NATIONAL TECHNICAL UNIVERSITY OF ATHENS

Postgraduate Dissertation

GENERAL GEOTECHNICAL DESIGN FOR RETAINING WALL AND CRACKS PREVENTION, A REAPPRAISAL FOR BS 8110, BASED ON PROF. KOTSOVOS'S THEORY OF CFP (COMPRESSIVE-FORCE PATH)

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ABSTRACT

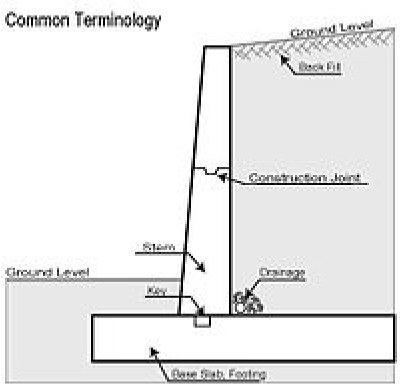
A retaining wall is a structure designed and constructed to resist the lateral pressure of soil and water when there is a change of elevation of the ground surface that exceeds e.g. the angle of repose of sand.

The main types of retaining wall among the various types of retaining wall that are used in civil engineering [10] are:

- Mass construction gravity wall;
- Reinforced concrete walls;
- Crib walls;
- Gabion walls;
- Sheet pile walls;
- Diaphragm walls;
- Reinforced soil walls;
- Anchored earth walls;

The most popular wall can be used for the case of deep excavation is the reinforced concrete cantilever wall or mass concrete wall. Both types are the free standing structure without any supports.

Typical reinforced concrete cantilever wall

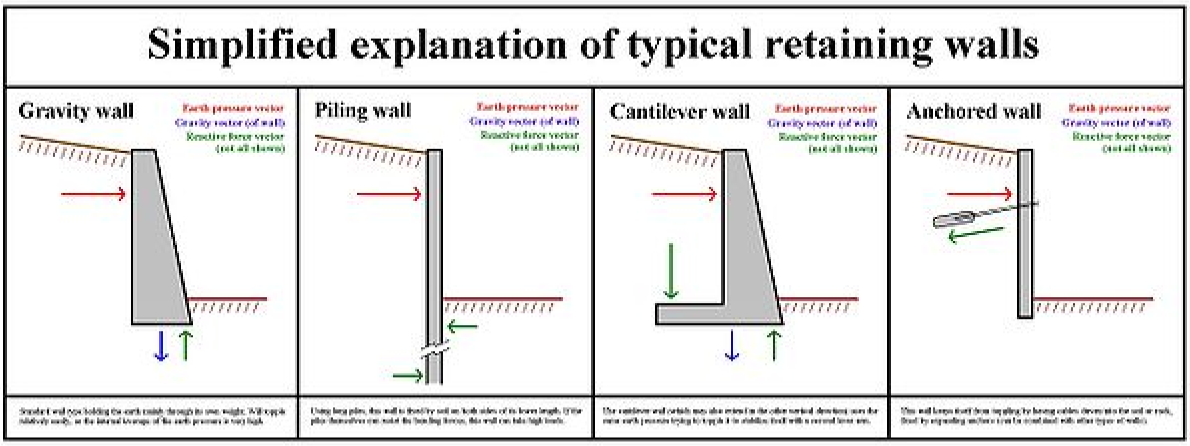


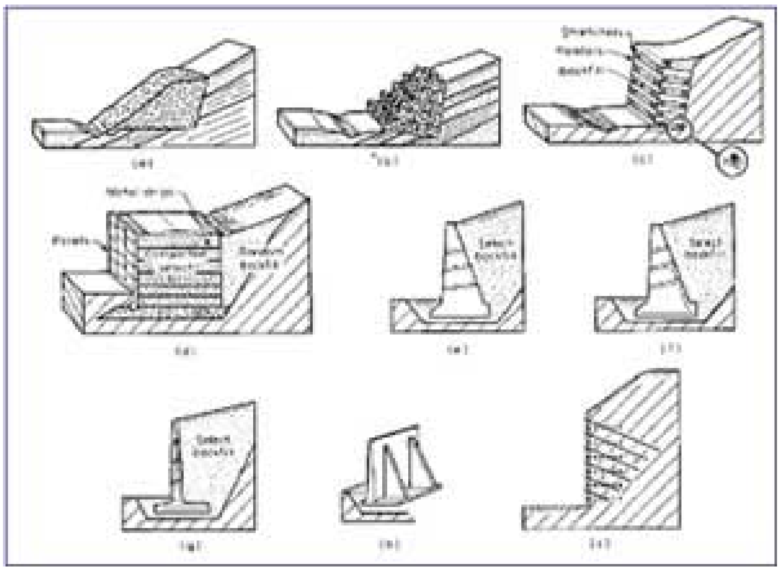
Typically retaining walls are cantilevered from a footing extending up beyond the grade on one side and retaining a higher level grade on the opposite side. The walls must resist the lateral pressures generated by different types of soils or, in some cases, water pressures, surcharge and dynamic factors (caused by traffic or seismic excitation). Different types of wall will be used for the different conditions, such as: immerse in water of not, excavation depth, temporary or permanent, construction site condition (for example: in deep excavation depth of building foundation, we will use the diaphragm or sheet pile wall due to space limitation).

The most important consideration in proper design and installation of retaining walls is to recognize and counteract the fact that the retained material is attempting to move forward and down slope due to gravity. This creates lateral earth pressure behind the wall which depends on the angle of internal friction (φ) and the cohesive strength (c) of the retained material, as well as the direction and magnitude of movement the retaining structure undergoes.

Lateral earth pressure starts increasing by the value of the surcharge or external load at the top of the wall (without is zero) and - in homogenous ground - increase proportionally to a maximum value at the lowest depth. Earth pressures acting on the wall will create the passive stress and the overturning moment to the wall. Also, the ground water behind the wall that is not dissipated by a drainage system will cause a hydrostatic pressure on the wall. Depending on the type of wall and stress (static or dynamic), the acted point will be different. The total pressure normally acts on 0,6H of the wall from the top.

Several typical types of wall





A case of deep excavation with multi-propped wall is presented in this dissertation with the comparison of different prop forces, wall moment and displacement for various design methods. The design method idealizes the earth pressures applied to the wall, determination of the embedment depth for the overall stability and use of the factor of safety.

Calculations and analyses are performed using the advanced numerical analyses as well as limit equilibrium methods. Numerical analyses were performed by using continuum finite element program PLAXIS while the analyses based on the codes of practice were performed using the ReWaRD program.

Construction of Retaining Wall

Retaining wall’s materials can be various, such as: Stone, mass concrete, reinforced concrete; steel etc. In this example, the wall is constructed by reinforced concrete. When we cut the wall in to a representative cross - section, the wall can then be designed as a single beam by the code of practice and new reappraisal [10] in design can be performed using as input data the results of the geotechnical calculation.

I/. Introduction:

The thesis includes three main parts:

- The first part: Geotechnical analyses were performed by the continuum finite element and the codes of practice by using PLAXIS and ReWaRD program, respectively.
- The second part: Structural design, the wall was designed as a simple beam by using BS 8110 code of practice.
- The third part: Design transverse reinforcement to prevent the failure, based on reappraisal in “Ultimate limit-state design of concrete structures: a new approach” for current design methods.

In this dissertation, we have the design of diaphragm retaining wall in the condition of soil layers with high friction angle and low cohesive strength. The design involves the calculation of required embedment depth for the overall stability and the use of factor safety in different codes of practice. The movements of the wall are considered as long term and the loads on the active side of the wall are increased due to ground water pressure [2].

In the geotechnical part, the structure and geotechnical calculations were performed and checked by the Finite Element program PLAXIS and the analyses based on the codes of practice were performed by using the ReWaRD program. For the reasons of safety factors and practical considerations, the structural forces calculated by limit equilibrium methods (using ReWaRD) are higher than the values obtained from numerical analyses (using PLAXIS).

The structural part concentrates in designing the wall by BS 8110, and then designing crack prevention by the theory in “Ultimate limit-state design of concrete structure: A new approach” [10], that has some reappraisals for the recent codes of practice. Eurocode somehow underestimates the capacity of the prop, since the upper prop withstands the stress that is small than the lower prop. The use of mobilization factor should be taken varying with the depth of the soil, because serviceability limit state fails to take into account the fact that the strain needed to mobilize the peak stress varies with soil and depth in the soil. On the other hand, the wall and soil deformation vary with depth, the mobilization factor should also be varied with the change of deformed shape of wall in order to be compatible with the mobilized shear strength at the observed deformation. The difference between Euro Code and BS8002 is the mobilization factor in BS8002 changes with depth while in Euro Code does not [2].

Prop loads can be obtained from Terzaghi and Peck's envelopes by dividing the distributed prop load diagrams into segments at the midpoints between the props i. e. the span will work as a simply-supported beam.

The table below presents the values of factors of safety from the comparative analyses that were performed based on the limit equilibrium method (BS 8002, Eurocode 7 and CIRIA 104).

Table 1: Partial factors applied in design standards that use limit state methods

<table>
<tr><th colspan="2">CIRIA 104</th><th colspan="2">A. Moderately Conservative (Permanent works)</th></tr>
<tr><td colspan="2">Gross pressure method</td><td colspan="2">$F_p = 1.2\text{-}2.0$ for $\varphi' = 20\text{-}30^0$</td></tr>
<tr><td colspan="2">Net pressure method</td><td colspan="2">$F_r = 1.5 - 2.0$</td></tr>
<tr><td colspan="2">Strength factor method</td><td colspan="2">$F_s = 1.2 \varphi' > 30^0$ else $F_s = 1.5$</td></tr>
<tr><td colspan="4">Action</td></tr>
<tr><td colspan="2">DESIGN STANDARD</td><td>Unfavorable (Permanent)</td><td>Favorable (Permanent)</td></tr>
<tr><td colspan="2">BS 8002</td><td colspan="2">1.0</td></tr>
<tr><td rowspan="2">EuroCode 7</td><td>A - B - C</td><td>1.0-1.35-1</td><td>0.95-1-1</td></tr>
<tr><td>Serviceability</td><td>1.0</td><td>1.0</td></tr>
</table>

Material properties				
DESIGN STANDARD		γ_{φ}	γ_{c}	γ_{cu}
BS 8002		1.2		1.5
EuroCode 7	A - B - C	1.1-1-1.25	1.3-1-1.6	1.2-1-1.4
	Serviceability	1.0		
Geometric Properties				
DESIGN STANDARD		Unplanned Excavation (Δ_H)		
BS 8002		10% of the clear height/minimum of 0.5 m		
EuroCode 7	A - B - C	10% of the clear height/minimum of 0.5 m		
	Serviceability	None		

The example was taken from a case study. The design and construction of a road running through the centre of Thessaloniki, Greece. The retaining wall under consideration is a concrete diaphragm wall in three soil layers. The first soil layer is 6m of manmade deposit (fill) with the level of ground water is 2m below the ground surface. Formation A is 8m of silty sand loose seashore sediment; formation B is 9m of a transition zone of clay and clayey sand; and formation C is a stiff to very stiff clay including thin layers of clayey sand. [1], [8].

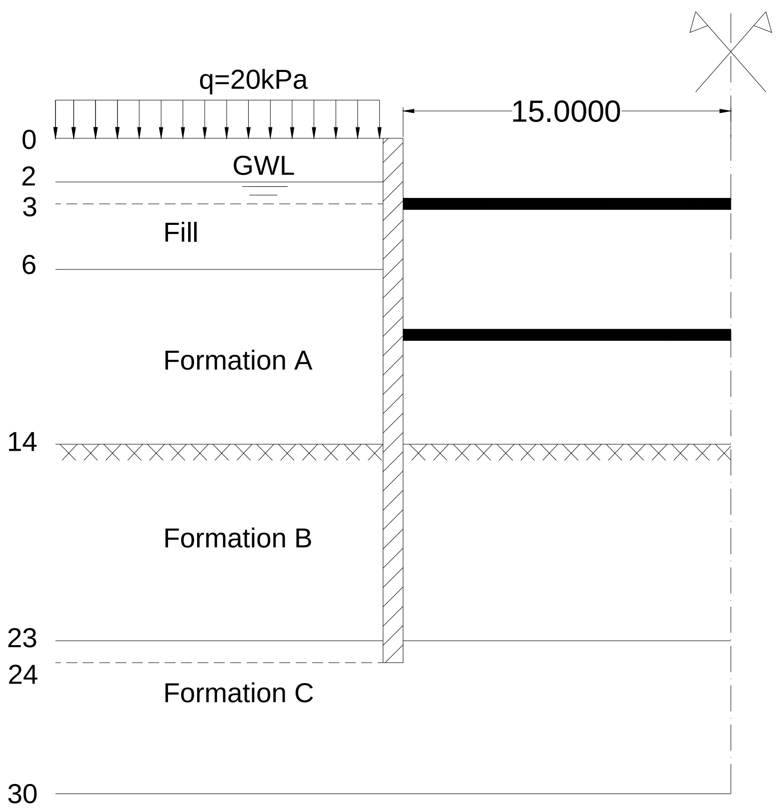
The wall is 1m thick and 24m long. The wall is assumed to behave as an elastic material with Young modulus of 20 GPA [8]. Construction progress is constructed step by step by casting concrete within a slurry stabilized trench of 4m long. The trench is excavated first and then reinforcement is installed. After casting concrete, the neighbour panel can be excavated. After all of the panels have been constructed, the major excavation was carried out with internal bracing installed as excavation progresses. The construction stages in the analyses include dewatering, excavation and installation of struts. The construction stages are simulated separately as the removal of elements.

The table and figure below show the soil properties and the schematic cross - section of the retaining wall geometry and site geology:

Table 2: Soil properties

Soil	Unit Weight (kN/m^3)	Young's Modulus E (MPa)	Friction Angle φ' (degrees)	Cohesion intercept C' (kPa)	Permeability (m/s)
Fill	21	10	33	0	$10^{-4} – 10^{-6}$
Formation A	19	15	30	0	10^{-5}
Formation B	20	30	30	5	$5x10^{-7}$
Formation C	10	50	33	15	$5x10^{-7}$

Figure 1: Cross – section of the retaining wall geometry and site geology



In BS8002, the wall and soil interaction is modelled as the simplified beam; we will use this model for the design of retaining wall's structure [3].

II/. Geotechnical Part:

The analyses were performed by the Finite Element program PLAXIS and the program based on practice codes ReWaRD.

In fact, the analyses using soil-structure interaction analyses are more reliable than either empirical methods (trapezoidal strut load) or inherently flawed methods (as advised by BS 8002 as a simplified beam).

1/. Input data and assumption:

The soil mass was modelled as an elastic/ Mohr-Coulomb plastic material [2]. The wall and the props are modelled as the beam and support, respectively. The wall is modelled as a reinforced concrete beam with the cross-section 1000x1000 mm.

The construction stages were simulated as the removal of elements. The table below describes the excavation, dewatering depth and the properties of props [8].

Table 3: Excavation, Dewatering and prop properties

Excavation depth (m)	Dewatering depth (m)	Prop number	Depth (m)	Area (m^2)	Moment of inertia (m^4)
4	5	1	3	$218x10^{-4}$	$6.6x10^{-4}$
10	11	2	9	$354x10^{-4}$	$36.0x10^{-4}$
14	14	-	-	-	-

2/. PLAXIS:

PLAXIS is a continuum finite-element program; it allows analysing by the model of plane strain or axisymmetry with the element of 6 or 15 modes. The standard elements includes fifteen - noded linear strain triangle, Soil structure interface elements, discrete bar and beam elements. The soil structure was divided into the triangle meshes; the element distribution in the structure in the analysis is very fine. The construction steps were performed and modelled by simulating the removal of elements. To model construction stages, the elements are added into the original mesh but are inactive [6]. The soil was modelled as elasto - plastic obeying Mohr-Coulomb failure criterion [1].

The construction includes six phases act as six construction stages:

- Phase 1: Install wall and external load (i. e surcharge)
- Phase 2: The first excavation
- Phase 3: Install the first strut
- Phase 4: The second excavation
- Phase 5: Install the second strut
- Phase 6: Final excavation

The calculations and analyses resulted in:

- Displacement (Total, vertical and horizontal displacement) and displacement increment.
- Increment (Total, vertical and horizontal increment)
- Total strain, total increment strain
- Effective stresses, Total stresses
- Over consolidation ratio
- Plastic point
- Active pore pressure
- Excess pore pressure
- Ground water head

- Flow field
- Axial force, shear force and bending moment in beam

All of the above values and diagrams are available in the chosen cross - section. In this thesis, we concentrate into the final results, the values that have resulted in the final construction step. The calculations can be presented in different types of graph with different advantages. The graphs can be in shading (show the affected field clearly), contour line (show the values at the important point), principal direction (show magnitude, principal direction…) etc.

