DeepEX - Finite Element Analysis Verification
Comparison with Other Software and Case History

Deep Excavation LLC
Software program: DeepEX 2020
Document version: 1.0
June 26, 2020
www.deepexcavation.com
www.deepex.com

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Introduction

The purpose of this document is to perform a verification of the DeepEX Finite Element Analysis engine, DeepFEM.

The document presents a series of deep excavation models, simulated and analyzed with DeepEX – Shoring Design Software and with Plaxis 2D – Introductory version. The cases below include the soil properties and the analysis assumptions, the generated models in DeepEX (all construction stages) and images with the calculated results in both software programs.

The following cases are examined in this document:
Case 1: Cantilever Retaining Wall (Mohr-Coulomb Constitutive Law Verification)
Case 2: Retaining Wall with Struts (Mohr-Coulomb Constitutive Law Verification)
Case 3: Embedded Pile Row Reinforcing Slope (Mohr-Coulomb Constitutive Law Verification)
Case 4: Triaxial Test Verification (Mohr-Coulomb and Soil Hardening Model)
Case 5: Anchored Retaining Wall in Berlin Sand (Case History – Measured Results Verification)

Case 1: Cantilever Retaining Wall

This case simulates a 3m cantilever excavation, supported by an AZ 26 sheet pile wall.
The soil properties of the elastic-perfectly plastic model (Mohr coulomb constitutive law) used in the case 1 comparison are: Friction Angle ϕ= 30°, Dilatancy Angle ψ= 5°, Cohesion c= 2 Kpa and Young Modulus E= 15000 Kpa. The reduction factor for the zero-thickness interface of the wall is R=0.8 and the stiffness of the wall is EI= 111.1E3 Kpa*m^4. Figure 1 presents the model in each construction stage.

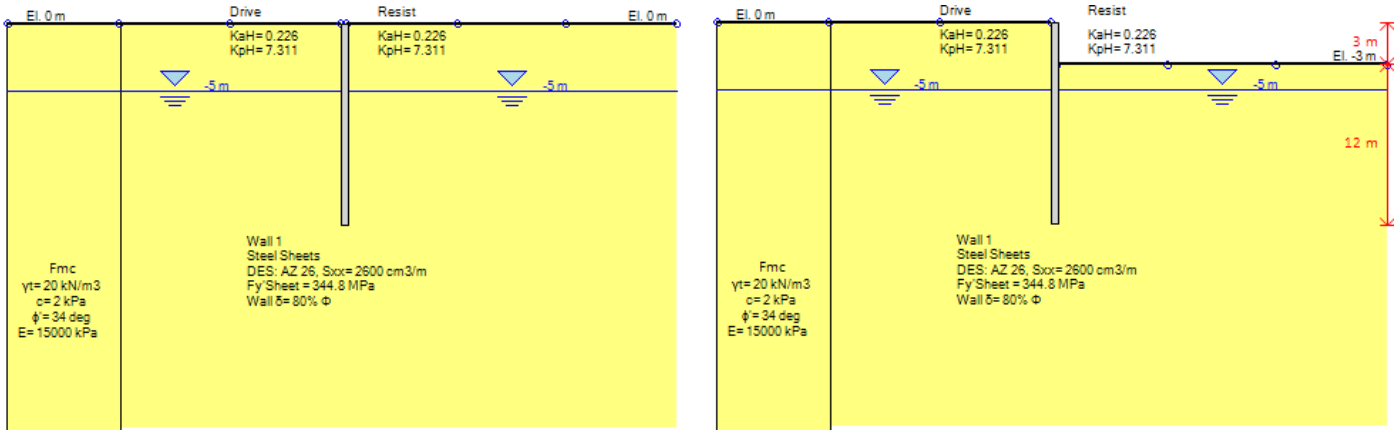


Figure 1: Construction Stages (Case 1)

Figure 2 presents the displacement of the retaining wall, as well as, the moment and shear force diagrams for both programs.

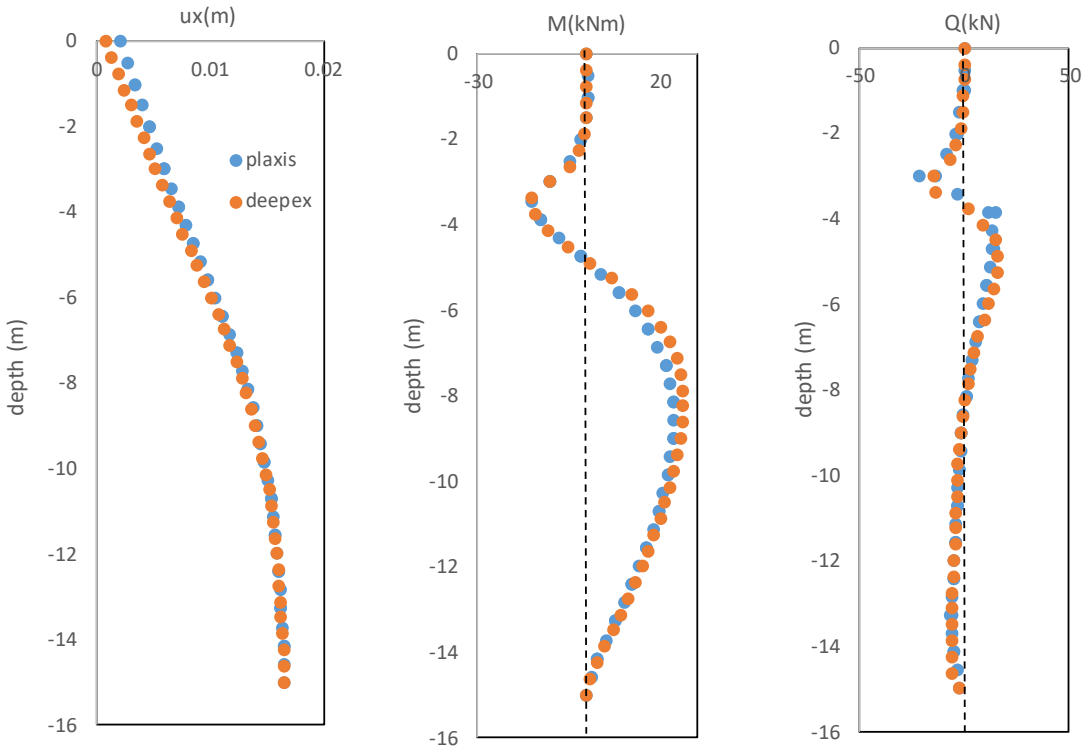


Figure 2: Comparison of the Retaining Wall a) Displacement b) Moment c) Shear Force

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 3 presents the displacement distribution within the simulated soil medium for both programs.

