Analysis Example with EC7

A simplified analysis example is presented in this section for the purpose of illustrating use of EC7 methods. The example involves the analysis of steel sheet pile wall supported by a single level of tiebacks with the following assumptions:

- Retained ground surface level (uphill side) El. +200
- Maximum excavation level (downhill side) El. +191
- Water level on retained side El. +195
- Water level on excavated side El. +191
- Water density γ_{WATER}= 10kN/m^3
- Soil properties: γ_{TOTAL}= 20kN/m^3, γ_{DRY}= 19kN/m^3, c'= 3 kPa, ϕ= 32 deg,

  Exponential soil model: E_{load}= 15000 kPa, E_{reload} = 45000 kPa, a_h = 1 , a_v=0

  K_{pBase} =3.225 (Rankine), K_{aBase}= 0.307 (Rankine)

  Ultimate Tieback bond capacity q_{ult} = 150 kPa

  User specified safety on bond values FS Geo= 1.5
- Tieback Data: Elevation El. +197,

  Horizontal spacing = 2m

  Angle = 30 deg from horizontal

  Prestress = 400 kN (i.e. 200kN/m)

  Structural Properties: 4 strands/1.375 cm diameter each,

  Thus A_{STEEL} = 5.94 cm^2

  Steel yield strength F_y = 1862 MPa

  Fixed body length L_{FIX} = 9 m

  Fixed body Diameter D_{FIX} = 0.15m
- Wall Data: Steel Sheet pile AZ36, Fy = 355 MPa

  Wall top. El. +200

  Wall length 18m

  Moment of Inertia I_{xx} = 82795.6 cm^4/m

Section Modulus Sxx = 3600 cm^3/m

- Surcharge: Variable triangular surcharge on wall

  Pressure 5kPa at El. +200 (top of wall)

  Pressure 0kPa at El. +195

The construction sequence is illustrated in Figures 4.1 through 4.4. For the classical analysis the following assumptions will be made:

Rankine passive pressures on resisting side

Cantilever excavation: Active pressures (Free earth analysis)

Final stage: Apparent earth pressures from active x 1.3, redistributed top from 0 kPa at wall top to full pressure at 25% of Hexc., Active pressures beneath subgrade.

Free earth analysis for single level of tieback analysis.

Water pressures: Simplified flow

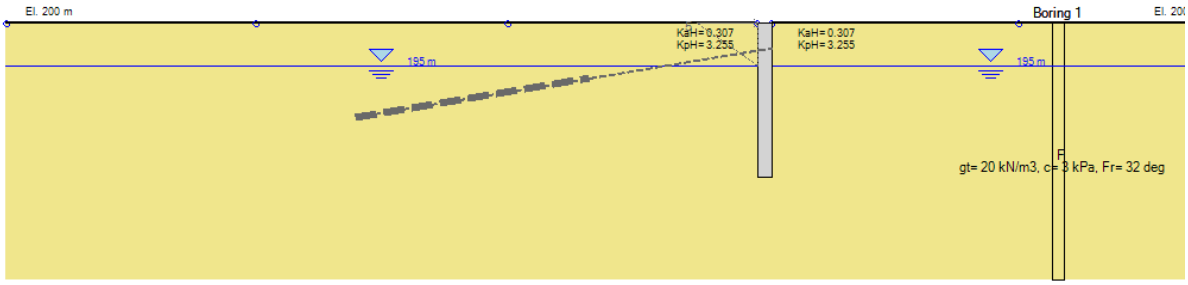

Figure 5.1: Initial Stage (Stage 0, Distorted Scales)

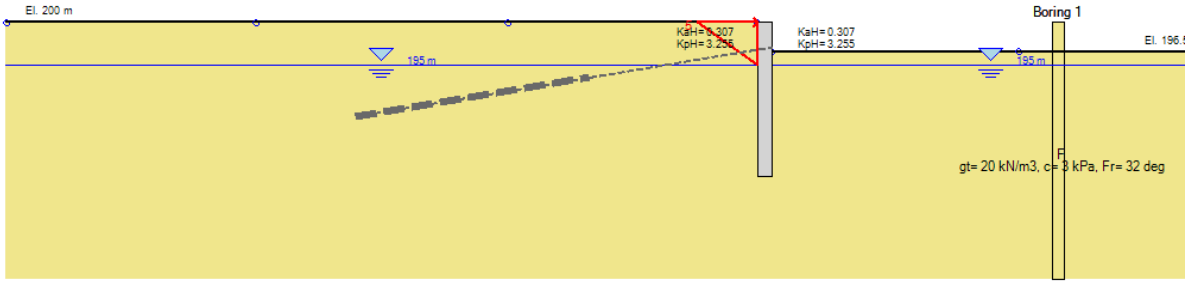

Figure 5.2: Stage 1, cantilever excavation to El. +196.5 (tieback is inactive)

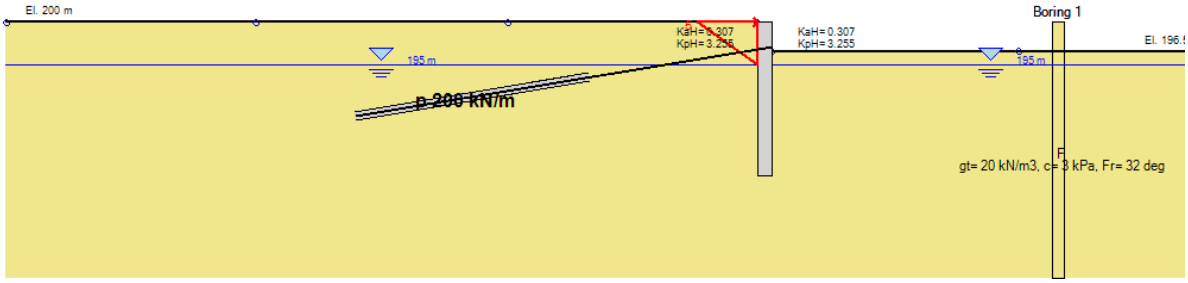

Figure 5.3: Stage 2, activate and prestress ground anchor at El. +197

Design Section

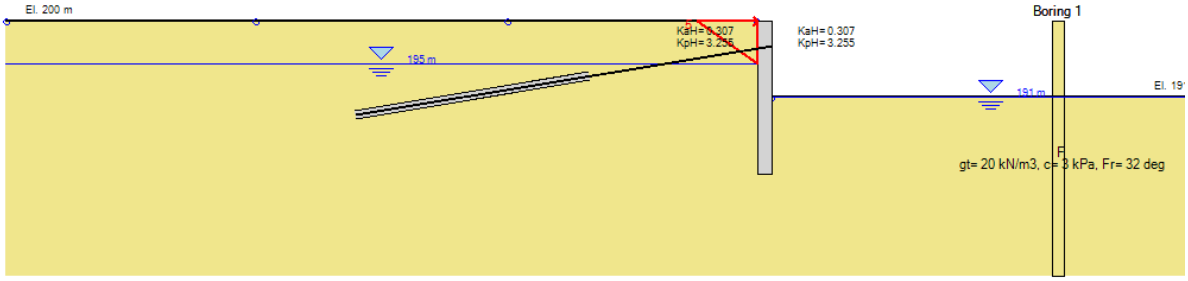

Figure 5.4: Stage 3, excavate to final subgrade at El. +191

The first step will be to evaluate the active and passive earth pressures for the service case as illustrated in Figure 5.

Top triangular pressure height= 0.25 Hexc = 2.25 m Hexc= 9 m
Apparent Earth Pressure Factor: 1.3 (times active)

		Eurocode Safety factors		1		1	1			
SOIL UNIT WEIGHT (kPa)	DRY UNIT WEIGHT (kPa)	WATER UNIT WEIGHT (kPa)	WATER TABLE ELEV. (m)	ϕ (deg)	Ka	Kp	c' (kPa)	WATER TABLE ELEV. (m)	Hydraulic travel length m	Hydraulic loss gradient i m/m
				32	0.307	3.255	3	195	22	0.1818
				Modified for calculation/Strength Reductions						
20	19	10	195	32.00	0.307	3.255	3.000			

LEFT EXCAVATION SIDE PRESSURES							RIGHT SIDE PRESSURES (PASSIVE)					
ELEV. (m)	TOTAL VERTICAL STRESS (kPa)	WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	Acive LATERAL SOIL STRESS (kPa)	Apparent Earth Pressures	TOTAL LATERAL STRESS	TOTAL VERTICAL STRESS (kPa)	WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	LATERAL SOIL STRESS (kPa)	TOTAL LATERAL STRESS (kPa)	NET (kPa)
200	0	0	0	0	0.00	0.00						0.00
199.43	10.82	0.00	10.82	0.00	-7.93	-7.93						-7.93
197.75	42.75	0.00	42.75	-9.81	-31.33	-31.33						-31.33
195	95	0	95	-25.86	-31.33	-31.33						-31.33
191	175	-32.7	142.3	-40.39	-31.33	-64.06						-64.06
191	175	-32.7	142.3	-40.39	-40.39	-73.12	0	0	0	10.82	10.82429	-62.3
182	355	-106.4	248.64	-73.07	-73.07	-179.43	180	106.4	73.64	250.48	356.84	177.4

Total active earth force above subgrade:

			ΔFx
From El.	200.00 to El.	199.43	0.0 kN/m
From El.	199.43 to El.	197.75	8.2 kN/m
From El.	197.75 to El.	195.00	49.1 kN/m
From El.	195.00 to El.	191.00	132.5 kN/m
		Sum=	189.8 kN/m
		Factored Forc	246.7
		Max. Apparent Earth Pressure=	31.3 kPa