Figure 2: Plot of Deformed mesh

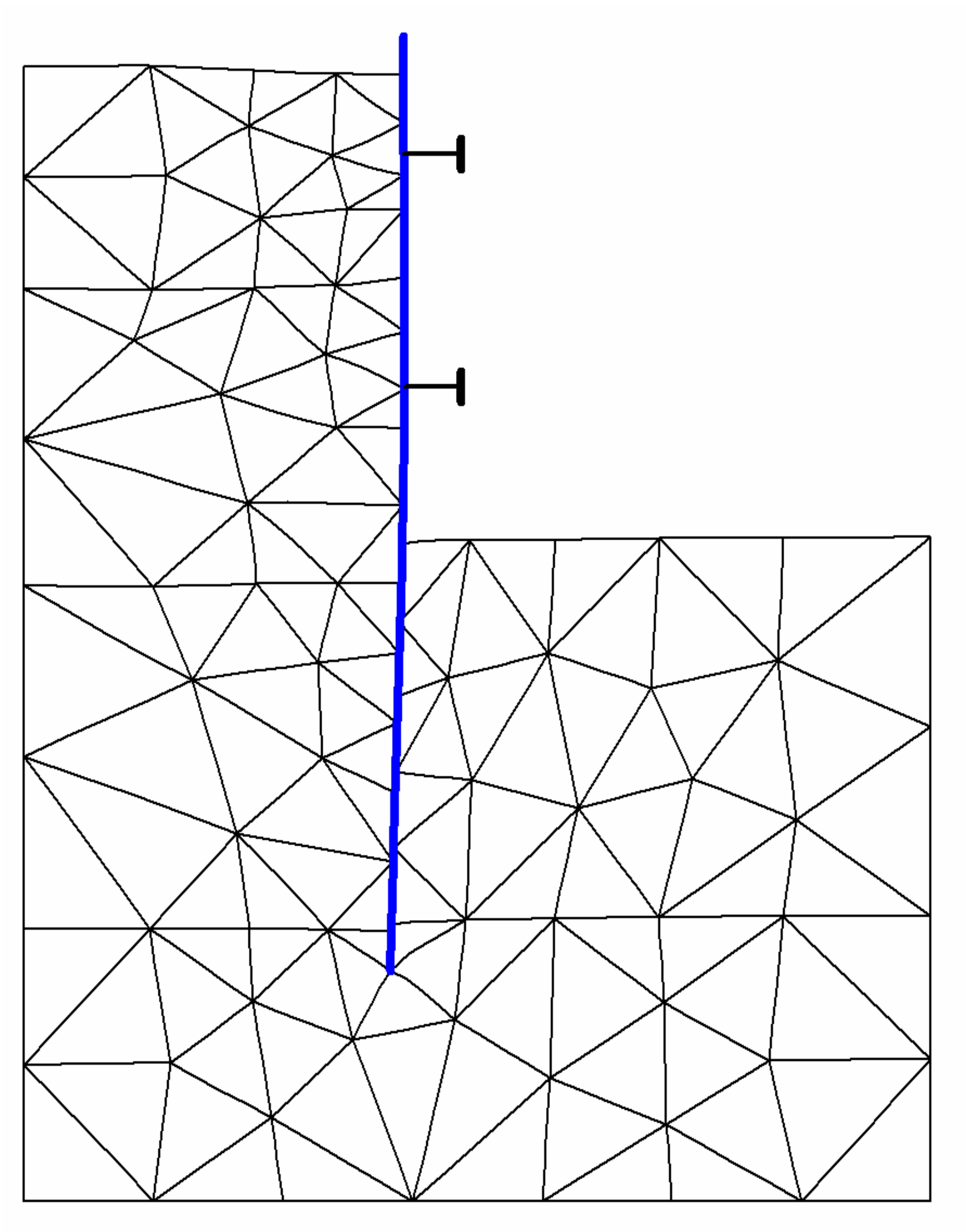


Figure 3: Plot of Total displacement (Mean shading)

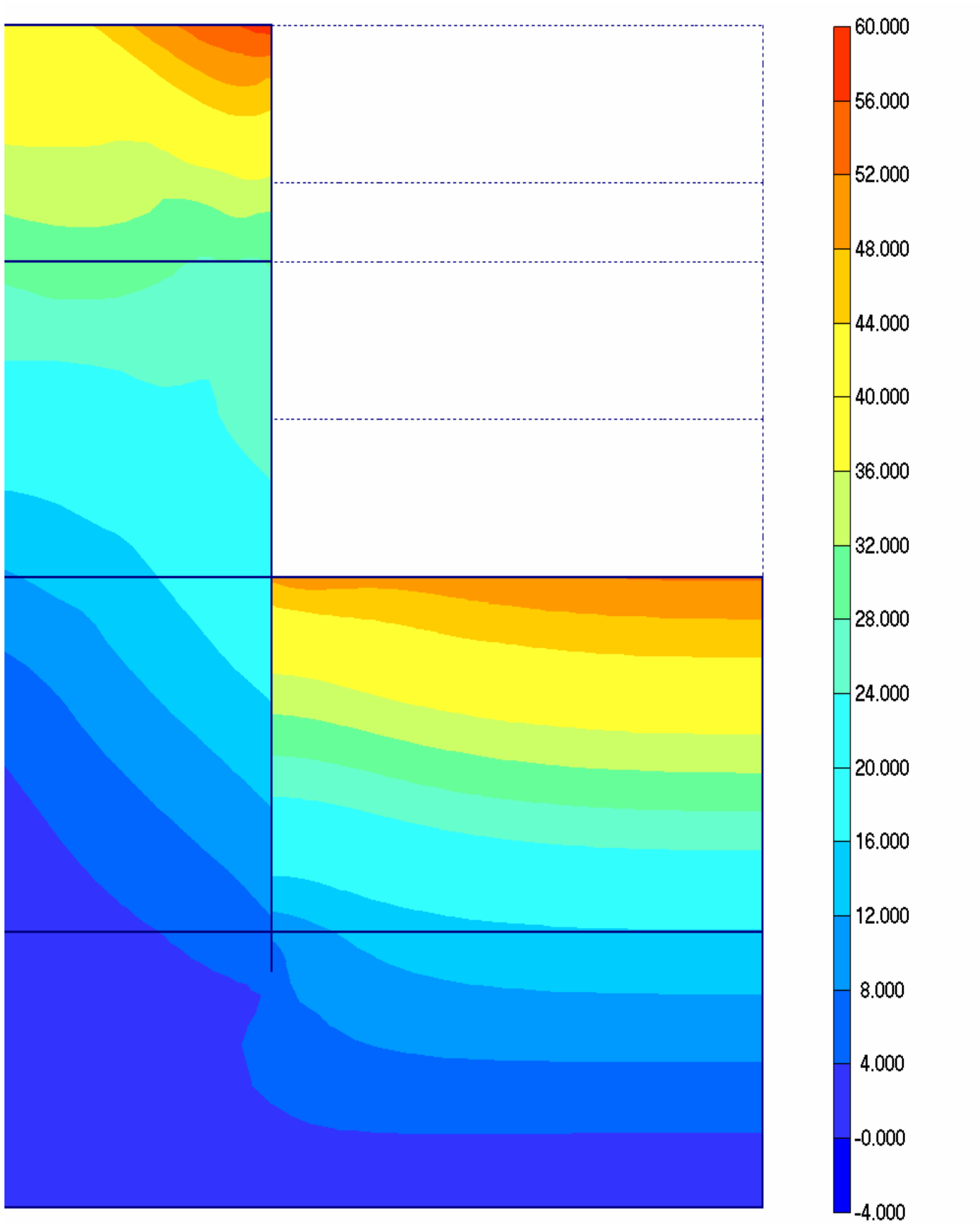


Figure 4: Plot of horizontal displacement (Contour lines)

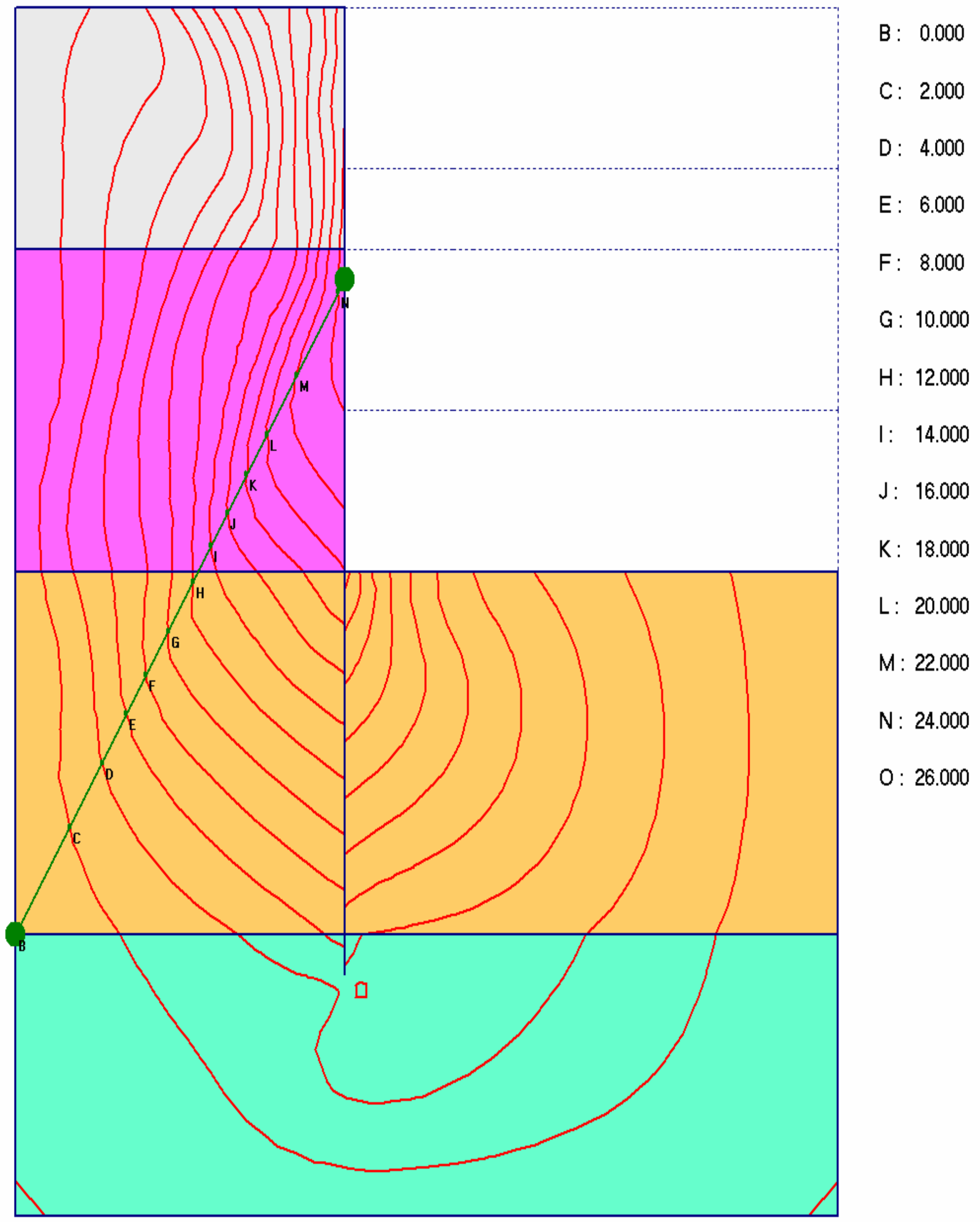
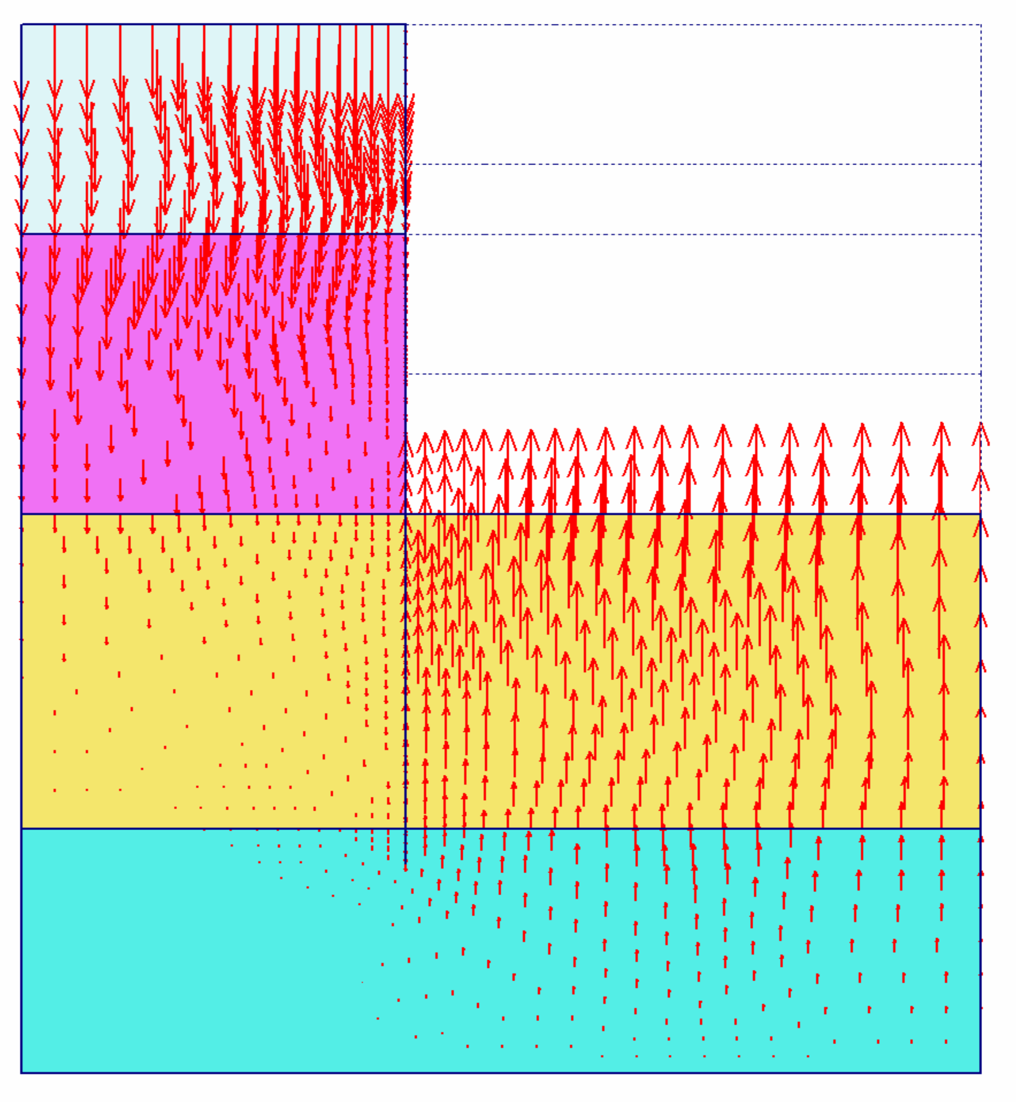


Figure 5: Plot of vertical displacement (Arrows)



The hereafter table is the displacement table that resulted from PLAXIS

Table 4: Table of Deformation phase (phase 6)

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
1	25.000	0.000	0.000	0.000	0.000	0.000
2	25.000	0.875	0.000	0.000	1.525	1.801
3	25.000	1.750	0.000	0.000	3.134	3.664
4	25.000	2.625	0.000	0.000	4.808	5.584
5	22.321	0.000	0.000	0.000	0.000	0.000
6	23.214	0.000	0.000	0.000	0.000	0.000
7	24.107	0.000	0.000	0.000	0.000	0.000
29	25.000	4.375	0.000	0.000	8.268	9.569
30	25.000	5.250	0.000	0.000	10.005	11.624
31	25.000	6.125	0.000	0.000	11.708	13.712
38	25.000	3.500	0.000	0.000	6.527	7.554
55	18.750	0.000	0.000	0.000	0.000	0.000
56	19.643	0.000	0.000	0.000	0.000	0.000
57	20.536	0.000	0.000	0.000	0.000	0.000
64	21.429	0.000	0.000	0.000	0.000	0.000
65	23.971	7.000	128.914	555.469	13.346	15.814
66	22.941	7.000	298.141	1.110	13.333	15.762
67	21.912	7.000	546.726	1.663	13.278	15.672
71	25.000	7.000	0.000	0.000	13.347	15.831
75	25.000	8.125	0.000	0.000	16.579	20.268
76	25.000	9.250	0.000	0.000	19.457	24.775
77	25.000	10.375	0.000	0.000	21.896	29.337
81	17.857	0.000	0.000	0.000	0.000	0.000
85	15.179	0.000	0.000	0.000	0.000	0.000
86	16.071	0.000	0.000	0.000	0.000	0.000
87	16.964	0.000	0.000	0.000	0.000	0.000
97	20.882	7.000	910.852	2.212	13.133	15.540
98	20.016	7.000	1.328	2.667	12.893	15.392
99	19.151	7.000	1.859	3.114	12.492	15.204
100	18.285	7.000	2.505	3.548	11.882	14.970
145	14.286	0.000	0.000	0.000	0.000	0.000
149	11.607	0.000	0.000	0.000	0.000	0.000

