment	[kNm/m]	35534.18	35534.28	0.00	44106.07	44104.18	0.00	11851.36	11850.9	0.00	25878.25	25878.25	0.00	50199.28	50199.62	0.00
Resisting moment	[kNm/m]	33890.61	33898.17	0.02	37415.50	36969.04	1.21	8511.81	8642.15	1.51	27716.12	27458.96	0.94	48106.10	46495.89	3.46
Benchmark name		bm5-06b			bm5-06e			bm5-06h			bm5-06k			bm5-06n		
Model		Uplift-Van			Uplift-Van			Uplift-Van			Uplift-Van			Uplift-Van		
		WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]
Safety factor	[-]	0.945	0.944	0.11	0.811	0.799	1.50	1.164	1.178	1.19	1.107	1.125	1.60	0.901	0.881	2.27
Forces :																
Force Ia	[kN/m]	404.13	403.25	0.22	192.92	179.94	7.21	247.00	274.45	10.00	304.86	301.44	1.13	209.77	230.97	9.18
Force Ip	[kN/m]	397.08	396.32	0.19	188.64	175.32	7.60	259.82	281.94	7.85	139.26	138.00	0.91	115.44	120.87	4.49
Force Fs	[kN/m]	25.29	25.36	0.28	4.76	4.98	4.42	20.57	25.89	20.55	236.75	234.61	0.91	103.17	110.01	6.22
Moments :																
Active driving moment	[kNm/m]	44482.44	44482.16	0.00	29648.78	29656.41	0.03	10842.09	10845.03	0.03	31099.17	31085.60	0.04	52522.75	52518.79	0.01
Active resisting moment	[kNm/m]	31043.68	31042.11	0.01	20086.75	20062.91	0.12	7992.45	7569.99	5.58	26600.92	27098.24	1.84	40315.81	38731.55	4.09
Passive driving moment	[kNm/m]	-1699.63	-1687.78	0.70	-221.97	-234.69	5.42	-1061.36	-1061.65	0.03	-593.10	-594.62	0.26	-151.82	-157.36	3.52
Passive resisting moment	[kNm/m]	2848.96	2849.28	0.01	1102.03	986.60	11.70	1698.64	1971.00	13.82	1066.12	1065.59	0.05	701.99	720.15	2.52
Benchmark name		bm5-06c			bm5-06f			bm5-06i			bm5-06l			bm5-06o		
Model		Spencer			Spencer			Spencer			Spencer			Spencer		
		WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]	WTI Macro-Stability	D-Geo Stability	Error [%]
Safety factor	[-]	1.351	1.351	0.00	1.222	1.198	2.00	0.776	0.769	0.91	1.904	1.925	1.09	1.243	1.208	2.90