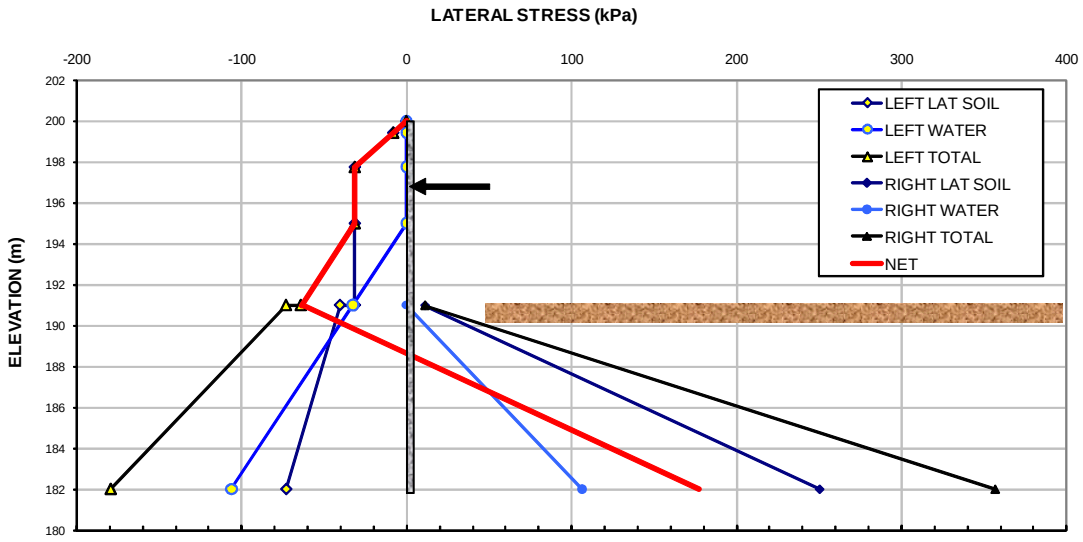

Figure 6: Calculation of lateral earth and water pressures for service case

As Figure 6 shows, the calculated maximum apparent earth pressure is 31.3 kPa which is very close to the 31.4 kPa apparent earth pressure envelope calculated from the software (Figure 7.1). All other pressure calculations are also very well confirmed (within rounding error accuracy).

