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Notitie

Opdrachtgever
NUON-Warmte

Opgesteld door
J. Tjon-A-San

Datum
19 december 2017

Project
GWL terrein

Kenmerk
AE16002-13-N04-0

Onderwerp
Bepalen trekkracht Flexwelll leiding

Pagina
1 van 5

1. Inleiding

Met D-Geo Pipeline kunnen de trekkrachten, voor een boring, berekend worden. Om de berekening te kunnen maken dienen de specificaties van de leiding te worden ingevoerd. Aangezien D-geo rekent op basis van een gladde buis is het noodzakelijk om de stijfheid van een Flexwell leiding te vertalen naar een gladde buis. In deze notitie wordt toegelicht hoe de invoer van de D-geo berekening is bepaald, en welke verwachte trekkracht dit oplevert.

2. Uitgangspunten

Een Flexwell leiding bestaat uit een stalen mediumvoerende buis, pur, stalen mantelbuis en PE coating laag. Voor de benadering zijn alleen de stalen medium voerende buis en stalen mantelbuis beschouwt, de pur en coating bezitten een hoge flexibiliteit en zijn om deze reden niet meegenomen in de berekening. Zowel de medium voerende buis als de stalen behuizing zijn beide maatgevend voor de stijfheid. De bepaalde gladde buis dient dezelfde buitendiameter en zelfde buigstijfheid te bezitten als de Flexwell leiding om de trekkrachten correct te kunnen bepalen.

3. Geometrie Flexwell leiding

De geometrie van de DN150 Flexwell leiding is door de fabrikant verstrekt en wordt in het vervolg van deze notitie gebruikt, de specificaties van de geometrie staan in bijlage 1. Voor de medium voerende buis en stalen mantelbuis worden de volgende waarden gehanteerd:

- binnendiameter voor de medium voerend buis: 197,5 mm
- binnendiameter voor de stalen mantelbuis: 268,0 mm

Voor het bepalen van de vervangende gladde buis zijn de binnen diameters van de geribbelde buizen genomen.

De aangehouden wanddiktes zijn voor de medium voerende buis 1,2 mm en voor de stalen mantelbuis 1,3 mm.

4. Bepalen traagheidsmomenten Flexwell leiding

Voordat de stijfheid van een element bepaald kan worden dient het traagheidmoment als eerste te worden berekend.

Met de geometrie, bepaald in hoofdstuk 2, is het traagheidsmoment te bereken aan de hand van de volgende formule:

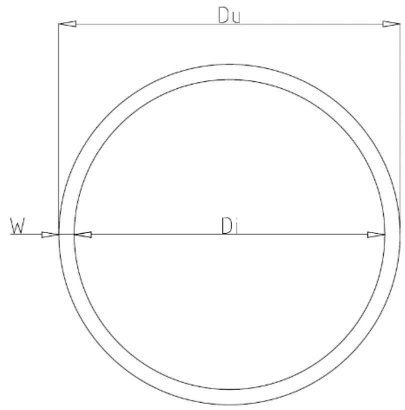
$$\frac{\pi}{64} * (D_u^4 - D_i^4) = I_{traagheidsmoment}\ in\ mm^4$$

Hierin is:

D_u de buiten diameter;

D_i de binnen diameter.

In de schematische tekening hieronder zijn D_u en D_i weergegeven.



Figuur 1 doorsnede buis

Het invullen van de gegevens uit hoofdstuk 2 in de formule geeft de volgende traagheidsmomenten:

- Medium voerende buis I_X = 3697009,552 mm^4
- Stalen mantelbuis I_X = 9970625,827 mm^4

De medium voerende buis bevindt zich binnen in de stalen mantelbuis, de traagheidsmomenten mogen dus gesommeerd worden. Dit geeft het volgende resultaat.

$I_X totaal$ = 13667635,378 mm^4

Het totale traagheidsmoment, berekend uit de twee buizen, wordt gebruikt voor het vervangend gladde buis model.

5. Berekenen geometrie vervangende gladde buis

Op basis van het berekende totale traagheidsmoment bekend kan de geometrische afmeting van de in te voeren gladde buis worden bepaald. Voor de berekening is de I_X gelijk aan 13249281,63 mm^4, de diameter en wanddikte is bereken aan de hand van de volgende formule:

$$\sqrt[4]{((-64 * (I_{medium} + I_{mantel})/\pi) + D_u^4)} = D_i \; in\, mm$$

Invullen van de formule geeft een diameter lengte 267,02 mm. Tijdens de boring ondervindt de leiding wrijving op de buitenste diameter, met deze diameter wordt de wanddikte bepaald op de volgende manier.

$$\frac{D_{buitendiameter} - D_i}{2} = w_{wanddikte} \; in\, mm$$

Hieruit volgt dat w gelijk is aan 1,8 mm, en D_u gelijk aan 270,6 mm. .

