Leibniz Universität Hannover

Calculation Examples
IGtHPile V 3.0 (January 2015)

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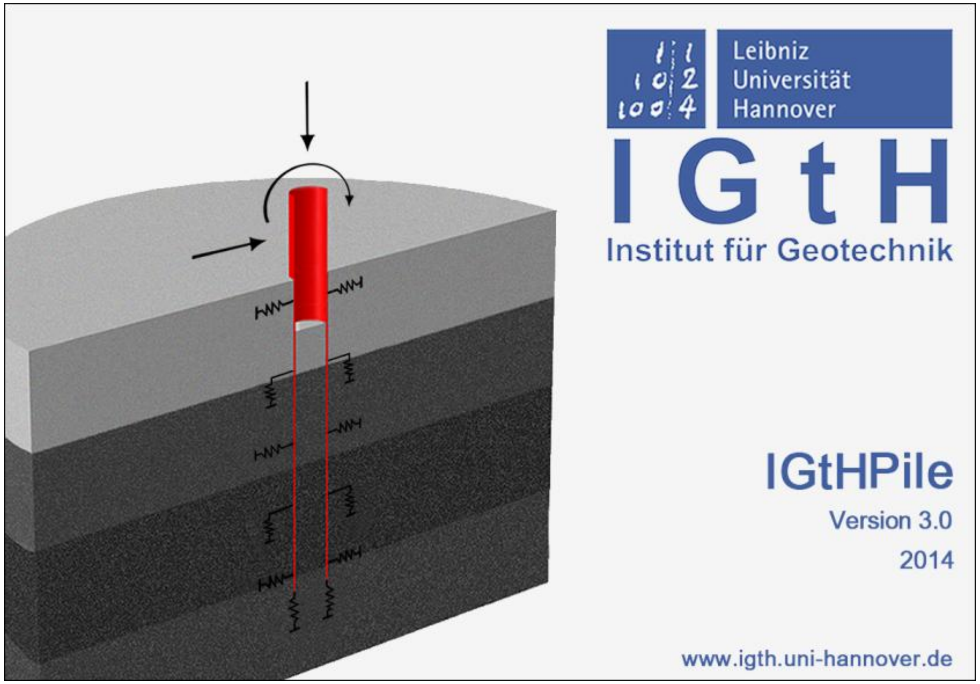
Preface

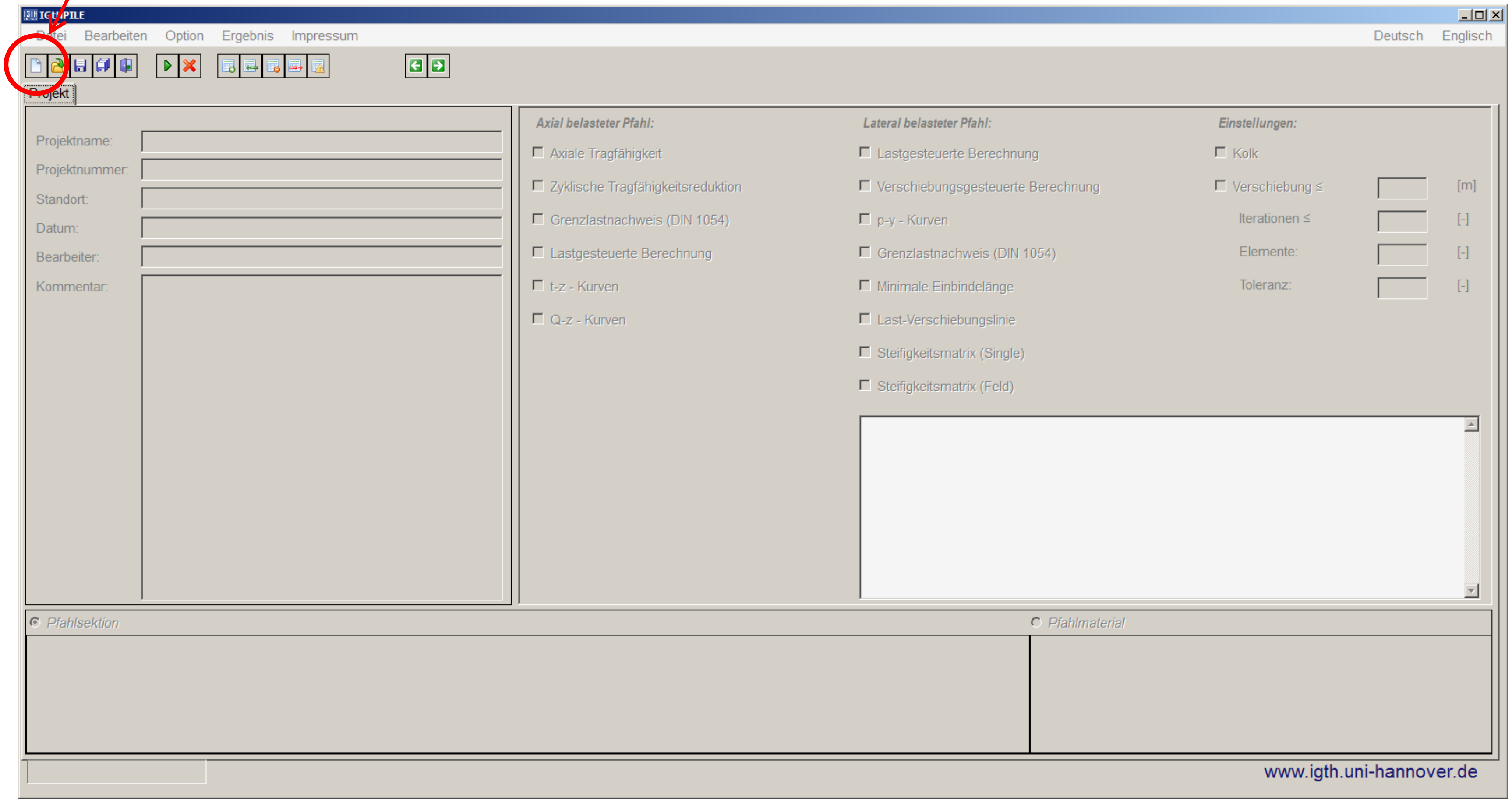
IGtHPile was developed in the scope of several research activities of the Institute for Geotechnical Engineering (IGtH), Leibniz University Hannover (Germany), in the field of foundations for offshore wind energy structures. It enables the calculation of the behavior of open pipe piles under lateral as well as axial loading with focus on design needs for offshore wind foundations. Various state-of-the-art approaches are implemented and therefore the program can be used as a tool for parametric studies and also for routine pile design.



Part 1: Laterally Loaded Piles

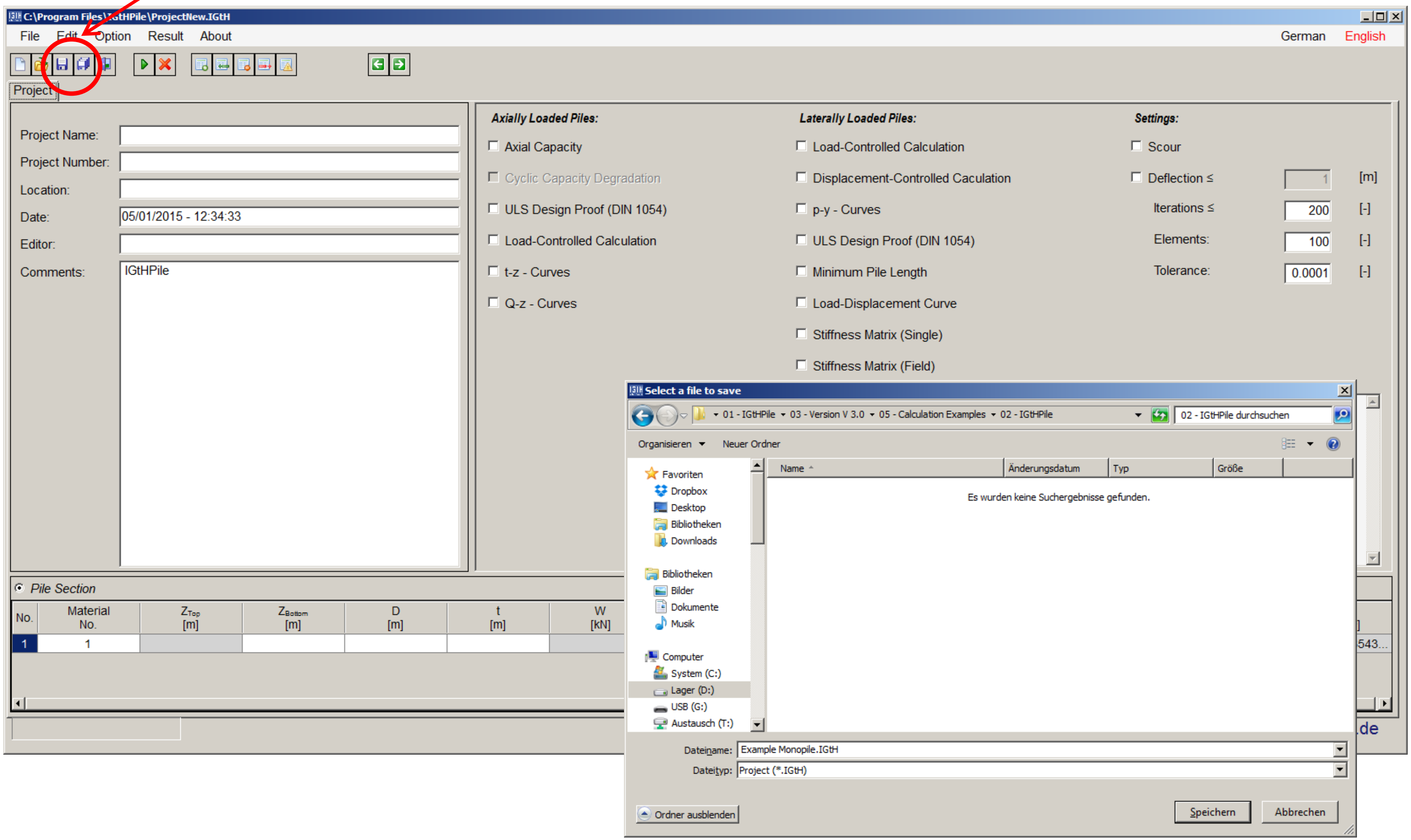
Laterally Loaded Piles – Generate Project

Generate project



Laterally Loaded Piles – Save Project

Save project

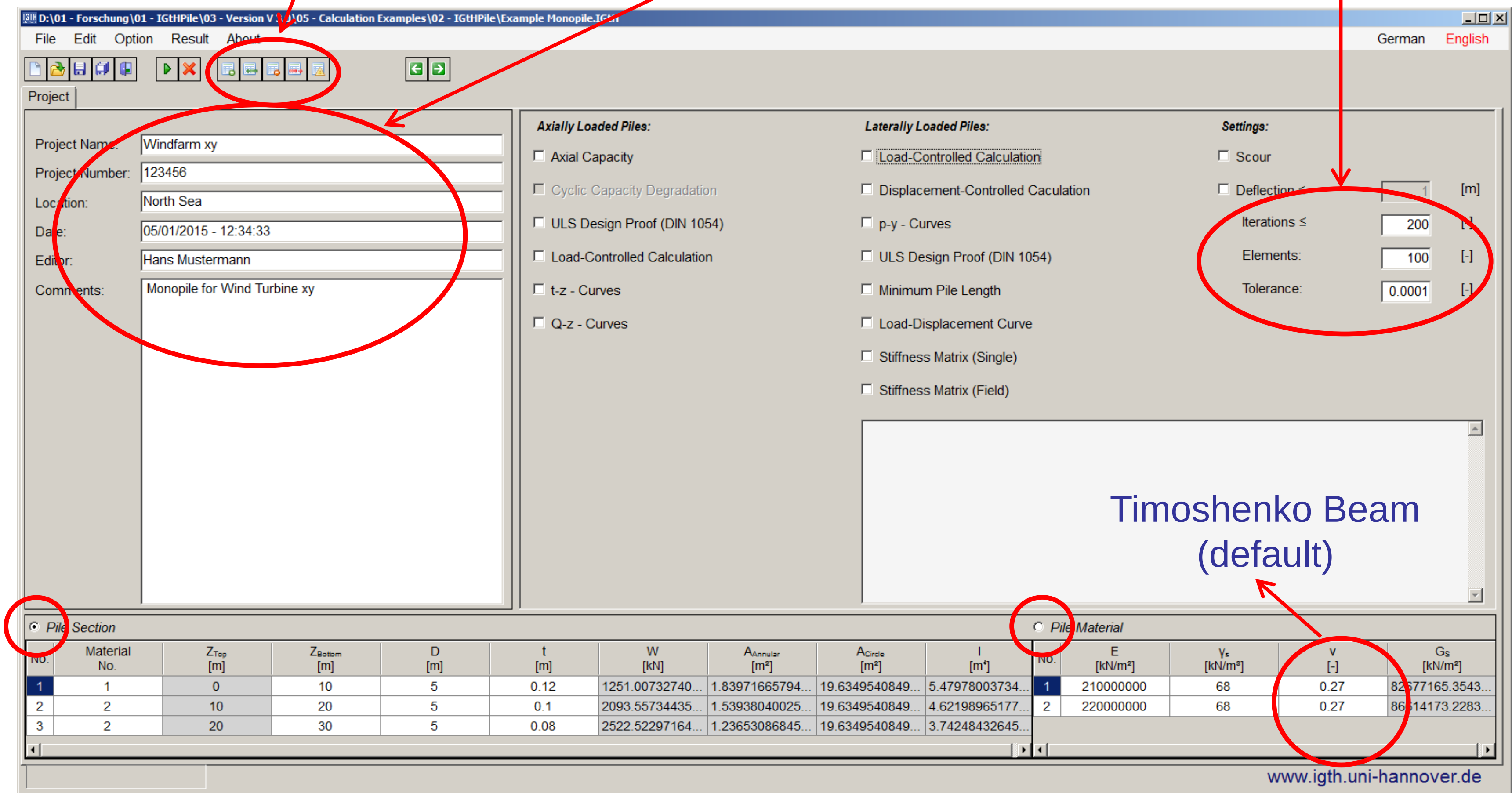


Laterally Loaded Piles – Insert Pile Data

Add, insert or delete rows of pile section or pile material, respectively

Describe project

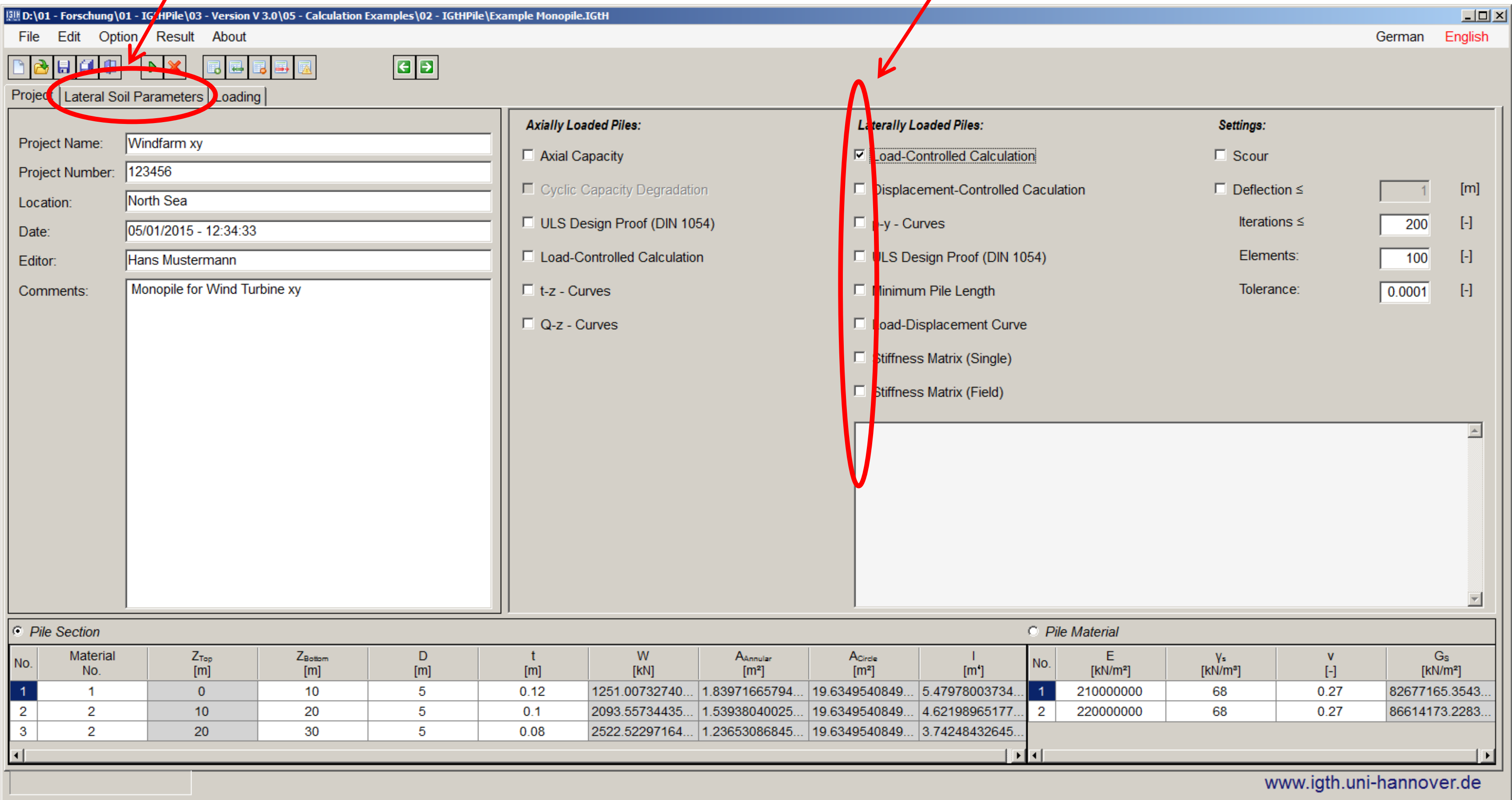
Control parameter



Laterally Loaded Piles – Choose Between Calculation Types

Define soil parameters

Choose calculation type

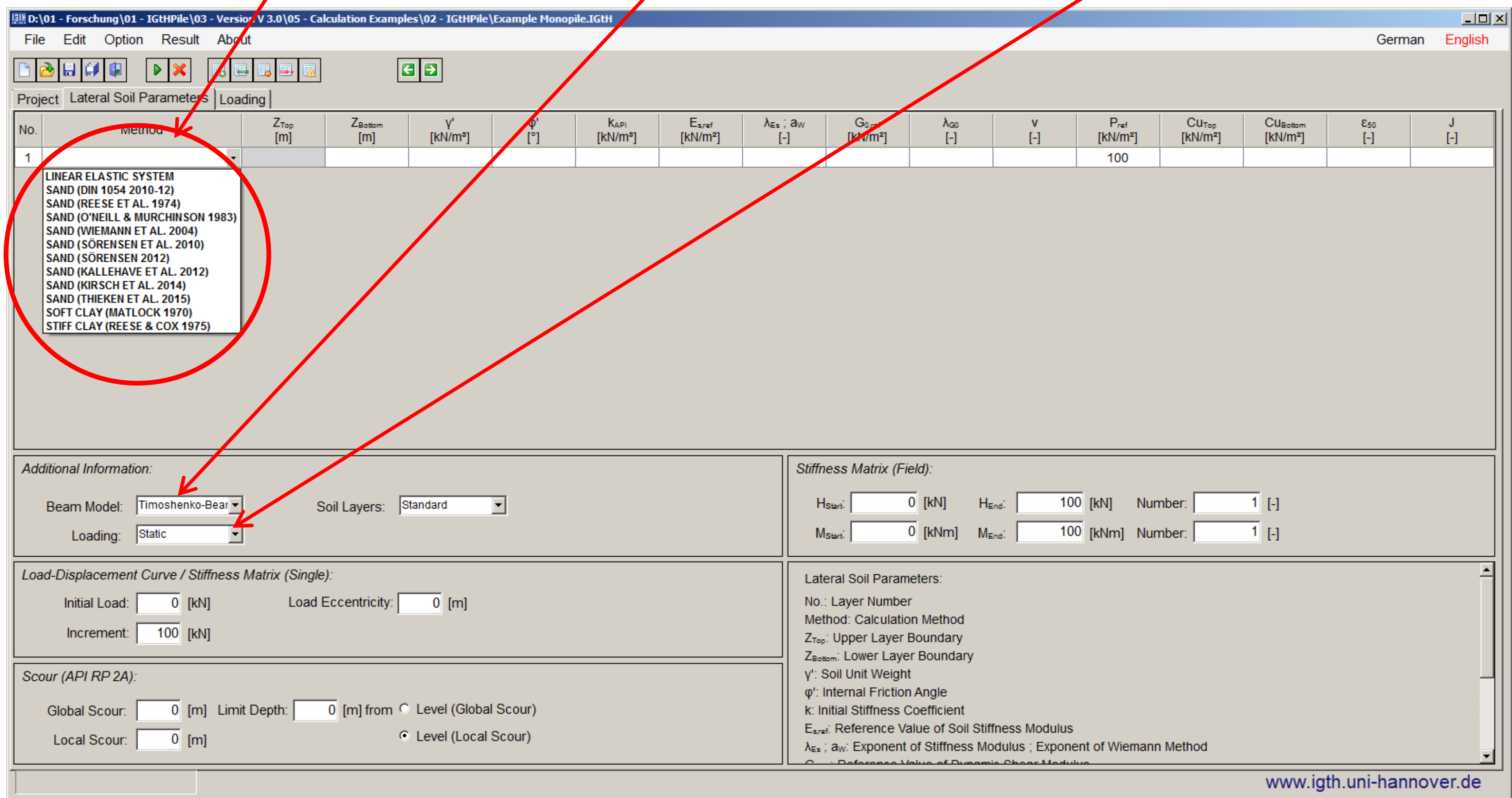


Laterally Loaded Piles – Lateral Soil Parameters

12 p-y methods available

Beam model: Timoshenko/ Bernoulli

Loading type: Static or cyclic p-y curves



Laterally Loaded Piles – References p-y Methods (1)

DIN 1054:2010-12: *Deutsches Institut für Normung e.V. (DIN), DIN 1054:2010-02: Baugrund - Sicherheitsnachweise im Erd- und Grundbau - Ergänzende Regelungen zur DIN EN 1997-1, 2010 (in German).*

Note: *Spatial earth pressure is used for determination of maximum bedding resistance.*

Kallehave et al. 2012: *Kallehave, D., LeBlanc Thilsted, C., Liingaard M.A.: Modification of the API p-y formulation of initial stiffness of sand, Proceedings of the 7th International Conference Offshore Site Investigation and Geotechnics, 2012, pp. 465 - 472.*

Reese et al. 1974: *Reese, L.C., Cox, W.R., Koop, F.D.: Analysis of Laterally Loaded Piles in Sand, Proceedings of the Offshore Technology Conference, 1974, Paper No. OTC 2080.*

O'Neill & Murchison 1983: *Murchison J.M., O'Neill M.W.: (1984). Evaluation of p-y-Relationship in Cohesionless Soils, Analysis and Design of Pile Foundations (ASCE), 1984, pp. 174-191.*

Identical to: *American Petroleum Institute (API): Recommended Practice 2GEO - Geotechnical and Foundation Design Considerations, Version October 2014.*

Det Norske Veritas (DNV): Offshore Standard DNV-OS-J101, Design of Offshore Wind Turbine Structures. January 2013.

Wiemann et al. (2004): *Wiemann, J., Lesny, K., Richwien, W.: Evaluation of the Pile Diameter Effects on Soil-Pile Stiffness, Proceedings of the 7th German Wind Energy Conference (DEWEK), 2004.*

Sørensen et al. 2010: *Sørensen, S.P.H., Ibsen, L.B., Augustesen, A.H.: Effects of diameter on initial stiffness of p-y curves for large-diameter piles in sand, Proceedings of the 7th European Conference on Numerical Methods in Geotechnical Engineering, 2010, pp. 907-912.*

Laterally Loaded Piles – References p-y Methods (2)

Sørensen 2012: *Sørensen S.P.H.: Soil-structure interaction for non-slender large-diameter offshore monopiles, PhD Thesis, Aalborg University Denmark, Department of Civil Engineering, 2012.*

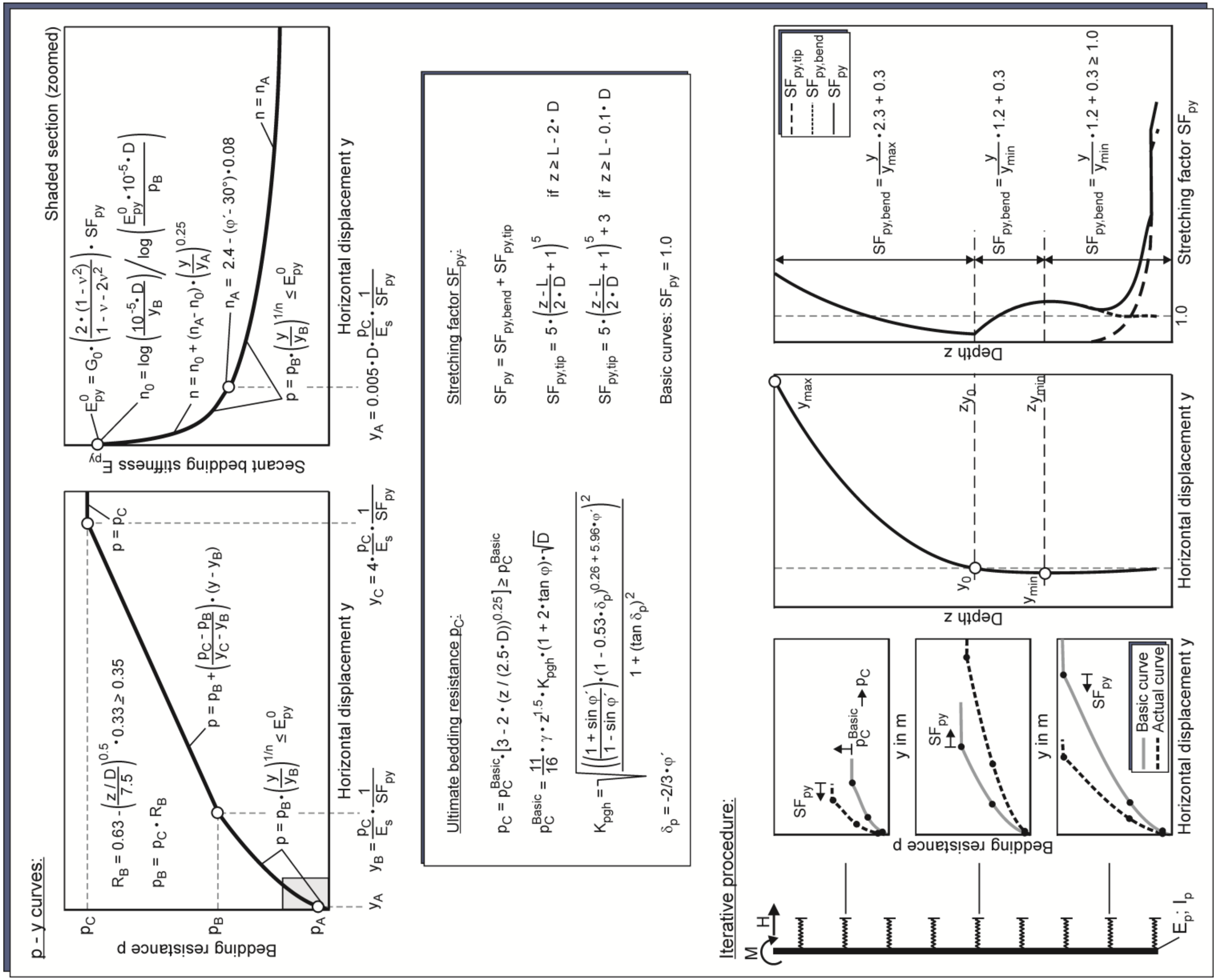
Kirsch et al. 2014: *Kirsch, F., Richter, T., Coronel, M.: Geotechnische Aspekte bei der Gründungsbemessung von Offshore-Windenergieanlagen auf Monopfählen mit sehr großen Durchmessern, Stahlbau Spezial 2014 - Erneuerbare Energien, 2014, pp. 61 - 67 (in German).*

Thieken et al. 2015: *Thieken, K., Achmus, M., Lemke, K.: A new static p-y approach for piles with arbitrary dimensions in sand, Geotechnik (submitted).*

Matlock 1970: *Matlock, H.: Correlations for Design of Laterally Loaded Piles in Soft Clay, Proceedings of the Offshore Technology Conference, Paper No. OTC 1204, Houston, Texas, 1970.*

Reese et al. 1975: *Field testing and analysis of latterally loaded piles in stiff clay, Proceedings of the Offshore Technology Conference, Paper No. OTC 2312, Dallas, Texas, 1975.*

Laterally Loaded Piles – p-y method: Thieken et al. 2015



p-y curves iteratively modified in dependence of pile deflection line and distance to pile tip by stretching factor SF_{py}

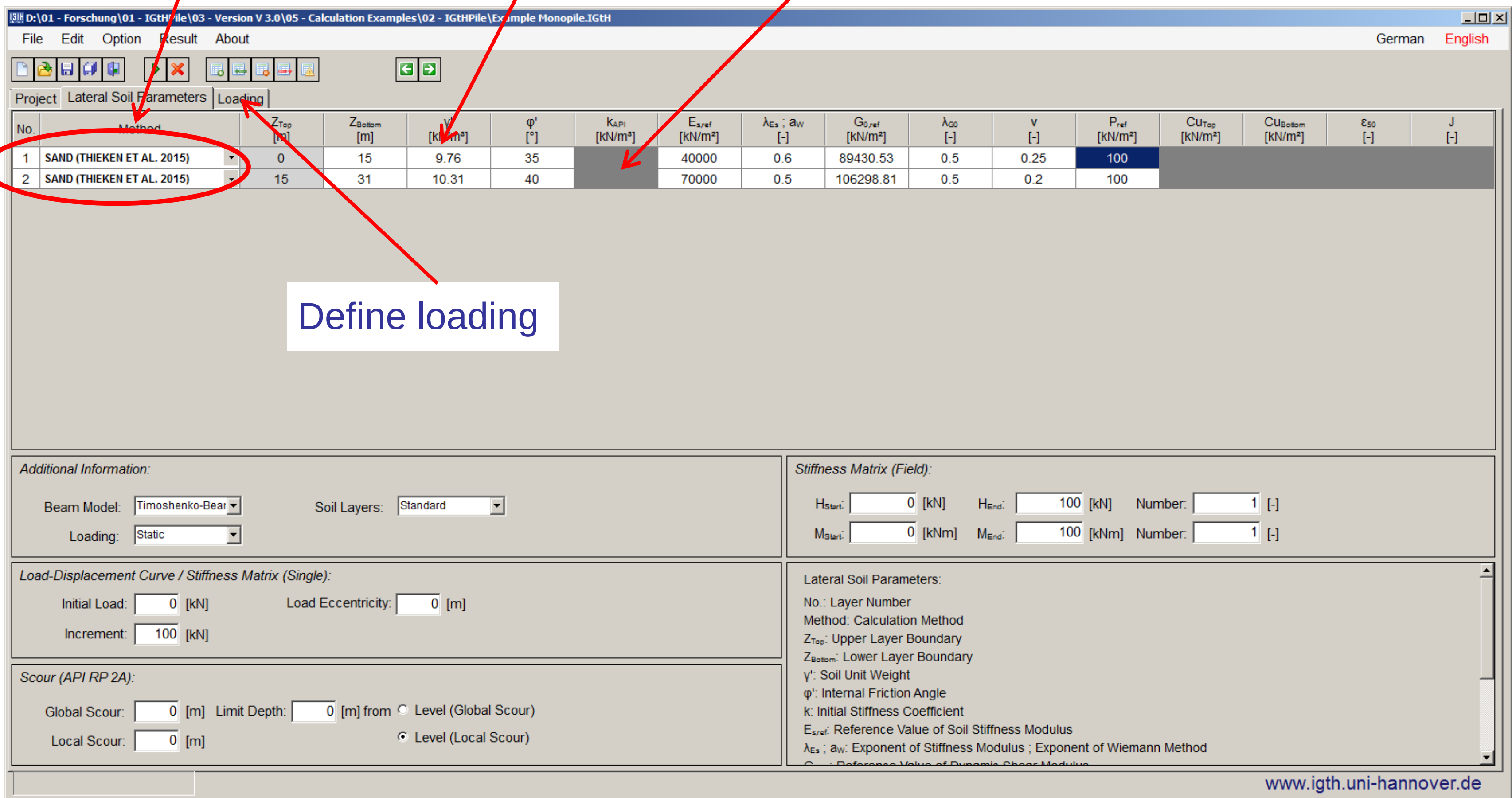
Laterally Loaded Piles – Assigned Soil Parameters

p-y method
(arbitrary combinations)

Insert soil data
in white fields

By default:

$$k_{API}\left[MN/m^3\right] = 0.008085 \cdot \varphi'^{\,2.45} - 26.09$$

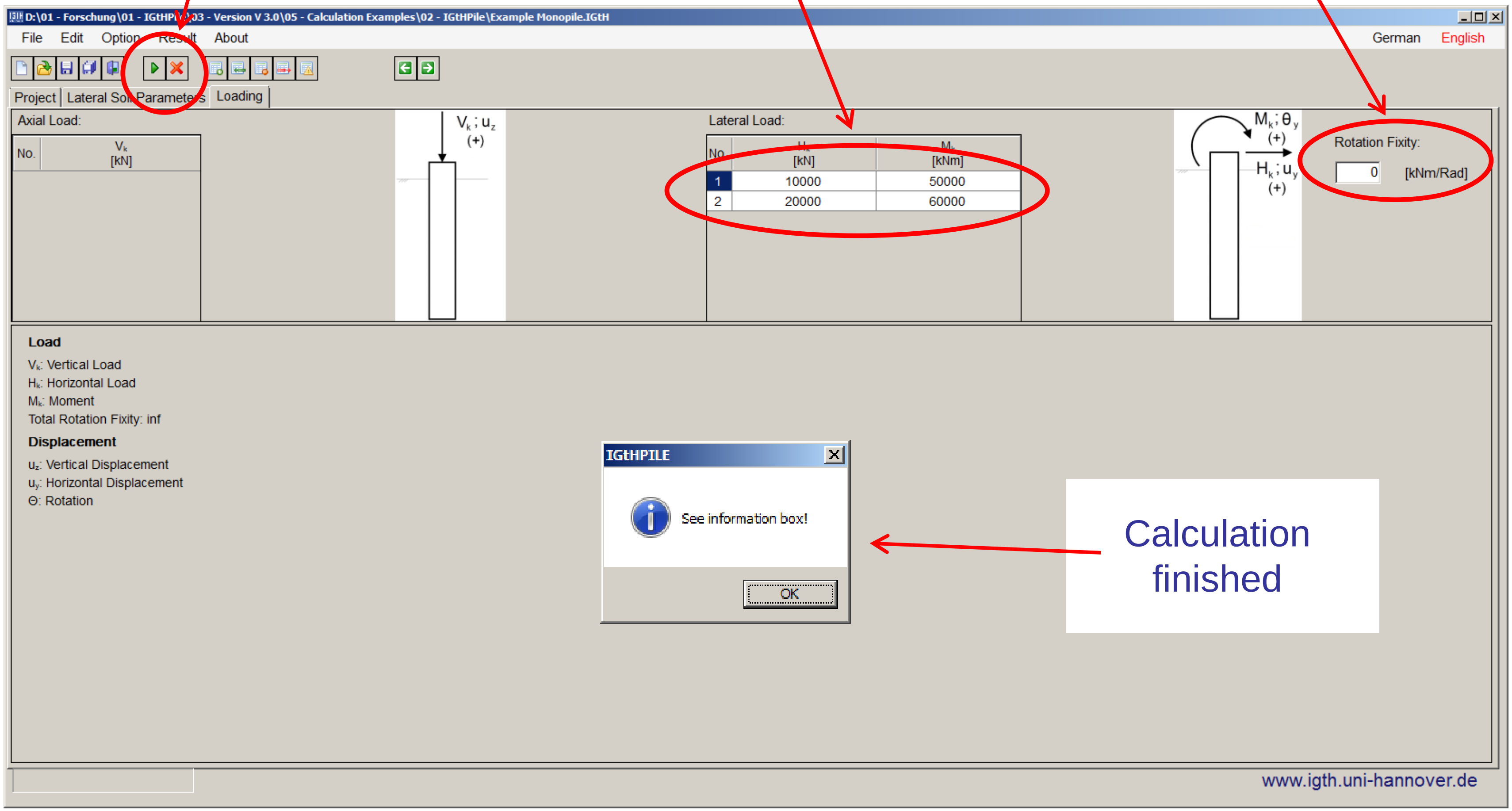


Laterally Loaded Piles – Load Controlled Calculation

Start / Stop calculation

Insert pile head loadings (Unlimited load cases)

Rotation Fixity at pile head
0 => free
inf => Full fixity



Calculation finished

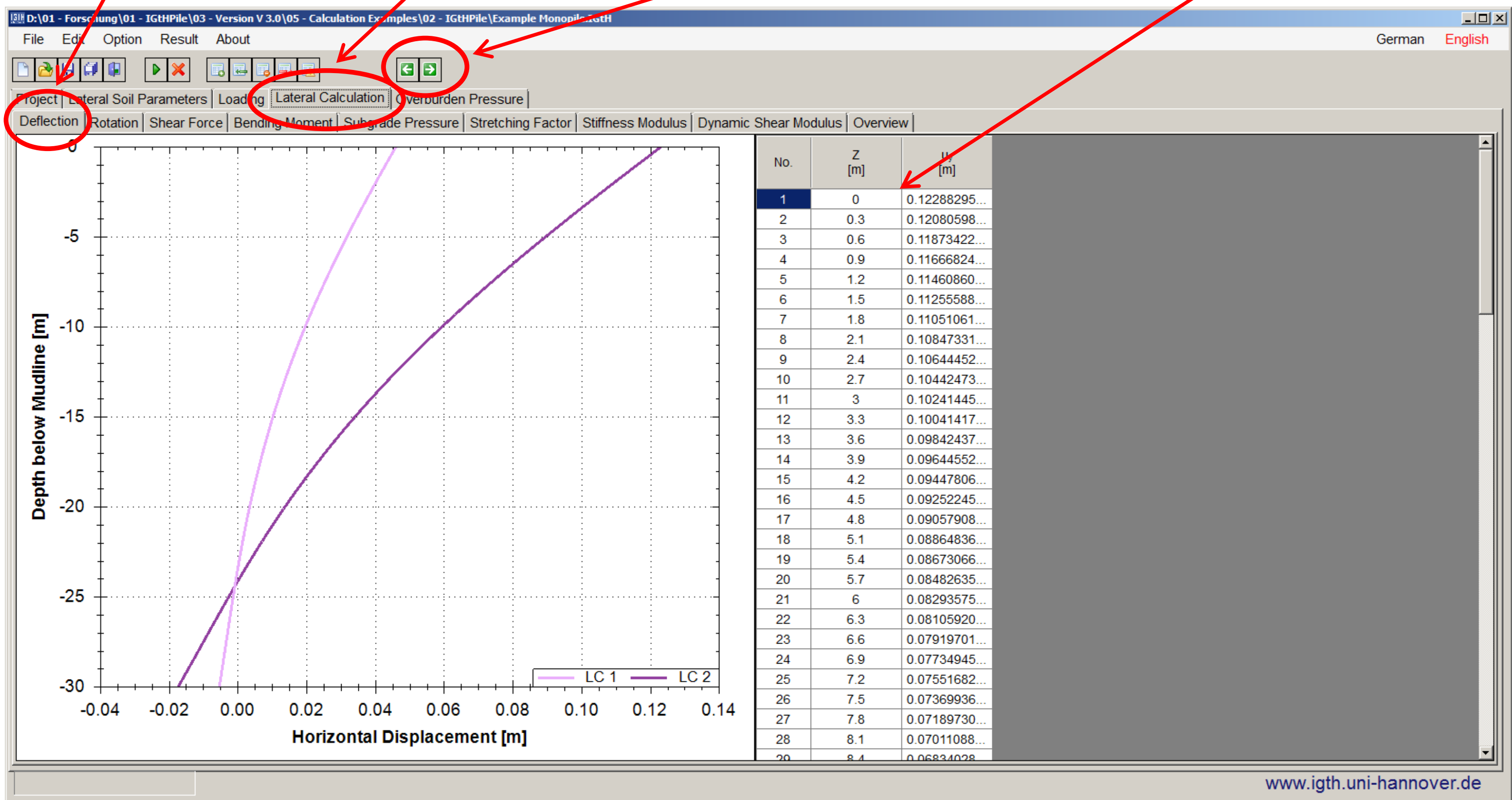
Laterally Loaded Piles – Calculation Output

Deflection line

Calculation output

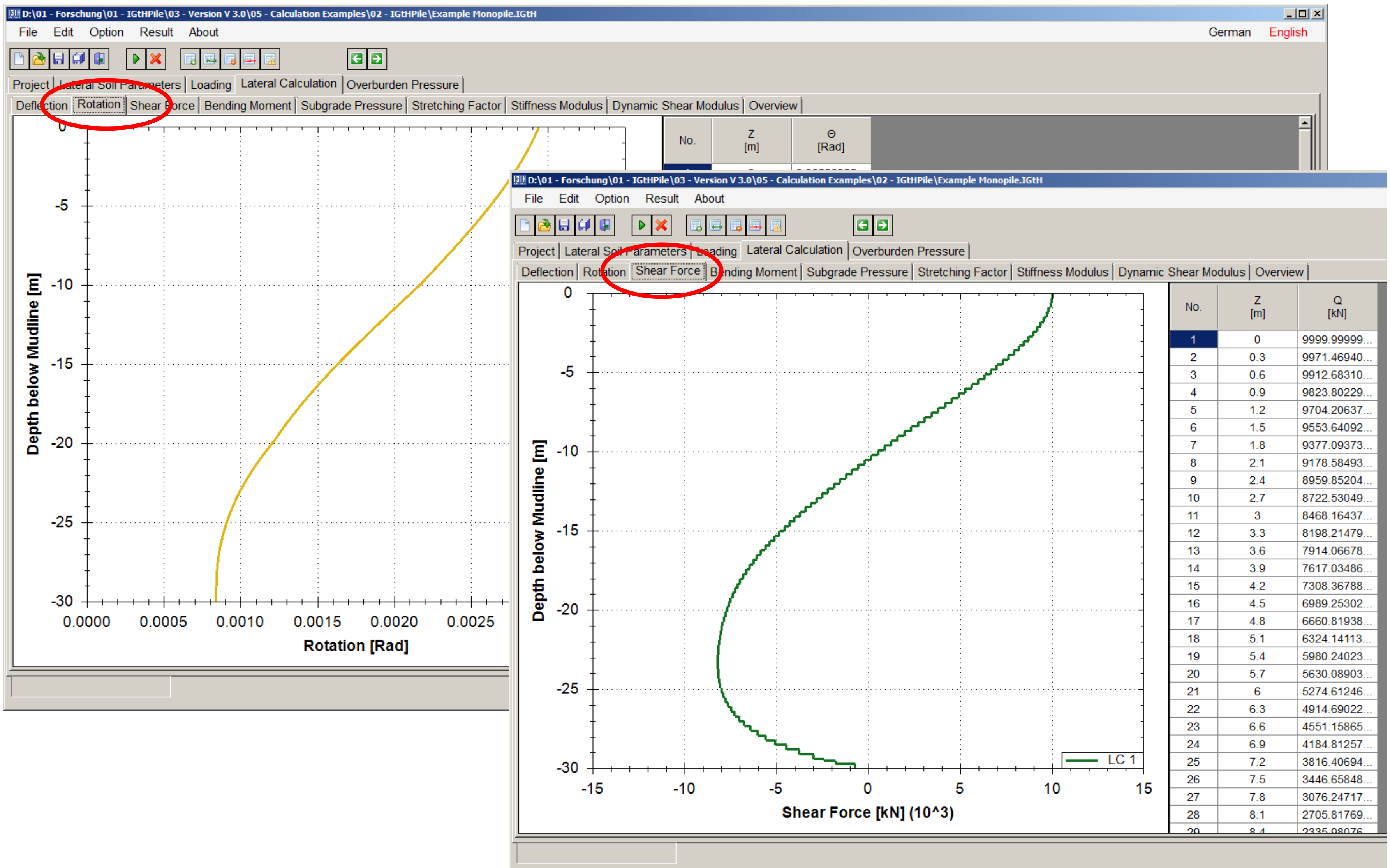
Change load cases

Results in tabular form

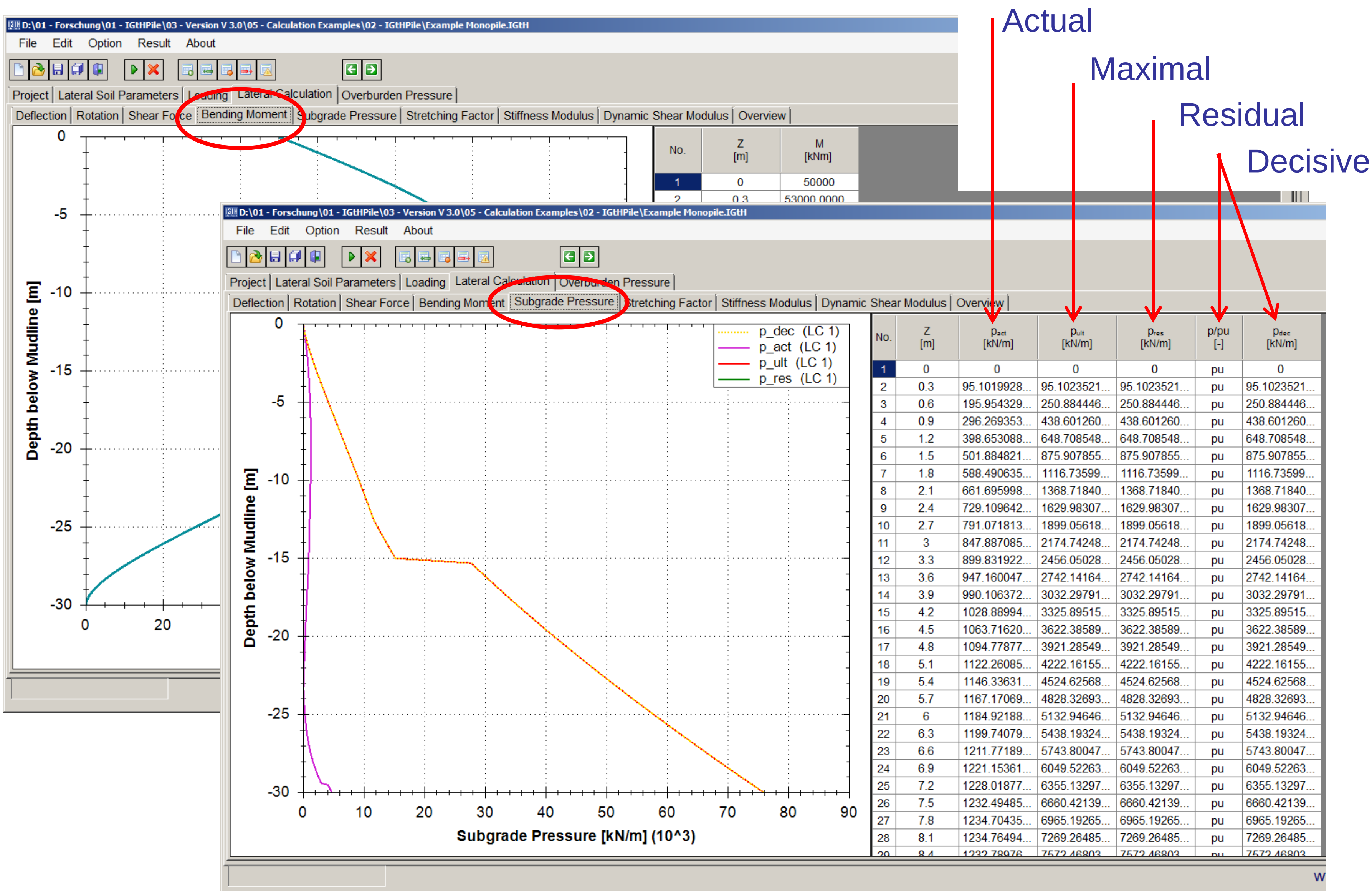


No.	Z [m]	u [m]
1	0	0.12288295...
2	0.3	0.12080598...
3	0.6	0.11873422...
4	0.9	0.11666824...
5	1.2	0.11460860...
6	1.5	0.11255588...
7	1.8	0.11051061...
8	2.1	0.10847331...
9	2.4	0.10644452...
10	2.7	0.10442473...
11	3	0.10241445...
12	3.3	0.10041417...
13	3.6	0.09842437...
14	3.9	0.09644552...
15	4.2	0.09447806...
16	4.5	0.09252245...
17	4.8	0.09057908...
18	5.1	0.08864836...
19	5.4	0.08673066...
20	5.7	0.08482635...
21	6	0.08293575...
22	6.3	0.08105920...
23	6.6	0.07919701...
24	6.9	0.07734945...
25	7.2	0.07551682...
26	7.5	0.07369936...
27	7.8	0.07189730...
28	8.1	0.07011088...

