

# Optimizing of Counterfort Retaining Wall Design with Varying Heights

Chua Guang Seng<sup>1</sup>, Koh Heng Boon<sup>2\*</sup>,

<sup>1</sup> Student, Faculty of Civil Engineering and Built Environment  
University Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

\*Corresponding Author: [koh@uthm.edu.my](mailto:koh@uthm.edu.my)  
DOI: <https://doi.org/10.30880/rtcebe.2025.06.01.013>

## Article Info

Received: 08 January 2024

Accepted: 15 April 2024

Available online: 6 May 2025

## Keywords

Counterfort Retaining Wall, Standard Design Table, StaadPro software, Excel spreadsheet

## Abstract

Retaining wall is generally classified as geotechnical structures that used for retaining soil and resisting lateral earth pressure. The ability of cantilever retaining wall or gravity wall to resist the backfill have a height limitation up to 6m. This paper presents the outcomes of the analysis and design of counterfort retaining wall ranging from 8m to 12m. The counterfort retaining wall was subjected to the lateral earth pressure due to granular material and a surcharge loading of 10 kN/m<sup>2</sup>. Due to complexity of the counterfort retaining wall, member forces of counterfort retaining wall were determined based on the analysis from StaadPro software. The structure elements of the counterfort retaining wall were designed based on Eurocode 2. An Excel spreadsheet was developed to conduct the repetitive design and calculation for structural members design. In general, the bending moments for short span and long span at stem and base are increase linearly as the height of counterfort retaining wall increase. From the data analysis, the support moments always greater than the midspan moments for both short and long spans of stem and base. A series of standard design tables with detailing were produced. The standard design tables serve as a quick reference for the engineers in selecting appropriate dimensions and reinforcement for counterfort retaining wall based on the desired concrete grade.

## 1. Introduction

In construction and development field, counterfort retaining wall is a good retaining structure that is widely built to resist the pressure of soil (Ching, F. D. et al., 2006). Counterfort retaining walls are usually constructed to support soil vertically which enabled it to be held at various heights on the two sides. The effect of lateral earth pressure lead the counterfort retaining structure to overturn or slide, so they must design to retain them.

Earth pressure and surcharge loading are the two main forces that are important for the analysis and design of the retaining wall. The earth pressures subjected to the retaining wall are divided into lateral and vertical earth pressure. Conventional theories from Rankine and Coulomb were used in the counterfort retaining wall design to calculate magnitude and distribution of active earth pressure (Das. B. M., 2011; Bowles. J. E., 1996). If the retaining structures are not designed properly and calculate accurately under full load, the earth's pressure could cause some geotechnical failure such as sliding, overturning, bearing, stability, and settlement (S. P. Parmar, 2012). The stability of the retaining wall to prevent sliding and overturning failure must be determined before construction by taking into consideration of the ground's capacity to withstand the combined loading of vertical, horizontal, and rotational (Shoeb Mohammed Sayeed et al., 2014).

Generally, the height of cantilever retaining walls had a limitation which can constructed up to 6m (S.S Patil et al.,2015). However, from the precious research, a comparative review of cantilever and counterfort retaining walls, which the counterfort retaining walls are suitable for constructing at retained fill heights ranging from 8.0 m to 10.m (Yash Chaliawala et al.,2015). Besides that, a research on counterfort retaining walls achieve a good stability with smaller earth pressure, and lower overturning moment (Tonne V.R et al., 2015). Therefore, the objective of this paper is to analysis and design the counterfort retaining wall with varying height ranging from 8m to 12m by using StaadPro software and produce a standard design table and detailing drawing.

## 2. Analysis and Design Procedures

This design project involved of the identify the dimension and parameters of counterfort retaining wall, analyse and design counterfort retaining wall, and produce a standard design table and detailing for counterfort retaining wall.