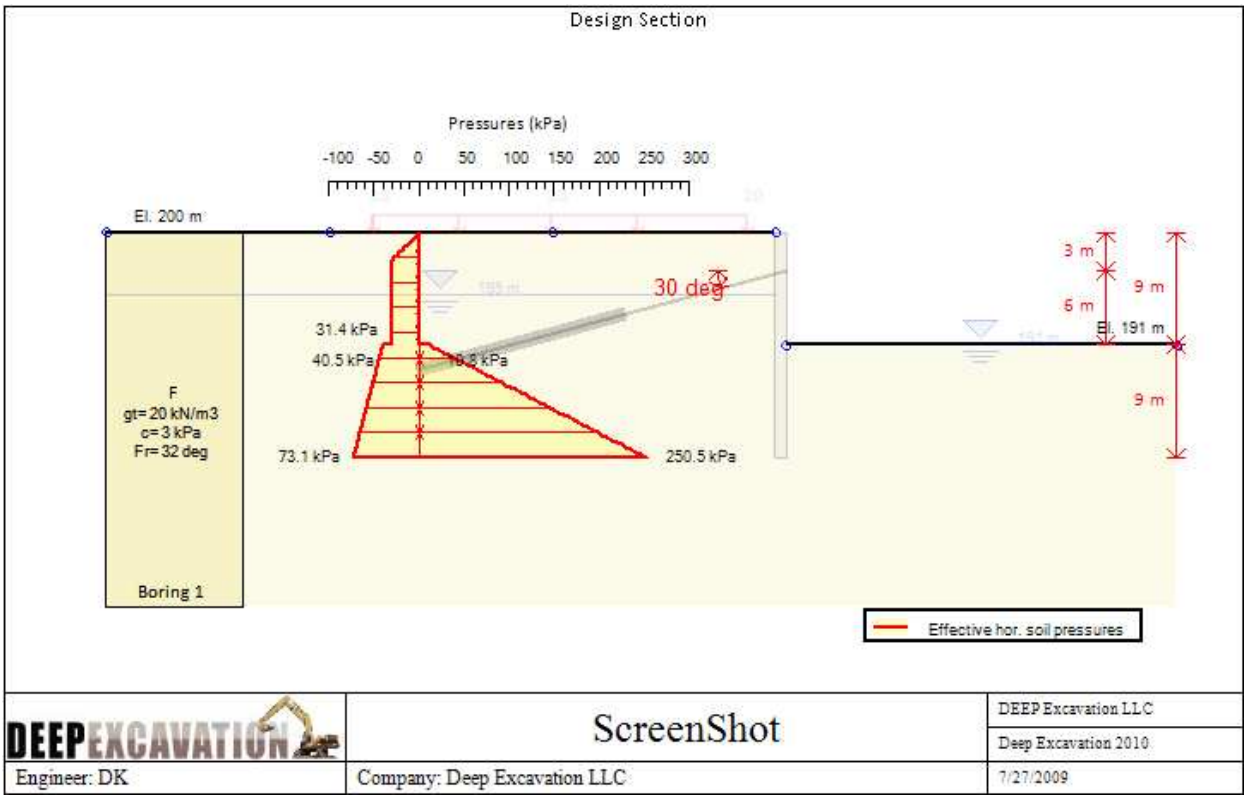

Figure 7.1: Apparent lateral earth pressures from conventional analysis

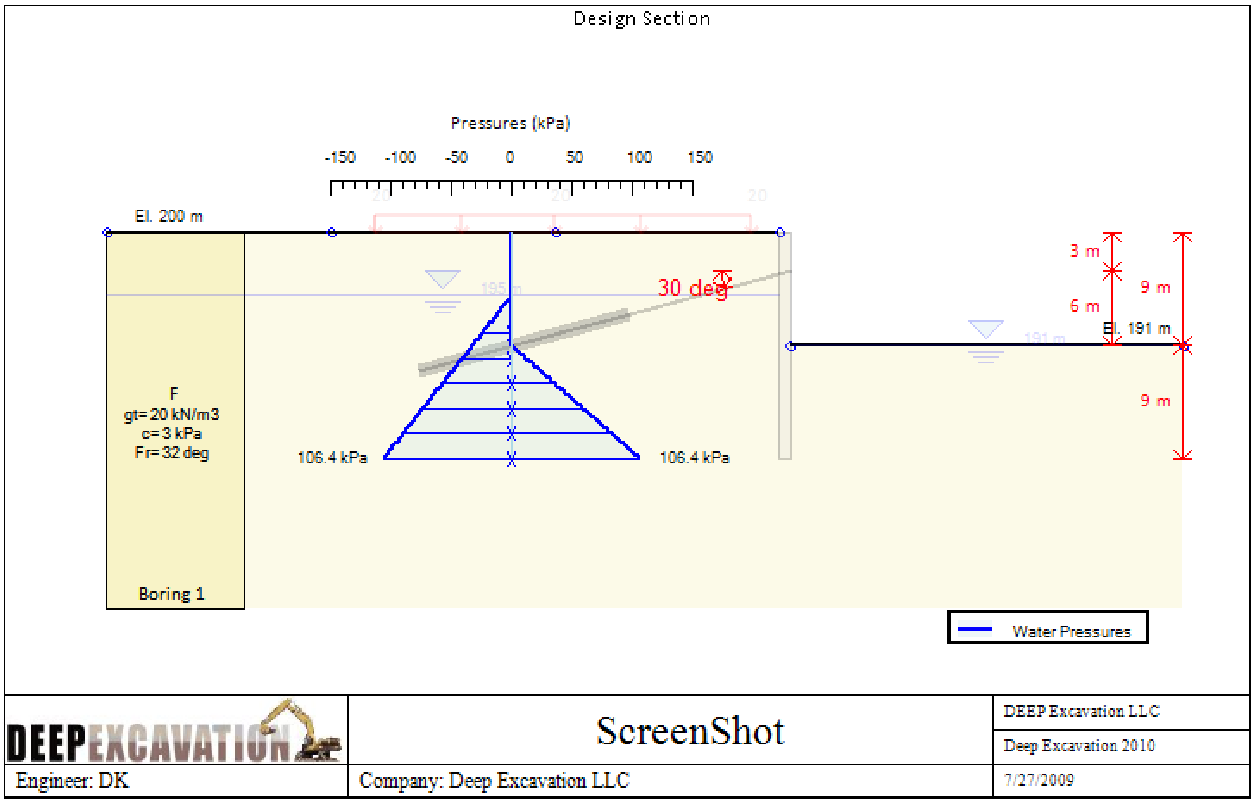

Figure 7.2: Simplified flow groundwater pressures from conventional analysis

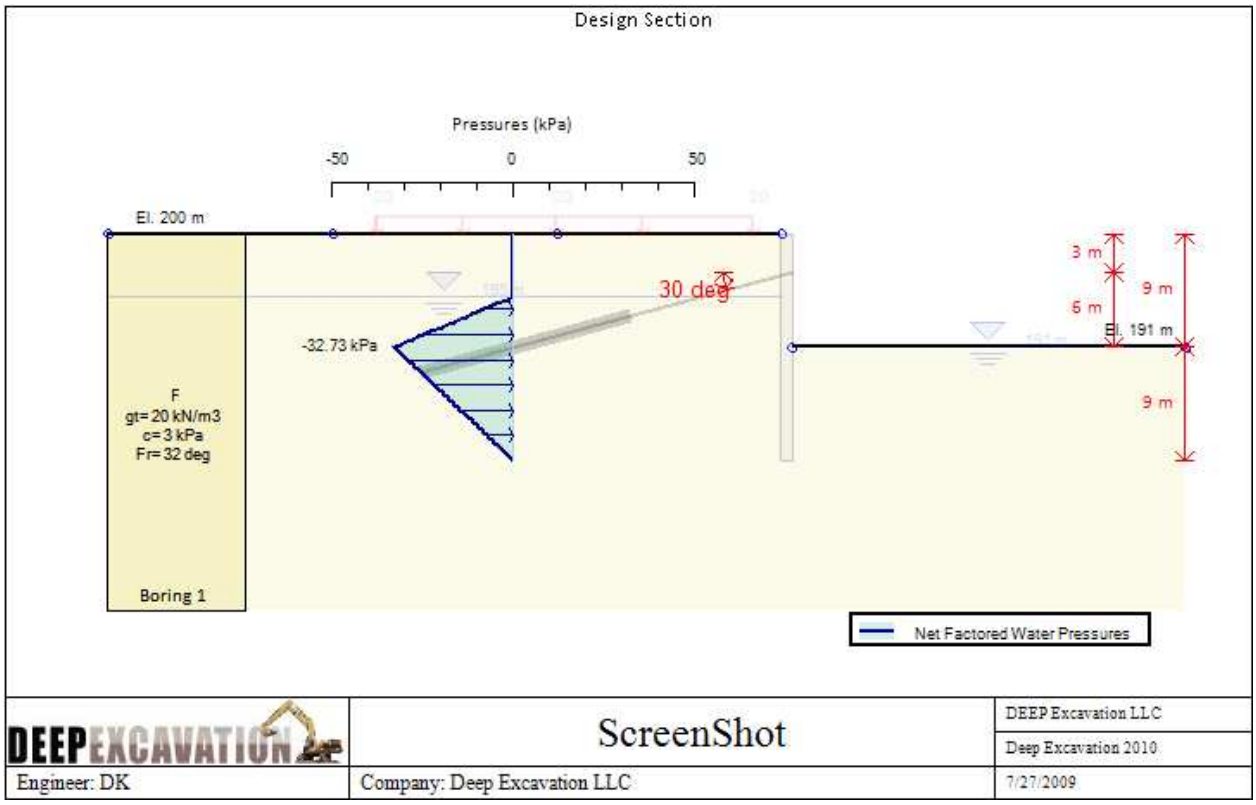

Figure 7.3: Simplified flow net groundwater pressures from conventional analysis

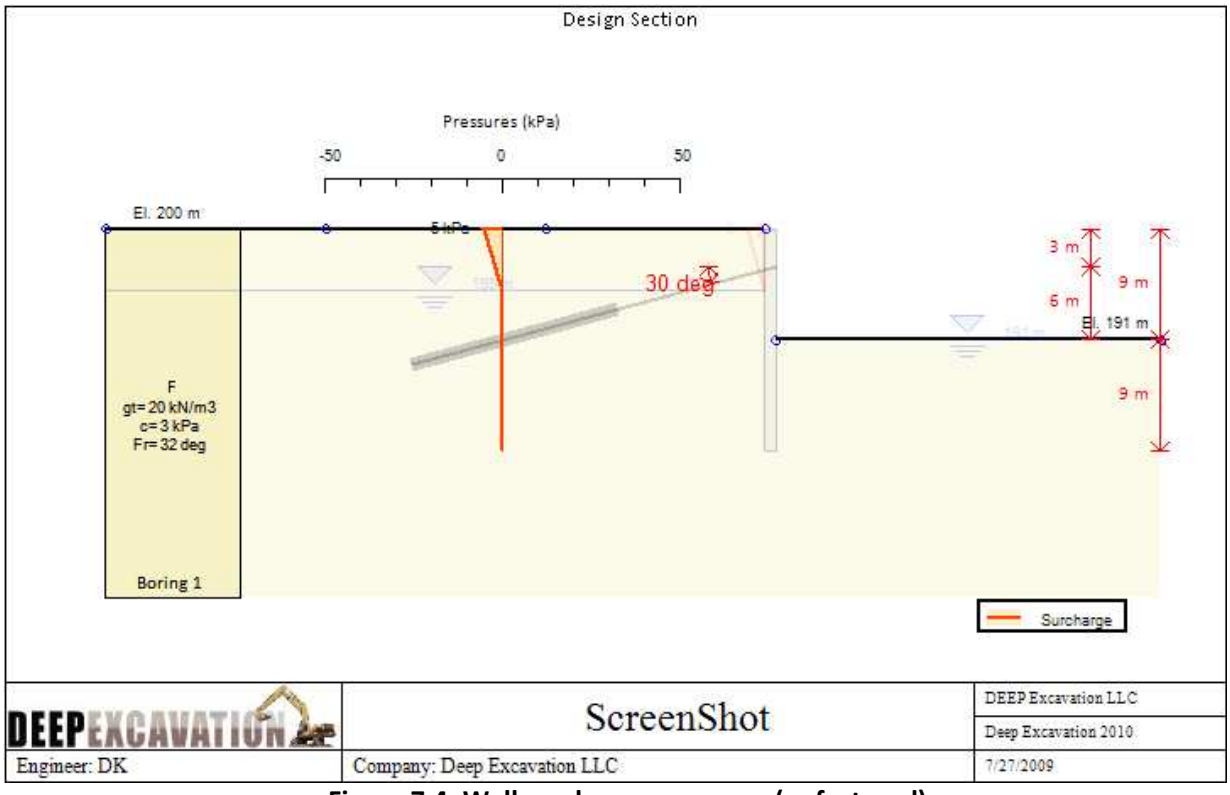

Figure 7.4: Wall surcharge pressures (unfactored)

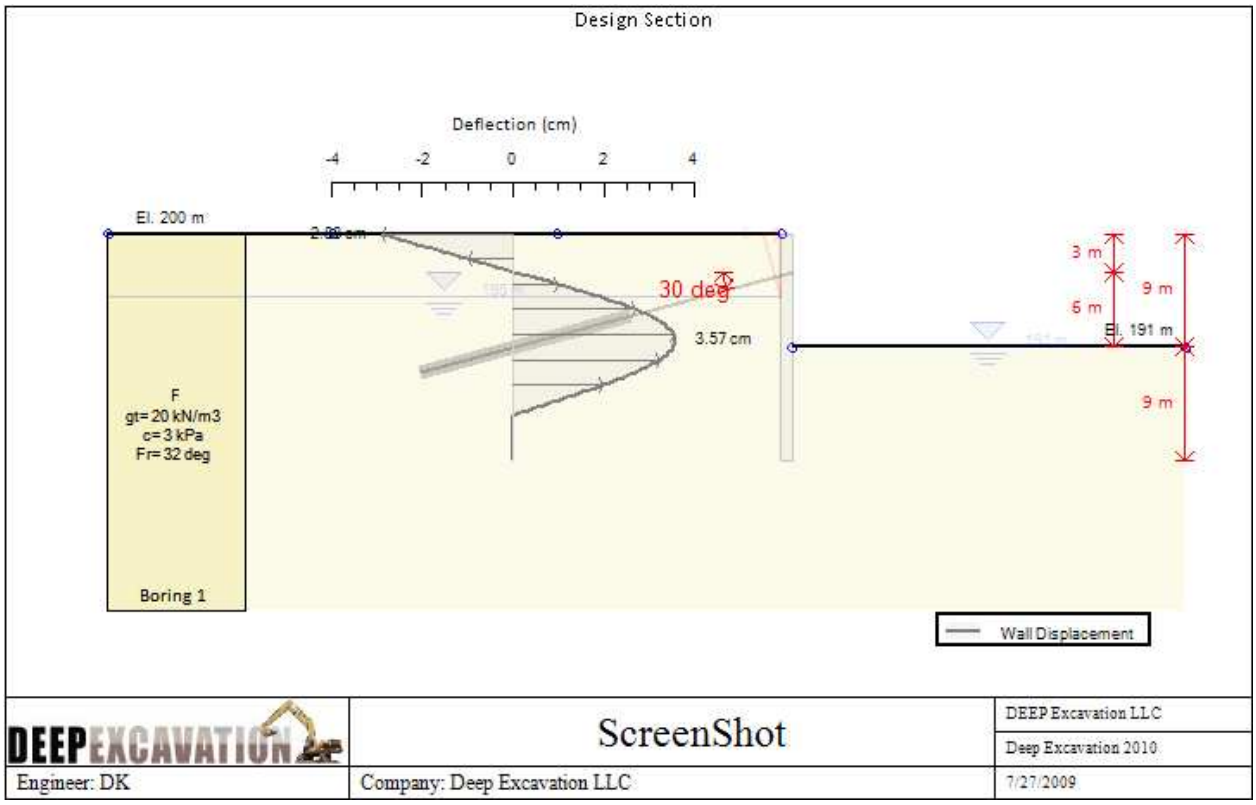

Figure 7.5: Wall displacements from conventional analysis (last stage)

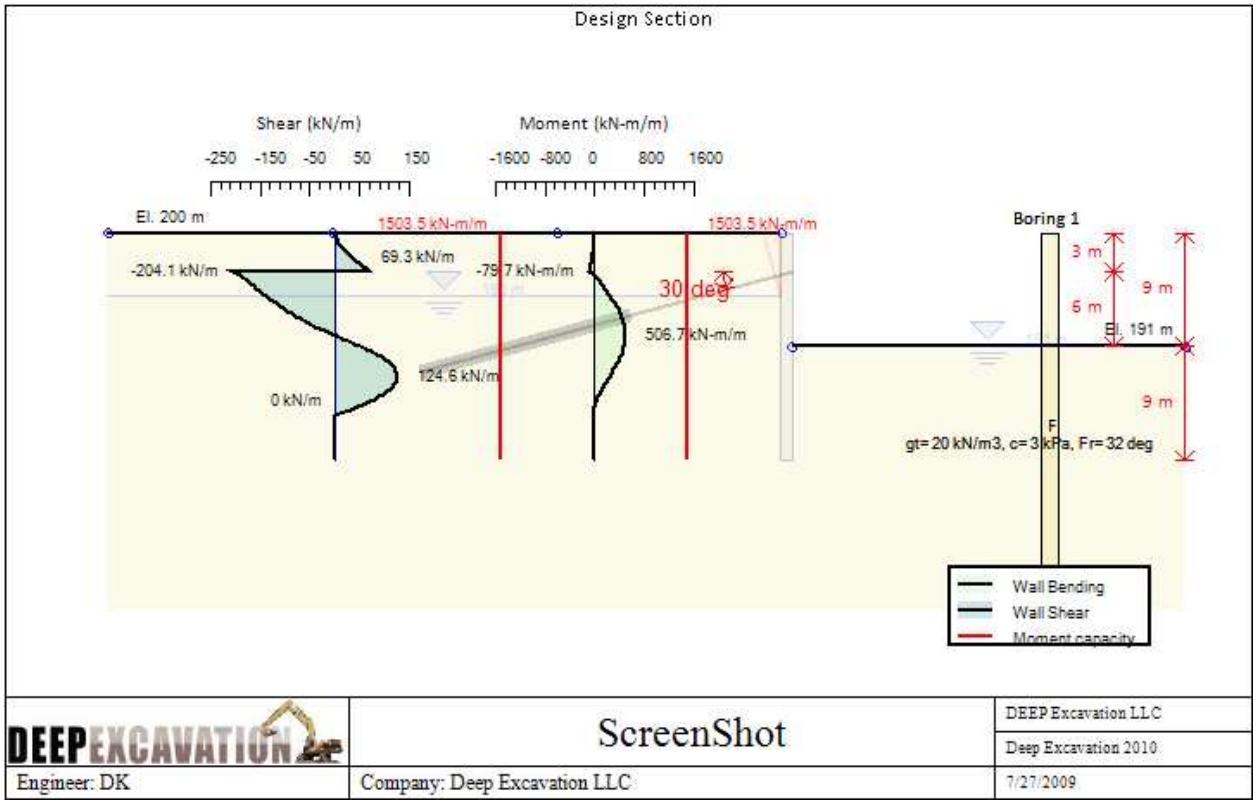

Figure 7.6: Shear and moment diagrams with support reaction and stress checks drawn (red lines on moment diagram show wall capacity).

