In Malaysia, Reinforced Concrete (RC) gravity retaining wall has been commonly designed by engineers based on conventional practices in which adequate margin of overall Factor of Safety (FOS) against potential failure modes, i.e. overturning, sliding and bearing capacity shall be obtained to ensure a safe design. With the introduction of EN1997 Eurocode 7: Geotechnical Design (EC7) and the official publication of Malaysian National Annex, it is understood that the three (3) potential failure modes of RC gravity retaining wall are in principle still required to be considered and checked but according to limit state principles with various partial factors applied to actions or the effects of actions, soil parameters and resistances respectively. This paper presents a worked example of a RC gravity retaining wall which is duly computed based on the conventional geotechnical practice and EC7 with Malaysian National Annex for technical comparisons to find out which approach/code produces more critical design and which produces more economical design. Besides that, the Annex C of EC7 give two (2) new sets of coefficients of lateral earth pressure for both active (K_a) and passive state (K_p) in the forms of charts and numerical equations. Comparison among these two new sets of coefficients together with the most commonly used Rankine's and Coulomb's equations of coefficients of lateral earth pressures is carried out with few case scenarios considering different wall friction and slope angle of the retained fill. Malaysian National Annex has also recommended partial modifications to bearing resistance calculation method as given in Annex D of EC7, particularly on equation of N_γ factor for bearing resistance calculation and consideration of ground inclination factor. The paper will address the recommended modifications and its significances to the design of RC gravity retaining wall.

Comparison of Conventional Geotechnical Practice with EC7 and Malaysia National Annex for Design of Reinforced Concrete Gravity Retaining Wall

Deng-Ing Ting, Yean-Chin Tan

INTRODUCTION

Generally, Reinforced Concrete (RC) gravity retaining wall can be described as an earth retaining wall made of two main RC elements mainly slab and wall where earth fill will be placed above the slab, particularly at the retained side, to act as gravity mass for stabilization purpose. RC gravity retaining wall is widely used in Malaysia to retain filled platforms, embankments, roads and etc. with exposed height ranges from 1 meter to as high as 6 meter.

CONVENTIONAL DESIGN METHODOLOGY FOR RC GRAVITY RETAINING WALL USED IN MALAYSIA

Besides Geotechnical Engineers, most of the Civil and Structural Engineers in the country can also perform the RC wall design without trouble. Regardless of whatever computer programmes used, the design principle of the RC retaining wall in Malaysia is generally based on conventional Overall Factor of Safety (OFS) method. External wall stability check against overturning, sliding and bearing capacity (see Figure 1) would be performed to ensure total resistances are greater than total disturbing forces or moments by certain margin of safety. This margin of safety is commonly known as factor of safety (FOS). The requirement of these FOS values could be varying from country to country but in Malaysia, is basically specified in a published guideline by Public Works Department (PWD). Table 1 summarizes the minimum FOS required by PWD for the respective failure modes.

Figure 1: Typical Failure Modes of Overturning, Sliding and Bearing Capacity (extracted from Hong Kong Geoguide 1: Guide to Retaining Wall Design)

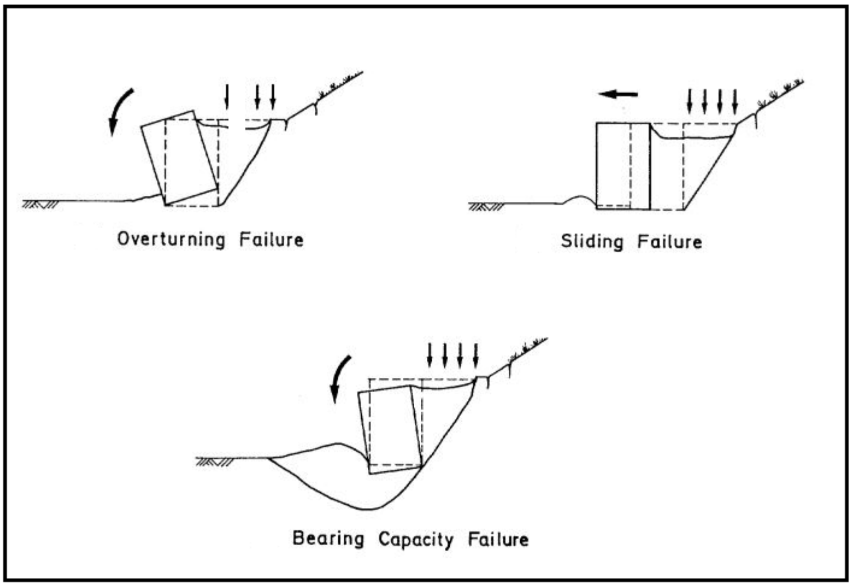


Table 1: Summary of Minimum Factor of Safety based on Public Works Department Malaysia

