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Analytical and numerical assessment of Egyptian code compared with international standards for the analysis of braced diaphragm wall

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Abstract : In urban areas where space and property are a major constraint when constructing a deep excavation, the use of a stable and effective retaining system is essential. The choice of the retaining system will depend on the site condition, the expected earth pressure and the existence of water. Diaphragm walls are commonly used as a retaining system that can withstand high values of earth pressure and also have good performance with water existence. The design output of retaining system depends mainly on soil parameters, site conditions and adapted design approach. There are well known two design approaches for geotechnical problems: working stress design approach WSD which adapts a global safety factor for all uncertaintiesassociated with geotechnical design, and limit state design approach LSD which accounts for uncertainties by applying partial safety factors for different variables that affects the design output. Different standards adapt different design approachesi.e., the Egyptian code of practice ECP 202 adapts WSD approach; EN 1997 along with BS8002 and AASHTO adapts LSD approach. This study aims to emphasize the influence of adapting different design approaches on design output results for a strutted diaphragm wall. Comparing the design output results between ECP 202, AASHTO, EN 1997 DA1-1, EN 1997 DA1-2, and BS 8002 it was found that AASHTO design output gave the most conservative results for embedment depth and straining actions on the retaining system, as it uses load and resistance factored design method LRFD. The ECP 202 gave a high estimate for embedment depth when compared to EN 1997 DA1-1, EN 1997 DA1-2, and BS 8002.

1. Introduction

Diaphragm walls are deep embedded earth retaining structures used for deep excavations. Geotechnical codes of practice from different countries provide procedures for analysis of deep foundation. The proposed study will compare the analysis of diaphragm wall using different standards; ECP 202, BS8002, EN1997, and AASHTO.

Evaluation of Strut forces and deflection of Diaphragm wall for deep excavation has become increasingly an important topic for its wide uses in several projects nowadays, also the effect of the excavation on nearby structures. The choice of soil shear strength parameters affects the results for strut forces, deflection and settlement profiles, different standards implement different methodologies for design and factors of safety to ensure the stability of the excavation system.

The safety of the shoring system is affected by the uncertainty in the geotechnical design variables and equations, in order to address this uncertainty in geotechnical design a conservative factor of safety is used. The stability of the wall is essentially from the passive resistance if the soil in front of the wall, so it’s important to determine the design depth of embedment, it can be determined by considering the classical limit equilibrium mechanism. The main variables affecting the penetration depth are the soil shear strength parameters, the height of excavation and the surcharge.

(Sarhan & Riazi, 2016)compared between a block work quarry walls in marine structures when designed based on BS6349 which adapts allowable stress or working stress design approach, and

Eurocode 8 which adapts ultimate limit state design approach or load and resistance factor design LRFD; by checking the design of a gravity quarry wall with heights ranging from 10.5 to 23.6 m under static and seismic conditions. The results show that for low seismic conditions with $a_{max}< 0.1g$, there is a little difference in quarry wall section design, but under higher seismic conditions with $a_{max}> 0.1$ g, results show LRFD gave a significant increase in concrete volume compared to ASD.

(James & Kurian, 2020)compared between EN 1997-1, AS 4678, BS 8002, BS 8004, Canadian foundation engineering manual, IS 9556, ACI 318, AS 3600, BS 8110, BS EN 1538, CSAA23.3, EN 1992-1-1 and IS 456 in diaphragm wall design procedures. The difference between standards is in design equations, safety factors and moment capacity that results in varied design outcome. The depth of embedment for the study was constant regardless of design specifications. The obtained minimum wall deflection was estimated by EN-1997 DA-1, and the maximum bending moment obtained from American and Canadian codes which applies LRFD with a percentage increase with respect to minimum of 200%.

(Shaldykova et al., 2020)compared the design of shallow foundations using Kazakhstani and European approaches, considering two types of shallow foundation, strip footing and pad foundation. The given results were compared for calculation of bearing capacity and pad foundation and it was found that EN 1997 provides more conservative results compared to Kazakhstani design approach.

(Paternesi et al., 2017) compared the use of different design approaches in Eurocode 7 regarding the design of shallow tunnels with a numerical simulation focusing their study in comparing between design approaches. It was found that using only one of the two combinations DA2 or DA3 (which is equivalent to DA1) might lead to a less safe design either from a geotechnical or a structural point. Hence the use of a combination between DA2 and DA3 would achieve a safe design.

(Mansour et al., 2018) compared working stress design WSD adapted by ECP 202 and limit state design adapted by Eurocode 7 for a cantilever retaining wall, finding that a partial safety factor of 1.25 in the future version of the Egyptian Code for limit state design is most suitable partial safety factor for design of cantilever retaining wall in cohesionless soil.

(Simpson 2010) investigated the effects of recent advances in retaining structure design codes, focusing mostly on European and American codes. While the American preference LRFD applies loads and resistance factors, Eurocode 7 EN-1997 employs a mix of resistance and material strength factors. Making a contrast based on a gravity and embedded retaining wall, it was discovered that for multi-probed walls, material factors may be added during the analysis or only at individual stages, and the selection has a considerable impact on the outcome. Additionally, the Eurocode and AASHTO factoring schemes produced comparable results for the two examples considered. However, variations in configuration for inclined loads and "unplanned excavation" can be significant.