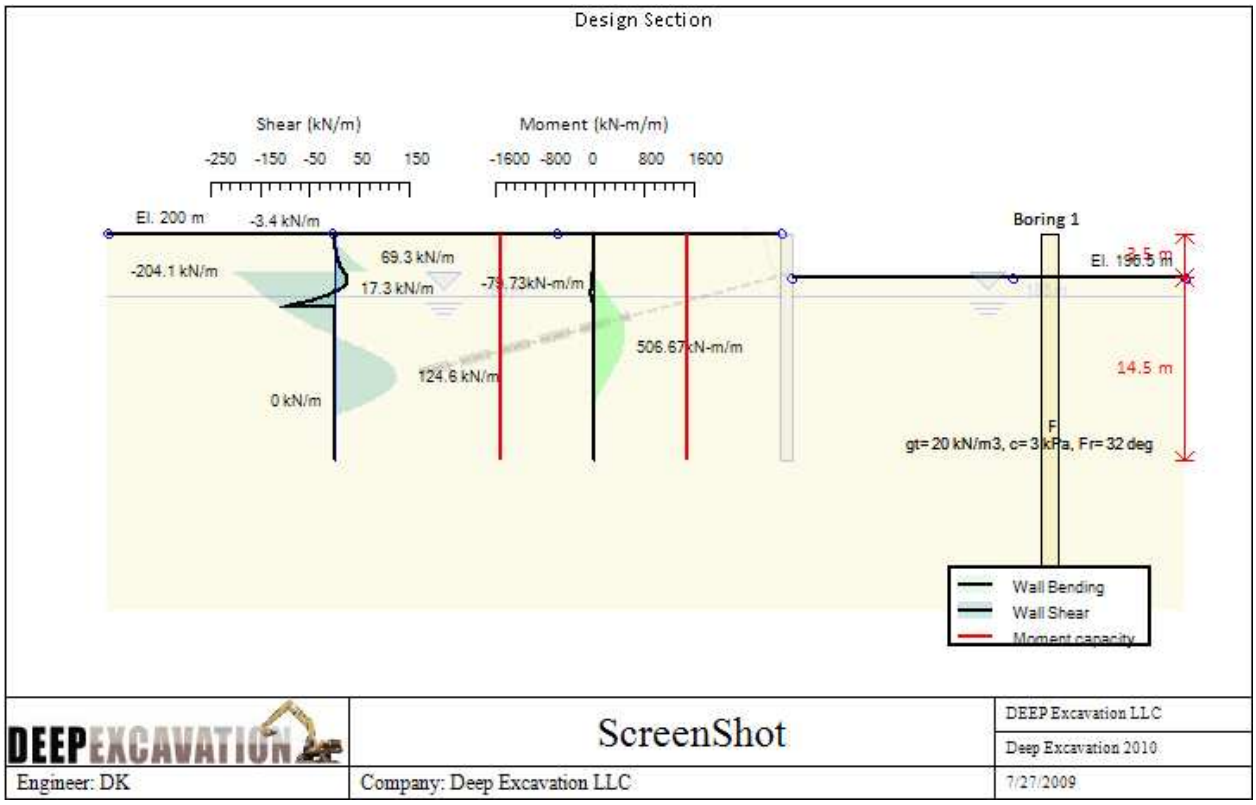

Figure 7.7: Shear and moment diagram envelopes (for current design section only)

Next, the EC7 combination DA-3 approach will be examined in detail. However, all EC7 design approaches will be analyzed simultaneously. The model is linked to the base design section.

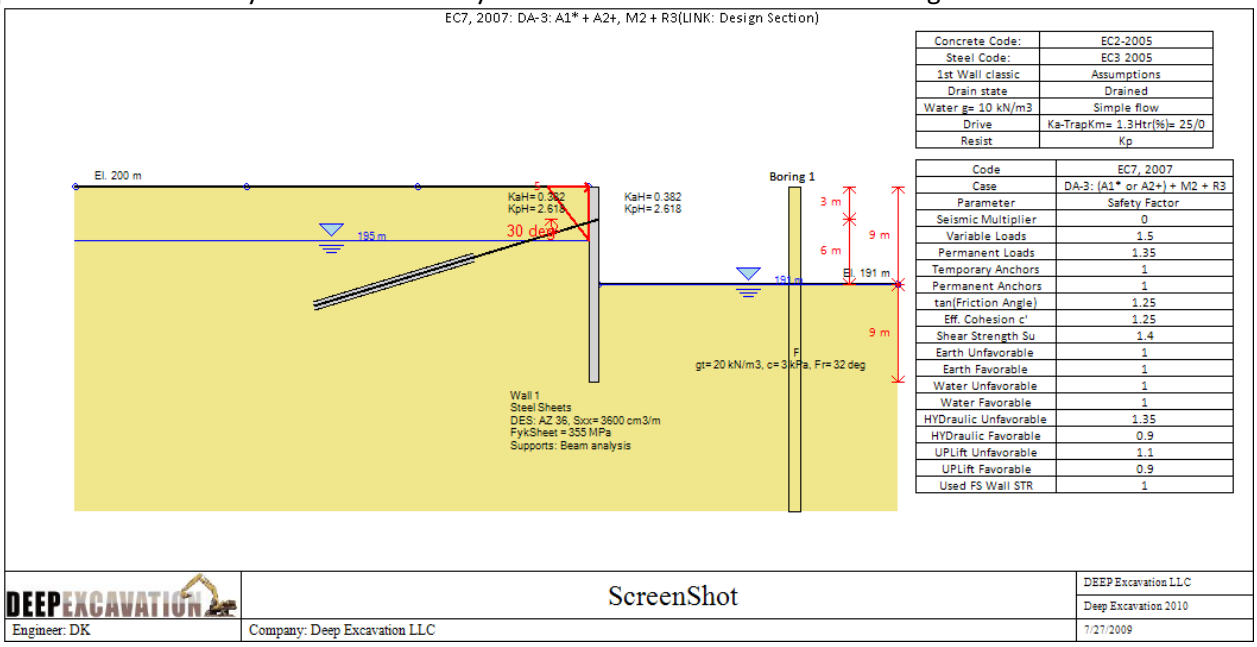

Figure 8.1: General model for EC7 DA-3 Approach

The corresponding safety factors are:

FS(tan(ϕ)) =	1.25
FS(c') =	1.25
FS(Su) =	1.5 (this is also used for the ultimate bond resistance)
FS(Actions temp) =	1.3
FS(Anchors)=	1.1
FS(Water Drive)=	1.0
FS(Drive_Earth)=	1.0

Next the active and passive earth pressures, as well as the net water pressures for the DA3 approach will be calculated as illustrated in Figure 8.2. As Figures 8.3 through 8.4 demonstrate, the software calculates essentially the same lateral earth pressures as the spreadsheet shown in Figure 8.2.

Top triangular pressure height= 0.25 Hexc = 2.25 m Hexc= 9 m
Apparent Earth Pressure Factor: 1.3 (times active)

		Eurocode Safety factors		1.25		1	1.25						
SOIL UNIT WEIGHT (kPa)	DRY UNIT WEIGHT (kPa)	WATER UNIT WEIGHT (kPa)	WATER TABLE ELEV. (m)	ϕ (deg)	Ka	Kp	c' (kPa)	WATER TABLE ELEV. (m)	Hydraulic travel length m	Hydraulic loss gradient i m/m	Safety factor on net water pressures	Safety factor on earth pressures	Safety factor on Passive Resistance
				32	0.307	3.255	3	195	22	0.1818	1	1	1
				Modified for calculation/Strength Reductions									
20	19	10	195	26.56	0.382	2.618	2.400						

LEFT EXCAVATION SIDE PRESSURES							RIGHT SIDE PRESSURES (PASSIVE)						
ELEV. (m)	TOTAL VERTICAL STRESS (kPa)	UNFACTORED WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	Acive LATERAL SOIL STRESS (kPa)	Apparent Earth Pressures	TOTAL LATERAL STRESS (factored earth)	TOTAL VERTICAL STRESS (kPa)	WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	LATERAL SOIL STRESS (kPa)	TOTAL LATERAL STRESS (kPa)	Net water pressure (factored) (kPa)	NET (kPa)
200	0	0	0	0	0.00	0.00						0	0.00
199.59	7.77	0.00	7.77	0.00	-7.37	-7.37						0	-7.37
197.75	42.75	0.00	42.75	-13.37	-40.60	-40.60						0	-40.60
195	95	0	95	-33.33	-40.60	-40.60						0	-40.60
191	175	-32.7	142.3	-51.39	-40.60	-73.33						-32.73	-73.3
191	175	-32.7	142.3	-51.39	-51.39	-84.11	0	0	0	7.77	7.765837	-32.73	-76.3
182	355	-106.4	248.64	-92.02	-92.02	-198.39	180	106.4	73.64	200.51	306.88	0.00	108.5

Total active earth force above subgrade:

			ΔFx
From El.	200.00 to El.	199.59	0.0 kN/m
From El.	199.59 to El.	197.75	12.3 kN/m
From El.	197.75 to El.	195.00	64.2 kN/m
From El.	195.00 to El.	191.00	169.4 kN/m
		Sum=	245.9 kN/m
		Factored Forc	319.7
		Max. Apparent Earth Pressure=	40.60 kPa

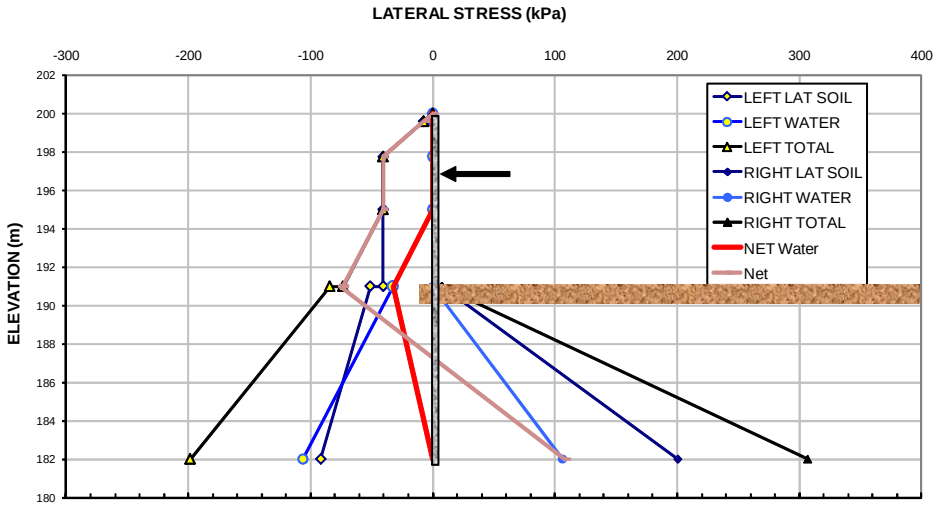

Figure 8.2: Calculation of lateral earth and water pressures for DA3 Approach

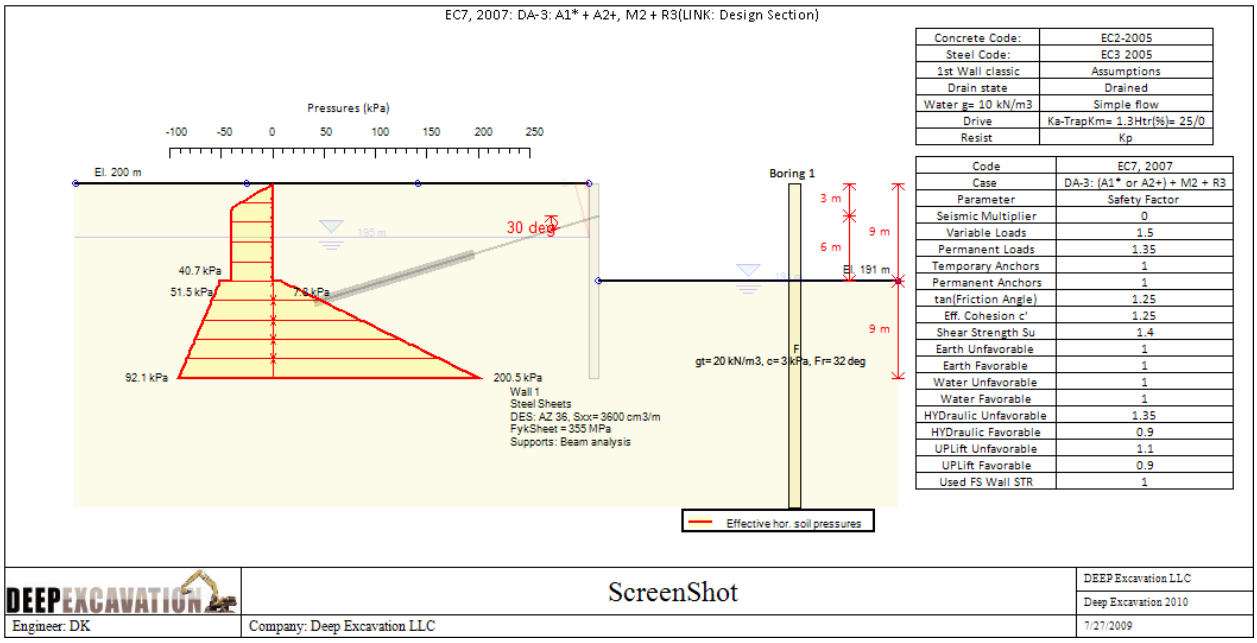

Figure 8.2: Apparent lateral earth pressures for DA3 Approach (40.7 kPa pressure verified spreadsheet calculations)

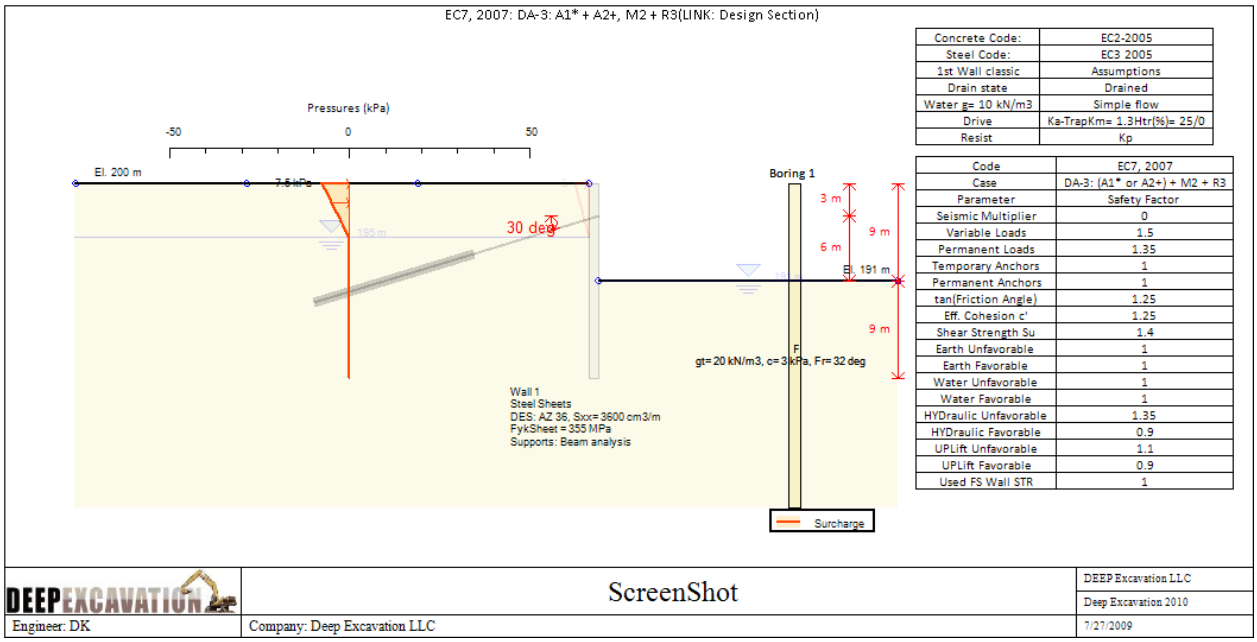

Figure 8.3: Factored lateral surcharge pressures for DA3 Approach (7.5 kPa pressure = 5 kPa x 1.5)

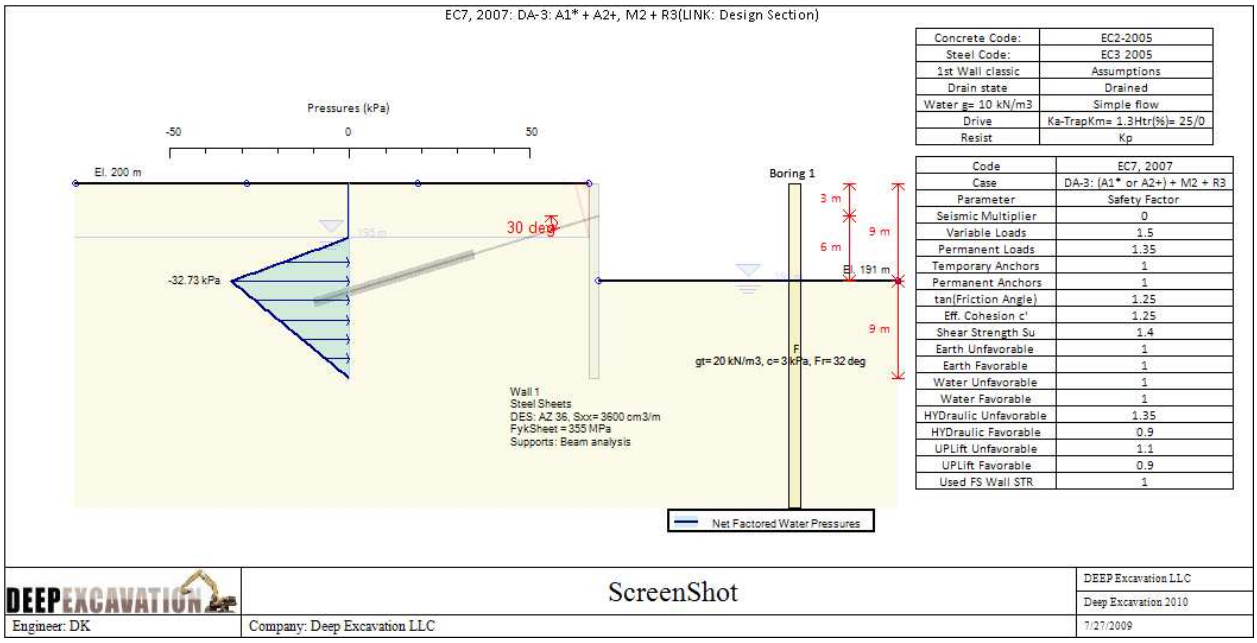

Figure 8.4: Net Factored water pressures for DA3 Approach 32.73 kPa pressure = 32.73 kPa x 1.0 , 32.7 kPa from Figure 6.3; Spreadsheet calculation 32.7 kPa