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
150	12.500	0.000	0.000	0.000	0.000	0.000
151	13.393	0.000	0.000	0.000	0.000	0.000
171	25.000	11.500	0.000	0.000	23.822	33.937
175	25.000	12.625	0.000	0.000	25.164	38.560
176	25.000	13.750	0.000	0.000	26.258	43.182
177	25.000	14.875	0.000	0.000	26.791	47.802
181	16.691	7.000	3.936	4.294	10.064	14.388
182	15.963	7.000	4.643	4.602	8.902	14.042
183	15.235	7.000	5.336	4.881	7.548	13.632
187	17.419	7.000	3.252	3.964	11.016	14.681
235	25.000	16.000	0.000	0.000	25.259	52.461
236	23.971	16.000	-2.318	640.457	28.189	52.465
237	22.941	16.000	-6.264	1.255	28.054	52.372
238	21.912	16.000	-10.025	1.877	28.434	52.244
251	14.508	7.000	5.969	5.128	6.050	13.148
255	13.895	7.000	6.415	5.307	4.736	12.668
256	13.283	7.000	6.772	5.459	3.452	12.112
257	12.671	7.000	7.016	5.590	2.291	11.460
298	10.000	8.350	9.551	8.652	-24.322	-4.341
299	10.000	7.900	7.811	7.988	-24.307	-4.329
300	10.000	7.450	6.099	7.322	-24.291	-4.318
323	12.059	7.000	7.105	5.699	1.328	10.677
327	11.544	7.000	7.042	5.763	1.189	9.916
328	11.029	7.000	6.418	5.899	276.348	8.932
329	10.515	7.000	5.437	5.993	-2.138	7.964
333	10.000	7.000	3.652	6.860	-1.361	5.677
337	10.000	6.750	3.457	6.278	-24.269	-4.302
338	10.000	6.500	2.511	5.903	-24.260	-4.297
339	10.000	6.250	1.565	5.527	-24.252	-4.292
340	10.000	7.000	4.398	6.652	-24.276	-4.308
383	20.882	16.000	-12.359	2.524	30.149	52.081
384	20.016	16.000	-15.143	3.066	29.938	51.853
385	19.151	16.000	-20.919	3.598	30.316	51.589
386	18.285	16.000	-28.497	4.144	31.488	51.295
399	10.714	0.000	0.000	0.000	0.000	0.000

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
400	8.036	0.000	0.000	0.000	0.000	0.000
401	8.929	0.000	0.000	0.000	0.000	0.000
402	9.821	0.000	0.000	0.000	0.000	0.000
409	7.143	0.000	0.000	0.000	0.000	0.000
413	4.464	0.000	0.000	0.000	0.000	0.000
414	5.357	0.000	0.000	0.000	0.000	0.000
415	6.250	0.000	0.000	0.000	0.000	0.000
473	10.000	10.150	17.084	11.301	-24.394	-4.390
474	10.000	9.700	15.089	10.637	-24.375	-4.377
475	10.000	9.250	13.177	9.976	-24.357	-4.365
476	10.000	8.800	11.335	9.314	-24.339	-4.353
497	10.000	10.600	19.169	11.968	-24.415	-4.403
498	10.000	11.950	25.999	14.005	-24.486	-4.444
499	10.000	11.500	23.629	13.318	-24.461	-4.430
500	10.000	11.050	21.351	12.640	-24.437	-4.417
549	10.000	6.000	619.728	5.149	-24.244	-4.287
559	10.000	7.000	4.705	6.452	-20.246	-3.712
563	9.572	7.000	4.837	6.151	-17.172	-2.939
564	9.145	7.000	4.552	5.777	-13.928	-2.248
565	8.717	7.000	3.996	5.368	-11.231	-1.753
591	17.419	16.000	-36.680	4.738	33.129	50.942
592	16.691	16.000	-42.293	5.265	29.956	50.528
593	15.963	16.000	-50.464	5.819	27.488	50.094
594	15.235	16.000	-60.750	6.452	26.374	49.641
601	14.508	16.000	-62.810	7.208	33.157	49.173
602	13.895	16.000	-52.674	7.999	52.192	48.822
603	13.283	16.000	-34.374	9.005	78.191	48.594
604	12.671	16.000	-16.181	10.287	104.318	48.504
679	10.000	12.400	28.446	14.701	-24.515	-4.458
680	10.000	13.750	35.930	16.848	-24.622	-4.500
681	10.000	13.300	33.461	16.123	-24.581	-4.486
682	10.000	12.850	30.946	15.407	-24.546	-4.472
689	3.571	0.000	0.000	0.000	0.000	0.000
690	0.000	2.625	0.000	0.000	606.343	207.433
691	0.000	1.750	0.000	0.000	348.945	185.883

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
692	0.000	0.875	0.000	0.000	136.723	117.201
693	0.000	0.000	0.000	0.000	0.000	0.000
694	0.893	0.000	0.000	0.000	0.000	0.000
695	1.786	0.000	0.000	0.000	0.000	0.000
696	2.679	0.000	0.000	0.000	0.000	0.000
713	10.000	14.200	38.259	17.580	-24.668	-4.515
714	10.000	15.550	42.547	19.769	-24.775	-4.560
715	10.000	15.100	41.773	19.049	-24.753	-4.544
716	10.000	14.650	40.303	18.316	-24.717	-4.529
775	8.290	7.000	3.390	4.975	-9.137	-1.445
779	7.751	7.000	2.874	4.596	-7.045	-1.190
780	7.212	7.000	2.477	4.260	-5.377	-1.021
781	6.674	7.000	2.169	3.949	-3.978	-889.184
811	6.135	7.000	1.924	3.651	-2.767	-777.689
812	5.456	7.000	1.674	3.280	-1.449	-658.770
813	4.778	7.000	1.484	2.909	-360.964	-559.474
814	4.099	7.000	1.357	2.530	469.944	-481.167
821	0.000	3.500	0.000	0.000	878.346	184.436
825	0.000	6.125	0.000	0.000	1.413	-147.777
826	0.000	5.250	0.000	0.000	1.336	10.422
827	0.000	4.375	0.000	0.000	1.140	119.533
905	11.544	16.000	6.737	13.336	148.901	48.589
906	11.029	16.000	12.688	15.064	152.508	47.937
907	10.515	16.000	23.396	17.744	135.687	46.839
911	10.000	16.000	55.746	20.951	99.878	44.303
915	10.000	16.000	42.607	20.466	-24.783	-4.574
916	10.000	17.500	38.779	22.483	-24.792	-4.621
917	10.000	17.000	40.647	21.874	-24.790	-4.606
918	10.000	16.500	41.950	21.199	-24.787	-4.591
919	12.059	16.000	-14.181	11.891	121.547	48.489
961	10.000	16.000	42.817	19.954	-23.770	-6.663
962	9.572	16.000	43.074	19.205	-23.993	-6.705
963	9.145	16.000	42.730	18.547	-25.053	-6.676
964	8.717	16.000	42.054	17.940	-26.469	-6.628
981	10.000	18.000	36.433	23.022	-24.793	-4.635

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
982	10.000	19.500	27.496	24.197	-24.793	-4.675
983	10.000	19.000	30.687	23.877	-24.793	-4.662
984	10.000	18.500	33.702	23.486	-24.794	-4.649
1017	3.420	7.000	1.282	2.141	1.055	-426.021
1018	2.565	7.000	1.049	1.634	1.444	-380.425
1019	1.710	7.000	808.570	1.107	1.523	-365.577
1020	0.855	7.000	441.140	559.777	1.410	-363.462
1021	0.000	7.000	0.000	0.000	1.320	-363.842
1025	0.000	10.375	0.000	0.000	-2.230	-2.366
1026	0.000	9.250	0.000	0.000	-1.037	-1.423
1027	0.000	8.125	0.000	0.000	742.822	-786.917
1083	10.000	20.000	24.242	24.451	-24.792	-4.686
1084	10.000	20.750	19.489	24.728	-24.791	-4.703
1085	10.000	20.500	21.037	24.648	-24.791	-4.698
1086	10.000	20.250	22.627	24.556	-24.792	-4.692
1097	10.000	21.000	17.994	24.798	-24.791	-4.708
1098	10.000	22.125	12.560	25.071	-24.790	-4.730
1099	10.000	21.750	14.239	25.003	-24.790	-4.723
1100	10.000	21.375	16.047	24.911	-24.790	-4.716
1117	8.290	16.000	41.256	17.363	-27.224	-6.547
1118	7.751	16.000	41.153	16.593	-28.761	-6.464
1119	7.212	16.000	40.559	15.793	-31.916	-6.314
1120	6.674	16.000	35.305	14.949	-34.781	-6.219
1127	0.000	11.500	0.000	0.000	3.160	-3.846
1131	0.000	14.875	0.000	0.000	-6.760	-7.784
1132	0.000	13.750	0.000	0.000	3.351	-6.238
1133	0.000	12.625	0.000	0.000	5.337	-5.076
1147	10.000	22.500	10.995	25.115	-24.789	-4.736
1148	10.000	23.625	6.882	25.095	-24.788	-4.754
1149	10.000	23.250	8.167	25.126	-24.789	-4.748
1150	10.000	22.875	9.535	25.133	-24.789	-4.743
1167	6.135	16.000	27.180	14.071	-37.262	-6.387
1168	5.456	16.000	21.062	12.200	-33.665	-7.623
1169	4.778	16.000	22.725	10.017	-17.419	-9.269
1170	4.099	16.000	19.168	8.188	-11.095	-10.317

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
1197	10.000	24.000	5.670	25.040	-24.788	-4.759
1198	10.000	25.500	1.369	24.633	-24.787	-4.777
1199	10.000	25.000	2.725	24.796	-24.788	-4.771
1200	10.000	24.500	4.152	24.934	-24.788	-4.766
1221	10.000	30.000	-10.227	23.299	-24.784	-4.798
1222	10.000	29.625	-9.256	23.394	-24.784	-4.798
1223	10.000	29.250	-8.284	23.489	-24.784	-4.798
1224	10.000	28.875	-7.312	23.583	-24.784	-4.797
1261	10.000	26.000	65.301	24.454	-24.787	-4.781
1262	10.000	26.750	-1.835	24.174	-24.786	-4.787
1263	10.000	26.500	-1.206	24.267	-24.786	-4.785
1264	10.000	26.250	-573.118	24.360	-24.787	-4.783
1280	10.000	27.000	-2.463	24.083	-24.786	-4.789
1281	10.000	28.500	-6.340	23.678	-24.784	-4.796
1282	10.000	28.125	-5.369	23.774	-24.785	-4.795
1283	10.000	27.750	-4.398	23.872	-24.785	-4.793
1284	10.000	27.375	-3.430	23.975	-24.786	-4.791
1291	2.565	16.000	19.156	5.338	-15.446	-10.949
1292	1.710	16.000	20.734	3.930	-22.710	-10.735
1293	0.855	16.000	13.688	2.200	-24.641	-10.357
1294	0.000	16.000	0.000	0.000	-23.262	-10.335
1295	0.000	19.000	0.000	0.000	-47.200	-18.936
1296	0.000	18.000	0.000	0.000	-46.276	-16.144
1297	0.000	17.000	0.000	0.000	-37.525	-13.118
1301	3.420	16.000	16.777	6.835	-11.351	-10.834
1369	10.000	24.000	6.106	24.751	-24.467	-13.824
1370	9.572	24.000	6.561	22.320	-25.876	-16.435
1371	9.145	24.000	7.002	19.475	-27.351	-19.715
1372	8.717	24.000	7.409	16.724	-28.881	-22.527
1405	0.000	20.000	0.000	0.000	-43.599	-20.707
1409	0.000	23.000	0.000	0.000	-62.795	-26.625
1410	0.000	22.000	0.000	0.000	-48.388	-24.727
1411	0.000	21.000	0.000	0.000	-36.816	-22.798
1469	8.290	24.000	7.764	14.934	-30.461	-23.523
1470	7.751	24.000	8.149	13.942	-32.549	-24.130

Node No.	X-coord.	Y-coord.	dU_x [10^-6 m]	U_x [10^-3 m]	dU_y [10^-6 m]	U_y [10^-3 m]
1471	7.212	24.000	8.392	12.961	-34.762	-24.997
1472	6.674	24.000	8.506	11.784	-37.112	-26.265
1489	6.135	24.000	8.624	10.345	-39.795	-27.592
1490	5.456	24.000	7.441	8.765	-44.139	-28.611
1491	4.778	24.000	4.963	7.456	-50.731	-29.177
1492	4.099	24.000	6.553	6.247	-53.829	-29.513
1502	10.000	30.000	-10.245	23.397	-28.982	-53.203
1503	9.572	30.000	-10.466	20.807	-29.675	-53.535
1504	9.145	30.000	-10.887	19.080	-30.598	-53.018
1505	8.717	30.000	-11.354	17.529	-31.773	-52.506
1519	0.000	24.000	0.000	0.000	-70.812	-28.618
1520	2.565	24.000	9.158	3.799	-58.290	-29.341
1521	1.710	24.000	7.905	2.496	-61.836	-28.974
1522	0.855	24.000	5.551	1.243	-68.214	-28.723
1523	0.000	26.250	0.000	0.000	-69.319	-33.696
1524	0.000	25.500	0.000	0.000	-70.798	-32.113
1525	0.000	24.750	0.000	0.000	-72.295	-30.398
1535	3.420	24.000	8.055	5.134	-56.694	-29.595
1556	8.290	30.000	-11.786	15.894	-33.170	-52.097
1565	0.000	27.000	0.000	0.000	-68.656	-35.152
1587	6.135	30.000	-12.835	10.436	-42.199	-48.282
1591	7.751	30.000	-12.245	14.933	-35.157	-51.405
1592	7.212	30.000	-12.586	13.609	-37.359	-50.598
1593	6.674	30.000	-12.786	12.050	-39.722	-49.612
1598	3.420	30.000	-10.501	3.041	-55.072	-41.970
1610	5.456	30.000	-12.671	8.294	-45.416	-46.332
1614	4.778	30.000	-12.245	6.069	-48.683	-44.210
1615	4.099	30.000	-11.531	4.276	-51.930	-42.657
1616	0.855	30.000	-3.292	610.019	-63.723	-42.986
1620	2.565	30.000	-8.666	2.354	-58.730	-41.968
1621	0.000	29.250	0.000	0.000	-65.533	-41.421
1622	0.000	28.500	0.000	0.000	-66.450	-39.556
1623	0.000	27.750	0.000	0.000	-67.435	-37.436
1624	1.710	30.000	-6.242	1.406	-61.721	-42.496

Figure 6: Plot of effective stresses (Principal direction)

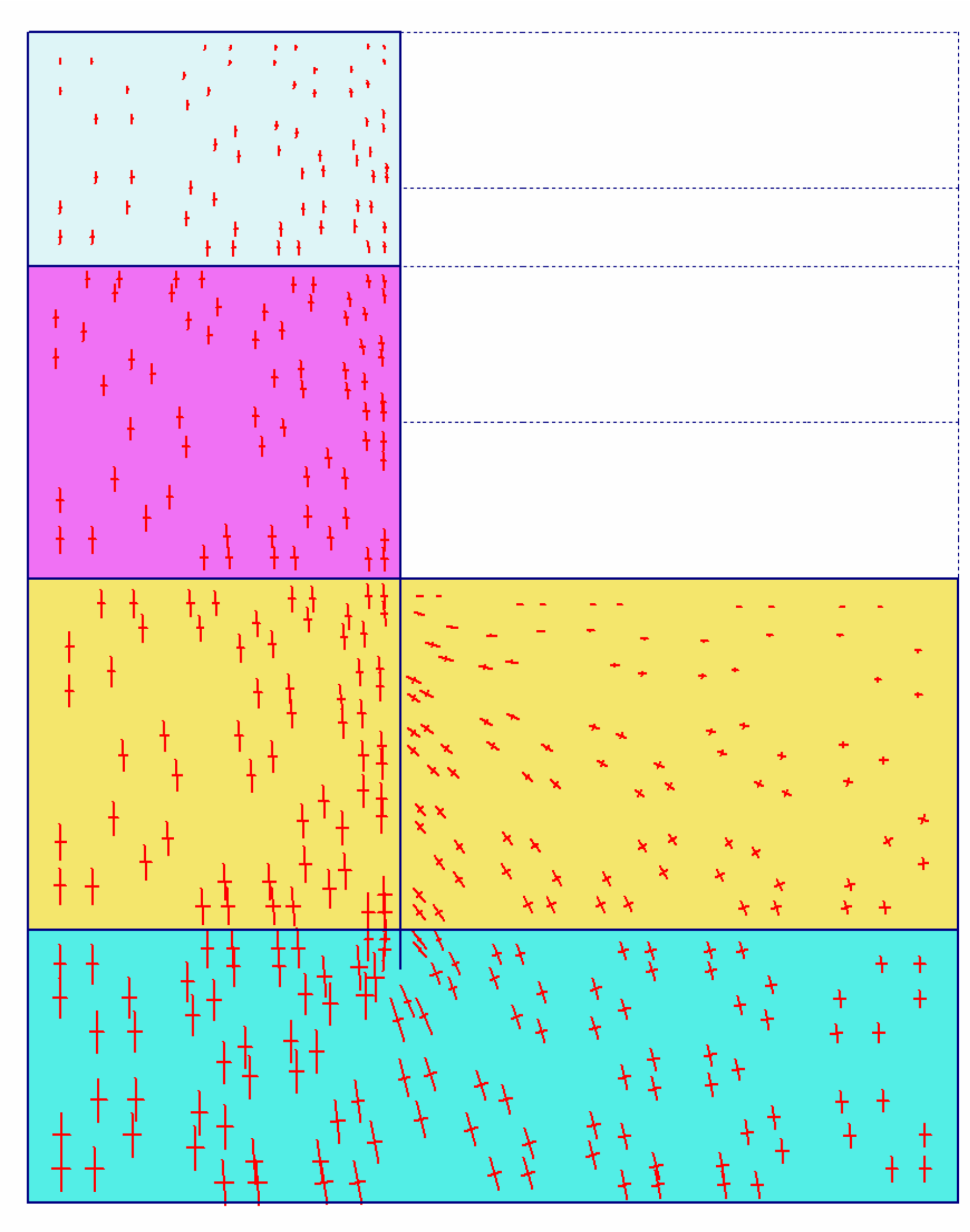


Figure 7: Plot of effective stresses (Mean shading)