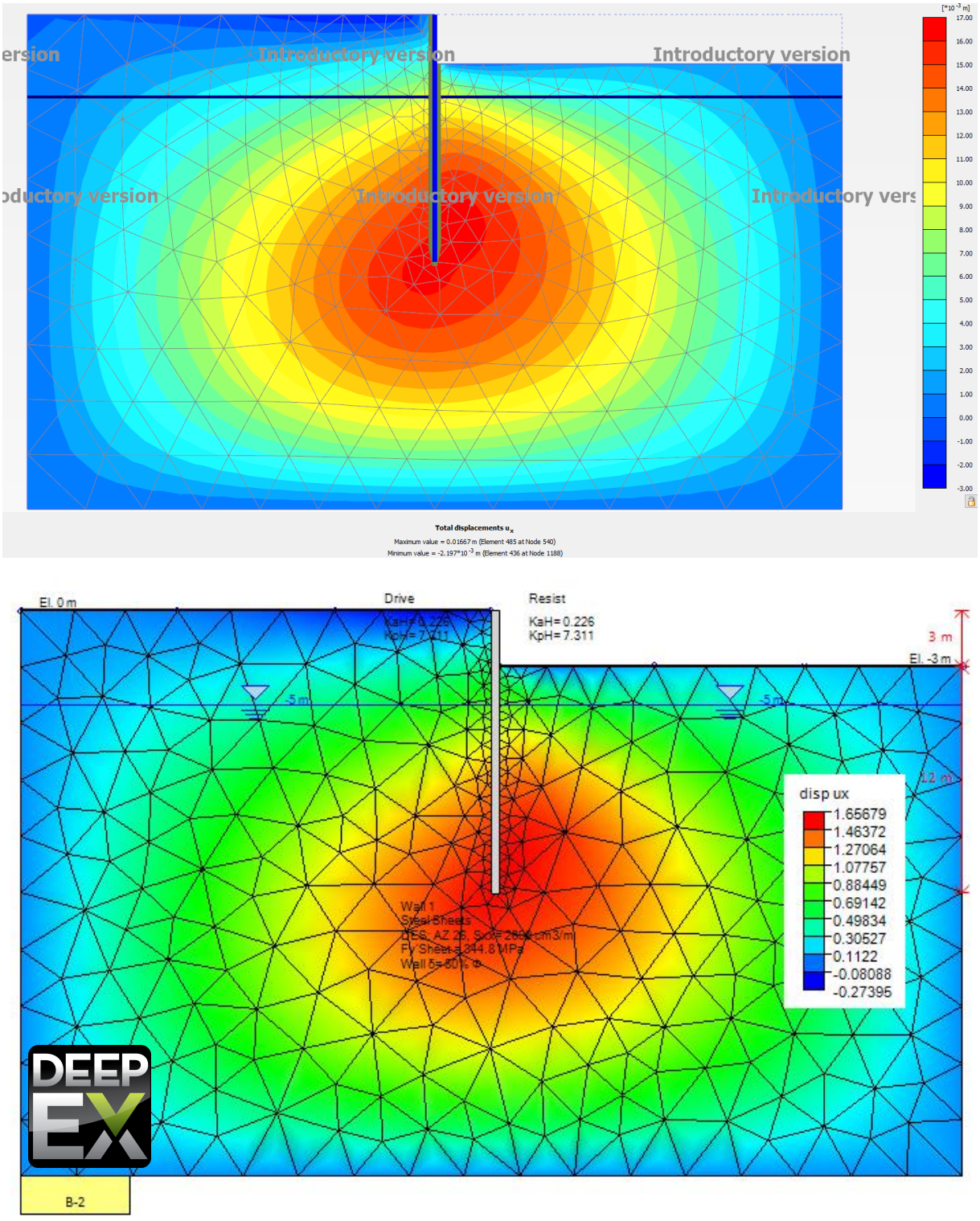
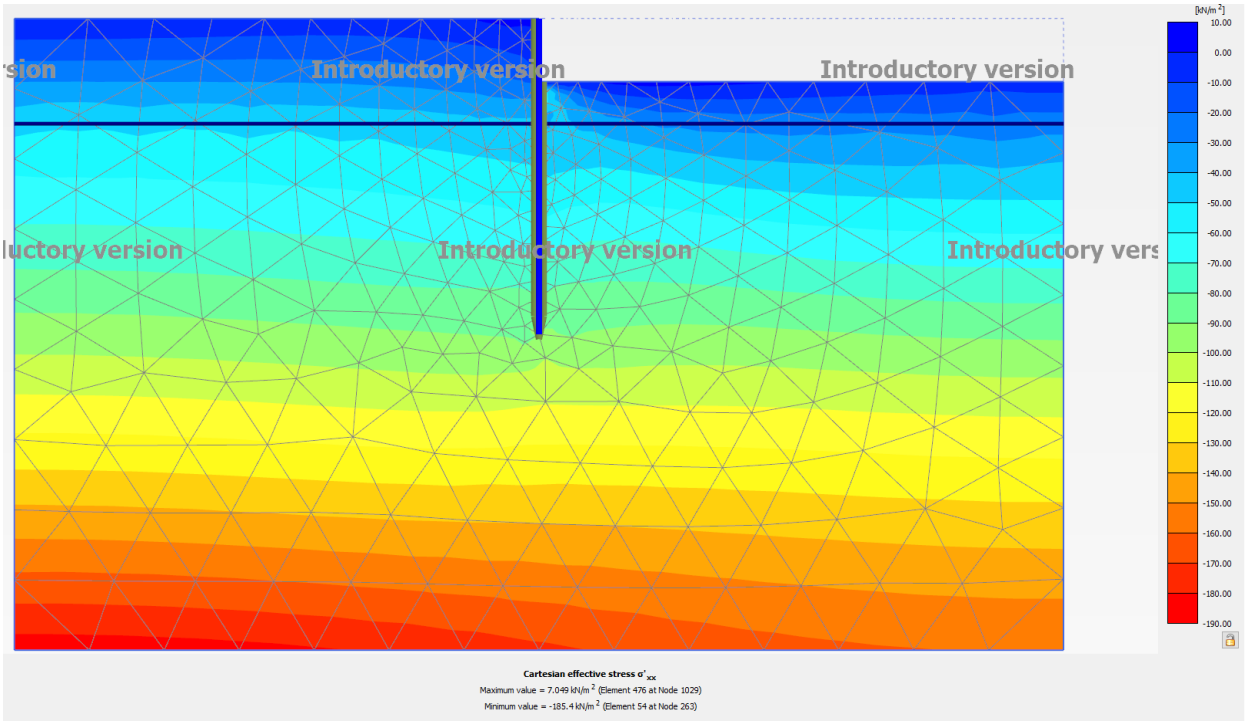


Figure 3: Comparison of Soil Horizontal Displacement a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 4 presents the effective horizontal stress distribution within the simulated soil medium for both programs.



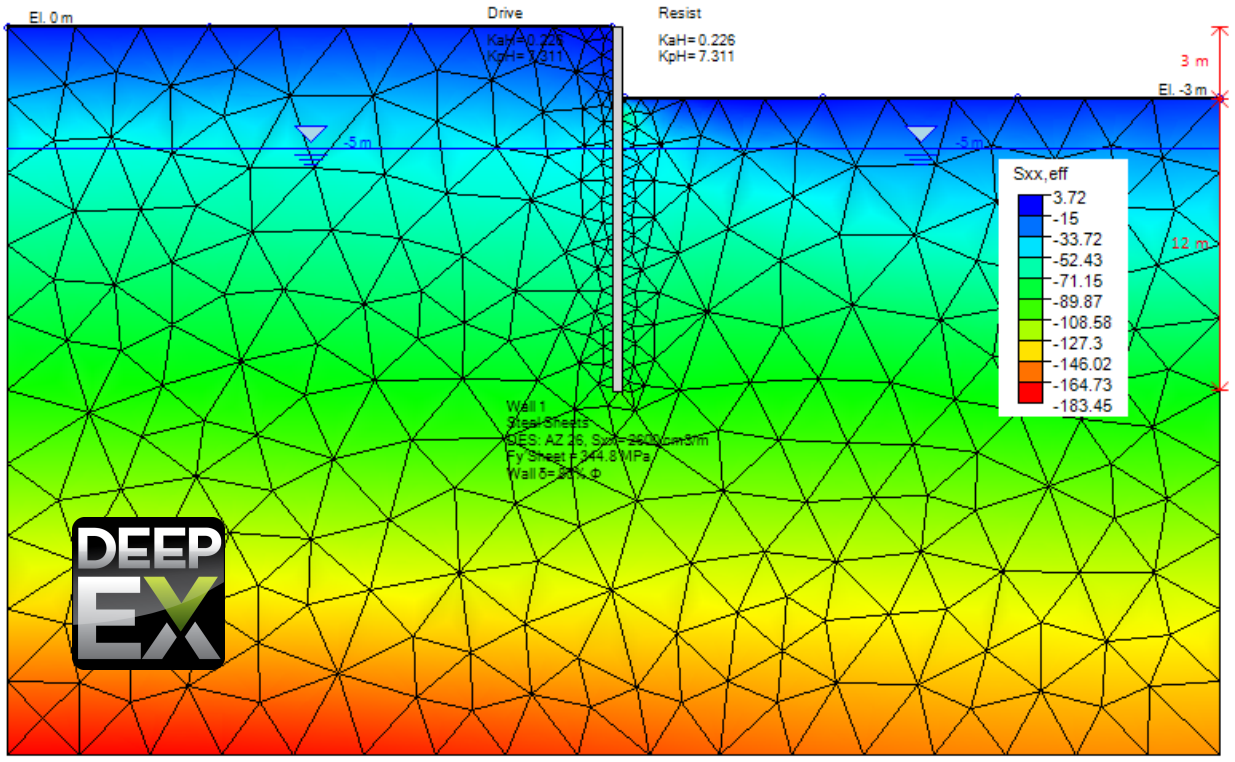


Figure 4: Comparison of Soil Effective Horizontal Stress a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Case 2: Retaining Wall with Struts

This case simulates a braced sheet pile wall (AZ 26 piles, braced with struts – simulated with a spring support), supporting an 8 m excavation.
The soil properties of the elastic-perfectly plastic model (Mohr-Coulomb constitutive law) used in the case 2 comparison are: Friction Angle ϕ=30°, Dilatancy Angle ψ=5°, Cohesion c=2 Kpa and Young Modulus E= 15000 Kpa. The reduction factor for the zero-thickness interface of the wall is R=0.8 and the stiffness of the wall is EI= 111.1E3 Kpa*m^4. The strut stiffness is equal to EA= 6.003E6 and spacing L= 1m. Figure 5 presents the model in the last construction stage.