Laterally Loaded Piles – Calculation Output



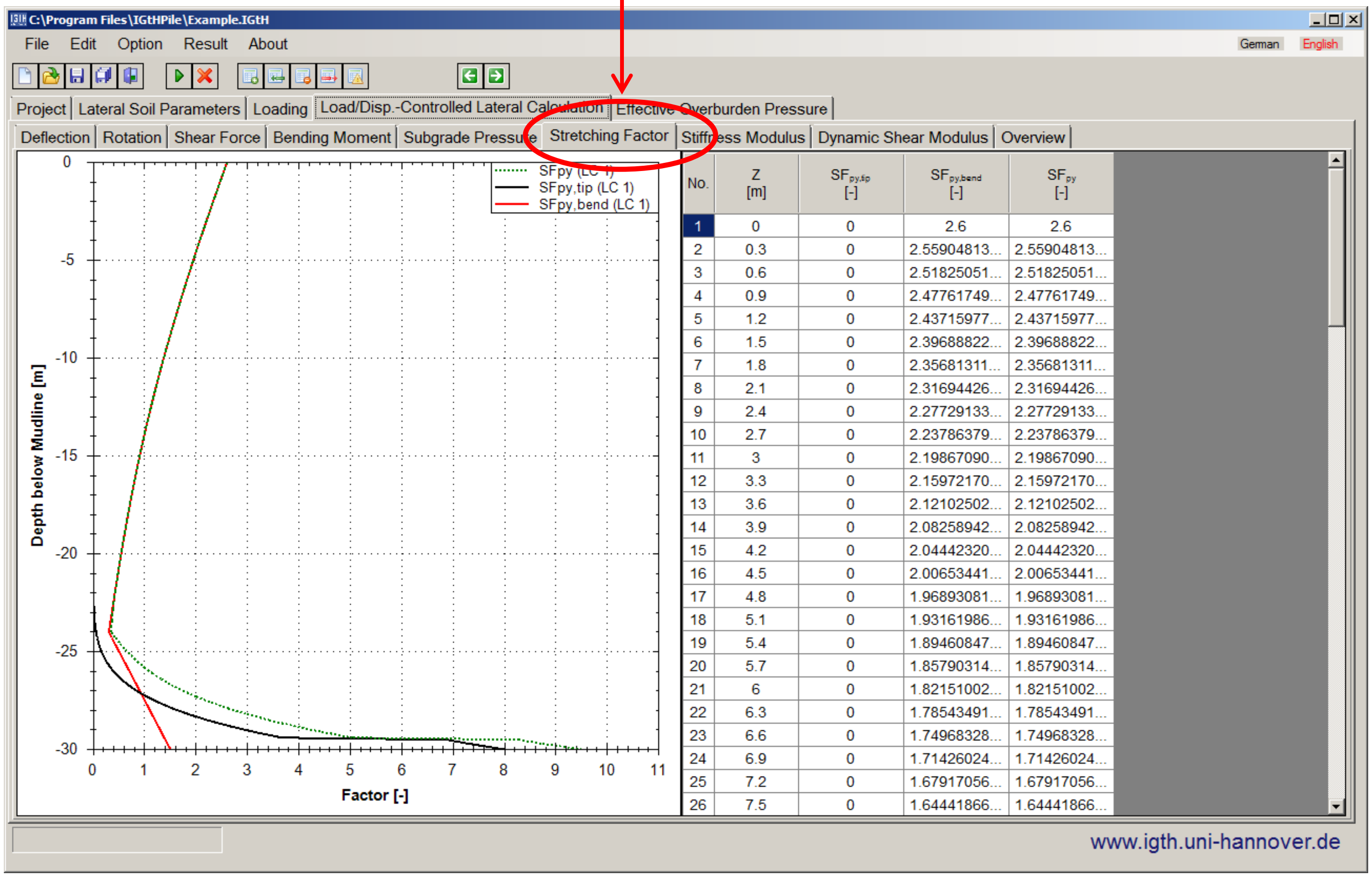
Laterally Loaded Piles – Calculation Output



No.	Z [m]	p_{act} [kN/m]	p_{ult} [kN/m]	p_{res} [kN/m]	p/pu [-]	p_{dec} [kN/m]
1	0	0	0	0	pu	0
2	0.3	95.1019928...	95.1023521...	95.1023521...	pu	95.1023521...
3	0.6	195.954329...	250.884446...	250.884446...	pu	250.884446...
4	0.9	296.269353...	438.601260...	438.601260...	pu	438.601260...
5	1.2	398.653088...	648.708548...	648.708548...	pu	648.708548...
6	1.5	501.884821...	875.907855...	875.907855...	pu	875.907855...
7	1.8	588.490635...	1116.73599...	1116.73599...	pu	1116.73599...
8	2.1	661.695998...	1368.71840...	1368.71840...	pu	1368.71840...
9	2.4	729.109642...	1629.98307...	1629.98307...	pu	1629.98307...
10	2.7	791.071813...	1899.05618...	1899.05618...	pu	1899.05618...
11	3	847.887085...	2174.74248...	2174.74248...	pu	2174.74248...
12	3.3	899.831922...	2456.05028...	2456.05028...	pu	2456.05028...
13	3.6	947.160047...	2742.14164...	2742.14164...	pu	2742.14164...
14	3.9	990.106372...	3032.29791...	3032.29791...	pu	3032.29791...
15	4.2	1028.88994...	3325.89515...	3325.89515...	pu	3325.89515...
16	4.5	1063.71620...	3622.38589...	3622.38589...	pu	3622.38589...
17	4.8	1094.77877...	3921.28549...	3921.28549...	pu	3921.28549...
18	5.1	1122.26085...	4222.16155...	4222.16155...	pu	4222.16155...
19	5.4	1146.33631...	4524.62568...	4524.62568...	pu	4524.62568...
20	5.7	1167.17069...	4828.32693...	4828.32693...	pu	4828.32693...
21	6	1184.92188...	5132.94646...	5132.94646...	pu	5132.94646...
22	6.3	1199.74079...	5438.19324...	5438.19324...	pu	5438.19324...
23	6.6	1211.77189...	5743.80047...	5743.80047...	pu	5743.80047...
24	6.9	1221.15361...	6049.52263...	6049.52263...	pu	6049.52263...
25	7.2	1228.01877...	6355.13297...	6355.13297...	pu	6355.13297...
26	7.5	1232.49485...	6660.42139...	6660.42139...	pu	6660.42139...
27	7.8	1234.70435...	6965.19265...	6965.19265...	pu	6965.19265...
28	8.1	1234.76494...	7269.26485...	7269.26485...	pu	7269.26485...
29	8.4	1232.78976...	7572.46803...	7572.46803...	pu	7572.46803...

Laterally Loaded Piles – Calculation Output

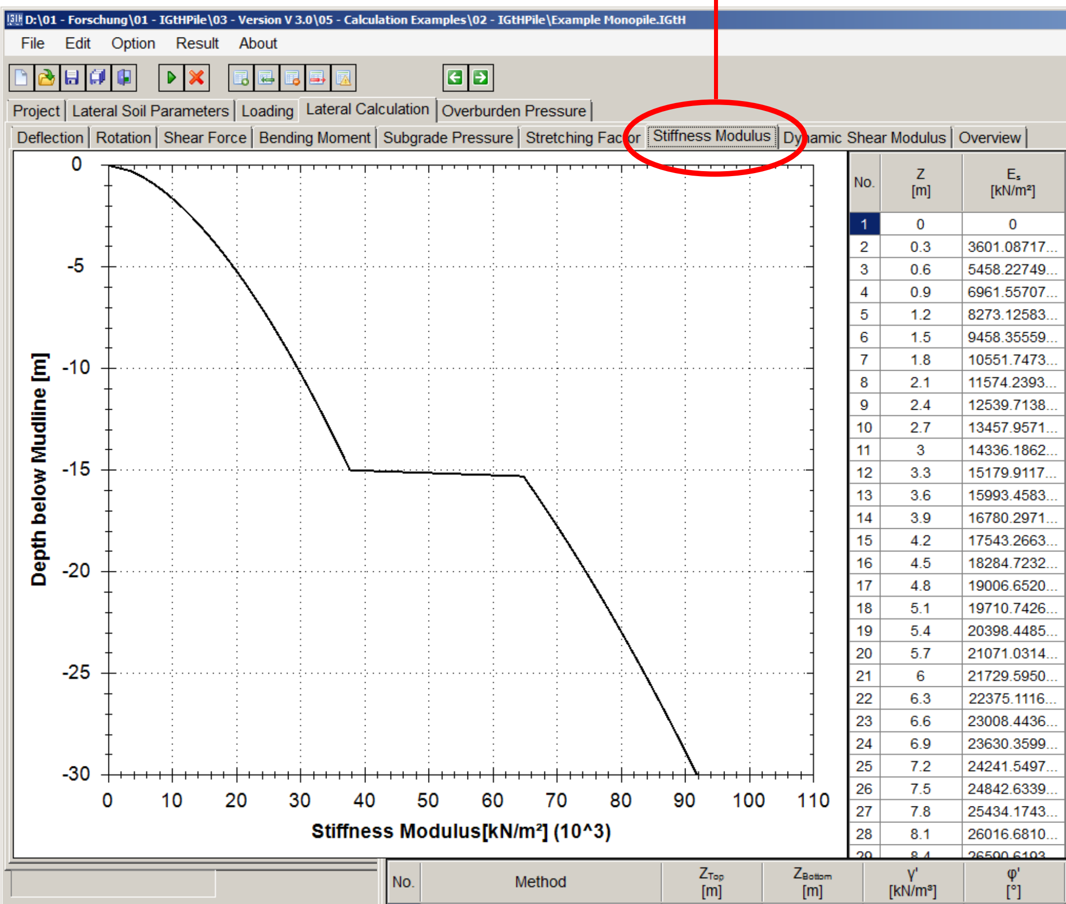
The stretching factor SF_{py} is depicted additionally if the p-y method according to Thieken et al. (2015) is used.



No.	Z [m]	$SF_{py,tip}$ [-]	$SF_{py,bend}$ [-]	SF_{py} [-]
1	0	0	2.6	2.6
2	0.3	0	2.55904813...	2.55904813...
3	0.6	0	2.51825051...	2.51825051...
4	0.9	0	2.47761749...	2.47761749...
5	1.2	0	2.43715977...	2.43715977...
6	1.5	0	2.39688822...	2.39688822...
7	1.8	0	2.35681311...	2.35681311...
8	2.1	0	2.31694426...	2.31694426...
9	2.4	0	2.27729133...	2.27729133...
10	2.7	0	2.23786379...	2.23786379...
11	3	0	2.19867090...	2.19867090...
12	3.3	0	2.15972170...	2.15972170...
13	3.6	0	2.12102502...	2.12102502...
14	3.9	0	2.08258942...	2.08258942...
15	4.2	0	2.04442320...	2.04442320...
16	4.5	0	2.00653441...	2.00653441...
17	4.8	0	1.96893081...	1.96893081...
18	5.1	0	1.93161986...	1.93161986...
19	5.4	0	1.89460847...	1.89460847...
20	5.7	0	1.85790314...	1.85790314...
21	6	0	1.82151002...	1.82151002...
22	6.3	0	1.78543491...	1.78543491...
23	6.6	0	1.74968328...	1.74968328...
24	6.9	0	1.71426024...	1.71426024...
25	7.2	0	1.67917056...	1.67917056...
26	7.5	0	1.64441866...	1.64441866...

Laterally Loaded Piles – Soil Stiffness Modulus

Control applied soil stiffness modulus E_s



No.	z [m]	E_s [kN/m²]
1	0	0
2	0.3	3601.08717...
3	0.6	5458.22749...
4	0.9	6961.55707...
5	1.2	8273.12583...
6	1.5	9458.35559...
7	1.8	10551.7473...
8	2.1	11574.2393...
9	2.4	12539.7138...
10	2.7	13457.9571...
11	3	14336.1862...
12	3.3	15179.9117...
13	3.6	15993.4583...
14	3.9	16780.2971...
15	4.2	17543.2663...
16	4.5	18284.7232...
17	4.8	19006.6520...
18	5.1	19710.7426...
19	5.4	20398.4485...
20	5.7	21071.0314...
21	6	21729.5950...
22	6.3	22375.1116...
23	6.6	23008.4436...
24	6.9	23630.3599...
25	7.2	24241.5497...
26	7.5	24842.6339...
27	7.8	25434.1743...
28	8.1	26016.6810...
29	8.4	26590.6193...

No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	k_{API} [kN/m³]	$E_{s,ref}$ [kN/m²]	λ_{Es} ; a_W [-]	$G_{0,ref}$ [kN/m²]	λ_{G0} [-]	ν [-]	P_{ref} [kN/m²]
1	SAND (THIEKEN ET AL. 2015)	0	15	9.76	35		40000	0.6	89430.53	0.5	0.25	100
2	SAND (THIEKEN ET AL. 2015)	15	31	10.31	40		70000	0.5	106298.81	0.5	0.2	100

$\lambda_{Es} = 0.0$
$\Rightarrow E_s = \text{constant}$

$0.0 > \lambda_{Es} < 1.0$
$\Rightarrow E_s = \text{parabolic}$

$\lambda_{Es} = 1.0$
$\Rightarrow E_s = \text{linear}$

Overburden pressure

$$\sigma_m = \left(\frac{\sigma_v + 2 \cdot \sigma_v \cdot (1 - \sin\varphi')}{3} \right)$$

$$E_s = E_{s,ref} \cdot \left(\frac{\sigma_m}{p_{ref}} \right)^{\lambda_{Es}}$$

Relevant: DIN 1054:2010-12; Sörensen (2012); Kirsch et al. (2014); Thieken et al. (2015)

Laterally Loaded Piles – Soil Stiffness Modulus

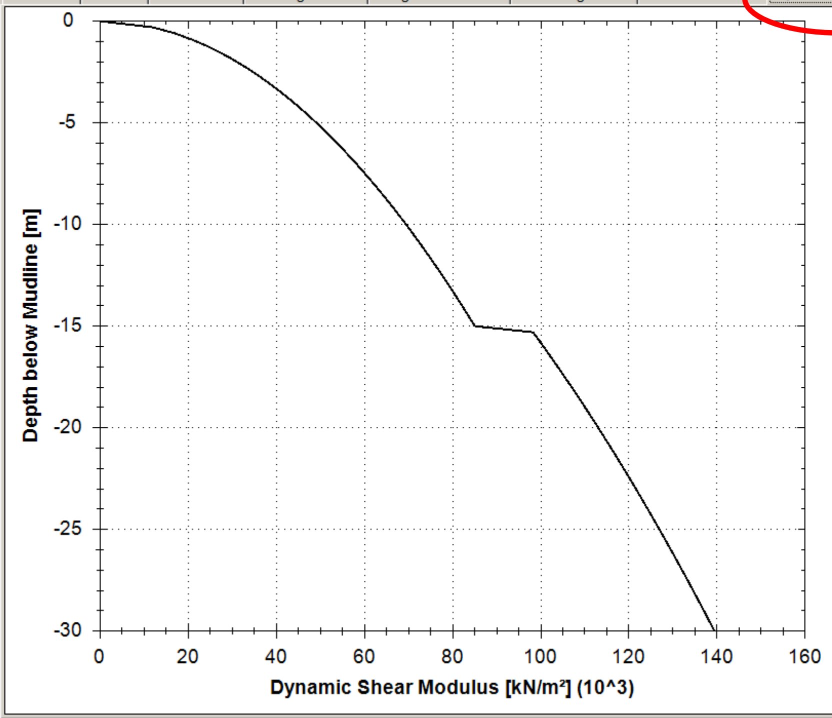
Control applied dynamic shear modulus G_0

D:\01 - Forschung\01 - IGtHPile\03 - Version V 3.0\05 - Calculation Examples\02 - IGtHPile\Example Monopile.IGtH

File Edit Option Result About

Project | Lateral Soil Parameters | Loading | Lateral Calculation | Overburden Pressure

Deflection | Rotation | Shear Force | Bending Moment | Subgrade Pressure | Stretching Factor | Stiffness Modulus | Dynamic Shear Modulus | Overview



No.	Z [m]	G_0 [kN/m²]
1	0	0
2	0.3	12026.2577...
3	0.6	17007.6968...
4	0.9	20830.0894...
5	1.2	24052.5155...
6	1.5	26891.5298...
7	1.8	29458.1950...
8	2.1	31818.4872...
9	2.4	34015.3936...
10	2.7	36078.7732...
11	3	38030.3662...
12	3.3	39886.5845...
13	3.6	41660.1789...
14	3.9	43361.2889...
15	4.2	44998.1361...
16	4.5	46577.4959...
17	4.8	48105.0310...
18	5.1	49585.5309...
19	5.4	51023.0904...
20	5.7	52421.2422...
21	6	53783.0597...
22	6.3	55111.2364...
23	6.6	56408.1488...
24	6.9	57675.9060...
25	7.2	58916.3900...
26	7.5	60131.2887...
27	7.8	61322.1229...
28	8.1	62490.2683...
29	8.4	63636.0744...

$\lambda_{G0} = 0.0$
$\Rightarrow G_0 = \text{constant}$

$0.0 > \lambda_{G0} < 1.0$
$\Rightarrow G_0 = \text{parabolic}$

$\lambda_{G0} = 1.0$
$\Rightarrow G_0 = \text{linear}$

Overburden pressure

$$\sigma_m = \left(\frac{\sigma_v + 2 \cdot \sigma_v \cdot (1 - \sin\varphi')}{3} \right)$$

$$G_0 = G_{0,ref} \cdot \left(\frac{\sigma_m}{p_{ref}} \right)^{\lambda_{G0}}$$

No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	k_{API} [kN/m³]	$E_{s,ref}$ [kN/m²]	λ_{Es} ; a_W [-]	$G_{0,ref}$ [kN/m²]	λ_{G0} [-]	ν [-]	P_{ref} [kN/m²]
1	SAND (THIEKEN ET AL. 2015)	0	15	9.76	35		40000	0.6	89430.53	0.5	0.25	100
2	SAND (THIEKEN ET AL. 2015)	15	31	10.31	40		70000	0.5	106298.81	0.5	0.2	100

Relevant: Kirsch et al. (2014); Thieken et al. (2015)

Laterally Loaded Piles – Overview of Main Results

Overview of main calculation results
(for post processing)

D:\01 - Forschung\01 - IGtHPile\03 - Version V 3.0\05 - Calculation Examples\02 - IGtHPile\Example Monopile.IGtH

File Edit Option Result About German English

Project | Lateral Soil Parameters | Loading | Lateral Calculation | Overburden Pressure

Deflection | Rotation | Shear Force | Bending Moment | Subgrade Pressure | Stretching Factor | Stiffness Modulus | Dynamic Shear Modulus | Overview

No.	Z [m]	y [m]	Θ [Rad]	Q [kN]	M [kNm]	p [kN/m]	pu [kN/m]	$SF_{py,tip}$ [-]	$SF_{py,bend}$ [-]	SF_{py} [-]
1	0	0.0458377055067263	0.00293825377902587	9999.9999999993	50000	0	0	0	2.6	2.6
2	0.3	0.0449385177417575	0.0029248410932575	9971.46940213258	53000.0000000019	95.1019928927908	95.1023521524393	0	2.55488142705736	2.5548814270573
3	0.6	0.0440435270859796	0.00291064820056653	9912.68310318873	55991.44082064	195.954329806948	250.884446330502	0	2.50997345259544	2.5099734525954
4	0.9	0.0431530267647355	0.00289567851208142	9823.80229706477	58965.2457515933	296.269353760011	438.601260652057	0	2.46529078979154	2.4652907897915
5	1.2	0.0422673083084512	0.00287993779657637	9704.20637048571	61912.3864407148	398.65308861325	648.708548761651	0	2.42084806677708	2.4208480667770
6	1.5	0.0413866623846502	0.00286343419841906	9553.64092404832	64823.6483518593	501.88482141972	875.90785534253	0	2.37665986838558	2.3766598683855
7	1.8	0.0405113773578446	0.00284617827175398	9377.09373332455	67689.740629077	588.490635774592	1116.73599501118	0	2.3327406638923	2.3327406638923
8	2.1	0.0396417282549178	0.00282818279558795	9178.58493379969	70502.8687490709	661.695998403421	1368.71840147831	0	2.28910425332986	2.2891042533298
9	2.4	0.0387779780589793	0.00280946242188645	8959.85204118778	73256.4442292098	729.109642045602	1629.98307920662	0	2.24576383241008	2.2457638324100
10	2.7	0.0379203816833495	0.00279003345064473	8722.53049715413	75944.3998415675	791.07181344386	1899.05618523724	0	2.2027321919267	2.2027321919267
11	3	0.037069185698242	0.00276991369811964	8468.16437156728	78561.1589907035	847.887085249142	2174.74248841987	0	2.16002170404113	2.1600217040411
12	3.3	0.0362246280747342	0.00274912237261859	8198.21479492038	81101.6083021723	899.83192217232	2456.05028893579	0	2.11764430943566	2.1176443094356
13	3.6	0.0353869379483484	0.00272767995709815	7914.06678056926	83561.0727406479	947.160047850029	2742.14164089607	0	2.07561150545064	2.0756115054506
14	3.9	0.0345563354034648	0.0027056080979764	7617.0348687701	85935.2927748188	990.106372648321	3032.29791717695	0	2.03393433526698	2.0339343352669
15	4.2	0.0337330312791	0.00268292949967196	7308.36788574385	88220.4032354467	1028.88994341946	3325.89515516458	0	1.99262337816069	1.9926233781606
16	4.5	0.0329172269961394	0.0026596678244633	6989.25302362174	90412.9136011712	1063.71620709574	3622.38589734059	0	1.95168874083392	1.9516887408339
17	4.8	0.0321091144058186	0.00263584759732311	6660.81938967295	92509.6895082518	1094.77877980767	3921.28549301802	0	1.91114004981217	1.9111400498121
18	5.1	0.0313088756590515	0.00261149411542954	6324.14113424552	94507.9353251569	1122.2608514177	4222.1615530779	0	1.87098644488764	1.8709864448876
19	5.4	0.030516683096075	0.00258663336209357	5980.24023948007	96405.1776654273	1146.33631590131	4524.62568827339	0	1.83123657358182	1.8312365735818
20	5.7	0.0297326991557855	0.00256129192487137	5630.0890318579	98199.2497372739	1167.17069203634	4828.32693678713	0	1.79189858659639	1.7918985865963
21	6	0.0289570763040912	0.00253549691765446	5274.61246747369	99888.2764468305	1184.92188130977	5132.94646475273	0	1.75298013421803	1.7529801342180
22	6.3	0.02818995698056	0.00250927590655034	4914.69022812805	101470.660187067	1199.74079780691	5438.19324183877	0	1.71448836364145	1.7144883636414
23	6.6	0.0274314735626266	0.00248265683938238	4551.15865925021	102945.067255506	1211.77189626875	5743.80047463839	0	1.67642991717338	1.6764299171733
24	6.9	0.0266817483466085	0.00245566797865133	4184.81257374497	104310.41485328	1221.15361832688	6049.5226367234	0	1.63881093128002	1.6388109312800
25	7.2	0.0259408935447779	0.00242833783781243	3816.40694202445	105565.858625405	1228.01877240411	6355.1329740208	0	1.60163703644009	1.6016370364400
26	7.5	0.0252090112977402	0.00240069512073141	3446.6584842045	106710.780708011	1232.4948594072	6660.42139288223	0	1.564913357766	1.564913357766
27	7.8	0.0244861937013783	0.00237276866419132	3076.24717805666	107744.778253272	1234.70435380336	6965.19265925414	0	1.52864451635577	1.5286445163557
28	8.1	0.0237725228476305	0.00234458738332907	2705.8176937385	108667.652406691	1234.76494773633	7269.26485298805	0	1.49283463133919	1.4928346313391

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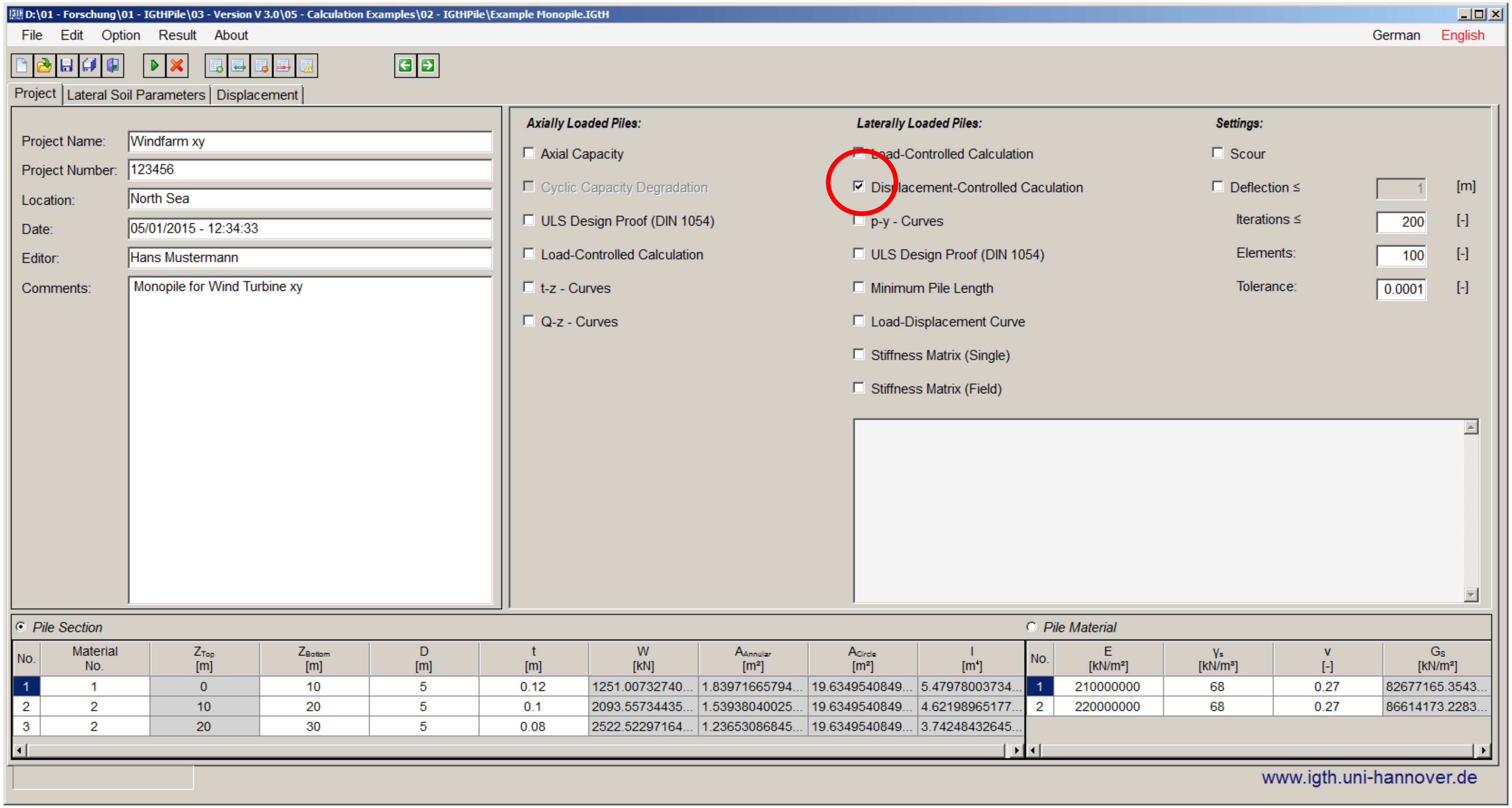
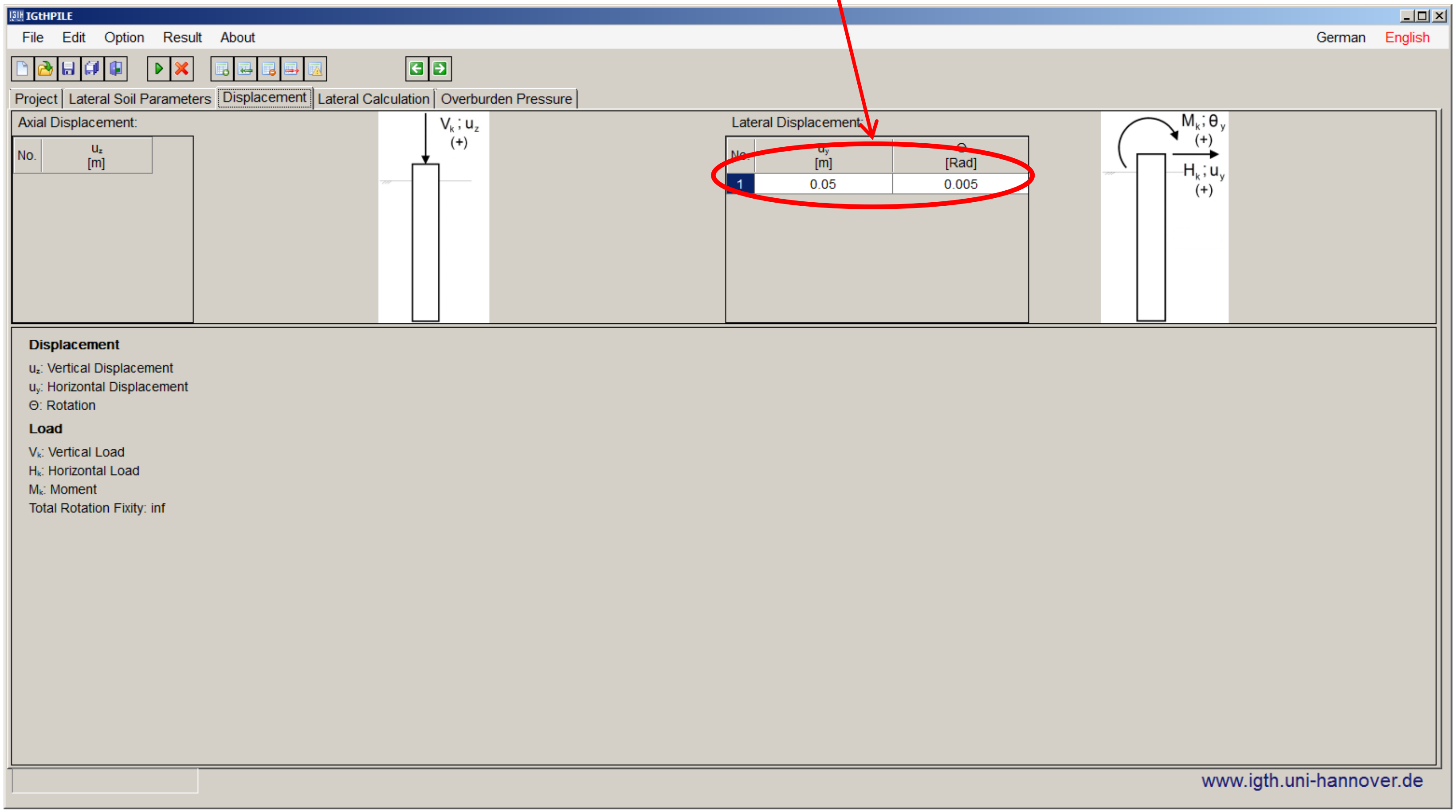
Laterally Loaded Piles – Displacement-Controlled Calculation

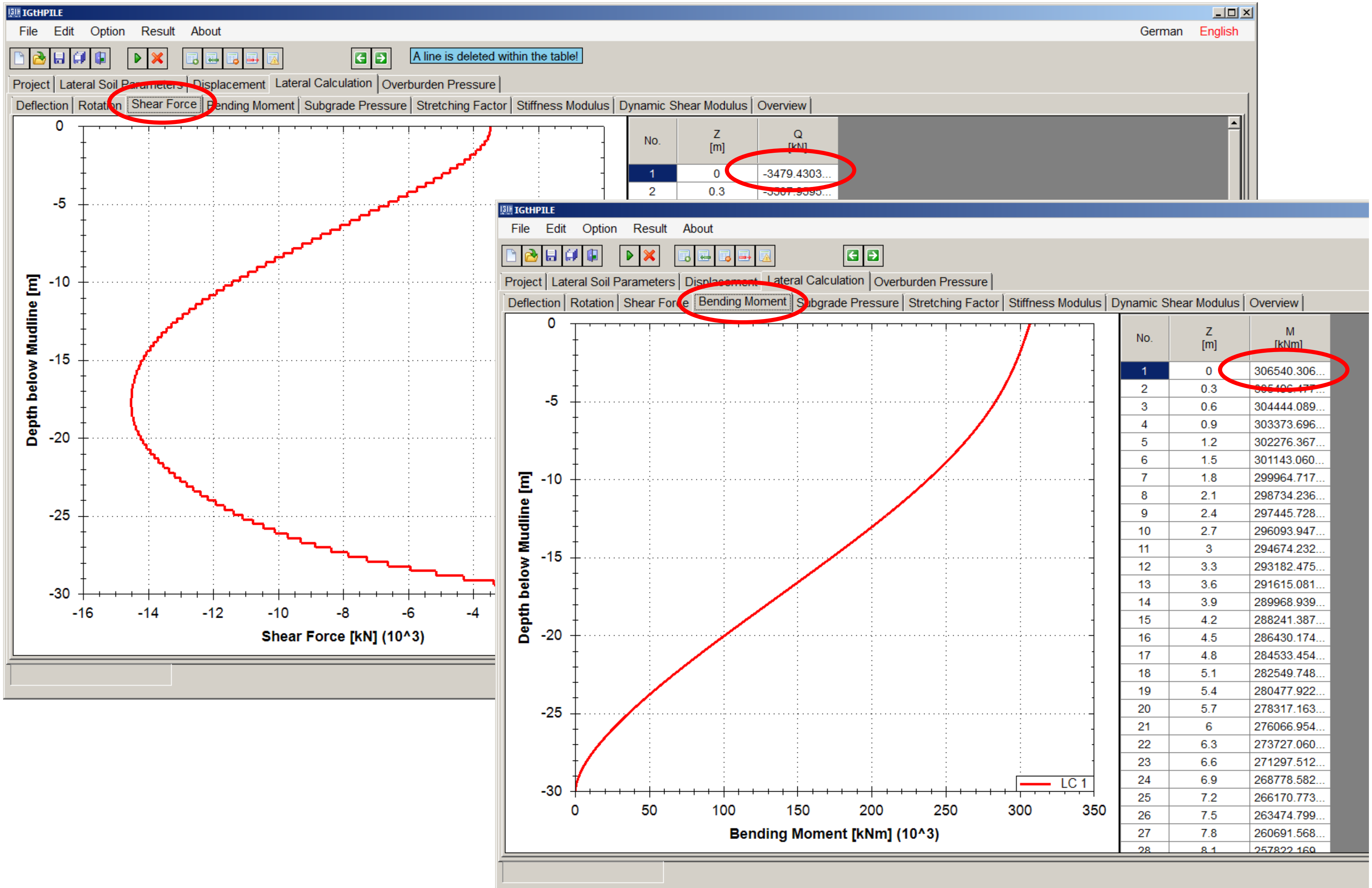


Laterally Loaded Piles – Displacement-Controlled Calculation

Insert pile head displacements & rotations
(Unlimited load cases)

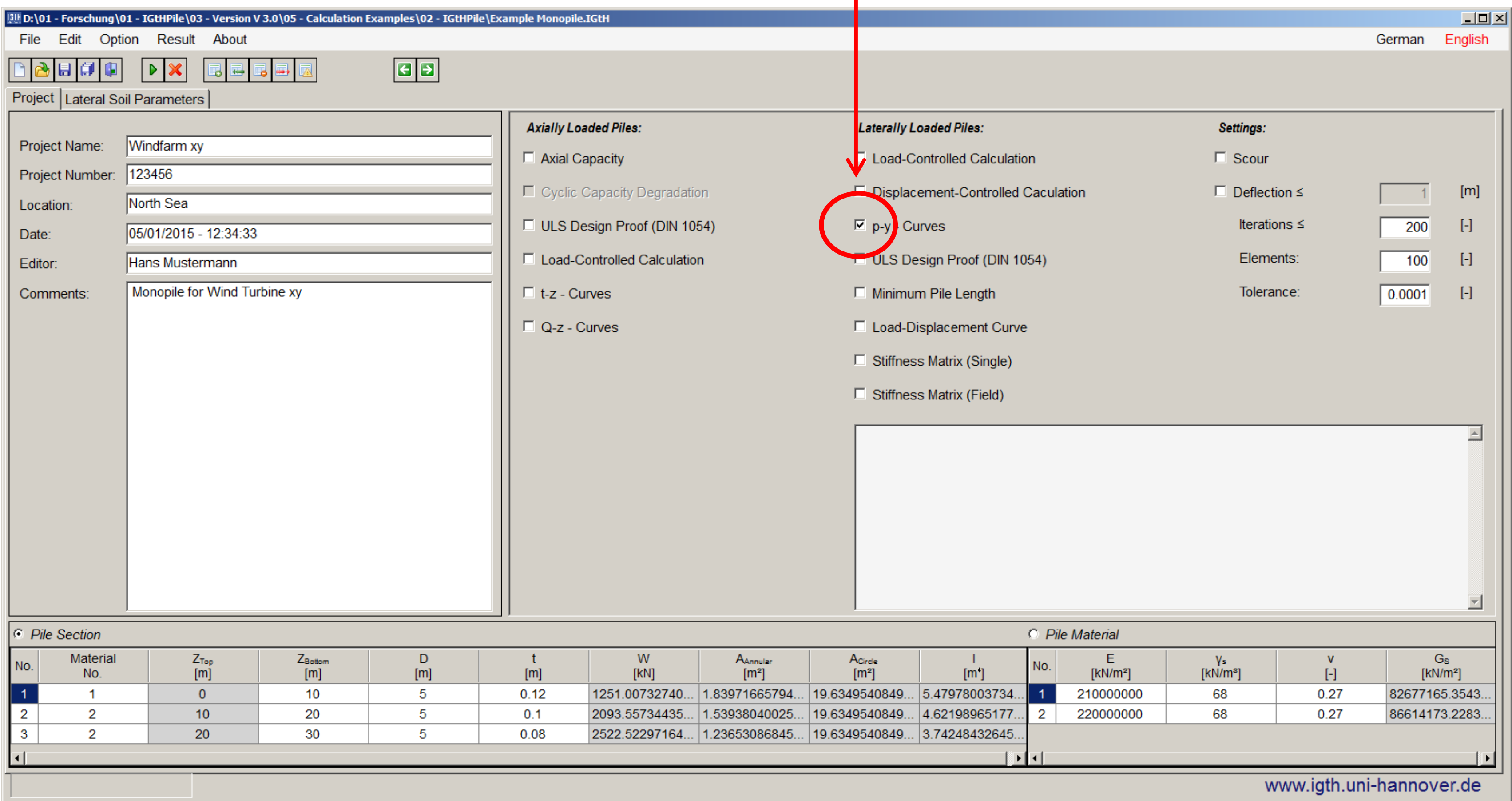


Laterally Loaded Piles – Displacement-Controlled Calculation



Laterally Loaded Piles – p-y Curves

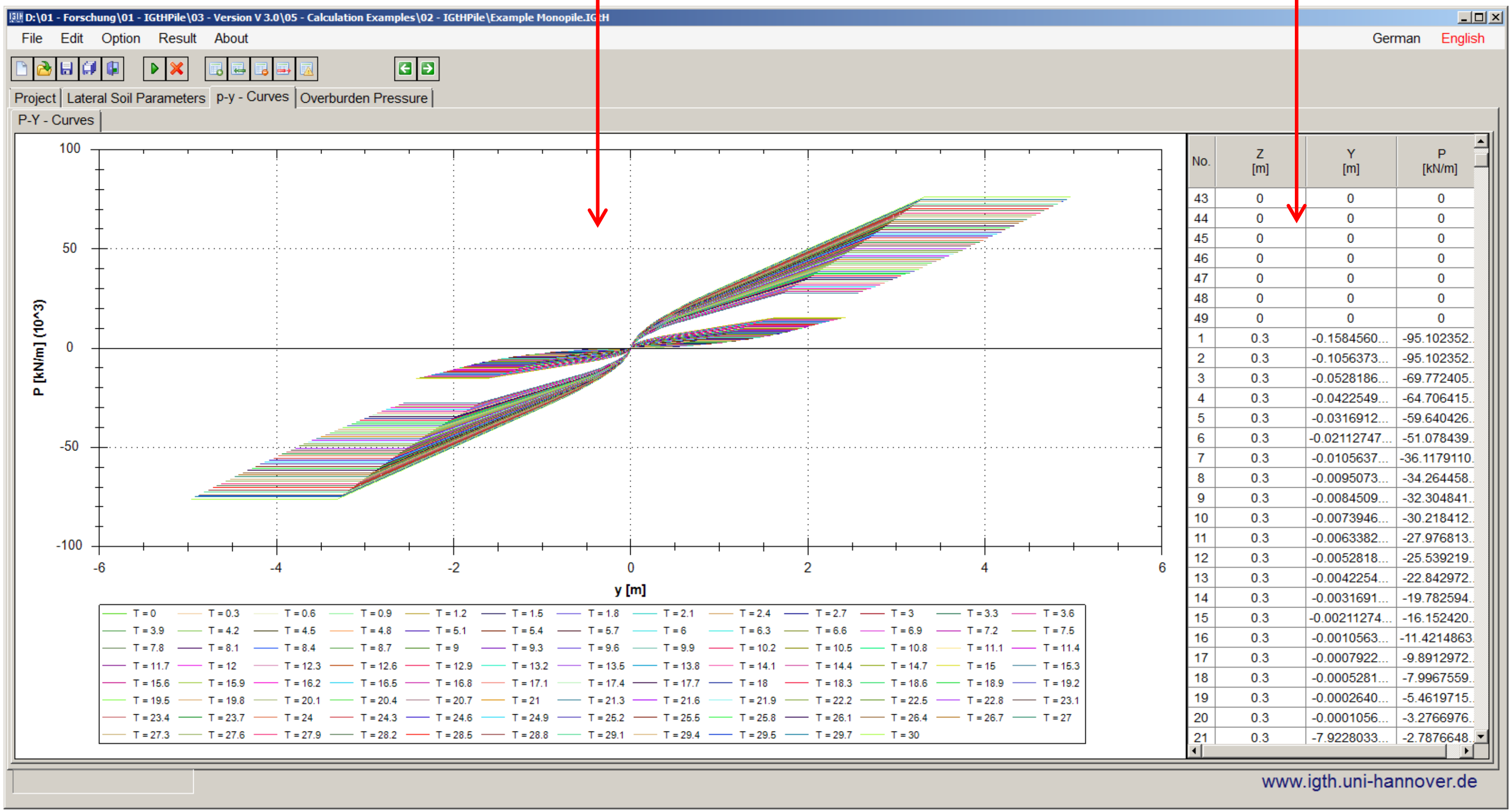
Presentation of p-y curves



Laterally Loaded Piles – p-y Curves

Graphical presentation of p-y curves; Basic curves in case of p-y curves according to Thieken et al. 2015

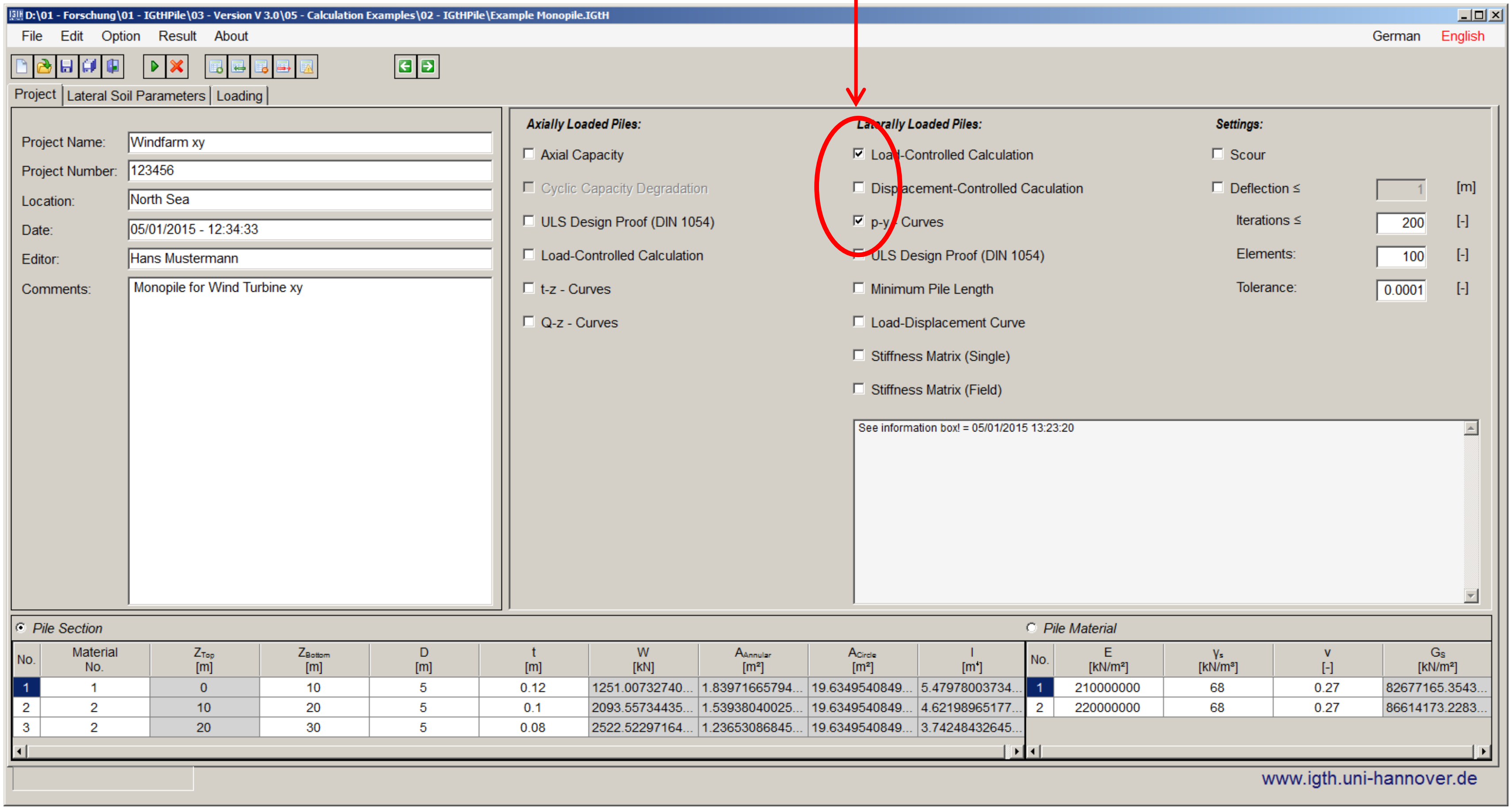
Data of p-y curves displayed in vertical list



No.	Z [m]	Y [m]	P [kN/m]
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
1	0.3	-0.1584560...	-95.102352..
2	0.3	-0.1056373...	-95.102352..
3	0.3	-0.0528186...	-69.772405..
4	0.3	-0.0422549...	-64.706415..
5	0.3	-0.0316912...	-59.640426..
6	0.3	-0.02112747...	-51.078439..
7	0.3	-0.0105637...	-36.1179110.
8	0.3	-0.0095073...	-34.264458..
9	0.3	-0.0084509...	-32.304841..
10	0.3	-0.0073946...	-30.218412..
11	0.3	-0.0063382...	-27.976813..
12	0.3	-0.0052818...	-25.539219..
13	0.3	-0.0042254...	-22.842972..
14	0.3	-0.0031691...	-19.782594..
15	0.3	-0.00211274...	-16.152420..
16	0.3	-0.0010563...	-11.4214863.
17	0.3	-0.0007922...	-9.8912972..
18	0.3	-0.0005281...	-7.9967559..
19	0.3	-0.0002640...	-5.4619715..
20	0.3	-0.0001056...	-3.2766976..
21	0.3	-7.9228033...	-2.7876648..

Laterally Loaded Piles – p-y Curves

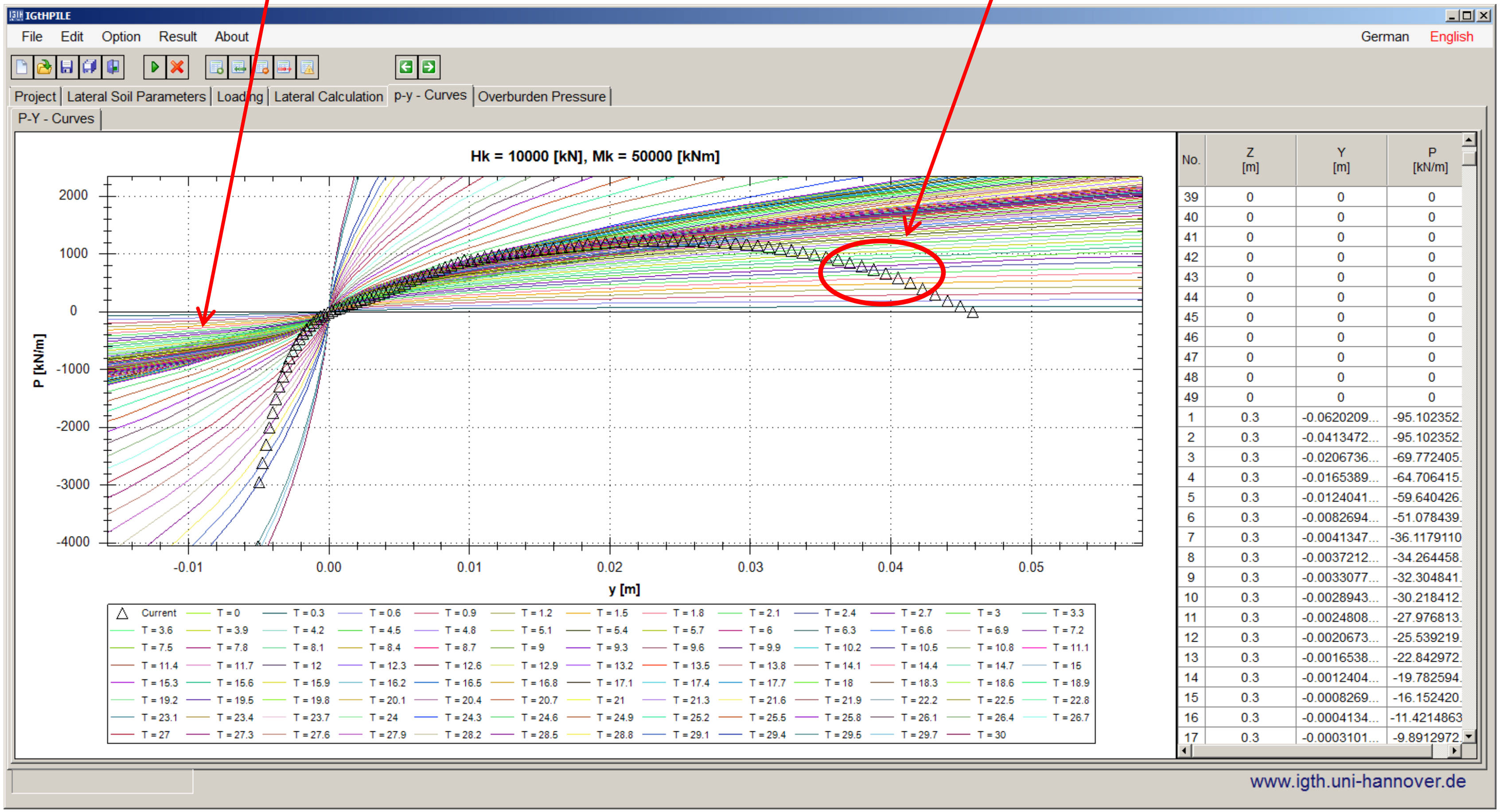
Presentation of p-y curves with p-y values for applied loading



Laterally Loaded Piles – p-y Curves

p-y curves with stretching factors
for method: Thieken et al. (2015)

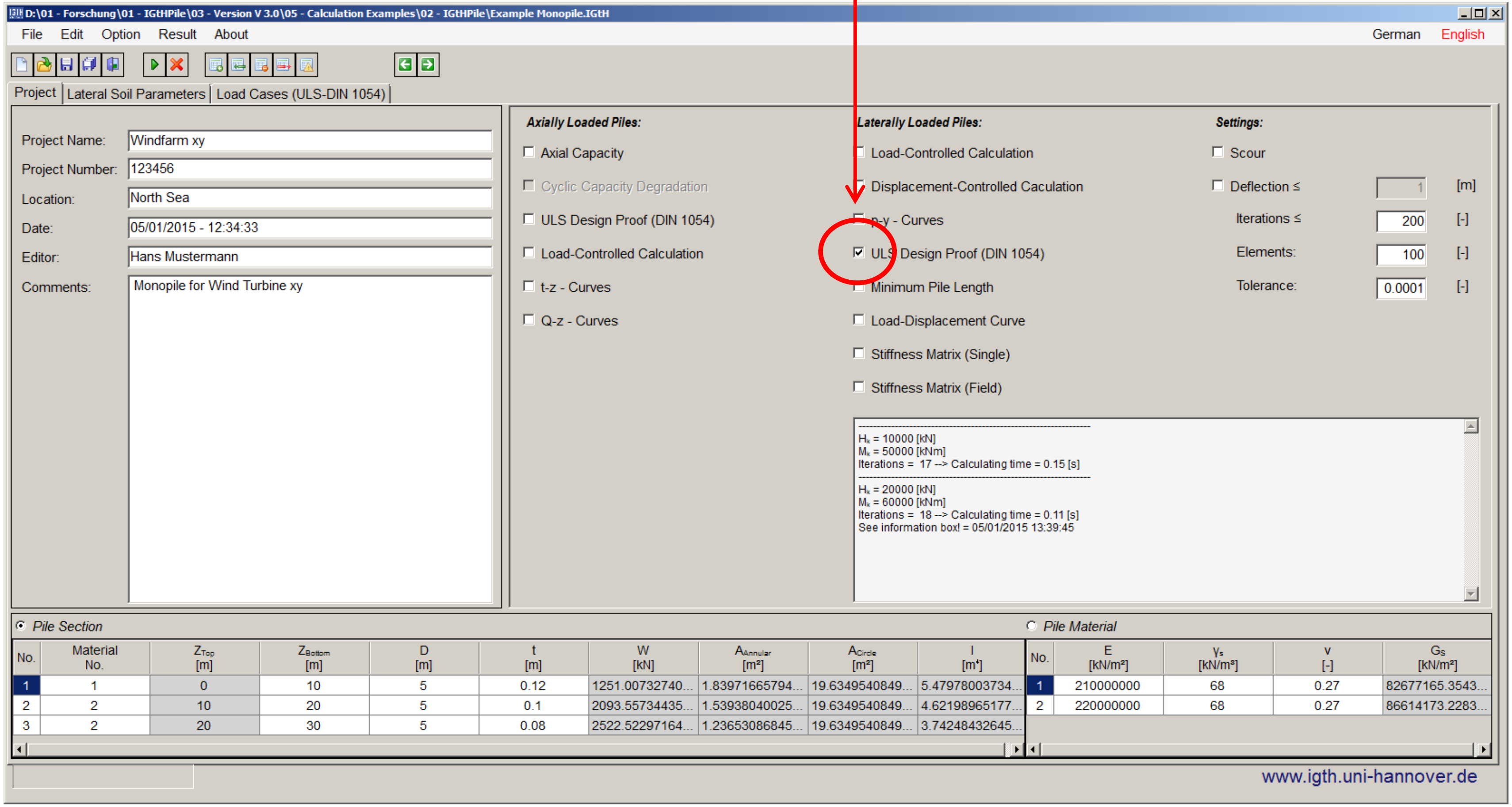
p-y values for applied loading



No.	Z [m]	Y [m]	P [kN/m]
39	0	0	0
40	0	0	0
41	0	0	0
42	0	0	0
43	0	0	0
44	0	0	0
45	0	0	0
46	0	0	0
47	0	0	0
48	0	0	0
49	0	0	0
1	0.3	-0.0620209...	-95.102352.
2	0.3	-0.0413472...	-95.102352.
3	0.3	-0.0206736...	-69.772405.
4	0.3	-0.0165389...	-64.706415.
5	0.3	-0.0124041...	-59.640426.
6	0.3	-0.0082694...	-51.078439.
7	0.3	-0.0041347...	-36.1179110
8	0.3	-0.0037212...	-34.264458.
9	0.3	-0.0033077...	-32.304841.
10	0.3	-0.0028943...	-30.218412.
11	0.3	-0.0024808...	-27.976813.
12	0.3	-0.0020673...	-25.539219.
13	0.3	-0.0016538...	-22.842972.
14	0.3	-0.0012404...	-19.782594.
15	0.3	-0.0008269...	-16.152420.
16	0.3	-0.0004134...	-11.4214863
17	0.3	-0.0003101...	-9.8912972.