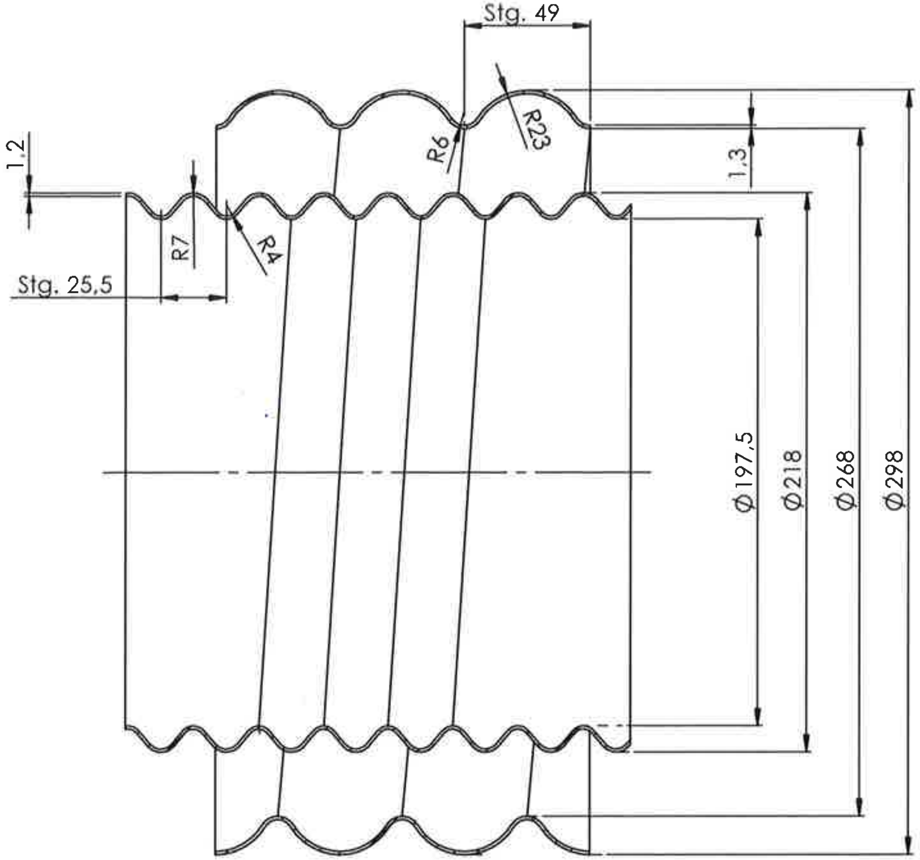
6. D-Geo berekening

Met de geometrie van de gladde buis is de trekkracht en de grondbelasting te bepalen aan de hand van D-Geo Pipeline. Het programma bepaald de waarden door een berekening en noteert dit vervolgens in een rapport, het rapport voor DN150 Flexwell leiding is bijgevoegd in bijlage 2. Uit het D-Geo rapport volgt een maatgevende trekkracht van 57 kN en een gereduceerde grondbelasting van 40 $\mathrm{kN/m^2}$. Om conservatief te kunnen rekenen is er een veiligheidsfactor van 1,4 toegepast op de trekkracht, hierdoor is de rekenwaarde voor de trekkracht gelijk aan 79,8 kN.

7. Conclusie

Uit de geometrische berekening volgt dat een DN150 Flexwell leiding benaderbaar is met een gladde buis. De diameter en wanddikte van de vervangende gladde buis hoort gelijk te zijn aan 270,6 mm en 1,8 mm, beide waarden zijn conservatief. Het invoeren van de geometrie in D-Geo Pipeline geeft een kort rapport met daarin een analyse van de boring. Uit het rapport volgt tevens een berekende trekkracht van 79,8 kN. hierin is veiligheidsfactor van 1,4 meegerekend. Voor de grondbelasting is de gereduceerde grondbelasting als maatgevend beschouwt waardoor de grondbelasting gelijk is aan 40 $\mathrm{kN/m^2}$.

BIJLAGE 1 GEOMETERISCHE AFMETINGEN FLEXWELL 200/310 (DN 150)



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02. DEZ. 2016

BRUGG PIPESYSTEMS
Flexible solutions

FHK 200-310 - 01

Modell: FHK 200-310

BIJLAGE 2 D-GEO PIPELINE FLEXWELL DN150 RAPPORT

Report for D-Geo Pipeline 16.1

Model : Horizontal Directional Drilling
Developed by Deltares

Date of report:	19-12-2017
Time of report:	10:17:55
Filename:	F:\..\8–Results\4–Berekening\D-Geo\HDD Haarlemmervaart
Project identification:	HDD Haarlemmervaart

1 Table of Contents

2 Input Data

2.1 Model Used

Model Used : Horizontal Directional Drilling

2.2 Layer Boundaries

Boundary number	Co-ordinates [m]				
9 - X -	0,000	49,925	50,325	51,725	52,125
9 - Y -	-0,100	-0,101	-0,900	-0,900	-0,101
9 - X -	59,200	63,085	66,275	90,725	91,873
9 - Y -	-0,103	-1,316	-2,300	-2,300	-1,446
9 - X -	94,375	200,000			
9 - Y -	0,650	0,813			
8 - X -	0,000	63,085	66,275	90,725	91,873
8 - Y -	-1,000	-1,316	-2,300	-2,300	-1,446
8 - X -	94,375	200,000			
8 - Y -	0,650	0,813			
7 - X -	0,000	63,085	66,275	90,725	91,873
7 - Y -	-1,000	-1,316	-2,300	-2,300	-1,446
7 - X -	200,000				
7 - Y -	-2,000				
6 - X -	0,000	200,000			
6 - Y -	-2,000	-3,000			
5 - X -	0,000	200,000			
5 - Y -	-4,500	-5,500			
4 - X -	0,000	200,000			
4 - Y -	-12,300	-12,000			
3 - X -	0,000	200,000			
3 - Y -	-12,800	-12,500			
2 - X -	0,000	200,000			
2 - Y -	-16,500	-16,800			
1 - X -	0,000	200,000			
1 - Y -	-18,500	-18,000			
0 - X -	0,000	200,000			
0 - Y -	-20,500	-20,500			

2.3 PI-lines

PI-line number	Co-ordinates [m]				
1 - X -	0,000	200,000			
1 - Y -	-0,417	-0,417			

2.4 Phreatic Line

Piezo-line 1 is used as phreatic line (groundwater).