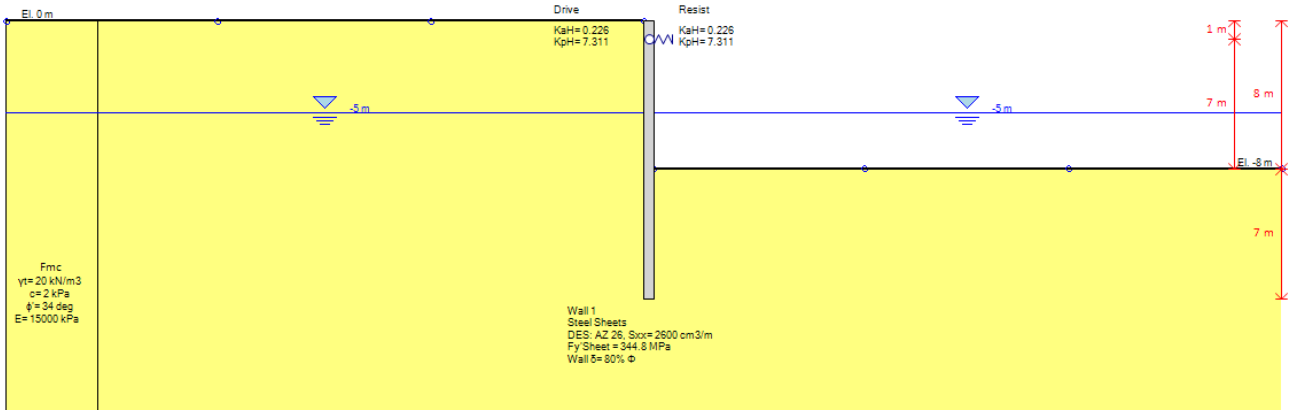


Figure 5: Last Construction Stage (Case 2)

Figure 6 presents the displacement of the retaining wall, as well as, the moment and shear force diagrams for both programs.

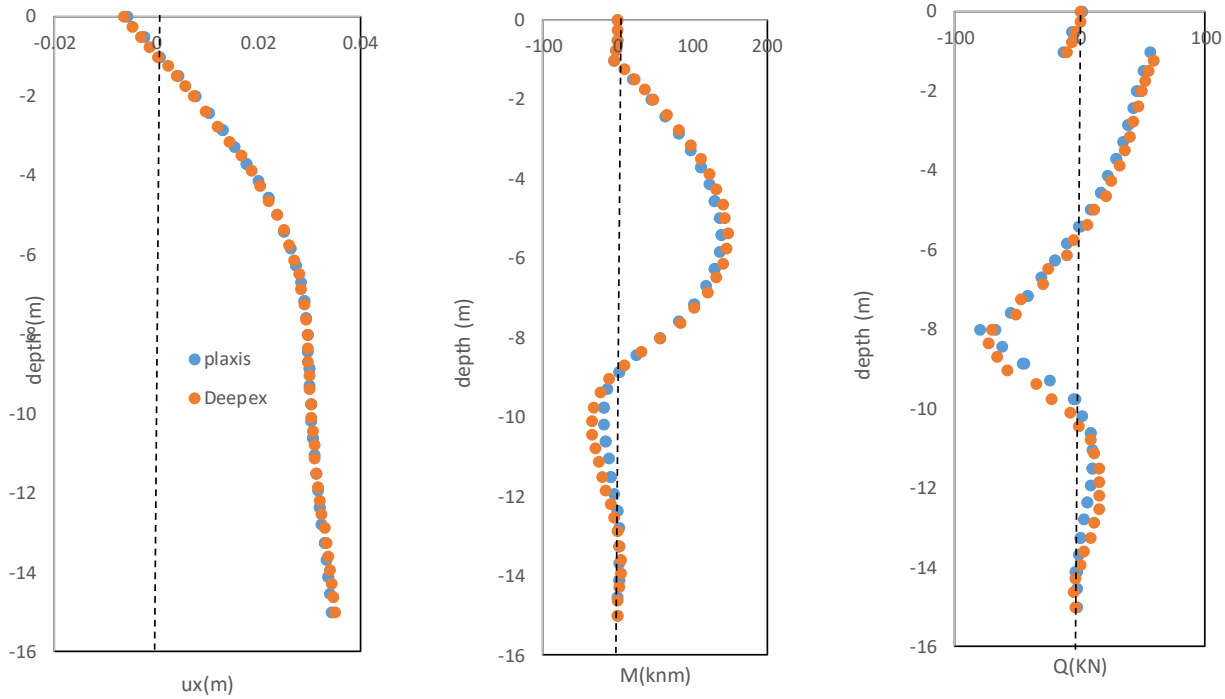


Figure 6: Comparison of the Retaining Wall a) Displacement b) Moment c) Shear Force

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 7 presents the displacement distribution within the simulated soil medium for both programs.

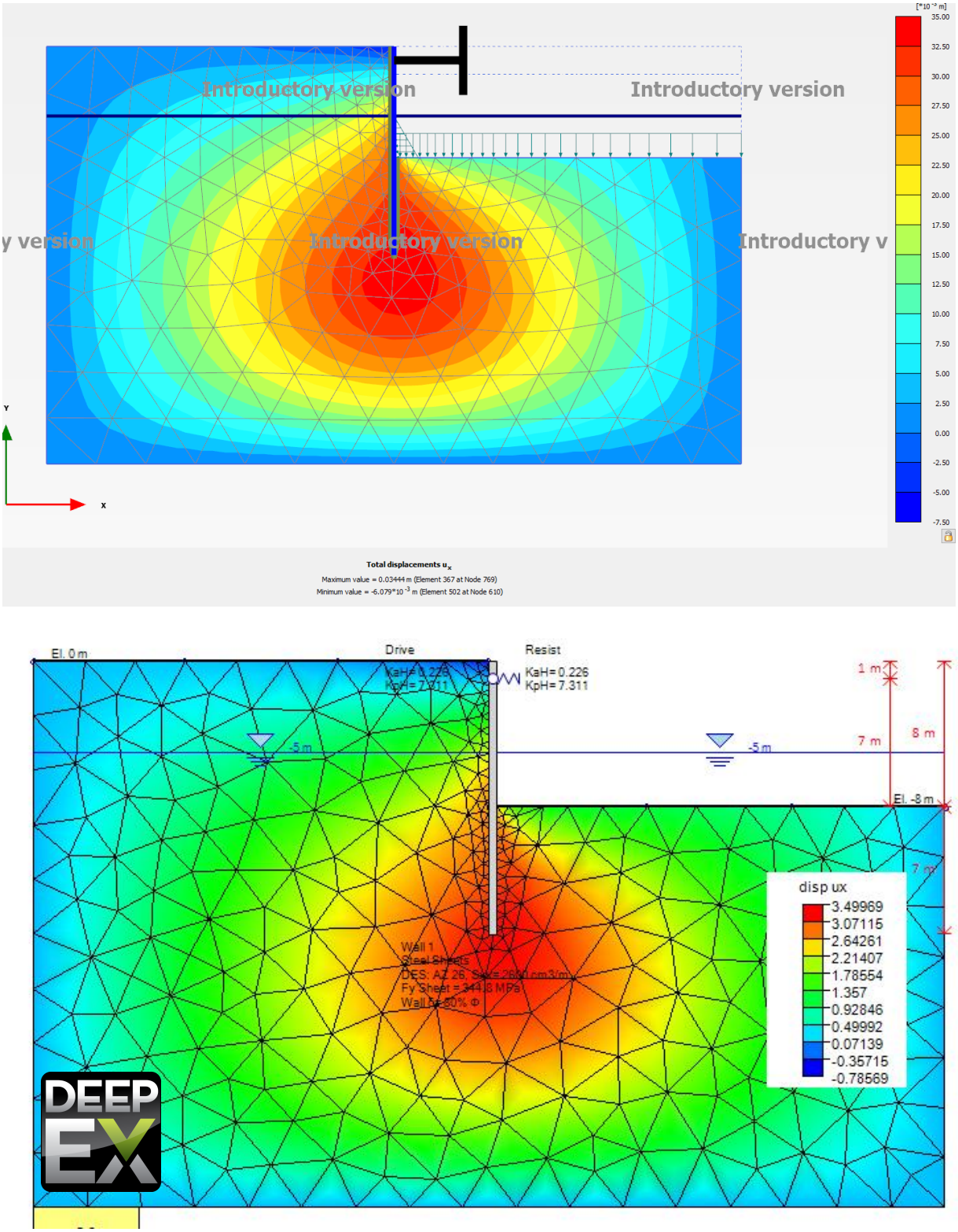


Figure 7: Comparison of Soil Horizontal Displacement a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 8 presents the effective horizontal stress distribution within the simulated soil medium for both programs.