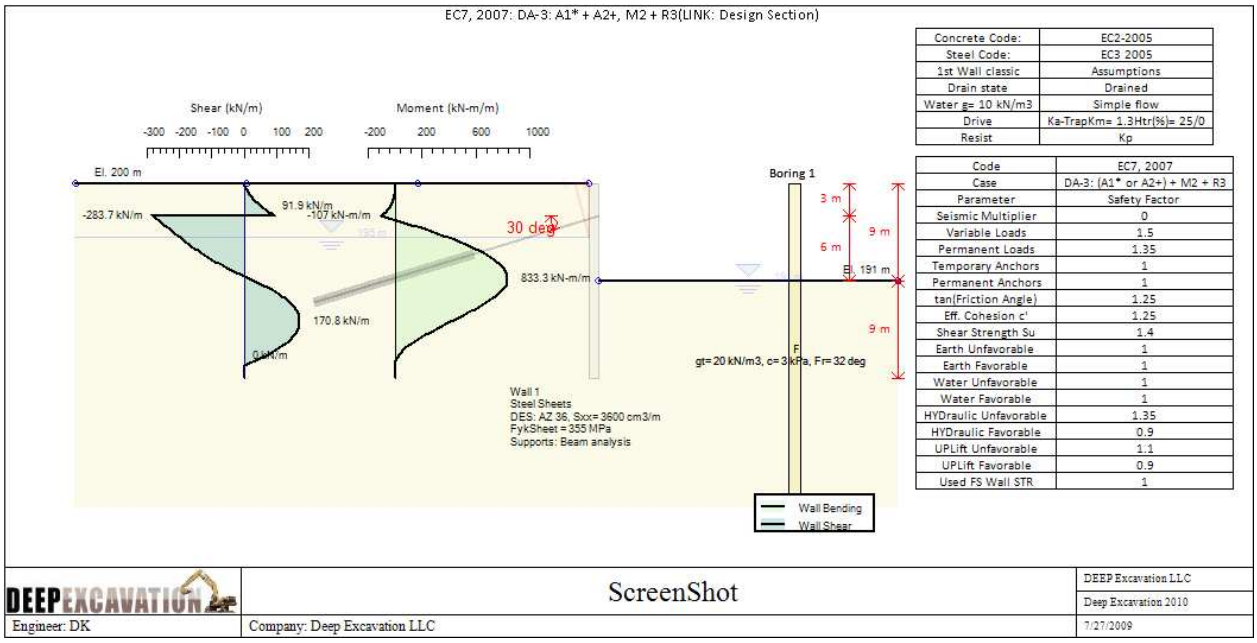

Figure 8.5: Wall shear and moment for DA3 Approach

Next we examine the case of DA1-1 where earth and water pressures are multiplied by safety factors while the soil strength parameters are maintained.

Top triangular pressure height= 0.25 Hexc = 2.25 m Hexc= 9 m
Apparent Earth Pressure Factor: 1.3 (times active)

		Eurocode Safety factors		1		1		1						
SOIL UNIT WEIGHT (kPa)	DRY UNIT WEIGHT (kPa)	WATER UNIT WEIGHT (kPa)	WATER TABLE ELEV. (m)	ϕ (deg)	Ka	Kp		c' (kPa)	WATER TABLE ELEV. (m)	Hydraulic travel length m	Hydraulic loss gradient i m/m	Safety factor on net water pressures	Safety factor on earth pressures	Safety factor on Passive Resistance
				32	0.307	3.255		3	195	22	0.1818	1.35	1.35	1
				Modified for calculation/Strength Reductions										
20	19	10	195	32.00	0.307	3.255		3.000						

LEFT EXCAVATION SIDE PRESSURES							RIGHT SIDE PRESSURES (PASSIVE)						
ELEV. (m)	TOTAL VERTICAL STRESS (kPa)	UNFACTORED WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	Acive LATERAL SOIL STRESS (kPa)	Apparent Earth Pressures	TOTAL LATERAL STRESS (factored earth)	TOTAL VERTICAL STRESS (kPa)	WATER PRESSURE (kPa)	EFFECTIVE VERTICAL STRESS (kPa)	LATERAL SOIL STRESS (kPa)	TOTAL LATERAL STRESS (kPa)	Net water pressure (factored) (kPa)	NET (kPa)
200	0	0	0	0	0.00	0.00						0	0.00
199.43	10.82	0.00	10.82	0.00	-7.93	-10.71						0	-10.71
197.75	42.75	0.00	42.75	-9.81	-31.33	-42.30						0	-42.30
195	95	0	95	-25.86	-31.33	-42.30						0	-42.30
191	175	-32.7	142.3	-40.39	-31.33	-75.02						-44.18	-86.5
191	175	-32.7	142.3	-40.39	-40.39	-87.25	0	0	0	10.82	10.82429	-44.18	-87.9
182	355	-106.4	248.64	-73.07	-73.07	-205.01	180	106.4	73.64	250.48	356.84	0.00	151.8

Total active earth force above subgrade:

			ΔFx
From El.	200.00 to El.	199.43	0.0 kN/m
From El.	199.43 to El.	197.75	8.2 kN/m
From El.	197.75 to El.	195.00	49.1 kN/m
From El.	195.00 to El.	191.00	132.5 kN/m
		Sum=	189.8 kN/m
		Factored For	246.7
		Max. Apparent Earth Pressure=	31.33 kPa

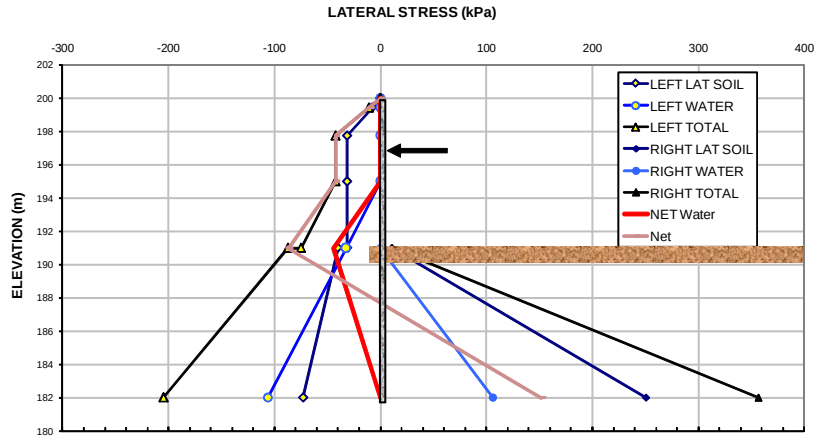

Figure 8.6: Calculation of lateral earth and water pressures for DA1-1 Approach

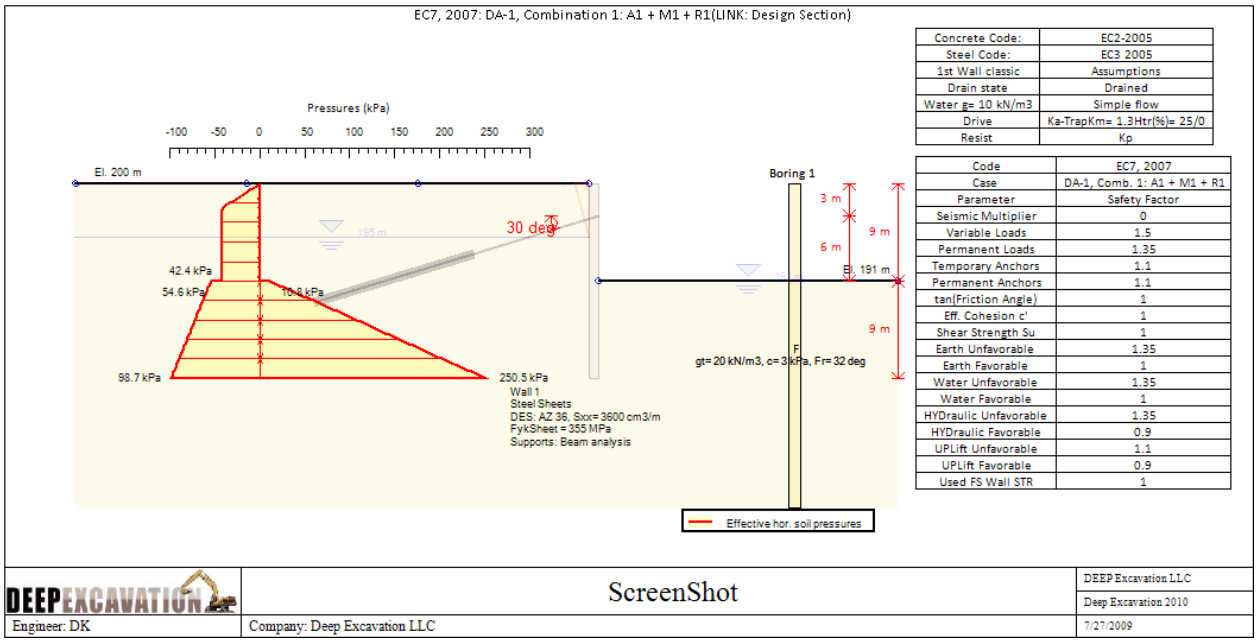

Figure 8.7: Apparent lateral earth pressures for DA1-1 Approach (42.4 kPa pressure verified spreadsheet calculations)