Laterally Loaded Piles – ULS Design Proof acc. to DIN 1054

ULS design proof according to
German standard DIN 1054:2010-05



No.	Material No.	Z_{Top} [m]	Z_{Bottom} [m]	D [m]	t [m]	W [kN]	$A_{Annular}$ [m²]	A_{Circle} [m²]	I [m⁴]
1	1	0	10	5	0.12	1251.00732740...	1.83971665794...	19.6349540849...	5.47978003734...
2	2	10	20	5	0.1	2093.55734435...	1.53938040025...	19.6349540849...	4.62198965177...
3	2	20	30	5	0.08	2522.52297164...	1.23653086845...	19.6349540849...	3.74248432645...

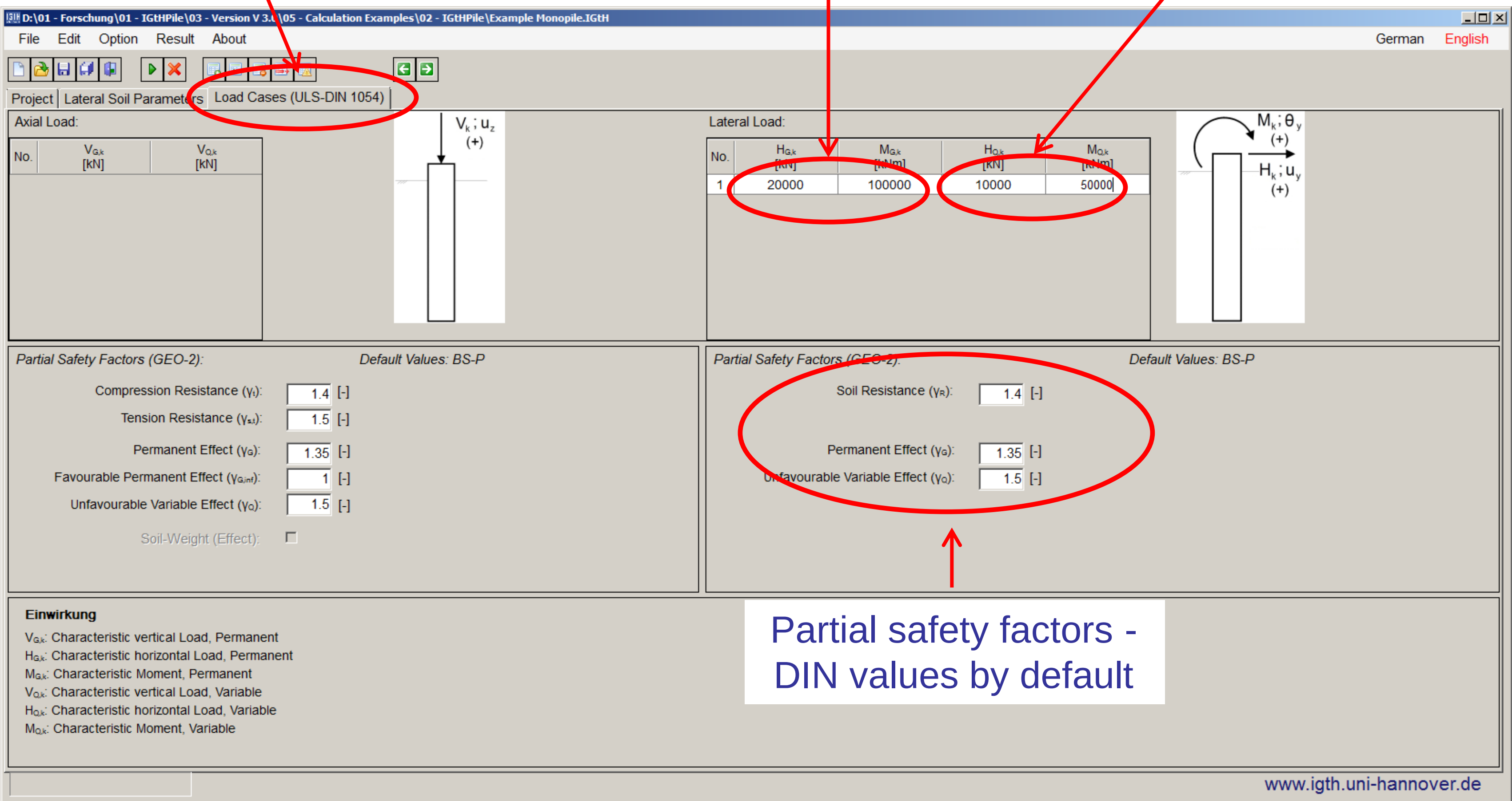
No.	E [kN/m²]	γ_s [kN/m³]	ν [-]	G_S [kN/m²]
1	210000000	68	0.27	82677165.3543...
2	220000000	68	0.27	86614173.2283...

Laterally Loaded Piles – ULS Design Proof acc. to DIN 1054

ULS design proof according to DIN 1054:2010-05

Characteristic, permanent loading

Characteristic, variable loading



Partial safety factors - DIN values by default

Laterally Loaded Piles – ULS Design Proof acc. to DIN 1054

Variable loading existing:

Determination of $B_{G+Q,k}$

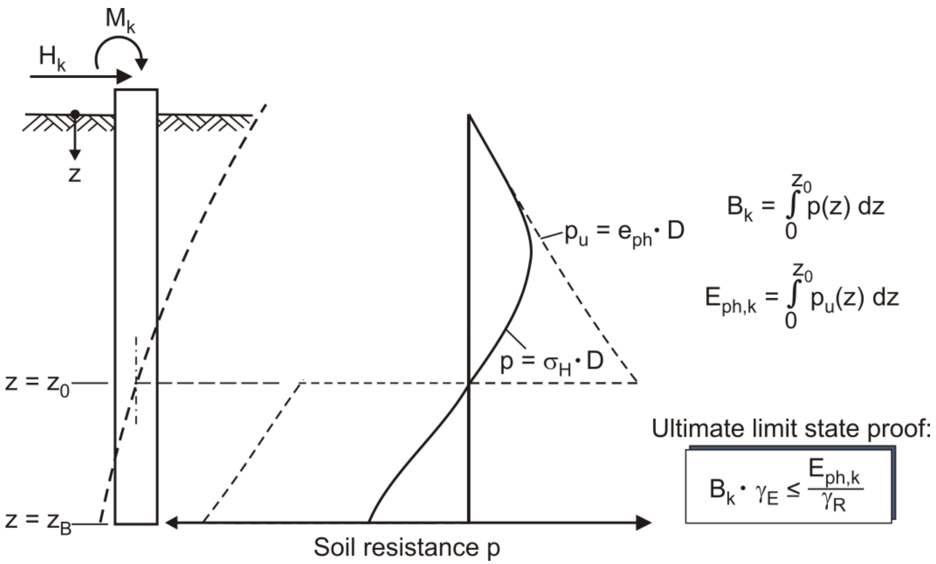
$\rightarrow$ Load: $H_{G,k} + H_{Q,k}$ / $M_{G,k} + M_{Q,k}$

Determination of $B_{Q,k}$

$\rightarrow$ Load: $H_{Q,k}$ / $M_{Q,k}$

Determination of $B_{G,k}$

$\rightarrow B_{G,k} = B_{G+Q,k} - B_{Q,k}$



Design proof:

$$B_{G,d} + B_{Q,d} \leq E_{ph,d}$$

$$B_{G,k} \cdot \gamma_G + B_{Q,k} \cdot \gamma_Q \leq \frac{E_{ph,k}}{\gamma_R}$$

Regarding the suitability of the ULS design proof according to DIN 1054 please see:

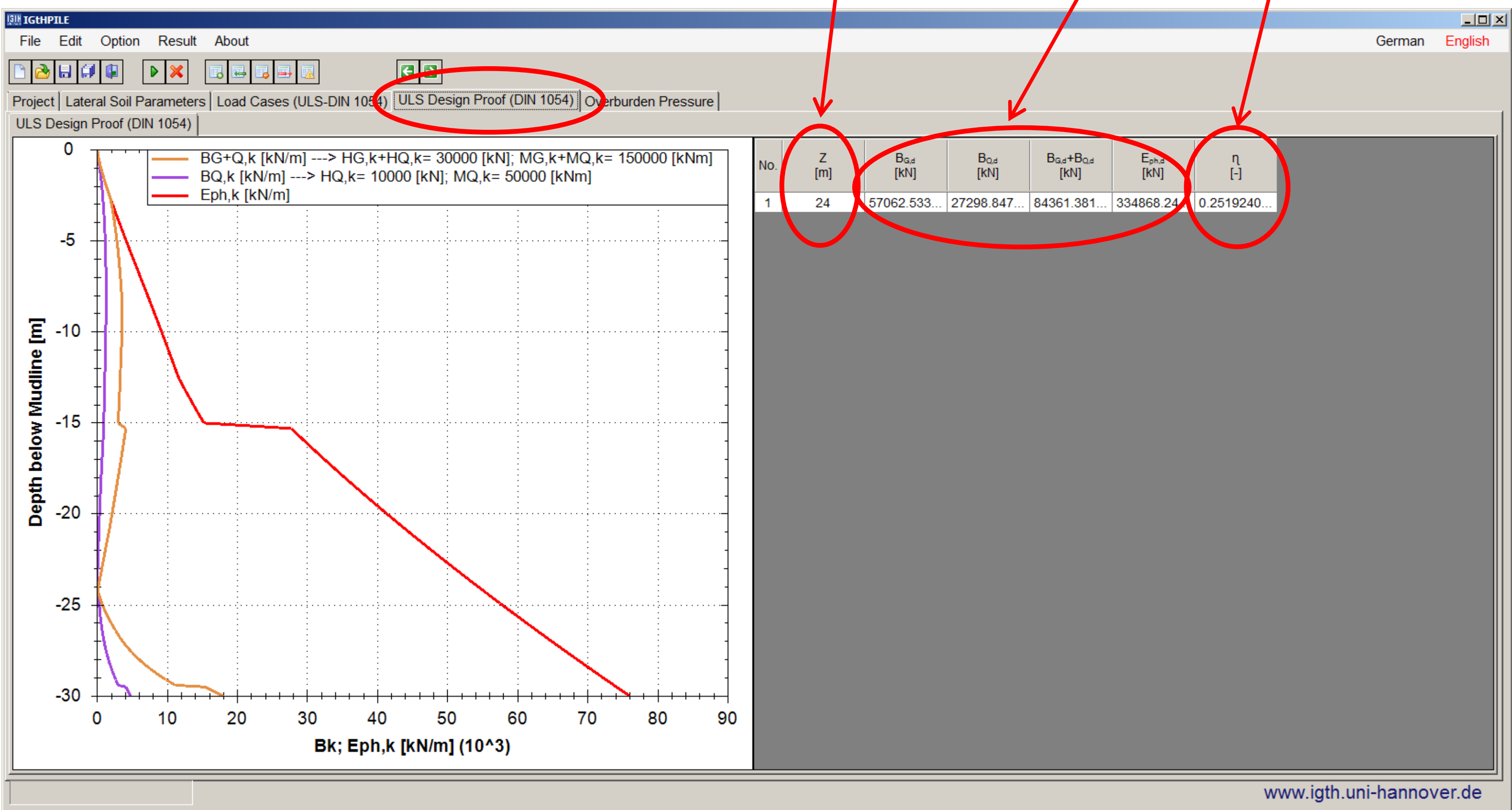
Thieken, K., Achmus, M., Schmoor, K.A. (2014): "On the ultimate limit state design proof for laterally loaded piles", Geotechnik 37 (1), pp. 19-31.

Laterally Loaded Piles – ULS Design Proof acc. to DIN 1054

Corresponding point of rotation

Design proof

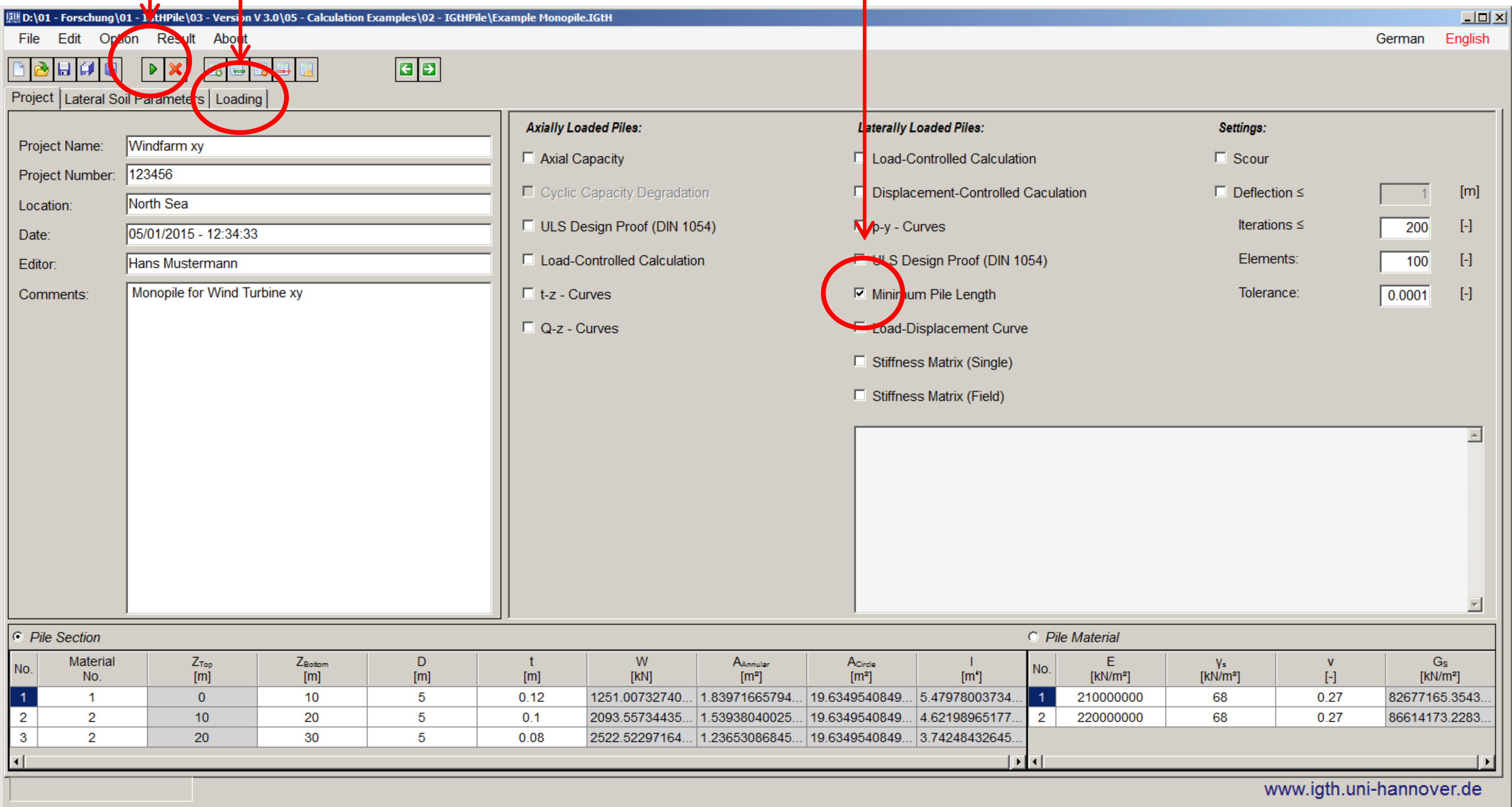
Utilization ratio



Laterally Loaded Piles – Minimum Pile Length

Insert loading of interest,
start calculation

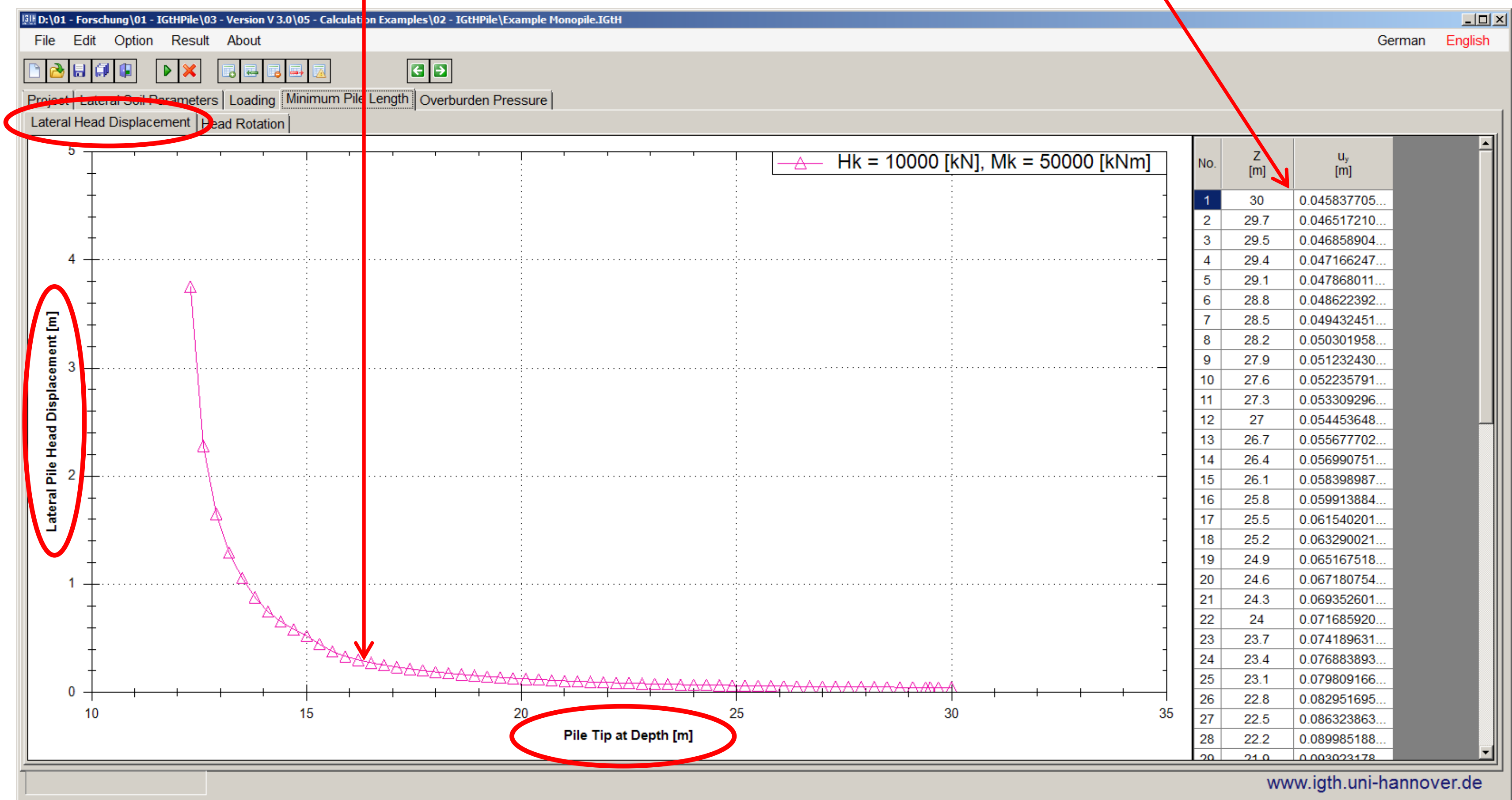
Reducing pile length to minimum



Laterally Loaded Piles – Minimum Pile Length

Find minimum pile length for
tolerable head displacement / head rotation

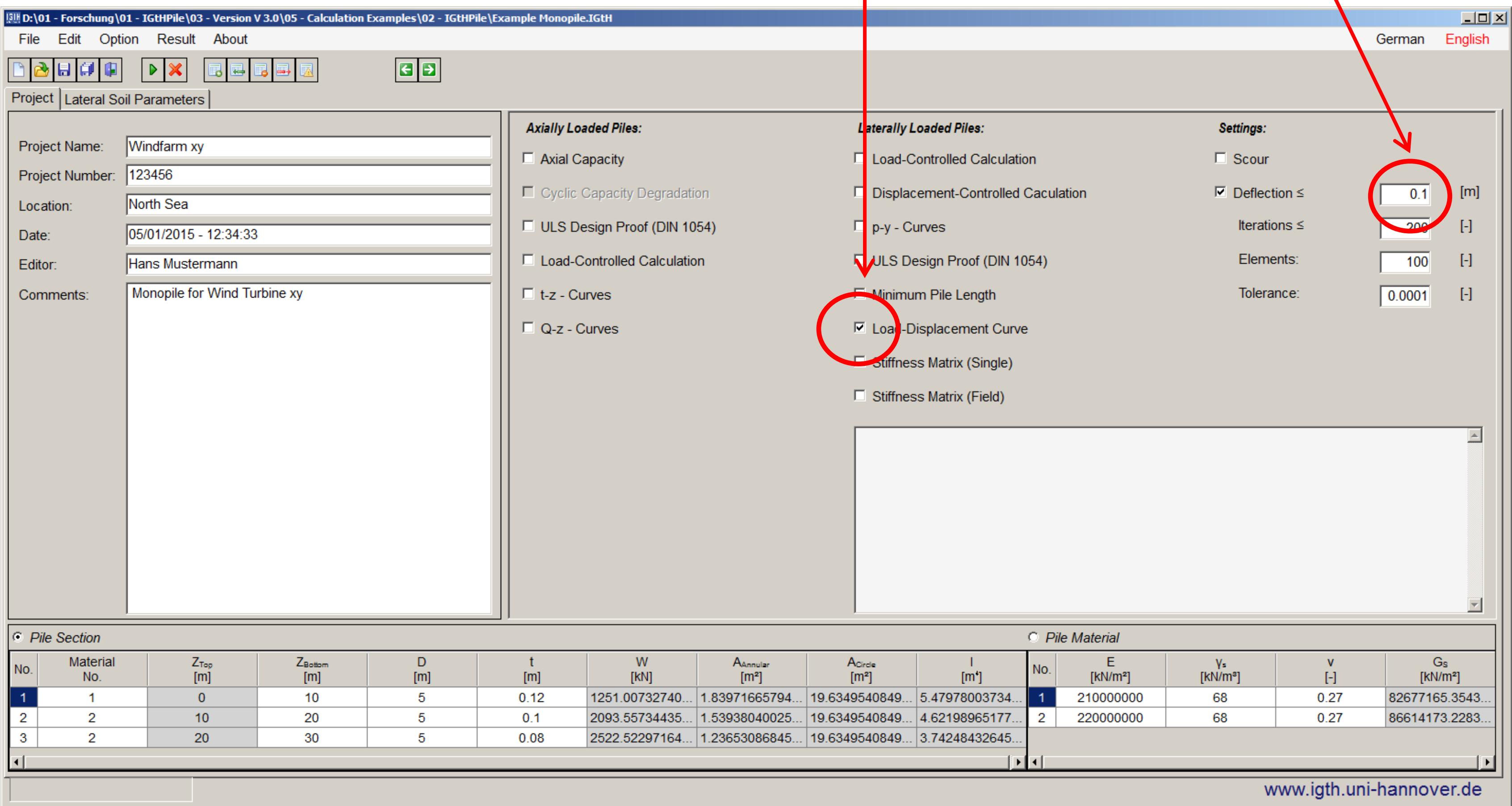
Data for pile length z
displayed in vertical list



Laterally Loaded Piles – Load-Displacement Curve

Generate load-displacement curve

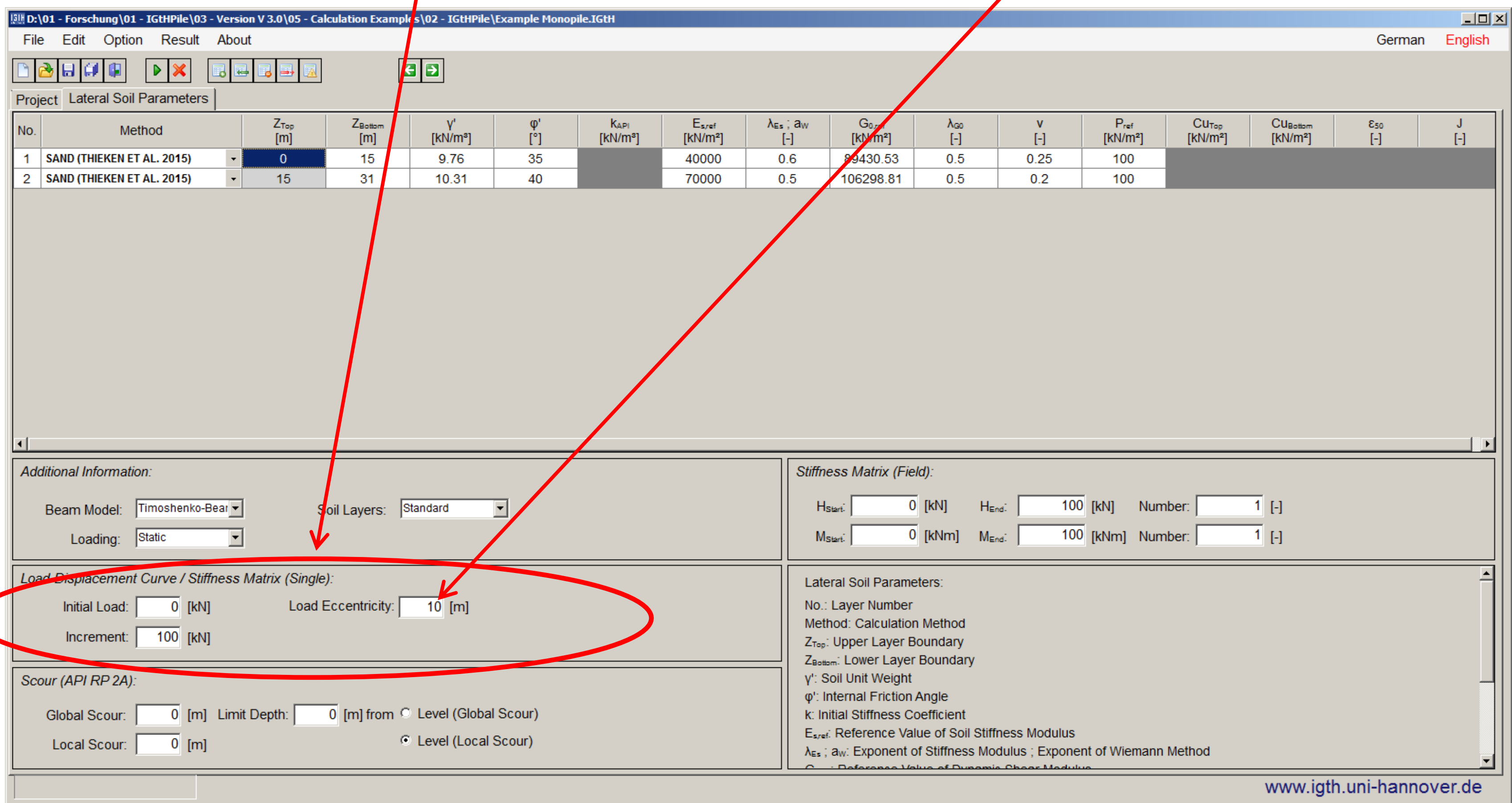
Stop calculation at certain pile head displacement



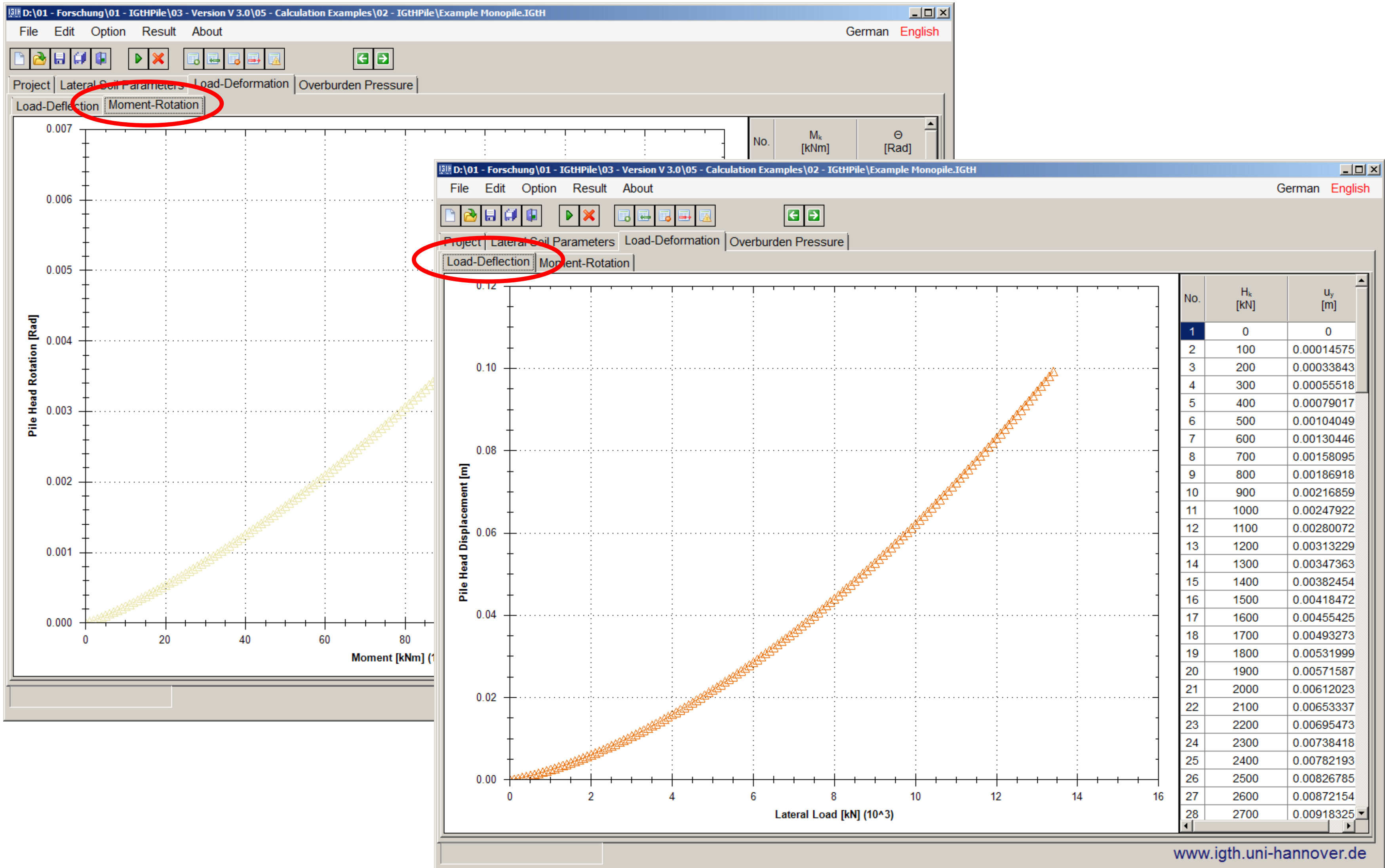
Laterally Loaded Piles – Load-Displacement Curve

Define initial horizontal load H, horizontal load increment and horizontal load eccentricity

Pile head moment
M = H · 10 m



Laterally Loaded Piles – Load-Displacement Curve

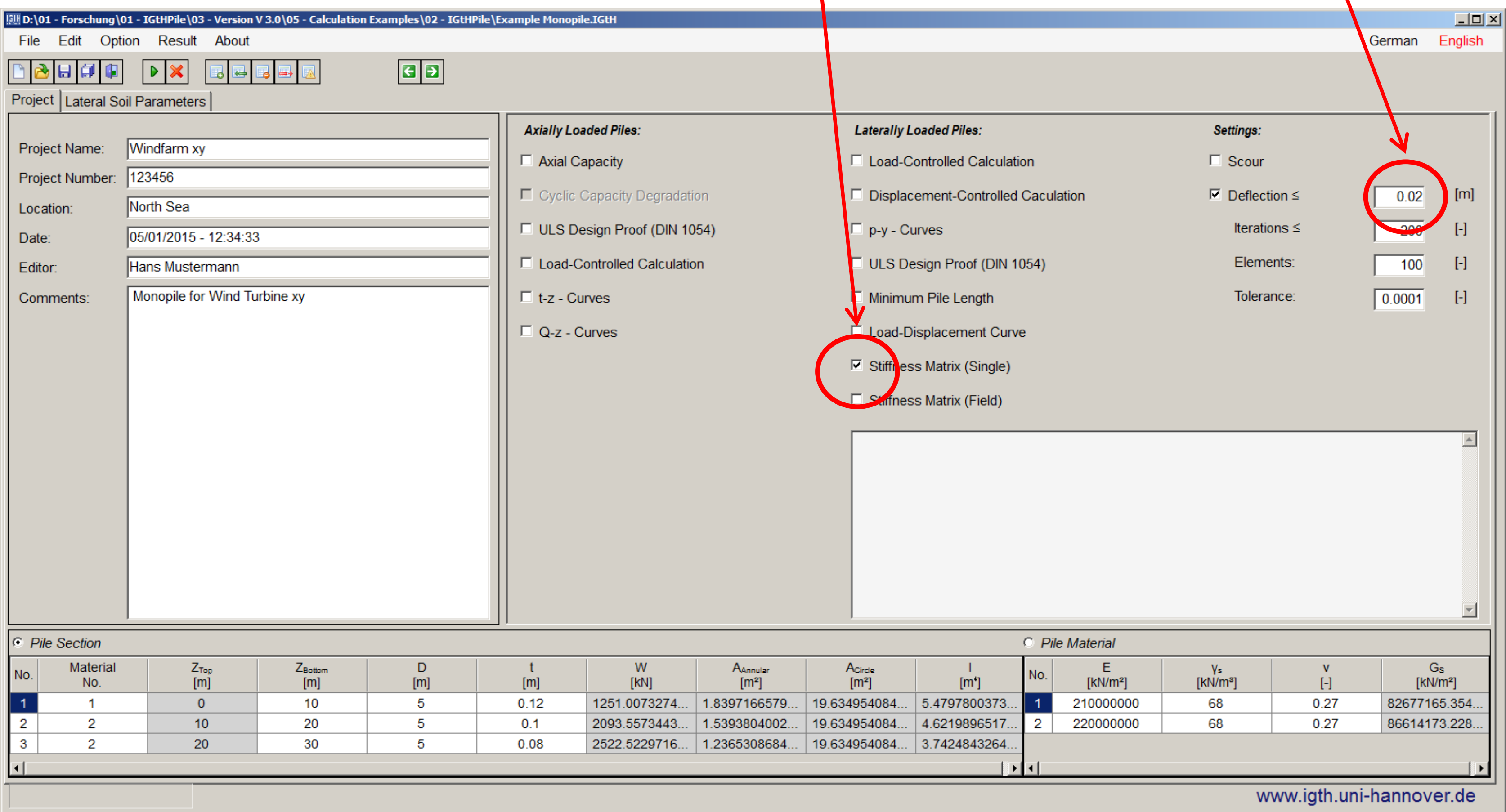


No.	H_k [kN]	u_y [m]
1	0	0
2	100	0.00014575
3	200	0.00033843
4	300	0.00055518
5	400	0.00079017
6	500	0.00104049
7	600	0.00130446
8	700	0.00158095
9	800	0.00186918
10	900	0.00216859
11	1000	0.00247922
12	1100	0.00280072
13	1200	0.00313229
14	1300	0.00347363
15	1400	0.00382454
16	1500	0.00418472
17	1600	0.00455425
18	1700	0.00493273
19	1800	0.00531999
20	1900	0.00571587
21	2000	0.00612023
22	2100	0.00653337
23	2200	0.00695473
24	2300	0.00738418
25	2400	0.00782193
26	2500	0.00826785
27	2600	0.00872154
28	2700	0.00918325

Laterally Loaded Piles – Stiffness Matrix (Single)

Generate stiffness matrices for single load eccentricity

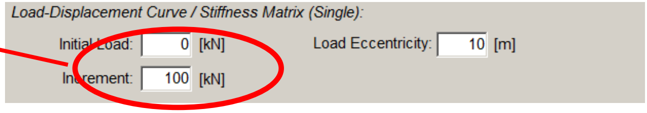
Stop calculation at certain pile head displacement



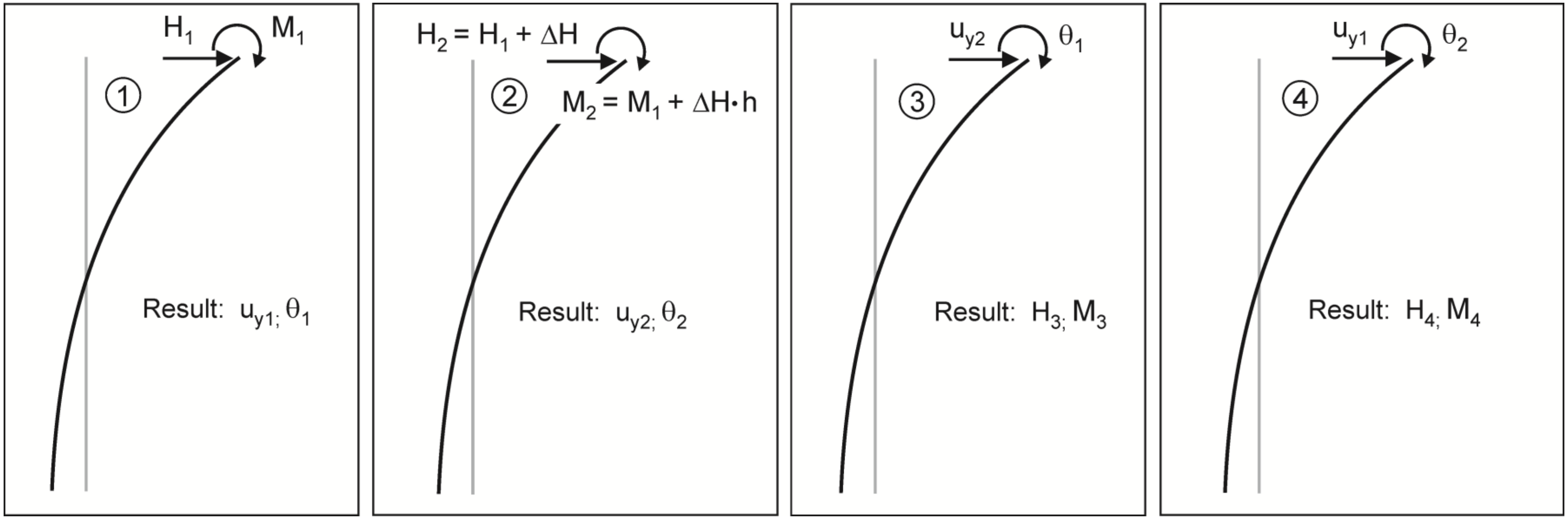
Laterally Loaded Piles – Stiffness Matrix (Single)

$$\begin{pmatrix}\Delta H\\ \Delta M\end{pmatrix} = \begin{pmatrix}K_{22} & K_{23}\\ K_{32} & K_{33}\end{pmatrix}\cdot\begin{pmatrix}\Delta u_y\\ \Delta\Theta\end{pmatrix} \leftrightarrow \begin{pmatrix}H_2 - H_1\\ M_2 - M_1\end{pmatrix} = \begin{pmatrix}K_{22} & K_{23}\\ K_{32} & K_{33}\end{pmatrix}\cdot\begin{pmatrix}u_{y2} - u_{y1}\\ \Theta_2 - \Theta_1\end{pmatrix}$$

with: $\Delta H = 1E\text{-}6 \cdot H_{inc}$



Calculation procedure for generating stiffness matrices (1) → (4)

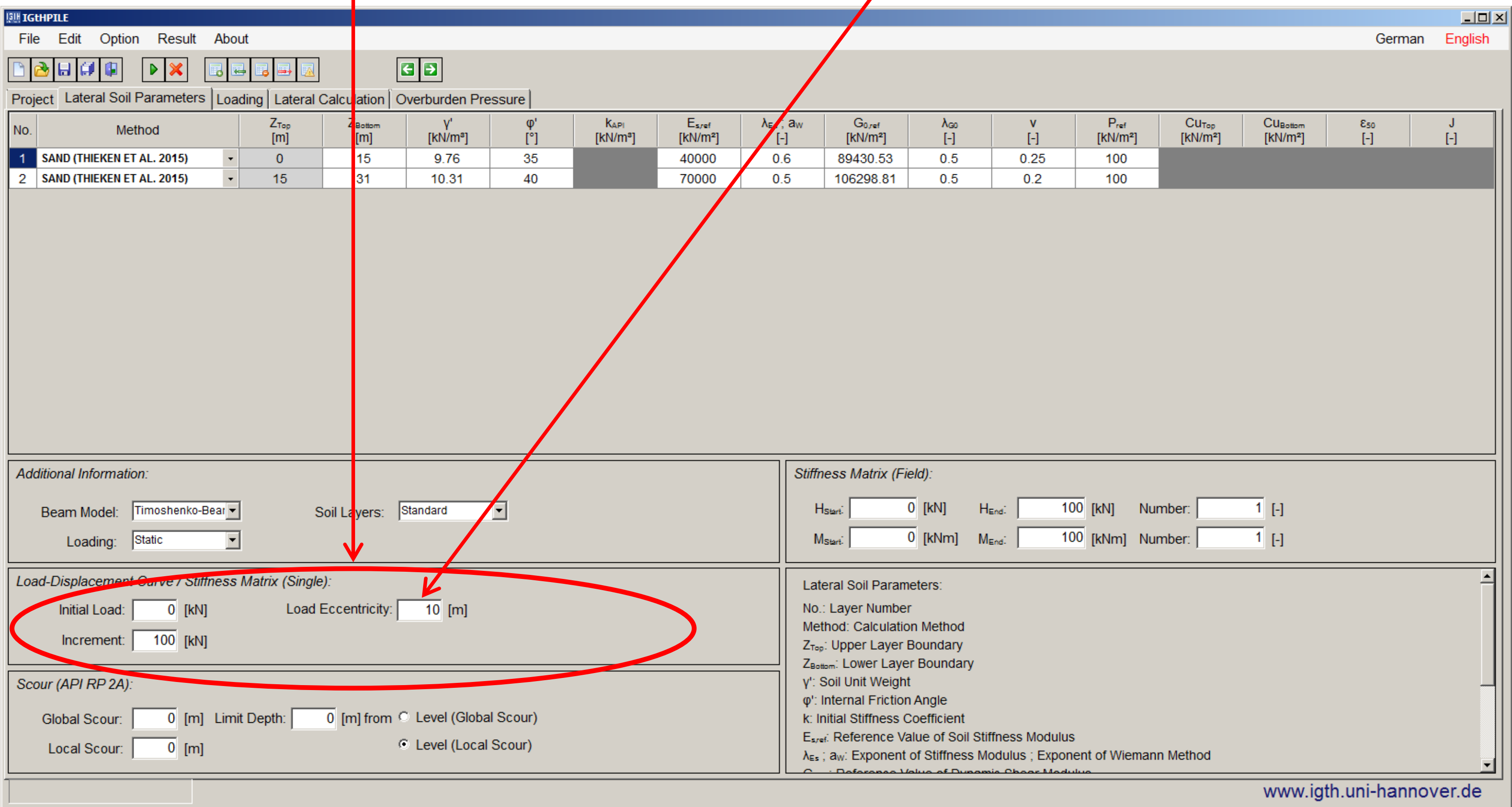


$$K_{22} = \frac{H_3 - H_1}{u_{y2} - u_{y1}} \qquad K_{23} = \frac{H_4 - H_1}{\theta_2 - \theta_1} \qquad K_{32} = \frac{M_3 - M_1}{u_{y2} - u_{y1}} \qquad K_{33} = \frac{M_4 - M_1}{\theta_2 - \theta_1}$$

Laterally Loaded Piles – Stiffness Matrix (Single)

Define initial horizontal load H, horizontal load increment and horizontal load eccentricity

Pile head moment
$M = H \cdot 10$ m

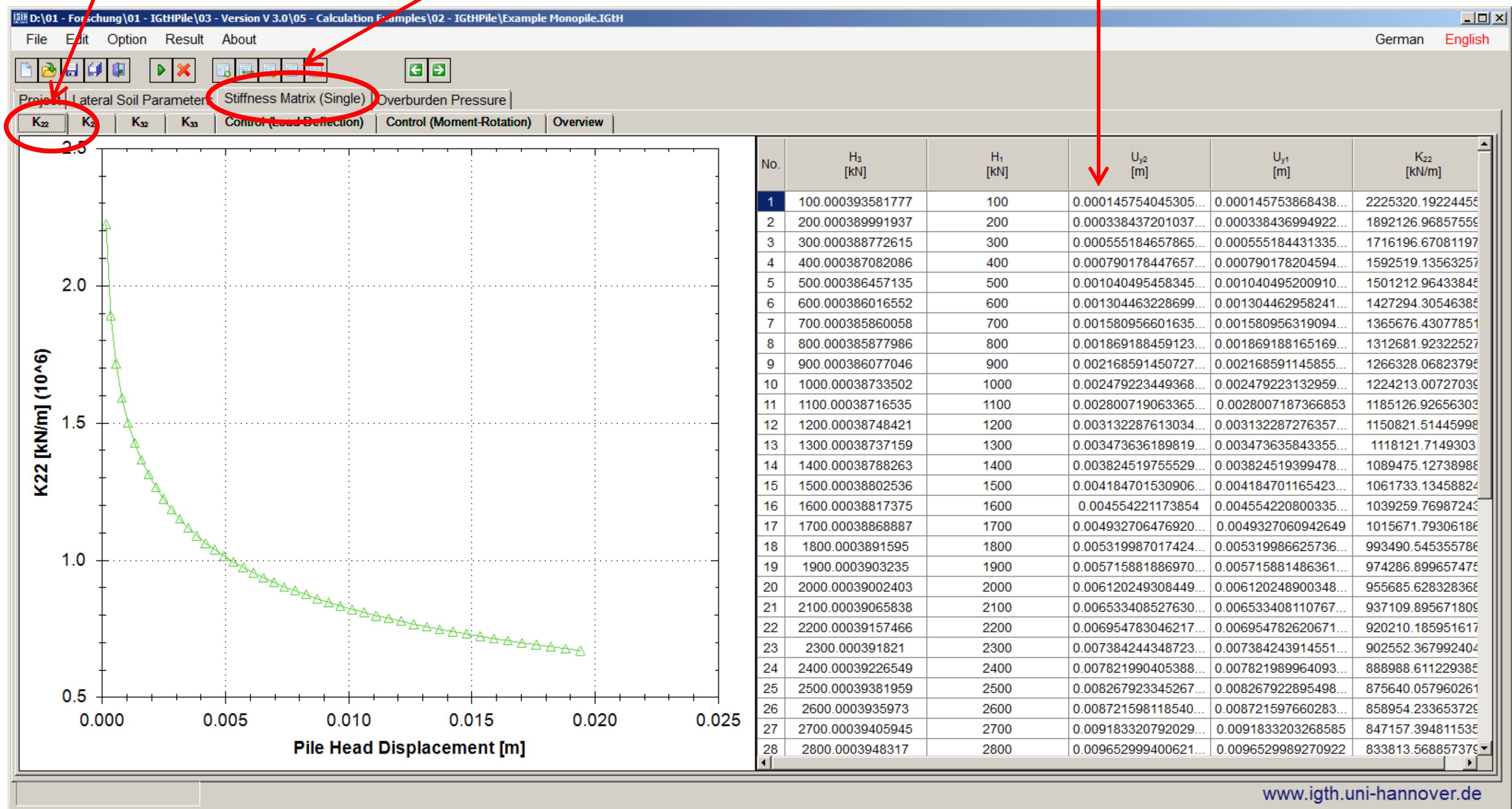


Laterally Loaded Piles – Stiffness Matrix (Single)