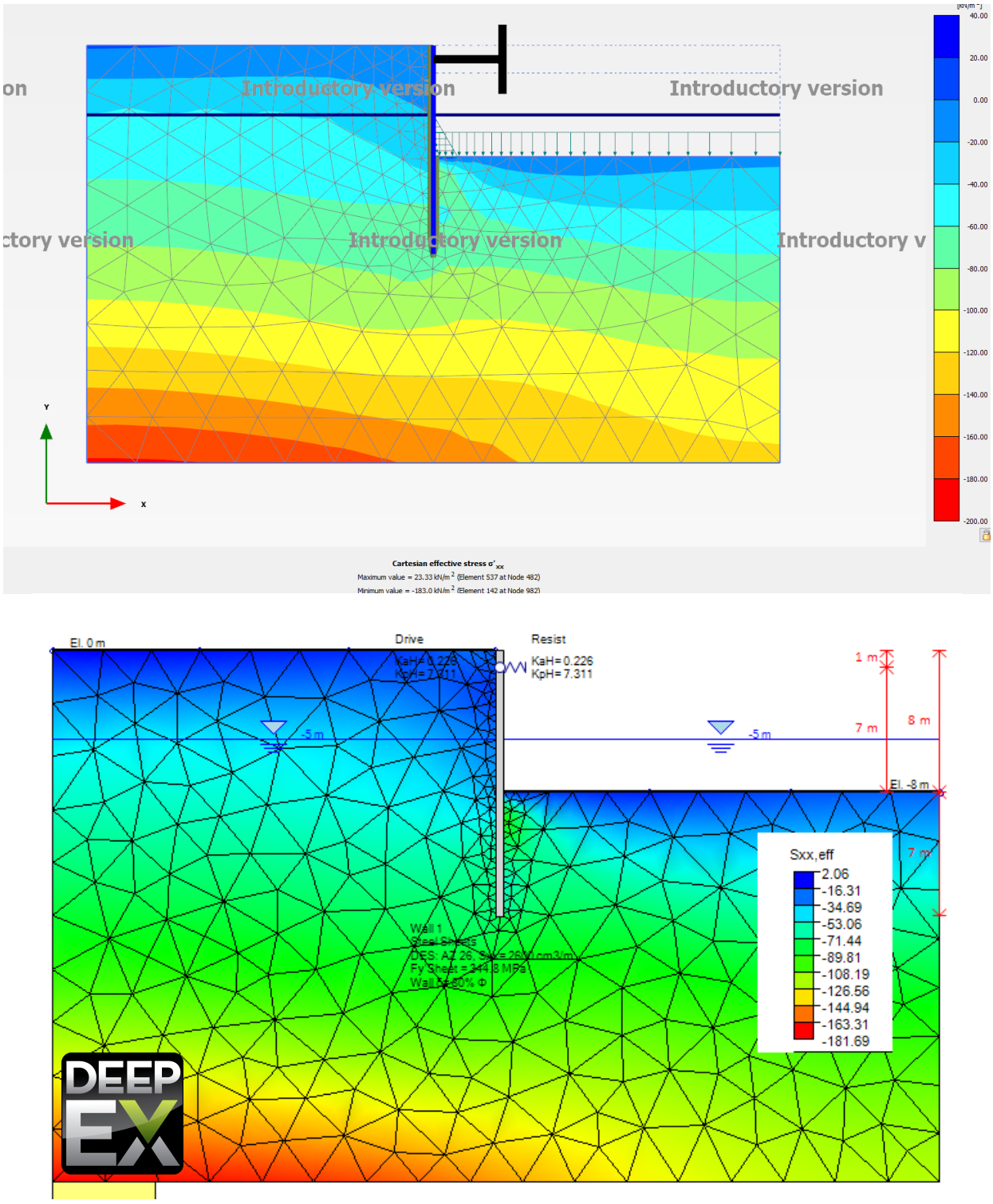


Figure 8: Comparison of Soil Effective Horizontal Stress a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Case 3: Embedded Pile Row Reinforcing Slope

This case examines the effect of a foundation pile row on a slope surface.

The soil properties of the elastic-perfectly plastic model (Mohr-Coulomb constitutive law) used in case 3 are: Friction Angle ϕ= 36°, Dilatancy Angle ψ= 5°, Cohesion c= 10 Kpa and Young Modulus E= 15000 Kpa. On the initial stage water table is at z= -5m. On the 2nd stage an embedded pile row of circular section D= 0.5m, $L_{spacing}$=1m and E= 29000Mpa are installed. On the 3rd stage the water table is considered to be elevated to the slope surface.

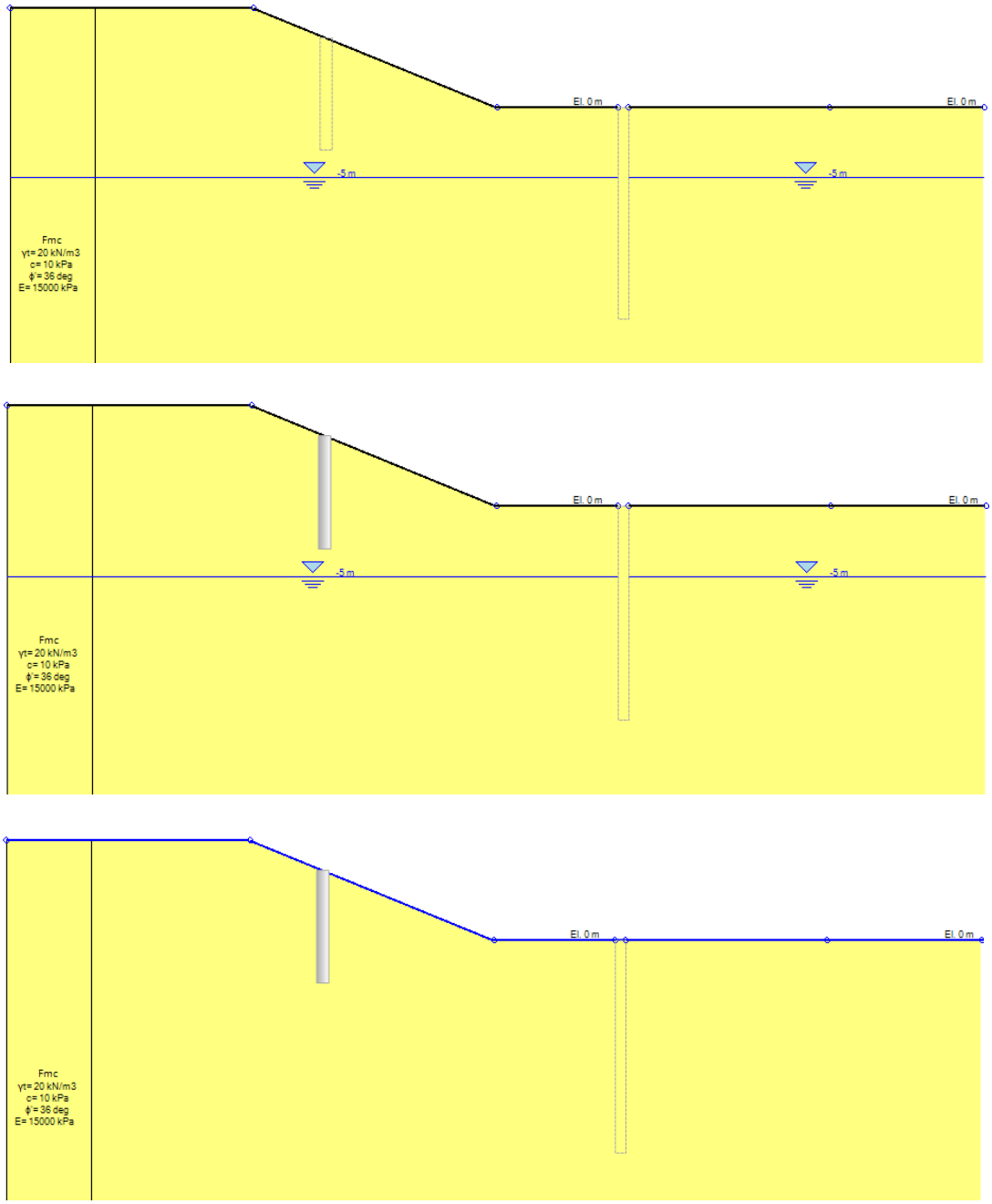


Figure 9: Construction Stages (Case 3)

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 10 presents the displacement of the retaining wall, as well as, the moment and shear force diagrams for both programs.