Mode of Failure	Minimum Factor of Safety
Overturning	2.0
Sliding	1.5
Bearing Capacity	2.0

DESIGN PRACTICE ACCORDING TO EC7 AND MALAYSIAN NATIONAL ANNEX

On the other hand, the design of RC gravity retaining wall according to EN1997 Eurocode 7: Geotechnical Design (EC7) is based on limit states principle where partial factors are applied for actions/effects of actions, soil materials and resistance. Malaysia National Annex to EC7, which has been published in year 2012, specifies that only Design Approach 1 (DA-1) with Combinations 1 & 2 shall be adopted along with the respective partial factors as summarized in Table 2.

Table 2: Summary of Partial Factors for Actions/Effects of Actions, Materials and Resistance according to Malaysia National Annex MS EN1997-1:2012

			Design Approach 1					
			Combination 1			Combination 2		
			A1	M1	R1	A2	M2	R1
Actions	Permanent	Unfavourable	1.35			1.00		
		Favourable	1.00			1.00		
	Variable	Unfavourable	1.50			1.30		
		Favourable	0.00			0.00		
Soil	tan ϕ'			1.00			1.25	
	Effective Cohesion			1.00			1.25	
	Undrained Shear Strength			1.00			1.40	
	Unconfined Strength			1.00			1.40	
Resistance	Bearing Capacity				1.00			1.00
	Sliding Resistance				1.00			1.00
	Earth Resistance				1.00			1.00

Assessment of ultimate limit state with regard to RC gravity retaining wall shall also be carried out to check at least the three (3) limit modes similar with the conventional practice as shown earlier in Figure 1.

COMPARISON OF CONVENTIONAL GEOTECHNICAL PRACTICE WITH EC7 AND MALAYSIAN NATIONAL ANNEX USING WORKED EXAMPLE

Assumptions of Worked Example

In the following sections, the ultimate limit state design of a RC gravity retaining wall according to EC7 and Malaysian National Annex will be performed using an example and compared with those of the conventional OFS method. The worked example for all the design approaches follows the same wall configurations as illustrated in Figure 2 in which two RC wall of 2m and 5m exposed height respectively. The ground beneath the wall base and the ground in front of the wall base (i.e. at the toe of the wall) have the same soil properties as the retained ground. The underside of the wall base is considered rough (i.e. concrete cast against the ground) whilst the vertical face of the wall base on both active and passive side is considered to be smooth (i.e. concrete cast against a smooth formwork). Meanwhile, the other parameters used in the worked example are summarized in Table 3. For consistency of comparison, coefficient of lateral earth pressure for active state (k_a) is uniformly based on commonly used Rankine equation.

Figure 2: Typical Configuration of L-shaped RC Gravity Retaining Wall used in the Worked Example

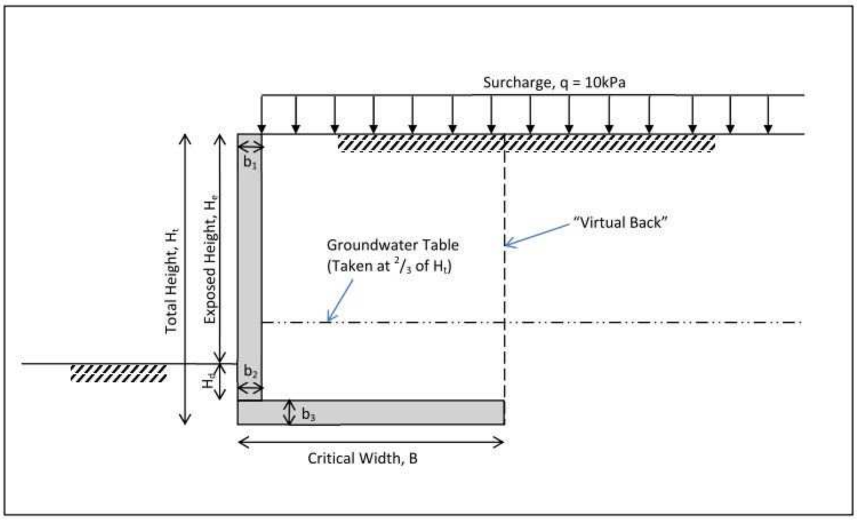


Table 3: Assumed Soil Parameters and Wall Geometrical Data used in the Worked Example