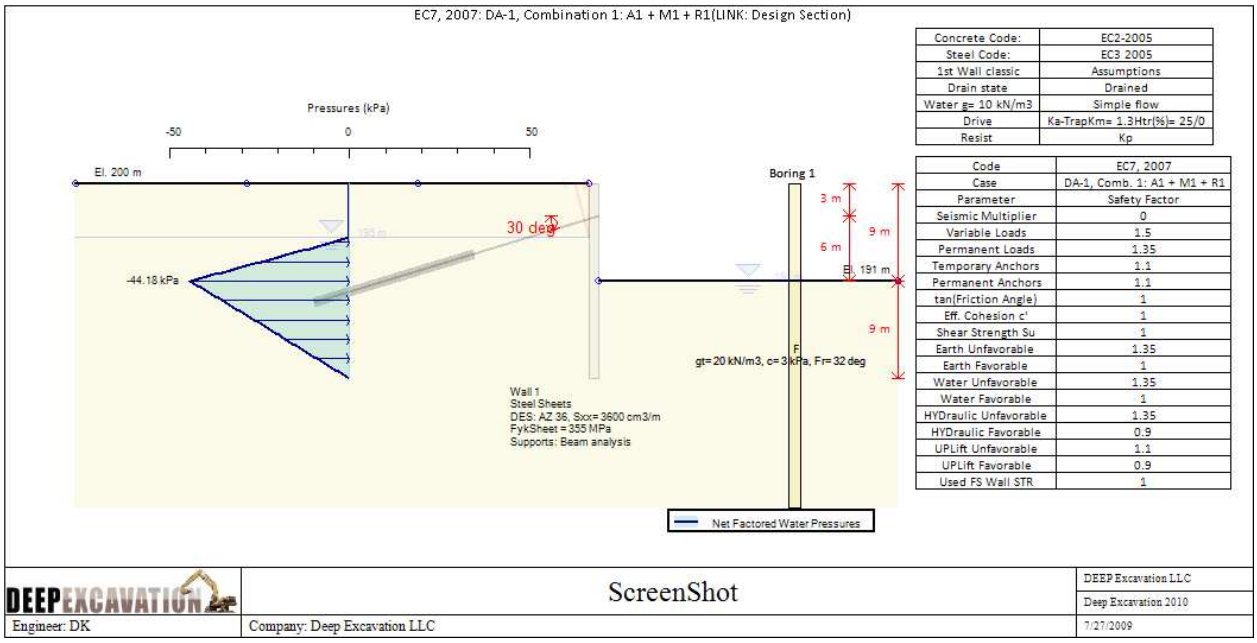

Figure 8.8: Net Factored water pressures for DA1-1 Approach
44.18 kPa pressure = 32.73 kPa x 1.35 , 32.7 kPa from Figure 6.3
Spreadsheet calculation 44.18 kPa

In the following pages, the non-linear solution to the same problem is briefly presented.

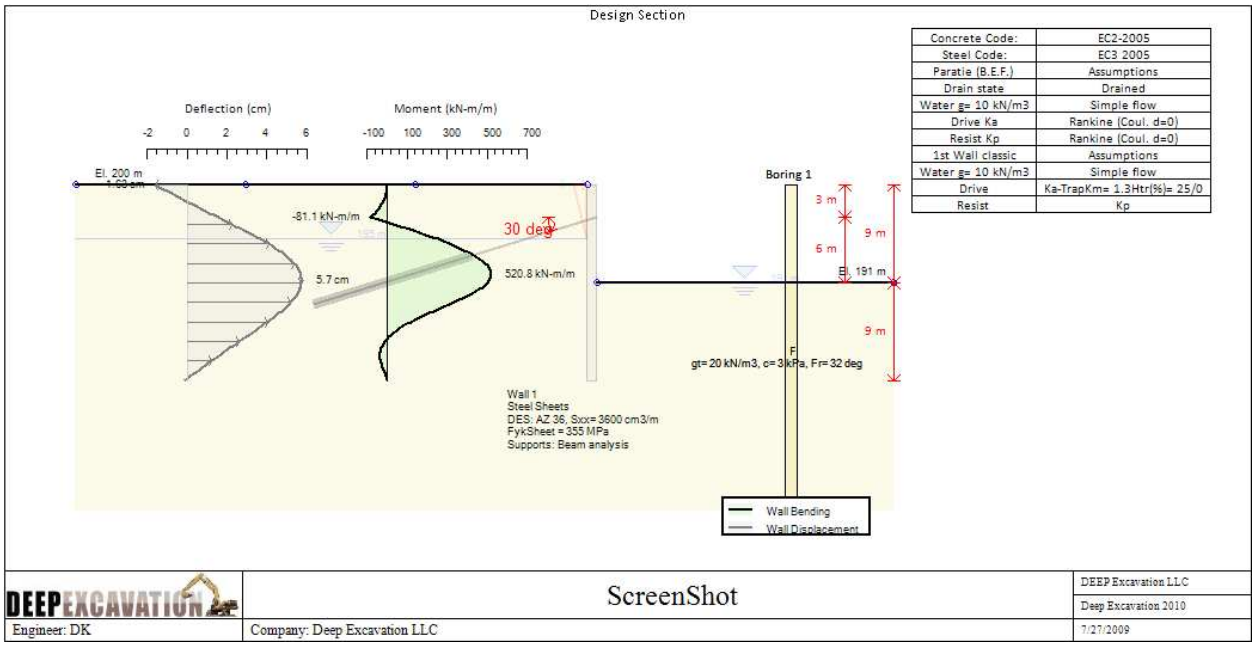

Figure 9.1: Wall bending moments and shear forces for Paratie Solution for service case.

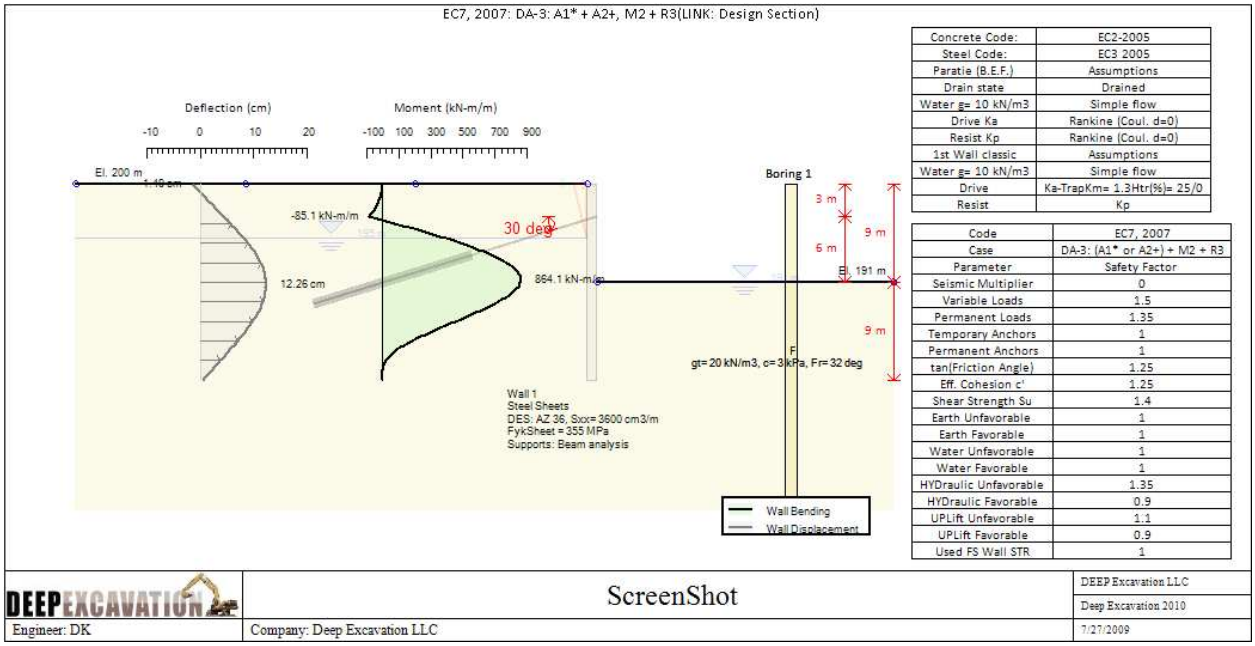

Figure 9.2: Wall bending moments and shear forces for Paratie Solution for DA3 case.

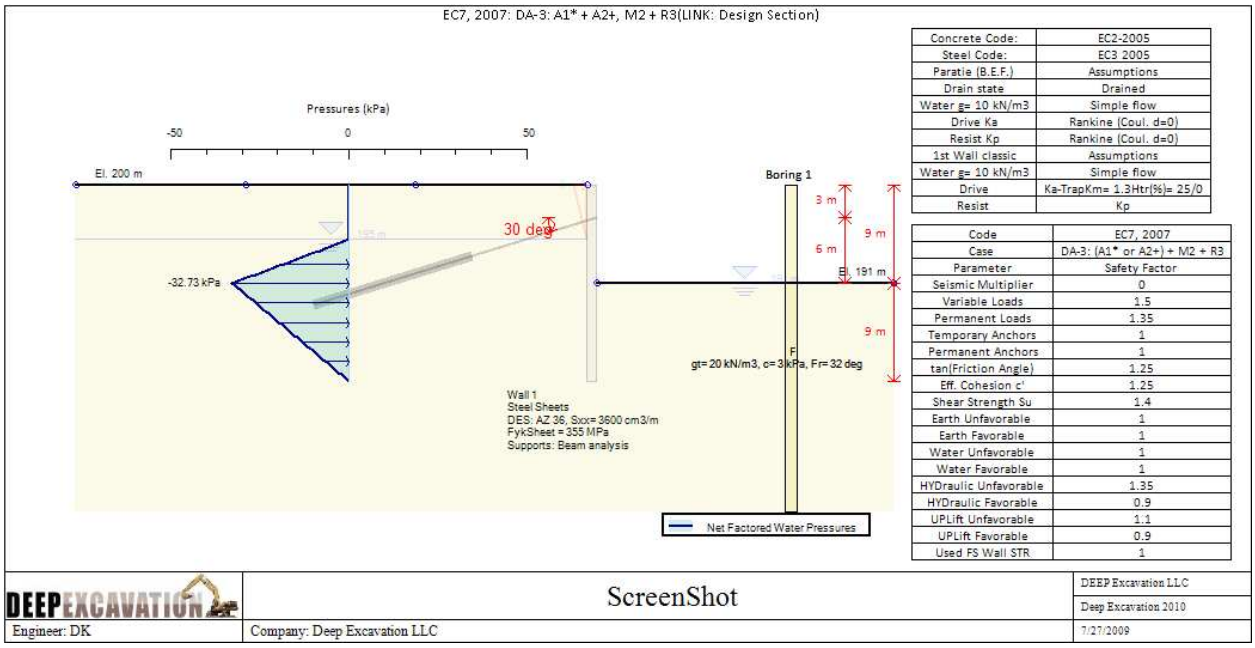

Figure 9.3: Net water pressures for Paratie Solution for DA3 case (not yet factored)