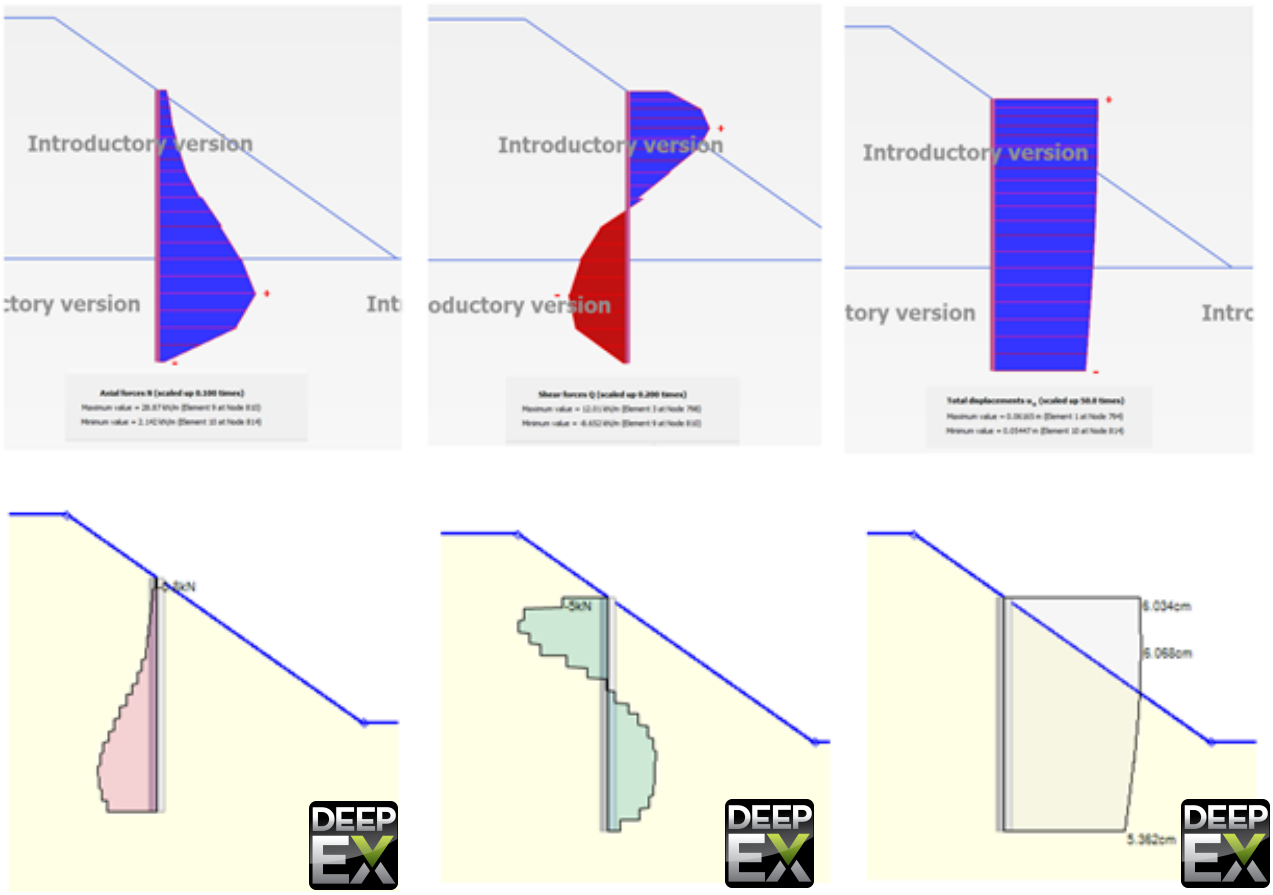
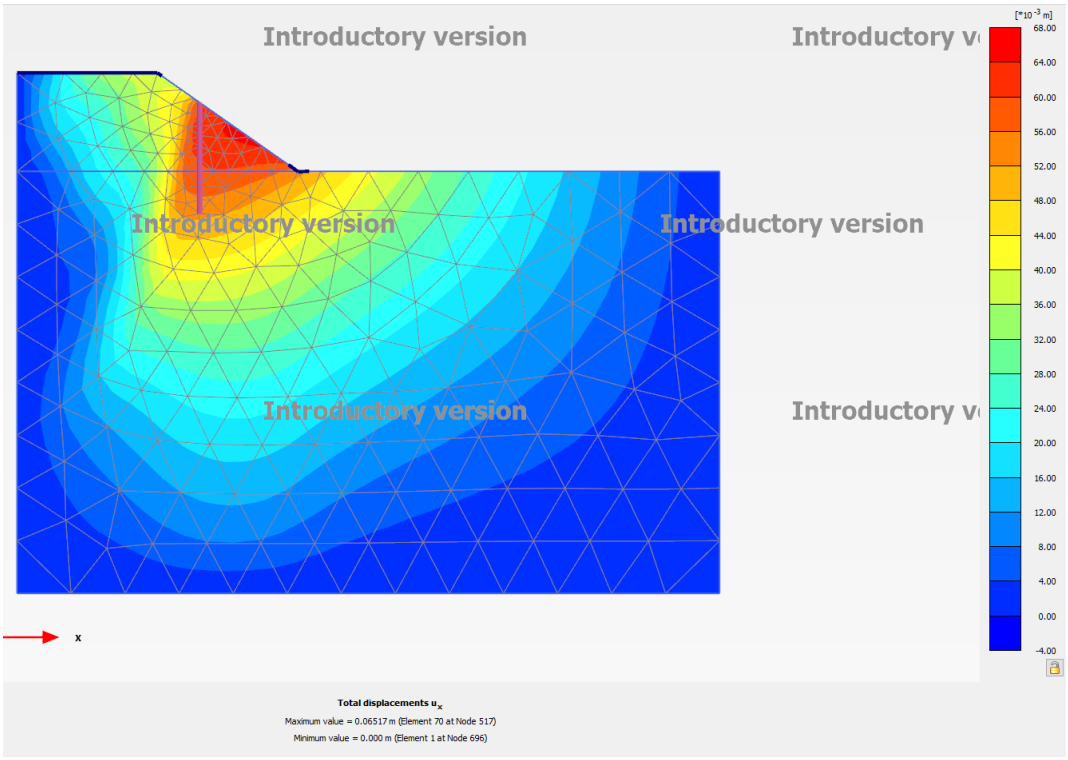


Figure 10: Comparison of the Embedded Wall a) Axial force , b) Shear force and c) Displacement

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 11 presents the displacement distribution within the simulated soil medium for both programs.