Soil Properties	Assumed Design Value	
Angle of Shearing, ϕ'	30°	
Effective Cohesion, c	0 kPa	
Bulk Unit Weight, γ_b	20 kN/m^3	
Wall Geometry	Assumed Dimension (1)	Assumed Dimension (2)
Exposed Height, H_e	2 m	5 m
Embedded Depth, H_d	0.25 m	0.50 m
Width of top stem, b_1	0.20 m	0.50 m
Width of bottom stem, b_2	0.20 m	0.50 m
Width of wall base, b_3	0.20 m	0.50 m
Critical Width, B	To be calculated	To be calculated

The objective of the worked example is to calculate the given wall geometry and soil parameters, and to determine the required minimum width of the wall base complying with the requirements among the conventional method and EC7 design approaches. In other words, the most critical wall base is the minimum width of the wall base required to meet and pass all the ultimate limit states in the ground in all the design approaches. Thereafter, the over-design/ redundancy factors (in terms of ratio of total resistance over total imposed forces/moments) of the other least critical design approaches based on the same critical width of the wall base are examined.

This paper does not cover design check for serviceability limit state. Nevertheless, serviceability requirements relate to the displacements of the wall and the retained ground are still recommended to be checked in actual project assessment.

Results and Findings using Worked Example

Table 4 presents the results of the worked examples for 2m & 5m RC gravity retaining wall respectively based on same wall geometry and soil parameters as well as the same critical width of wall base, which can safely comply with the Malaysian current conventional practice and EC7 design approaches.

Table 4: Results of Ultimate Limit State Design of RC Gravity Retaining Wall considering all earth pressures, effects of surcharge and groundwater table

	2m High RC Wall			5m High RC Wall		
	EC7 Design Approach 1		OFS Method	EC7 Design Approach 1		OFS Method
	Comb. 1	Comb. 2		Comb. 1	Comb. 2	
Critical Width of Wall Base - B (m)	2.71	2.71	2.71	5.65	5.65	5.65
A. Design against Overturning						
Design value of resisting moment - $M_{R,d}$ (kNm/m)	183.92	183.76	183.92	1959.41	1957.67	1959.41
Design value of overturning moment - $M_{o,d}$ (kNm/m)	37.84	36.85	27.28	424.94	402.07	313.24
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $M_{R,d}/M_{o,d}$	4.86	4.99	6.74	4.61	4.87	6.26
Minimum required value of $M_{R,d}/M_{o,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
B. Design against Sliding						
Design value of horizontal sliding resistance - $R_{h,d}$ (kN/m)	75.62	60.58	75.62	385.84	309.06	385.84
Design value of total horizontal actions - $E_{h,d}$ (kN/m)	41.70	40.20	31.12	206.27	194.53	157.29
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{h,d}/E_{h,d}$	1.81	1.51	2.43	1.87	1.59	2.45
Minimum required value of $R_{h,d}/E_{h,d}$ for stability	1.00	1.00	1.50	1.00	1.00	1.50
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
C. Design against Bearing Resistance Failure						
Design value of bearing resistance - $R_{v,d}$ (kN/m)	186.01	91.56	252.00	420.28	212.41	543.72
Design value of total vertical actions - $E_{v,d}$ (kN/m)	93.33	91.21	81.09	217.42	212.11	193.08
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{v,d}/E_{v,d}$	1.99	1.00	3.11	1.93	1.00	2.82
Minimum required value of $R_{v,d}/E_{v,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Critical	Not Critical	Not Critical	Critical	Not Critical

Meanwhile, in order to examine the extent of effects on the outcome of RC wall design using the different design methods, the external loadings in terms of groundwater and surcharge on the retained side of the RC wall will be assigned or ignored to form another three (3) cases of external loading condition. These 3 loading cases and its results are presented in Tables 5 to 7 respectively.

Table 5: Results of Ultimate Limit State Design of RC Gravity Retaining Wall considering all earth pressures and effects of surcharge only without groundwater table