Using a benchmarked case studies for monitored braced excavation (D. C. Konstantakos et al., 2012) analyzed the difference between monitoring results and AASHTO (2010) by re-analyzing the same cases with limit equilibrium and non-linear analysis methods. They concluded that the adapted LRFD for braced excavation might produce unsafe design for many braced excavations and the limit equilibrium method underestimate benchmarked cases bending moment.

(Yang et al., 2014) for several retaining wall adapting LRFD design criteria were analyzed using limit state design method and factor of safety for sliding and overturning and comparing the results with Taylor’s series simple reliability analysis; found that the safety factors calculated by LRFD were lower than those calculated using WSD.

Common Design Approaches

Two design approaches are commonly used for diaphragm wall design: Global safety factor which is adapted by Egyptian Code of Practice ECP 202. The earth pressure of soil behind the wall is calculated using Rankine’s theory for earth pressure, then the depth of embedment is calculated by means of rotation equilibrium around strut point, then a safety factor is considered by multiplying the calculated depth with a global factor of 1.4.

$D_d = D_{req} \times 1.4$

And the total required depth is calculated by dividing the excavation to increments and calculating the depth of embedment for each. Then the summation of all required depths gives the total required depth of embedment for multi layered struts.The forces acting on the retaining wall Fig [1].

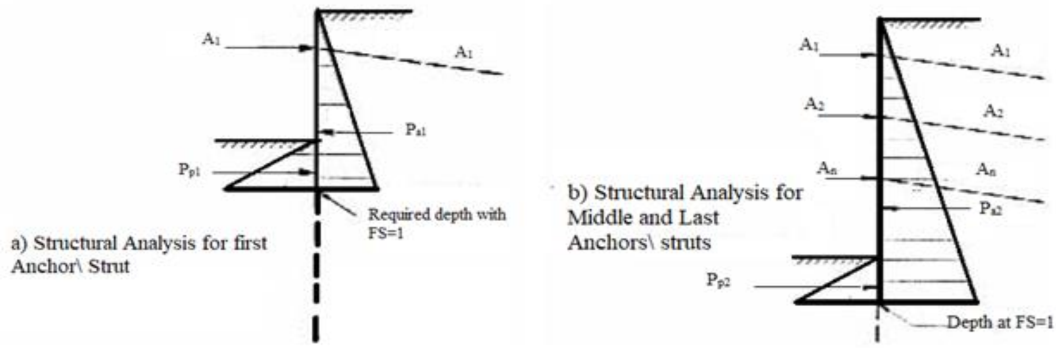
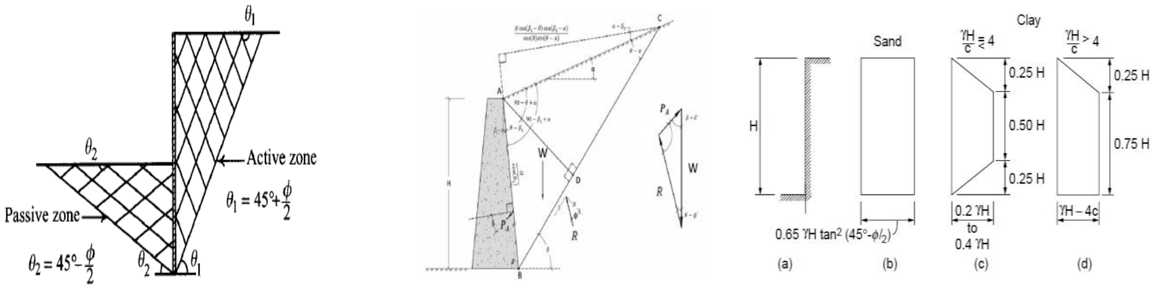


Fig. [1] Analysis method of a multi-level strutted or anchored excavation (reproduced from ECP 202).

The second approach for designing a diaphragm wall is the limit state design approach LSD which applies partial safety factors for different design variables, the EN 1997 DA1 applies to set of combinations DA1-1 and DA1-2, LRFD design method adapted by AASHTO applies safety factors by increasing action on wall and decreasing resistance. BS8002 also use partial safety factors in design combinations to achieve the required level of safety in the retaining structure. The partial safety factors by different standards are summarized in table [1].

The ECP 202 uses Rankine's earth pressure theory to calculate the earth pressure on the retaining system, whilst AASHTO and BS 8002 use Peck's and Terzaghi's theory for earth pressure calculations. EN 1997 which gives a flexibility for the earth pressure theory choice based on designer's preference. The use of Rankine's, Coulomb or Peck's theory for earth pressure calculation is accepted by the EN 1997. In the presented study the analytical solution was made by using Geo5 sheeting design which uses limit equilibrium method, while the straining actions on the retaining wall are calculated by numerical simulations using PLAXIS 2D V20 applying hardening soil model. Fig. [2] gives a summary for earth pressure theories.



a- Rankine's theory   b- Coulomb's theory   c- Peck's theory

Fig. [2] A summary for earth pressure theories

Table [1] Summary of different Factor of Safety applied for soil parameters and actions