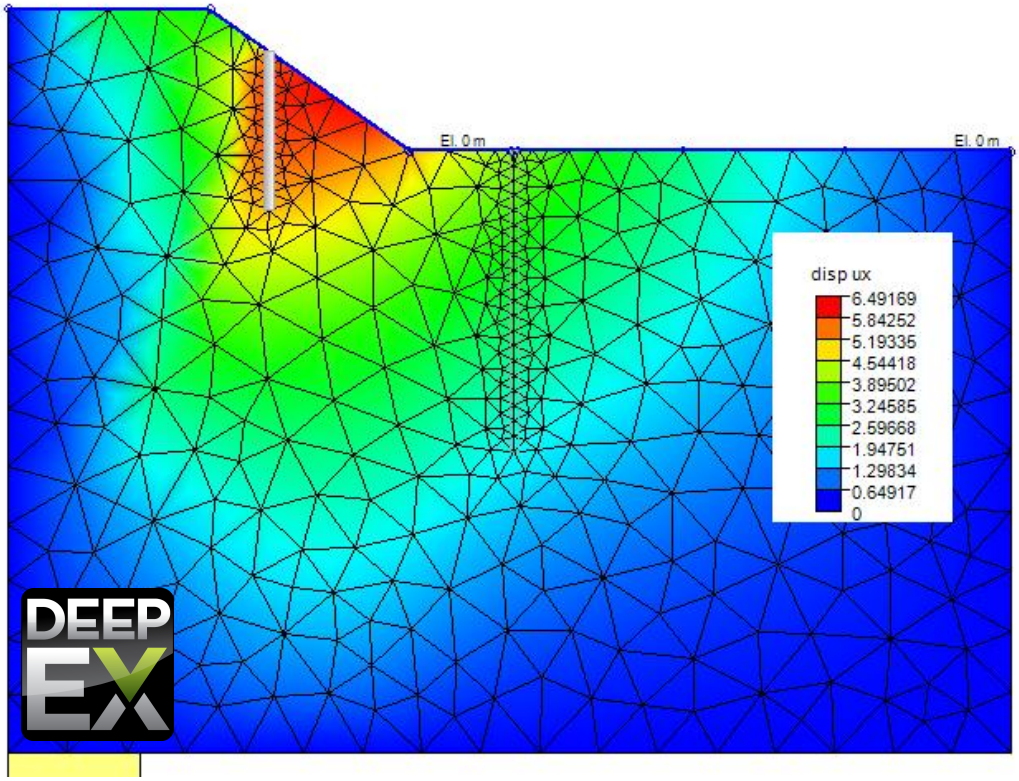


Figure 11: Comparison of Soil Horizontal Displacement a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Figure 12 presents the effective horizontal stress distribution within the simulated soil medium for both programs.

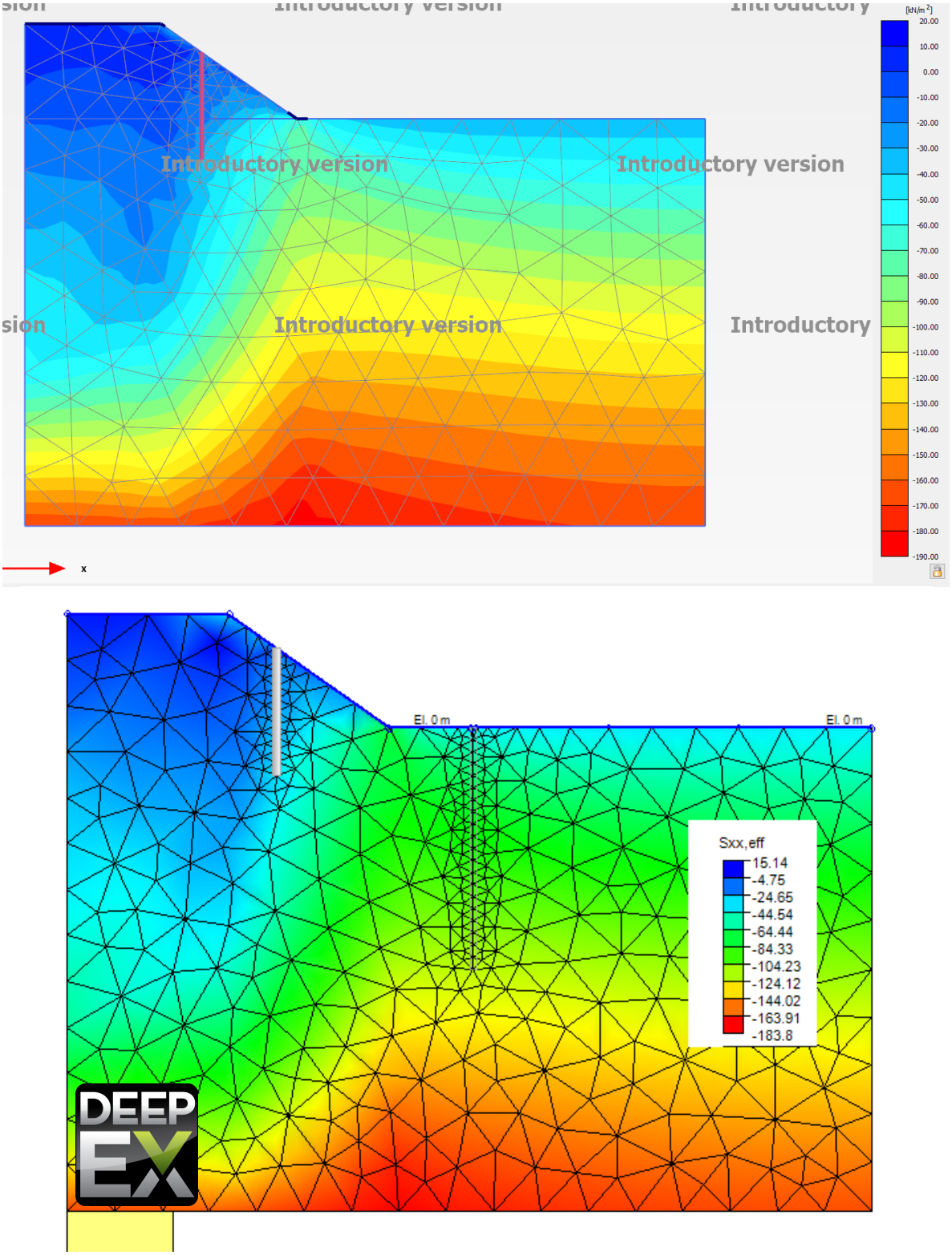


Figure 12: Comparison of Soil Effective Horizontal Stress a) Plaxis b) DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Case 4: Triaxial Comparison – Soil Hardening

In case 4, a comparison is made between the results obtained by Hardening Soil model in PLAXIS as reported in (Benz 2007) and simulation results of the Hardening Soil model in DeepEx. The parameters used for the hardening soil model are illustrated in Figure 13.

Parameter (Symbol)	Unit	Sand(D)
I. User defind parameters		
E_{50}^{ref}	$[\frac{kN}{m^2}]$	30000
E_{oed}^{ref}	$[\frac{kN}{m^2}]$	30000
E_{ur}^{ref}	$[\frac{kN}{m^2}]$	90000
m	$[-]$	0.55
c	$[\frac{kN}{m^2}]$	0.00
φ	$[^\circ]$	42.0
ψ	$[^\circ]$	16.0
ν_{ur}	$[-]$	0.25
p^{ref}	$[\frac{kN}{m^2}]$	100
K_0^{nc}	$[-]$	0.40
R_f	$[-]$	0.90
$\sigma_{Tension}$	$[\frac{kN}{m^2}]$	0.00
E_0^{ref}	$[\frac{kN}{m^2}]$	270000
$\gamma_{0.7}$	$[-]$	0.0002
II. Internal parameters		
E_i^{ref}	$[\frac{kN}{m^2}]$	65488
α	$[-]$	1.47
K_S/K_C	$[-]$	1.84

Figure 13: Soil Hardening Model Parameters (Benz 2007)

The comparison results obtained in Benz 2007 for different constitutive models available in Plaxis and the experimental data are illustrated in Figure 14.