2.5 Soil Profiles

Layer number	Material name	Piezo-line at top	Piezo-line at bottom
9	Matig vast zand	1	1
8	Matig vast zand	1	1
7	Matig vast klei	1	1
6	Veen	1	1
5	Matig vast klei	1	1
4	Veen	1	1
3	Matig vast zand	1	1
2	Matig vast klei	1	1
1	Vast Zand	1	1

2.6 Selected Boundaries

The boundary between cohesive top layers and under laying non-cohesive drained layers, is situated at the top of layer number 3: Matig vast zand
The boundary between compressible top layers and under laying non-compressible layers, is situated at the top of layer number 1: Vast Zand

2.7 Configuration of the Pipe Line

X co-ordinate left point	13,67	[m]
Y co-ordinate left point	-0,10	[m]
Z co0ordinate left point	0,00	[m]
X co-ordinate right point	173,06	[m]
Y co-ordinate right point	0,80	[m]
Z co-ordinate right point	0,00	[m]
Angle left	18,00	[degrees]
Angle right	18,00	[degrees]
Lowest level of pipe (centre bore hole)	-13,20	[m]
Angle of pipe (between radii)	0,00	[degrees]
Bending radius pipe on rollers	150,00	[m]
Bending radius left, vertical in/out	200,00	[m]
Bending radius right, vertical in/out	200,00	[m]
Number of horizontal bends	1	[-]

The pulling direction of the product pipe is from left to right

Bending nr.	X1-coord [m]	Z1-coord [m]	X2-coord [m]	Z2-coord [m]	Bending radius [m]	Direction [-]
1	13,67	0,00	173,06	0,00	115,00	right

2.8 Calculation Verticals

Vertical nr.	L-coord [m]	Z-coord [m]	Additional settlement [mm]
1	20,00	-2,16	0,00
2	30,00	-5,30	0,00
3	40,00	-7,92	0,00
4	50,00	-9,99	0,00
5	60,00	-11,55	0,00
6	70,00	-12,59	0,00
7	80,00	-13,12	0,00
8	90,00	-13,20	0,00
9	100,00	-13,20	0,00
10	110,00	-13,20	0,00
11	120,00	-13,14	0,00
12	130,00	-12,64	0,00
13	140,00	-11,63	0,00
14	150,00	-10,12	0,00
15	160,00	-8,07	0,00
16	170,00	-5,49	0,00
17	180,00	-2,38	0,00

Locations of the calculation verticals; L represents distance along the pipe line projection in the horizontal plane, incremented with the entry co-ordinate.

2.9 Material Types

Name	Gamma unsat [kN/m³]	Gamma sat [kN/m³]	Cohesion [kN/m²]	Phi [degrees]	Cu top [kN/m²]	Cu bottom [kN/m²]	Emod top [kN/m²]	Emod bottom [kN/m²]
Veen	10,00	12,00	1,25	15,00	10,00	20,00	200	500
Matig vast klei	17,00	17,00	5,00	17,50	50,00	50,00	2000	2000
Matig vast zand	18,00	20,00	0,00	32,50	0,00	0,00	45000	45000
Vast Zand	19,50	21,50	0,00	37,50	0,00	0,00	75000	110000

Name	Adhesion A [kN/m²]	Delta D [degrees]	Nu [-]
Veen	-	-	0,20
Matig vast klei	-	-	0,41
Matig vast zand	-	-	0,31
Vast Zand	-	-	0,29

2.10 Product Pipe Material Data

Material	Steel	
Quality	Flexwell	
Negative wall thickness tolerance	10	[%]
Yield strength (Re)	235	[N/mm²]
Partial material factor	1,10	[-]
Partial material factor for test pressure	1,00	[-]
Young's modulus	207000	[N/mm²]
Outer diameter product pipe	267,02	[mm]
Wall thickness (Nominal)	1,80	[mm]
Unit weight pipe material	370,09	[kN/m³]
Design pressure	23,00	[bar]
Test pressure	50,00	[bar]
Temperature variation	120,00	[deg C]