Choose matrix entry

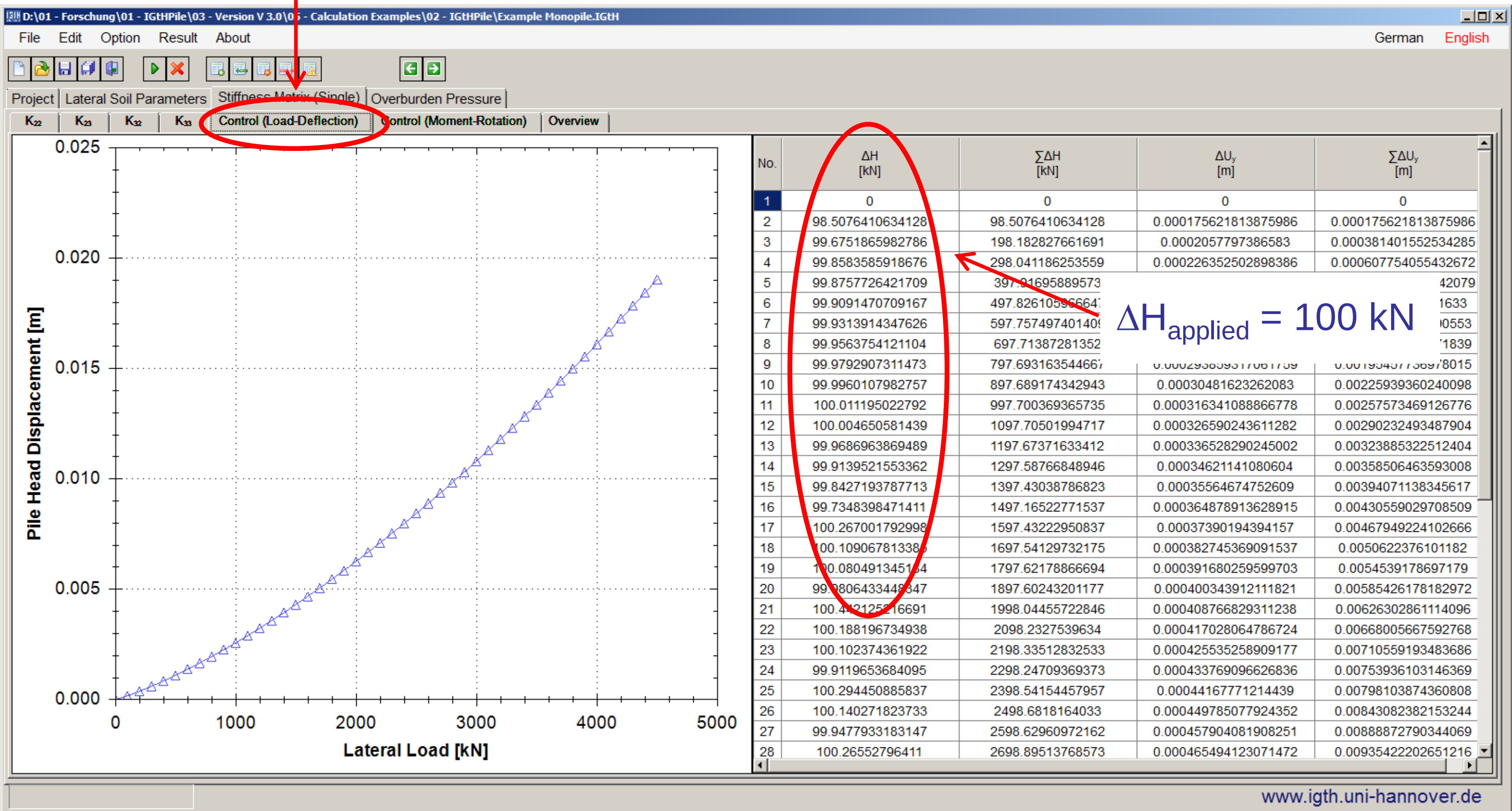
Show stiffness matrix

Values in tabular form



No.	H_3 [kN]	H_1 [kN]	U_{y2} [m]	U_{y1} [m]	K_{22} [kN/m]
1	100.000393581777	100	0.000145754045305...	0.000145753868438...	2225320.19224455
2	200.000389991937	200	0.000338437201037...	0.000338436994922...	1892126.96857559
3	300.000388772615	300	0.000555184657865...	0.000555184431335...	1716196.67081197
4	400.000387082086	400	0.000790178447657...	0.000790178204594...	1592519.13563257
5	500.000386457135	500	0.00104049545834 5...	0.00104049520091 0...	1501212.96433845
6	600.000386016552	600	0.001304463228699...	0.001304462958241...	1427294.30546385
7	700.000385860058	700	0.001580956601635...	0.001580956319094...	1365676.43077851
8	800.000385877986	800	0.001869188459123...	0.001869188165169...	1312681.92322527
9	900.000386077046	900	0.002168591450727...	0.002168591145855...	1266328.06823795
10	1000.00038733502	1000	0.002479223449368...	0.002479223132959...	1224213.00727039
11	1100.00038716535	1100	0.002800719063365...	0.0028007187366853	1185126.92656303
12	1200.00038748421	1200	0.003132287613034...	0.003132287276357...	1150821.51445998
13	1300.00038737159	1300	0.003473636189819...	0.003473635843355...	1118121.7149303
14	1400.00038788263	1400	0.003824519755529...	0.003824519399478...	1089475.12738988
15	1500.00038802536	1500	0.004184701530906...	0.004184701165423...	1061733.13458824
16	1600.00038817375	1600	0.004554221173854	0.004554220800335...	1039259.76987243
17	1700.00038868887	1700	0.004932706476920...	0.0049327060942649	1015671.79306186
18	1800.0003891595	1800	0.005319987017424...	0.005319986625736...	993490.545355786
19	1900.0003903235	1900	0.005715881886970...	0.005715881486361...	974286.899657475
20	2000.00039002403	2000	0.006120249308449...	0.006120248900348...	955685.628328368
21	2100.00039065838	2100	0.006533408527630...	0.006533408110767...	937109.895671809
22	2200.00039157466	2200	0.006954783046217...	0.006954782620671...	920210.185951617
23	2300.000391821	2300	0.007384244348723...	0.007384243914551...	902552.367992404
24	2400.00039226549	2400	0.007821990405388...	0.007821989964093...	888988.611229385
25	2500.00039381959	2500	0.008267923345267...	0.008267922895498...	875640.057960261
26	2600.0003935973	2600	0.008721598118540...	0.008721597660283...	858954.233653729
27	2700.00039405945	2700	0.009183320792029...	0.0091833203268585	847157.394811535
28	2800.0003948317	2800	0.009652999400621...	0.0096529989270922	833813.568857379

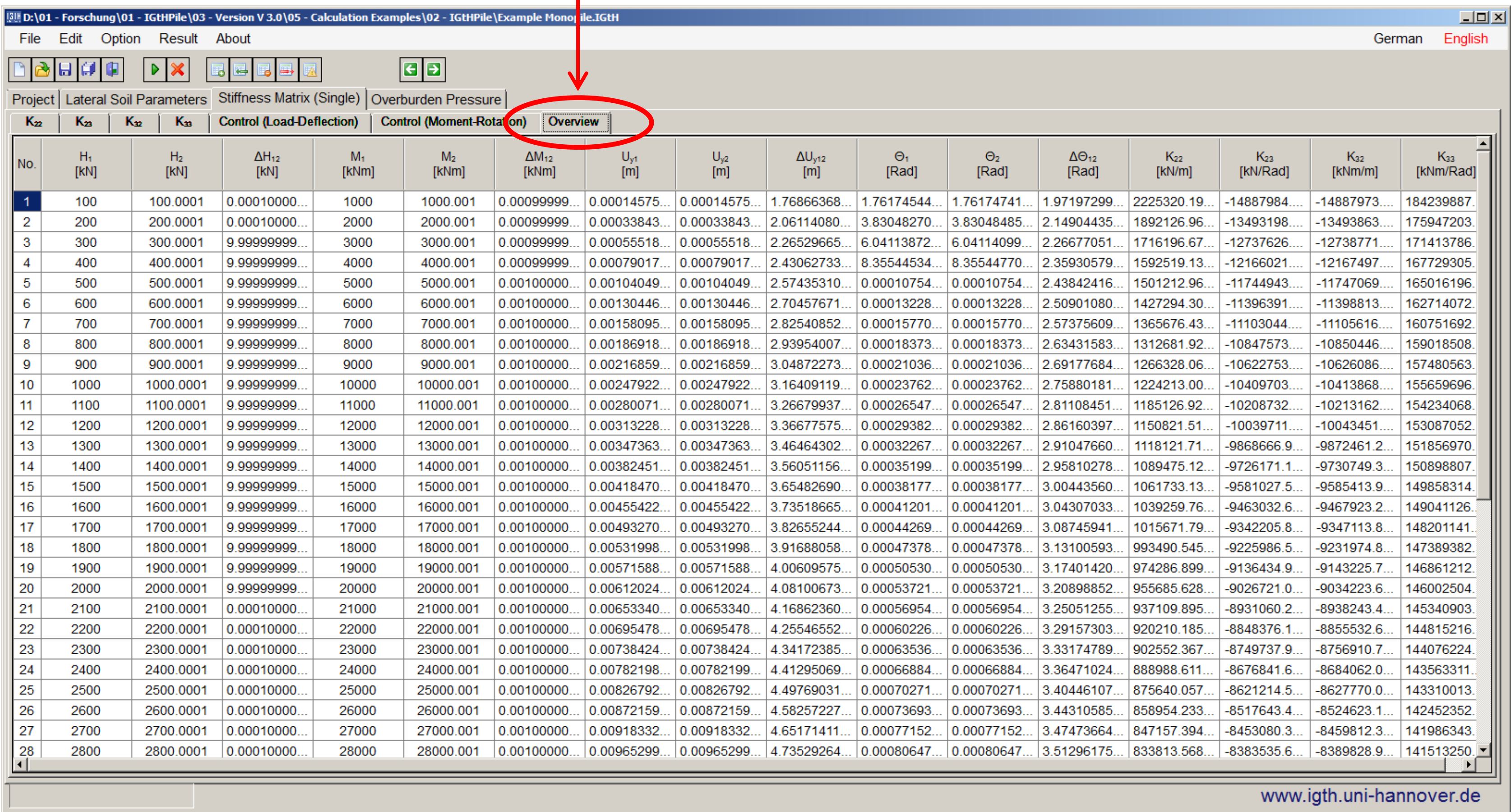
<u>Note:</u> The matrices are valid for tangential calculations. Therefore, the calculation accuracy depends on the applied load increment. The control windows depict the load-deflection curve and the moment-rotation curve based on the multiplied stiffness matrix. Make sure that the deviation to the applied load increment is small enough for your purpose.



No.	ΔH [kN]	∑ΔH [kN]	ΔU_y [m]	$\sum\Delta U_y$ [m]
1	0	0	0	0
2	98.5076410634128	98.5076410634128	0.000175621813875986	0.000175621813875986
3	99.6751865982786	198.182827661691	0.0002057797386583	0.000381401552534285
4	99.8583585918676	298.041186253559	0.000226352502898386	0.000607754055432672
5	99.8757726421709	397.91695889573	[illegible]	[illegible]
6	99.9091470709167	497.82610596664	[illegible]	[illegible]
7	99.9313914347626	597.75749740140	[illegible]	[illegible]
8	99.9563754121104	697.71387281352	[illegible]	[illegible]
9	99.9792907311473	797.69316354466	[illegible]	[illegible]
10	99.9960107982757	897.689174342943	0.00030481623262083	0.00225939360240098
11	100.011195022792	997.700369365735	0.000316341088866778	0.00257573469126776
12	100.004650581439	1097.70501994717	0.000326590243611282	0.00290232493487904
13	99.9686963869489	1197.67371633412	0.000336528290245002	0.00323885322512404
14	99.9139521553362	1297.58766848946	0.00034621141080604	0.00358506463593008
15	99.8427193787713	1397.43038786823	0.00035564674752609	0.00394071138345617
16	99.7348398471411	1497.16522771537	0.000364878913628915	0.00430559029708509
17	100.267001792998	1597.43222950837	0.00037390194394157	0.00467949224102666
18	100.109067813385	1697.54129732175	0.000382745369091537	0.0050622376101182
19	100.080491345164	1797.62178866694	0.000391680259599703	0.0054539178697179
20	99.9806433448347	1897.60243201177	0.000400343912111821	0.00585426178182972
21	100.442125216691	1998.04455722846	0.000408766829311238	0.00626302861114096
22	100.188196734938	2098.2327539634	0.000417028064786724	0.00668005667592768
23	100.102374361922	2198.33512832533	0.000425535258909177	0.00710559193483686
24	99.9119653684095	2298.24709369373	0.000433769096626836	0.00753936103146369
25	100.294450885837	2398.54154457957	0.00044167771214439	0.00798103874360808
26	100.140271823733	2498.6818164033	0.000449785077924352	0.00843082382153244
27	99.9477933183147	2598.62960972162	0.000457904081908251	0.00888872790344069
28	100.26552796411	2698.89513768573	0.000465494123071472	0.00935422202651216

Laterally Loaded Piles – Stiffness Matrix (Single)

Overview of all relevant calculation values (for post processing)



No.	H_1 [kN]	H_2 [kN]	ΔH_{12} [kN]	M_1 [kNm]	M_2 [kNm]	ΔM_{12} [kNm]	U_{y1} [m]	U_{y2} [m]	ΔU_{y12} [m]	Θ_1 [Rad]	Θ_2 [Rad]	$\Delta\Theta_{12}$ [Rad]	K_{22} [kN/m]	K_{23} [kN/Rad]	K_{32} [kNm/m]	K_{33} [kNm/Rad]
1	100	100.0001	0.00010000...	1000	1000.001	0.00099999...	0.00014575...	0.00014575...	1.76866368...	1.76174544...	1.76174741...	1.97197299...	2225320.19...	-14887984....	-14887973....	184239887.
2	200	200.0001	0.00010000...	2000	2000.001	0.00099999...	0.00033843...	0.00033843...	2.06114080...	3.83048270...	3.83048485...	2.14904435...	1892126.96...	-13493198....	-13493863....	175947203.
3	300	300.0001	9.99999999...	3000	3000.001	0.00099999...	0.00055518...	0.00055518...	2.26529665...	6.04113872...	6.04114099...	2.26677051...	1716196.67...	-12737626....	-12738771....	171413786.
4	400	400.0001	9.99999999...	4000	4000.001	0.00099999...	0.00079017...	0.00079017...	2.43062733...	8.35544534...	8.35544770...	2.35930579...	1592519.13...	-12166021....	-12167497....	167729305.
5	500	500.0001	9.99999999...	5000	5000.001	0.00100000...	0.00104049...	0.00104049...	2.57435310...	0.00010754...	0.00010754...	2.43842416...	1501212.96...	-11744943....	-11747069....	165016196.
6	600	600.0001	9.99999999...	6000	6000.001	0.00100000...	0.00130446...	0.00130446...	2.70457671...	0.00013228...	0.00013228...	2.50901080...	1427294.30...	-11396391....	-11398813....	162714072.
7	700	700.0001	9.99999999...	7000	7000.001	0.00100000...	0.00158095...	0.00158095...	2.82540852...	0.00015770...	0.00015770...	2.57375609...	1365676.43...	-11103044....	-11105616....	160751692.
8	800	800.0001	9.99999999...	8000	8000.001	0.00100000...	0.00186918...	0.00186918...	2.93954007...	0.00018373...	0.00018373...	2.63431583...	1312681.92...	-10847573....	-10850446....	159018508.
9	900	900.0001	9.99999999...	9000	9000.001	0.00100000...	0.00216859...	0.00216859...	3.04872273...	0.00021036...	0.00021036...	2.69177684...	1266328.06...	-10622753....	-10626086....	157480563.
10	1000	1000.0001	9.99999999...	10000	10000.001	0.00100000...	0.00247922...	0.00247922...	3.16409119...	0.00023762...	0.00023762...	2.75880181...	1224213.00...	-10409703....	-10413868....	155659696.
11	1100	1100.0001	9.99999999...	11000	11000.001	0.00100000...	0.00280071...	0.00280071...	3.26679937...	0.00026547...	0.00026547...	2.81108451...	1185126.92...	-10208732....	-10213162....	154234068.
12	1200	1200.0001	9.99999999...	12000	12000.001	0.00100000...	0.00313228...	0.00313228...	3.36677575...	0.00029382...	0.00029382...	2.86160397...	1150821.51...	-10039711....	-10043451....	153087052.
13	1300	1300.0001	9.99999999...	13000	13000.001	0.00100000...	0.00347363...	0.00347363...	3.46464302...	0.00032267...	0.00032267...	2.91047660...	1118121.71...	-9868666.9...	-9872461.2...	151856970.
14	1400	1400.0001	9.99999999...	14000	14000.001	0.00100000...	0.00382451...	0.00382451...	3.56051156...	0.00035199...	0.00035199...	2.95810278...	1089475.12...	-9726171.1...	-9730749.3...	150898807.
15	1500	1500.0001	9.99999999...	15000	15000.001	0.00100000...	0.00418470...	0.00418470...	3.65482690...	0.00038177...	0.00038177...	3.00443560...	1061733.13...	-9581027.5...	-9585413.9...	149858314.
16	1600	1600.0001	9.99999999...	16000	16000.001	0.00100000...	0.00455422...	0.00455422...	3.73518665...	0.00041201...	0.00041201...	3.04307033...	1039259.76...	-9463032.6...	-9467923.2...	149041126.
17	1700	1700.0001	9.99999999...	17000	17000.001	0.00100000...	0.00493270...	0.00493270...	3.82655244...	0.00044269...	0.00044269...	3.08745941...	1015671.79...	-9342205.8...	-9347113.8...	148201141.
18	1800	1800.0001	9.99999999...	18000	18000.001	0.00100000...	0.00531998...	0.00531998...	3.91688058...	0.00047378...	0.00047378...	3.13100593...	993490.545...	-9225986.5...	-9231974.8...	147389382.
19	1900	1900.0001	9.99999999...	19000	19000.001	0.00100000...	0.00571588...	0.00571588...	4.00609575...	0.00050530...	0.00050530...	3.17401420...	974286.899...	-9136434.9...	-9143225.7...	146861212.
20	2000	2000.0001	9.99999999...	20000	20000.001	0.00100000...	0.00612024...	0.00612024...	4.08100673...	0.00053721...	0.00053721...	3.20898852...	955685.628...	-9026721.0...	-9034223.6...	146002504.
21	2100	2100.0001	0.00010000...	21000	21000.001	0.00100000...	0.00653340...	0.00653340...	4.16862360...	0.00056954...	0.00056954...	3.25051255...	937109.895...	-8931060.2...	-8938243.4...	145340903.
22	2200	2200.0001	0.00010000...	22000	22000.001	0.00100000...	0.00695478...	0.00695478...	4.25546552...	0.00060226...	0.00060226...	3.29157303...	920210.185...	-8848376.1...	-8855532.6...	144815216.
23	2300	2300.0001	0.00010000...	23000	23000.001	0.00100000...	0.00738424...	0.00738424...	4.34172385...	0.00063536...	0.00063536...	3.33174789...	902552.367...	-8749737.9...	-8756910.7...	144076224.
24	2400	2400.0001	0.00010000...	24000	24000.001	0.00100000...	0.00782198...	0.00782199...	4.41295069...	0.00066884...	0.00066884...	3.36471024...	888988.611...	-8676841.6...	-8684062.0...	143563311.
25	2500	2500.0001	0.00010000...	25000	25000.001	0.00100000...	0.00826792...	0.00826792...	4.49769031...	0.00070271...	0.00070271...	3.40446107...	875640.057...	-8621214.5...	-8627770.0...	143310013.
26	2600	2600.0001	0.00010000...	26000	26000.001	0.00100000...	0.00872159...	0.00872159...	4.58257227...	0.00073693...	0.00073693...	3.44310585...	858954.233...	-8517643.4...	-8524623.1...	142452352.
27	2700	2700.0001	0.00010000...	27000	27000.001	0.00100000...	0.00918332...	0.00918332...	4.65171411...	0.00077152...	0.00077152...	3.47473664...	847157.394...	-8453080.3...	-8459812.3...	141986343.
28	2800	2800.0001	0.00010000...	28000	28000.001	0.00100000...	0.00965299...	0.00965299...	4.73529264...	0.00080647...	0.00080647...	3.51296175...	833813.568...	-8383535.6...	-8389828.9...	141513250.

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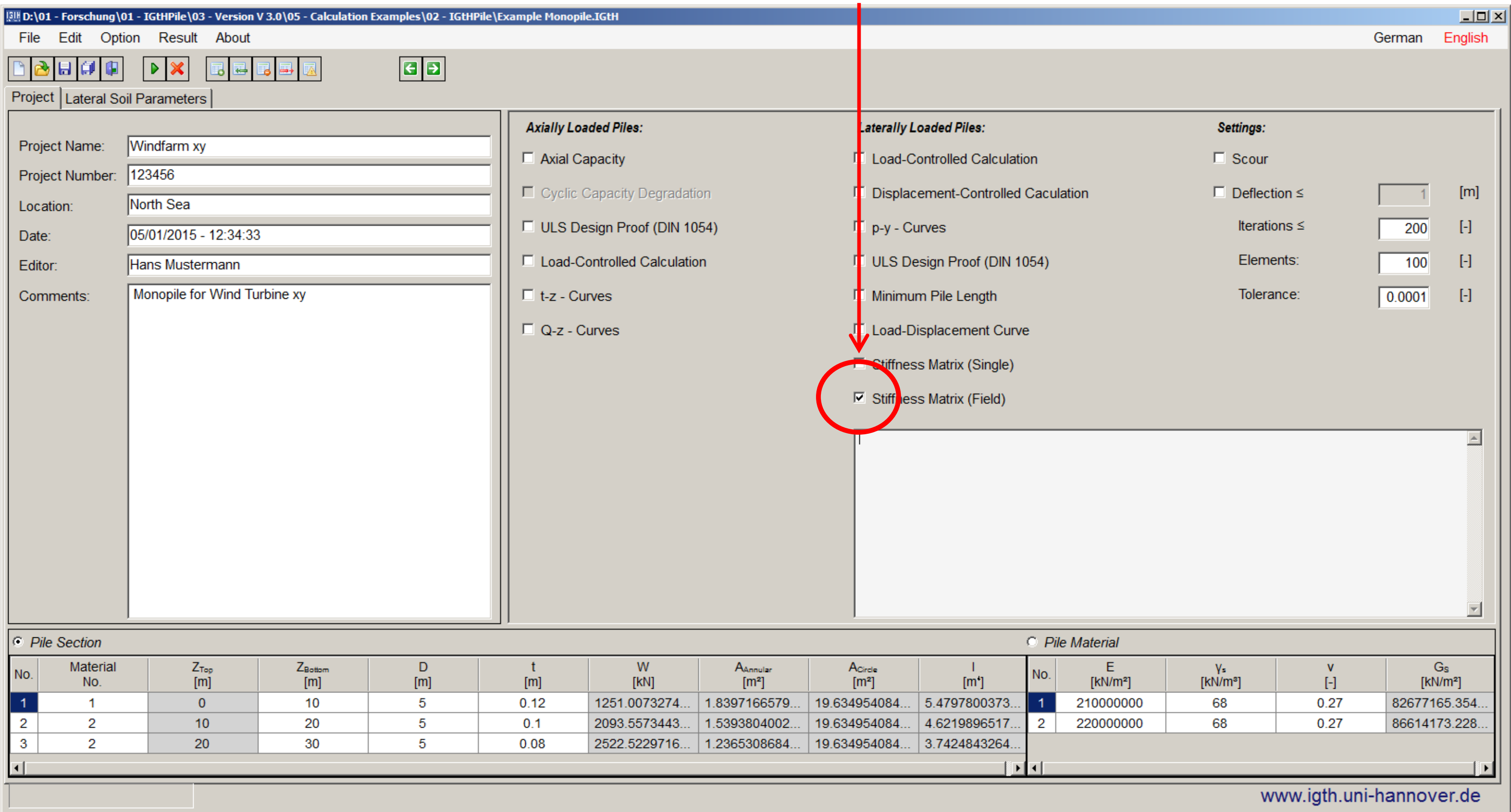
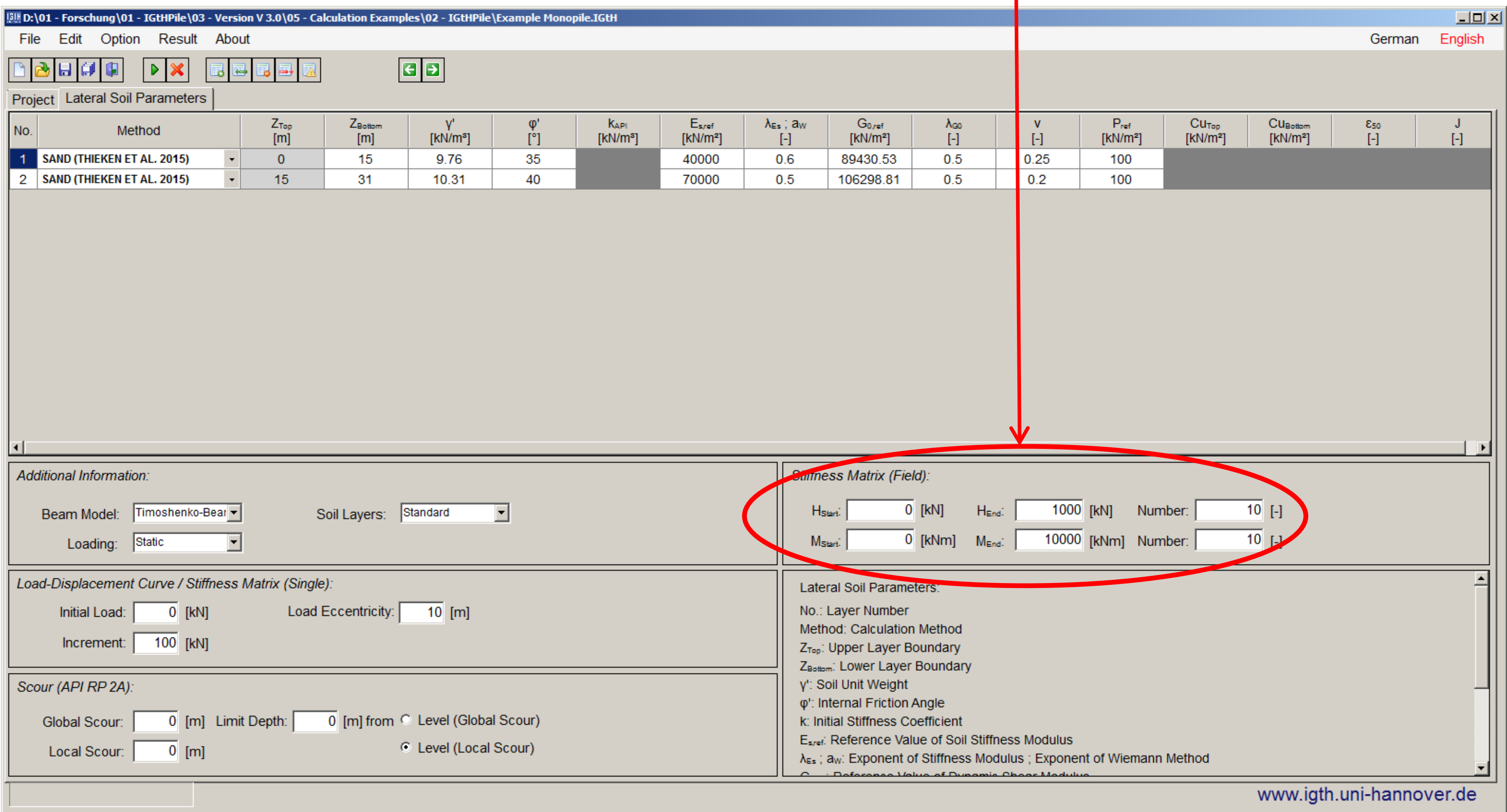
Laterally Loaded Piles – Stiffness Matrix (Field)

Generate stiffness matrices for several load eccentricities simultaneously



Laterally Loaded Piles – Stiffness Matrix (Field)

Define field of stiffness matrices



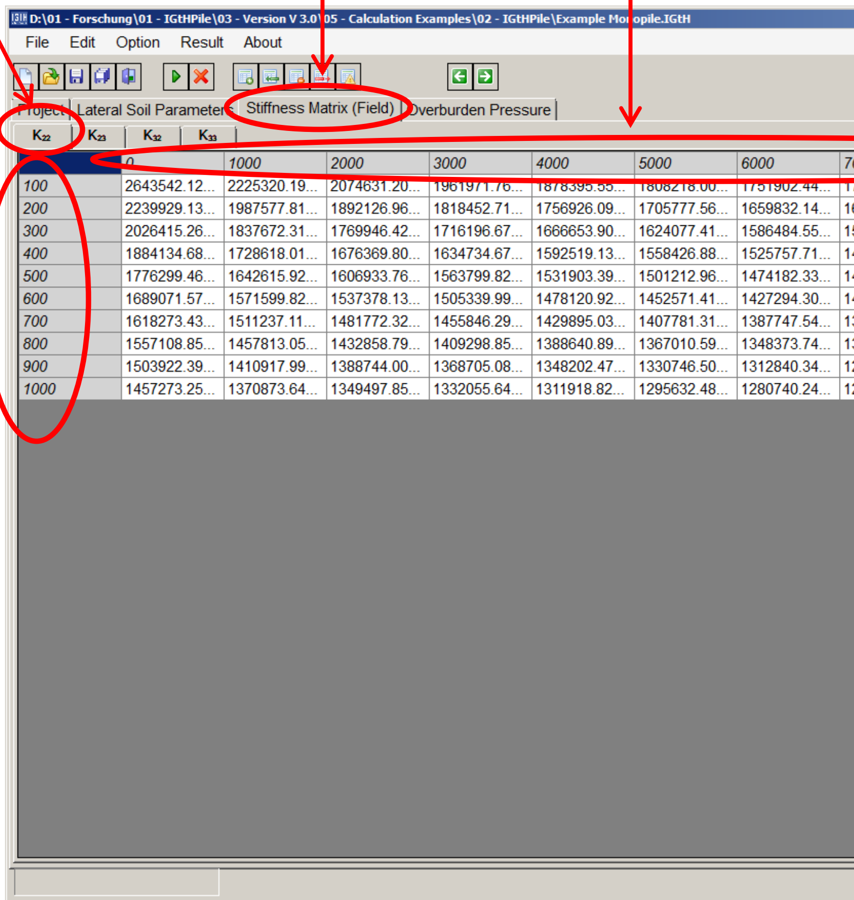
Laterally Loaded Piles – Stiffness Matrix (Field)

Matrix entry

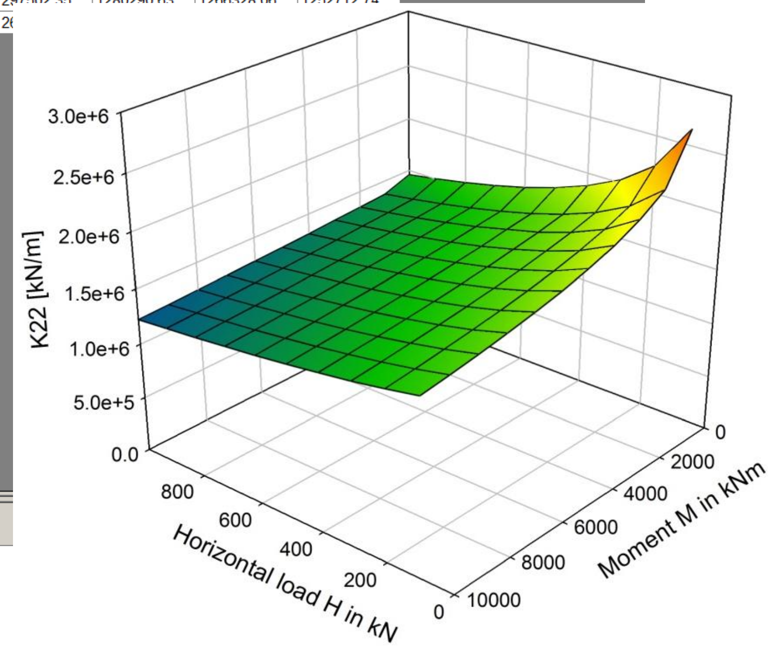
Results

Moment

Horizontal load



	0	1000	2000	3000	4000	5000	6000	7000	8000	9000	10000
100	2643542.12...	2225320.19...	2074631.20...	1961971.76...	1878395.55...	1808218.00...	1751902.44...	1702101.27...	1655101.05...	1615641.20...	1580209.40...
200	2239929.13...	1987577.81...	1892126.96...	1818452.71...	1756926.09...	1705777.56...	1659832.14...	1619200.44...	1584099.81...	1550687.85...	1521093.35...
300	2026415.26...	1837672.31...	1769946.42...	1716196.67...	1666653.90...	1624077.41...	1586484.55...	1553674.52...	1524399.28...	1495094.20...	1467937.60...
400	1884134.68...	1728618.01...	1676369.80...	1634734.67...	1592519.13...	1558426.88...	1525757.71...	1497340.05...	1471323.49...	1447673.64...	1424141.90...
500	1776299.46...	1642615.92...	1606933.76...	1563799.82...	1531903.39...	1501212.96...	1474182.33...	1448678.41...	1425288.49...	1403908.85...	1382860.58...
600	1689071.57...	1571599.82...	1537378.13...	1505339.99...	1478120.92...	1452571.41...	1427294.30...	1405885.81...	1383808.74...	1365201.22...	1345018.30...
700	1618273.43...	1511237.11...	1481772.32...	1455846.29...	1429895.03...	1407781.31...	1387747.54...	1365676.43...	1348197.01...	1328520.45...	1313313.53...
800	1557108.85...	1457813.05...	1432858.79...	1409298.85...	1388640.89...	1367010.59...	1348373.74...	1329632.81...	1312681.92...	1297685.38...	1280296.79...
900	1503922.39...	1410917.99...	1388744.00...	1368705.08...	1348202.47...	1330746.50...	1312840.34...	1297502.35	1280290.63	1266328.06	1252712.74
1000	1457273.25...	1370873.64...	1349497.85...	1332055.64...	1311918.82...	1295632.48...	1280740.24...	126			

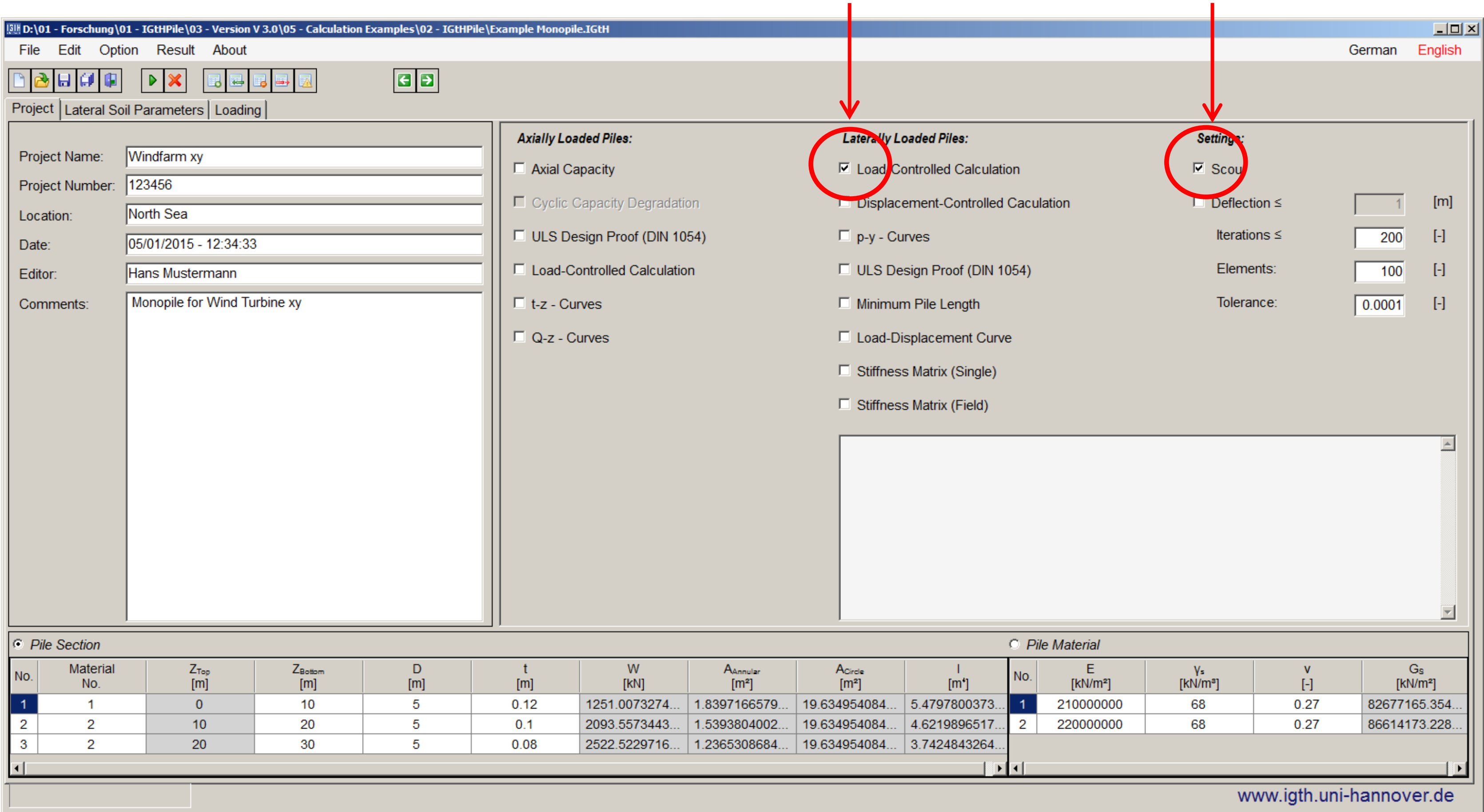


Laterally Loaded Piles – Scour

Note: The scour function is available for all calculation types

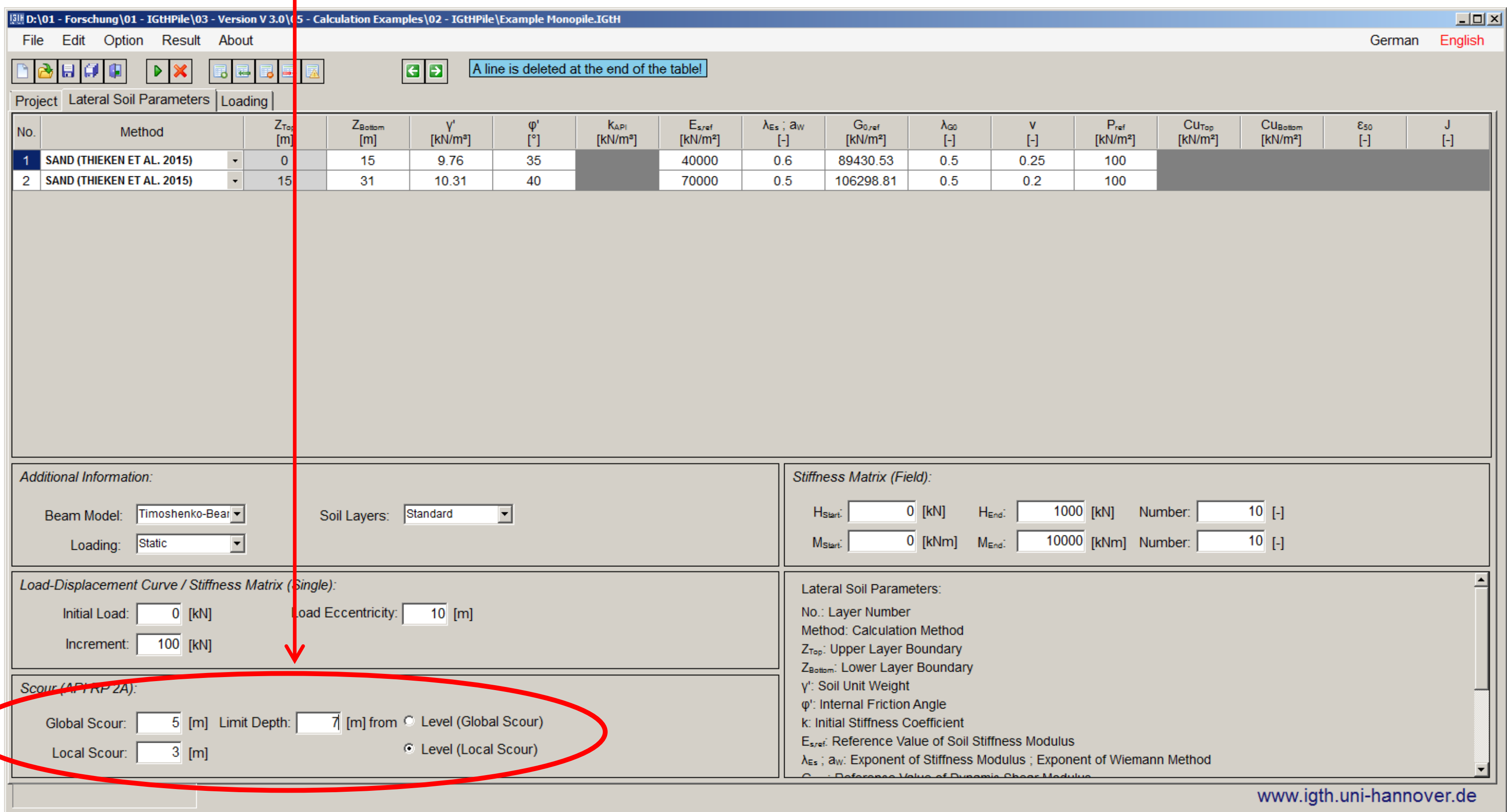
Choose calculation type

Scour



Laterally Loaded Piles – Scour

Define scour and limit depth for
effect on effective stresses



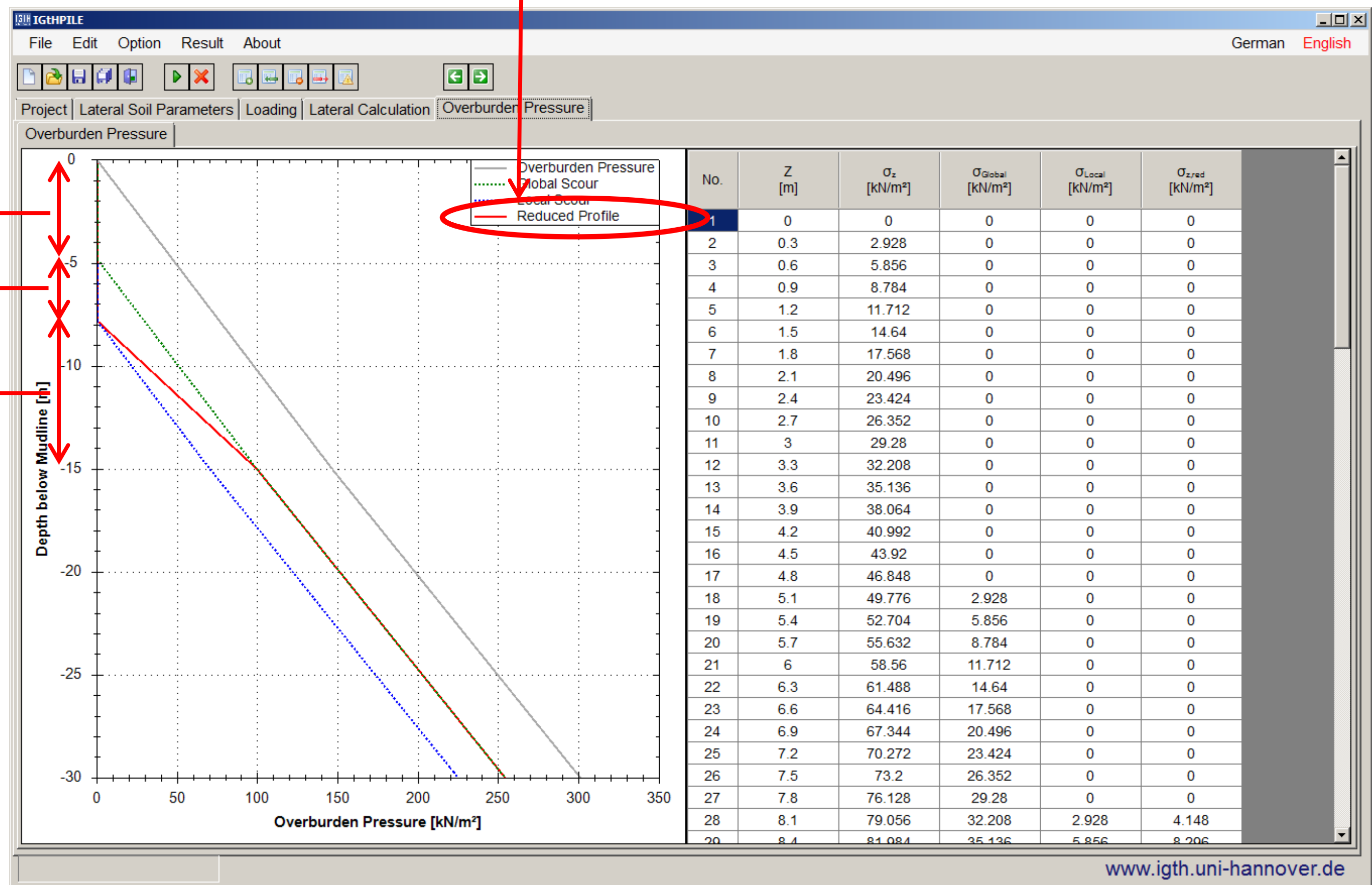
Laterally Loaded Piles – Scour

Overburden pressure
considered in calculations

Global scour

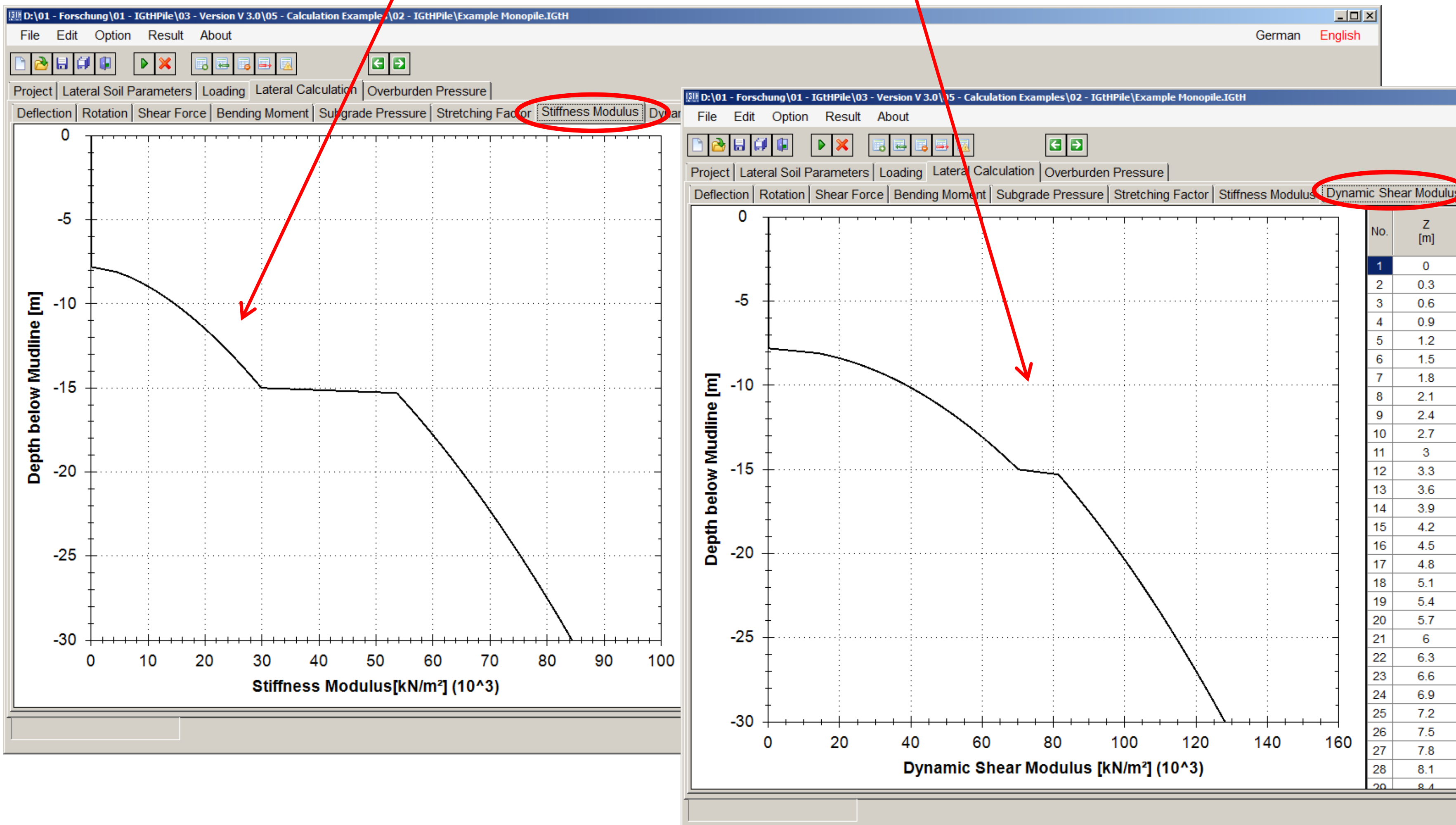
Local scour

Linear transition
(limit depth)



No.	Z [m]	σ_z [kN/m²]	σ_{Global} [kN/m²]	σ_{Local} [kN/m²]	$\sigma_{z,red}$ [kN/m²]
1	0	0	0	0	0
2	0.3	2.928	0	0	0
3	0.6	5.856	0	0	0
4	0.9	8.784	0	0	0
5	1.2	11.712	0	0	0
6	1.5	14.64	0	0	0
7	1.8	17.568	0	0	0
8	2.1	20.496	0	0	0
9	2.4	23.424	0	0	0
10	2.7	26.352	0	0	0
11	3	29.28	0	0	0
12	3.3	32.208	0	0	0
13	3.6	35.136	0	0	0
14	3.9	38.064	0	0	0
15	4.2	40.992	0	0	0
16	4.5	43.92	0	0	0
17	4.8	46.848	0	0	0
18	5.1	49.776	2.928	0	0
19	5.4	52.704	5.856	0	0
20	5.7	55.632	8.784	0	0
21	6	58.56	11.712	0	0
22	6.3	61.488	14.64	0	0
23	6.6	64.416	17.568	0	0
24	6.9	67.344	20.496	0	0
25	7.2	70.272	23.424	0	0
26	7.5	73.2	26.352	0	0
27	7.8	76.128	29.28	0	0
28	8.1	79.056	32.208	2.928	4.148
29	8.4	81.984	35.136	5.856	8.296

Note: Decrease in overburden pressure also reduce soil stiffness modulus E_s and dynamic shear modulus G_0 if $\lambda \neq 0.0$!!!