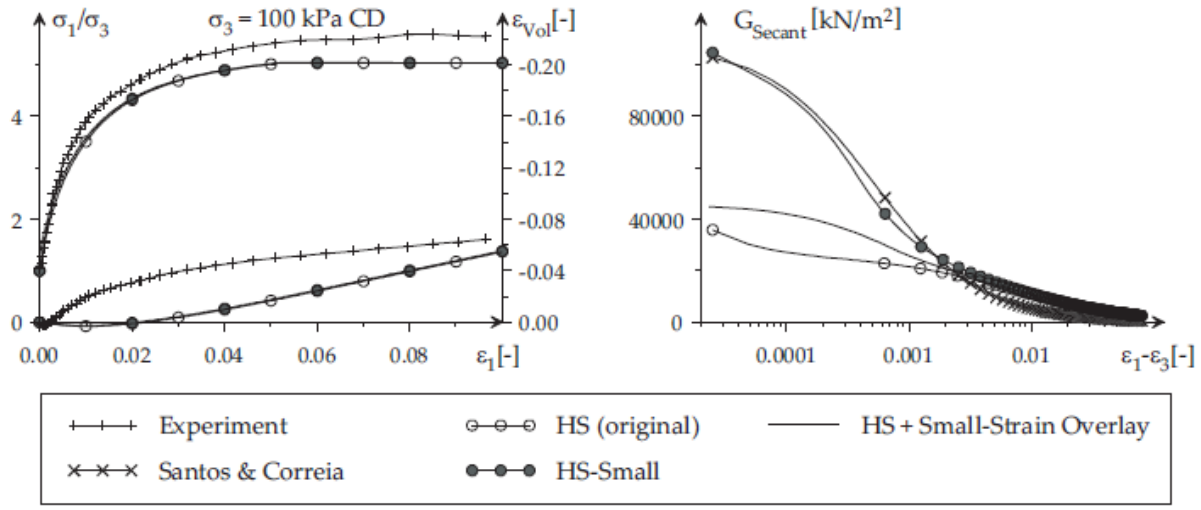


Figure 14: Comparison of Experimental Results with different HS Models in Plaxis (Benz 2007)

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Finally, the triaxial results for the Deepex software soil hardening model are illustrated in figure 15.

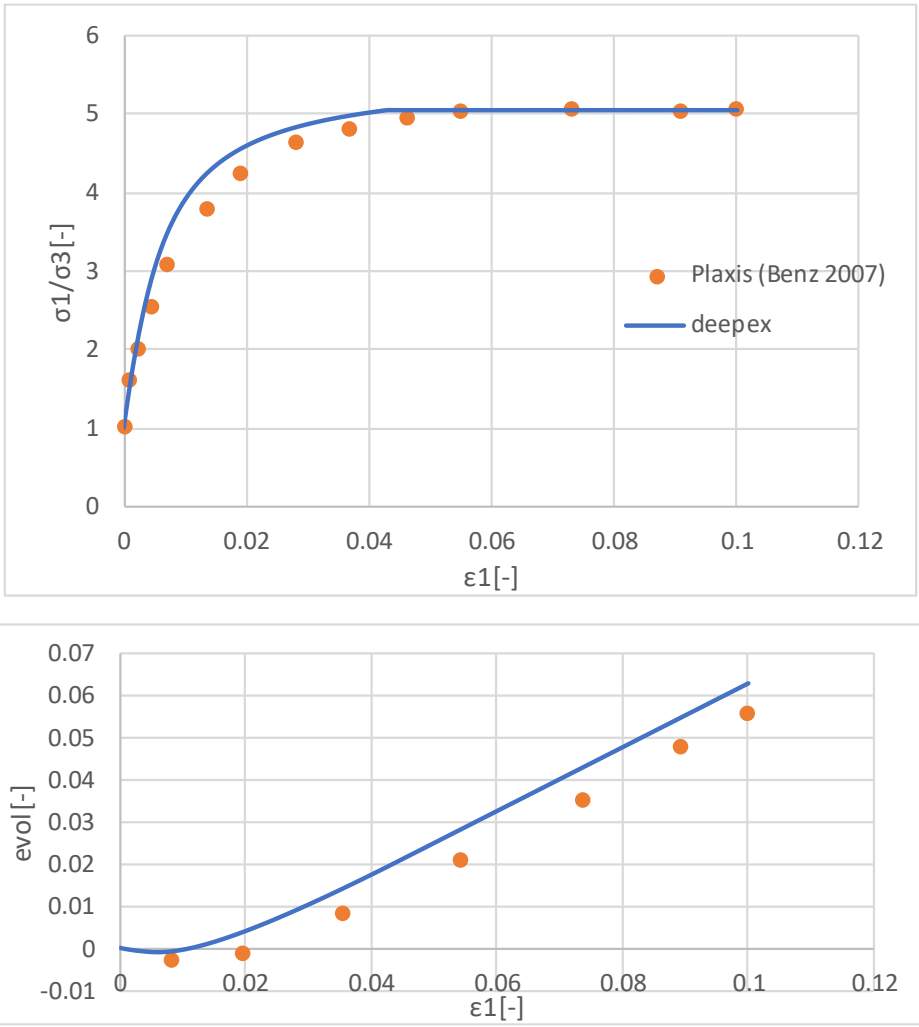
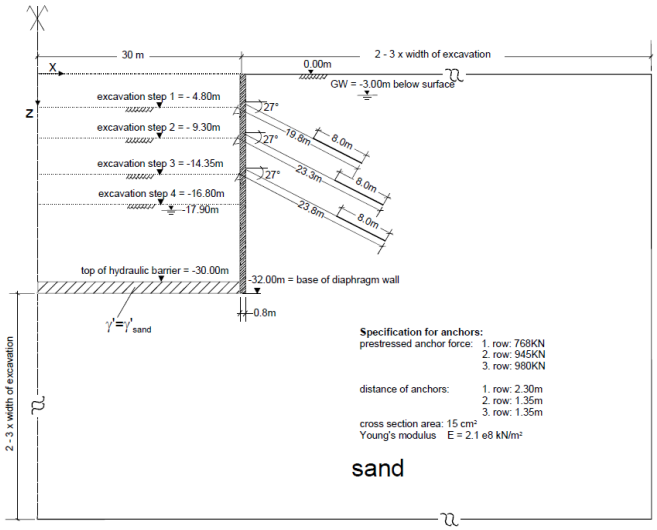


Figure 15: Comparison of Benz 2007 results with DeepEx

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

Case 5: Anchored Wall in Berlin Sand

This case examines the efficiency of DeepEx for a measured deep excavation problem in Berlin sand reported in a benchmarking exercise by the German society of geotechnics (Schweiger, 2002). Results obtained by the commercial finite element code PLAXIS V7.2 was also published in the report. The properties of the of the deep excavation are presented in the following figures:



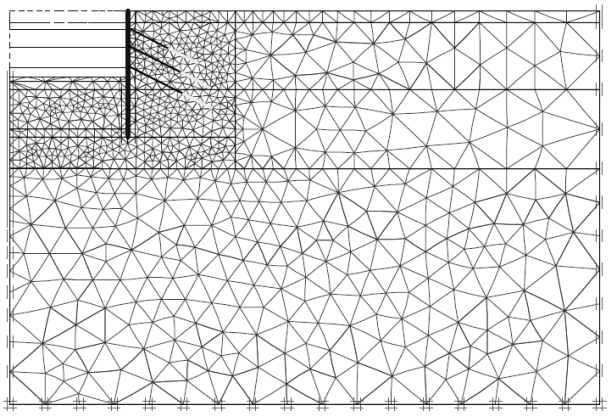


Fig. 2 Finite element mesh for reference solution

Figure 16: Deep Excavation Properties and Plaxis Model (Schweiger, 2002)

depth of layer	E_{50}^{ref}	E_{ur}^{ref}	E_{oed}^{ref}	ν	P	c	$<_{ur}$	p_{ref}	m	R_f	R_{inter}
m	kPa	kPa	kPa	°	°	kPa	-	kPa	-	-	-
0 - 20	45 000	180 000	45 000	35	5	1.0	0.2	100	0.55	0.9	0.8
20 - 40	75 000	300 000	75 000	38	6	1.0	0.2	100	0.55	0.9	0.8
> 40	105 000	315 000	105 000	38	6	1.0	0.2	100	0.55	0.9	-

Figure 17: Soil Properties from (Schweiger, 2002)

Figure 18 presents the model (final construction stage), as modeled in DeepEX Software.