### 2.1 Design Parameters of Counterfort Retaining Wall

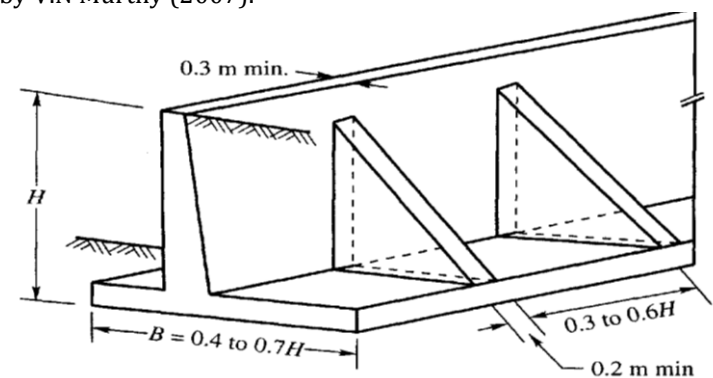
All the important design parameters to carry out the analysis and design of counterfort retaining wall are shown in table 1.

**Table 1** Design Parameter and Properties

Design Parameter and Properties	Values	Unit
Soil Properties & Density		
Granular Soil	20	$kN/m^3$
Concrete Grade & Characteristics Strength		
C25	25	$N/mm^2$
C30	30	$N/mm^2$
C35	35	$N/mm^2$
Reinforcement		
Yield Strength	500	$N/mm^2$
Loading		
Surcharge	10	$kN/m^2$
Mat Foundation		
Modulus of Subgrade Reaction	200000	$kN/m^3$

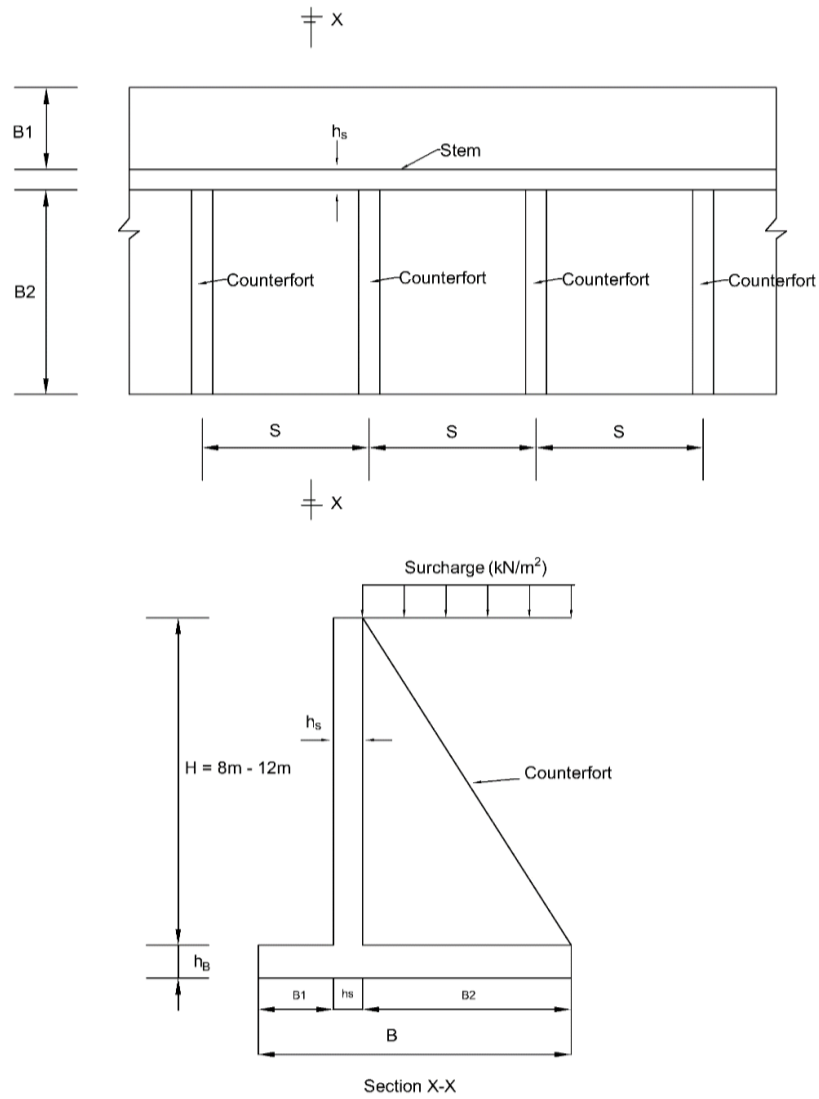
### 2.2 Dimension of Counterfort Retaining Wall