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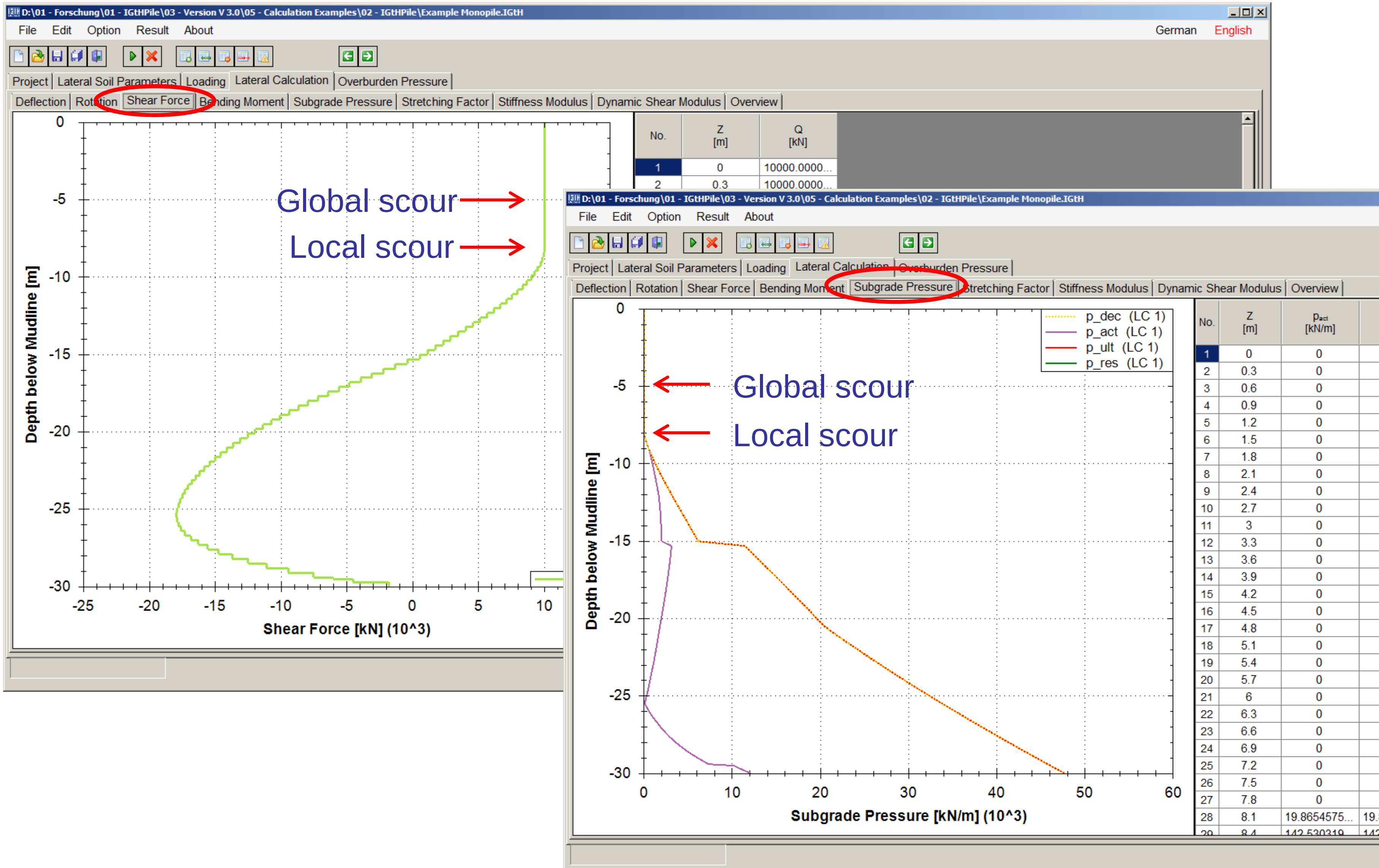
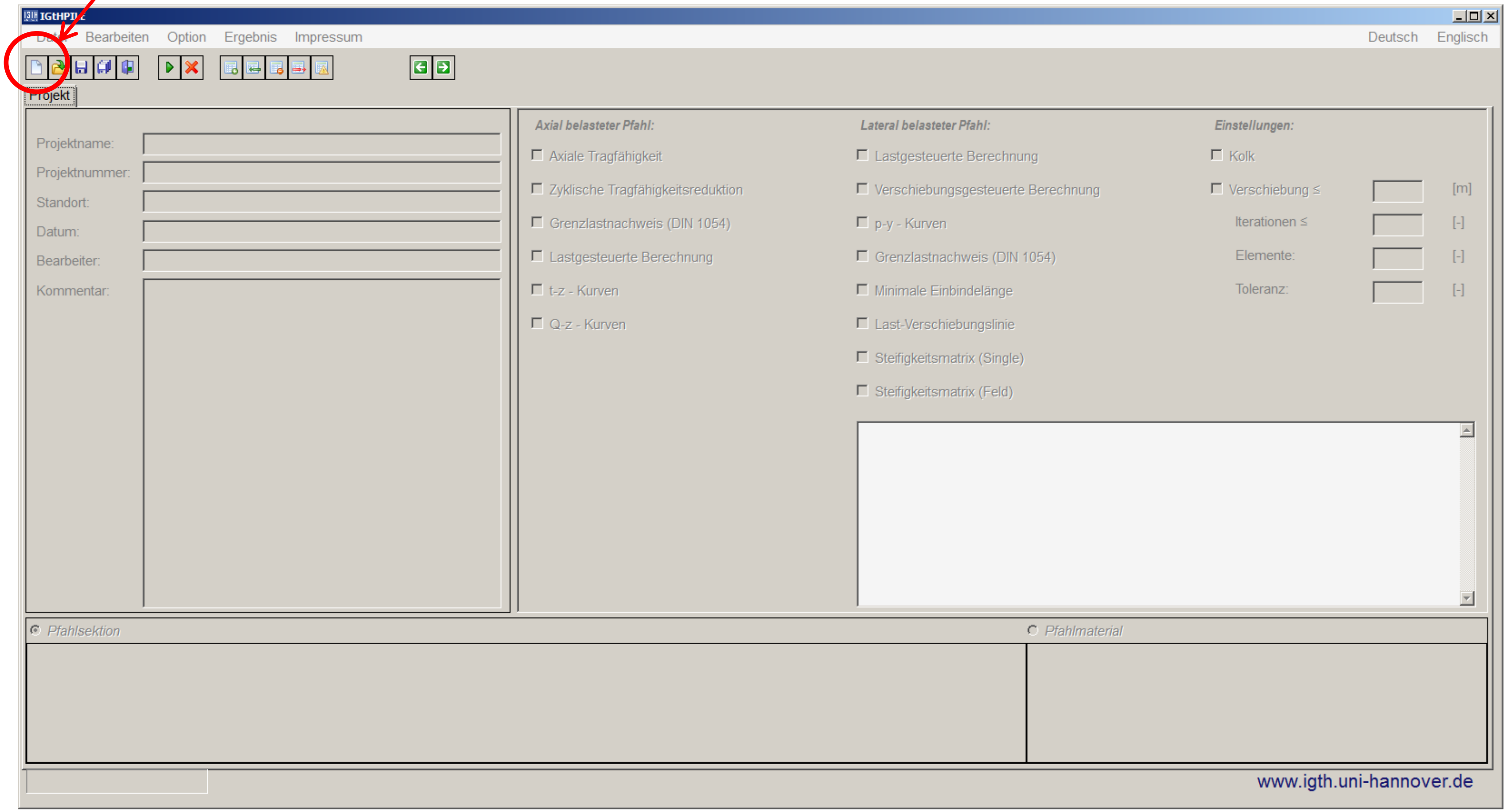
Laterally Loaded Piles – Scour



Part 2: Axially Loaded Piles

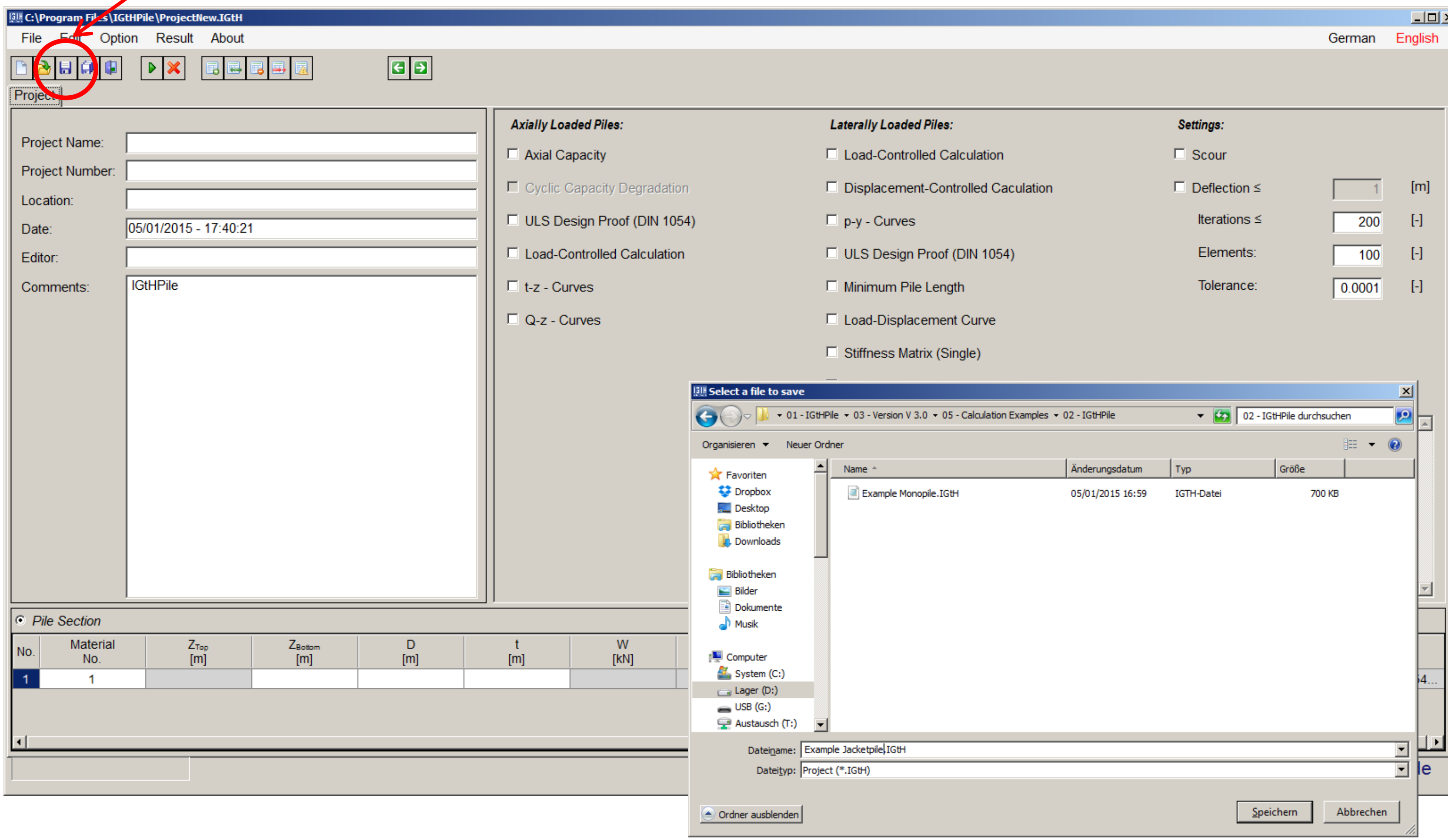
Axially Loaded Piles – Generate Project

Generate project



Axially Loaded Piles – Save Project

Save project

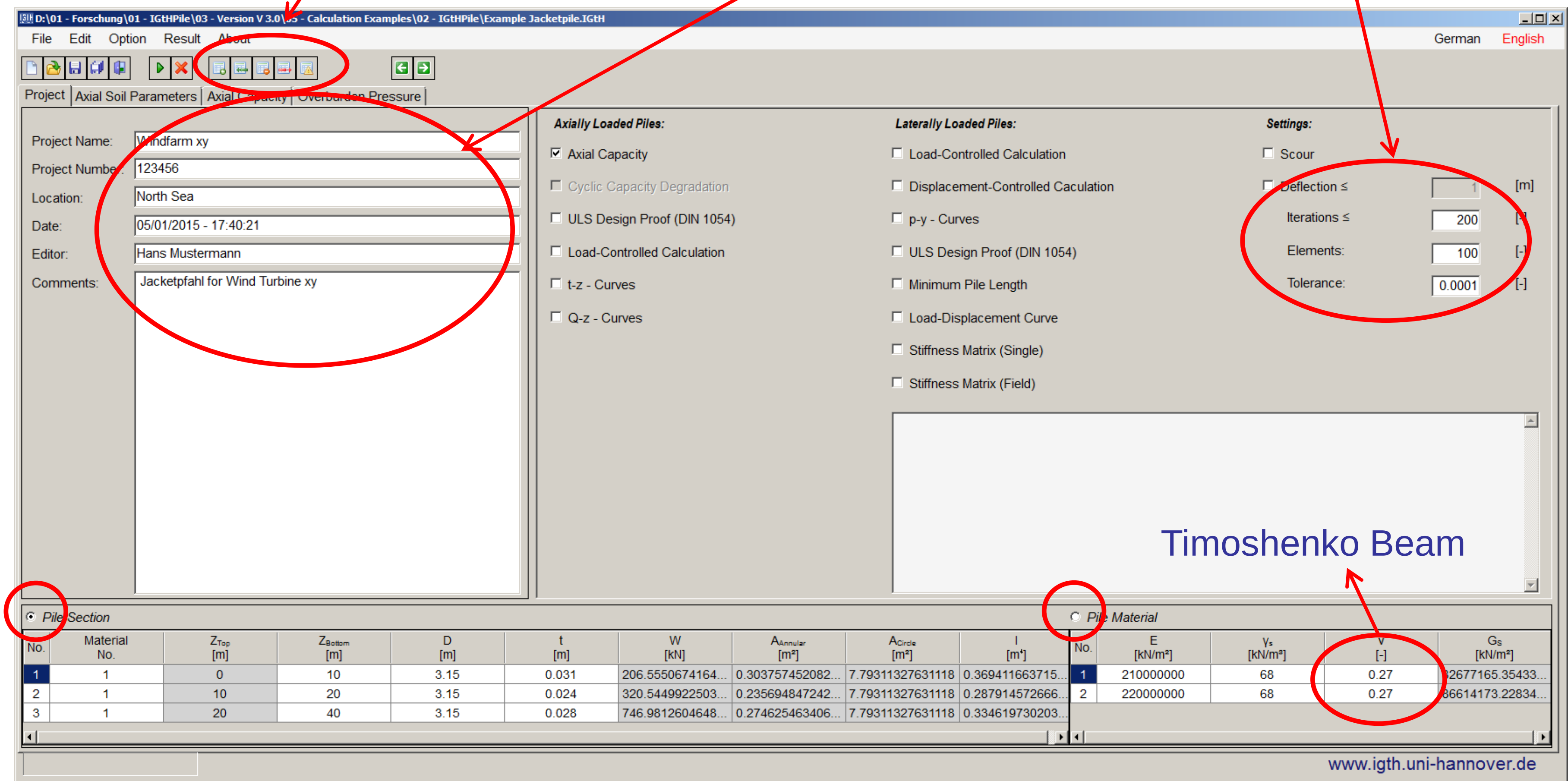


Axially Loaded Piles – Insert Pile Data

Add, insert or delete rows for pile sections or pile material, respectively

Describe project

Control parameter

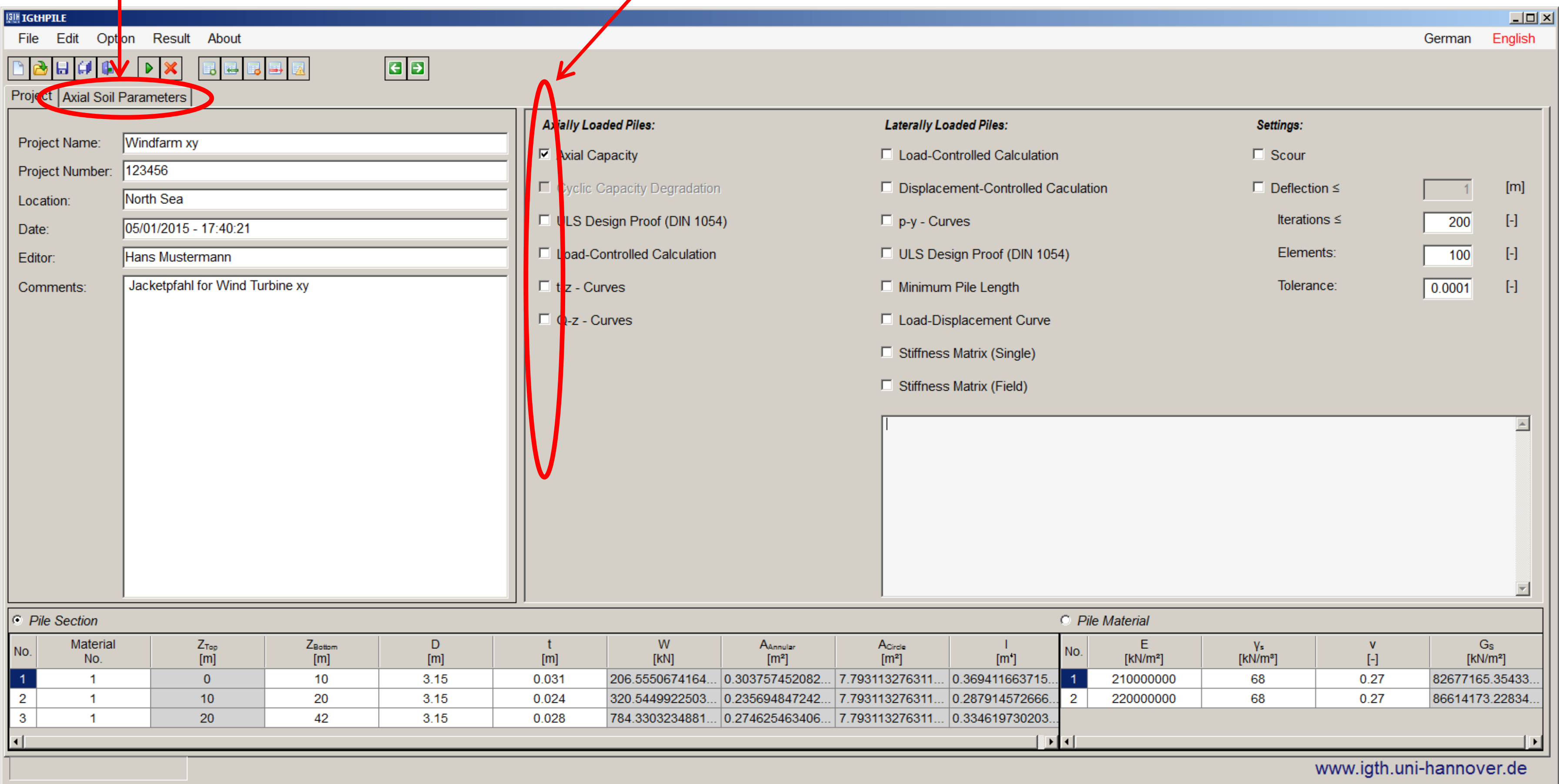


Timoshenko Beam

Axially loaded piles – Choose Between Calculation Types

Define soil parameters

Choose calculation type



No.	Material No.	Z_{Top} [m]	Z_{Bottom} [m]	D [m]	t [m]	W [kN]	$A_{Annular}$ [m²]	A_{Circle} [m²]	I [m⁴]
1	1	0	10	3.15	0.031	206.5550674164...	0.303757452082...	7.793113276311...	0.369411663715...
2	1	10	20	3.15	0.024	320.5449922503...	0.235694847242...	7.793113276311...	0.287914572666...
3	1	20	42	3.15	0.028	784.3303234881...	0.274625463406...	7.793113276311...	0.334619730203...

No.	E [kN/m²]	γ_s [kN/m³]	ν [-]	G_s [kN/m²]
1	210000000	68	0.27	82677165.35433...
2	220000000	68	0.27	86614173.22834...

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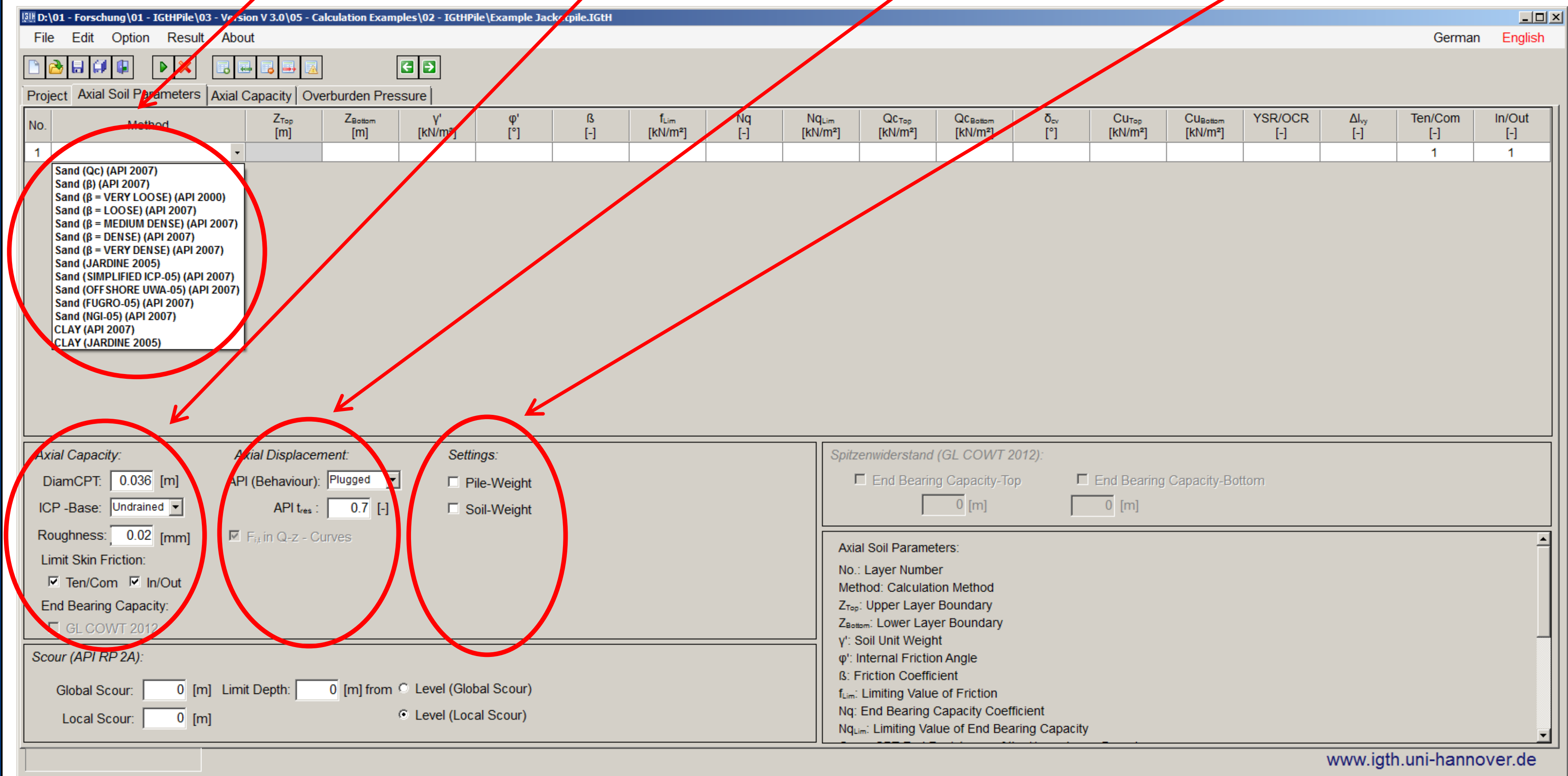
Axially Loaded Piles – Choose of Capacity Method

Eight capacity methods available

Capacity settings

Capacity and displacement settings

Displacement settings

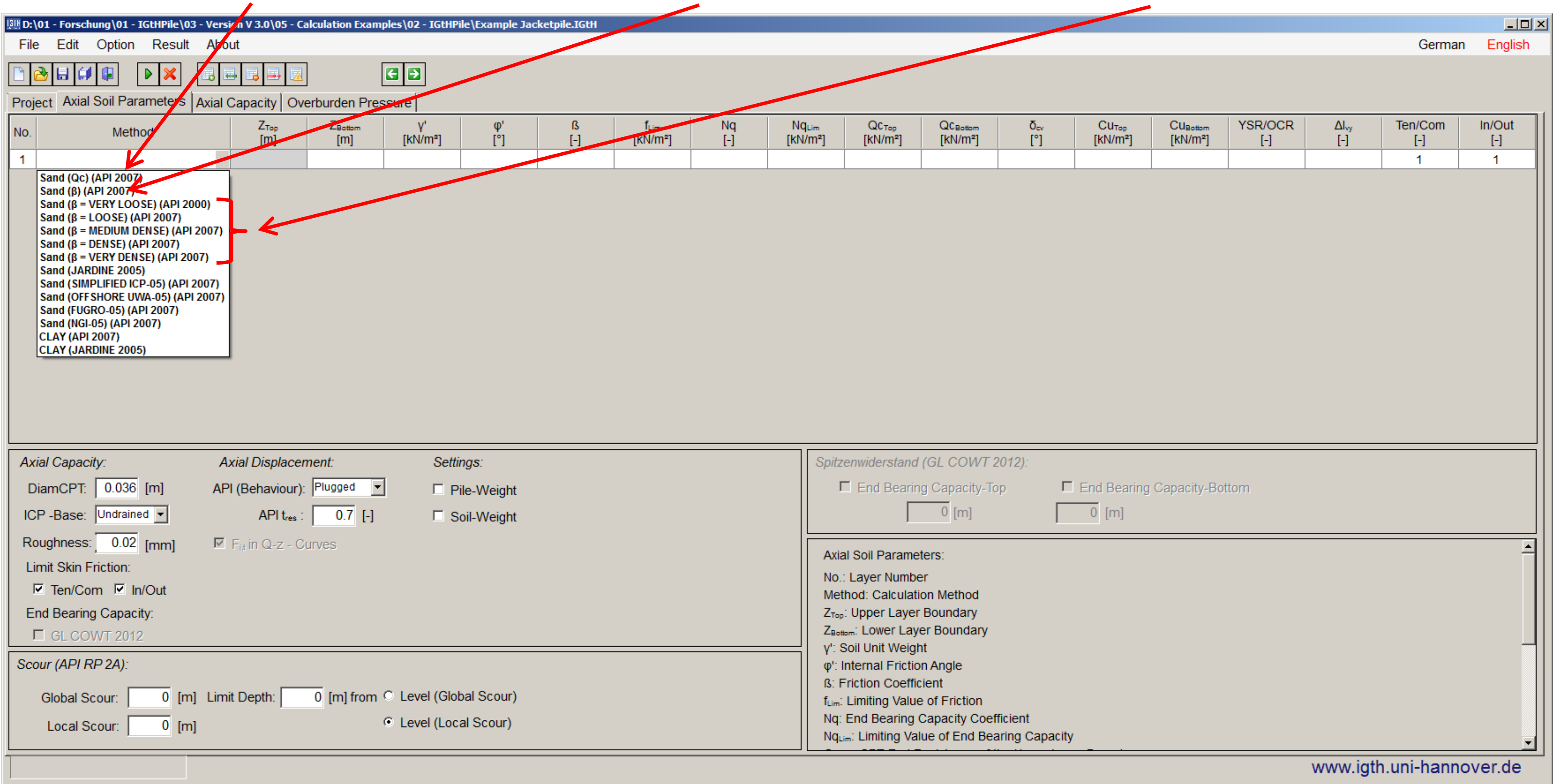


Axially Loaded Piles – Sand (API 2007) Method

Input via CPT data

Self-defined β-values

Input via β-values according API 2007



Axially Loaded Piles – References

Methods	Reference
Sand (Qc) (API 2007)	(R.2)
Sand (β) (API 2007)	(R.2)
Sand (β = VERY LOOSE) (API 2000)	(R.1)
Sand (β = LOOSE) (API 2007)	(R.2)
Sand (β = MEDIUM DENSE) (API 2007)	(R.2)
Sand (β = DENSE) (API 2007)	(R.2)
Sand (β = VERY DENSE) (API 2007)	(R.2)
Sand (JARDINE 2005)	(R.3)
Sand (SIMPLIFIED ICP-05) (API 2007)	(R.2)
Sand (OFFSHORE UWA-05) (API 2007)	(R.2)
Sand (FUGRO-05) (API 2007)	(R.2)
Sand (NGI-05) (API 2007)	(R.2)
CLAY (API 2007)	(R.2)
CLAY (JARDINE 2005)	(R.3)

References:

(R.1) API 2000: "Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms- Working Stress Design", API Recommended Practice 2A-WSD (RP 2A-WSD), 21st edition, American Petroleum Institute (API), Dallas, 2000.

(R.2) API 2007: "Errata and Supplement 3 - API Recommended Practice 2A-WSD, Recommended Practice for Planning, Designing, Constructing Fixed Offshore Platforms – Working Stress Design", American Petroleum Institute (API), Dallas, 2007.

(R.3) Jardine, J.; Chow, F.; Overy, R.; Standing, J. (2005): "ICP design methods for driven piles in sand and clays", London, Thomas Telford, 2005.

Axially Loaded Piles – Insert Soil Data

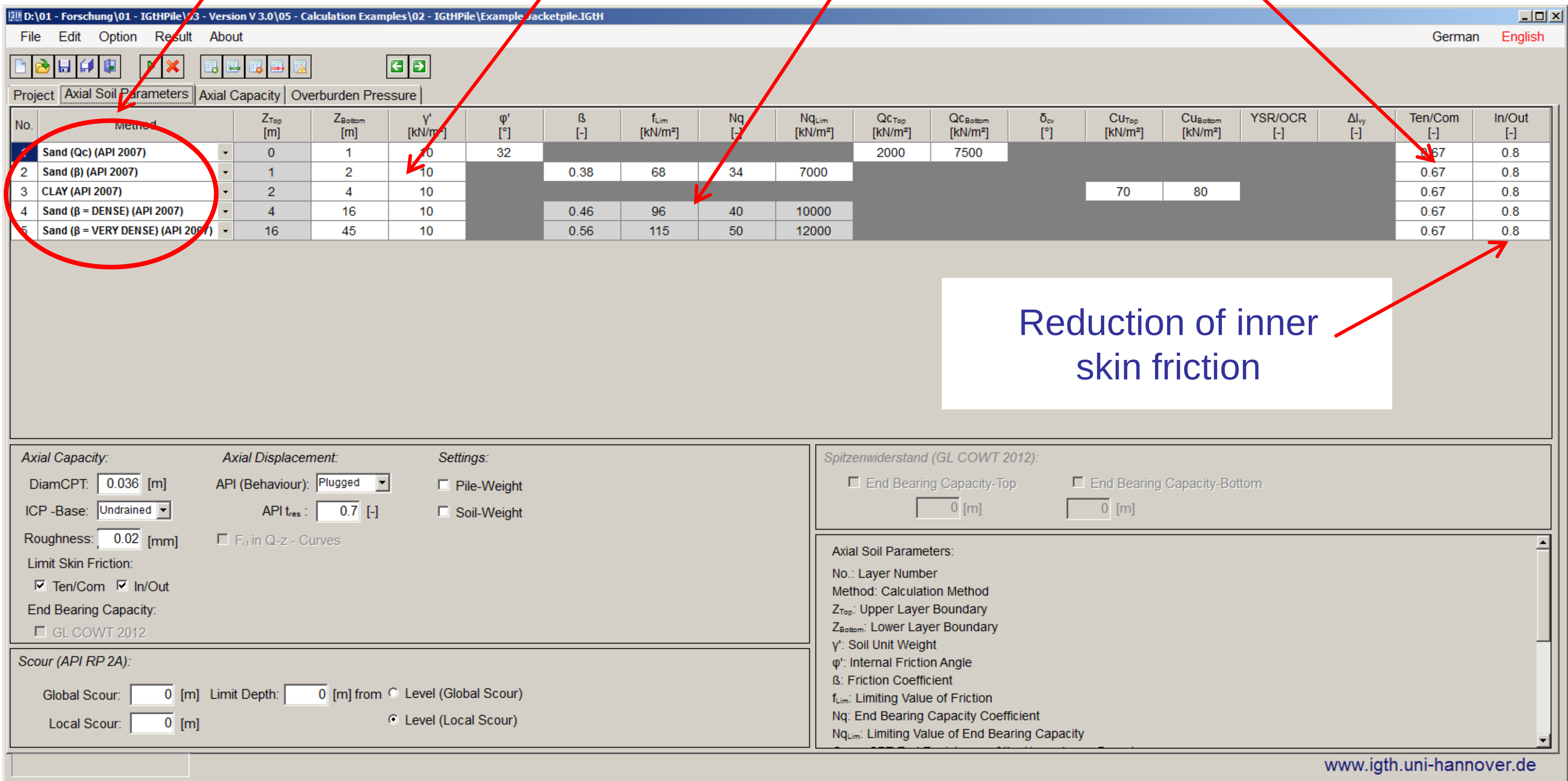
Arbitrary combinations

Insert soil data in white fields

By default

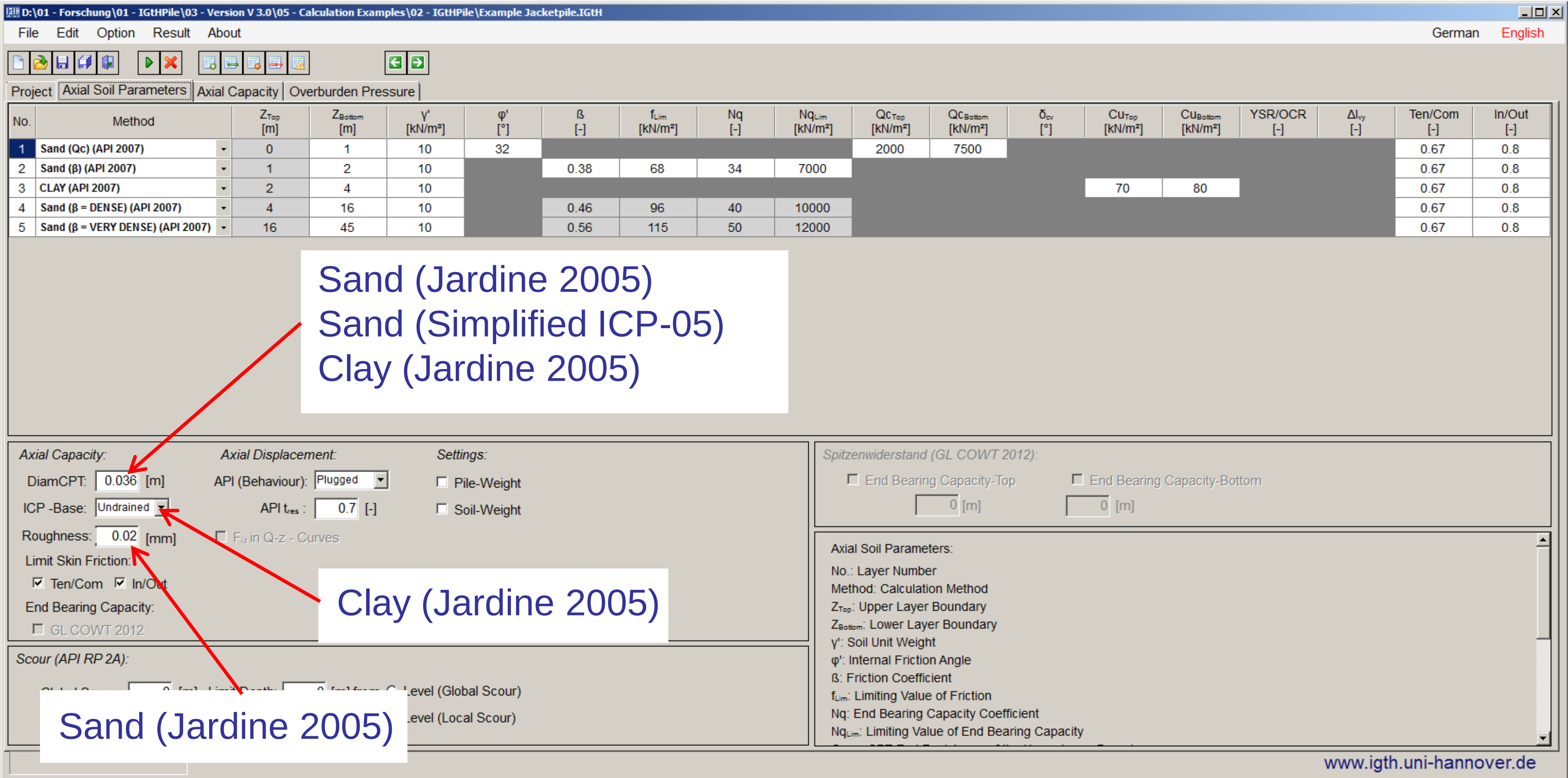
Reduction of capacity in tension

Reduction of inner skin friction



No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	ß [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	$δ_{cv}$ [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	$Δl_{vy}$ [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	68	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = DENSE) (API 2007)	4	16	10		0.46	96	40	10000								0.67	0.8
5	Sand (β = VERY DENSE) (API 2007)	16	45	10		0.56	115	50	12000								0.67	0.8

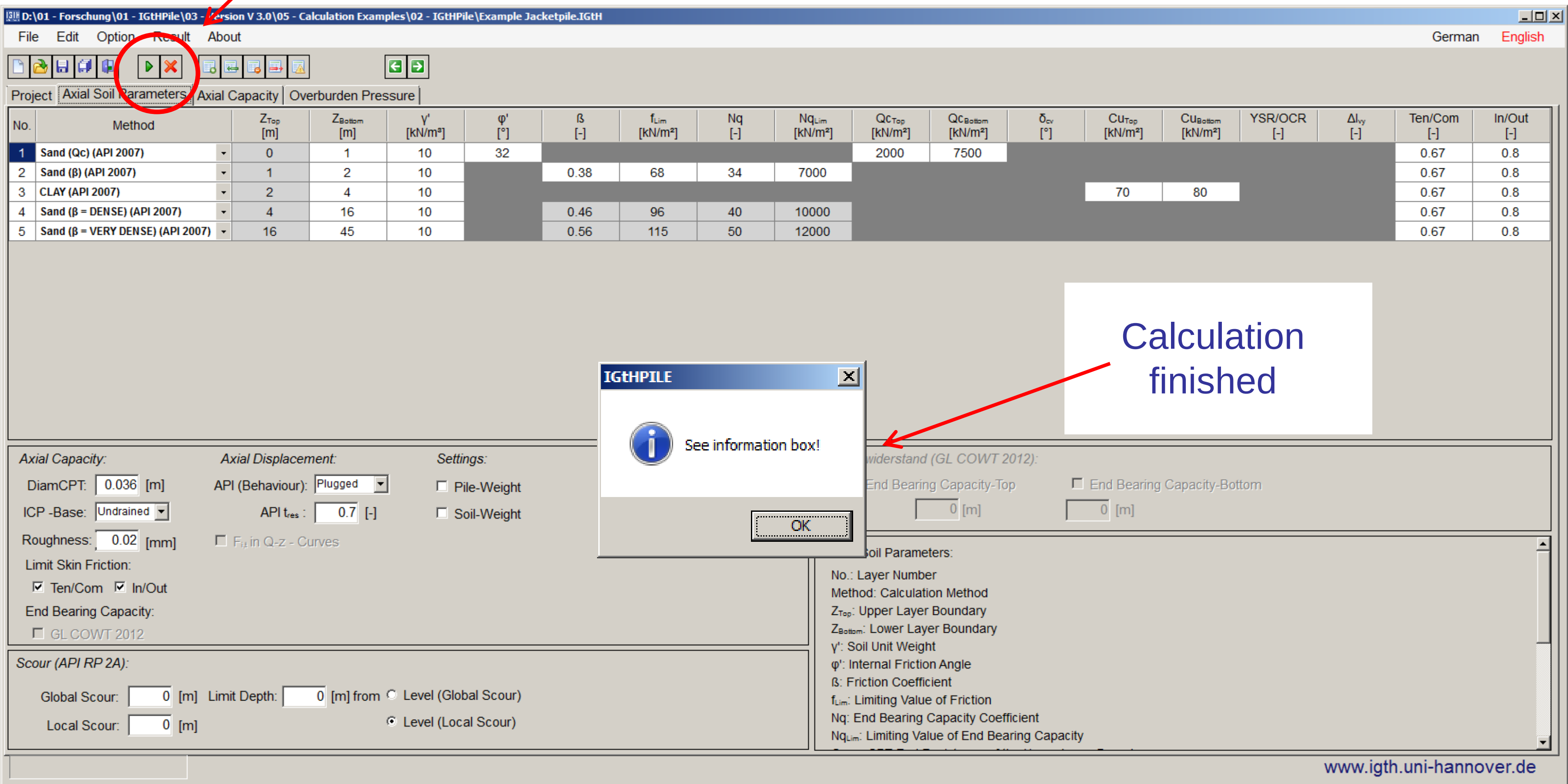
Axially Loaded Piles – Assigned Soil Parameters



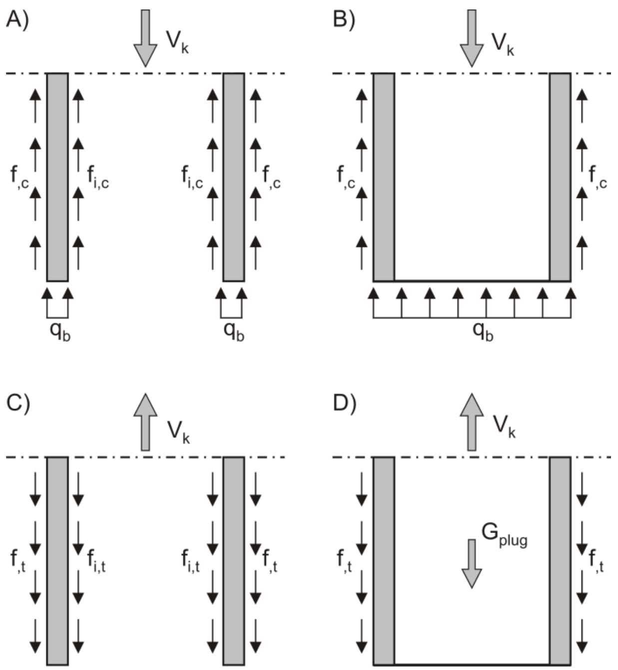
No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	ß [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	δ_{cv} [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	Δl_{vy} [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	68	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = DENSE) (API 2007)	4	16	10		0.46	96	40	10000								0.67	0.8
5	Sand (β = VERY DENSE) (API 2007)	16	45	10		0.56	115	50	12000								0.67	0.8

Axially Loaded Piles – Axial Capacity

Start / Stop calculation



Axially Loaded Piles – Axial Capacity



Calculation of axial capacity:

- In case of compression load
  - a) unplugged $R_{c,k} = F_{,c} + F_{i,c} + Q_b$
  - b) plugged $R_{c,k} = F_{,c} + Q_b$
- In case of tension load
  - c) unplugged $R_{t,k} = F_{,t} + F_{i,t}$
  - d) plugged $R_{t,k} = F_{,t} + G_{plug}$

with:

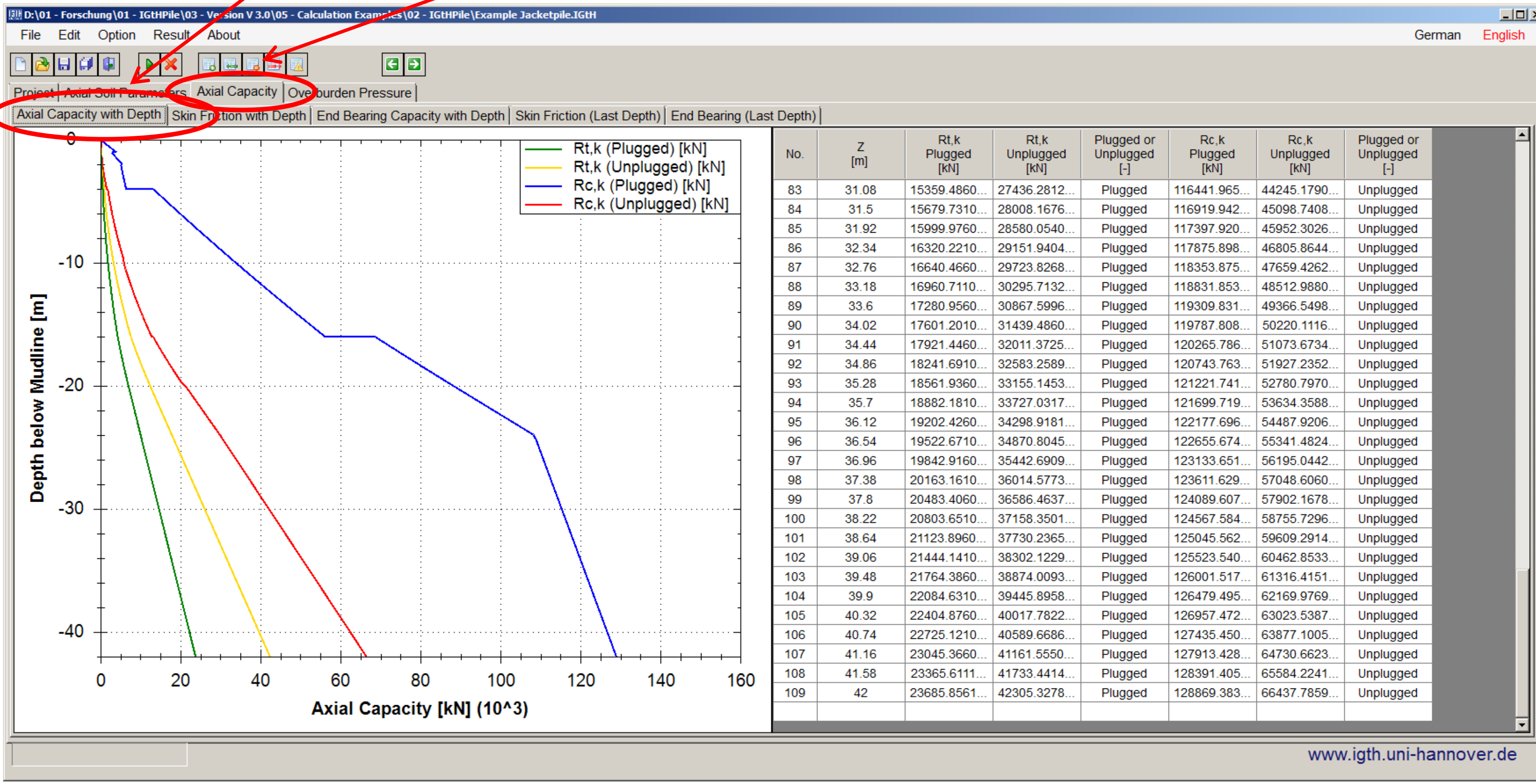
$F_{,c} = \int f_{,c}\, dz$	Outer Skin Friction in Compression	$F_{,t} = \int f_{,t}\, dz$	Outer Skin Friction in Tension
$F_{i,c} = \int f_{i,c}\, dz$	Inner Skin Friction in Compression	$F_{i,t} = \int f_{i,t}\, dz$	Inner Skin Friction in Tension
$Q_b = q_b \cdot \frac{\pi}{4}\left[D^2 - (D-2t)^2\right]$	Tip Resistance (unplugged)	G_{plug}	Weight of Soil Plug
$Q_b = q_b \cdot \frac{\pi}{4} D^2$	Tip Resistance (plugged)		

Note: The inner skin friction $f_{i,c}$ and $f_{i,t}$ is zero for the CPT methods.

Axially Loaded Piles – Axial Capacity

Total axial capacity with depth

Calculation output



No.	Z [m]	Rt,k Plugged [kN]	Rt,k Unplugged [kN]	Plugged or Unplugged [-]	Rc,k Plugged [kN]	Rc,k Unplugged [kN]	Plugged or Unplugged [-]
83	31.08	15359.4860...	27436.2812...	Plugged	116441.965...	44245.1790...	Unplugged
84	31.5	15679.7310...	28008.1676...	Plugged	116919.942...	45098.7408...	Unplugged
85	31.92	15999.9760...	28580.0540...	Plugged	117397.920...	45952.3026...	Unplugged
86	32.34	16320.2210...	29151.9404...	Plugged	117875.898...	46805.8644...	Unplugged
87	32.76	16640.4660...	29723.8268...	Plugged	118353.875...	47659.4262...	Unplugged
88	33.18	16960.7110...	30295.7132...	Plugged	118831.853...	48512.9880...	Unplugged
89	33.6	17280.9560...	30867.5996...	Plugged	119309.831...	49366.5498...	Unplugged
90	34.02	17601.2010...	31439.4860...	Plugged	119787.808...	50220.1116...	Unplugged
91	34.44	17921.4460...	32011.3725...	Plugged	120265.786...	51073.6734...	Unplugged
92	34.86	18241.6910...	32583.2589...	Plugged	120743.763...	51927.2352...	Unplugged
93	35.28	18561.9360...	33155.1453...	Plugged	121221.741...	52780.7970...	Unplugged
94	35.7	18882.1810...	33727.0317...	Plugged	121699.719...	53634.3588...	Unplugged
95	36.12	19202.4260...	34298.9181...	Plugged	122177.696...	54487.9206...	Unplugged
96	36.54	19522.6710...	34870.8045...	Plugged	122655.674...	55341.4824...	Unplugged
97	36.96	19842.9160...	35442.6909...	Plugged	123133.651...	56195.0442...	Unplugged
98	37.38	20163.1610...	36014.5773...	Plugged	123611.629...	57048.6060...	Unplugged
99	37.8	20483.4060...	36586.4637...	Plugged	124089.607...	57902.1678...	Unplugged
100	38.22	20803.6510...	37158.3501...	Plugged	124567.584...	58755.7296...	Unplugged
101	38.64	21123.8960...	37730.2365...	Plugged	125045.562...	59609.2914...	Unplugged
102	39.06	21444.1410...	38302.1229...	Plugged	125523.540...	60462.8533...	Unplugged
103	39.48	21764.3860...	38874.0093...	Plugged	126001.517...	61316.4151...	Unplugged
104	39.9	22084.6310...	39445.8958...	Plugged	126479.495...	62169.9769...	Unplugged
105	40.32	22404.8760...	40017.7822...	Plugged	126957.472...	63023.5387...	Unplugged
106	40.74	22725.1210...	40589.6686...	Plugged	127435.450...	63877.1005...	Unplugged
107	41.16	23045.3660...	41161.5550...	Plugged	127913.428...	64730.6623...	Unplugged
108	41.58	23365.6111...	41733.4414...	Plugged	128391.405...	65584.2241...	Unplugged
109	42	23685.8561...	42305.3278...	Plugged	128869.383...	66437.7859...	Unplugged

Axially Loaded Piles – Axial Capacity

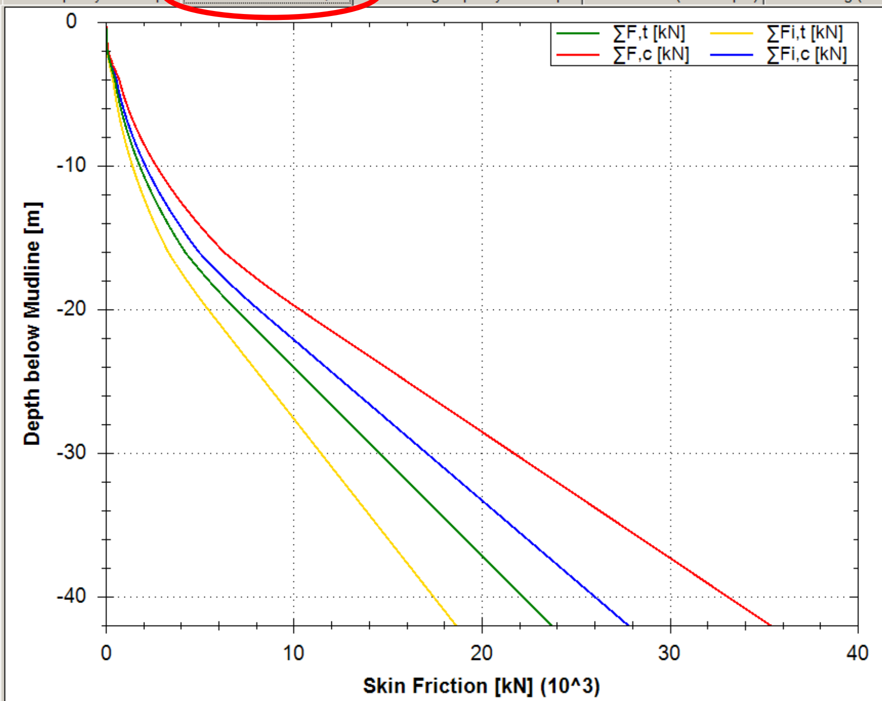
Skin friction force with depth

D:\01 - Forschung\01 - IGtHPile\03 - Version V 3.0\05 - Calculation Examples\02 - IGtHPile\Example Jacketpile.IGtH

File Edit Option Result About German English

Project | Axial Soil Parameters | Axial Capacity | Overburden Pressure

Axial Capacity with Depth | Skin Friction with Depth | End Bearing Capacity with Depth | Skin Friction (Last Depth) | End Bearing (Last Depth)



No.	Z [m]	∑F,t [kN]	∑Fi,t [kN]	∑F,c [kN]	∑Fi,c [kN]
83	31.08	15359.4860...	12076.7951...	22924.6060...	18025.0674...
84	31.5	15679.7310...	12328.4365...	23402.5836...	18400.6516...
85	31.92	15999.9760...	12580.0779...	23880.5612...	18776.2358...
86	32.34	16320.2210...	12831.7194...	24358.5389...	19151.8200...
87	32.76	16640.4660...	13083.3608...	24836.5165...	19527.4041...
88	33.18	16960.7110...	13335.0022...	25314.4941...	19902.9883...
89	33.6	17280.9560...	13586.6436...	25792.4717...	20278.5725...
90	34.02	17601.2010...	13838.2850...	26270.4493...	20654.1567...
91	34.44	17921.4460...	14089.9264...	26748.4269...	21029.7409...
92	34.86	18241.6910...	14341.5678...	27226.4045...	21405.3251...
93	35.28	18561.9360...	14593.2092...	27704.3822...	21780.9093...
94	35.7	18882.1810...	14844.8506...	28182.3598...	22156.4935...
95	36.12	19202.4260...	15096.4920...	28660.3374...	22532.0776...
96	36.54	19522.6710...	15348.1334...	29138.3150...	22907.6618...
97	36.96	19842.9160...	15599.7748...	29616.2926...	23283.2460...
98	37.38	20163.1610...	15851.4162...	30094.2702...	23658.8302...
99	37.8	20483.4060...	16103.0576...	30572.2478...	24034.4144...
100	38.22	20803.6510...	16354.6990...	31050.2255...	24409.9986...
101	38.64	21123.8960...	16606.3404...	31528.2031...	24785.5828...
102	39.06	21444.1410...	16857.9818...	32006.1807...	25161.1670...
103	39.48	21764.3860...	17109.6233...	32484.1583...	25536.7511...
104	39.9	22084.6310...	17361.2647...	32962.1359...	25912.3353...
105	40.32	22404.8760...	17612.9061...	33440.1135...	26287.9195...
106	40.74	22725.1210...	17864.5475...	33918.0911...	26663.5037...
107	41.16	23045.3660...	18116.1889...	34396.0688...	27039.0879...
108	41.58	23365.6111...	18367.8303...	34874.0464...	27414.6721...
109	42	23685.8561...	18619.4717...	35352.0240...	27790.2563...