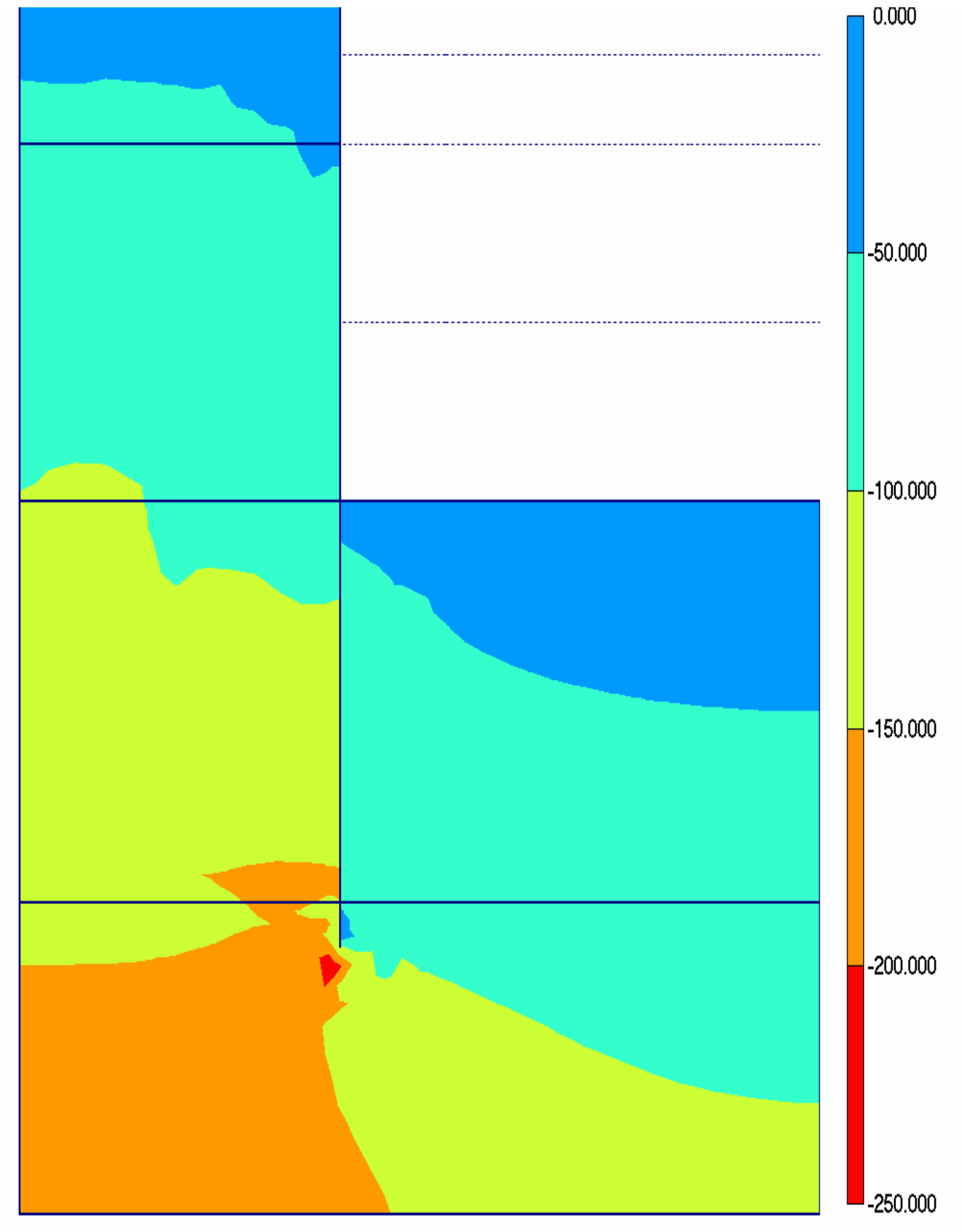


Figure 8: Plot of total stresses (Principal direction)

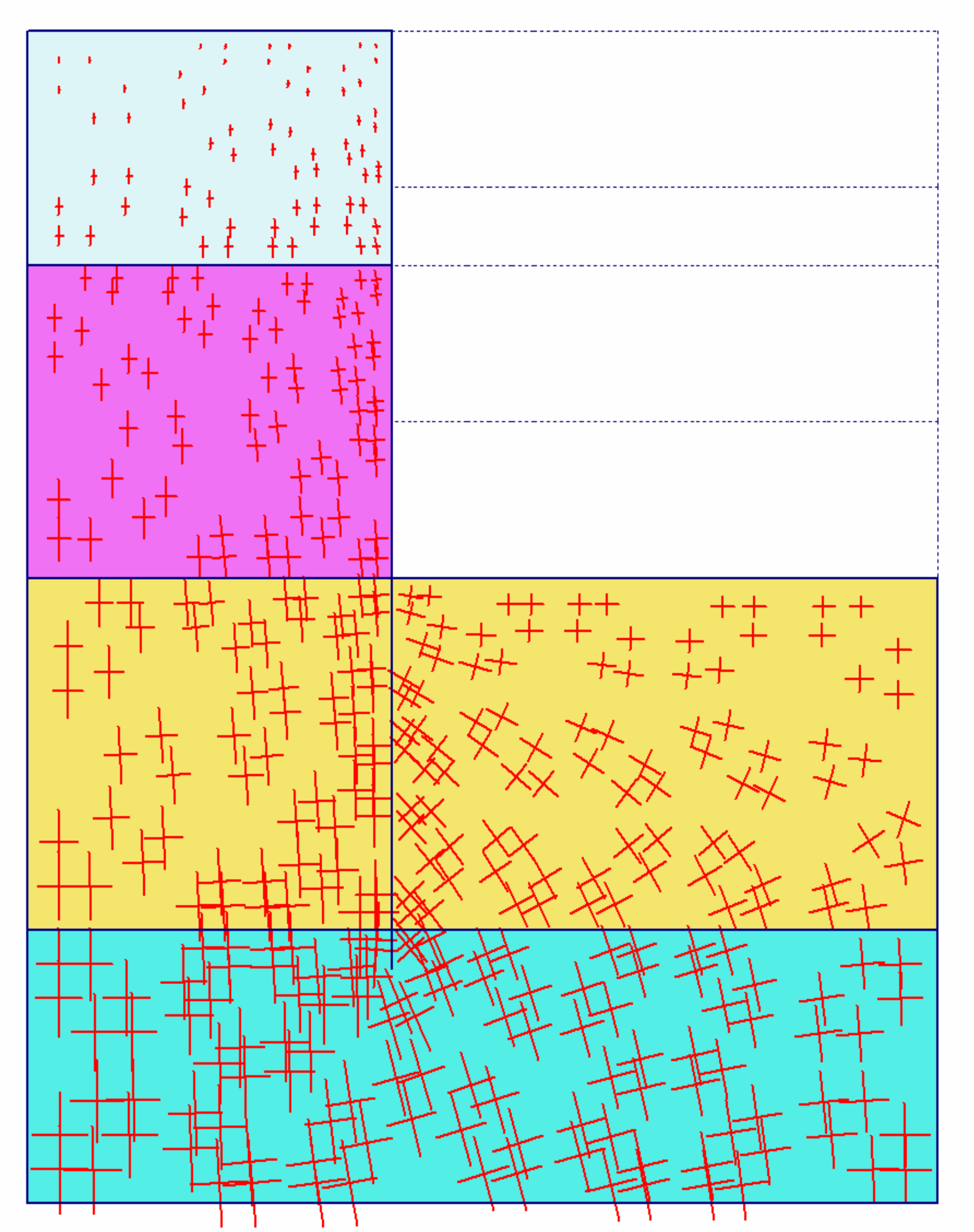


Figure 9: Plot of total stresses (Mean Shading)

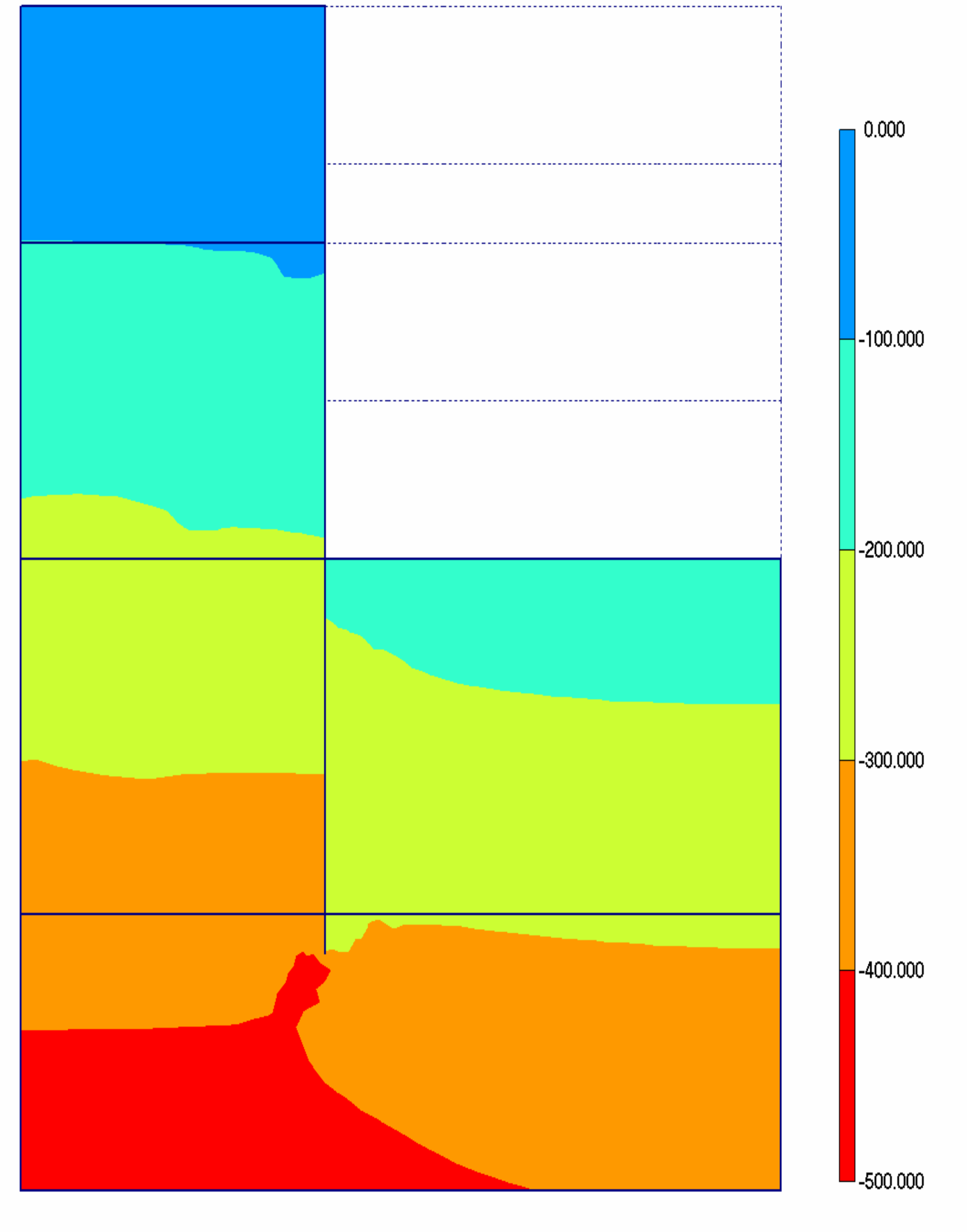


Table 5: Total Stresses

Cluster	Soil element	X-coord. [m]	Y-coord. [m]	σ_{xx} [kN/m²]	σ_{yy} [kN/m²]	σ_{xy} [kN/m²]	σ_{zz} [kN/m²]
1	1	17.368	5.168	-312.191	-353.661	11.945	-295.968
		34.613	12.036	-601.144	-672.171	24.362	-567.334
		49.497	18.904	-887.176	-998.944	42.778	-840.303
	2	11.969	4.843	-322.065	-389.279	32.309	-310.969
		26.150	11.688	-606.978	-719.093	52.928	-584.612
		38.346	18.532	-887.859	-1056.125	84.008	-859.211
	3	11.799	6.937	-287.921	-338.302	36.838	-276.706
		21.929	13.874	-593.023	-593.455	80.204	-533.621
		32.059	20.000	-859.510	-819.698	99.134	-773.658
	4	8.506	6.937	-286.147	-476.815	8.668	-317.727
		18.398	13.063	-570.237	-866.261	-47.307	-612.007
		28.290	20.000	-860.176	-1328.753	-54.928	-926.575
	5	6.387	5.373	-323.679	-484.004	5.630	-337.664
		14.413	12.255	-614.822	-952.577	16.975	-654.644
		20.692	19.138	-908.939	-1410.491	26.438	-969.319
	6	6.079	5.373	-322.712	-483.780	5.574	-337.306
		12.052	12.255	-616.633	-940.785	14.523	-651.649
		15.823	19.138	-907.712	-1395.064	20.863	-964.323
	7	0.216	3.942	-343.035	-507.120	0.289	-356.372
		3.205	10.721	-634.994	-963.219	5.569	-670.285
		3.420	17.500	-924.448	-1421.023	6.066	-983.959
	8	17.770	5.168	-312.028	-352.424	11.251	-295.548
		38.225	12.036	-601.466	-663.789	17.663	-564.916
		55.872	18.904	-890.646	-981.128	29.219	-835.999
	9	21.402	6.779	-290.395	-311.944	4.963	-270.198
		46.142	10.721	-613.947	-680.064	5.399	-579.025
		70.882	17.500	-903.867	-990.075	5.743	-848.500
	10	21.879	0.221	-360.493	-448.069	7.490	-359.405
		46.654	0.442	-720.192	-894.413	8.024	-718.055
		71.429	3.500	-1053.215	-1280.861	8.438	-1038.903
	11	10.242	5.970	-256.016	-249.432	30.062	-244.502
		21.927	10.751	-583.564	-645.714	68.216	-559.480

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	**σ xx** [kN/m²]	**σ yy** [kN/m²]	**σ xy** [kN/m²]	**σ zz** [kN/m²]
		33.838	17.532	-856.395	-972.530	96.391	-828.862
	12	14.261	3.398	-340.566	-405.916	20.894	-327.535
		28.591	9.994	-629.996	-740.974	40.586	-605.143
		40.709	14.588	-954.698	-1135.863	71.637	-919.624
	13	8.994	4.433	-318.355	-537.315	10.801	-355.978
		18.821	10.378	-627.754	-1086.423	-28.874	-706.502
		27.261	17.135	-919.791	-1562.615	-16.565	-1026.563
	14	8.758	4.379	-328.839	-531.221	5.747	-357.521
		16.963	11.080	-620.988	-1003.755	18.416	-676.745
		23.529	16.273	-947.835	-1491.348	23.445	-1017.190
	15	3.121	0.221	-411.110	-573.108	5.901	-412.102
		3.346	3.279	-770.196	-1095.869	6.207	-781.664
		3.571	3.500	-1181.286	-1668.163	6.594	-1193.515
	16	4.113	3.872	-343.966	-509.763	3.860	-357.732
		10.058	9.028	-669.541	-997.254	8.866	-697.917
		13.695	15.693	-964.614	-1455.577	14.766	-1013.907
	17	17.927	1.663	-352.502	-425.205	15.478	-344.135
		35.998	1.784	-717.387	-883.384	33.200	-708.310
		56.965	1.904	-1079.250	-1334.840	43.040	-1069.563
	18	9.214	4.277	-312.067	-530.174	28.577	-352.598
		20.703	8.877	-636.809	-937.854	67.766	-670.907
		30.751	14.667	-1062.326	-1703.841	200.854	-1121.980
	19	6.600	1.868	-370.614	-547.094	12.720	-385.281
		10.599	2.003	-783.318	-1121.877	20.881	-798.722
		17.493	2.138	-1193.110	-1692.709	41.221	-1210.104
	20	6.885	2.453	-358.470	-538.551	10.994	-376.637
		15.548	6.525	-680.412	-1064.601	22.809	-731.817
		22.018	11.410	-1011.154	-1558.377	26.882	-1076.563
	21	6.572	2.417	-360.652	-539.006	9.989	-377.580
		12.729	7.265	-691.260	-1032.779	14.292	-722.438
		17.054	10.831	-1040.075	-1548.452	18.435	-1084.677
	22	7.050	1.868	-368.717	-546.799	14.642	-384.624
		14.396	2.003	-777.320	-1115.202	37.739	-794.921
		24.636	2.138	-1171.969	-1647.420	75.876	-1190.175