The proportioning of the counterfort retaining wall is according to a rule of thumb that proposed by V.N Murthy (2007). The base length (B) is 0.7 to the height of wall. The length of toe slab (B1) is 0.15 to base while the portion of heel slab (B2) is 0.85 to the base. Moreover, the spacing of the counterfort, Sc is 0.5 to the height of retaining wall. The thickness of counterfort is same with the thickness of the stem wall. Last but not least, the thickness of slab ( $h_B$ ) is 1.3 to the thickness of stem ( $h_s$ ). Figure 1 shows the the proportioning of counterfort retaining wall proposed by V.N Murthy (2007).



**Fig. 1** Proportioning of Counterfort Retaining Wall

Figure 2 shows the typical cross section of counterfort retaining wall from plan and side view. All the dimensions of counterfort retaining wall are represented with the symbols. The geometry of the counterfort retaining wall based on the rule of proportioning had been tabulated in table 2.



**Fig. 2** The Plan and Side View of Counterfort Retaining Wall

**Table 2** Geometry of the Counterfort Retaining Wall

Height, H (m)	Dimension (m)					
	B1	B2	h <sub>B</sub>	h <sub>s</sub>	h <sub>c</sub>	Sc
8	0.79	4.46	0.455	0.35	0.35	4.0
9	0.89	5.06	0.455	0.35	0.35	4.5
10	0.99	5.61	0.52	0.40	0.40	5.0
11	1.09	6.19	0.546	0.42	0.42	5.5
12	1.19	6.76	0.585	0.45	0.45	6.0

### 2.3 Stability Checking

The stability of counterfort retaining wall can be performed by analysing regarding sliding, overturning, and bearing capacity. All these three checking are based on the safety factors that stated in MS EN1990:2010.

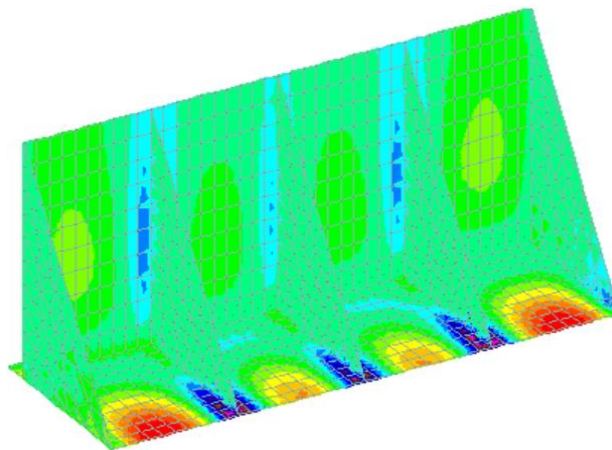
The factor loading for sliding force is  $1.35 G_k + 1.5 Q_k$  and friction force is  $\mu V_k$ . The friction force should greater than the sliding force, thus sliding checking is considered as pass.

The factor loading for overturning moment is  $1.10 G_k + 1.5 Q_k$  and restraining moment is  $0.9 G_k + 0 Q_k$ . The restraining moment should greater than the overturning moment, thus overturning checking is succeed.