Limit State case	Cohesion (C)	Angle of internal Friction (φ)	Earth Pressure		Loads Permanent	
			A. EP	P. EP	Favorable	Unfavorable
EN 1997 DA1-1	1	1	-	-	1	1.35
EN 1997 DA1-2	1.25	1.25	-	-	1	1
BS 8002	1.25	1.25	-	-	1	1
AASHTO	-	-	0.9-1.5	0.75	0.7	1.5

Methodology

The choice for this study was 2 situations, the first one having two levels of struts and excavation height H_e = 7 mFig. [3-1] and the second having 5 levels of struts and excavation height H_e = 16 m Fig. [3-2] and water level at 2 meters below ground surface for the two cases, studying both situations for different soil types in drained condition as it is most likely to be the critical condition in retaining structures for cohesive soil. Applying the recommended values of safety factors by the given standards.

The retaining wall system consists of a diaphragm wall and struts the horizontal spacing between struts S_h = 4 m and the vertical spacing between struts in the conducted simulation was S_v = 3 m, the applied surcharge was 20 kN/m^2 the excavation is assumed to be symmetric and excavation width = 20 m. The properties of the shoring system are given in table [2] and table [3].

Table [2] properties of diaphragm wall

Parameters	Value
Wall stiffness EI (kN.m^2-m)	5.407 x 10^5
Compression Stiffness EA (kN/m)	3.678 x 10^7
Poisson's ration ν	0.15

Table [3] strut properties

Parameters	Value
Material type	Elastic
Compression Stiffness EA (kN/m)	1.473 x 10^6

The unfactored soil parameters for the study is given in Table [4] and Table [5] where the soil in this study is cohesionless soil and cohesive soil with different values of internal angle of friction and cohesion and the GWT was taken to be 2 meters below ground surface.

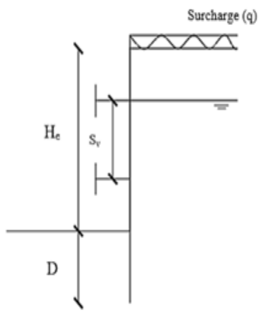


Fig. [3] (1): 2 level struts

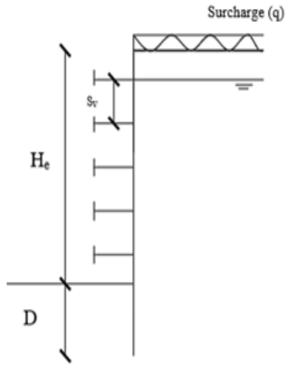


Fig. [3] (2): 5 level struts

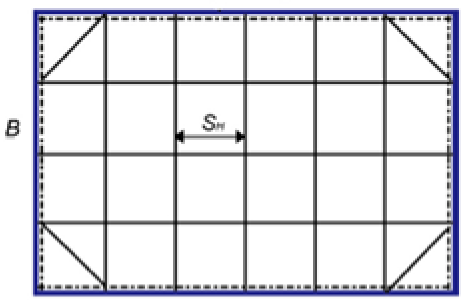


Fig. [3] (3): horizontal spacing between struts

Fig. [3] Strutted diaphragm wall for case 1 and case 2

Table [4] Unfactored soil parameters for hardening soil model (cohesionless soil)

Parameters	V.Loose Sand	Loose Sand	M. Dense Sand	Dense Sand	V. Dense Sand
Unit weight (γ) kN/m^3	16.8	17.5	18.2	19.1	19.5
Sat. Unit weight (γ_{sat}) kN/m^3	17.2	18.7	19.8	20.2	20.8
Angle of friction φ^0	28	30	33	35	39
Cohesion (C) kN/m^2	0.01	0.01	0.01	0.01	0.01
ψ^0	0	0	3	5	9
E_{50}kN/m^2	10,000	15,000	30,000	48,000	55,000
ν_{ur}	0.2	0.2	0.3	0.35	0.35

Table [5] Unfactored soil parameters for hardening soil model (cohesive soil drained condition)

Parameters	V.Soft Clay	Soft Clay	Medium Stiff Clay	Stiff Clay	V. Stiff Clay
Unit weight (γ) kN/m^3	16	16.9	17.8	18.3	19.2
Sat. Unit weight (γ_{sat}) kN/m^3	17.2	17.8	18.8	19.1	20.1
Angle of friction φ^0	24	26	29	32	34
Cohesion (C) kN/m^2	0.05	0.05	0.05	0.05	0.05
ψ^0	0	0	0	0	0
E_{50} kN/m^2	2000	5000	10,000	15,000	20,000
ν_{ur}	0.2	0.2	0.2	0.3	0.3

The passive earth pressure contributes to the overall stability of the retaining system. To calculate the depth of embedment and applying the given specifications safety factors, GEO 5 Sheeting Design V20 is used, as there are built-in standards for AASHTO, EN 1997 DA1-1, and EN 1997DA1-2, and British Standards BS8002; as for the ECP 202 the chosen standard is user defined based on the built-in specification of no reduction of strength parameters, and then multiplying the embedment depth with the given safety factor by the ECP 202 specification which is defined to be 1.4.The required embedment depth by different standards is shown for case a and case b in table [6] and table [7] and illustrated in graphs in Fig. [4] and Fig. [5].