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ $_{xx}$ [kN/m²]	σ $_{yy}$ [kN/m²]	σ $_{xy}$ [kN/m²]	σ $_{zz}$ [kN/m²]
	23	14.180	2.671	-350.242	-422.680	22.757	-338.500
		25.354	2.864	-738.990	-938.980	61.321	-726.967
		39.423	3.056	-1113.323	-1417.927	92.287	-1099.904
	24	14.725	0.120	-372.408	-475.141	28.818	-371.521
		32.346	0.240	-737.990	-934.873	47.887	-736.372
		49.822	1.904	-1091.349	-1361.575	64.449	-1081.213
	25	14.627	3.422	-339.521	-402.941	19.741	-326.231
		31.805	8.341	-655.164	-762.394	32.135	-626.009
		46.501	14.960	-944.715	-1095.294	50.674	-902.909
	26	10.356	0.396	-389.181	-526.259	36.924	-390.739
		19.299	4.144	-713.055	-1051.522	60.558	-747.614
		26.465	6.273	-1075.925	-1594.054	74.718	-1128.116
	27	0.469	3.724	-346.935	-510.963	0.590	-359.601
		4.186	7.493	-692.759	-1022.307	4.311	-718.796
		7.428	14.055	-989.217	-1482.496	9.604	-1036.192
	28	3.801	0.359	-408.079	-571.030	7.548	-409.992
		10.203	2.452	-775.317	-1115.080	18.509	-792.413
		14.358	5.693	-1129.591	-1636.544	22.845	-1159.378
	29	17.260	1.856	-351.944	-423.347	16.696	-342.606
		31.880	4.647	-699.747	-840.284	37.895	-678.150
		46.388	4.960	-1071.792	-1312.759	66.852	-1047.959
	30	17.467	2.166	-348.456	-416.024	15.600	-338.073
		34.846	6.763	-668.249	-781.484	27.865	-642.239
		49.673	9.864	-1011.635	-1190.153	47.729	-972.688
	31	20.391	3.145	-334.142	-388.256	8.407	-321.367
		38.486	5.027	-684.260	-808.281	23.111	-662.322
		59.620	5.365	-1044.258	-1254.800	32.375	-1020.623
	32	20.350	3.776	-327.214	-375.218	7.946	-312.747
		41.000	10.420	-619.472	-690.897	14.088	-585.185
		58.965	15.365	-934.332	-1047.357	25.125	-883.725
	33	20.148	3.454	-330.981	-382.235	8.570	-317.322
		37.911	8.077	-650.139	-745.940	20.158	-620.665
		55.762	10.269	-997.622	-1160.152	34.858	-957.796
	34	0.478	3.283	-355.063	-518.842	0.614	-366.244

Cluster	Soil element	X-coord. [m]	Y-coord. [m]	σ xx [kN/m²]	σ yy [kN/m²]	σ xy [kN/m²]	σ zz [kN/m²]
		3.852	3.728	-761.615	-1088.255	7.060	-774.935
		7.579	7.055	-1114.821	-1607.751	11.035	-1140.631
	35	24.492	3.277	-330.744	-381.933	0.912	-317.900
		45.345	6.522	-663.413	-767.368	8.392	-637.559
		66.941	6.961	-1022.271	-1211.097	16.451	-994.261
	36	24.457	3.718	-326.019	-372.777	0.930	-311.895
		45.576	10.274	-619.297	-689.631	6.368	-585.361
		66.394	13.961	-947.150	-1065.948	13.576	-898.999
	37	11.015	0.479	-385.006	-512.901	37.131	-385.134
		25.038	3.435	-732.107	-930.715	59.843	-720.039
		36.916	7.588	-1064.473	-1342.044	93.400	-1043.592
	38	10.672	0.547	-386.191	-518.647	36.474	-386.929
		22.206	4.768	-715.747	-931.077	73.127	-709.686
		31.465	8.667	-1033.897	-1448.789	106.121	-1061.948
2	39	9.892	8.573	-283.389	-424.741	0.294	-301.561
		18.398	15.686	-590.556	-892.537	8.604	-629.739
		28.290	22.800	-901.665	-1350.749	4.100	-956.224
	40	9.892	14.427	-187.200	-298.582	9.922	-208.513
		19.784	30.314	-352.243	-563.877	20.866	-393.825
		28.290	46.200	-519.394	-836.770	30.678	-582.049
	41	8.254	11.450	-231.900	-364.425	9.356	-255.074
		18.128	22.216	-477.683	-739.989	14.316	-520.728
		28.002	34.442	-698.893	-1084.166	21.744	-763.027
	42	8.089	13.841	-194.899	-315.068	10.692	-218.404
		17.951	26.451	-409.575	-651.100	18.881	-454.574
		27.813	40.519	-602.525	-956.897	28.547	-668.589
	43	8.254	11.223	-235.813	-369.560	9.067	-258.811
		18.128	20.303	-510.387	-782.554	10.656	-551.919
		28.002	30.842	-760.001	-1163.082	15.196	-821.234
	44	5.940	9.149	-270.922	-413.764	9.362	-291.934
		12.187	16.304	-582.358	-866.630	18.897	-616.726
		20.182	23.460	-892.575	-1328.713	29.464	-943.918
	45	7.737	14.182	-191.178	-310.777	10.583	-214.468

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ $_{xx}$ [kN/m²]	σ $_{yy}$ [kN/m²]	σ $_{xy}$ [kN/m²]	σ $_{zz}$ [kN/m²]
		15.861	30.051	-358.697	-584.596	20.097	-403.160
		22.237	45.919	-527.190	-860.988	30.240	-592.916
	46	6.184	9.263	-268.706	-412.268	9.536	-290.309
		14.422	16.532	-574.629	-873.387	18.868	-615.413
		24.046	25.260	-854.831	-1295.870	20.565	-914.642
	47	7.981	14.068	-191.610	-309.720	10.634	-214.791
		17.735	28.364	-378.673	-608.349	22.139	-423.867
		26.102	44.119	-548.479	-887.199	31.201	-615.266
	48	4.488	13.793	-196.246	-313.902	15.105	-218.675
		10.346	29.634	-364.801	-589.208	26.112	-408.251
		14.002	45.474	-539.034	-885.051	31.605	-605.690
	49	8.116	11.659	-228.561	-359.940	9.927	-251.785
		17.852	24.095	-446.139	-700.359	17.889	-490.924
		25.814	37.762	-643.250	-1017.721	29.752	-711.463
	50	3.739	7.155	-309.408	-449.209	6.622	-323.087
		9.679	14.310	-620.659	-901.227	15.725	-647.569
		15.312	23.460	-891.544	-1314.415	25.018	-939.319
	51	6.166	9.543	-263.232	-406.650	9.653	-285.721
		15.772	18.551	-538.580	-822.771	11.938	-580.324
		23.759	29.702	-775.356	-1194.777	21.363	-840.481
	52	4.765	13.662	-198.847	-321.131	13.588	-222.215
		12.260	27.685	-391.697	-634.184	23.536	-438.584
		18.394	43.394	-563.243	-917.663	32.202	-632.099
	53	0.496	15.841	-175.111	-299.453	-0.671	-198.786
		4.597	29.634	-372.623	-619.177	11.981	-419.588
		7.867	45.474	-546.732	-914.997	15.655	-616.983
	54	4.883	13.374	-203.163	-329.531	12.329	-227.324
		12.649	25.101	-430.272	-689.302	22.814	-478.317
		20.261	38.836	-626.951	-1008.042	32.913	-698.834
	55	0.216	10.932	-238.030	-389.570	0.792	-266.785
		0.432	18.216	-542.615	-838.790	1.358	-587.849
		3.420	25.500	-849.033	-1285.696	7.238	-908.769
	56	4.753	13.093	-207.115	-336.260	11.783	-231.794
		10.569	22.931	-464.241	-737.539	21.785	-512.744

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ $_{xx}$ [kN/m²]	σ $_{yy}$ [kN/m²]	σ $_{xy}$ [kN/m²]	σ $_{zz}$ [kN/m²]
		18.205	34.376	-695.521	-1102.763	32.401	-767.891
	57	0.579	11.087	-237.337	-390.537	3.211	-266.169
		3.931	18.526	-541.049	-834.504	9.503	-584.697
		9.177	27.960	-806.057	-1241.750	18.575	-871.624
	58	0.281	11.908	-226.924	-375.906	1.526	-254.961
		4.166	25.418	-429.017	-706.150	12.173	-481.571
		4.446	40.974	-606.313	-1006.474	12.925	-682.551
	59	0.644	11.496	-231.919	-382.517	2.663	-260.300
		5.954	21.337	-488.659	-781.187	11.887	-540.335
		10.203	34.434	-693.992	-1109.553	26.544	-769.210
3	60	8.403	20.132	-119.115	-194.409	9.816	-131.370
		18.288	40.200	-239.865	-386.735	19.378	-262.890
		28.172	61.079	-349.760	-562.656	29.966	-382.624
	61	8.220	22.077	-94.505	-154.630	11.577	-103.396
		18.092	43.243	-200.441	-325.478	20.946	-219.144
		27.963	65.625	-289.812	-474.143	29.042	-317.856
	62	8.506	23.905	-72.192	-127.999	3.624	-80.578
		18.398	46.595	-157.242	-270.888	10.463	-174.893
		28.290	70.500	-226.071	-387.584	19.070	-251.071
	63	9.892	17.748	-149.583	-233.056	9.311	-162.715
		18.398	33.874	-321.177	-502.505	18.515	-350.166
		28.290	50.000	-489.651	-767.735	26.601	-535.416
	64	8.403	19.943	-121.665	-198.925	9.644	-134.332
		18.288	38.200	-265.019	-423.948	19.034	-290.500
		28.172	58.079	-387.962	-619.282	28.462	-424.423
	65	6.053	17.904	-146.562	-230.838	11.448	-160.449
		12.309	34.041	-318.588	-506.406	20.668	-349.816
		20.311	50.178	-490.431	-777.187	29.591	-537.692
	66	8.105	21.925	-96.138	-157.508	11.060	-105.429
		16.380	42.191	-213.755	-350.587	20.491	-235.354
		26.136	63.204	-323.076	-527.554	29.319	-354.633
	67	8.377	23.787	-75.853	-133.983	1.290	-83.998
		16.490	46.054	-168.802	-288.229	11.296	-185.970

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ_{xx} [kN/m²]	σ_{yy} [kN/m²]	σ_{xy} [kN/m²]	σ_{zz} [kN/m²]
		26.253	68.625	-255.432	-433.336	18.806	-281.950
	68	7.869	22.361	-91.567	-155.234	6.795	-101.432
		16.002	46.243	-165.759	-287.976	9.437	-184.139
		22.388	70.125	-240.380	-427.117	11.208	-268.894
	69	6.297	18.030	-145.519	-231.082	10.899	-159.648
		14.543	34.293	-314.790	-499.134	19.897	-345.372
		24.176	52.178	-462.814	-731.961	29.152	-506.939
	70	5.746	17.904	-148.413	-240.569	7.258	-163.924
		9.493	34.041	-324.335	-530.528	11.238	-358.777
		15.441	50.178	-494.798	-799.717	22.358	-545.760
	71	3.179	22.806	-89.437	-164.267	-1.005	-101.525
		8.942	46.720	-164.192	-306.805	-0.899	-187.196
		12.503	70.634	-240.103	-451.579	-2.085	-273.885
	72	5.548	21.161	-111.161	-194.547	0.310	-124.447
		13.519	41.437	-227.447	-381.077	11.547	-251.961
		21.320	63.373	-324.335	-542.694	19.463	-358.800
	73	5.419	21.408	-106.770	-186.285	1.716	-119.550
		13.092	43.591	-202.658	-351.409	7.209	-226.040
		19.283	67.294	-279.370	-493.465	8.986	-313.092
	74	6.290	18.287	-142.833	-229.347	9.523	-157.177
		15.915	36.429	-286.772	-455.968	18.809	-314.511
		24.058	56.257	-409.064	-654.270	28.756	-449.356
	75	0.216	19.495	-135.578	-233.440	-0.004	-150.851
		0.432	35.748	-309.435	-520.015	1.081	-343.558
		3.420	52.000	-485.240	-810.563	4.046	-538.041
	76	0.402	23.914	-76.288	-147.132	-0.352	-87.510
		3.194	46.720	-166.301	-312.887	-1.906	-189.653
		6.368	70.634	-242.207	-457.805	-3.550	-276.384
	77	5.986	18.487	-139.823	-223.975	10.332	-153.772
		13.825	38.515	-259.925	-418.864	20.726	-286.047
		19.242	59.426	-372.259	-611.934	21.808	-411.510
	78	5.103	21.440	-106.732	-187.865	0.936	-119.870
		10.977	45.175	-183.683	-332.565	1.491	-207.644
		14.267	67.803	-275.469	-500.433	0.651	-311.748

Cluster	Soil element	X-coord. [m]	Y-coord. [m]	σ xx [kN/m²]	σ yy [kN/m²]	σ xy [kN/m²]	σ zz [kN/m²]
	79	0.587	19.633	-132.648	-230.189	0.309	-148.385
		3.947	36.023	-305.684	-516.699	3.662	-340.215
		9.306	54.178	-452.271	-758.539	8.642	-502.849
	80	0.698	19.959	-127.919	-222.918	0.586	-143.334
		6.169	38.441	-270.528	-459.761	4.431	-301.825
		11.070	59.348	-384.143	-658.689	5.264	-429.453
	81	0.513	20.240	-125.539	-218.494	-0.230	-140.042
		5.229	41.428	-235.393	-411.789	-0.211	-263.601
		8.132	63.803	-330.580	-584.803	-1.162	-371.392
	82	2.576	22.554	-93.354	-170.698	-1.348	-105.752
		2.762	46.215	-173.061	-323.043	-1.647	-196.974
		2.948	66.634	-296.022	-539.641	-2.667	-334.879
4	83	10.130	8.573	-280.255	-278.759	25.879	-256.826
		20.260	15.686	-575.698	-540.094	61.056	-519.549
		32.059	22.800	-856.301	-873.708	95.093	-799.503
	84	14.895	9.305	-260.241	-269.840	19.278	-244.854
		27.302	16.471	-543.197	-596.062	48.507	-523.058
		41.695	23.637	-828.185	-917.861	68.936	-800.545
	85	14.140	13.664	-211.530	-169.039	7.163	-180.384
		28.477	29.495	-356.183	-292.616	7.519	-317.312
		40.830	45.326	-500.951	-416.228	7.226	-454.285
	86	11.799	15.886	-144.642	-123.230	-0.716	-136.573
		21.929	31.773	-295.789	-251.029	6.062	-276.468
		32.059	46.200	-534.795	-431.571	35.312	-465.110
	87	11.233	12.876	-235.920	-203.809	25.755	-201.677
		21.322	26.875	-474.767	-390.144	53.016	-393.936
		31.411	39.415	-711.111	-608.971	77.396	-601.758
	88	11.233	12.649	-236.555	-208.657	26.184	-204.343
		21.322	24.962	-474.158	-431.330	50.507	-414.720
		31.411	35.815	-722.130	-676.973	73.827	-641.665
	89	11.873	10.280	-252.740	-254.000	27.318	-233.464
		22.009	20.751	-504.909	-505.695	50.988	-465.201
		32.144	29.763	-775.511	-779.394	75.938	-715.637

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ_{xx} [kN/m²]	σ_{yy} [kN/m²]	σ_{xy} [kN/m²]	σ_{zz} [kN/m²]
	90	12.003	10.052	-254.906	-258.512	27.503	-236.489
		22.268	18.838	-528.429	-535.393	53.896	-489.778
		34.203	26.163	-808.610	-856.133	85.317	-764.788
	91	14.478	13.664	-209.034	-167.098	6.988	-179.053
		31.514	29.495	-352.657	-290.429	7.050	-315.598
		46.190	45.326	-496.864	-413.859	7.432	-452.348
	92	17.091	7.166	-285.858	-312.459	12.846	-274.946
		32.325	16.471	-545.982	-581.405	30.919	-519.497
		47.055	23.637	-831.226	-901.986	50.183	-796.695
	93	12.327	10.105	-253.923	-257.010	27.086	-235.506
		24.585	17.484	-534.493	-577.300	57.309	-510.261
		39.331	27.001	-792.517	-842.571	77.052	-752.124
	94	11.362	13.103	-236.487	-197.388	24.847	-198.898
		23.251	28.789	-383.705	-322.791	24.512	-337.800
		33.470	43.015	-624.084	-508.025	55.359	-529.166
	95	11.631	13.048	-233.084	-195.231	23.156	-197.478
		25.576	26.511	-448.503	-366.770	32.922	-380.683
		37.733	42.141	-602.528	-494.816	32.407	-522.668
	96	11.962	10.533	-250.373	-248.620	27.010	-230.000
		23.330	23.053	-487.382	-458.732	52.970	-435.494
		33.554	33.778	-736.878	-706.416	76.854	-664.087
	97	20.964	9.022	-260.231	-264.461	4.739	-244.509
		38.842	16.168	-546.237	-575.153	15.844	-519.062
		59.527	23.314	-831.358	-880.308	21.820	-791.688
	98	20.521	13.451	-194.674	-171.291	1.345	-176.958
		41.174	29.267	-339.251	-294.937	1.466	-313.953
		59.020	45.083	-483.881	-418.647	1.370	-450.983
	99	14.184	12.907	-222.203	-185.592	12.730	-191.958
		26.650	23.411	-472.320	-433.608	39.103	-421.829
		41.535	33.327	-725.792	-688.987	58.060	-657.562
	100	12.231	10.705	-248.632	-244.376	26.591	-227.431
		26.181	23.812	-469.943	-424.571	38.954	-416.600
		37.818	36.504	-706.961	-629.224	63.981	-619.685
	101	17.004	12.746	-212.246	-186.899	6.275	-190.085