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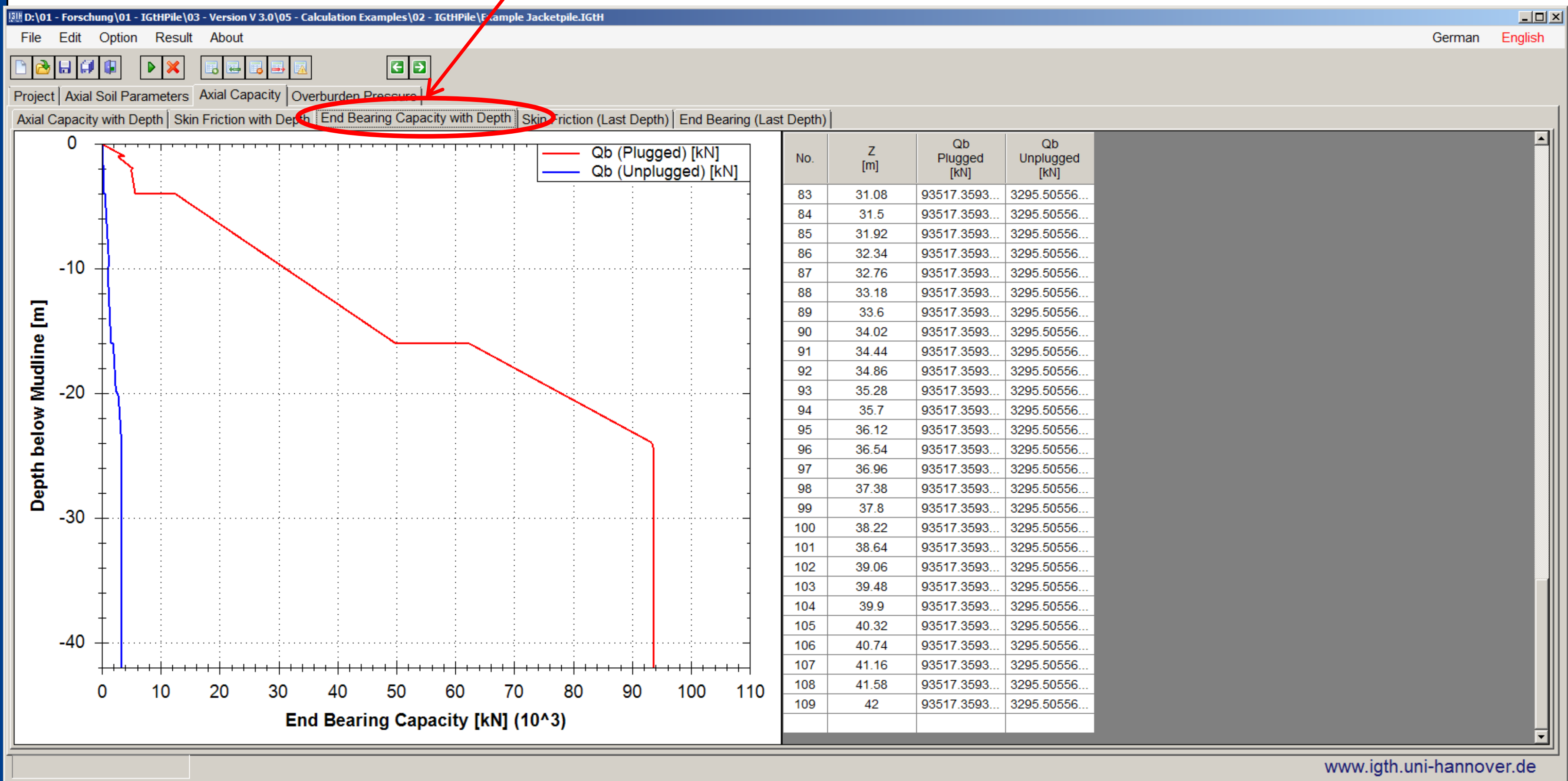
Axially Loaded Piles – Axial Capacity

End bearing capacity with depth



No.	Z [m]	Qb Plugged [kN]	Qb Unplugged [kN]
83	31.08	93517.3593...	3295.50556...
84	31.5	93517.3593...	3295.50556...
85	31.92	93517.3593...	3295.50556...
86	32.34	93517.3593...	3295.50556...
87	32.76	93517.3593...	3295.50556...
88	33.18	93517.3593...	3295.50556...
89	33.6	93517.3593...	3295.50556...
90	34.02	93517.3593...	3295.50556...
91	34.44	93517.3593...	3295.50556...
92	34.86	93517.3593...	3295.50556...
93	35.28	93517.3593...	3295.50556...
94	35.7	93517.3593...	3295.50556...
95	36.12	93517.3593...	3295.50556...
96	36.54	93517.3593...	3295.50556...
97	36.96	93517.3593...	3295.50556...
98	37.38	93517.3593...	3295.50556...
99	37.8	93517.3593...	3295.50556...
100	38.22	93517.3593...	3295.50556...
101	38.64	93517.3593...	3295.50556...
102	39.06	93517.3593...	3295.50556...
103	39.48	93517.3593...	3295.50556...
104	39.9	93517.3593...	3295.50556...
105	40.32	93517.3593...	3295.50556...
106	40.74	93517.3593...	3295.50556...
107	41.16	93517.3593...	3295.50556...
108	41.58	93517.3593...	3295.50556...
109	42	93517.3593...	3295.50556...

Axially Loaded Piles – Axial Capacity

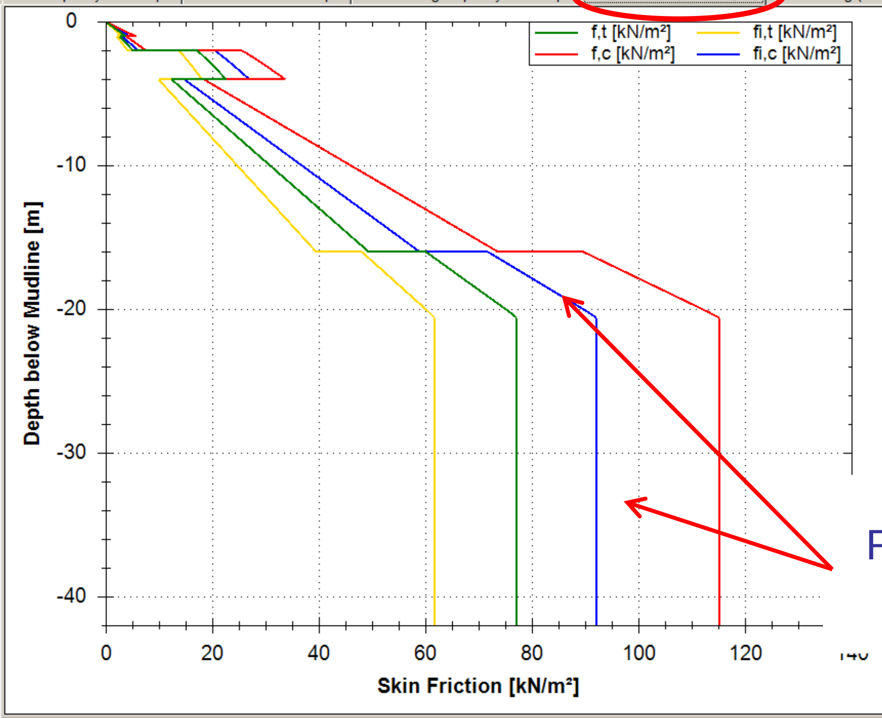
Skin friction on pile shaft for last depth

D:\01 - Forschung\01 - IGtHPile\03 - Version V 3.0\05 - Calculation Examples\02 - IGtHPile\Example Jacketpile.IGtH

File Edit Option Result About German English

Project | Axial Soil Parameters | Axial Capacity | Overburden Pressure

Axial Capacity with Depth | Skin Friction with Depth | End Bearing Capacity with Depth | Skin Friction (Last Depth) | End Bearing (Last Depth)



No.	Z [m]	f,t [kN/m²]	fi,t [kN/m²]	f,c [kN/m²]	fi,c [kN/m²]	Method [-]
83	31.08	77.05	61.64	115	92	Sand (β = V...
84	31.5	77.05	61.64	115	92	Sand (β = V...
85	31.92	77.05	61.64	115	92	Sand (β = V...
86	32.34	77.05	61.64	115	92	Sand (β = V...
87	32.76	77.05	61.64	115	92	Sand (β = V...
88	33.18	77.05	61.64	115	92	Sand (β = V...
89	33.6	77.05	61.64	115	92	Sand (β = V...
90	34.02	77.05	61.64	115	92	Sand (β = V...
91	34.44	77.05	61.64	115	92	Sand (β = V...
92	34.86	77.05	61.64	115	92	Sand (β = V...
93	35.28	77.05	61.64	115	92	Sand (β = V...
94	35.7	77.05	61.64	115	92	Sand (β = V...
95	36.12	77.05	61.64	115	92	Sand (β = V...
96	36.54	77.05	61.64	115	92	Sand (β = V...
97	36.96	77.05	61.64	115	92	Sand (β = V...
98	37.38	77.05	61.64	115	92	Sand (β = V...
99	37.8	77.05	61.64	115	92	Sand (β = V...
100	38.22	77.05	61.64	115	92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
					92	Sand (β = V...
109	42	77.05	61.64	115	92	Sand (β = V...

Reduction of skin friction and limit skin friction

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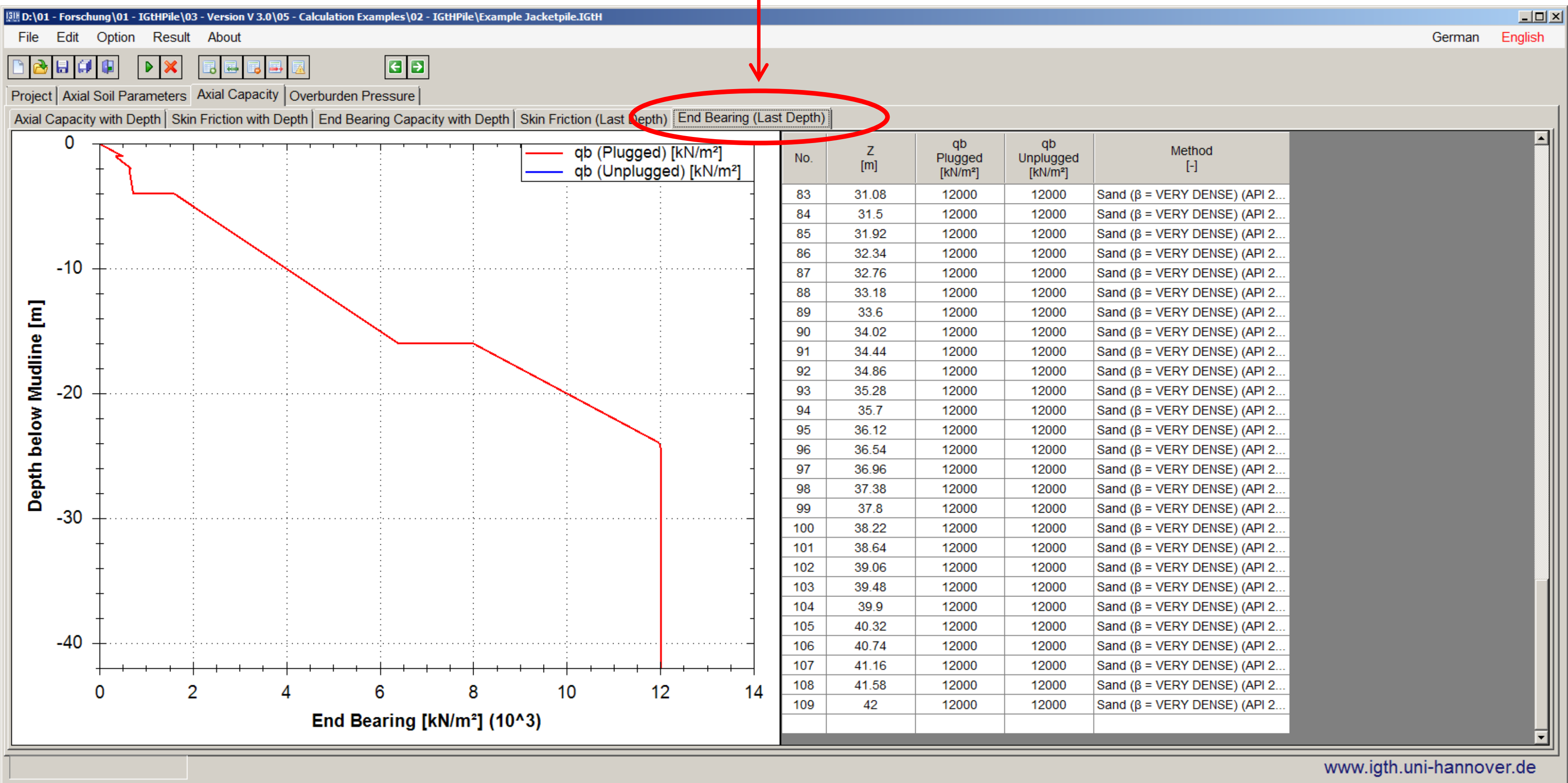
No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	β [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	δ_{cv} [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	Δ [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	67	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = VERY DENSE) (API 2007)	4	16	10		0.560166...	114.8	50	12000								0.67	0.8
5	Sand (β = DENSE) (API 2007)	16	45	10		0.461880...	95.7	40	9600								0.67	0.8

Axially Loaded Piles – Axial Capacity

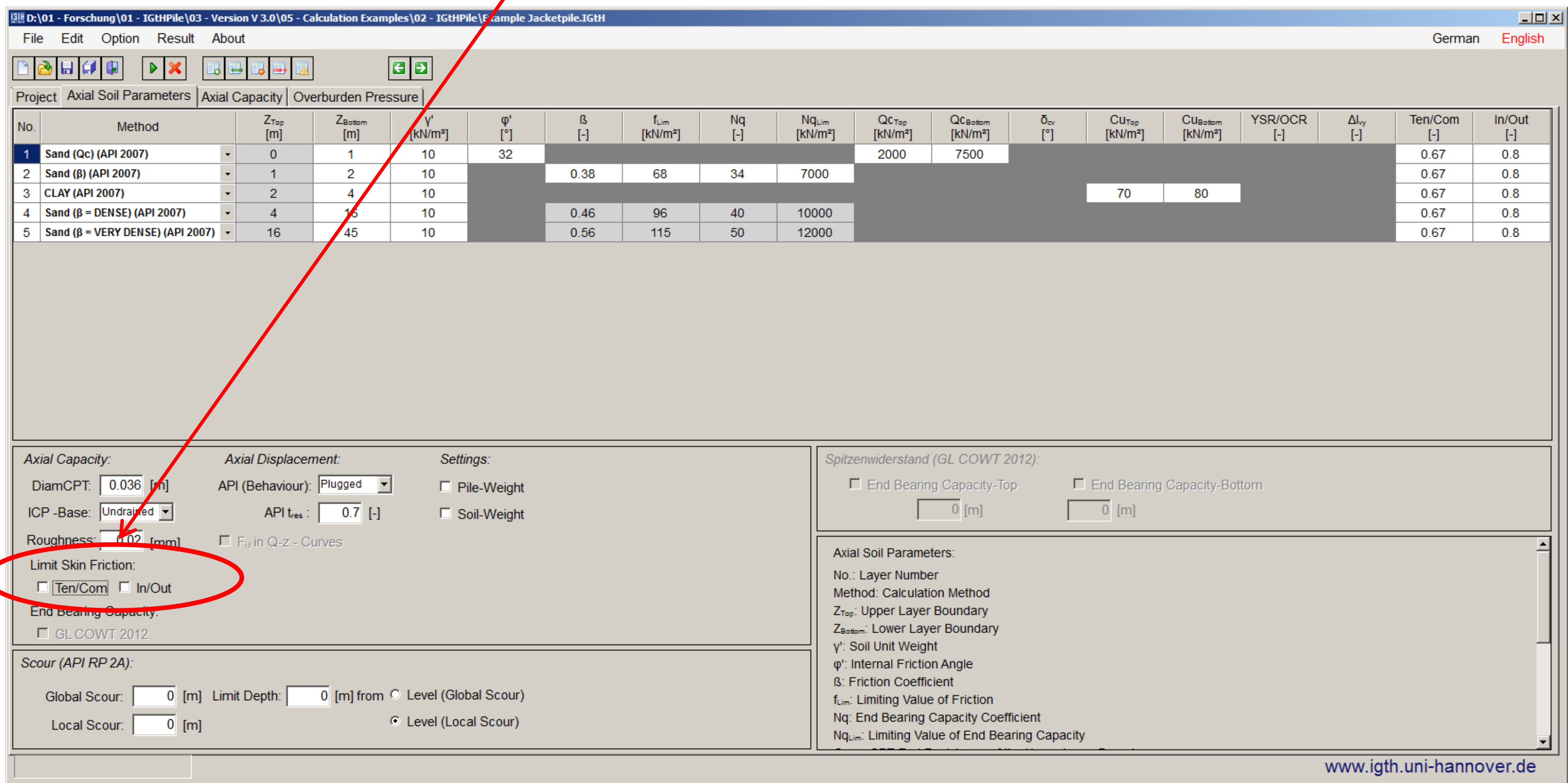
End bearing for last depth



No.	Z [m]	qb Plugged [kN/m²]	qb Unplugged [kN/m²]	Method [-]
83	31.08	12000	12000	Sand (β = VERY DENSE) (API 2...
84	31.5	12000	12000	Sand (β = VERY DENSE) (API 2...
85	31.92	12000	12000	Sand (β = VERY DENSE) (API 2...
86	32.34	12000	12000	Sand (β = VERY DENSE) (API 2...
87	32.76	12000	12000	Sand (β = VERY DENSE) (API 2...
88	33.18	12000	12000	Sand (β = VERY DENSE) (API 2...
89	33.6	12000	12000	Sand (β = VERY DENSE) (API 2...
90	34.02	12000	12000	Sand (β = VERY DENSE) (API 2...
91	34.44	12000	12000	Sand (β = VERY DENSE) (API 2...
92	34.86	12000	12000	Sand (β = VERY DENSE) (API 2...
93	35.28	12000	12000	Sand (β = VERY DENSE) (API 2...
94	35.7	12000	12000	Sand (β = VERY DENSE) (API 2...
95	36.12	12000	12000	Sand (β = VERY DENSE) (API 2...
96	36.54	12000	12000	Sand (β = VERY DENSE) (API 2...
97	36.96	12000	12000	Sand (β = VERY DENSE) (API 2...
98	37.38	12000	12000	Sand (β = VERY DENSE) (API 2...
99	37.8	12000	12000	Sand (β = VERY DENSE) (API 2...
100	38.22	12000	12000	Sand (β = VERY DENSE) (API 2...
101	38.64	12000	12000	Sand (β = VERY DENSE) (API 2...
102	39.06	12000	12000	Sand (β = VERY DENSE) (API 2...
103	39.48	12000	12000	Sand (β = VERY DENSE) (API 2...
104	39.9	12000	12000	Sand (β = VERY DENSE) (API 2...
105	40.32	12000	12000	Sand (β = VERY DENSE) (API 2...
106	40.74	12000	12000	Sand (β = VERY DENSE) (API 2...
107	41.16	12000	12000	Sand (β = VERY DENSE) (API 2...
108	41.58	12000	12000	Sand (β = VERY DENSE) (API 2...
109	42	12000	12000	Sand (β = VERY DENSE) (API 2...

Axially Loaded Piles – Axial Capacity

Deactivate effect on
limit skin friction



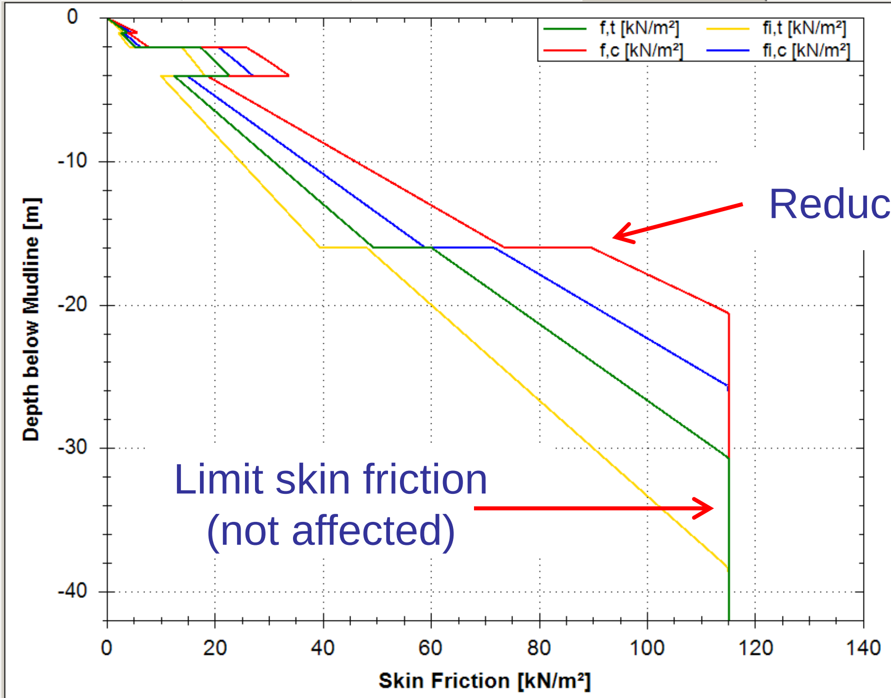
Axially Loaded Piles – Axial Capacity

IGtHPILE

File Edit Option Result About | German English

Project | Axial Soil Parameters | Axial Capacity | Overburden Pressure

Axial Capacity with Depth | Skin Friction with Depth | End Bearing Capacity with Depth | Skin Friction (Last Depth) | End Bearing (Last Depth)



Reduction of skin friction

No.	Z [m]	f,t [kN/m²]	fi,t [kN/m²]	f,c [kN/m²]	fi,c [kN/m²]	Method [-]
83	31.08	115	93.289728	115	115	Sand (β = V...
84	31.5	115	94.5504	115	115	Sand (β = V...
85	31.92	115	95.811072	115	115	Sand (β = V...
86	32.34	115	97.071744	115	115	Sand (β = V...
				115	115	Sand (β = V...
				115	115	Sand (β = V...
				115	115	Sand (β = V...
				115	115	Sand (β = V...
91	34.44	115	103.375104	115	115	Sand (β = V...
92	34.86	115	104.635776	115	115	Sand (β = V...
93	35.28	115	105.896448	115	115	Sand (β = V...
94	35.7	115	107.15712	115	115	Sand (β = V...
95	36.12	115	108.417792	115	115	Sand (β = V...
96	36.54	115	109.678464	115	115	Sand (β = V...
97	36.96	115	110.939136	115	115	Sand (β = V...
98	37.38	115	112.199808	115	115	Sand (β = V...
99	37.8	115	113.46048	115	115	Sand (β = V...
100	38.22	115	114.721152	115	115	Sand (β = V...
101	38.64	115	115	115	115	Sand (β = V...
102	39.06	115	115	115	115	Sand (β = V...
103	39.48	115	115	115	115	Sand (β = V...
104	39.9	115	115	115	115	Sand (β = V...
105	40.32	115	115	115	115	Sand (β = V...
106	40.74	115	115	115	115	Sand (β = V...
107	41.16	115	115	115	115	Sand (β = V...
108	41.58	115	115	115	115	Sand (β = V...
109	42	115	115	115	115	Sand (β = V...

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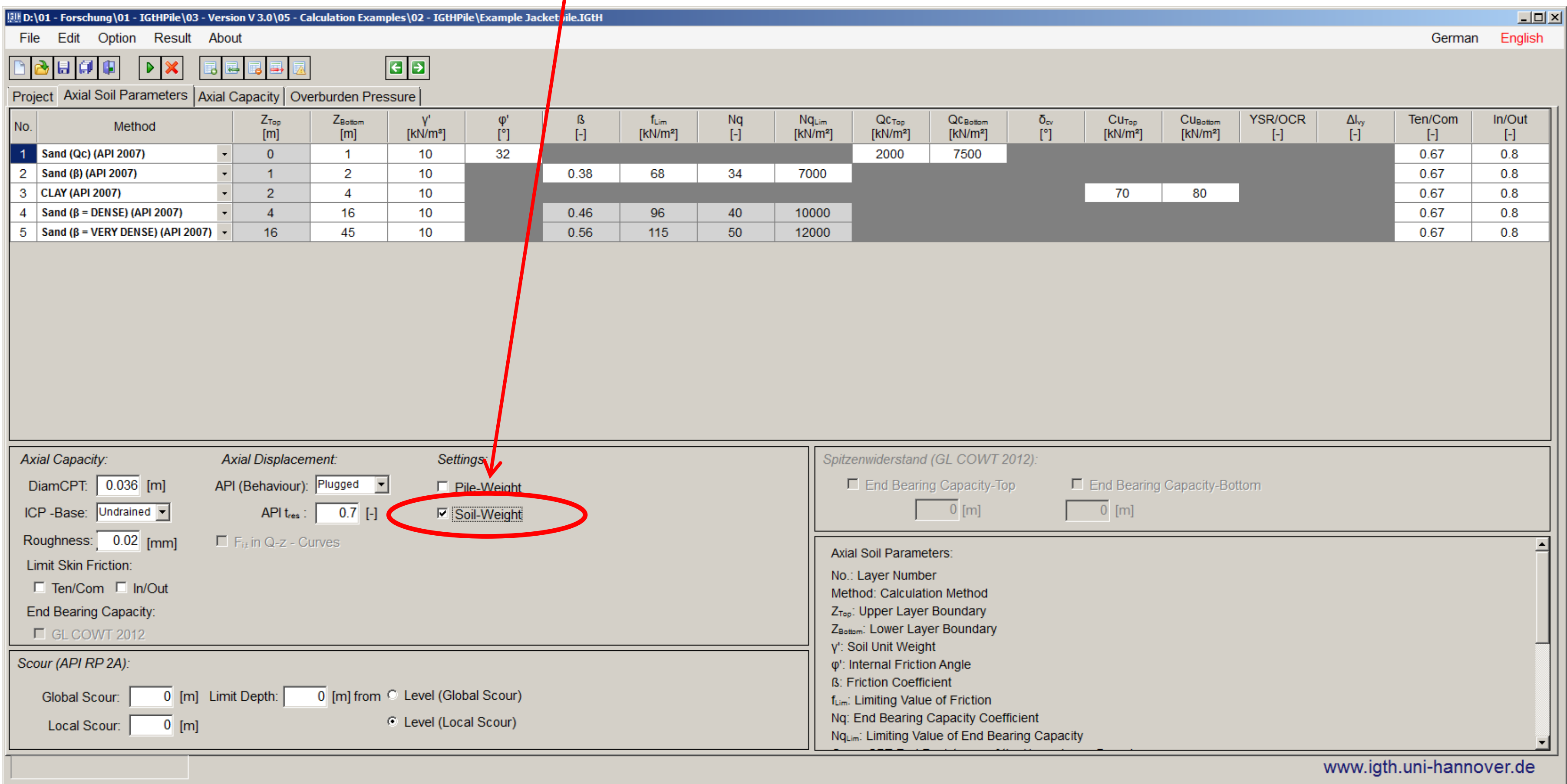
No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	β [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	δ_{cv} [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	Δl_{cy} [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	67	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = VERY DENSE) (API 2007)	4	16	10		0.560166...	114.8	50	12000								0.67	0.8
5	Sand (β = DENSE) (API 2007)	16	45	10		0.461880...	95.7	40	9600								0.67	0.8

Axially Loaded Piles – Axial Capacity

Consideration of inner soil-weight



Axially Loaded Piles – Axial Capacity

Consideration of inner soil weight

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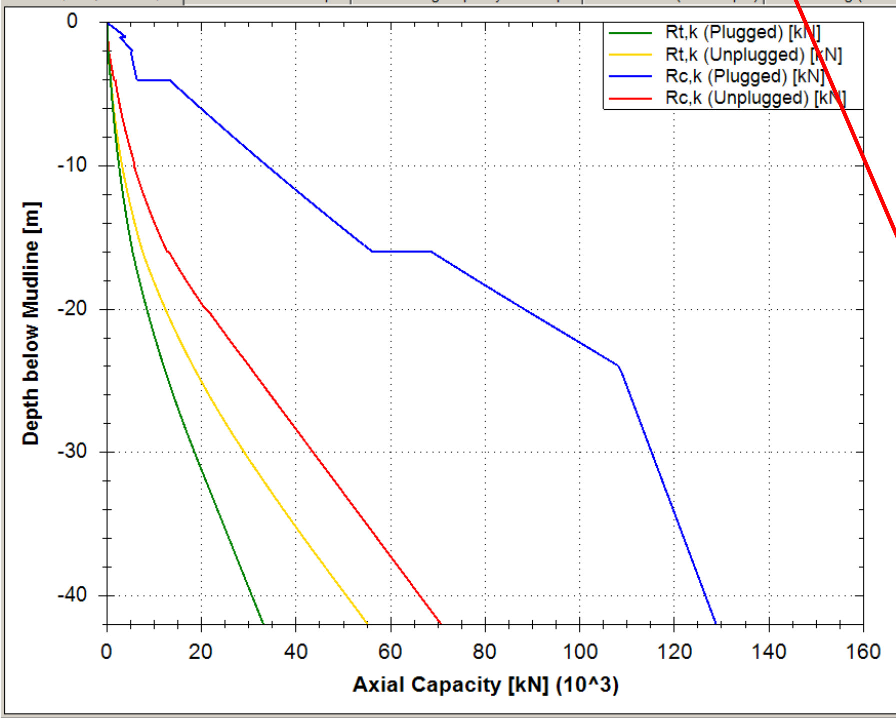
Project | Axial Soil Parameters | Axial Capacity | Overburden Pressure

Axial Capacity with Depth | Skin Friction with Depth | End Bearing Capacity with Depth | Skin Friction (Last Depth) | End Bearing (Last Depth)



- In case of compression load
  - a) unplugged $F_{,c} + F_{i,c} + Q_b$
  - b) plugged $F_{,c} + Q_b$
- In case of tension load
  - c) unplugged $F_{,t} + F_{i,t}$
  - d) plugged $F_{,t} + G_{plug}$

No.							
83							
84							
85							
86							
87							
88							
89							
90							
91							
92							
93							
94							
95							
96							
97	36.96	26970.8747...	43826.7720...	Plugged	123133.651...	59339.9250...	Unplugged
98	37.38	27480.4300...	44762.7983...	Plugged	123611.629...	60287.3828...	Unplugged
99	37.8	27989.9853...	45703.9711...	Plugged	124089.607...	61234.8406...	Unplugged
100	38.22	28499.5405...	46650.2906...	Plugged	124567.584...	62182.2985...	Unplugged
101	38.64	29009.0958...	47597.7484...	Plugged	125045.562...	63129.7563...	Unplugged
102	39.06	29518.6511...	48545.2063...	Plugged	125523.540...	64077.2142...	Unplugged
103	39.48	30028.2063...	49492.6641...	Plugged	126001.517...	65024.6720...	Unplugged
104	39.9	30537.7616...	50440.1220...	Plugged	126479.495...	65972.1299...	Unplugged
105	40.32	31047.3168...	51387.5798...	Plugged	126957.472...	66919.5877...	Unplugged
106	40.74	31556.8721...	52335.0377...	Plugged	127435.450...	67867.0456...	Unplugged
107	41.16	32066.4274...	53282.4955...	Plugged	127913.428...	68814.5034...	Unplugged
108	41.58	32575.9826...	54229.9534...	Plugged	128391.405...	69761.9613...	Unplugged
109	42	33085.5379...	55177.4112...	Plugged	128869.383...	70709.4191...	Unplugged

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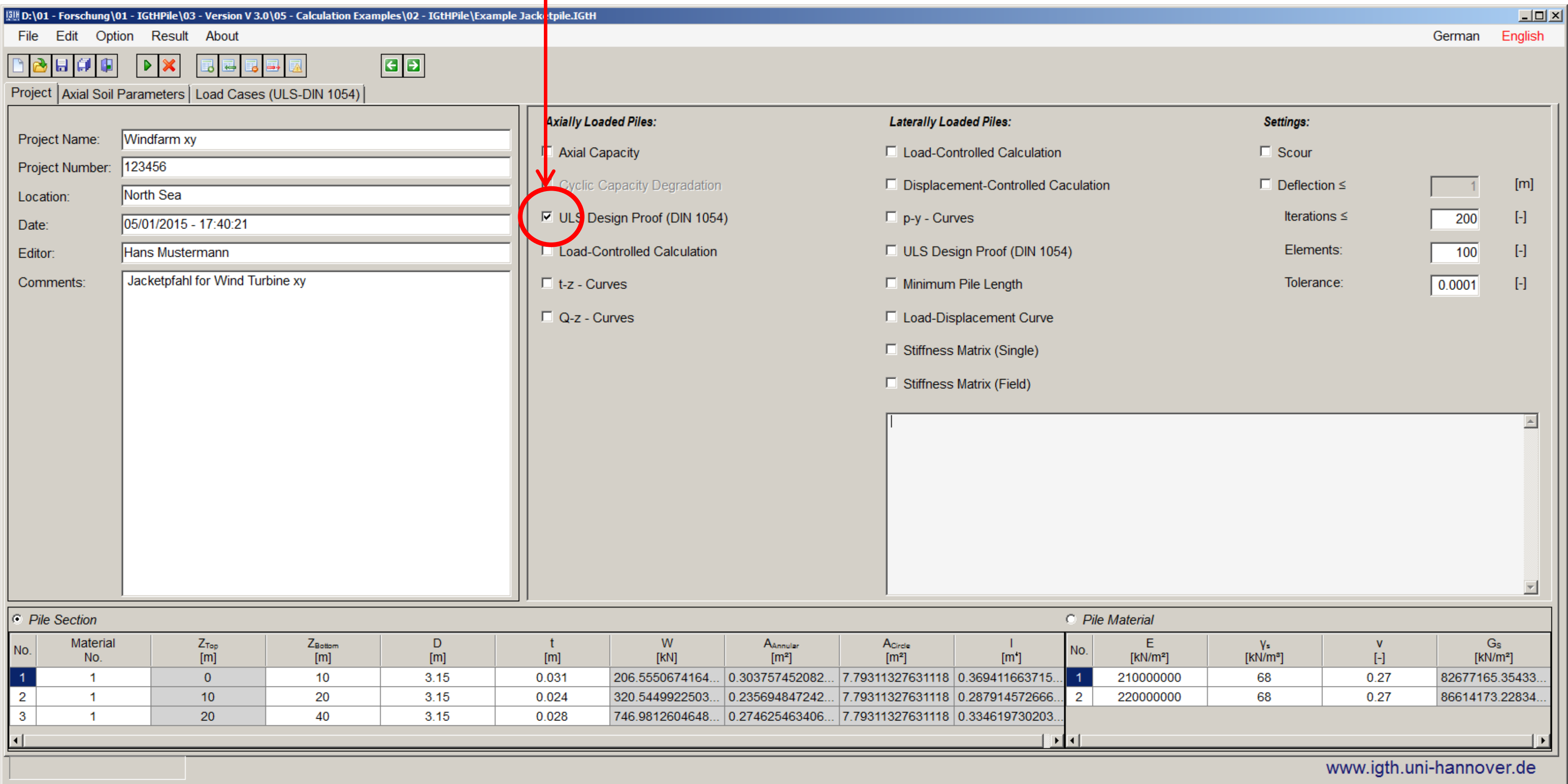
Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

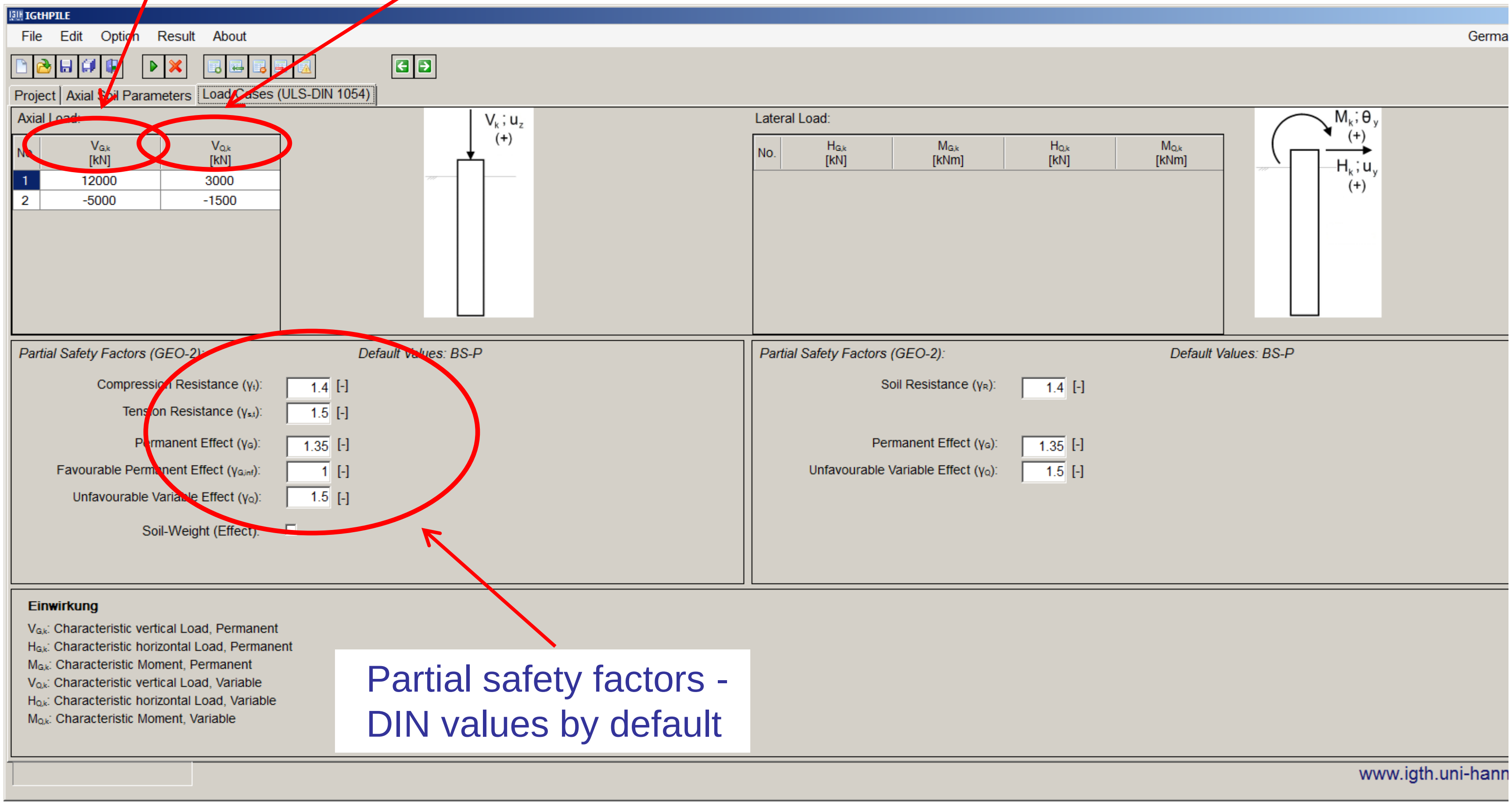
ULS design proof according to
DIN 1054:2010-05



Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

Characteristic, permanent loading

Characteristic, variable loading



Partial safety factors - DIN values by default

Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

ULS design proof according to DIN 1054

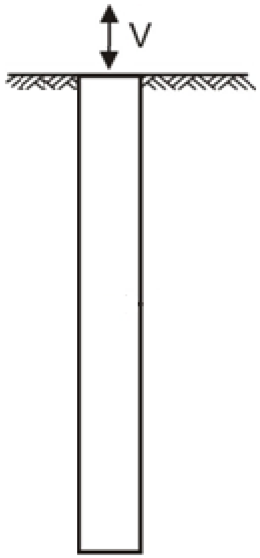
- In case of compression load:

a) unplugged

$$(V_{G,k} + G_{pile})\,\gamma_G + V_{Q,k}\,\gamma_Q \leq (F_{,c} + F_{i,c} + Q_b) / \gamma_t$$

b) plugged

$$(V_{G,k} + G_{pile})\,\gamma_G + V_{Q,k}\,\gamma_Q \leq (F_{,c} + Q_b) / \gamma_t$$



- In case of tension load:

c) unplugged

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - G_{pile}\,\gamma_{G,inf} \leq (F_{,t} + F_{i,t}) / \gamma_{s,t}$$

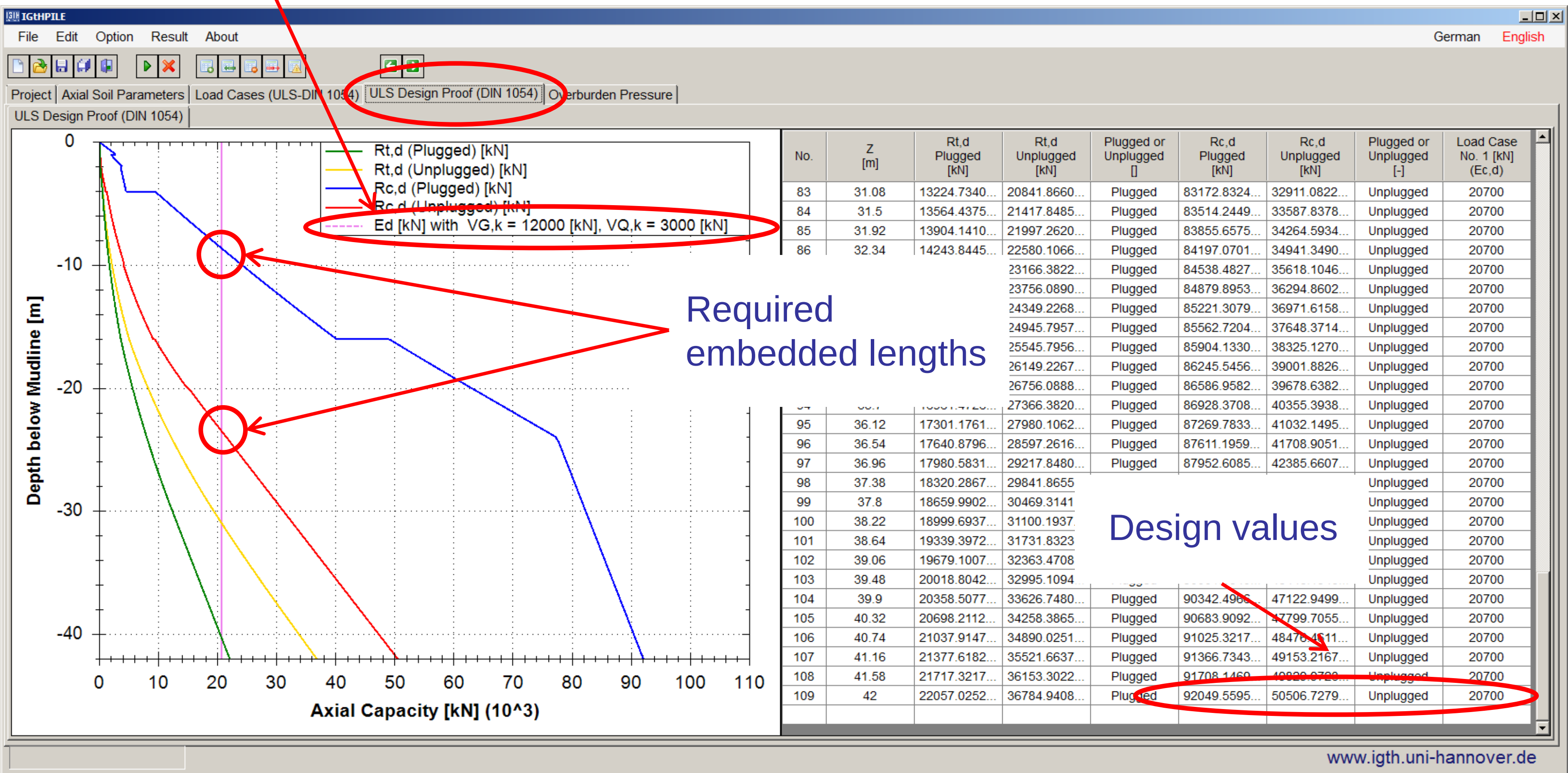
d) plugged

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - G_{pile}\,\gamma_{G,inf} \leq (F_{,t} + G_{plug}) / \gamma_{s,t}$$ (with soil-weight *as resistance*)

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - (G_{pile} + G_{plug})\,\gamma_{G,inf} \leq (F_{,t}) / \gamma_{s,t}$$ (with soil-weight as effect)

Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

Load case: Compression

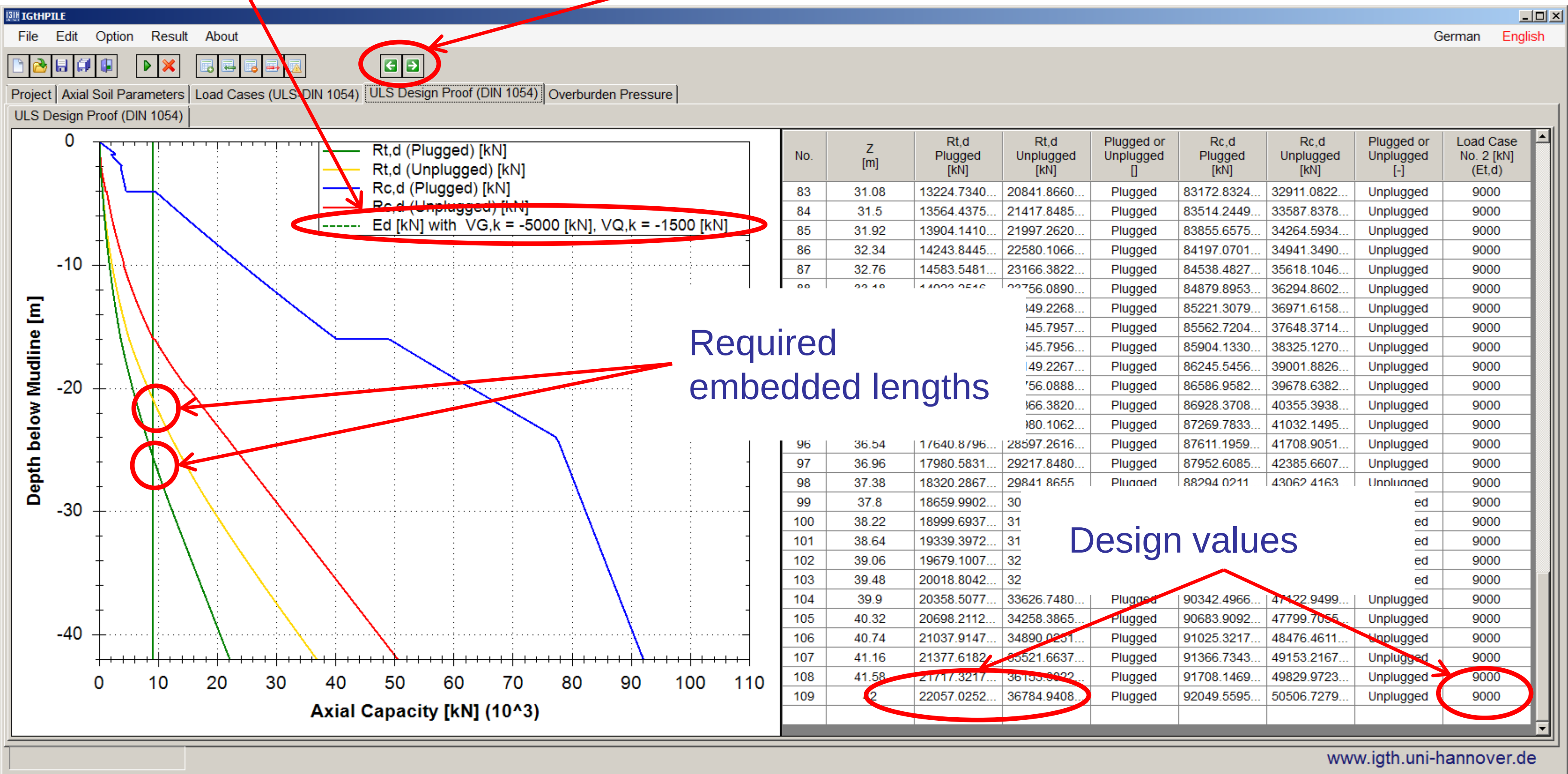


No.	Z [m]	Rt,d Plugged [kN]	Rt,d Unplugged [kN]	Plugged or Unplugged []	Rc,d Plugged [kN]	Rc,d Unplugged [kN]	Plugged or Unplugged [-]	Load Case No. 1 [kN] (Ec,d)
83	31.08	13224.7340...	20841.8660...	Plugged	83172.8324...	32911.0822...	Unplugged	20700
84	31.5	13564.4375...	21417.8485...	Plugged	83514.2449...	33587.8378...	Unplugged	20700
85	31.92	13904.1410...	21997.2620...	Plugged	83855.6575...	34264.5934...	Unplugged	20700
86	32.34	14243.8445...	22580.1066...	Plugged	84197.0701...	34941.3490...	Unplugged	20700
			23166.3822...	Plugged	84538.4827...	35618.1046...	Unplugged	20700
			23756.0890...	Plugged	84879.8953...	36294.8602...	Unplugged	20700
			24349.2268...	Plugged	85221.3079...	36971.6158...	Unplugged	20700
			24945.7957...	Plugged	85562.7204...	37648.3714...	Unplugged	20700
			25545.7956...	Plugged	85904.1330...	38325.1270...	Unplugged	20700
			26149.2267...	Plugged	86245.5456...	39001.8826...	Unplugged	20700
			26756.0888...	Plugged	86586.9582...	39678.6382...	Unplugged	20700
			27366.3820...	Plugged	86928.3708...	40355.3938...	Unplugged	20700
95	36.12	17301.1761...	27980.1062...	Plugged	87269.7833...	41032.1495...	Unplugged	20700
96	36.54	17640.8796...	28597.2616...	Plugged	87611.1959...	41708.9051...	Unplugged	20700
97	36.96	17980.5831...	29217.8480...	Plugged	87952.6085...	42385.6607...	Unplugged	20700
98	37.38	18320.2867...	29841.8655				Unplugged	20700
99	37.8	18659.9902...	30469.3141				Unplugged	20700
100	38.22	18999.6937...	31100.1937				Unplugged	20700
101	38.64	19339.3972...	31731.8323				Unplugged	20700
102	39.06	19679.1007...	32363.4708				Unplugged	20700
103	39.48	20018.8042...	32995.1094				Unplugged	20700
104	39.9	20358.5077...	33626.7480...	Plugged	90342.4966...	47122.9499...	Unplugged	20700
105	40.32	20698.2112...	34258.3865...	Plugged	90683.9092...	47799.7055...	Unplugged	20700
106	40.74	21037.9147...	34890.0251...	Plugged	91025.3217...	48476.4611...	Unplugged	20700
107	41.16	21377.6182...	35521.6637...	Plugged	91366.7343...	49153.2167...	Unplugged	20700
108	41.58	21717.3217...	36153.3022...	Plugged	91708.1469...	[illegible]	Unplugged	20700
109	42	22057.0252...	36784.9408...	Plugged	92049.5595...	50506.7279...	Unplugged	20700