Table [6] Estimated depth of embedment for Case 1

Case 1	ECP 202	AASHTO	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002
V. Loose	7	11	4	5	5
Loose	6	9	3	4	4
M. Dense	6	8	3	3	3
Dense	5	6	2	3	3
V. Dense	4	5	2	2	2
V. Soft	11	13	8	9	9
Soft	9	10	6	7	7
M. Stiff	7	7	4	5	5
Stiff	5	5	3	4	4
V. Stiff	4	4	3	3	3

Table [7] Estimated depth of embedment (m) for Case 2

Case 2	ECP 202	AASHTO	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002
V. Loose	17	24	11	12	12
Loose	15	20	8	10	10
M. Dense	11	15	6	7	7
Dense	9	12	5	6	6
V. Dense	7	9	3	4	4
V. Soft	20	31	15	16	16
Soft	18	25	12	13	13
M. Stiff	14	20	8	10	10
Stiff	11	15	6	7	7
V. Stiff	10	12	5	6	6

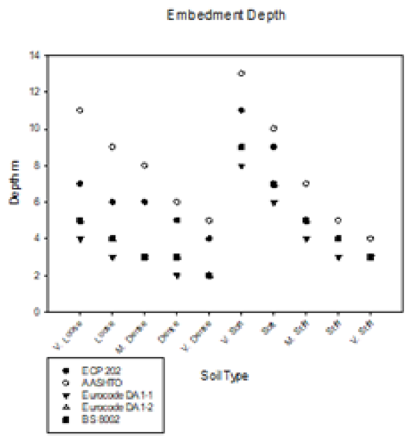


Fig. [4] Embedment depth for case 1

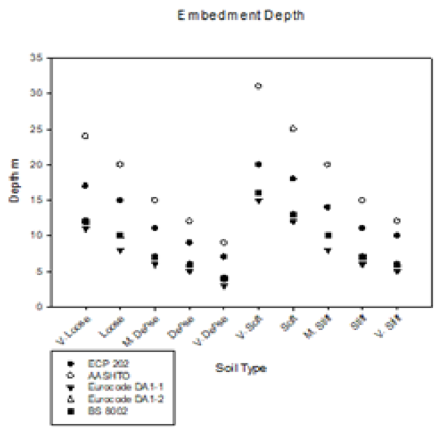


Fig. [5] Embedment depth for case 2

The numerical simulations for the two cases were done by using finite element analysis program PLAXIS 2D V20, half of the excavation model was developed due to symmetrical conditions for both the excavation sequence and geometry. A fine mesh size was adopted for 2D analysis to improve the accuracy of calculations, the given analysis aimed to establish the effect of implementing different safety factors on the design output i.e., strut forces and induced moment on the retaining system of a braced diaphragm wall. The construction sequence for the 5 level struts for numerical analysis is shown in table [6].

Table [6] Typical construction phases for 2D analysis with He = 7 m

Phases	Construction details
Phase 1	Install the diaphragm wall
Phase 2	Activate surcharge
Phase 3	Dewatering to 4 m below ground surface inside excavation
Phase 4	Excavate to 3 m below ground surface
Phase 5	Install strut system at level 2m below ground surface
Phase 6	Dewatering to 7 m below ground surface inside excavation
Phase 7	Excavate to 6 m below ground surface
Phase 8	Install strut system at level 5m below ground surface
Phase 9	Excavate to 7 m below ground surface

Analysis results

After using geo 5 sheeting design to determine the embedment depth that achieves the required stability for the retaining system calculated by different standards. PLAXIS 2D V20 is then used to determine the straining actions on the retaining system applying hardening soil model. A summary of maximum strut forces induced by excavation for all cases and different soil types is shown in tables [7] and [8]. Fig. [6] and Fig. [7] illustrates a sample for the results in case for medium dense sand.

Table [7] Summary of strut forces (kN) for case 1

	ECP 202		AASHTO		EN 1997 DA1-1		EN 1997 DA1-2		BS 8002	
	1st level	2nd level	1st level	2nd level	1st level	2nd level	1st level	2nd level	1st level	2nd level
V.Loose	-543.345	-477.288	-1489.72	-1487.77	-598.634	-734.052	-709.039	-953.906	-709.039	-953.906
Loose	-440.399	-326.119	-1066.56	-906.449	-508.889	-427.992	-625.715	-513.961	-625.715	-513.961
M.Dense	-436.938	-310.13	-803.22	-540.358	-464.741	-447.989	-618.163	-491.526	-618.163	-491.526
Dense	-307.963	-197.872	-680.821	-419.001	-325.638	-218.632	-344.38	-221.466	-344.38	-221.466
V.Dense	-264.761	-102.822	-499.529	-255.129	-298.437	-133.46	-302.802	-150.847	-302.802	-150.847
V.Soft	-474.627	-477.223	-1252.29	-1028.29	-513.917	-502.358	-593.99	-577.448	-593.99	-577.448
Soft	-407.995	-352.835	-1076.39	-936.07	-449.067	-377.984	-524.196	-459.743	-524.196	-459.743
M.Stiff	-337.303	-266.758	-1170.95	-1137.06	-373.166	-304.161	-468.413	-364.256	-468.413	-364.256
Stiff	-295.153	-203.954	-952.848	-792.25	-332.175	-248.296	-356.695	-263.206	-356.695	-263.206
V.Stiff	-232.357	-155.647	-736.505	-685.147	-305.349	-204.787	-327.818	-230.97	-327.818	-230.97