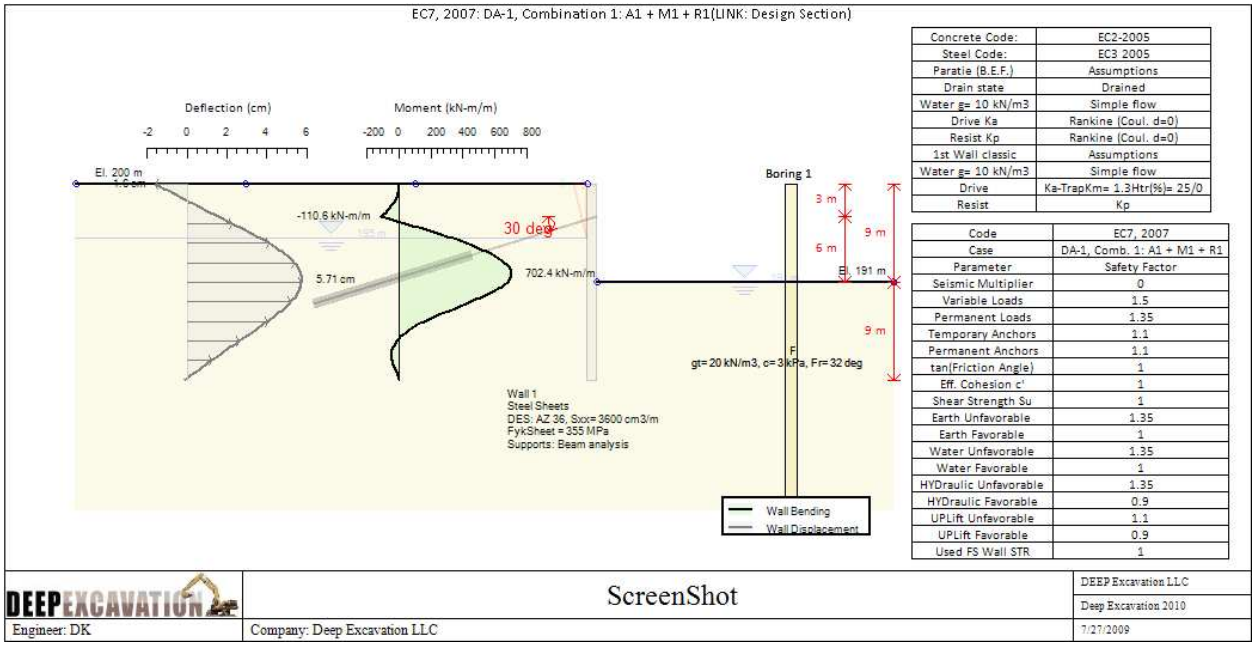

Figure 9.4: Wall bending moments and shear forces for Paratie Solution for DA1-1 case.

IMPORTANT For DA1-1:

In Paratie when Water Unfavorable or Earth Unfavorable are greater than 1, wall bending, wall shear, and support reaction results are obtained from an equivalent service analysis approach. In this approach, all surcharge magnitudes are standardized by Earth Unfavorable (1.35 in DA1-1), thus, unfavorable variable loads will be multiplied by 1.5/1.35=1.111 while permanent loads by 1.35/1.35=1. When the analysis is completed the wall moment, wall shear, and support reaction results are multiplied x 1.35. The displacements however are not multiplied.

The tieback STR & GEO capacity calculations will be performed for Case DA1-1:

gamma_r = 1.1 (temporary tieback)
gamma_su = 1 (Shear strength also used for bond values)
FS Geo = 1.0 User specified safety factor in this example, recommended value 1.35 in other conditions.

Fixed body length L_{FIX} = 9 m

Fixed body Diameter D_{FIX} = 0.15m

Ultimate Skin friction q_{ULT} = 150 kPa

Then the ultimate geotechnical capacity is:

$R_{ULT.GEO} = L_{FIX} \times \pi \times D_{FIX} \times q_{ULT}/gamma\_r)$

$R_{ULT.GEO}$ = 578.33 kN per ground anchor

The design geotechnical capacity (for stress check ratios) is calculated as:

$R_{DES.GEO} = L_{FIX} \times \pi \times D_{FIX} \times q_{ULT}/gamma\_r \times gamma\_su \times FS\ Geo) = 578.33$ kN

The Ultimate Structural capacity can be calculated as:

$R_{ULT.STR} = A_{FIX.STEEL} \times F_y/gamma\_M)$

Note that $1/gamma\_M = \phi$ in the EC = 0.87

$R_{ULT.STR} = 0.87\ A_{FIX.STEEL} \times F_y$

$R_{ULT.STR} = 0.87 \times 5.94\ cm^2 \times 1862$ MPa = 961.8 kN

These results are verified by the software program:

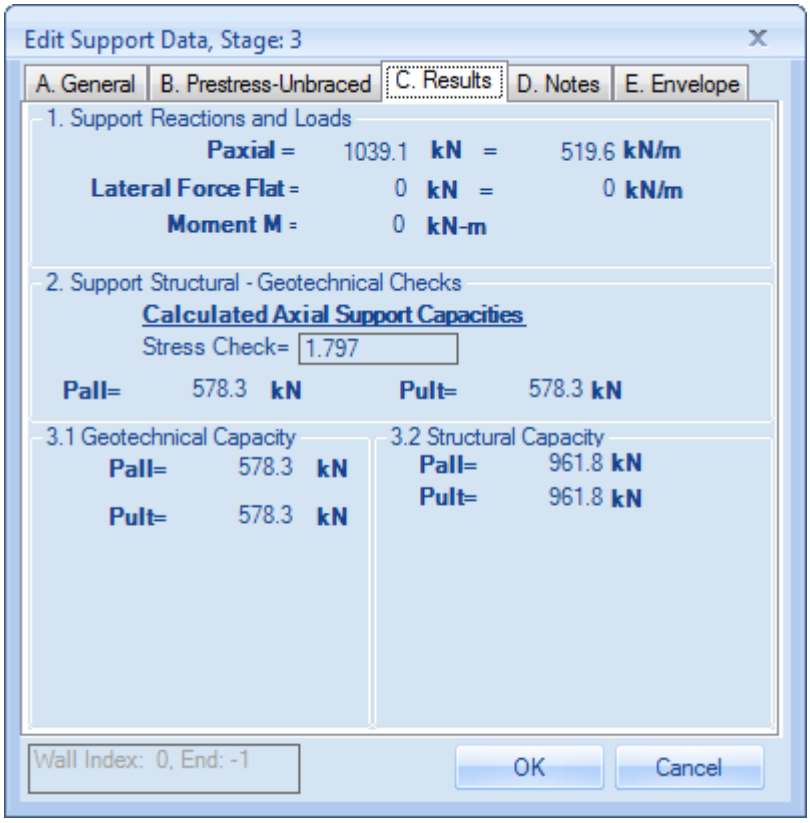

Figure 9.6: Individual support reactions/capacity

The tieback GEO capacity calculations for Case DA1-2:

gamma_r = 1.1 (temporary tieback)
gamma_su = 1.4 (Shear strength also used for bond values)
FS Geo = 1.0 In M2 cases this factor is automatically set to 1.0 in order to produce consistent capacities with available design charts for bond resistance of ground anchors (where an FS=2.0).

Fixed body length L_{FIX} = 9 m

Fixed body Diameter D_{FIX} = 0.15m

Ultimate Skin friction q_{ULT} = 150 kPa

Then the ultimate geotechnical capacity is:

$R_{ULT.GEO} = L_{FIX} \times \pi \times D_{FIX} \times q_{ULT}/gamma\_r \times gamma\_su \times FS\ Geo)$

$R_{ULT.GEO}$ = 578.33 kN per ground anchor

The design geotechnical capacity (for stress check ratios) is calculated as:

$R_{DES.GEO} = L_{FIX} \times \pi \times D_{FIX} \times q_{ULT}/gamma\_r \times gamma\_su \times FS\ Geo) = 413.1$ kN

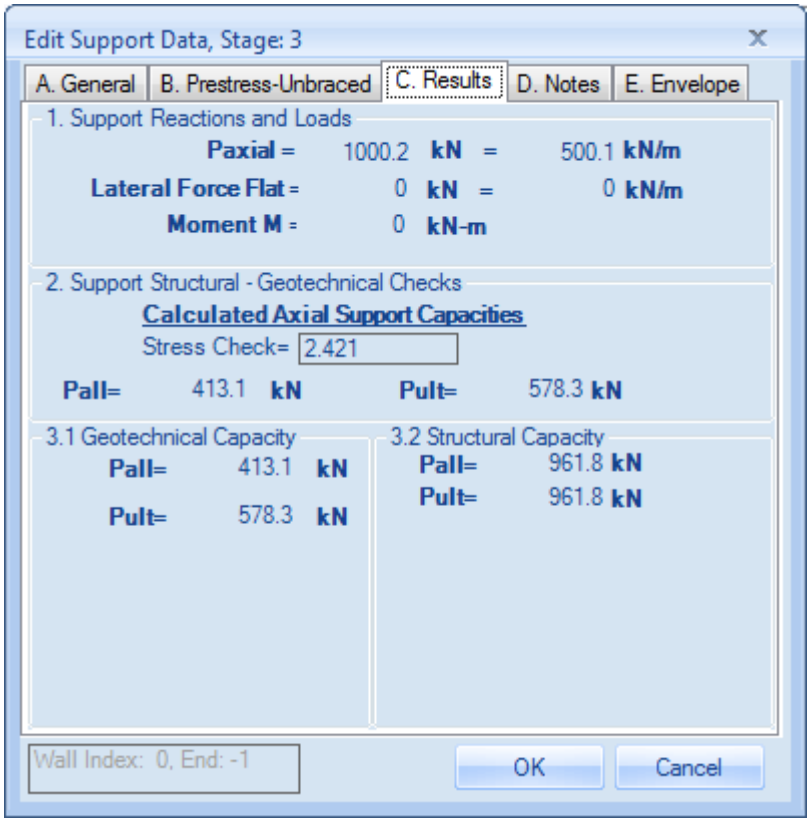

Figure 9.7: Individual support reactions/capacity for DA1-2