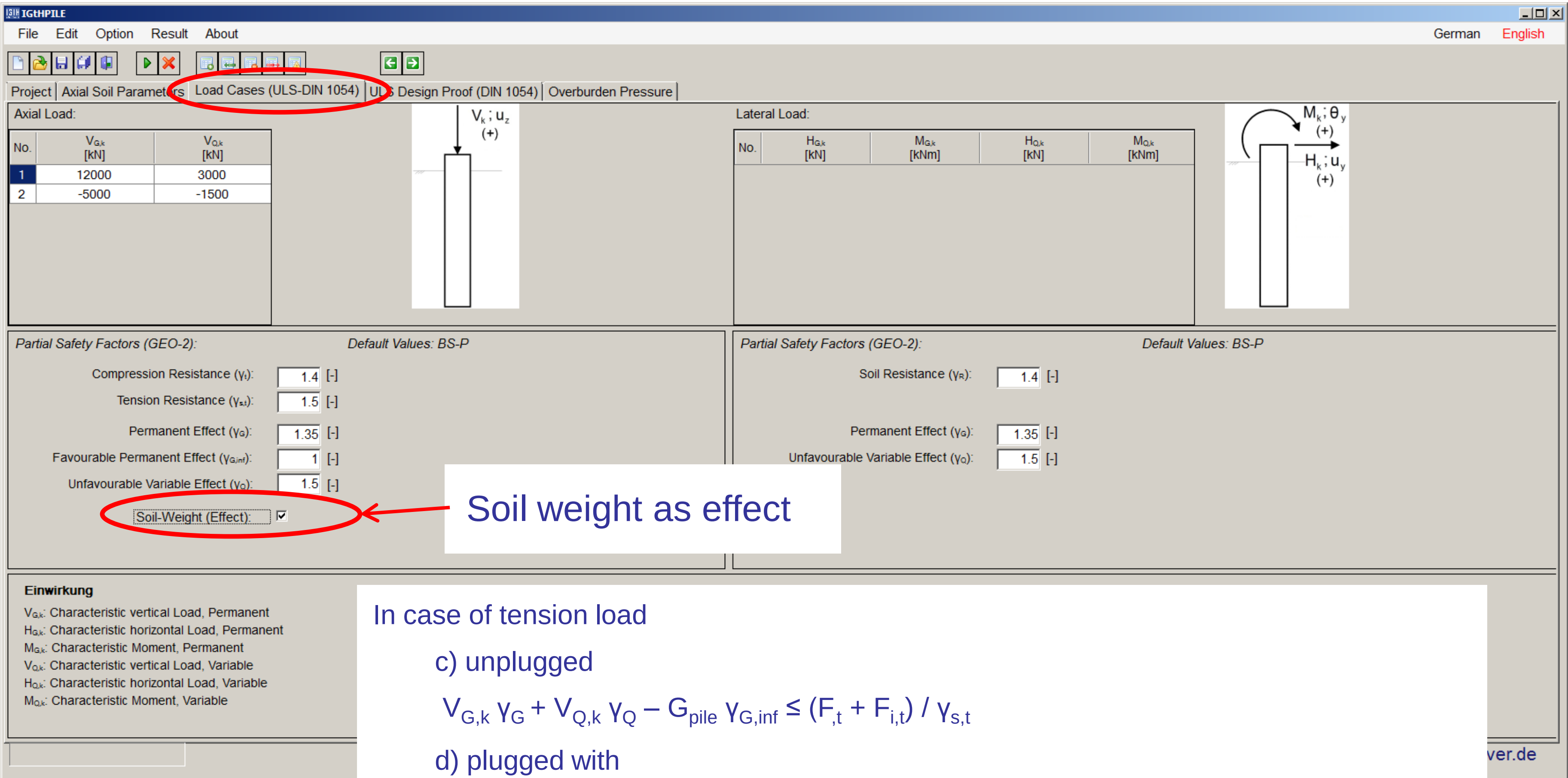
Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

Load case: Tension

Change load case



Axially Loaded Piles – ULS Design Proof acc. to DIN 1054



Soil weight as effect

In case of tension load

c) unplugged

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - G_{pile}\,\gamma_{G,inf} \leq (F_{,t} + F_{i,t}) \,/\, \gamma_{s,t}$$

d) plugged with

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - G_{pile}\,\gamma_{G,inf} \leq (F_{,t} + G_{plug}) \,/\, \gamma_{s,t}$$ (with soil-weight as resistance)

$$V_{G,k}\,\gamma_G + V_{Q,k}\,\gamma_Q - (G_{pile} + G_{plug})\,\gamma_{G,inf} \leq F_{,t} \,/\, \gamma_{s,t}$$ (with soil-weight as effect)

Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

Considered load case: Tension

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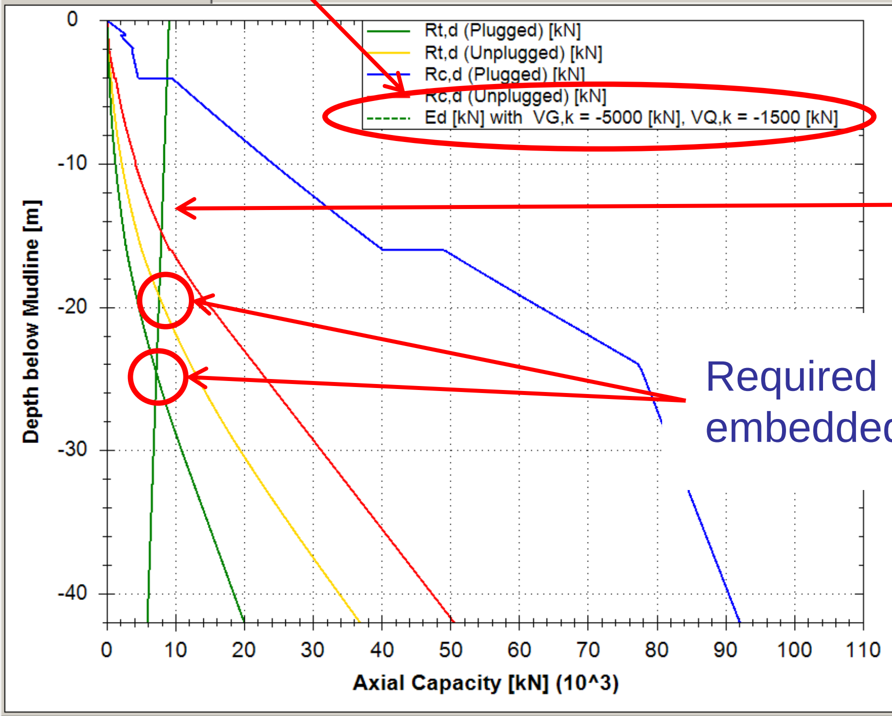
Project | Axial Soil Parameters | Load Cases (ULS-DIN 1054) | ULS Design Proof (DIN 1054) | Overburden Pressure

ULS Design Proof (DIN 1054)



Decreasing loading

Required embedded lengths

No.	Z [m]	Rt,d Plugged [kN]	Rt,d Unplugged [kN]	Plugged or Unplugged []	Rc,d Plugged [kN]	Rc,d Unplugged [kN]	Plugged or Unplugged [-]	Load Case No. 2 [kN] (Et,d)
83	31.08	11666.1633...	20841.8660...	Plugged	83172.8324...	32911.0822...	Unplugged	6662.14393...
84	31.5	11984.8151...	21417.8485...	Plugged	83514.2449...	33587.8378...	Unplugged	6630.56628...
85	31.92	12303.4668...	21997.2620...	Plugged	83855.6575...	34264.5934...	Unplugged	6598.98863...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4197.0701...	34941.3490...	Unplugged	6567.41098...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4538.4827...	35618.1046...	Unplugged	6535.83333...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4879.8953...	36294.8602...	Unplugged	6504.25568...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5221.3079...	36971.6158...	Unplugged	6472.67803...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5562.7204...	37648.3714...	Unplugged	6441.10039...
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5904.1330...	38325.1270...	Unplugged	6409.52274...
92	34.86	14534.0290...	26149.2267...	Plugged	86245.5456...	39001.8826...	Unplugged	6377.94509...
93	35.28	14852.6807...	26756.0888...	Plugged	86586.9582...	39678.6382...	Unplugged	6346.36744...
[illegible]	[illegible]	171.3325...	27366.3820...	Plugged	86928.3708...	40355.3938...	Unplugged	6314.78979...
[illegible]	[illegible]	489.9842...	27980.1062...	Plugged	87269.7833...	41032.1495...	Unplugged	6283.21214...
[illegible]	[illegible]	808.6360...	28597.2616...	Plugged	87611.1959...	41708.9051...	Unplugged	6251.63449...
[illegible]	[illegible]	127.2877...	29217.8480...	Plugged	87952.6085...	42385.6607...	Unplugged	6220.05684...
[illegible]	[illegible]	445.9395...	29841.8655...	Plugged	88294.0211...	43062.4163...	Unplugged	6188.47919...
[illegible]	[illegible]	764.5912...	30469.3141...	Plugged	88635.4337...	43739.1719...	Unplugged	6156.90155...
[illegible]	[illegible]	083.2429...	31100.1937...	Plugged	88976.8463...	44415.9275...	Unplugged	6125.32390...
[illegible]	[illegible]	401.8947...	31731.8323...	Plugged	89318.2588...	45092.6831...	Unplugged	6093.74625...
102	39.06	17720.5464...	32363.4708...	Plugged	89659.6714...	45769.4387...	Unplugged	6062.16860...
103	39.48	18039.1982...	32995.1094...	Plugged	90001.0840...	46446.1943...	Unplugged	6030.59095...
104	39.9	18357.8499...	33626.7480...	Plugged	90342.4966...	47122.9499...	Unplugged	5999.01330...
105	40.32	18676.5017...	34258.3865...	Plugged	90683.9092...	47799.7055...	Unplugged	5967.43565...
106	40.74	18995.1534...	34890.0251...	Plugged	91025.3217...	48476.4611...	Unplugged	5935.85800...
107	41.16	19313.8051...	35521.6637...	Plugged	91366.7343...	49153.2167...	Unplugged	5904.28036...
108	41.58	19632.4569...	36153.3022...	Plugged	91708.1469...	49829.9723...	Unplugged	5872.70271...
109	42	19951.1086...	36784.9408...	Plugged	92049.5595...	50506.7279...	Unplugged	5841.12506...

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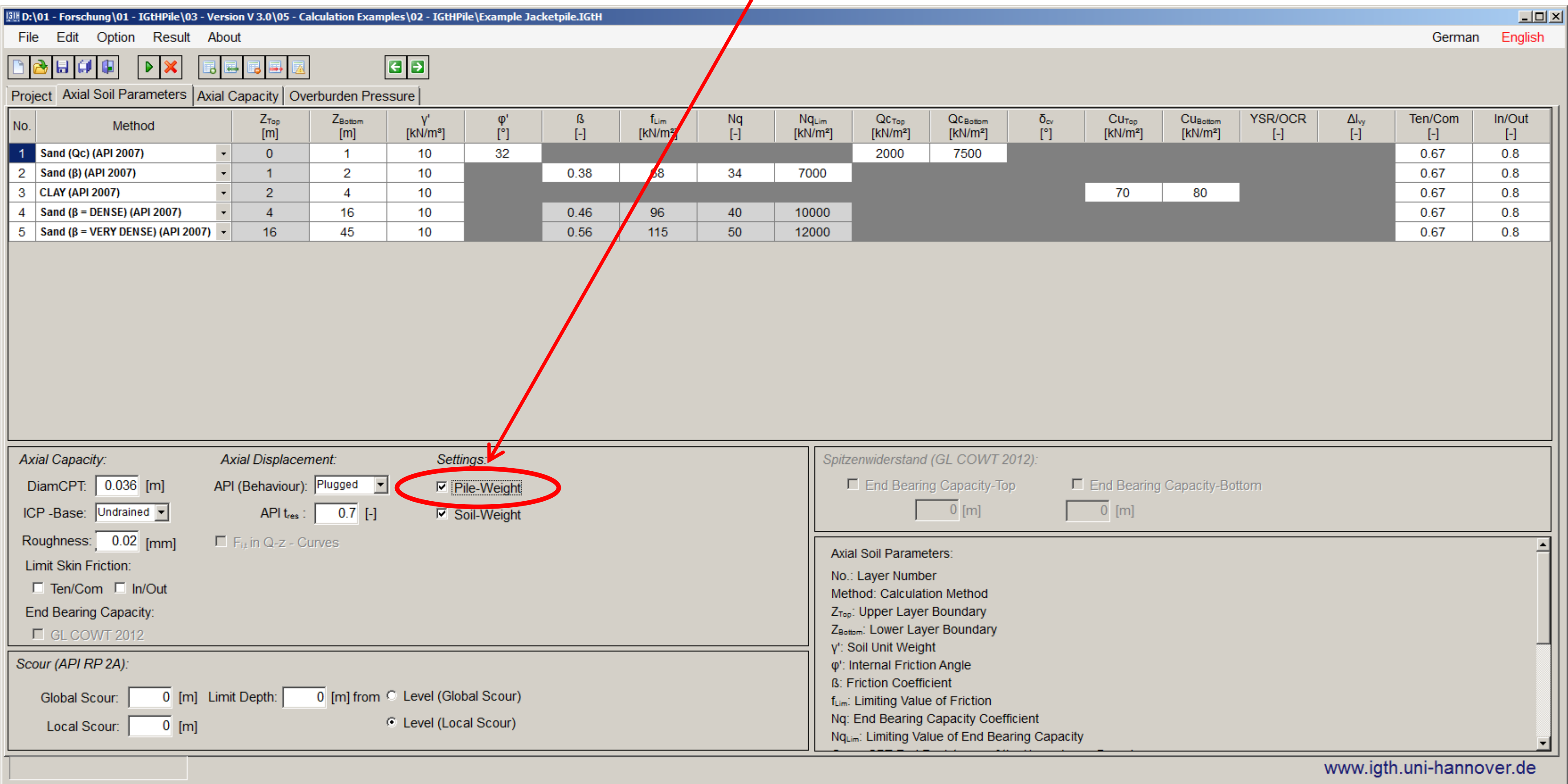
Design Values

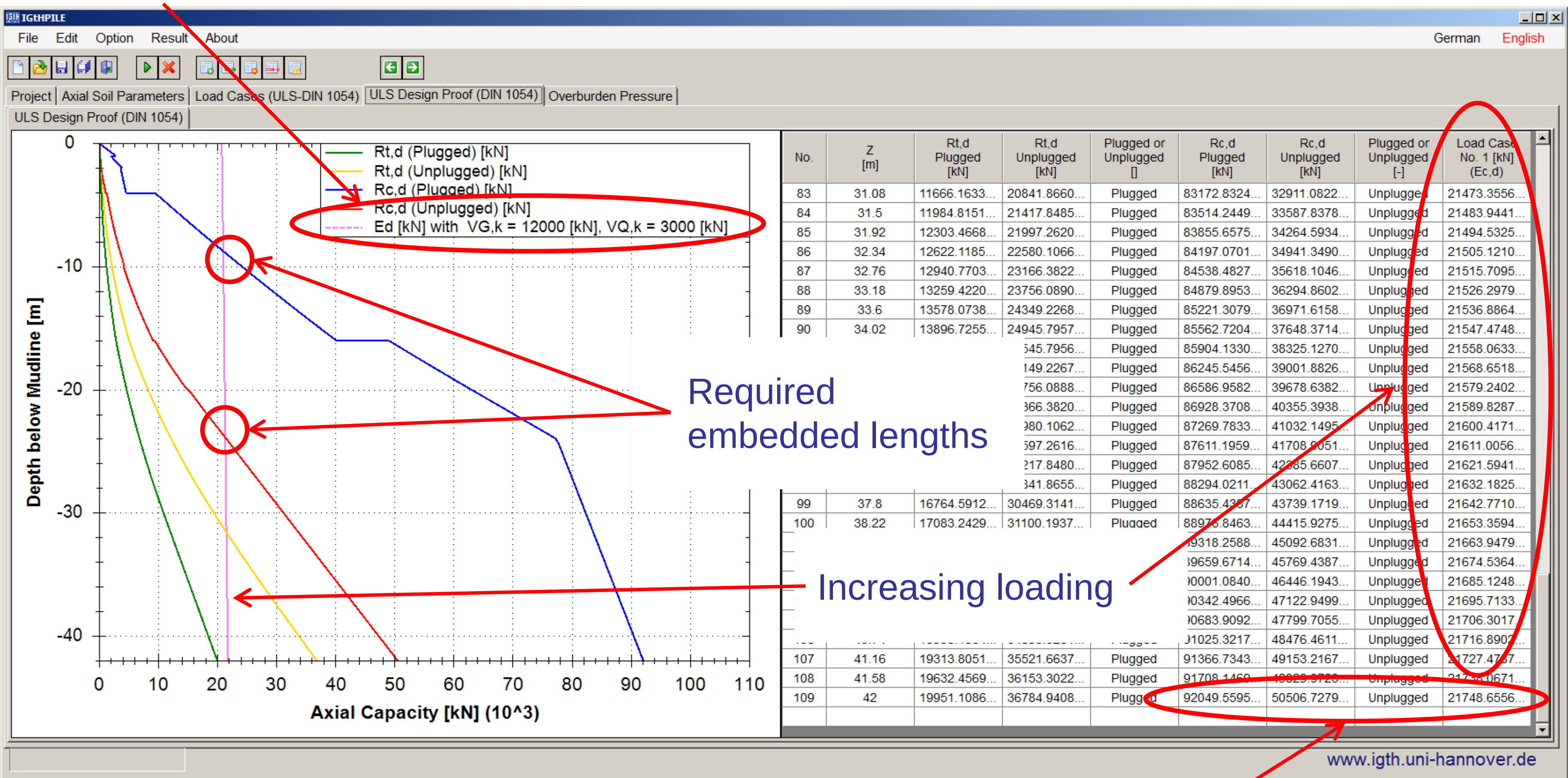
Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

Consideration of pile-weight



Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

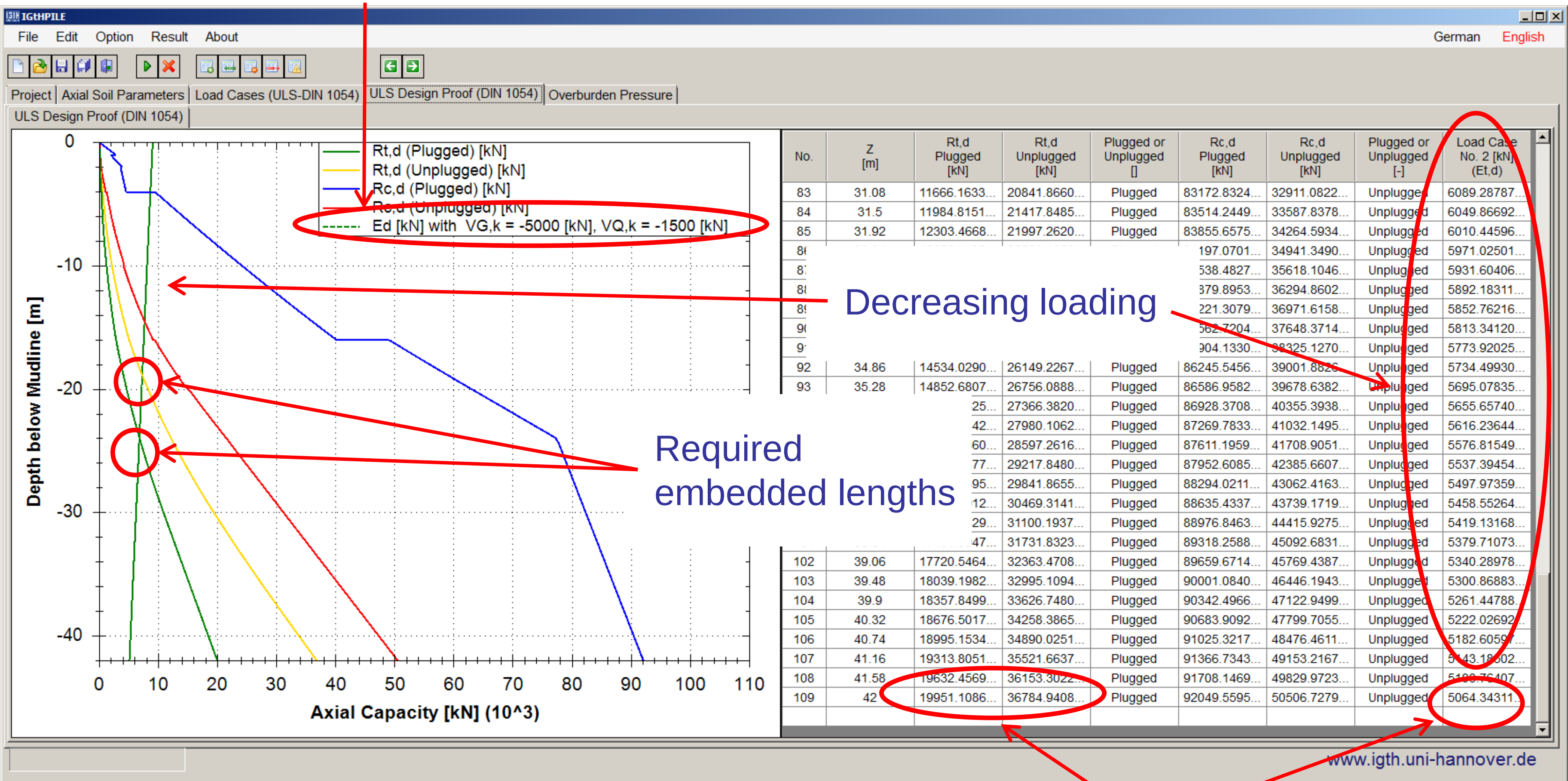
Considered load case: Compression



Design Values

Axially Loaded Piles – ULS Design Proof acc. to DIN 1054

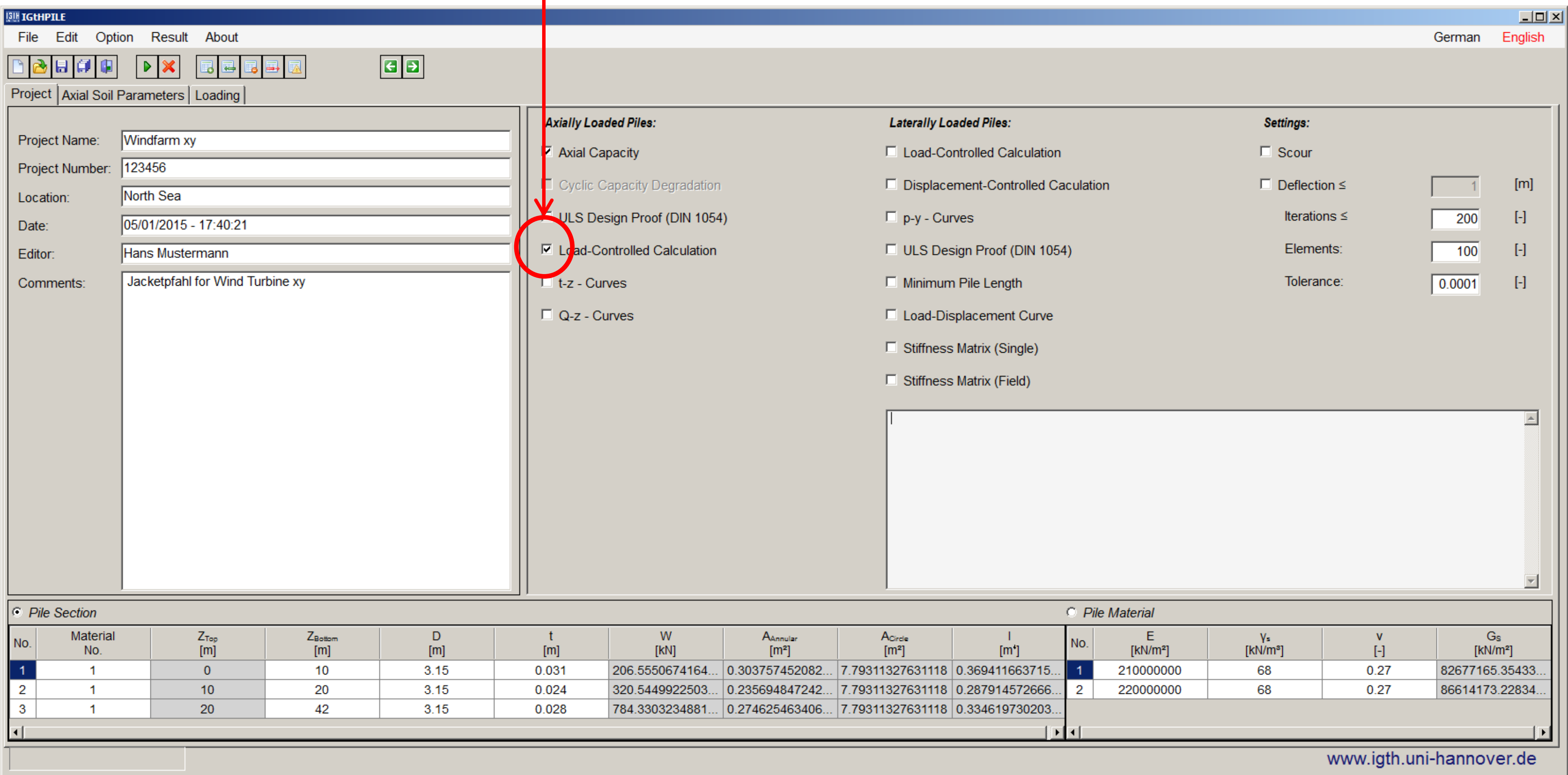
Considered load case: Tension



No.	Z [m]	Rt,d Plugged [kN]	Rt,d Unplugged [kN]	Plugged or Unplugged []	Rc,d Plugged [kN]	Rc,d Unplugged [kN]	Plugged or Unplugged [-]	Load Case No. 2 [kN] (Et,d)
83	31.08	11666.1633...	20841.8660...	Plugged	83172.8324...	32911.0822...	Unplugged	6089.28787...
84	31.5	11984.8151...	21417.8485...	Plugged	83514.2449...	33587.8378...	Unplugged	6049.86692...
85	31.92	12303.4668...	21997.2620...	Plugged	83855.6575...	34264.5934...	Unplugged	6010.44596...
92	34.86	14534.0290...	26149.2267...	Plugged	86245.5456...	39001.8826...	Unplugged	5734.49930...
93	35.28	14852.6807...	26756.0888...	Plugged	86586.9582...	39678.6382...	Unplugged	5695.07835...
102	39.06	17720.5464...	32363.4708...	Plugged	89659.6714...	45769.4387...	Unplugged	5340.28978...
103	39.48	18039.1982...	32995.1094...	Plugged	90001.0840...	46446.1943...	Unplugged	5300.86883...
104	39.9	18357.8499...	33626.7480...	Plugged	90342.4966...	47122.9499...	Unplugged	5261.44788...
105	40.32	18676.5017...	34258.3865...	Plugged	90683.9092...	47799.7055...	Unplugged	5222.02692...
106	40.74	18995.1534...	34890.0251...	Plugged	91025.3217...	48476.4611...	Unplugged	5182.6059...
107	41.16	19313.8051...	35521.6637...	Plugged	91366.7343...	49153.2167...	Unplugged	5143.18502...
108	41.58	19632.4569...	36153.3022...	Plugged	91708.1469...	49829.9723...	Unplugged	5103.76407...
109	42	19951.1086...	36784.9408...	Plugged	92049.5595...	50506.7279...	Unplugged	5064.34311...

Axially Loaded Piles – Load-Controlled Calculation

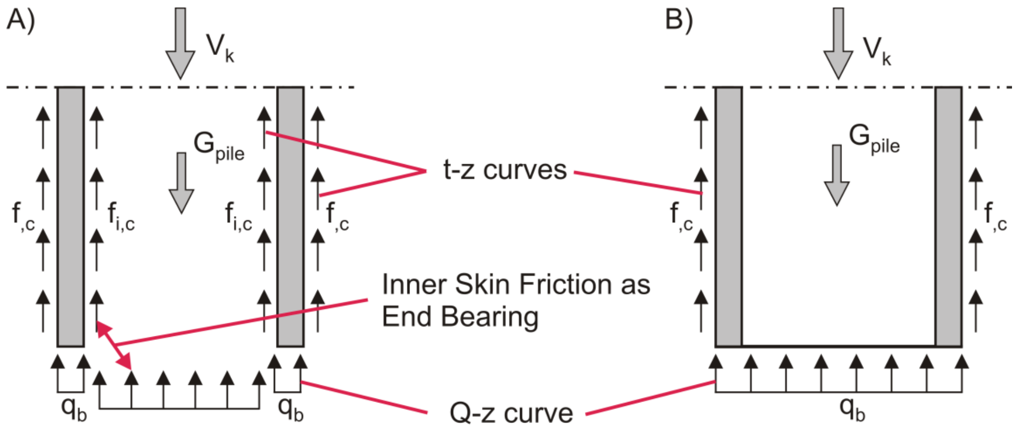
Load-controlled calculation



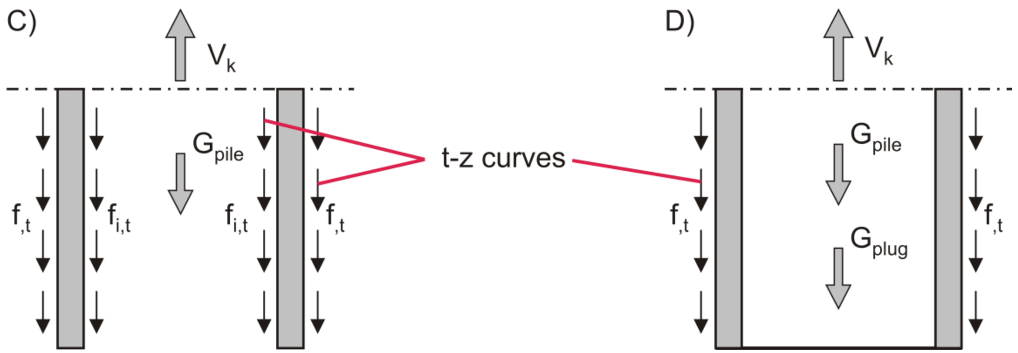
Axially Loaded Piles – Load-Controlled Calculation

Resistance forces assigned to t-z and Q-z curves

- In case of compression loads:



- In case of tension loads:

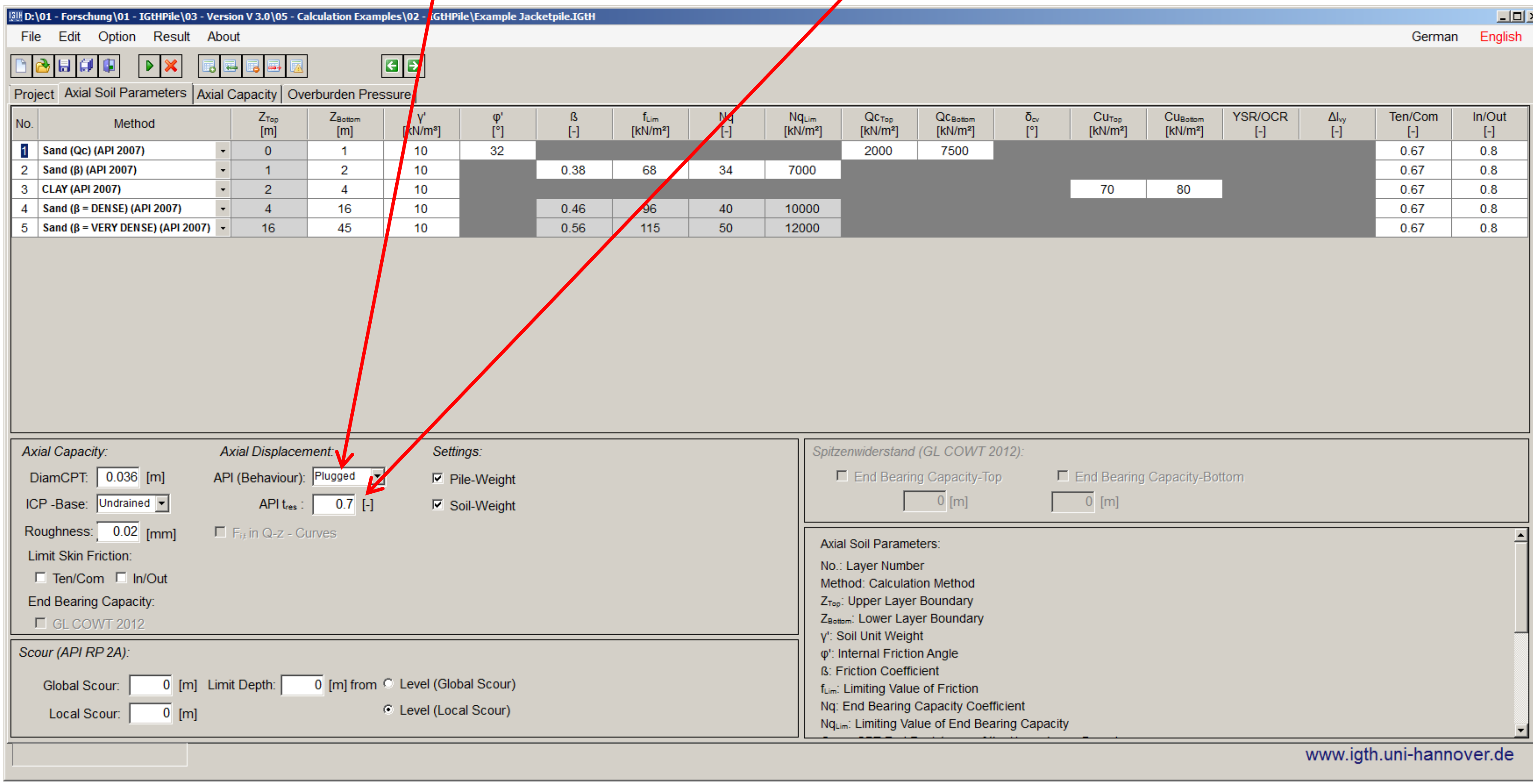


Note: The inner skin friction $f_{i,c}$ and $f_{i,t}$ is zero for the CPT methods.

Axially Loaded Piles – Load-Controlled Calculation

Residual resistance for cohesive soils

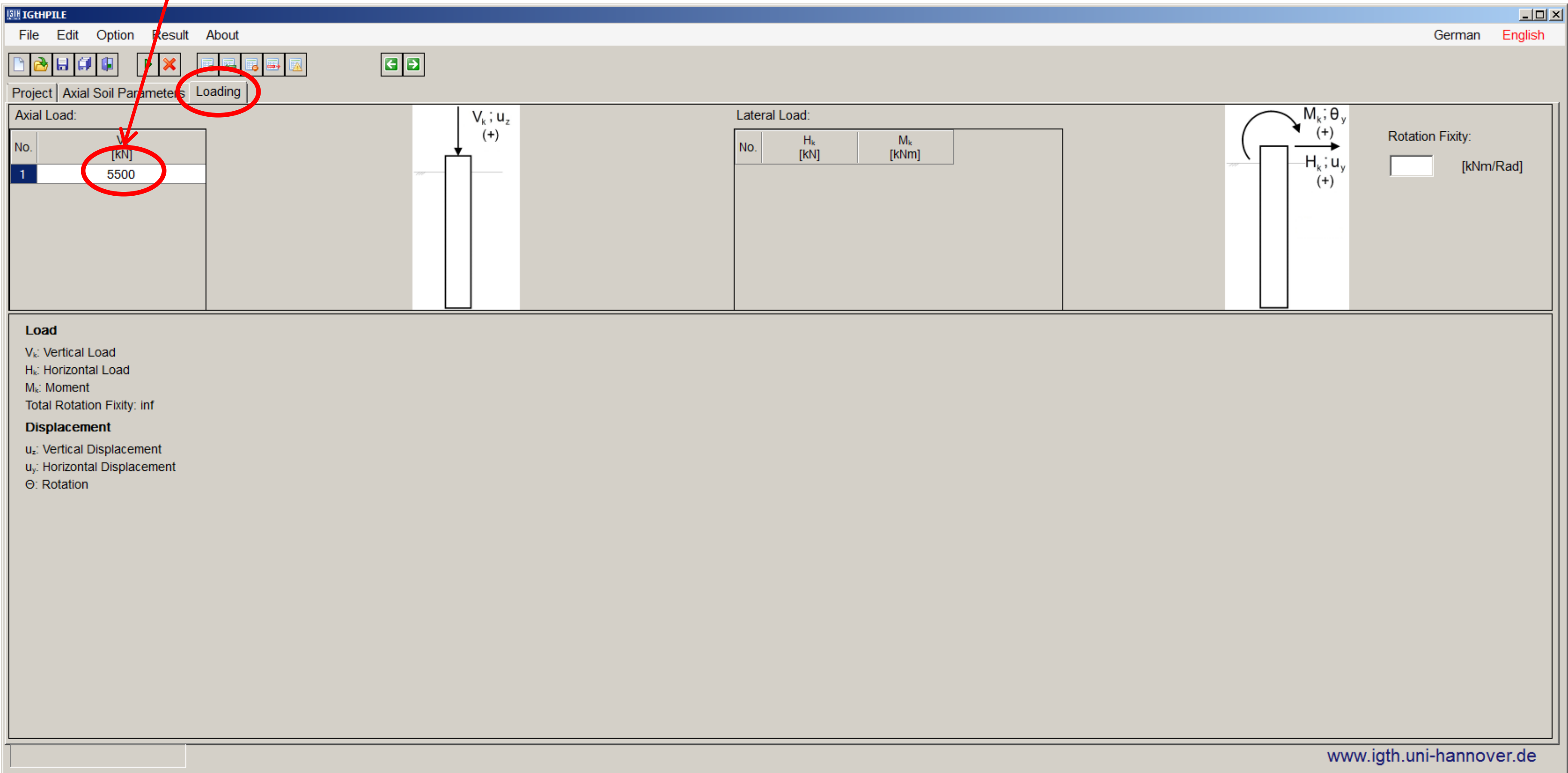
Bearing behavior: Plugged



No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	ß [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	δ_{cv} [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	Δl_{vy} [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	68	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = DENSE) (API 2007)	4	16	10		0.46	96	40	10000								0.67	0.8
5	Sand (β = VERY DENSE) (API 2007)	16	45	10		0.56	115	50	12000								0.67	0.8

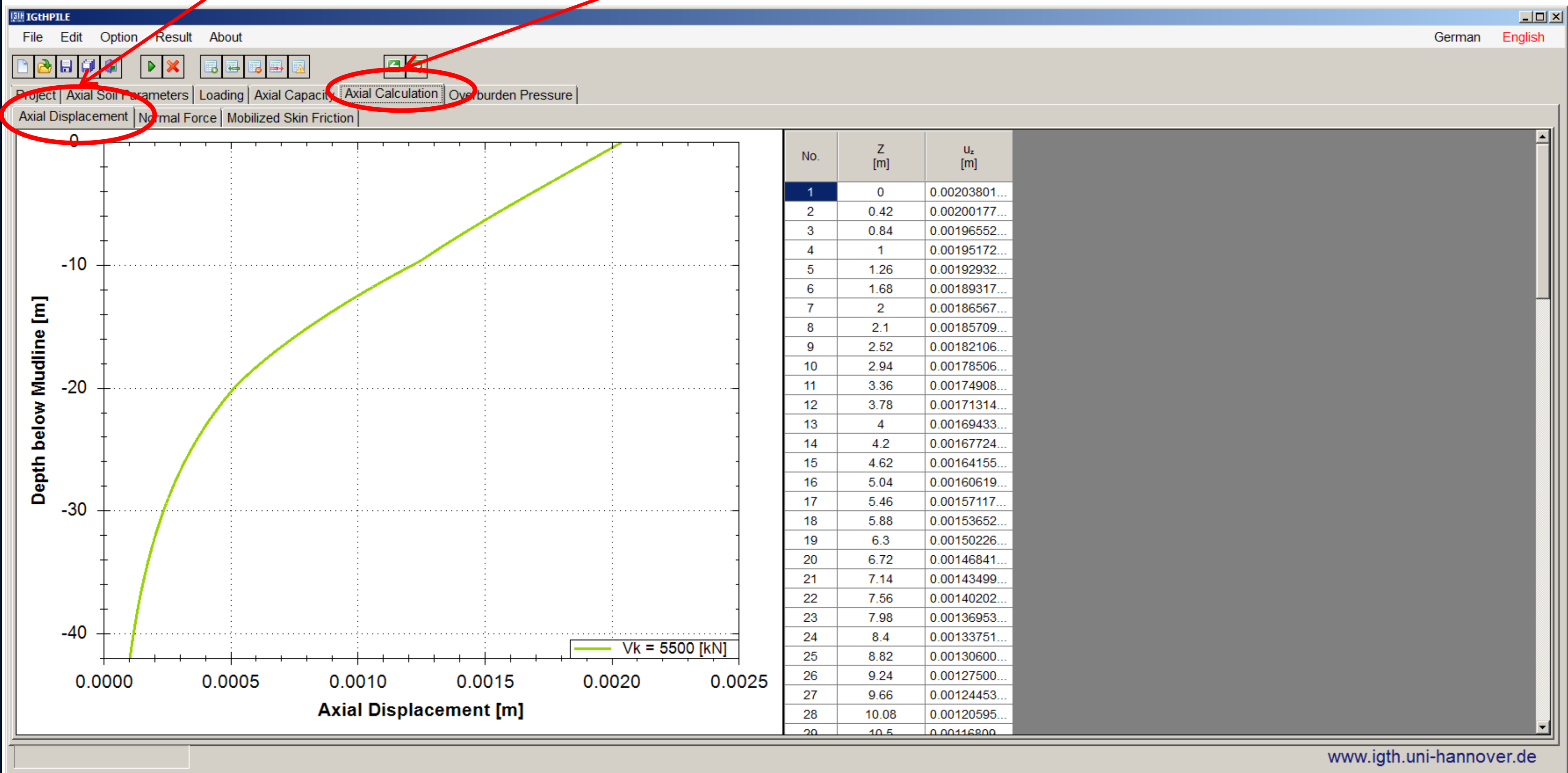
Axially Loaded Piles – Load-Controlled Calculation

Insert pile head loading



Axially Loaded Piles – Load-Controlled Calculation

Axial displacement Calculation output

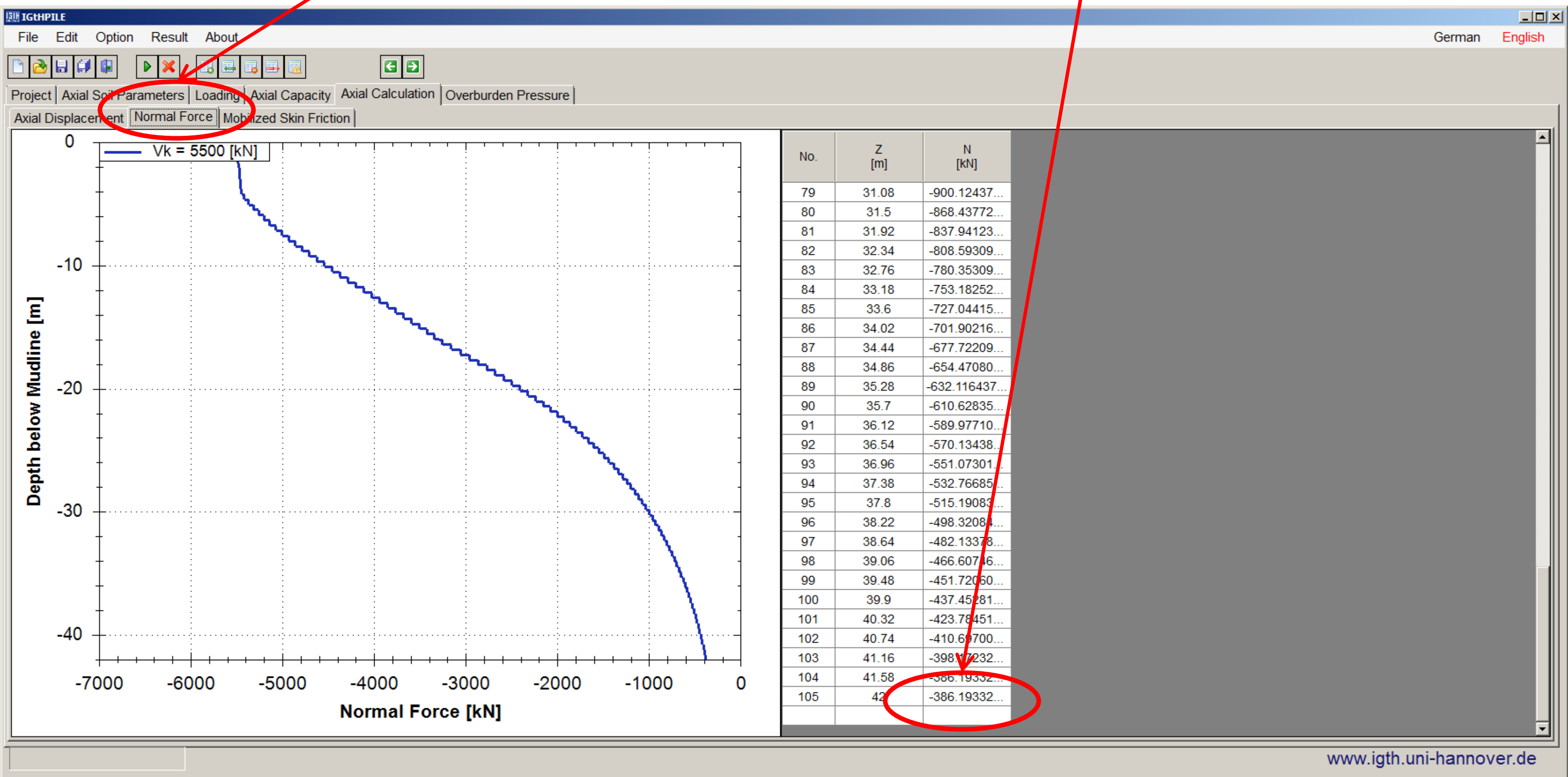


No.	Z [m]	u_z [m]
1	0	0.00203801...
2	0.42	0.00200177...
3	0.84	0.00196552...
4	1	0.00195172...
5	1.26	0.00192932...
6	1.68	0.00189317...
7	2	0.00186567...
8	2.1	0.00185709...
9	2.52	0.00182106...
10	2.94	0.00178506...
11	3.36	0.00174908...
12	3.78	0.00171314...
13	4	0.00169433...
14	4.2	0.00167724...
15	4.62	0.00164155...
16	5.04	0.00160619...
17	5.46	0.00157117...
18	5.88	0.00153652...
19	6.3	0.00150226...
20	6.72	0.00146841...
21	7.14	0.00143499...
22	7.56	0.00140202...
23	7.98	0.00136953...
24	8.4	0.00133751...
25	8.82	0.00130600...
26	9.24	0.00127500...
27	9.66	0.00124453...
28	10.08	0.00120595...
29	10.5	0.00116809...

Axially Loaded Piles – Load-Controlled Calculation

Normal force

End bearing force



No.	Z [m]	N [kN]
79	31.08	-900.12437...
80	31.5	-868.43772...
81	31.92	-837.94123...
82	32.34	-808.59309...
83	32.76	-780.35309...
84	33.18	-753.18252...
85	33.6	-727.04415...
86	34.02	-701.90216...
87	34.44	-677.72209...
88	34.86	-654.47080...
89	35.28	-632.116437...
90	35.7	-610.62835...
91	36.12	-589.97710...
92	36.54	-570.13438...
93	36.96	-551.07301...
94	37.38	-532.76685...
95	37.8	-515.19083...
96	38.22	-498.32084...
97	38.64	-482.13378...
98	39.06	-466.60746...
99	39.48	-451.72060...
100	39.9	-437.45281...
101	40.32	-423.78451...
102	40.74	-410.69700...
103	41.16	-398.17232...
104	41.58	-386.19332...
105	42	-386.19332...