Table [8- a] Summary of strut forces (kN) for case 2

	ECP 202					AASHTO				
	1st level	2nd level	3rd level	4th level	5th level	1st level	2nd level	3rd level	4th level	5th level
V.Loose	-355.999	-1057.71	-1426.24	-1984.47	-776.727	-1347.14	-3438.42	-4409.79	-4249.8	-2282.29
Loose	-328.766	-877.958	-1188.38	-1642.96	-665.168	-1016.09	-2477.16	-2943.22	-3342.52	-1373.48
M.dense	-288.006	-699.066	-917.607	-1358.83	-500.477	-703.525	-1559.28	-1865.75	-2396.44	-941.006
Dense	-296.034	-646.401	-904.515	-1158.95	-480.584	-674.071	-1347.34	-1611.51	-2114.52	-829.675
V.Dense	-237.224	-506.738	-731.876	-922.486	-404.338	-478.958	-987.216	-1274.39	-1651.52	-638.612
V.Soft	-443.133	-1651.29	-2172.45	-2969.13	-1190.38	-1302.25	-4750.77	-6131.01	-6613.72	-1470.844
Soft	-449.559	-1383.11	-1792.49	-2532.82	-985.41	-1401.05	-4340.19	-5126.16	-6148.66	-2050.74
M.stiff	-370.163	-1032.68	-1326.18	-1947.32	-746.218	-1056.02	-2859.73	-3349.8	-3935.77	-1580.7
stiff	-338.204	-859.847	-1180.18	-1578.75	-634.352	-848.373	-2060.42	-2627.3	-3072.59	-1194.23
V.Stiff	-295.427	-740.411	-1030.72	-1367.35	-528.357	-708.812	-1725.08	-2115.86	-2570.58	-1193.41

Table [8- b] Summary of strut forces (kN) for case 2

	EN 1997 DA1-1					BS 8002				
	1st level	2nd level	3rd level	4th level	5th level	1st level	2nd level	3rd level	4th level	5th level
V.Loose	-347.982	-1031.91	-1443.31	-1973.49	-770.586	-420.242	-1260.1	-1747.81	-2492.04	-967.081
Loose	-343.458	-895.857	-1262.74	-1937.66	-703.493	-470.619	-1183.83	-1603.65	-2205	-864.398
M.dense	-353.405	-819.163	-1057.98	-1433.76	-546.722	-430.978	-957.458	-1279.32	-1763.55	-664.506
Dense	-326.275	-712.667	-937.008	-1274.56	-471.227	-394.189	-843.68	-1099.23	-1575.43	-601.986
V.Dense	-261.606	-560.11	-771.959	-1048.59	-353.077	-325.071	-693.845	-924.815	-1310.01	-484.127
V.Soft	-462.334	-1664.57	-2214.31	-2936.7	-1095.42	-542.576	-1919.43	-2580.08	-3514.18	-1310.86
Soft	-442.795	-1332.62	-1844.72	-2452.56	-920.488	-524.424	-1596.2	-2185.6	-2959.67	-1477.88
M.stiff	-408.342	-1045.74	-1503.29	-1934.62	-762.288	-495.317	-1300.61	-1767.78	-2375.7	-921.479
stiff	-371.979	-938.177	-1250.48	-1644.72	-608.529	-448.584	-1135.76	-1502.32	-1966.41	-738.423
V.Stiff	-332.852	-813.042	-1099.89	-1443.94	-497.959	-401.434	-975.601	-1337.63	-1714.88	-609.544

Table [8- c] Summary of strut forces (kN) for case 2

	EN 1997 DA1-2				
	1st level	2nd level	3rd level	4th level	5th level
V.Loose	-420.242	-1260.1	-1747.81	-2492.04	-967.081
Loose	-470.619	-1183.83	-1603.65	-2205	-864.398
M.dense	-430.978	-957.458	-1279.32	-1763.55	-664.506
Dense	-394.189	-843.68	-1099.23	-1575.43	-601.986
V.Dense	-325.071	-693.845	-924.815	-1310.01	-484.127
V.Soft	-542.576	-1919.43	-2580.08	-3514.18	-1310.86
Soft	-524.424	-1596.2	-2185.6	-2959.67	-1477.88
M.stiff	-495.317	-1300.61	-1767.78	-2375.7	-921.479
stiff	-448.584	-1135.76	-1502.32	-1966.41	-738.423
V.Stiff	-401.434	-975.601	-1337.63	-1714.88	-609.544