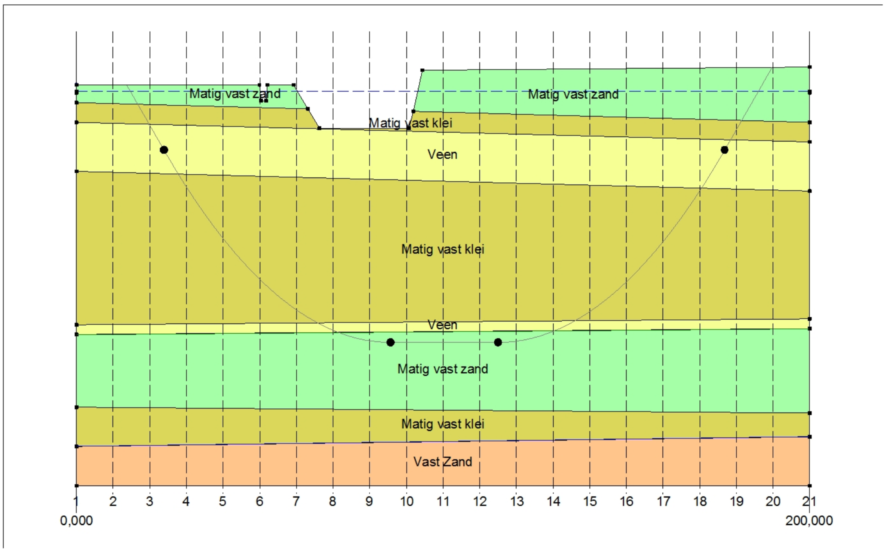
2.11 Pipe Engineering Data

Pipe filled with water on rollers	No	
Part of cross section filled with fluid	0	[%]
Unit weight fluid	10,00	[kN/m³]
Relative displacement	10,00	[mm]
Compression index	6,00	[-]
Linear settlement coefficient (alpha_g) for steel	0,00	[mm/mmK]
Linear settlement coefficient (alpha_g) for PE	0,00	[mm/mmK]
Modulus of subgrade reaction drilling fluid (Kv)	500,00	[kN/m³]
Phi drilling fluid	15,00	[degrees]
Cohesion drilling fluid	5,00	[kN/m²]
Bedding angle	120	[degrees]
Load angle	180	[degrees]
Factor of friction pipe-roller (f1)	0,10	[-]
Friction pipe-drilling fluid (f2)	0,000050	[N/mm²]
Factor of friction pipe-soil (f3)	0,20	[-]
Special stress analysis	not used	

2.12 Geometry

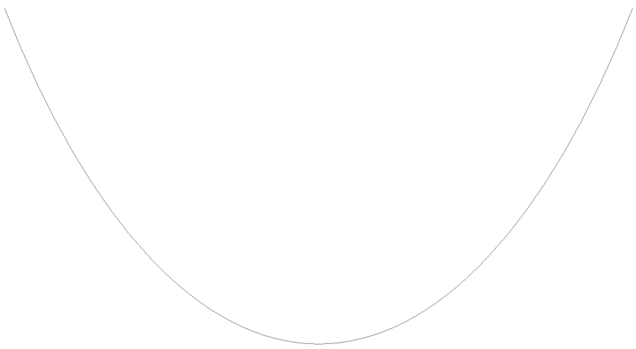
2.12.1 Geometry Section, Detailed

Input View



2.12.2 Geometry Top View

Top View



2.13 Drilling Fluid Data

Diameter pilot hole	0,150	[m]
Outer diameter pilot pipe	0,013	[m]
Diameter preream hole	0,250	[m]
Outer diameter drillpipe	0,080	[m]
Diameter bore hole product pipe	0,345	[m]
Outer diameter product pipe	0,267	[m]
Annular back flow rate pilot	780,0	[liter/minute]
Annular back flow rate pre-reaming	1960,2	[liter/minute]
Annular back flow rate ream and pull-back	949,8	[liter/minute]
Circulation loss factor pilot	0,30	[-]
Circulation loss factor pre-reaming	0,20	[-]
Circulation loss factor ream and pull-back	0,20	[-]
Unit weight drilling fluid (gamma)	11,1	[kN/m³]
Yieldpoint drilling fluid (Tau)	0,014	[kN/m²]
Plastic viscosity drilling fluid (Mu)	0,000040	[kN.s/m²]

2.14 Factors

Safety factor implosion (Long)	3,0	[-]
Safety factor implosion (Short)	1,5	[-]
Contingency factor on total unit weight material types below and above phreatic level	1,10	[-]
Contingency factor on Cu/cohesion	1,40	[-]
Contingency factor on Phi	1,10	[-]
Contingency factor on E-modulus	1,25	[-]
Contingency factor on pulling force	1,40	[-]
Contingency factor on modulus of subgrade reaction	1,60	[-]
Contingency factor on soil load Qn	1,10	[-]
Contingency factor on pressure borehole	1,10	[-]
Steel: Contingency factor on bending radius	1,10	[-]
Contingency factor on bending moment (Steel)	1,15	[-]
Contingency factor on bending moment (Polyethene)	1,40	[-]
Steel: Load factor on design pressure	1,20	[-]
Steel: Load factor on design pressure (combination)	1,20	[-]
Steel: Load factor on test pressure	1,00	[-]
Steel: Load factor installation	1,00	[-]
Steel: Load factor on soil load Qn	1,50	[-]
Steel: Load factor on temperature	1,00	[-]
Steel: Load factor on traffic load	1,35	[-]
Factor of importance (S)	1,00	[-]
Allowable deflection of steel pipe	15,00	[%]
Allowable piggability of steel pipe	6,00	[%]
Allowable deflection of polyethene pipe	8,00	[%]
Allowable piggability of polyethene pipe	6,00	[%]
Unit weight water	10,00	[kN/m³]
Safety factor cover (drained layer)	0,50	[-]
Safety factor cover (undrained layer)	0,50	[-]