Axially Loaded Piles – Load-Controlled Calculation

Mobilized skin friction

Actual

Maximal

Residual

Decisive

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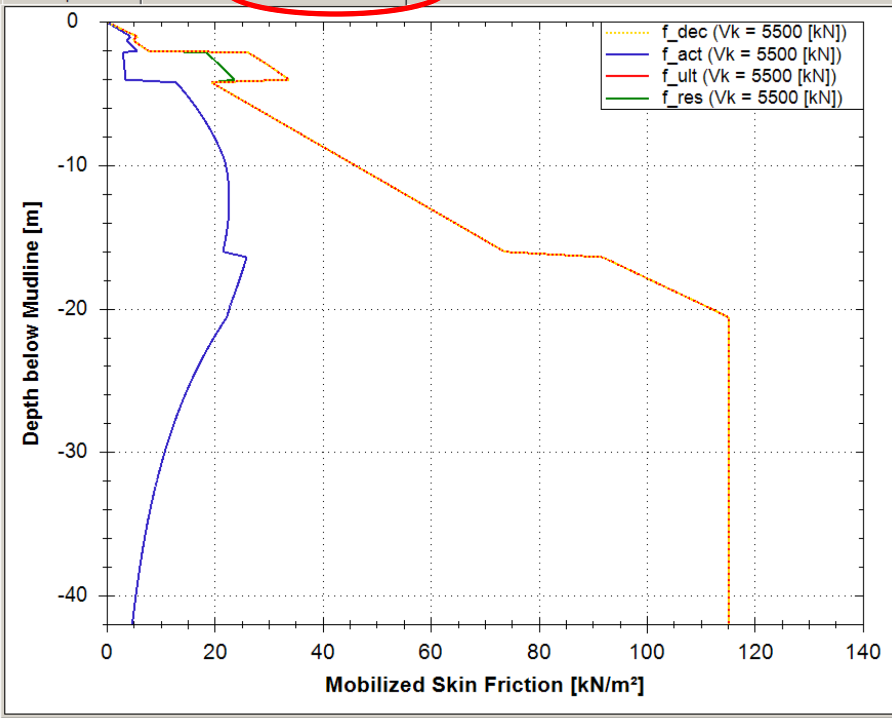
File Edit Option Result About

German English

Project | Axial Soil Parameters | Loading | Axial Capacity | Axial Calculation | Overburden Pressure

Axial Displacement | Normal Force | Mobilized Skin Friction



No.	Z [m]	f_{act} [kN/m²]	f_{ult} [kN/m²]	f_{res} [kN/m²]	f/fu [-]	f_{dec} [kN/m²]
1	0	0	0	0	fu	0
2	0.42	1.85416177...	2.352697326	2.352697326	fu	2.352697326
3	0.84	3.64117341...	4.705394652	4.705394652	fu	4.705394652
4	1	4.30430135...	5.6016603	5.6016603	fu	5.6016603
5	1.26	3.63685763...	4.788	4.788	fu	4.788
6	1.68	4.75827452...	6.384	6.384	fu	6.384
7	2	5.58233848...	7.6	7.6	fu	7.6
8	2.1	2.87866734...	26.0415401...	18.2290781...	fu	26.0415401...
9	2.52	3.02022383...	27.8626619...	19.5038633...	fu	27.8626619...
10	2.94	3.14334256...	29.5833456...	20.7083419...	fu	29.5833456...
11	3.36	3.25146091...	31.2302699...	21.8611889...	fu	31.2302699...
12	3.78	3.34684967...	32.8209166...	22.9746416...	fu	32.8209166...
13	4	3.39228533...	33.6358566...	23.5450996...	fu	33.6358566...
14	4.2	12.7575913...	19.32	19.32	fu	19.32
15	4.62	13.7347978...	21.252	21.252	fu	21.252
16	5.04	14.6606316...	23.184	23.184	fu	23.184
17	5.46	15.5360702...	25.116	25.116	fu	25.116
18	5.88	16.3621542...	27.048	27.048	fu	27.048
19	6.3	17.1399812...	28.98	28.98	fu	28.98
20	6.72	17.8707017...	30.912	30.912	fu	30.912
21	7.14	18.5555142...	32.844	32.844	fu	32.844
22	7.56	19.1956610...	34.776	34.776	fu	34.776
23	7.98	19.7924237...	36.708	36.708	fu	36.708
24	8.4	20.3471189...	38.64	38.64	fu	38.64
25	8.82	20.8610949...	40.572	40.572	fu	40.572
26	9.24	21.3357272...	42.504	42.504	fu	42.504
27	9.66	21.7724155...	44.436	44.436	fu	44.436
28	10.08	22.0147756...	46.368	46.368	fu	46.368
29	10.5	22.2121250	48.3	48.3	fu	48.3

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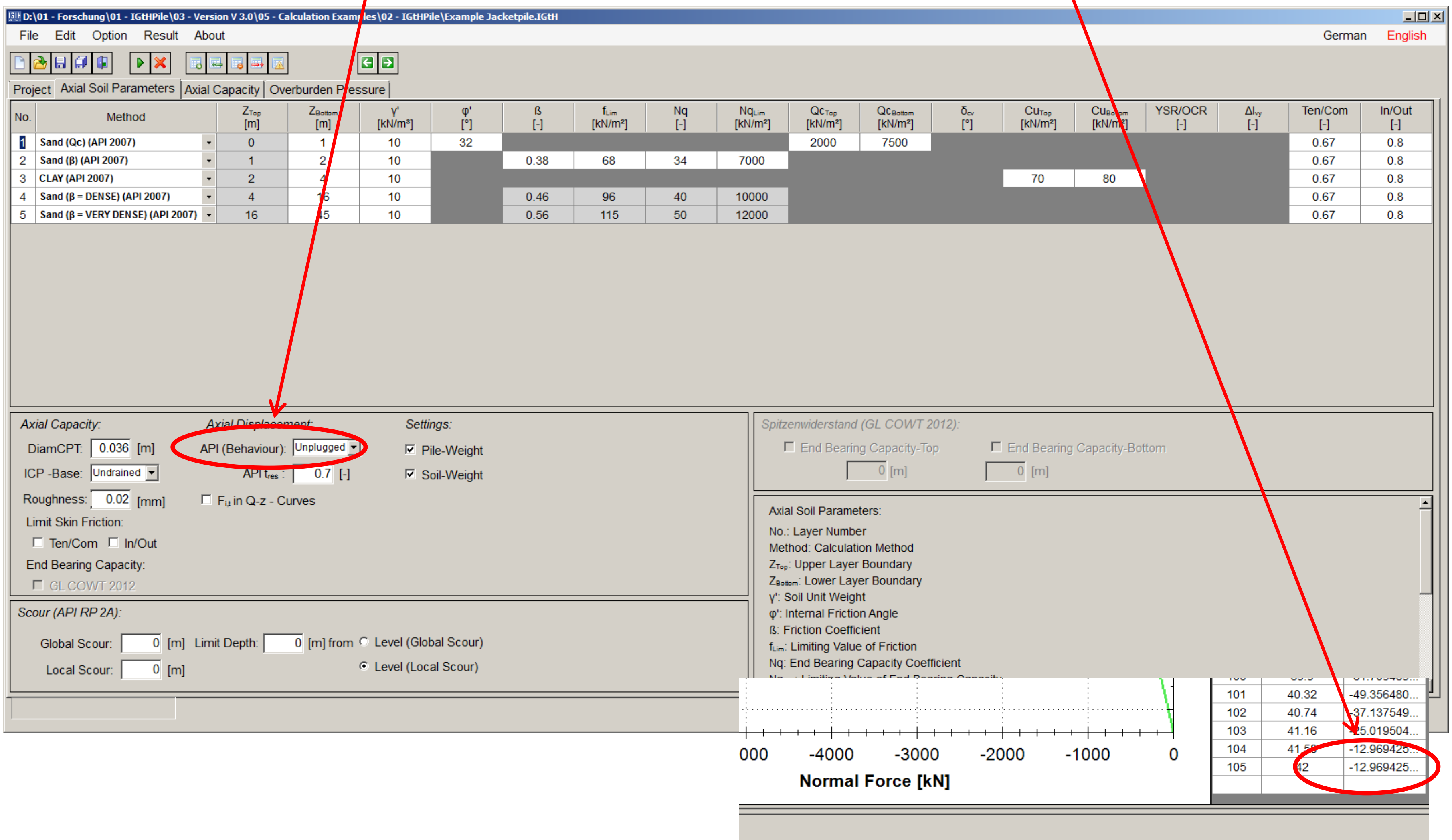
Axially Loaded Piles – Load-Controlled Calculation

Bearing behavior: Unplugged

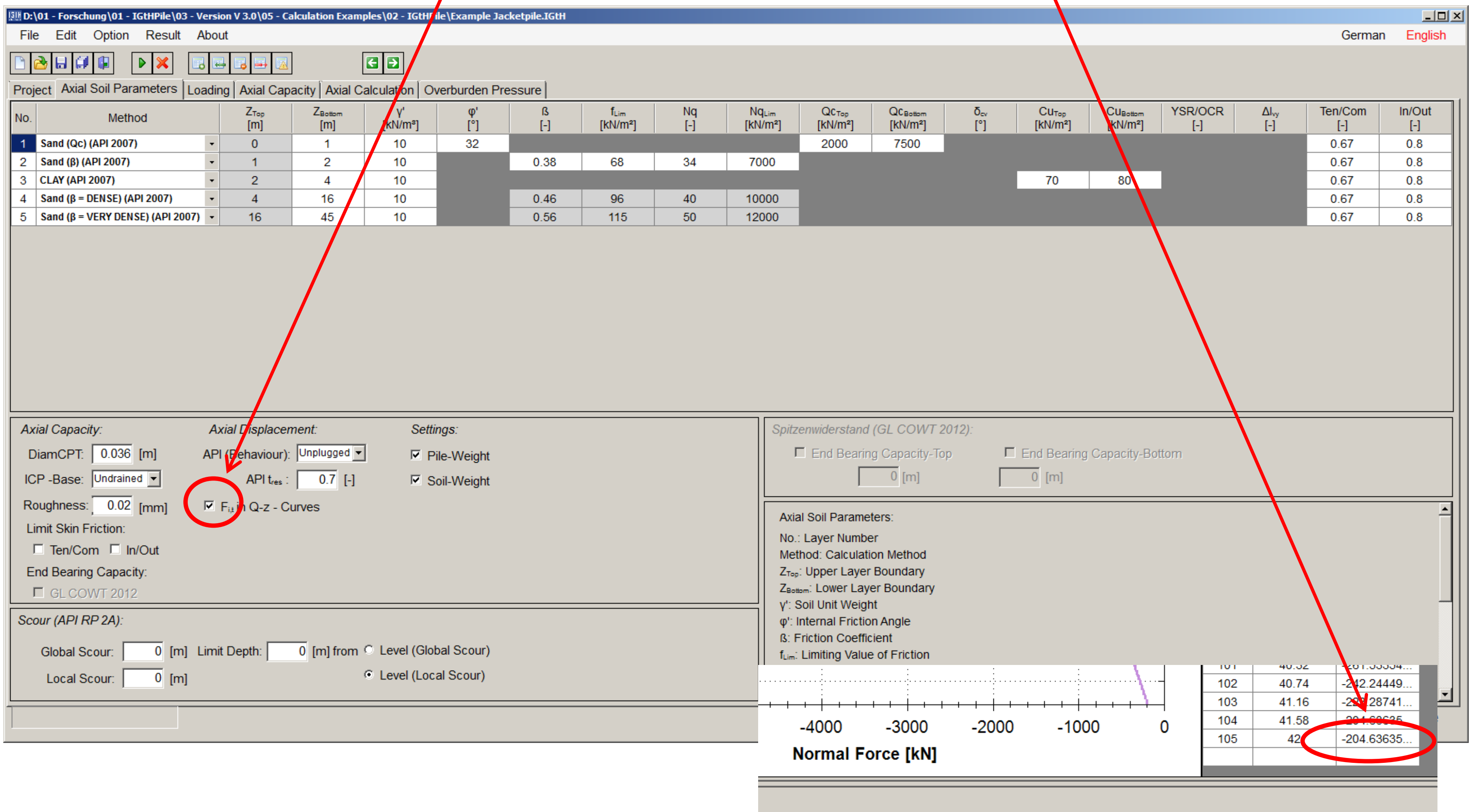
End bearing force



Axially Loaded Piles – Load-Controlled Calculation

The inner skin friction is considered in the Q-z curve and not in the t-z curves

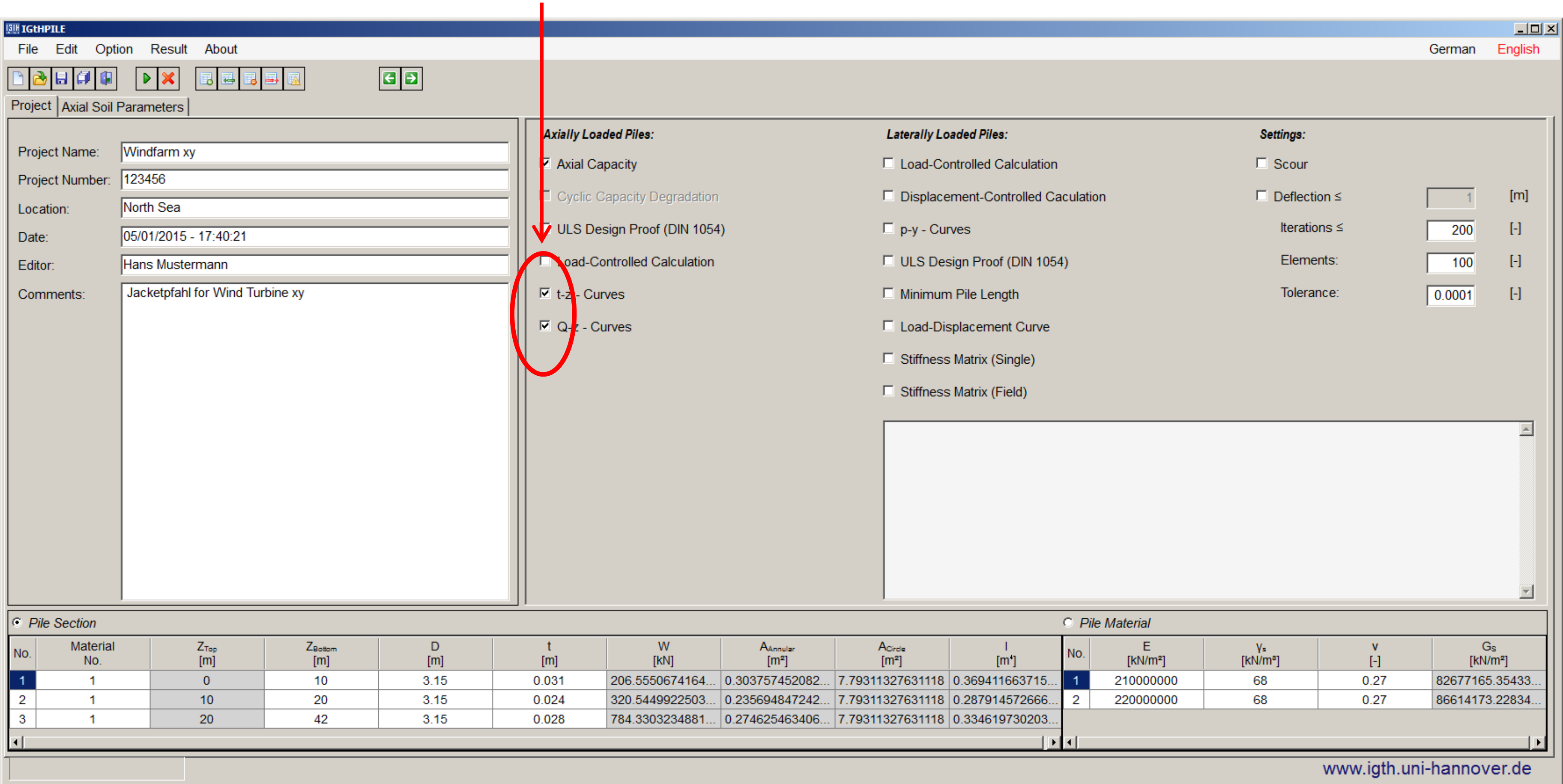
End Bearing Force



No.	Method	Z_{Top} [m]	Z_{Bottom} [m]	γ' [kN/m³]	φ' [°]	ß [-]	f_{Lim} [kN/m²]	Nq [-]	Nq_{Lim} [kN/m²]	Qc_{Top} [kN/m²]	Qc_{Bottom} [kN/m²]	$δ_{cv}$ [°]	Cu_{Top} [kN/m²]	Cu_{Bottom} [kN/m²]	YSR/OCR [-]	$Δl_{vy}$ [-]	Ten/Com [-]	In/Out [-]
1	Sand (Qc) (API 2007)	0	1	10	32					2000	7500						0.67	0.8
2	Sand (β) (API 2007)	1	2	10		0.38	68	34	7000								0.67	0.8
3	CLAY (API 2007)	2	4	10									70	80			0.67	0.8
4	Sand (β = DENSE) (API 2007)	4	16	10		0.46	96	40	10000								0.67	0.8
5	Sand (β = VERY DENSE) (API 2007)	16	45	10		0.56	115	50	12000								0.67	0.8

Axially Loaded Piles – t-z and Q-z Curves

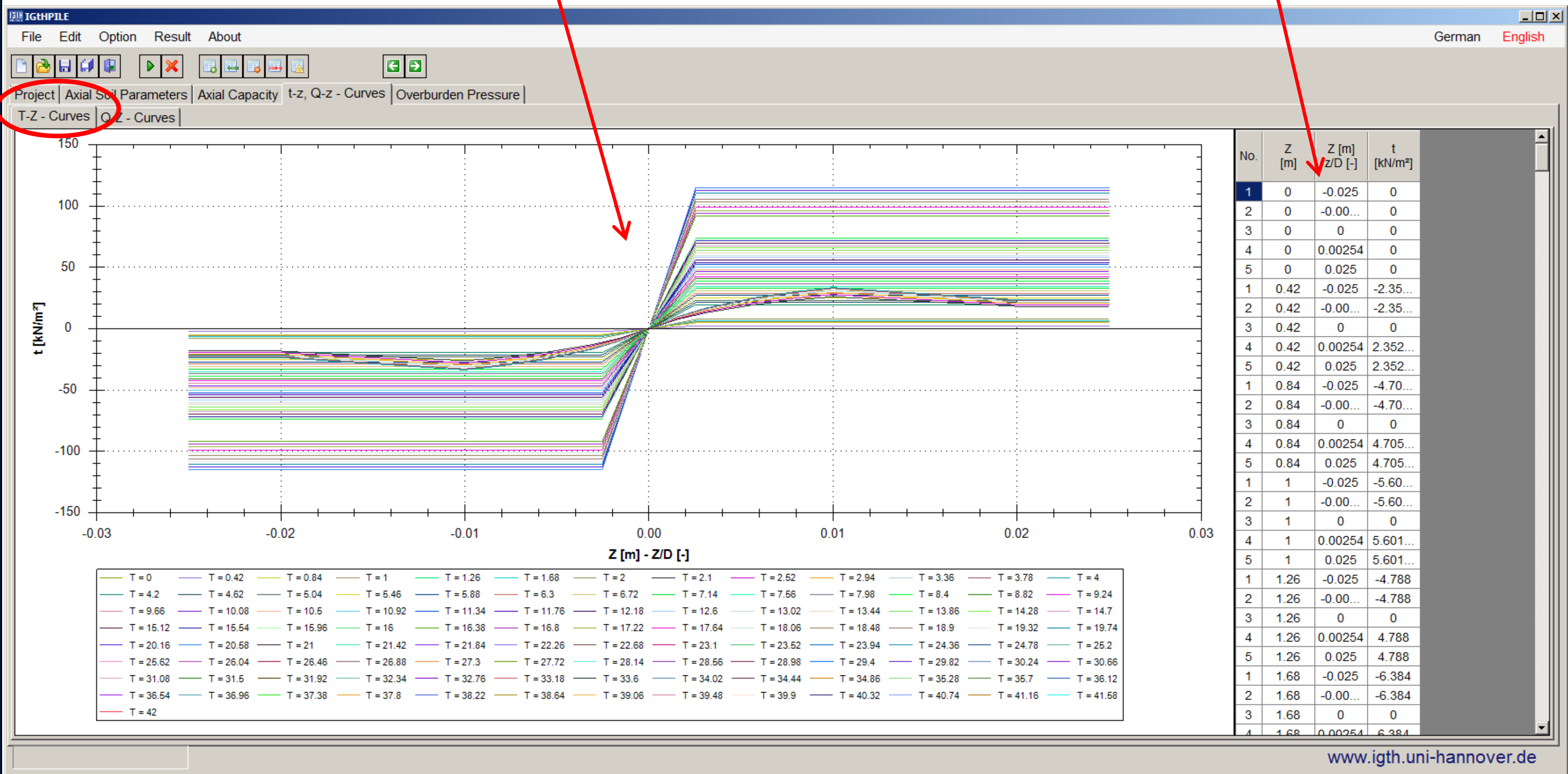
Presentation of t-z and Q-z curves



Axially Loaded Piles – t-z and Q-z Curves

Graphical presentation of t-z curves

Data of t-z curves displayed in vertical list



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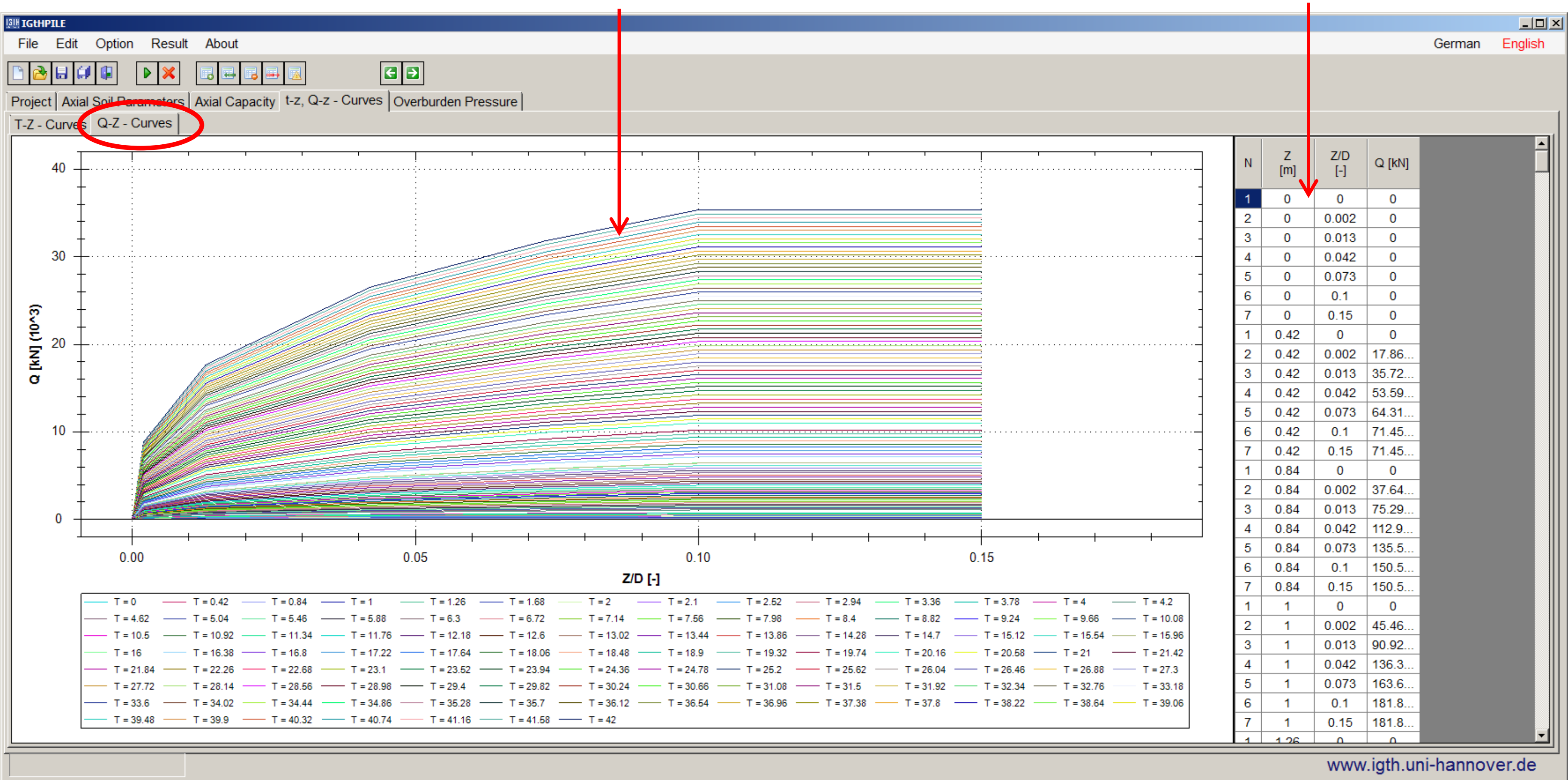
Axially Loaded Piles – t-z and Q-z Curves

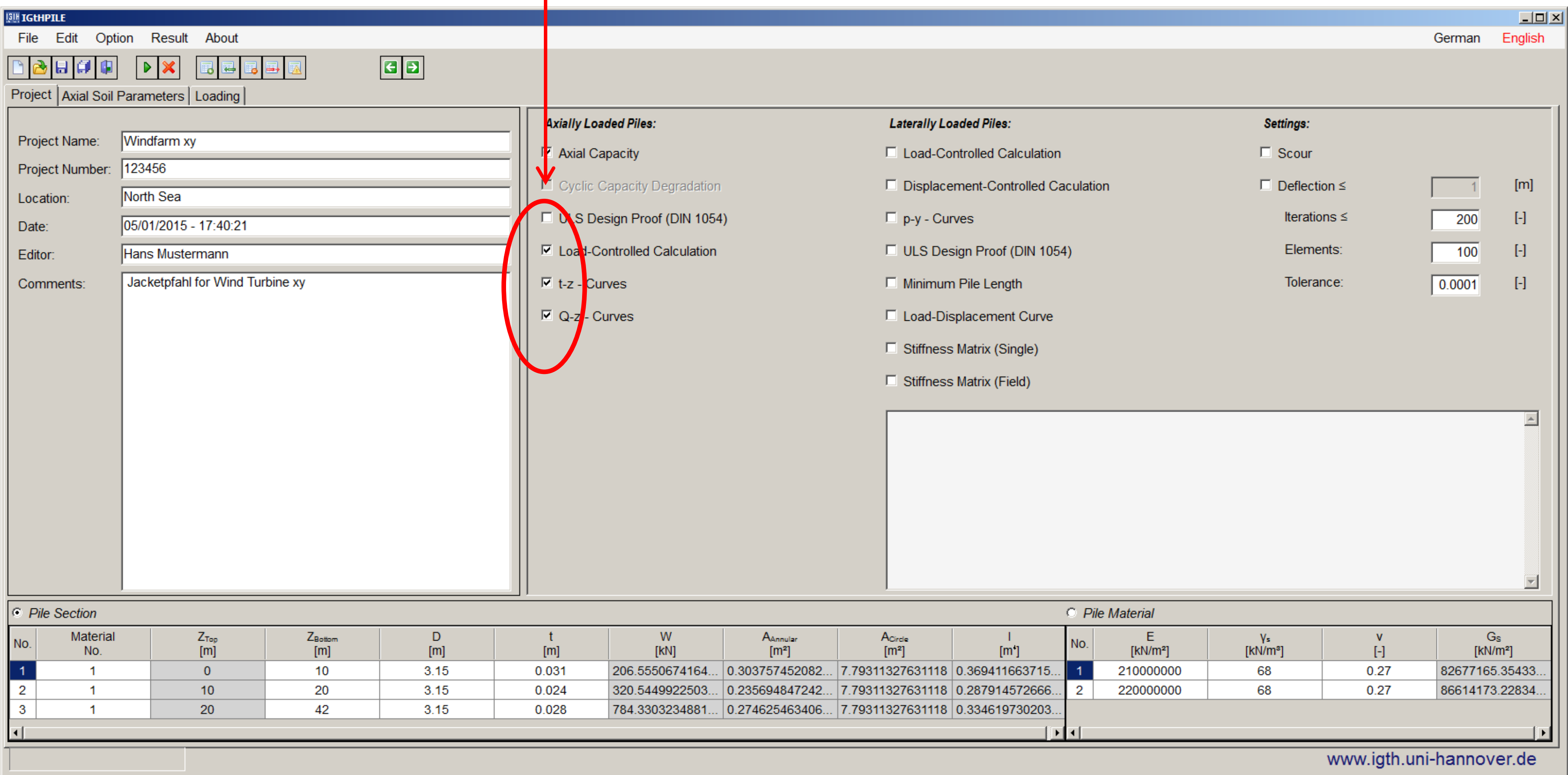
Graphical presentation of Q-z curves

Data of Q-z curves displayed in vertical list



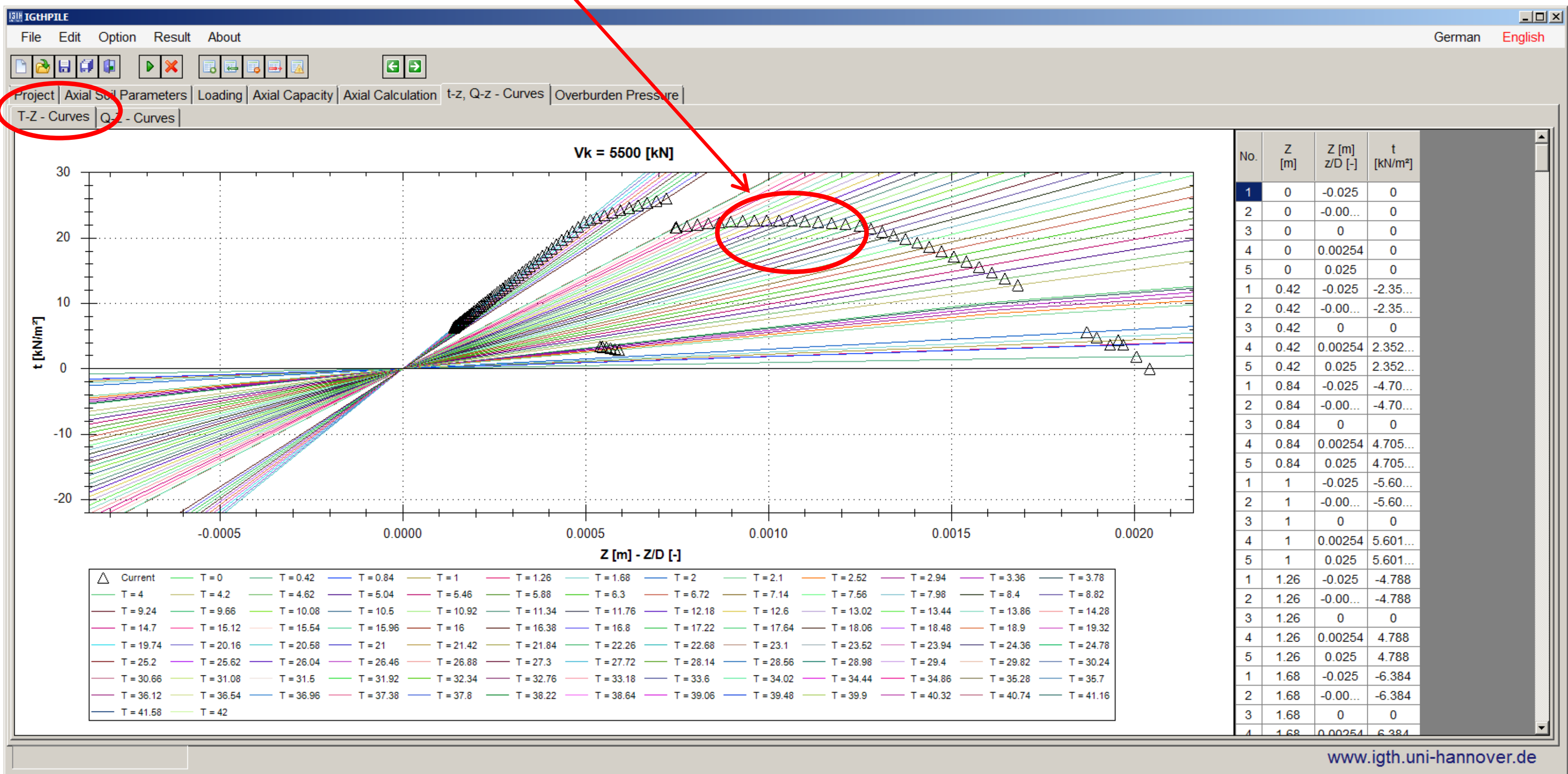
Axially Loaded Piles – t-z and Q-z Curves

Presentation of t-z and Q-z curves with
t-z and Q-z values for applied loading



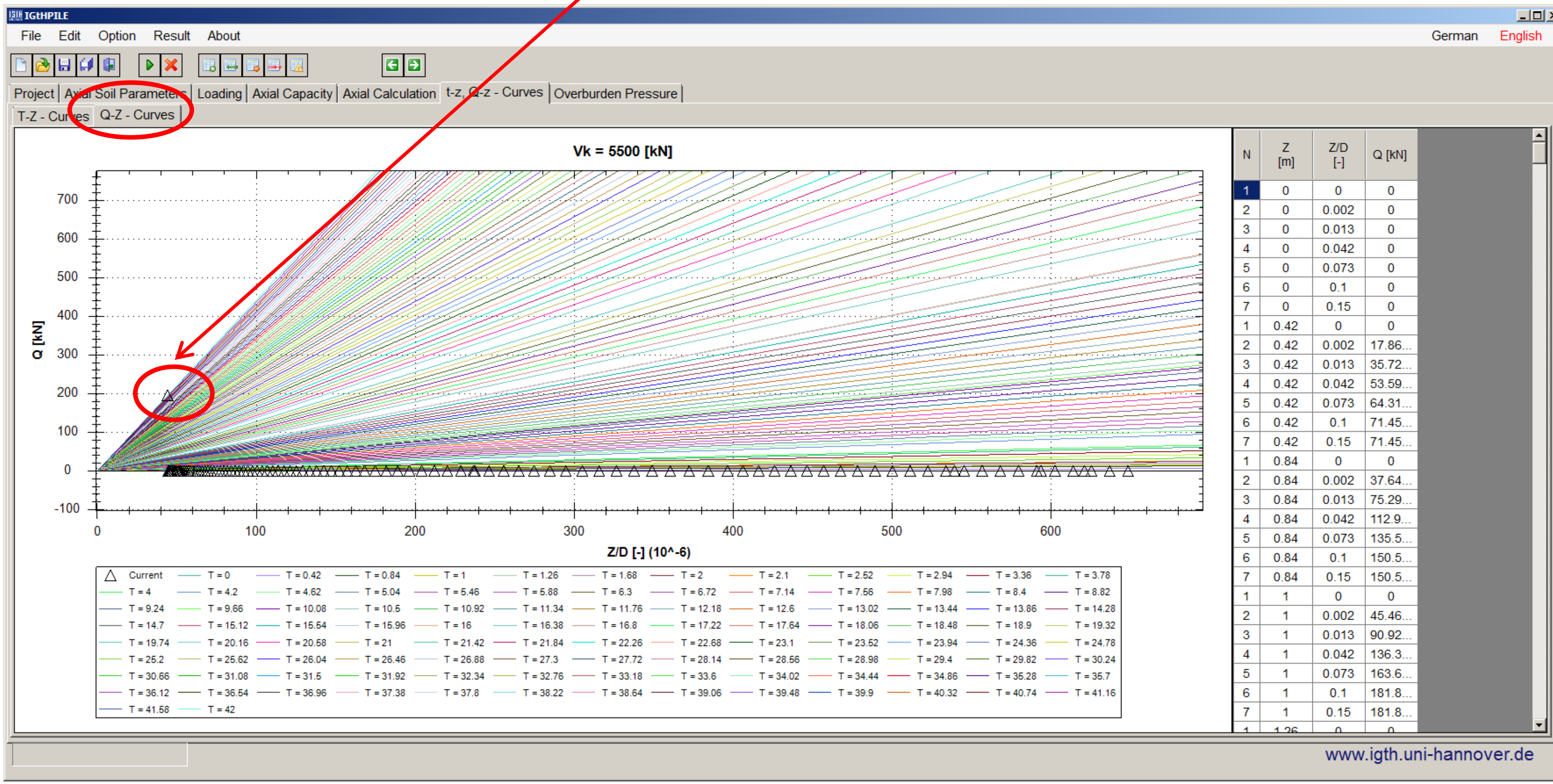
Axially Loaded Piles – t-z and Q-z Curves

t-z values for applied loading



Axially Loaded Piles – t-z and Q-z Curves

Q-z value for applied loading

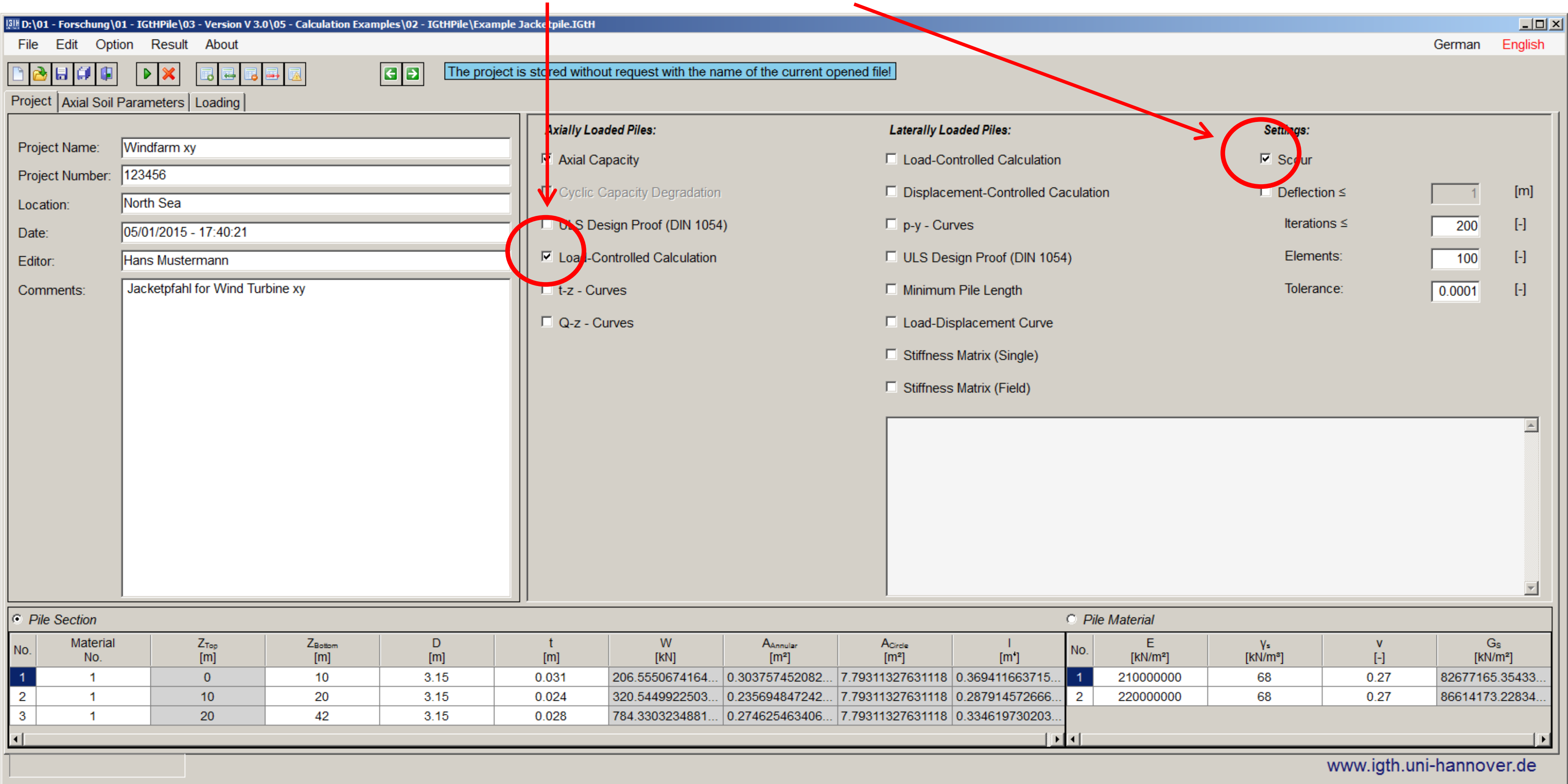


Axially Loaded Piles – Scour

Note: The scour function is available for all calculation types

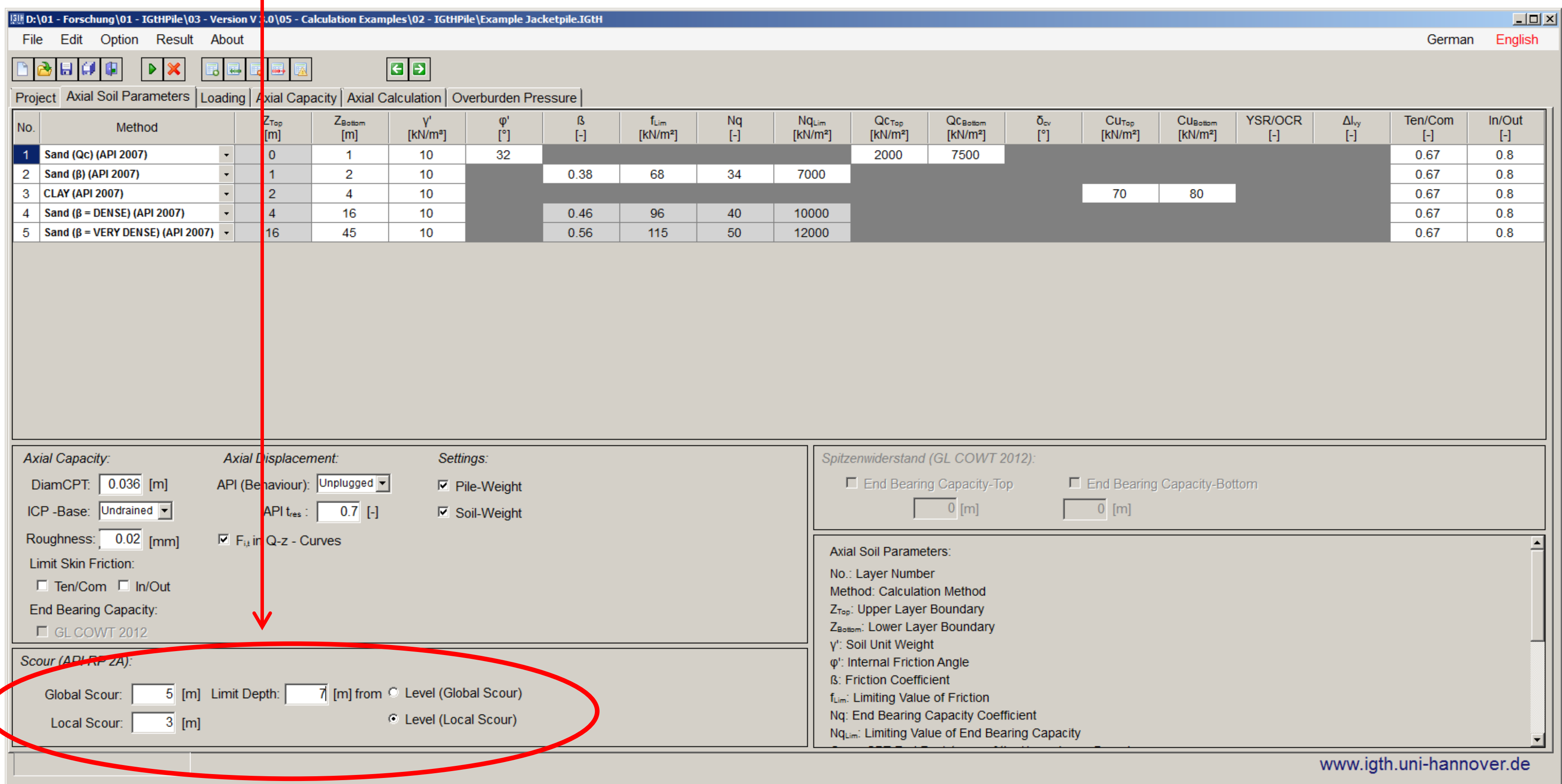
Choose calculation type

Scour



Axially Loaded Piles – Scour

Define scour and limit depth for
effect on effective stresses



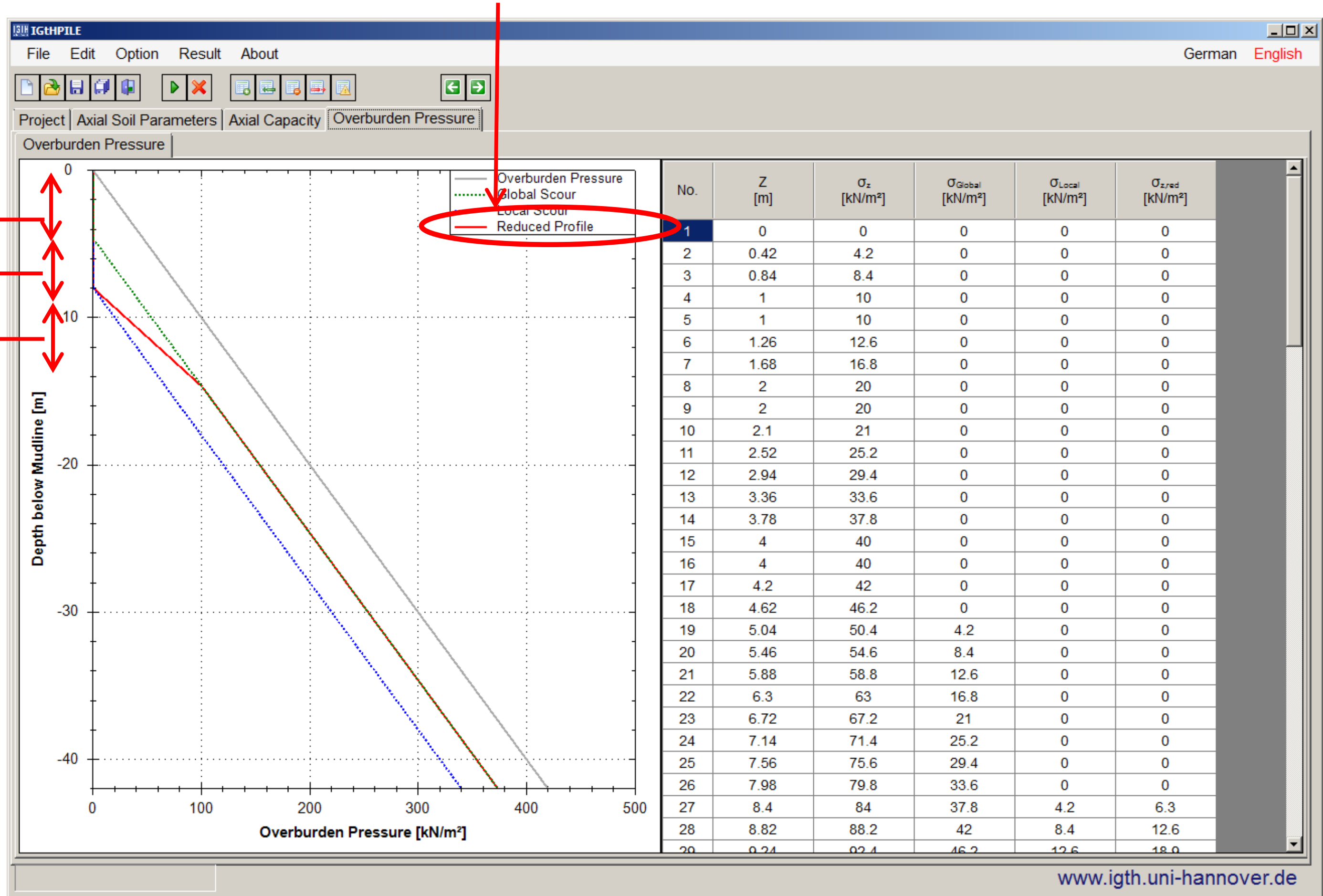
Axially Loaded Piles – Scour

Overburden pressure
considered in calculations

Global scour

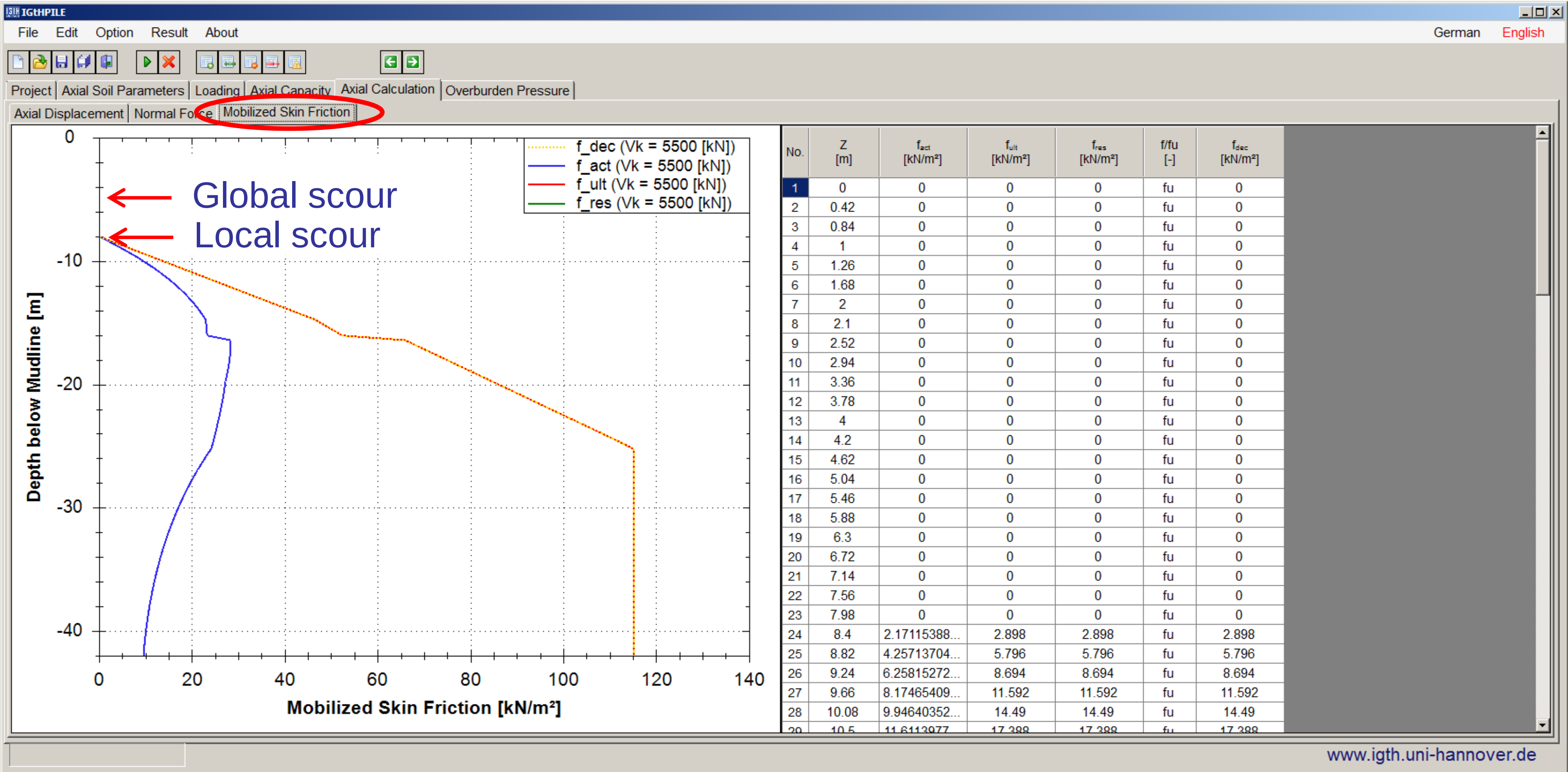
Local scour

Linear transition
(limit depth)



No.	Z [m]	σ_z [kN/m²]	σ_{Global} [kN/m²]	σ_{Local} [kN/m²]	$\sigma_{z,red}$ [kN/m²]
1	0	0	0	0	0
2	0.42	4.2	0	0	0
3	0.84	8.4	0	0	0
4	1	10	0	0	0
5	1	10	0	0	0
6	1.26	12.6	0	0	0
7	1.68	16.8	0	0	0
8	2	20	0	0	0
9	2	20	0	0	0
10	2.1	21	0	0	0
11	2.52	25.2	0	0	0
12	2.94	29.4	0	0	0
13	3.36	33.6	0	0	0
14	3.78	37.8	0	0	0
15	4	40	0	0	0
16	4	40	0	0	0
17	4.2	42	0	0	0
18	4.62	46.2	0	0	0
19	5.04	50.4	4.2	0	0
20	5.46	54.6	8.4	0	0
21	5.88	58.8	12.6	0	0
22	6.3	63	16.8	0	0
23	6.72	67.2	21	0	0
24	7.14	71.4	25.2	0	0
25	7.56	75.6	29.4	0	0
26	7.98	79.8	33.6	0	0
27	8.4	84	37.8	4.2	6.3
28	8.82	88.2	42	8.4	12.6

Axially Loaded Piles – Scour



No.	Z [m]	f_{act} [kN/m²]	f_{ult} [kN/m²]	f_{res} [kN/m²]	f/fu [-]	f_{dec} [kN/m²]
1	0	0	0	0	fu	0
2	0.42	0	0	0	fu	0
3	0.84	0	0	0	fu	0
4	1	0	0	0	fu	0
5	1.26	0	0	0	fu	0
6	1.68	0	0	0	fu	0
7	2	0	0	0	fu	0
8	2.1	0	0	0	fu	0
9	2.52	0	0	0	fu	0
10	2.94	0	0	0	fu	0
11	3.36	0	0	0	fu	0
12	3.78	0	0	0	fu	0
13	4	0	0	0	fu	0
14	4.2	0	0	0	fu	0
15	4.62	0	0	0	fu	0
16	5.04	0	0	0	fu	0
17	5.46	0	0	0	fu	0
18	5.88	0	0	0	fu	0
19	6.3	0	0	0	fu	0
20	6.72	0	0	0	fu	0
21	7.14	0	0	0	fu	0
22	7.56	0	0	0	fu	0
23	7.98	0	0	0	fu	0
24	8.4	2.17115388...	2.898	2.898	fu	2.898
25	8.82	4.25713704...	5.796	5.796	fu	5.796
26	9.24	6.25815272...	8.694	8.694	fu	8.694
27	9.66	8.17465409...	11.592	11.592	fu	11.592
28	10.08	9.94640352...	14.49	14.49	fu	14.49
29	10.5	11.6113977	17.388	17.388	fu	17.388

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