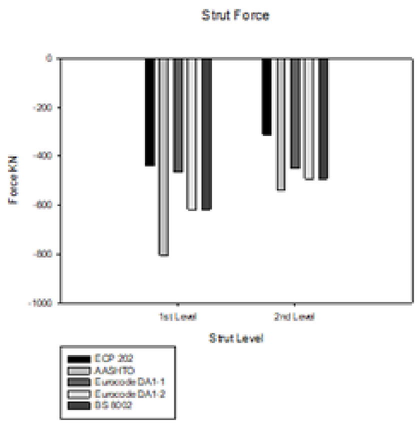


Fig. [6] Strut forces for case 1 in medium dense sand

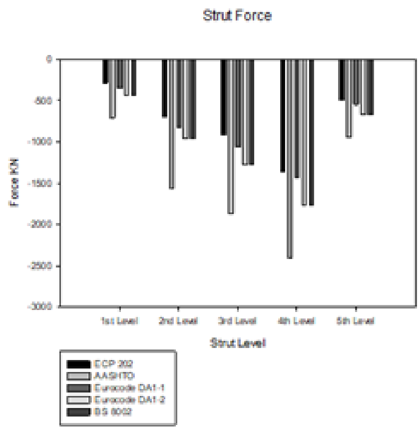


Fig. [7] Strut forces for case 2 in medium dense sand

The bending moment diagram on the retaining wall is calculated using PLAXIS 2D V20 hardening soil model. Table [9] and table [10] summarize the maximum calculated positive and negative bending moment induced on the raining structures. A histogram summarizing the difference between design standards for different soil types in case 1 and case 2 is shown in Fig. [9] and Fig. [10].

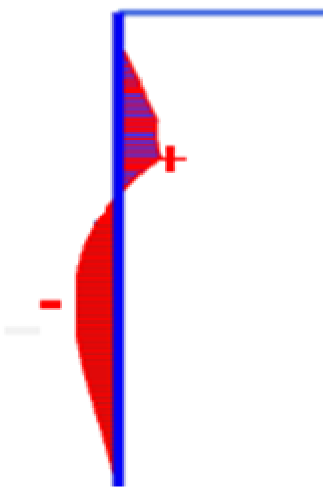


Fig. [8] BMD directions from PLAXIS 2D

Table [9-a] Maximum +ve bending moment (kN.m-m) case 1

	ECP 202	AASHTO	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002
V.Loose	14.34	84.99	49.58	107.06	107.06
Loose	15.40	47.23	27.72	34.72	34.72
M.Dense	14.76	39.05	25.86	33.00	33.00
Dense	15.94	36.90	26.79	18.09	18.09
V.Dense	12.25	24.35	18.10	15.07	15.07
V.Soft	8.77	39.18	9.84	8.07	8.07
Soft	8.48	23.28	7.11	7.56	7.56
M.Stiff	7.56	68.86	6.82	7.87	7.87
Stiff	5.92	53.70	5.95	8.75	8.75
V.Stiff	6.73	39.96	5.85	7.08	7.08

Table [9-b] Maximum -ve bending moment (kN.m-m) case 1

	ECP 202	AASHTO	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002
V.Loose	-214.03	-463.63	-99.89	-115.99	-115.99
Loose	-139.76	-313.08	-103.64	-146.04	-146.04
M.Dense	-142.73	-198.79	-100.22	-154.73	-154.73
Dense	-79.58	-151.20	-84.47	-87.73	-87.73
V.Dense	-64.83	-115.50	-77.91	-74.69	-74.69
V.Soft	-192.19	-749.92	-188.78	-250.47	-250.47
Soft	-164.65	-427.19	-162.67	-214.08	-214.08
M.Stiff	-126.51	-253.90	-130.72	-167.88	-167.88
Stiff	-114.73	-175.59	-111.70	-128.70	-128.70
V.Stiff	-95.13	-136.53	-108.18	-108.78	-108.78

Table [10-a] Maximum +ve bending moment (kN.m-m) case 2

	ECP 202	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002	AASHTO
V.Loose	329.11	309.08	460.16	460.16	1435.67
Loose	204.55	259.38	331.90	331.90	770.49
M.Dense	124.64	140.49	197.08	197.08	314.61
Dense	103.12	107.70	138.37	138.37	251.57
V.Dense	76.27	79.08	109.44	109.44	170.33
V.Soft	886.10	859.13	1113.50	1113.50	886.10
Soft	577.90	519.89	717.86	717.86	2406.89
M.Stiff	309.87	293.15	396.74	396.74	995.33
Stiff	190.31	198.41	255.94	255.94	631.88
V.Stiff	146.79	151.03	198.87	198.87	426.03

Table [10-b] Maximum -ve bending moment (kN.m-m) case 2

	ECP 202	EN 1997 DA1-1	EN 1997 DA1-2	BS 8002	AASHTO
V.Loose	-509.42	-524.21	-715.66	-715.66	-1554.71
Loose	-380.02	-499.02	-603.30	-603.30	-1038.39
M.Dense	-256.38	-351.51	-448.21	-448.21	-563.86
Dense	-216.76	-287.11	-357.32	-357.32	-436.53
V.Dense	-166.88	-252.94	-313.80	-313.80	-331.58
V.Soft	-947.09	-964.73	-1280.27	-1280.27	-947.09
Soft	-730.55	-752.97	-1057.56	-1057.56	-2395.61
M.Stiff	-490.61	-585.80	-748.55	-748.55	-1367.36
Stiff	-382.17	-478.68	-606.53	-606.53	-960.26
V.Stiff	-303.36	-403.11	-506.42	-506.42	-736.14