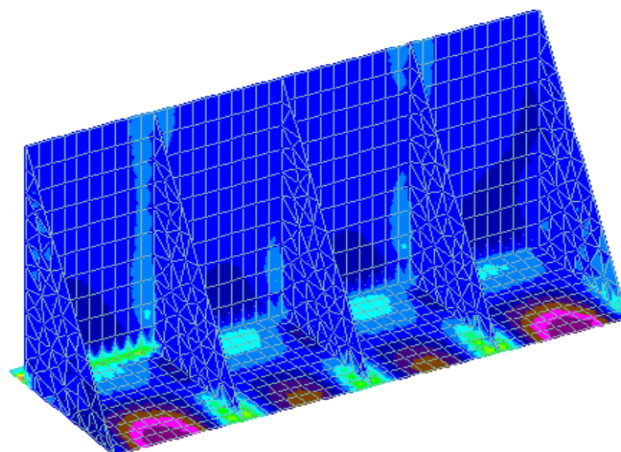
Bearing pressure is  $N/A \pm M_y/I$  and soil bearing is  $200 \text{ kN/m}^2$ . The soil bearing capacity must greater than bearing pressure, then the settlement checking is considered as pass.

## 2.4 Analysis of Counterfort Retaining Wall by using StaadPro

5 counterfort retaining walls with height ranging from 8m to 12m had been modeled in the StaadPro and perform a analysis to obtain their member forces. 7 load cases were created to analysis the counterfort retaining wall. The most critical bending moments in base, stem and counterfort were taken to design the structure components. Figure 3 shows the counterfort retaining wall was subjected under the combination of (Selfweight + Lateral Earth Pressure + Horizontal Surcharge). Moreover, the counterfort retaining wall was subjected under the combination of (Selfweight + Vertical Earth Pressure + Vertical Surcharge) is shown in figure 4.



**Fig. 3** Structure Behaviour of Counterfort Retaining Wall under Combination Load (Selfweight + Lateral Earth Pressure + Horizontal Surcharge)



**Fig. 4** Structure Behaviour of Counterfort Retaining Wall under Combination Load (Selfweight + Vertical Earth Pressure + Vertical Surcharge)

## 2.5 Development of Design Table

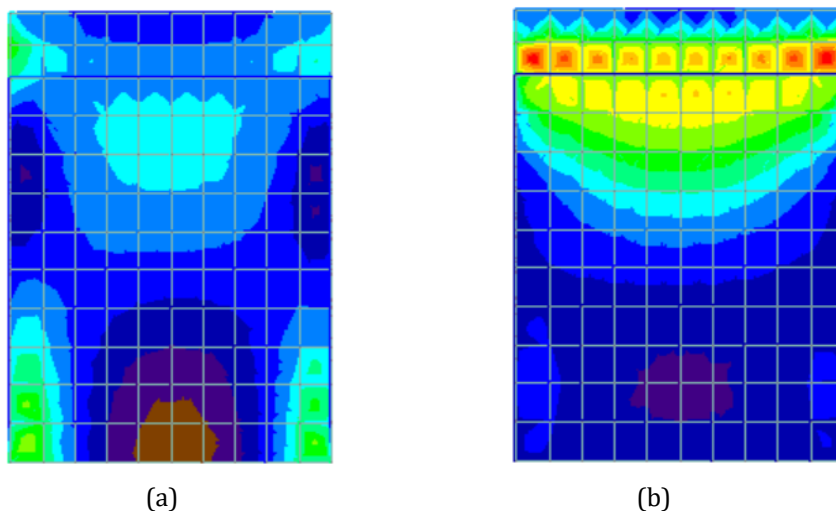
Excel spreadsheets were used not only to analyze the data but also to help in formatting the data to make it easier to understand. From the spreadsheet, all the parameters and formulas were keyed into the spreadsheet to determine the lateral earth pressure and surcharge loading that acting on the counterfort retaining wall and conduct the stability analysis. Besides that, the spreadsheet incorporates relevant equations and coefficients to perform calculations and generate standard design details. It takes inputs such as bending moments of each structure elements, concrete compressive strength. Through predefined equations, the spreadsheet produces outputs including rebar size and spacing.