	2m High RC Wall			5m High RC Wall		
	EC7 Design Approach 1		OFS Method	EC7 Design Approach 1		OFS Method
	Comb. 1	Comb. 2		Comb. 1	Comb. 2	
Critical Width of Wall Base - B (m)	2.50	2.50	2.50	5.11	5.11	5.11
A. Design against Overturning						
Design value of resisting moment - $M_{R,d}$ (kNm/m)	156.72	156.55	156.72	1605.59	1603.74	1605.59
Design value of overturning moment - $M_{o,d}$ (kNm/m)	37.07	36.02	26.34	414.00	390.31	299.98
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $M_{R,d}/M_{o,d}$	4.23	4.35	5.95	3.88	4.11	5.35
Minimum required value of $M_{R,d}/M_{o,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
B. Design against Sliding						
Design value of horizontal sliding resistance - $R_{h,d}$ (kN/m)	78.99	63.28	78.99	396.28	317.47	396.28
Design value of total horizontal actions - $E_{h,d}$ (kN/m)	39.26	37.59	28.17	192.00	179.20	139.99
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{h,d}/E_{h,d}$	2.01	1.68	2.80	2.06	1.77	2.83
Minimum required value of $R_{h,d}/E_{h,d}$ for stability	1.00	1.00	1.50	1.00	1.00	1.50
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
C. Design against Bearing Resistance Failure						
Design value of bearing resistance - $R_{v,d}$ (kN/m)	188.60	96.03	263.74	430.01	226.20	577.59
Design value of total vertical actions - $E_{v,d}$ (kN/m)	97.70	95.46	83.91	232.37	226.08	202.98
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{v,d}/E_{v,d}$	1.93	1.01	3.14	1.85	1.00	2.85
Minimum required value of $R_{v,d}/E_{v,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Critical	Not Critical	Not Critical	Critical	Not Critical

Table 6: Results of Ultimate Limit State Design of RC Gravity Retaining Wall considering all earth pressures and groundwater table only without effects of surcharge

	2m High RC Wall			5m High RC Wall		
	EC7 Design Approach 1		OFS Method	EC7 Design Approach 1		OFS Method
	Comb. 1	Comb. 2		Comb. 1	Comb. 2	
Critical Width of Wall Base - B (m)	2.00	2.00	2.00	4.93	4.93	4.93
A. Design against Overturning						
Design value of resisting moment - $M_{R,d}$ (kNm/m)	100.65	100.49	100.65	1494.74	1493.00	1494.74
Design value of overturning moment - $M_{o,d}$ (kNm/m)	22.83	20.88	17.27	334.94	306.33	253.24
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $M_{R,d}/M_{o,d}$	4.41	4.81	5.83	4.46	4.87	5.90
Minimum required value of $M_{R,d}/M_{o,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
B. Design against Sliding						
Design value of horizontal sliding resistance - $R_{h,d}$ (kN/m)	57.52	46.09	57.52	340.83	273.05	340.83
Design value of total horizontal actions - $E_{h,d}$ (kN/m)	29.45	27.17	22.96	176.27	162.62	137.29
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{h,d}/E_{h,d}$	1.95	1.70	2.51	1.93	1.68	2.48
Minimum required value of $R_{h,d}/E_{h,d}$ for stability	1.00	1.00	1.50	1.00	1.00	1.50
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
C. Design against Bearing Resistance Failure						
Design value of bearing resistance - $R_{v,d}$ (kN/m)	159.30	83.73	204.56	392.51	204.24	496.72
Design value of total vertical actions - $E_{v,d}$ (kN/m)	86.07	83.39	77.73	210.61	203.98	190.44
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{v,d}/E_{v,d}$	1.85	1.00	2.63	1.86	1.00	2.61
Minimum required value of $R_{v,d}/E_{v,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Critical	Not Critical	Not Critical	Critical	Not Critical

Table 7: Results of Ultimate Limit State Design of RC Gravity Retaining Wall considering all earth pressures only without effects of surcharge and groundwater table

	2m High RC Wall			5m High RC Wall		
	EC7 Design Approach 1		OFS Method	EC7 Design Approach 1		OFS Method
	Comb. 1	Comb. 2		Comb. 1	Comb. 2	
Critical Width of Wall Base - B (m)	1.80	1.80	1.80	4.42	4.42	4.42
A. Design against Overturning						
Design value of resisting moment - $M_{R,d}$ (kNm/m)	81.77	81.60	81.77	1204.47	1202.62	1204.47
Design value of overturning moment - $M_{o,d}$ (kNm/m)	22.06	20.06	16.34	324.00	294.57	239.98
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $M_{R,d}/M_{o,d}$	3.71	4.07	5.00	3.72	4.08	5.02
Minimum required value of $M_{R,d}/M_{o,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
B. Design against Sliding						
Design value of horizontal sliding resistance - $R_{h,d}$ (kN/m)	58.87	47.18	58.87	347.68	278.59	347.68
Design value of total horizontal actions - $E_{h,d}$ (kN/m)	27.01	24.56	20.01	162.00	147.29	119.99
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{h,d}/E_{h,d}$	2.18	1.92	2.94	2.15	1.89	2.90
Minimum required value of $R_{h,d}/E_{h,d}$ for stability	1.00	1.00	1.50	1.00	1.00	1.50
Remark on design	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical	Not Critical
C. Design against Bearing Resistance Failure						
Design value of bearing resistance - $R_{v,d}$ (kN/m)	162.81	89.33	217.22	404.56	220.02	532.38
Design value of total vertical actions - $E_{v,d}$ (kN/m)	92.63	89.23	82.04	227.55	219.08	201.74
Over-design factor for EC7 or Overall Factor of Safety for OFS method -- $R_{v,d}/E_{v,d}$	1.76	1.00	2.65	1.78	1.00	2.64
Minimum required value of $R_{v,d}/E_{v,d}$ for stability	1.00	1.00	2.00	1.00	1.00	2.00
Remark on design	Not Critical	Critical	Not Critical	Not Critical	Critical	Not Critical