3 Drilling Fluid Pressures

3.1 Drilling Fluid Data

Vertical nr.	Drilling fluid pressures pilot [kN/m²]			
	Max, deformation	Max, soil cover	Min, left	Min, right
1	172	172	26	126
2	182	182	67	155
3	227	227	102	179
4	255	255	130	196
5	276	276	153	208
6	231	231	170	214
7	340	247	181	215
8	352	268	187	210
9	433	352	193	205
10	436	357	198	199
11	430	342	203	193
12	269	263	203	182
13	291	291	197	166
14	270	270	186	143
15	242	242	169	115
16	146	146	145	81
17	188	188	117	41

Vertical nr.	Drilling fluid pressures preream [kN/m²]			
	Max, deformation	Max, soil cover	Min, left	Min, right
1	172	172	26	26
2	182	182	65	67
3	227	227	99	102
4	255	255	126	130
5	276	276	148	153
6	231	231	164	170
7	340	215	174	181
8	352	230	180	187
9	433	291	184	193
10	436	295	188	191
11	430	284	192	186
12	269	263	182	176
13	291	291	166	161
14	270	270	143	139
15	242	242	115	112
16	146	146	81	79
17	188	188	41	40

Vertical nr.	Drilling fluid pressures pull back [kN/m²]			
	Max, deformation	Max, soil cover	Min, left	Min, right
1	163	163	29	26
2	182	182	75	65
3	227	227	114	99
4	255	255	147	126
5	276	276	175	148
6	231	231	196	164
7	340	214	203	174
8	352	211	200	180
9	433	261	195	184
10	436	264	191	188
11	430	255	186	192
12	269	263	176	191
13	291	291	161	184
14	270	270	139	162
15	242	242	112	129

Vertical nr.	Drilling fluid pressures pull back [kN/m²]			
	Max, deformation	Max, soil cover	Min, left	Min, right
16	146	146	79	91
17	180	180	40	45

The minimum required drilling fluid pressure is calculated and can be compared with the calculated maximum allowable drilling fluid pressure. The maximum pressure based on deformation indicates the formation of cracks around the borehole, while the maximum pressure based on soilcover indicates a frac-out towards the surface.

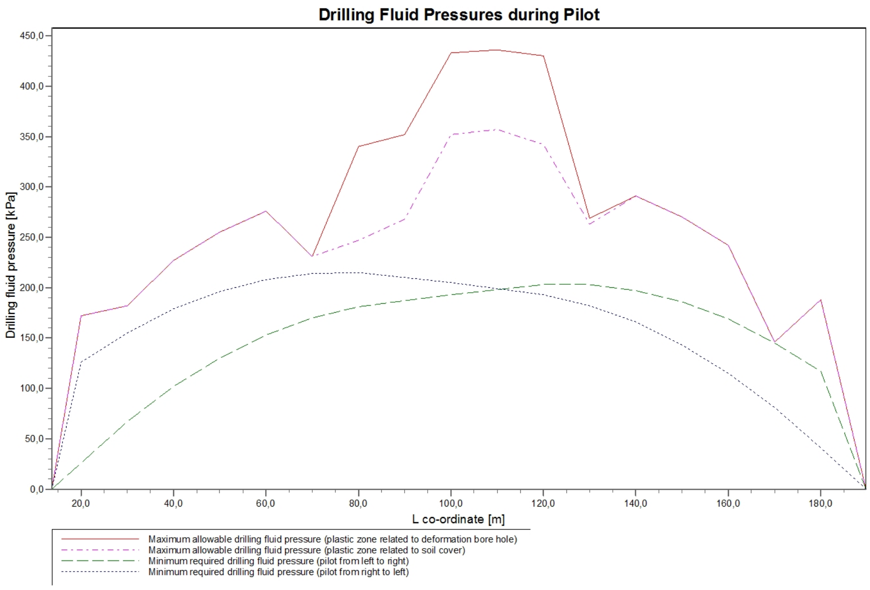
3.2 Equilibrium between Drilling Fluid Pressure and Pore Pressure

Vertical nr.	Static column pressure			
	Drilling fluid [kN/m²]	Water [kN/m²]	Safety [-]	Result
1	23	17	1,31	sufficient
2	58	49	1,19	sufficient
3	88	75	1,17	sufficient
4	112	96	1,16	sufficient
5	129	111	1,16	sufficient
6	142	122	1,16	sufficient
7	148	127	1,17	sufficient
8	150	128	1,17	sufficient
9	150	128	1,18	sufficient
10	151	128	1,18	sufficient
11	151	127	1,19	sufficient
12	146	122	1,20	sufficient
13	136	112	1,21	sufficient
14	119	97	1,23	sufficient
15	97	77	1,27	sufficient
16	69	51	1,37	sufficient
17	35	20	1,80	sufficient