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	**σ xx** [kN/m²]	**σ yy** [kN/m²]	**σ xy** [kN/m²]	**σ zz** [kN/m²]
		34.209	28.355	-365.635	-314.889	6.429	-331.960
		48.855	41.796	-576.427	-487.345	14.763	-514.150
	102	24.502	7.146	-284.280	-302.440	0.642	-271.559
		45.944	16.168	-544.268	-566.487	4.719	-515.871
		67.108	23.314	-829.230	-871.037	9.954	-788.268
	103	24.470	15.816	-144.800	-123.720	0.028	-137.084
		45.602	31.632	-289.423	-247.382	-0.120	-274.097
		66.601	45.083	-483.729	-418.934	1.259	-451.024
	104	18.073	10.051	-248.492	-245.640	9.101	-230.711
		33.548	19.564	-506.103	-509.018	26.221	-471.900
		50.880	26.938	-789.337	-816.132	38.487	-743.519
	105	20.287	13.229	-198.570	-176.217	1.813	-180.607
		37.899	28.822	-352.777	-304.561	1.583	-322.902
		55.310	41.553	-564.170	-491.650	7.213	-512.858
	106	15.203	10.049	-251.767	-251.450	17.634	-233.445
		32.062	22.394	-470.591	-447.326	25.335	-430.003
		46.564	35.433	-688.615	-629.067	36.188	-618.955
	107	18.458	10.030	-248.371	-245.530	8.282	-230.734
		36.175	17.385	-531.784	-552.024	19.690	-502.312
		56.978	26.615	-789.257	-812.178	24.545	-743.765
	108	17.116	12.154	-220.906	-199.901	7.635	-199.249
		32.576	22.012	-474.571	-455.216	24.545	-435.282
		50.633	32.408	-718.435	-693.200	33.289	-660.756
	109	21.259	13.168	-198.650	-177.252	1.288	-181.217
		45.989	25.051	-415.882	-380.396	1.426	-381.552
		70.719	40.583	-571.828	-509.753	1.529	-524.949
	110	18.410	10.613	-240.439	-232.724	7.716	-221.889
		38.755	23.482	-444.612	-416.155	9.926	-407.960
		56.224	35.854	-661.475	-611.116	16.344	-603.535
	111	20.600	12.670	-207.098	-187.403	2.234	-189.035
		39.266	23.084	-449.989	-424.211	9.680	-413.781
		60.278	32.698	-702.024	-675.967	14.011	-649.356
	112	21.702	9.306	-255.945	-257.801	3.599	-239.948
		46.464	16.736	-536.514	-554.176	3.899	-507.297

Cluster	Soil element	X-coord. [m]	Y-coord. [m]	σ xx [kN/m²]	σ yy [kN/m²]	σ xy [kN/m²]	σ zz [kN/m²]
		71.226	27.814	-765.961	-773.940	4.063	-719.908
	113	24.492	11.462	-223.714	-211.858	0.313	-206.793
		45.513	24.208	-429.201	-397.644	2.114	-394.519
		66.945	33.897	-679.924	-647.473	5.852	-628.781
5	114	8.752	26.160	-39.363	-88.959	1.607	-46.949
		18.662	52.230	-77.815	-154.890	10.105	-87.094
		28.572	79.111	-110.381	-212.654	17.130	-119.614
	115	8.437	27.669	-21.385	-58.722	2.422	-26.137
		18.324	54.805	-49.697	-114.914	9.380	-55.835
		28.211	83.157	-67.275	-152.133	17.193	-72.861
	116	8.506	29.905	-18.165	-21.889	0.192	-12.050
		18.398	58.595	-34.082	-53.030	5.482	-26.634
		28.290	88.500	-46.772	-73.229	7.581	-36.535
	117	9.892	25.748	-41.044	-74.088	9.083	-44.726
		18.398	49.874	-106.663	-200.071	10.540	-119.214
		28.290	74.000	-169.373	-312.055	19.275	-188.629
	118	6.468	25.657	-48.847	-109.588	-0.072	-58.101
		12.753	49.776	-116.206	-243.890	1.584	-135.634
		20.785	73.896	-182.781	-372.364	3.127	-211.183
	119	8.416	24.259	-64.273	-125.183	0.927	-73.284
		18.218	50.140	-104.187	-198.947	8.870	-117.014
		26.862	76.111	-146.100	-292.038	10.038	-166.763
	120	8.347	27.518	-22.631	-64.091	1.742	-28.756
		16.987	53.783	-60.429	-150.332	3.178	-73.981
		26.784	80.768	-90.811	-209.992	8.816	-105.974
	121	6.192	28.634	-16.986	-43.424	-3.053	-18.610
		14.204	58.535	-36.309	-65.065	-2.572	-30.934
		20.469	88.437	-53.851	-86.427	-3.047	-42.640
	122	8.393	29.758	-18.545	-21.918	0.904	-12.225
		16.722	57.616	-39.146	-78.539	1.202	-36.701
		26.501	86.157	-56.730	-117.895	7.041	-54.303
	123	3.777	24.120	-68.946	-140.221	-1.094	-79.784
		9.755	48.239	-136.940	-277.630	-0.795	-158.440

Cluster	Soil element	X-coord. [m]	Y-coord. [m]	σ_{xx} [kN/m²]	σ_{yy} [kN/m²]	σ_{xy} [kN/m²]	σ_{zz} [kN/m²]
		15.916	73.896	-184.856	-384.097	-0.399	-215.325
	124	6.622	25.790	-45.875	-102.737	0.143	-54.593
		14.807	50.042	-110.101	-227.734	0.900	-127.835
		23.222	76.006	-151.863	-320.118	2.429	-177.355
	125	6.617	26.020	-42.953	-98.065	-0.639	-51.345
		15.027	52.215	-81.677	-185.726	1.030	-97.566
		23.144	79.664	-104.972	-249.289	1.844	-126.656
	126	5.885	28.634	-16.334	-44.450	-3.731	-18.722
		11.843	58.535	-33.521	-67.122	-3.558	-30.715
		15.600	88.437	-43.588	-88.858	-3.697	-40.291
	127	8.079	27.854	-20.416	-57.123	0.366	-24.588
		16.223	57.608	-39.467	-83.968	0.771	-38.444
		22.545	86.094	-57.103	-131.197	-2.216	-58.443
	128	2.989	29.811	-9.910	-23.296	-0.031	-10.029
		3.205	59.621	-20.300	-46.931	-0.098	-20.304
		3.420	87.000	-45.713	-116.372	-0.478	-52.087
	129	2.989	24.189	-68.124	-139.678	-1.758	-79.082
		3.205	50.811	-103.430	-226.378	-2.730	-122.195
		3.420	75.000	-171.948	-367.634	-3.046	-201.869
	130	6.457	26.167	-41.541	-97.040	-0.544	-49.996
		14.415	53.762	-64.863	-159.479	-0.177	-78.140
		20.616	81.990	-81.977	-211.204	-3.966	-99.423
	131	3.961	27.338	-27.519	-73.253	-1.766	-33.729
		9.701	55.787	-44.472	-123.019	-5.046	-54.297
		13.314	85.503	-54.934	-147.258	-5.443	-64.809
	132	4.146	27.079	-31.043	-78.927	-1.645	-37.578
		10.328	53.209	-73.126	-176.921	-1.621	-88.180
		16.254	81.399	-90.303	-228.637	-5.539	-109.492
	133	3.980	26.799	-34.668	-84.760	-1.659	-41.593
		7.613	51.112	-101.206	-221.519	-3.038	-118.803
		13.630	76.962	-146.968	-325.297	-3.257	-173.421
	134	0.459	27.193	-28.012	-74.375	-0.579	-34.821
		4.038	54.441	-57.114	-149.625	-2.226	-70.006
		7.269	84.066	-68.372	-177.620	-2.248	-81.915

Cluster	**Soil element**	**X-coord.** [m]	**Y-coord.** [m]	σ_{xx} [kN/m²]	σ_{yy} [kN/m²]	σ_{xy} [kN/m²]	σ_{zz} [kN/m²]
	135	0.459	26.815	-32.968	-82.985	-0.970	-40.483
		3.690	51.198	-98.661	-218.657	-2.423	-116.821
		7.269	78.066	-132.217	-301.772	-4.058	-157.293

Figure 10: Shear force in beam

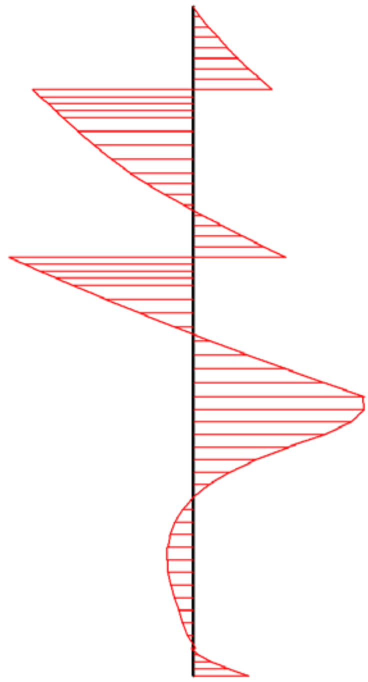
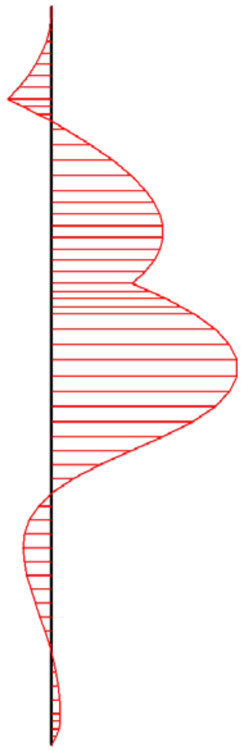


Figure 11: Bending moment in beam



The evaluation of the real values of stiffness is a very difficult task; hence a range of stiffness was used in the calculation and analyses for formations A and B, while the values for the fill layer and formation C remained unchanged [8].

Table 6: Variation of stiffness and strength parameters

	Parameter	Range of applied values
Strength parameter	φ'	26 to 35^0
	c'	0,5 to 15,15 kPa for layers A,B, respectively
Stiffness	E	15,30 to 20,50 Mpa for layers A,B, respectively

The final results in structural force and displacement are shown in the table below:

Table 7: Summary of analyses for the multi-propped wall in layered soils

Program	**Structural Force**		**Prop Force**		**Displacement max.**
	M (kNm/m)	**Q (kN/m)**	**T1(kN/m)**	**T2 (kN/m)**	**d (mm)**
PLAXIS	1760	612	331	792	80

2/. ReWaRD:

The ReWaRD program was used to perform the limit equilibrium analysis based on the code of practice. The displacement, shear force, bending moment … are estimates of the construction-induced and long term movements of the retaining wall. The props are considered as permanent and excavation stages are long term [4], [5].

The program gives the results in:

- Earth pressure at as-built (for specified wall length and safety factors)
- Earth pressure at minimum safe embedment (with the specified safety factors)
- Earth pressure at failure (with safety factors set to 1)
- Structural Force
- Durability
- Required embedment as-built
- Required embedment at minimum safe embedment
- Required embedment at failure

Table 8 presents the summary of comparative analyses undertaken for the reinforced concrete diaphragm wall. The table includes the results from the limit equilibrium methods (CIRIA 104, BS 8002, Eurocode 7). Beside the different factors, the differences between the calculations of the applied methods are also caused by the range of soil strength parameters and wall geometry.