Based on the results presented in Tables 4 to 7, the following findings can be deduced:

1) For all the analyses, EC7 Design Approach 1 Combination 2 always yields the most critical results in determining the minimum width of wall base required for adequate bearing capacity of both the lower and high retaining wall. OFS method appears as the second most critical whilst EC7 DA-1 Combination 1 is the least critical among the three approaches. Based on the critical width of wall base governed by EC7 DA-1 Combination 2, the margin of safety for bearing failure from the OFS method is about 30% to 57% greater than the required FOS (i.e. 2.0). Likewise, the EC7 DA-1 Combination 1 approach commands about 75% to 99% more safety margin on top of the value of adverse vertical actions (i.e. imposed loads or pressures) for the bearing capacity check.
2) Among the three failure modes checked, bearing capacity failure is the most crucial condition in all the analyses irrespective of which design methodology

is used meanwhile overturning failure seems to be the most unlikely concern for the retaining wall.

3) For the analysis results shown in Table 7, only lateral earth pressures are taken into account (i.e. without effects of surcharge and groundwater) in the GEO ultimate limit state check. It is observed that EC7 DA-1 Combination 2 method still dictates as most critical compared to the other two methods. Based on the same critical width of wall base, the redundancy of safety margin for bearing failure from the OFS method and the EC7 DA-1 Combination 1 method is about 32% and 77% greater than the minimum required value respectively.
4) Comparing the analysis results from Tables 5 & 6, it is noticed that the effect of surcharge in the form of uniformly distributed load over the retained ground is of rather significance to the ultimate limit state of the retaining wall as compared to the effect of water pressure. This is evident by the fact that the width of wall base reduces by 13% to 26% in the wall analysis without surcharge in relative to a reduction of 8% to 10% in the width of wall base in the wall analysis without groundwater. The logical explanation for such findings is attributed to the relatively higher partial factor applied to the surcharge load deemed to be unfavorable variable action in the EC7 approach. On the contrary, in this study, water pressure is derived corresponding to the most unfavorable water table at the retained ground with reliable drainage system during the life time of the retaining wall without applying any partial factor.

COMPARISON OF COEFFICIENT OF LATERAL EARTH PRESSURE FOR ACTIVE STATE (k_a) VALUES USING DIFFERENT EQUATIONS

Annex C of EC7 code encloses two (2) new sets of coefficient of lateral earth pressure for active state (k_a) in the form of charts and numerical equations. Adoption of these k_a coefficients is not made mandatory in EC7. Hence, decision whether or not to use the EC7's k_a coefficients is solely the discretion of the engineering practitioners.

Hence, a comparative study is initiated here to compile the data of the k_a values across four (4) different equations/theories. The 4 equations are based on most commonly used Rankine and Coulomb, and EC7 charts as well as numerical equation respectively. Besides the effective angle of friction of soil (ϕ'), another two (2) parameters, particularly wall-ground interface parameter (δ) and slope angle of retained ground (β), also contribute greatly to the magnitude of the coefficient of earth pressure. As such, total of six (6) cases with combinations of δ/ϕ'=0, 0.66 and 1.0 and β/ϕ'=0 & 0.8 are considered to obtain the k_a values for comparison purpose.

Figures 3 to 9 depict the plots of the recommended k_a from EC7 annex against the most commonly used k_a from Rankine and/or Coulomb formula for the aforesaid 6 cases.