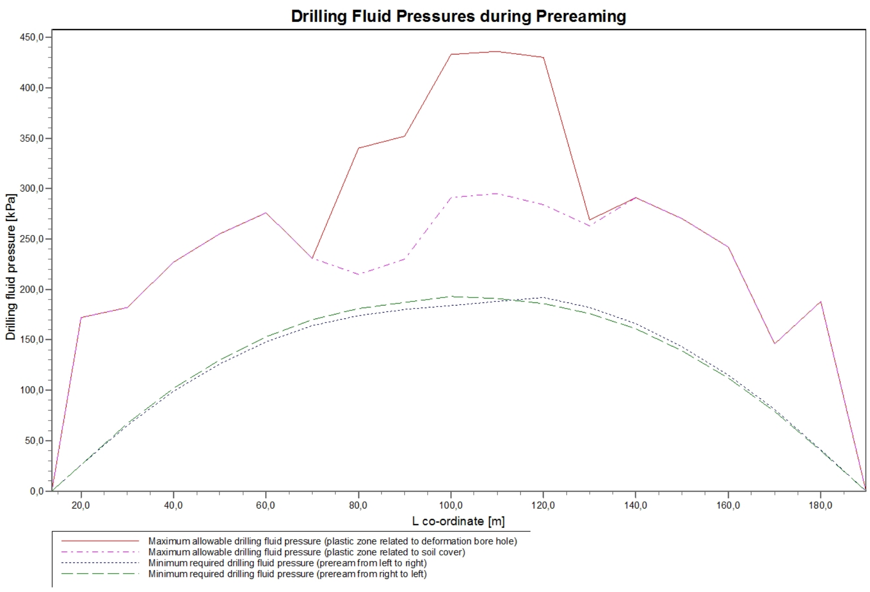
The static drilling fluid pressure is calculated and can be compared with the calculated groundwater pressure. The quotient of the drilling fluid pressure and the groundwater pressure yields the safey factor, which should be higher than the requested factor of safety of 1,10.

3.3 Drilling Fluid Pressure Plots

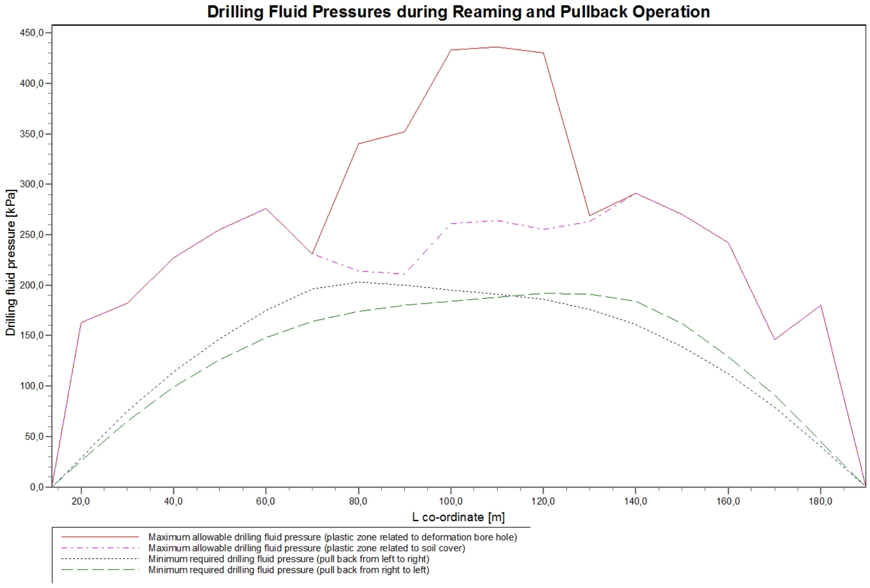
3.3.1 Drilling Fluid Pressures during Pilot



3.3.2 Drilling Fluid Pressures during Prereaming



3.3.3 Drilling Fluid Pressures during Reaming and Pullback Operation



4 Soil Mechanical Parameters

4.1 Soil Mechanical Parameters (Pipe: DN150/250)

The list with data and issues is shown hereafter:
Note: safety factors not applied.

Pv;p	Passive soil load	kN/m²
Pv;n	Neutral soil load	kN/m²
Ph;n	Neutral horizontal soil load	kN/m²
Pv,r;n	Reduced neutral soil load	kN/m²
kv;top	Vertical modulus of subgrade reaction upward	kN/m³
kv;top,max	Maximum vertical modulus of subgrade reaction upward	kN/m³
dv	Vertical displacement	mm
kv	Vertical modulus of subgrade reaction downward	kN/m³
Pv;e	Vertical bearing capacity	kN/m²
kh	Horizontal modulus of subgrade reaction	kN/m³
Ph;e	Horizontal bearing capacity	kN/m²
tmax	Maximal friction pipe-lubricant	kN/m²
dmax	Displacement at maximal friction	mm

Vertical nr.	Pv;p [kN/m²]	Pv;n [kN/m²]	Ph;n [kN/m²]	Pv;r;n [kN/m²]	kv;top [kN/m³]
1	43	19	14	19	28098
2	119	29	14	19	1541
3	158	47	20	27	3388
4	182	59	23	32	3388
5	200	68	25	34	3388
6	112	57	22	30	2694
7	666	61	21	29	19110
8	673	62	21	29	24549
9	920	98	28	37	25407
10	923	98	28	38	26266
11	922	98	28	38	23566
12	893	94	28	38	2359
13	239	90	29	40	3388
14	220	79	28	38	3388
15	194	66	25	34	3388
16	159	48	22	30	582
17	139	39	20	27	62937

Vertical nr.	dv [mm]	kv [kN/m³]	Pv;e [kN/m²]	kh [kN/m³]	Ph;e [kN/m²]	tmax [kN/m²]	dmax [mm]
1	0	402	129	281	43	0,05	8
2	0	3388	313	2371	119	0,05	8
3	0	3388	448	2371	158	0,05	8
4	0	3388	536	2371	182	0,05	8
5	0	19022	602	13315	200	0,05	8
6	0	83445	2041	58412	112	0,05	8
7	0	83445	2199	58412	666	0,05	8
8	0	83445	2229	58412	673	0,05	8
9	0	83445	3485	58412	920	0,05	8
10	0	83445	3502	58412	923	0,05	8
11	0	83445	3496	58412	922	0,05	8
12	0	83445	3337	58412	893	0,05	8
13	0	30856	756	21599	239	0,05	8
14	0	3388	681	2371	220	0,05	8
15	0	3388	580	2371	194	0,05	8
16	0	3388	452	2371	159	0,05	8
17	0	1098	384	769	139	0,05	8