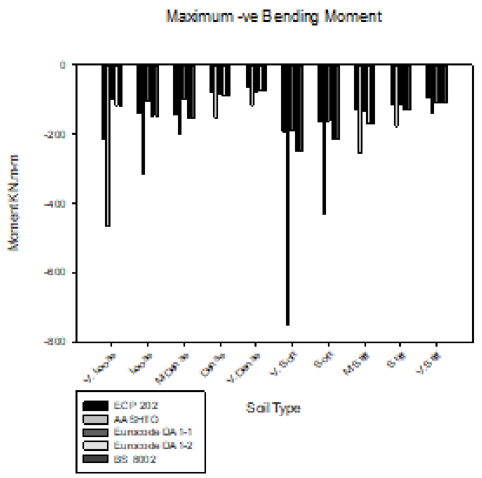


Fig. [9-a] Maximum -ve moment case 1

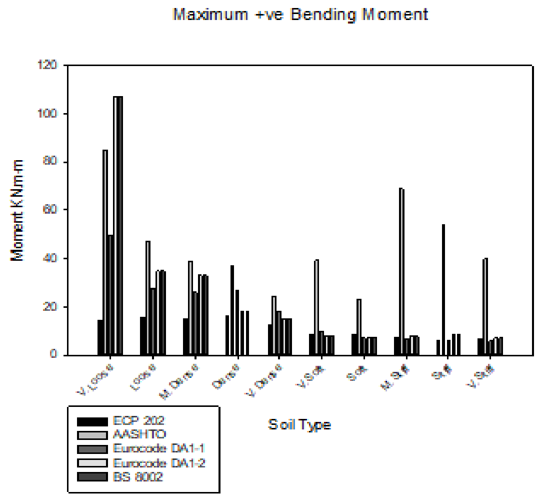


Fig. [9-b] Maximum +ve moment case 1

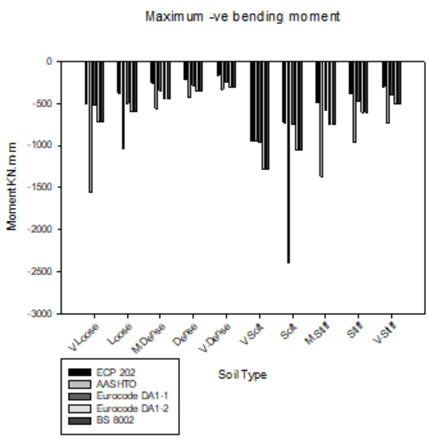


Fig. [10-a] Maximum -ve moment case 2

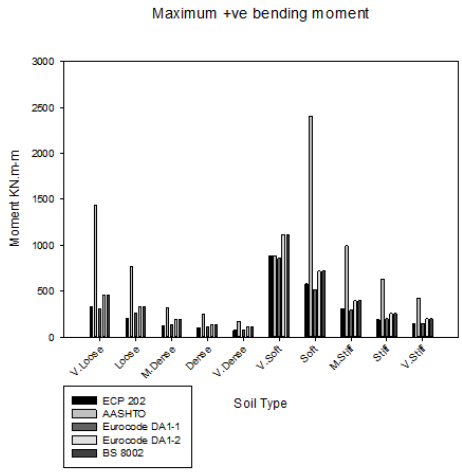


Fig. [10-b] Maximum +ve moment case 2

The difference between standards is practically in the design method of how to account for uncertainty in design equations, parameters and soil condition, in order to achieve the required stability for the retaining system, AASHTO, EN 1997 DA1-1 and EN 1997 DA1-2 and BS8002 account for uncertainty by using limit stated design method and apply partial safety factors for design variables, the ECP 202 account for uncertainty by applying a global safety factor 1.4 to increase passive resistance by increasing embedment depth. As a result, for this variation in accounting for uncertainty depending on area and design conditions the design output results are different. To differentiate between the results and study the impact of changing the safety factors the ECP 202 results are taken as a base on which the comparison is performed

Discussion

The analytical results for penetration depth estimation by Geo 5 sheeting design application show that, the application of partial safety factors by EN 1997 DA1-1, for increasing action by 1.35 gave the minimum values for embedment depth, and EN 1997 DA1-2 along with BS8002 gave the second minimum value after applying the strength reduction safety factors on shear strength parameters. The maximum value of the estimated depth was given by AASHTO design method as it applies load and resistance safety factor LRFD, by both increasing the surcharge load or acting earth pressure and decreasing passive resistance of soil, the maximum variance between AASHTO estimation and ECP 202 values for case 1 was at v. loose sandy soil with 157%. For case 2 the maximum and minimum values of embedment depth have the same trend of case 1 with maximum variance with respect to ECP 202 at v. soft clay with 155%.

The highest and lowest estimation for the maximum positive bending moment for case 1 varied between different standards with maximum variance with ECP 202 at 390% for v. soft clay estimated by AASHTO standards and the minimum variance with ECP 202 at v. loose sand with 47% calculated by EN 1997 DA1-1; the maximum negative bending moment with highest estimation by AASHTO and the minimum estimation varied between different standards with maximum variance with ECP 202 at m. stiff clay with 911%, and the minimum variance with ECP 202 at 84% for soft clay and estimated by EN 1997 DA1-1.