Figure 3: Plot of k_a value from EC7 Annex C against k_a value from Rankine / Coulomb formula for case where δ/ϕ'=0 and β/ϕ'=0

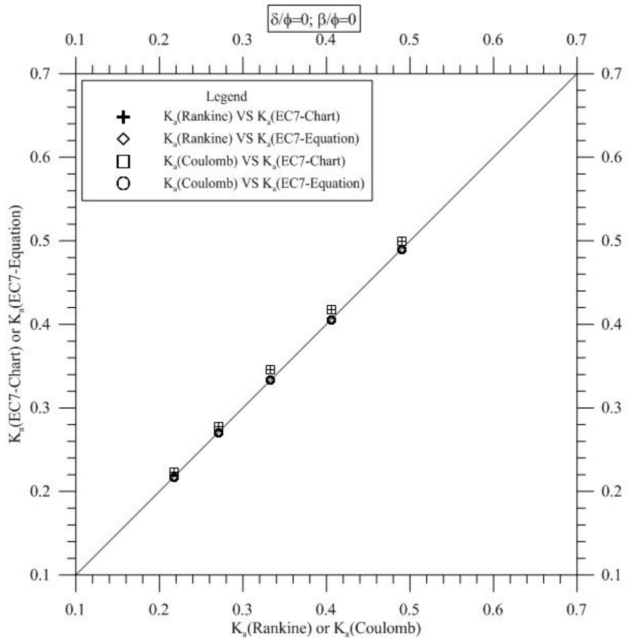


Figure 4: Plot of k_a value from EC7 Annex C against k_a value from Coulomb formula for case where δ/ϕ'=0.66 and β/ϕ'=0

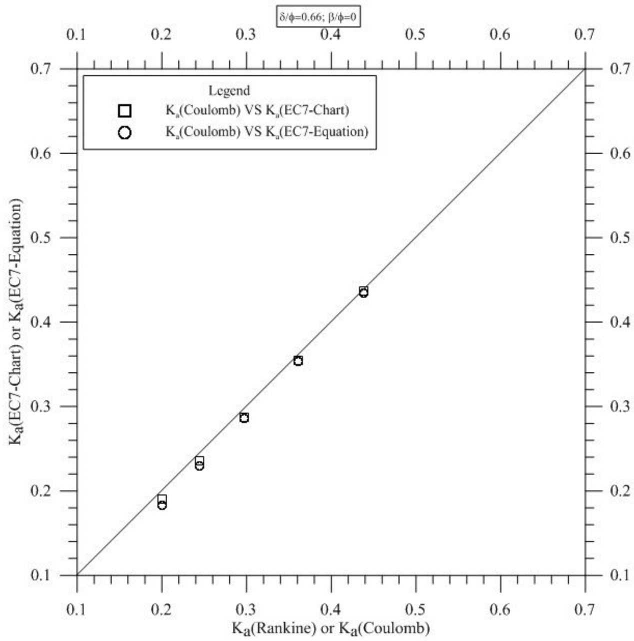


Figure 5: Plot of k_a value from EC7 Annex C against k_a value from Coulomb formula for case where δ/ϕ'=1.0 and β/ϕ'=0

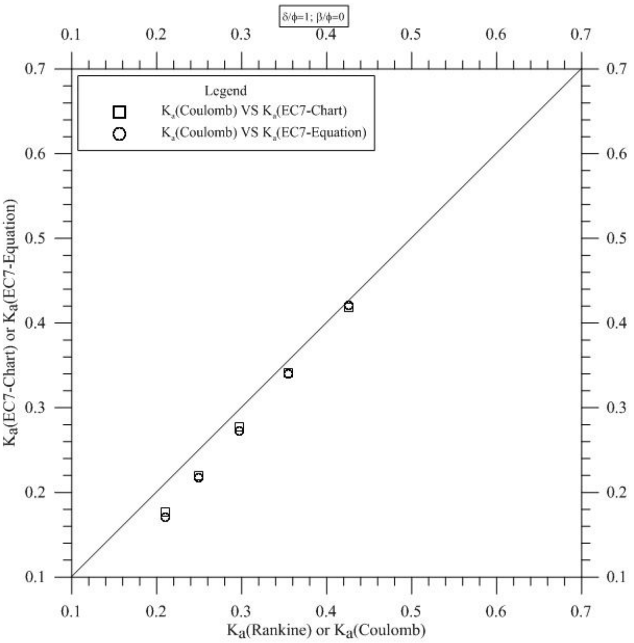


Figure 6: Plot of k_a value from EC7 Annex C against k_a value from Rankine / Coulomb formula for case where δ/ϕ'=0 and β/ϕ'=0.8