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

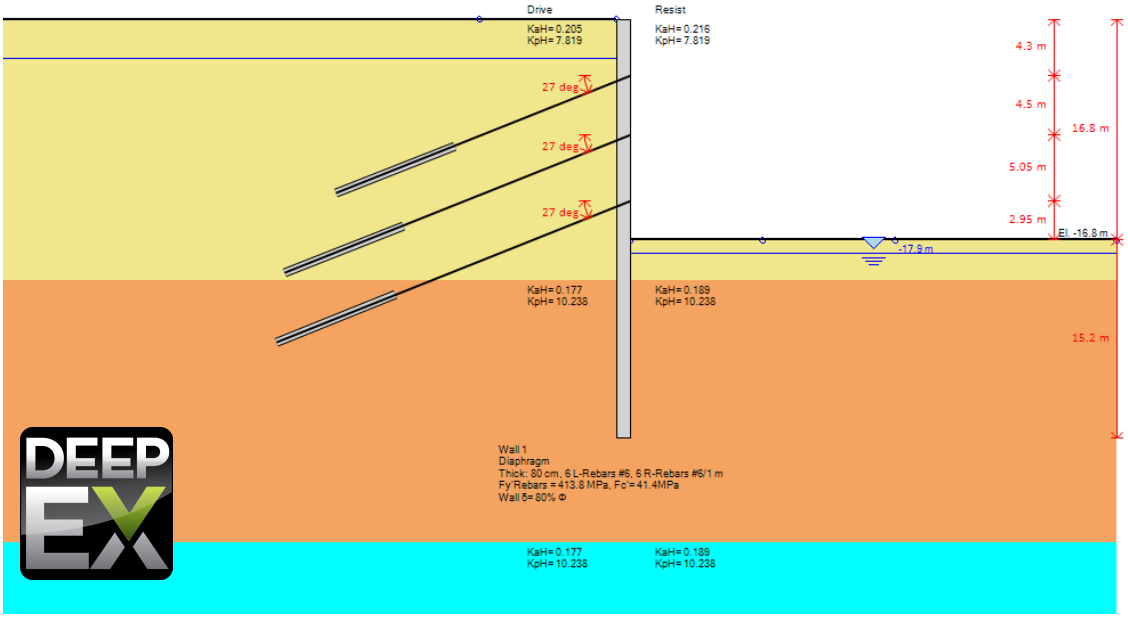


Figure 18: Model in DeepEX Software (Final Stage)

Figures 19 and 20 present the displacement and moments of the retaining wall for the two analysis methods and the on-site measurements for the 2nd stage and final stage respectively.

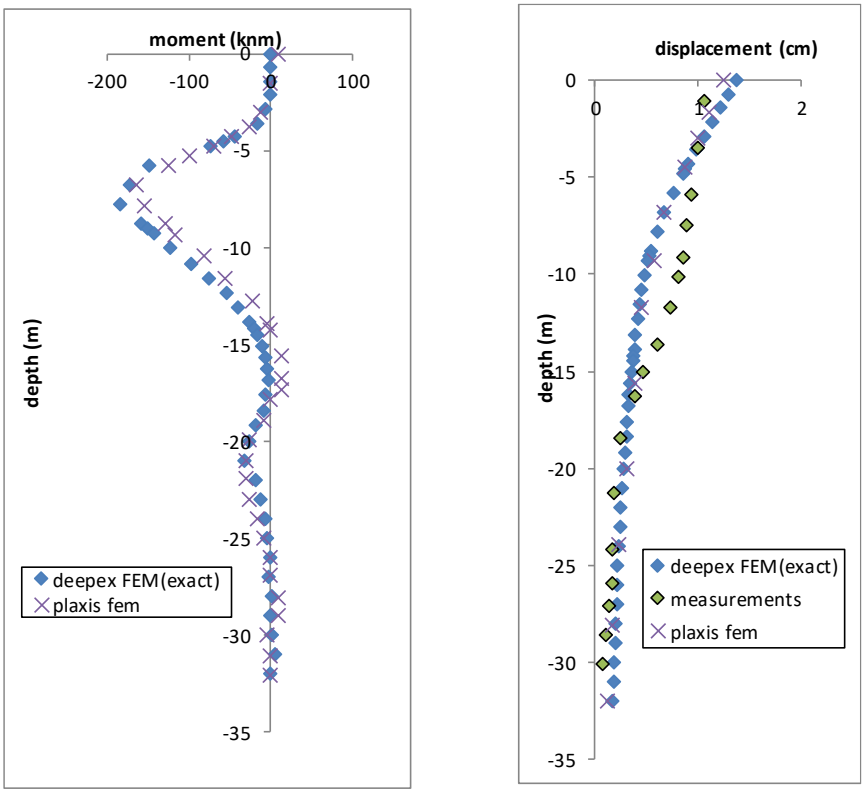


Figure 19: Moment and Displacement Comparison - Stage 1

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

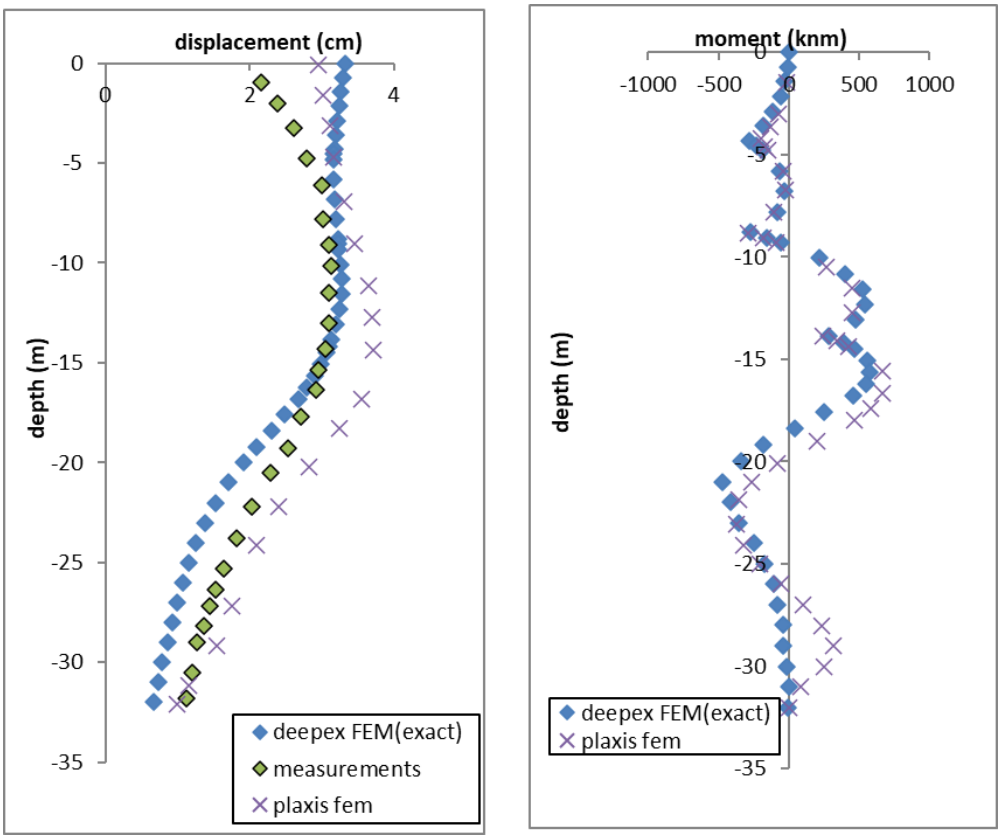


Figure 20: Moment and Displacement Comparison - Final Stage

References

Benz, T. (2007). Small-strain stiffness of soils and its numerical consequences. Phd thesis, Universitat Stuttgart.

Helmut F. Schweiger (2002), BENCHMARKING IN GEOTECHNICS_1, PART II: REFERENCE SOLUTION AND PARAMETRIC STUDY, *Computational geotechnics Group*.

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300

THANK YOU

DESIGN AND OPTIMIZE ANY DEEP EXCAVATION SYSTEM IN MINUTES AND GAIN A COMPETITIVE EDGE!

Learn tips and tricks of deep excavation design

CLICK HERE TO BOOK A FREE ONLINE PRESENTATION
E: training@deepexcavation.com

Learn from examples, videos and case studies

CLICK HERE FOR EXAMPLES, VIDEOS AND ARTICLES

Prices and Licensing Questions: sales@deepexcavation.com
Technical Support support@deepexcavation.com

TRUSTED BY

ARUP, United Rentals, PB&A inc, HATCH, MOTT MACDONALD, KELLER, Jacobs, MAGNUSSON KLEMENCIC ASSOCIATES, ATKINS, STALWORTH UNDERGROUND, GZA, SAMSUNG C&T, RUSSO Est. 1956, Gulf Consult Saudi Arabia, DANBRO DISTRIBUTORS, Al Ghurair, ATTIKO METRO A.E., Gannett Fleming, KLEINFELDER, TEMELTAŞ "temelden gelen güç"

www.deepexcavation.com
www.deepex.com
E: sales@deepexcavation.com
T: 1-206-279-3300