The highest estimation for maximum positive bending moment for case 2 was mostly given by AASHTO and the minimum estimation varied between standards the maximum variance with ECP 202 was at v. loose sand with 436% and the minimum variance was at v. soft clay with 90% and estimated by EN 1997 DA1-1. the highest estimation for negative bending moment was mostly given by AASHTO with maximum variance with ECP 202 at soft clay with 328% and the minimum estimation was given by ECP 202.

The maximum and minimum estimation of strut forces for all levels was by AASHTO and ECP 202 respectively, the first strut was highest estimated from ECP 202 by 347% at medium stiff. The second level of struts was highest estimated with a variance from ECP 202 with440% at v. stiff clay. For case 2 the maximum value for all levels of struts was by AASHTO anddifferentiate minimum estimated value mostly given byECP 202.The variance with ECP 202 for all strut forces are summarized in table [11].

Table [11-a] Variance of strut forces with respect to ECP 202 case 2

	AASHTO					EN 1997 DA1-2				
	1st level	2nd level	3rd level	4th level	5th level	1st level	2nd level	3rd level	4th level	5th level
V.Loose	378%	325%	309%	214%	294%	118%	119%	123%	126%	125%
Loose	309%	282%	248%	203%	206%	143%	135%	135%	134%	130%
M.dense	244%	223%	203%	176%	188%	150%	137%	139%	130%	133%
Dense	228%	208%	178%	182%	173%	133%	131%	122%	136%	125%
V.Dense	202%	195%	174%	179%	158%	137%	137%	126%	142%	120%
V.Soft	294%	288%	282%	223%	124%	122%	116%	119%	118%	110%
Soft	312%	314%	286%	243%	208%	117%	115%	122%	117%	150%
M.stiff	285%	277%	253%	202%	212%	134%	126%	133%	122%	123%
stiff	251%	240%	223%	195%	188%	133%	132%	127%	125%	116%
V.Stiff	240%	233%	205%	188%	226%	136%	132%	130%	125%	115%

Table [11-b] Variance of strut forces with respect to ECP 202 case 2

	EN 1997 DA1-1					BS 8002				
	1st level	2nd level	3rd level	4th level	5th level	1st level	2nd level	3rd level	4th level	5th level
V.Loose	98%	98%	101%	99%	99%	118%	119%	123%	126%	125%
Loose	104%	102%	106%	118%	106%	143%	135%	135%	134%	130%
M.dense	123%	117%	115%	106%	109%	150%	137%	139%	130%	133%
Dense	110%	110%	104%	110%	98%	133%	131%	122%	136%	125%
V.Dense	110%	111%	105%	114%	87%	137%	137%	126%	142%	120%
V.Soft	104%	101%	102%	99%	92%	122%	116%	119%	118%	110%
Soft	98%	96%	103%	97%	93%	117%	115%	122%	117%	150%
M.stiff	110%	101%	113%	99%	102%	134%	126%	133%	122%	123%
stiff	110%	109%	106%	104%	96%	133%	132%	127%	125%	116%
V.Stiff	113%	110%	107%	106%	94%	136%	132%	130%	125%	115%

Conclusion

The design specifications for retaining walls aims to give safe values for design parameters and account for uncertainty in design equations and assumptions, that is to avoid the catastrophic impact of any failure in the retaining system, the difference between standards lies in the method of considering uncertainty, the Egyptian code of practice ECP 202 consider increasing the passive resistance by increasing the depth of embedment

with a global safety factor, AASHTO, BS8002, EN 1997 DA1-1 and EN 1997 DA1-2 consider the use of partial safety factors on design variables, the variance of considering uncertainty between standards impacts the estimated
results of design output, the following is concluded from the study:

1- The LRFD adapted by AASHTO gave the largest depth of embedment as it increases action and decrease resistance with an average of 121 and 137% larger than ECP 202 estimation for case 1 and case 2 respectively.
2- EN 1997 DA1-1 gave the minimum estimation for depth with 58 and 57% average value less than ECP 202 for case 1 and case 2 respectively.
3- EN 1997 DA1-2 and BS8002 gave the same estimation for embedment depth as they consider the same set of combination for safety factors with an average of 68 and 67% less than ECP 202 estimation for case 1 and case 2.
4- The highest value for positive bending moment bending moment was mostly given by AASHTO with 473% and 299% larger estimation compared to ECP 202 for case 1 and case 2 respectively
5- EN 1997 DA1-2 along with BS8002 gave the second maximum value for positive bending moment with an average of 197% and 139% larger estimation compared to ECP 202 for case 1 and case 2 respectively.
6- AASHTO estimation for strut forces gave the maximum value for all strut levels with an average of 279% and 233% higher estimation compared to ECP 202 estimation for strut forces for case 1 and case 2 respectively
7- EN 1997 DA1-2 along with BS8002 gave the second maximum estimation for strut forces with an average of 137% and 128% higher estimation compared to ECP 202 estimation for strut forces for case 1 and case 2 respectively

Nearly the estimated results show that, the design output values after considering different safety factors mostly lies in a similar range to achieve the required stability for the shoring system, yet using the partial safety factor design method allows the engineer to account for different uncertainties depending on the design conditions.

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