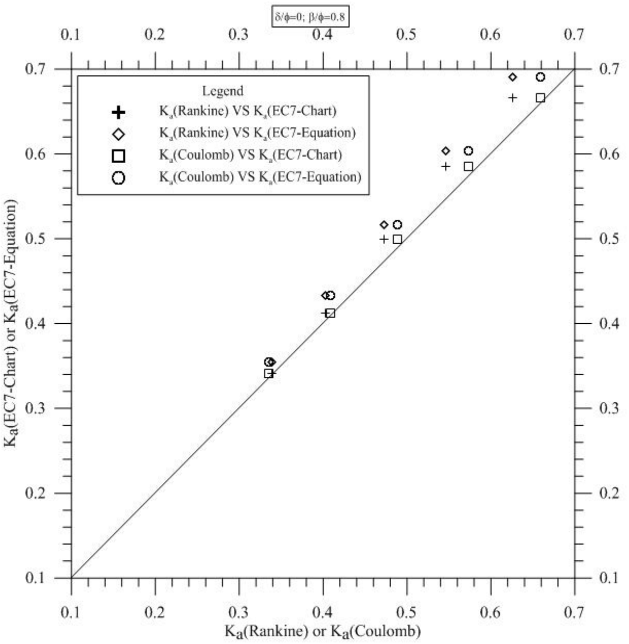


Figure 7: Plot of k_a value from EC7 Annex C against k_a value from Coulomb formula for case where δ/ϕ'=0.66 and β/ϕ'=0.8

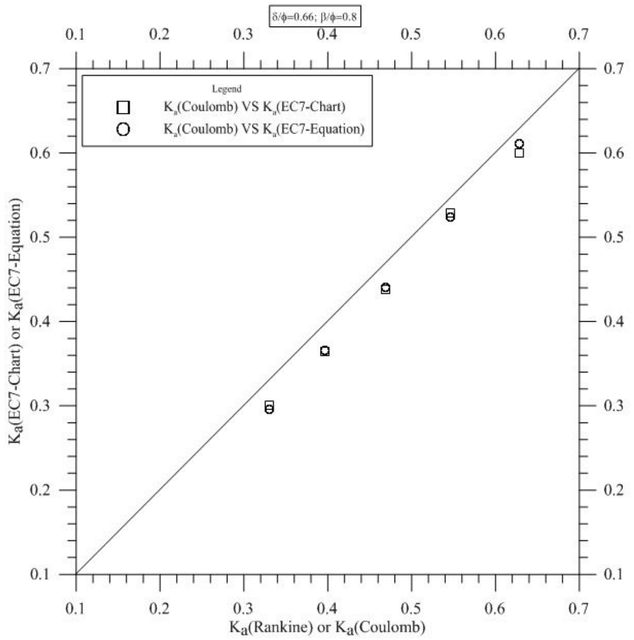
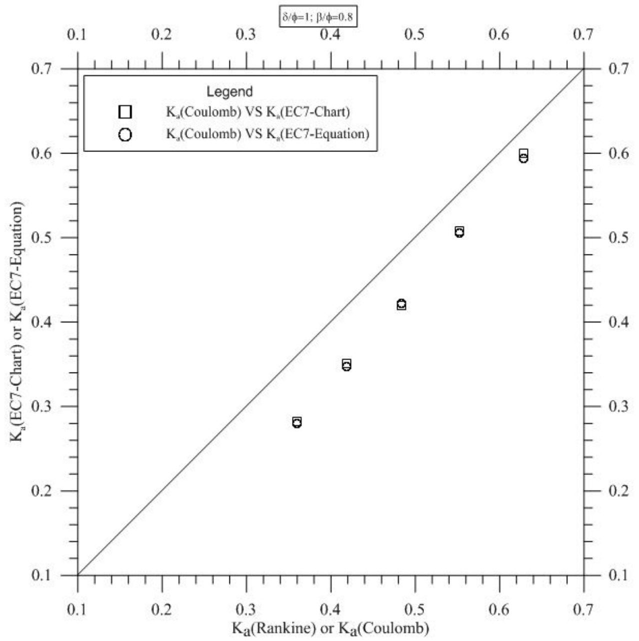


Figure 8: Plot of k_a value from EC7 Annex C against k_a value from Coulomb formula for case where δ/ϕ'=1.0 and β/ϕ'=0.8



Based on the compiled data shown in Figures 3 to 8, the following observations can be made:

1) For the case with no wall friction ($\delta/\phi'=0$) and no sloping ground ($\beta/\phi'=0$), the k_a values from all the different sources are almost identical. However, when a sloping retained ground is introduced at $\beta/\phi'=0.8$, the k_a values from EC7 annex becomes greater than the k_a values determined from Rankine and Coulomb equations as shown in Figure 6.
2) If wall friction is allowed ($\delta/\phi'>0$), the k_a values from Coulomb formula marginally exceed the k_a values from EC7 annex for flat retained ground ($\beta/\phi'=0$). The commonly used k_a values increase significantly exceeding the k_a values from EC7 annex when the case of sloping ground at $\beta/\phi'=0.8$ is assigned. In other words, the k_a coefficients of EC7 are less conservative (more optimistic in the other side of perspective) than the conventional k_a values from Coulomb equation.