Maximum soil load	:	Pv;n;max = 98 kN/m²
Maximum reduced soil load	:	Pv;r;n;max = 40 kN/m²
Maximum vertical modulus of subgrade reaction (without safety factor)		kv;max = 83445 kN/m³
Maximum vertical modulus of subgrade reaction (with safety factor)	:	kv;max = 169289 kN/m³

5 Data for Stress Analysis

5.1 General data

Pipeline diameter	:	Do = 267,02 mm
Wall thickness	:	t = 1,8 mm
Unit weight pipeline material	:	gamma_s = 370,09 kN/m³
Unit weight drilling fluid pullback operation	:	gamma_b = 11,10 kN/m³
Minimum bending radius	:	Rmin = 100 m
Bending radius on rollers	:	Rrol = 150 m
Friction coefficient pipe/rollers	:	f1 = 0,10
Friction between pipe and drilling fluid	:	f2 = 0,000050 N/mm²
Friction coefficient pipe / soil	:	f3 = 0,20
Maximal modulus of subgrade reaction	:	kv, max = 169289 kN/m³

5.2 Buoyancy Control

The friction between soil and pipe is partially caused by buoyancy of the pipeline in the drilling fluid. Uplift forces resulting from buoyancy can be neutralized by filling the pipeline. The optimal volume of fluid placed in the pipe provides the most advantageous distribution of buoyant forces.

Buoyancy of the pipeline when filled with fluid for 0%

Uplift forces	:	62	[kg/m]	
Weight of pipeline (including filling)	:	56	[kg/m]	

Result	:	7	[kg/m]	(Pipeline moves upwards)

5.3 Calculation Pulling Force

During the pullback operation the pipe experiences friction which is based on:

- friction between pipe and pipe-roller (f1 = 0,10)
- friction between pipe and drilling fluid (f2 = 0,000050 [N/mm²])
- friction between pipe and soil (f3 = 0,20)

Due to the friction a pulling force is induced in the pipeline.
The pulling direction of the product pipe is from left to right

This calculation takes into account that the length of the pipe on the rollers decreases while pulling back the pipeline. During the pull back operation the bore hole is supposed to be stable.

Characteristic points	Length pipe in bore hole (m)	Expected pulling force (kN)
T1	0	10
T2	11	11
T3	74	30
T4	103	34
T5	166	53
T6	179	55

The calculated pulling force is the mean value. It is recommended to use a contingency factor of at least 1.4 for the stress analysis. In the subsequent pipe stress analysis a factor of 1,40 is used and a load factor of 1,00 (steel only).

The maximum representative pulling force is 0 kN, calculation factor excluded. At this pulling force level the stresses in the pipeline are equal to the yield strength.

6 Stress Analysis of Pipe: DN150/250

6.1 Material Data of Pipe: DN150/250

The list with data and issues is shown hereafter:

Material pipeline	:	Steel Flexwell
Outer diameter	:	Do = 267,02 mm
Wall thickness	:	t = 1,80 mm
Negative wall thickness tolerance	:	10,00 %
Design pressure	:	pd = 23,00 bar
Test pressure	:	pt = 50,00 bar
Temperature variation	:	dt = 120,00 deg Celcius
Length pipeline	:	L = 179 m
Young's modulus	:	E = 207000 N/mm²
Yield strength	:	Re = 235 N/mm²
Partial material factor	:	gamma_m = 1,10
Partial material factor for test pressure	:	gamma_mtest = 1,00
Unit weight pipeline material	:	gamma_s = 370,09 kN/m³
Contingency factor on bending radius	:	sf = 1,10
Bedding angle	:	beta = 120 degrees
Load angle	:	alpha = 180 degrees
Moment coefficient soil top (indirect)	:	kt' = 0,061
Moment coefficient soil bottom (indirect)	:	kb' = 0,083
Moment coefficient soil top (direct)	:	kt = 0,131
Moment coefficient soil bottom (direct)	:	kb = 0,138
Deflection coefficient (indirect)	:	ky' = 0,048
Deflection coefficient (direct)	:	ky = 0,089
Maximal vertical soil load	:	Pv;r;n;max = 40 kN/m²
Maximal modulus of subgrade reaction	:	kv;max = 169289 kN/m³
Load factor installation	:	f_Install = 1,00
Load factor on soil load Qn	:	f_Qn1 = 1,50
Load factor on design pressure	:	f_pd = 1,20
Load factor on design pressure (combination)	:	f_pd;comb = 1,20
Load factor on test pressure	:	f_pt = 1,00
Load factor on temperature	:	f_temp = 1,00
Contingency factor on bending moment	:	f_M = 1,15
Contingency factor on bending radius	:	f_R = 1,10
Contingency factor on soil load Qn	:	f_Qn2 = 1,10
Contingency factor on modulus of subgrade reaction	:	f_kv = 1,60
Overall safety factor on moment (contribution of 3 factors)	:	f_k = f_M * f_Install / f_R = 1,05
Linear settlement coefficient	:	alpha_g = 1,24E-5 mm/mmK

6.2 Results Stress Analysis of Pipe: DN150/250

In the calculation 5 load combinations are considered:

- Load combination 1A: start pull-back operation
- Load combination 1B: end of pull-back operation
- Load combination 2: application internal pressure
- Load combination 3: pipeline in operation, no inner pressure
- Load combination 4: pipeline in operation, pressure applied

The nominal wall thickness is 1,8 mm. The calculation hereafter will prove that the pipeline wall thickness is not sufficient. The calculations are in accordance with NEN 3650 and NEN 3651.