Figure 12: Earth Pressure as-built

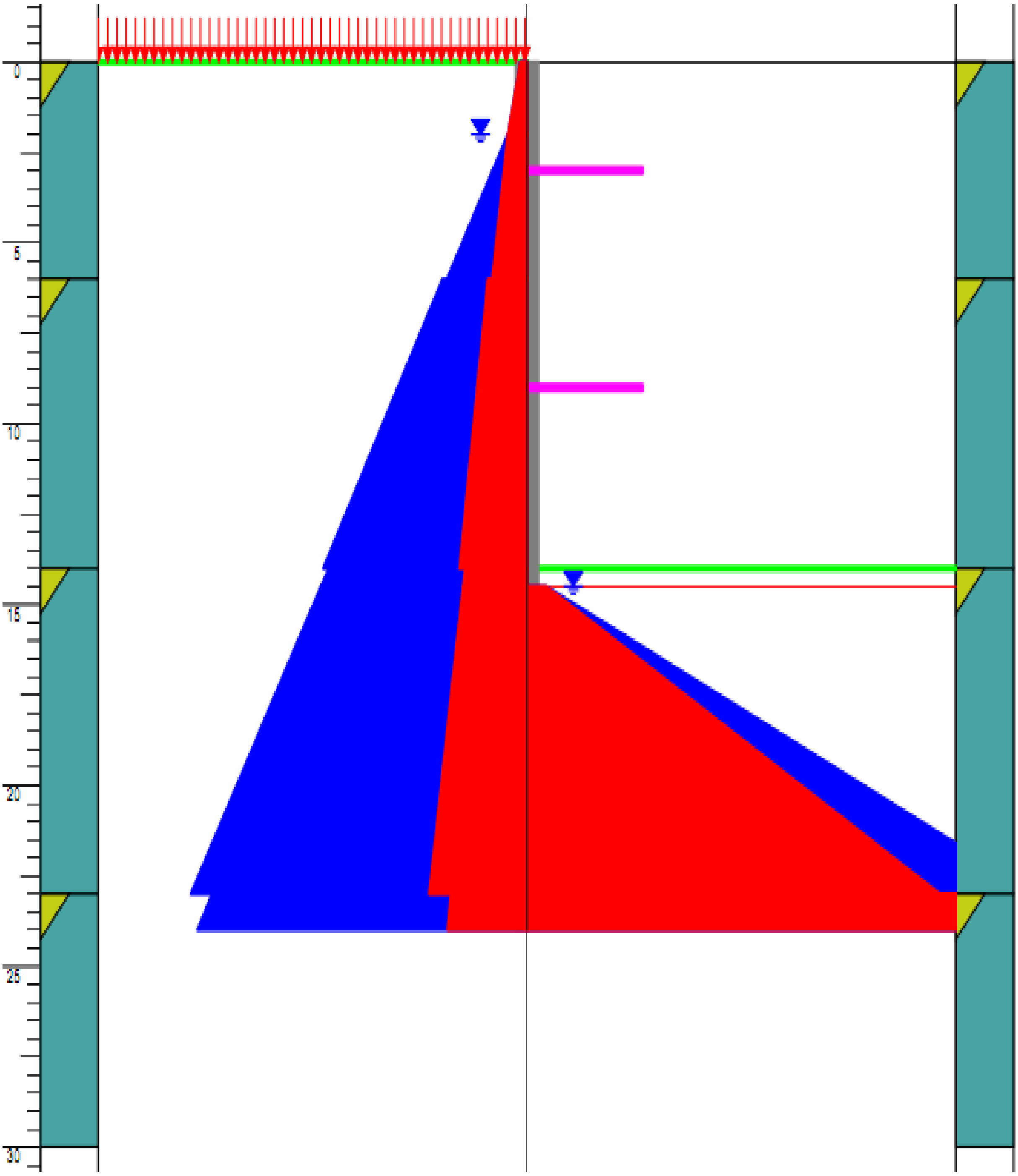


Figure 13: Structural Force

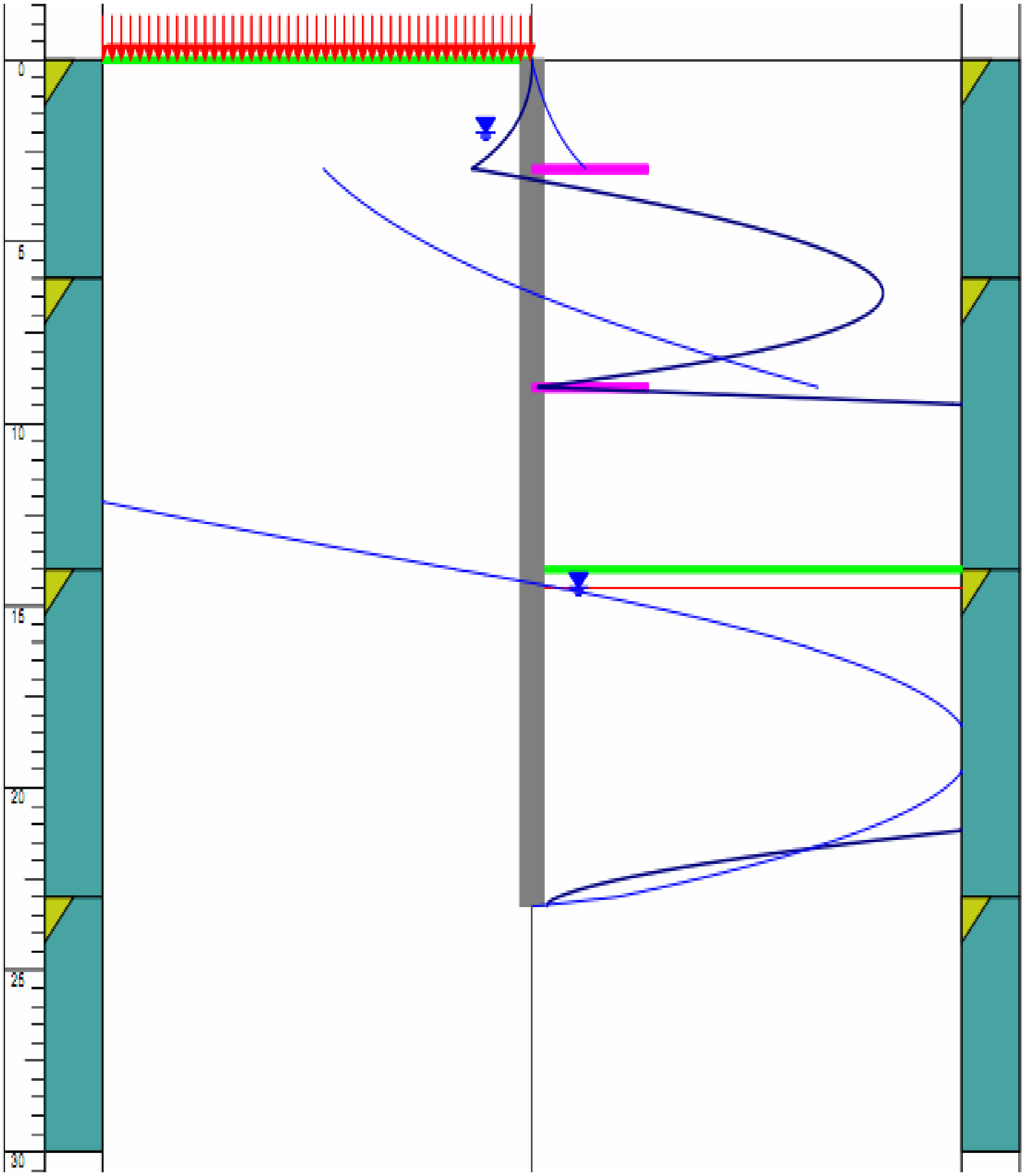


Table 8: Summary of comparative analyses

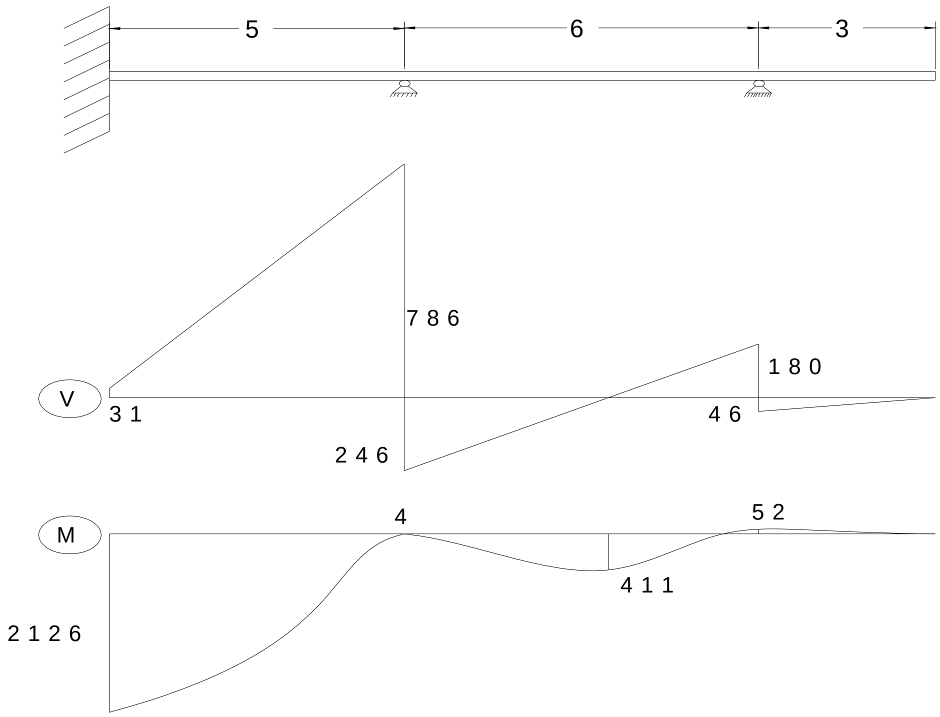
<table>
<tr><th colspan="2" rowspan="2">Design Method</th><th colspan="2">Structural Force</th><th colspan="2">Prop Force</th><th>Displacement max.</th></tr>
<tr><th>M (kNm/m)</th><th>Q (kN/m)</th><th>T1(kN/m)</th><th>T2 (kN/m)</th><th>d (mm)</th></tr>
<tr><td rowspan="3">CIRIA 104</td><td>Gross Pressure</td><td>2203</td><td>903</td><td>407</td><td>1664</td><td>80 (top)</td></tr>
<tr><td>Revised Method</td><td>2203</td><td>903</td><td>407</td><td>1664</td><td>80 (top)</td></tr>
<tr><td>Strength factor Method</td><td>2203</td><td>903</td><td>407</td><td>1664</td><td>80 (top)</td></tr>
<tr><td colspan="2">BS 8002</td><td>2292</td><td>786</td><td>226</td><td>1032</td><td>ditto</td></tr>
<tr><td rowspan="4">EUROCODE 7</td><td>Serviceability</td><td>1260</td><td>550</td><td>197</td><td>776</td><td>ditto</td></tr>
<tr><td>Case A</td><td>1832</td><td>682</td><td>207</td><td>916</td><td>-</td></tr>
<tr><td>Case B</td><td>2025</td><td>810</td><td>255</td><td>1112</td><td>-</td></tr>
<tr><td>Case C</td><td>2411</td><td>808</td><td>226</td><td>1054</td><td>-</td></tr>
</table>

III/. Part II - Beam design and crack prevention reappraisal:

In order to design the wall, we consider a part of the wall as the continuous beam with cross section 1000x1000 and the length is 14m (Because 10m of the beam is fixed in the soil, the length of the beam will be: 24 -10 = 14m). The beam is designed with the BS 8110. Any types of wall that can be simplified as a beam can be designed as following.

Loading diagram is from Figure 12: The wall is simplified as a beam.

Figure 14: Shear force and moment diagram



Assume the nominal cover is assumed 50mm. Tension reinforcement has the characteristic tensile strength $f_y = 500Mpa$

For the ease of construction and economical aspect, we use the maximum moment as the design moment for the whole beam. Since the difficulties in construction (joining different diameter may leads to the situation that the centroids of two different bars will not be coincided, the bearing capacity will be totally different) and the expense of joining will be higher if there are some different diameters of tension reinforcement, only one diameter of tension reinforcement will be used [15].

The calculation includes the following parts [10]:

- Assume that the effective span is the last span with 5m long.
- Calculate ultimate moment of resistance $M_u = 0.156 f_{cu} bd^2$ and compare with design moment M. Since, M_u > M, no compression reinforcement is required.
- Design for tension reinforcement: Use M as the design moment, we calculate coefficient K, lever arm z and area of tension reinforcement A_s by the following equations

$$K = \frac{M}{f_{cu} bd^2}, \quad z = d[0.5 + \sqrt{(0.25 - K/0.9)}, \quad A_s = \frac{M}{0.87 f_y z}$$

After the above calculations we have required area tension reinforcement A_s and choose the appropriate reinforcement.

- Design for links and links space: Calculate design shear force ϑ from Ultimate shear force V by the equation $\vartheta = \frac{V}{bd}$ and design shear stress ϑ_c from table 3.8, BS 8110 based on different f_{cu} and the value of $\frac{100 A_s}{bd}$. For the reason v < v_c + 0.4 at any points of the beam, we arrange nominal links along the whole length of the beam. According to formula: $\frac{A_{sv}}{s_v} = \frac{0.4b}{0.87 f_{yv}}$ we choose the links diameter and space of links following BS 8110. The space of links should not be exceed 0,75d = 712,5mm. The hereafter table shows the design table and chosen links diameter along with the link space:

Table 9: Design table with different concrete grade, According to BS 8110

M (kNm)	M_u (kNm)	b (mm)	d (mm)	f_{cu} (kPa)	k	z (mm)	fy	A_s (mm^2)	Longi. Rebar (mm)	Area (mm^2)	$100A_s/bd$	v_c (kN)	v = V/bd (kN)	$A_{sv}/s_v = 0,4b/0,87f_{yv}$
2126	3520	1000	950	25	0.094	837	500	5838	8H32	6431	0.615	0.532	0.827	0.920
2126	4224	1000	950	30	0.079	858	500	5695	8H32	6431	0.599	0.561	0.827	0.920
2126	4928	1000	950	35	0.067	873	500	5601	8H32	6431	0.590	0.588	0.827	0.920
2126	5632	1000	950	40	0.059	883	500	5534	8H32	6431	0.583	0.612	0.827	0.920

Table 10: Links diameter and space

d link (mm)	Space (mm)
8	100
10	150
12	225
16	300

- Check the Effective span, to assure that the assumed effective span is correct.

From table 3, we have the moment of inertia and area of the prop

The first prop: $\begin{cases} \dfrac{bh^3}{12} = 6,6.10^{-4} \\ bh = 218.10^{-4} \end{cases} \rightarrow h = 0.8m = 800mm$

The second prop: $\begin{cases} \dfrac{bh^3}{12} = 36,0.10^{-4} \\ bh = 354.10^{-4} \end{cases} \rightarrow h = 0.35m = 350mm$

Effective span is the lesser of the centre to centre distance between the supports (5m) and clear distance between supports plus the effective depth, which are:

The first prop: $5000 - \frac{800}{2} + 950 = 5550mm = 5{,}55m$

The second prop: $5000 - \frac{350}{2} + 950 = 5775mm = 5{,}775m$

Hence, the assumed effective span of 5m is correct.

- Deflection:

Actual span/ effective depth ratio: $\frac{5000}{950} = 5{,}263$

$$\frac{M}{bd^2} = \frac{2126.10^6}{1000.950^2} = 2{,}356$$

From equation 8 of table 3.10, BS 8110 we have the formula of service stress:

$$f_s = \frac{5}{8} x \frac{f_y . A_{s,req}}{A_{s,prov}} x \frac{1}{\beta_b}$$

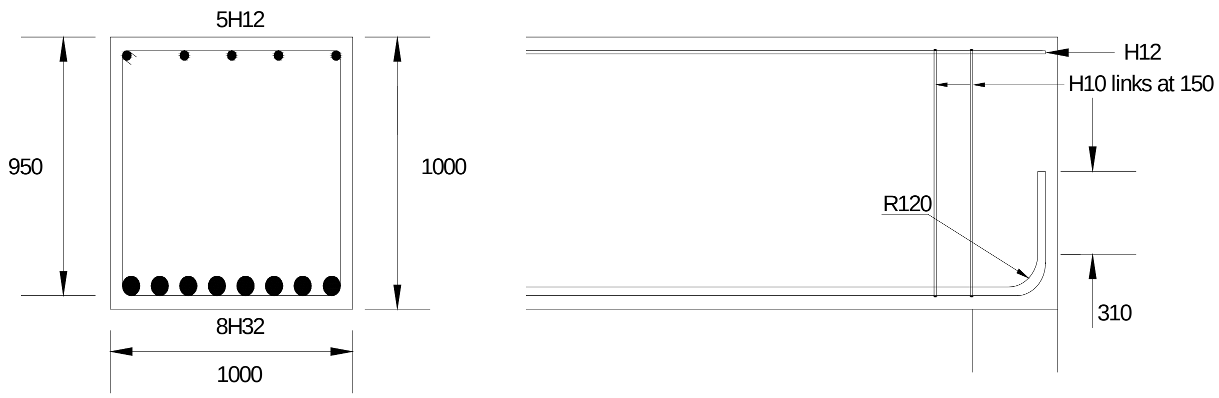
Apply table 3.9 and 3.10 BS8110 with the factor $\beta_b = 1$, we have the comparative values for permissible span/ effective depth ratio in the following table:

Table 11: Permissible span/ effective depth ratio

Service stress	Modification Factor	Permissible span/effective depth ratio
284	1.056	27.452
277	1.074	27.922
272	1.086	28.229
269	1.094	28.446

We can see that ratio is always higher than the actual value 5,263. Then, the beam therefore satisfies the deflection criteria in BS 8110.

Figure 15: Reinforcement scheduling and bending



IV/. Part III: Design of Crack prevention

1/. Underline theory from "Ultimate limit-state design of concrete structures: a new approach" [8] by M.D. Kotsovos and M.N. Pavlovíc

In the current design methodologies for the structural concrete member nowadays, the analytical formulations were used to express the strength characteristic as a function of the member geometry and dimensions, as well as the mechanical properties of the member's materials. One of the most important factors that contribute the code is the inclusion of empirical parameter. This factor is very important because it helps to regulate the formulations in the design code. Those calibrations are resulted from the experimental data of the strength and deformational characteristic of structural member. This point clearly means that the predicted analytical formulations are deviated from the corresponding values established by experiment. There are three main cases of the deviations:

The first case: the deviations up to approximately 10% are commonly considered as natural since they are typically due to the scatter of the experimental data used for the calibration of the semi-empirical formulations relevant to the design method employed.

The second case: the deviation between approximately 10% and 20% are normally attributed to the lack of experimental data sufficient to secure a conclusive calibration of the semi-empirical formulations. In this case, some additional data may improve the calibration, thus will result in the reduction of the deviation of the predicted values to the natural level, which may reduces to the order of 10%. This is somehow like carrying out more observation and test to have more data to analyse and reduce the range of deviation, to result it into a more accurate result.

The final case is when the deviations are larger than 20%, this can be concluded in the lack of a sound theory underlying the derivation of the semi-empirical analytical formulations. In this case, a reappraisal of the fundamental theory is essential before the needed of the prediction improvement by acquiring additional data for the more accurate calibration of the analytical formulations used.

The book "Ultimate limit-state design of concrete structures: a new approach" by M.D. Kotsovos and M.N Pavlovic introduces the "compressive - force path" method, which not only includes the description of its underlying theoretical concepts and their application but, also, presents the causes which led to the need for a new design methodology for the implementation of the limit - state philosophy into practical structural concrete design together with evidence, both experimental and analytical supporting its validity.

The book does not, of course, ignore the current code, because many reasonable guidelines and prediction for a wide range of reinforce concrete problem (especially those related to flexural failure). Mostly, the book concentrates in some clear problems (mainly those were shear failure) for which the current codes are less successful in their predictions, and such difficulties need to be addressed. The experiments were carried out by the cases of:

- Structural walls under transverse loading
- Simply supported reinforced concrete T-beam
- Structural wall under combined vertical and horizontal loading
- Column with additional reinforcement against seismic action
- Simply – supported beam with one overhang
- Failure of structural concrete under seismic load … and so on.

In all of the above taken tests, the deviations of the predicted from the experimental structure behaviours were considerable regarding to both mode of failure and load - carrying capacity. In most case, failure was not the predicted ductile behaviour as in current design methodologies but in brittle one. On the other hand, in the certain cases, the predicted values of load - carrying capacity were either to overestimate or to underestimate their experimental counterparts by a large margin.

The reasons of the above deviations are primarily the inability of current design methods to yield realistic prediction of shear capacity and, to a lesser extent, to the method used to assed flexural capacity. The found magnitude deviations were large enough for us to cast doubt on the adequacy of the theoretical basis of current design method. Moreover, in the case of earthquake, the insufficiency of theoretical method was also apparent.

The current design methodologies completely ignore some phenomena that clearly affect the strength of structure, such as:

- The transverse expansion of concrete as the peak of its stress-strain curved is neared (this factor is very important because it causes the development of complex triaxial stress field which basically dictates the failure mechanism of the structural member).
- The mechanical properties difference between concrete and steel platen (which the load act through, to the concrete specimen) will certainly causes the development of frictional forces at the interface between specimen and platen. Those forces restrain the lateral expansion of concrete at the end zones (both up and down) of the contact, so, clearly modify the intended stress conditions of these zones. Those factors lead to the contribution of micro-cracking process, effect of small transverse stresses on strength and deformation, tri-axiality and failure initiation by macro - cracking …

Therefore, the concepts which underlie the current somehow are incompatible with the behaviour of concrete as described in the mentioned experiments. The contribution of cracked concrete - through *"aggregate interlock"* to the shear capacity of beam - like structural concrete member is an instance of this incompatibility. As discussed in section 2.3.1.1 of [10] the descending branch of stress - strain curve does not describe the material behaviour, it only represents the interaction between specimen and loading platens. Moreover, concrete is a brittle material, so, the loss of load - carrying capacity will happen immediately as soon as the macro - cracking occurs. Obviously, this phenomenon does not allow any direct contribution of cracked concrete to the load - carrying capacity of structural - concrete member.

The cracking mechanism discussed in 2.3.1.2 of [10] also cast doubt shearing movement that is considered to effect *“aggregate interlock”*. This cracking mechanism involves crack extension in the direction of maximum principal compressive stress and crack - opening in the orthogonal direction. Also, the lack of shearing movement of the crack interfaces also contrast with the assumption that *“dowel action”* is one of the contributors of the shear capacity of a beam - like structural - concrete member. As the validity of *“truss analogy”* and *“shear capacity”* is based on the concepts of *“aggregate interlock”* and *“dowel action”*, those concepts are also cast doubts as inaccurate. Therefore, the objective of the experiment is toe provide the definitive conclusions regarding to the above concepts and also to identity both the true contributors to shear capacity and the causes which underlie the so - called “shear type” of failure.