DISCUSSION ON BEARING RESISTANCE CALCULATION GIVEN IN EC7 AND MALAYSIAN NATIONAL ANNEX

Annex D of EC7 has given a complete guide for bearing resistance calculation, which includes formulas for various essential factors, such as bearing capacity factors, shape factors, load inclination factors and inclination of foundation base factors, for both drained and undrained conditions. However, Malaysian National Annex does not entirely agree and instead recommends some modifications to two (2) elements in the EC7 bearing resistance calculation method.

Firstly, according to MS EN 1997-1: 2012, NA3.3, one of the bearing capacity factor, namely N_γ shall be modified from Eq. 1 to Eq. 2 as shown below:

$$N_\gamma = 2(N_q-1).\tan \phi' \qquad \text{(Eq. 1)}$$

$$N_\gamma = (N_q-1).\tan (1.4\phi') \qquad \text{(Eq. 2)}$$

The author does not know the rationale of using the modified N_γ factor as compared to the original EC7 N_γ factor. It seems that the N_γ factor in Eq. 2 adopts Meyerhof's equation. It should be pointed out here that the worked example is using the modified N_γ factor in accordance with Malaysian code. Nonetheless, a quick review can be conducted to the results shown in Table 4 to compare the values of bearing capacity determined using Eq. 1 and Eq. 2.

Table 8: Bearing Capacity of Wall Foundation using Different N_γ Factors

	2m High RC Wall			5m High RC Wall		
	EC7 Design Approach 1		OFS Method	EC7 Design Approach 1		OFS Method
	Comb. 1	Comb. 2		Comb. 1	Comb. 2	
Critical Width of Wall Base - B (m)	2.71	2.71	2.71	5.65	5.65	5.65
Design value of bearing resistance - $R_{v,d}$ (kN/m) based on Eq.1	217.69	107.96	297.65	486.04	247.36	634.08
Design value of bearing resistance - $R_{v,d}$ (kN/m) based on Eq.2	186.01	91.56	252.00	420.28	212.41	543.72
Reduction in value of bearing resistance based on Eq. 2 as compared to those of Eq. 1	-14.6%	-15.2%	-15.3%	-13.5%	-14.1%	-14.3%

As shown in Table 8 above, it can be surmised that the bearing capacity of the gravity retaining wall according to Malaysian National Annex (outlined in Eq. 2) is reduced by about 14% as compared to the recommendations in the document of EC7 Annex D (outlined in Eq. 1).

Second and lastly, ground inclination factor (or called as ground slope factor in some literatures) should be considered in the bearing capacity check as recommended by Malaysian National Annex. In this case, it is logical that the bearing capacity of a RC wall seated on the crest of a slope cannot be equal to or greater than the bearing capacity of a RC wall seated on entirely flat platform. Hence, an inclusion of ground inclination factor is understandably aimed to correct or reduce the bearing capacity to those of more cautious estimate for safety purpose.

As for the value of the ground inclination factor, Malaysian National Annex merely suggests to make reference to Foundations and Earth Structures Design Manual by US NAVFAC. For all retaining wall sitting on slope, the author suggests that the bearing capacity formula given in Hong Kong Geoguide 1, Figure A2 (in which the ground slope factor is considered) should be used as a coexisting check to ensure mistake of under-estimating the bearing capacity can be avoided for all types of ground geometry. In additional to that, it is very important that overall/global slope stability check shall be performed using limit equilibrium analysis for those retaining walls seated on slope.

CONCLUSION

This paper presents the author's perspective on Malaysian design methodology for reinforced concrete gravity retaining wall using overall factor of safety method and compares with the EC7 methodology together with the partial factors published in

Malaysian National Annex. Basically, a worked example comprising retaining wall of low (i.e. 2m) and high (i.e. 5m) exposed height is computed and the results of the ultimate limit state design for three (3) main failure modes, namely overturning, sliding and bearing failure, are presented. The study in this paper is not exhaustive as for the gravity retaining wall, there are still many contributing factors and some unclear analytical procedures in EC7 code yet to be ascertained. Nonetheless, it is hope that this comparative study can initiate further discussion and more researches among the local practitioners to reach a harmonized methodology complying with EC7 for Malaysian practice.

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