6.2.1 Load Combination 1A: Start Pullback Operation

Axial stress:

Sigma_b = Mb/Wb = f_k.E·Ib/(Rrol·Wb)	=	193	[N/mm²]
Sigma_t = f_pull * T1/A	=	10	[N/mm²]
Maximum axial stress Sigma_a,max	=	203	[N/mm²]

In this load combination the tangential stress is negligible.

6.2.2 Load Combination 1B: End Pullback Operation

Axial stress:

Sigma_b = Mb/Wb = f_k·E·Ib/(Rmin·Wb)	=	290	N/mm^2
Sigma_t = f_pull * Tmax/A	=	57	N/mm^2
Maximum axial stress Sigma_a,max	=	347	N/mm^2

Tangential stress:

Load qr on pipeline due to reaction of soil in bends (according to NEN 3650-1 annex 5 D3.3):

qr = kv·Y = (0.322·Lambda^2·E·I)/(f_R.Do.R)

Lambda = (kv·Do/(4·E·I))^0.25	=	1,4E-3	mm-1
qr	=	0,07399	N/mm^2
Sigma_qr = k'·qr·(rg/Ww)·Do	=	403	N/mm^2
Maximum tangential stress Sigma_t,max	=	403	N/mm^2

6.2.3 Load Combination 2: Application Internal Pressure

Due to internal pressure :

Sigma_py = pd·(Do - t)/(2·t)	=	226	N/mm^2
Sigma_px = 0.5·Sigma_py	=	113	N/mm^2
Sigma_ptest = sf.pt·(Do - t)/(2·t)	=	410	N/mm^2

6.2.4 Load Combination 3: In Operation (Situation without Pressure)

Axial stress:

Sigma_b = Mb/Wb = f_k.E·Ib/(Rrol·Wb)	=	290	N/mm^2
Maximum axial stress Sigma_a,max	=	290	N/mm^2

Tangential stress:

Sigma_qr = k'·qr·(rg/Ww)·Do	=	403	N/mm^2
Sigma_qn = k·qn·(rg/Ww)·Do	=	593	N/mm^2
Maximum tangential stress Sigma_t,max	=	996	N/mm^2

6.2.5 Load Combination 4: In Operation (with Internal Pressure)

Axial stress:

Sigma_b = Mb/Wb = f_k.E·Ib/(Rrol·Wb)	=	290	N/mm^2

Due to internal pressure :

Sigma_py = pd·(Do - t)/(2·t)	=	226	N/mm^2
Sigma_px = 0.5·Sigma_py	=	113	N/mm^2
Sigma_ptest = sf.pt·(Do - t)/(2·t)	=	410	N/mm^2

Sigma_Temp = dt * gamma_t * alpha_g * E	=	291	N/mm²
Maximum axial stress Sigma_a,max	=	693	N/mm²

Tangential stress:

Sigma_qr = k'·qr·(rg/Ww)·Do	=	403	N/mm²
Sigma_qn = k·qn·(rg/Ww)·Do	=	593	N/mm²
Rerounding factor Frr	=	0,095	
Rerounding factor F'rr	=	0,163	

Sigma_t,max = Sigma_py + ((F'rr·Sigma_qr) + (Frr·Sigma_qn))

Maximum tangential stress Sigma_t,max	=	348	N/mm²

6.3 Check on Calculated Stresses of Pipe: DN150/250

According to NEN 3650-2 art.5 D.3.1 the calculated stresses for the load combinations, must meet the following conditions (note: Re = 235 [N/mm²]) :

Load combination 1
Sigma_v =< Re/Gamma_m

Load combination 2
- Sigma_ptest =< Re/Gamma_test
- Sigma_py =< Re/Gamma_m
- Sigma_pm =< 1.1·Re/Gamma_m

Load combinations 3 and 4
- Sigma_vmax =< 0.85(Re+Re_20deg)/Gamma_m

In load combination 1B/2/3/4 stresses are NOT allowable.

	Max allowable stress [N/mm²]	Load combination1A	Load combination1B	Load combination2	Load combination3	Load combination4
Sigma_v	213,64	203	650	-	-	-
Sigma_ptest	235,00	-	-	410	-	-
Sigma_py	213,64	-	-	226	-	-
Sigma_pm	235,00	-	-	196	-	-
Sigma_vmax	363,18	-	-	-	1168	444

Stresses in pipeline [N/mm²]

The deflection of the pipeline is 40,7 mm (15,23% x Do). The maximum allowable deflection of the pipeline is 40,1 mm (15,00% x Do). The deflection is not allowable.
For piggability the maximum allowable deflection of the pipeline is 16,0 mm (6,00% x Do). The deflection is not allowable.

End of Report