The experiments were continuously carried out with two points loading the simply - supported beam in eight cases of the beams with the same geometry and longitudinal reinforcement:

- Case one: With regard to the transverse rebar, there are four classifications:

- Beam A: No transverse reinforcement is arranged.
- Beam B: Transverse reinforcement is arranged within the shear span only.
- Beam C: Transverse reinforcement is arranged throughout the beam span.

- Beam D: Transverse reinforcement is arranged within the flexural span in the region of point loads only.

- Case two: The classifications are divided basing on the arrangement of transverse reinforcement:

- Beam A1: No transverse reinforcement is arranged.
- Beam B1: Transverse reinforcement is arranged within the shear span only.
- Beam C1: Transverse reinforcement is arranged within the portion of the shear span extending to a distance equal to 200mm from the support.
- Beam D1: Transverse reinforcement is arranged within the portion of the shear span between the cross - section at a distance equal to 200mm from the support and the cross - section through the point load.

All of those above experiments, the results somehow have the conflict with the current underline concepts of design methodologies. The *"shear capacity of critical cross-section"* is concluded as invalid. *"Aggregate interlock"* is resulted as having no contribution to the shear capacity at the interfaces of inclined cracks. *"Dowel action"* which used to be considered as being effected by diameter of rebar, also be concluded as has no contribution to shear capacity, since the reduction of longitudinal reinforcement diameter has no effect on the shear capacity of the beam. On the other hand, *"truss analogy"* is also conclude invalid, since there is no justification for the assumption that a beam-like member with both longitudinal and transverse reinforcement acts as a truss when it suffers inclined cracking.

It is also proved from the experiment that the *compressive zone* has a sole contribution to the shear capacity. The comparison experiments have carried out to compare two beams with the only different is the density of stirrup. The reduction of stirrups spacing in compression zone significantly improve stiffness and strength of the beam without affecting ductility. This reduction increases the effective confinement then, increases compressive strength of concrete and also leads to an increase of flexural capacity, which is caused by the reduction of compressive - zone depth leading to increase of lever arm of the internal longitudinal actions.

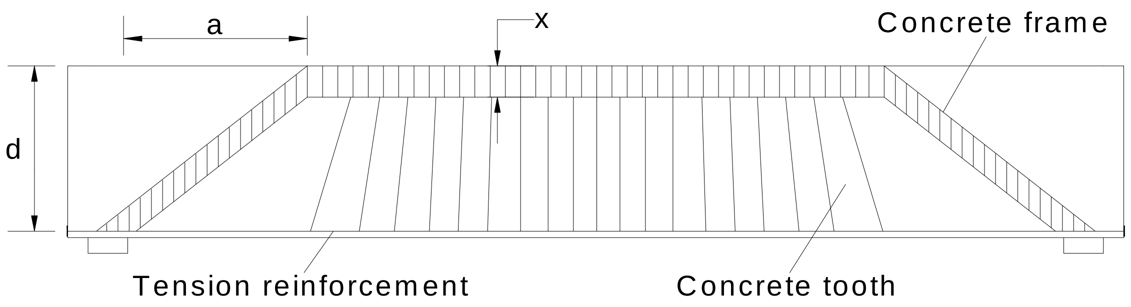
The triaxial compressive stress field in the region of the tip of the deepest inclined crack (which is caused by the local volume dilation of concrete under the large longitudinal compressive stresses) is also ignored by the current design methodologies. This triaxial compressive stress counters the tensile stresses due to the shear forces that act in the same region.

It is proved by experiment and discussed in 2.4.1.4 of [10] that it's not necessary for a beam at ultimate limit state to behave as a truss in order to resist the action of shear force. In fact, the contribution mechanism of *"transverse reinforcement"* in resistance of shear capacity is similar to the role of longitudinal rebar in flexural capacity. The reinforcement is designed to sustain the portion of tensile actions (in the direction of reinforcement) that can not be sustained by concrete alone.

The experiments and analyses are concluded in some conflicts with current design methodologies. Many concepts underlying current design methods are incompatible with fundamental characteristics of concrete behaviour at material level. These are the foundation for the design methods, such as: stress - strain relations, cracking processes, failure mechanism … This result leads to the fact that the assumptions such as "The uniaxial stress - strain response of concrete in the compressive zone of a critical cross - section in flexure" and the role of "aggregate interlock", "dowel action", "truss analogy" etc are not demonstrated by experimental evidence. The importance of triaxial stresses conditions which is the foundation of compressive zone also provides an additional shear capacity for the concrete member. The triaxial stresses cause the transverse tensile stresses which cause longitudinal cracking of compressive zone. This crack will propagate rapidly, leads to the immediate loss of load - carrying capacity and leads to collapse.

The physical model of beam is simplified as the following figure:

Figure 16: Physical model of beam



In all cases, the beam is modelled as a “comb - like” structure with the “teeth” fixed on to the horizontal element of a “frame” with inclined legs. The flexural reinforcement acted as a “tie” which if fully bonded to the “teeth” near their bottom face, an anchored at the bottom ends of the frame leg. The “frame” and the “teeth” also interact through this “tie”. In this model:

- The “frame” provides a simplified representation of the uncracked region of the beam which encloses the path of the compressive stress resultant that develops due to bending
- The “tie” represents the flexural reinforcement
- The “teeth” represent the plain - concrete cantilevers which form between successive flexural or inclined cracks within the tensile cracked zone of the beam.

The analyses finally are resulted in four types of failure behaviours for the simply - supported beam:

- Type I corresponds to the relative high value of $\frac{a_v}{d} > 5$ and is characterised by the flexural mode of failure.

- Type II corresponds to $2 < \frac{a_v}{d} < 5$ and is characterised by a brittle mode of failure which is associated with the formation of a deep inclined crack within the shear span of the beam. After this formation, the crack propagates in a nearly longitudinal direction, in the compressive zone, toward the point force. This leads to the immediate and total loss of load - carrying capacity of the beam. The crack can also propagate to the support, along the interface between concrete and rebar and destroys the bond between them.
- Type III corresponds to $1 < \frac{a_v}{d} < 2$ and is characterised by a brittle mode of failure as type II. The failures are associated with the development of inclined crack within the shear span of the beam. The difference between type II and type III is, in type III the inclined crack is formed separately with any pre-existing flexural of inclined crack. Furthermore, the crack does not lead to immediate failure; Failure only occurs when the applied load is increased more.
- Type IV corresponds to $\frac{a_v}{d} < 1$ and is characterised by two possible mode of failure:

+ Ductile mode of failure occurs when failure is within the middle narrow strip of the un - cracked portion of the beam.

+ Brittle mode of failure occurs when the failure is in the end blocks of the un - cracked portion of the beam in the region of the support.

2/. Crack prevention design:

In the considering structure, there are two important spans are the 10m long (The 5m long span is consider as a half of a span with 10m long) and 6m long span. According to Figure 4.1 and the enclose formula of [10]:

For the equilibrium: $F_c = F_s \Rightarrow f_c * x * b = f_y * A_s \Rightarrow x = \frac{f_y * A_s}{f_c * b}$

So: $z = d - 0{,}5x$ and $M_f = F_s * z = f_y * A_s * z$

10m long span: $\frac{L}{d} = \frac{10}{0{,}95} = 10{,}53$ and 6m long span: $\frac{L}{d} = \frac{6}{0{,}95} = 6{,}32$

Apply $M_c = 0{,}875.s.d.[0.342.b_1 + 0{,}3.(\frac{M_f}{d^2}).\sqrt{\frac{z}{s}}].\sqrt[4]{\frac{16{,}66}{\rho_w f_y}}$ for the calculation of Moment at the particular section.

- 10m long span has $\frac{L}{d} = \frac{10}{0{,}95} = 10{,}53 > 8$, this is the type I or type II of behaviour. Check the type of behaviour by comparing the values of M_c and βM_f with $\beta = 8\alpha(1-2\alpha)$, where $\alpha = \frac{d}{L}$.

Table 12: M_c, $\beta M_f^{'}$ and $q_f^{'}$ calculation

S (m)	d (m)	b_1 (m)	b_w (m)	z (m)	f_y (Mpa)	M_f (kNm)	M'_f (kNm)	ρ_w	A_s (mm^2)	M_c (kNm)	β	βM_f	q'_f (kN/m)
1.9	0.95	1	1	0.886	500	2848	3417	0.007	6431	1825	0.6156	2104	273
1.9	0.95	1	1	0.896	500	2882	3459	0.007	6431	1859	0.6156	2129	277
1.9	0.95	1	1	0.904	500	2907	3488	0.007	6431	1882	0.6156	2147	279
1.9	0.95	1	1	0.910	500	2925	3510	0.007	64301	1900	0.6156	2161	281

We can see that with all grades of concrete $M_c < \beta M_f^{'}$, these case are type II of behaviour. So, we have a = 2d for type II of behaviour

For the equilibrium at joint:

$T_f = V_f = q_f^{'} * \frac{l}{2} - q_f^{'} * 2d$ And $V_c = T_c = \frac{M_c(L-4d)}{2d(-2d)}$ from page 111 [10]

Type II of behaviour involves the near-horizontal splitting of the compressive zone of the beam in the region where the path of compressive stress results change direction. Failure will occur when $M_c < M_f$ or $V_c < V_f$.

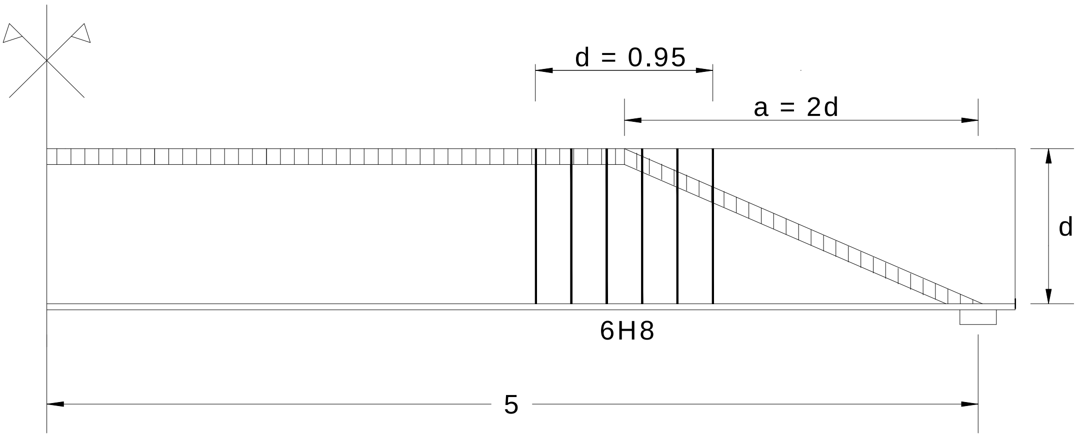
We have the requirement amount of transverse reinforcement $A_{sv} = \frac{V_f - V_c}{f_{yv} / \gamma_s}$

Table 13: Transverse reinforcement diameter

$T_f = V_f$ (kN)	$T_c = V_c$ (kN)	A_{sv} (mm^2)	Diameter (mm)
848	735	224	6H8
858	749	218	6H8
865	758	213	6H8
871	766	210	6H8

The reinforcement will be arranged in the field of joint in the distance of d.

Figure 17: Transverse reinforcement arrangement



- 6m long span:

We have: $\frac{L}{d} = \frac{6}{0,95} = 6,32 < 8$ And $a_v = \frac{M}{V} = \frac{411}{246} = 1,67 \Rightarrow \frac{a_v}{d} = \frac{1,67}{0,95} = 1,76 > 1$ => This case is type III of behaviour.

Type III of behaviour is characterised as the reduction of strength in the compressive zone of uncracked portion of the beam adjacent to the region of the change in the path of compressive stress resultant. The reason of this reduction is the deep penetration of the inclined crack closest to the support into the compressive zone, leads to the reduction of beam's flexural capacity.

We calculate M_c in two cases:

+ a_v = d: $M_c = M_f$

+ a_v = 2d: $M_c = 0,875.s.d.[0.342.b_1 + 0,3.(\frac{M_f}{d^2}).\sqrt{\frac{z}{s}}].\sqrt[4]{\frac{16,66}{\rho_w f_y}}$

And use interpolation to find the value of M_c at $a_v = 1,76d$

Table 14: Design table for M_c of a_v = 1,76d

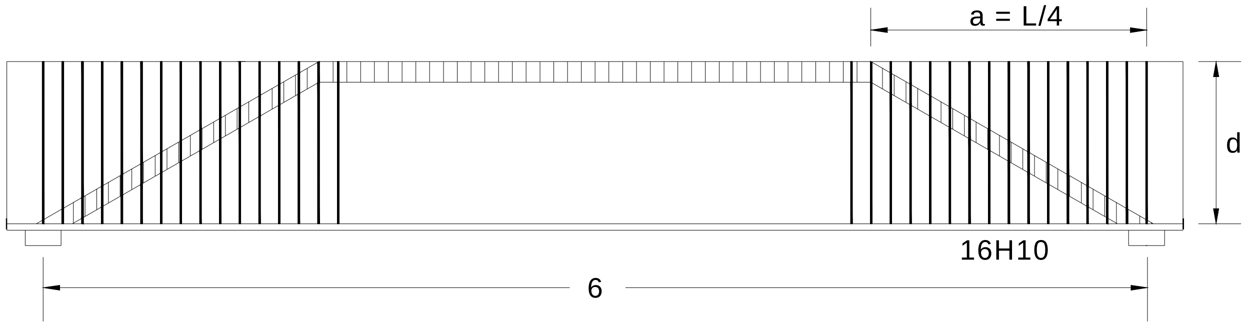
S (m)	d (m)	b_1 (m)	b_w (m)	z (m)	f_y (mPa)	M_f (kNm)	M'_f (kNm)	ρ_w	A_s (mm^2)	M_c at a_v=2d (kNm)	M_c at a_v=d (kNm)	M_c at a_v=1,76d (kNm)
1.9	1	1	1	0.886	500	2848	3417	0.0068	6431	1825	2848	2071
1.9	1	1	1	0.896	500	2882	3459	0.0068	6431	1859	2882	2104
1.9	1	1	1	0.904	500	2907	3488	0.0068	6431	1882	2907	2128
1.9	1	1	1	0.910	500	2925	3510	0.0068	6431	1900	2925	2146

Apply the formula: $T_{sv} = 8(3/4M_f - M_c)/L = A_{sv}.f_{yv}$ (Page 115 [10]) with the characteristic strength of transverse reinforcement $f_{sv} = 500Mpa$ we have the area of reinforcement:

Table 15: Transverse reinforcement diameter

T_{sv} for 6m span (kN)	A_{sv} (mm^2)	Diameter (mm)
656	1313	16H10
653	1306	16H10
651	1301	16H10
649	1297	16H10

Figure 18: Transverse reinforcement arrangement



V/. Conclusion:

In Conclusion, the applications of retaining wall in particular and earth-retained structure in general are very large. We can see the appearance of retaining wall in the highway, in bridge abutment, dam, dike, deep excavation etc. Retaining wall is used in different case, depending on the soil characteristic, construction condition and the requirement of the contractor.

Various types of retaining wall have been developed and in this thesis, we analysed the typical type of diaphragm wall. The wall analyses and designs were performed and checked by the continuum finite element program PLAXIS and codes of practice by ReWaRD program. PLAXIS divided the elements into the mesh and continued the finite element method. The final results are the geological data and in the structural force, prop force and the displacement. The wall is divided into more than 1000 nodes and the results are also showed on each node. The most important tables are displacement and stresses are printed with the thesis.

ReWaRD, somehow is simpler than PLAXIS. The advantage of ReWaRD is the applicability in the real construction. The program uses the codes of practice for design purpose. The mobilization factors are varied along the wall according to the codes of practice to provide a more accurate result. ReWaRD helps us to check the stability, required depth and condition of the wall in the different factors. The comparative results from different codes of practice show the different between the mobilization factors of the different codes. Structural forces from ReWaRD can be used as the input data for the design of retaining wall's structure.

The combination of ReWaRD and PLAXIS will be very good for a complete design of retaining wall. The wall depth and general physical properties can be assumed and then will be checked by using ReWaRD. All of the general properties such as stability, minimum depth requirement etc will be checked by

ReWaRD. Finally, the detail and complete analyses with defined depth of wall can be checked by PLAXIS.

The reinforced concrete wall can be simplified as the beam for the structural design. According to the structural force of BS 8002 from ReWaRD, the wall is simplified and design as a beam in the usual way. However, present codes of practice somehow underestimate or overestimate the response of the structure. In “Ultimate limit - state design of concrete structure: A new approach” [10] by M.N. Kotsovos and M.D. Pavlovíc, a new approach is presented with many experiments were perform considering all type of loading in different conditions. The new reappraisal succeeded in analysing and giving the new design that consider the effect of testing method, triaxial stresses etc. and especially, the contribution of compressive zone in the behaviour of structural member.

For any types of wall that can be simplified as a beam, we can use this direction of design to solve the problem. However, with the exception like mass concrete wall or the relevant type, this design can not be applied. The wall with high mass (for instance: mass concrete wall) can not stand with any crack.

VI/. References:

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