### 3. Results and Discussion

The results and discussion present the outcomes of the analysis and design for the counterfort retaining wall with varying height ranging from 8m to 12m. Development of the computational design table was completed, which serves as the foundation for the design process. The design outputs obtained from the analysis were then thoroughly reviewed and discussed.

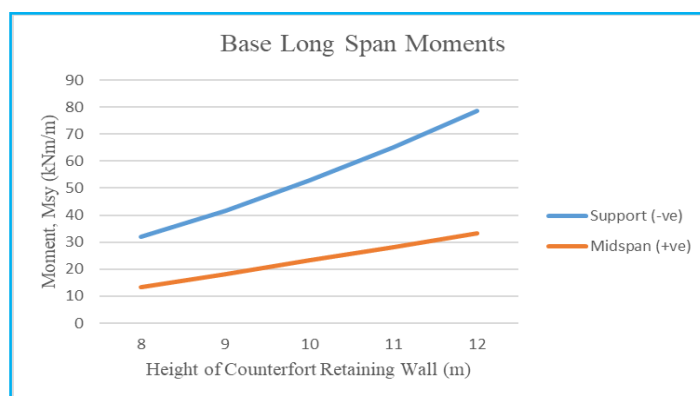
#### 3.1 Base Moments

Base of counterfort retaining wall was subjected to the ultimate combination load case of vertical earth pressure, vertical surcharges and its selfweight in the StaadPro analysis. Figure 5 shows the bending moments of short span and long span that analysed from StaadPro software. For both short and long span in base, the moment of support is generally greater than the midspan moment for counterfort retaining wall ranging from 8m to 12m.



**Fig. 5** Base Moments (a) Short Span ( $M_{sx}$ ) (b) Long Span ( $M_{sy}$ )

Two graphs were plotted to show the bending moments acting on the short span and long span of base. From figure 6, there is a distinct correlation between the counterfort retaining wall height and the bending moments according to the data analysis. The results shows the midspan and support moments increase linearly when the height of counterfort retaining wall increases. The support moment typically greater than the midspan moment in the long span.



**Fig. 6** Long Span Base Moments

From figure 7, it is observed that the midspan and support moments increase linearly as the height of counterfort retaining wall increases. The support moment typically greater than the midspan moment in the

short span. Notably, the short span moments consistently surpass the long span moments. From the observation, the support moments in both short and long spans are typically greater than the midspan moments.

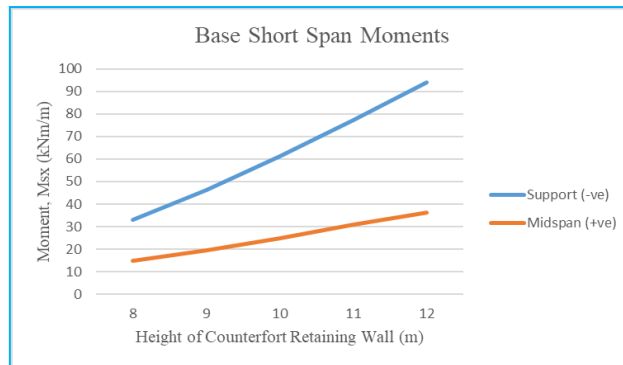


Fig. 7 Short Span Base Moments

### 3.2 Stem Moments

Stem of counterfort retaining wall was subjected to the ultimate combination load case of lateral earth pressure, horizontal surcharges and its selfweight during the simulation analysis in StaadPro. The stem moments of short span and long span are shown in the figure 8. From the simulation analysis in StaadPro software, the support moments in stem always surpass the midspan moments.

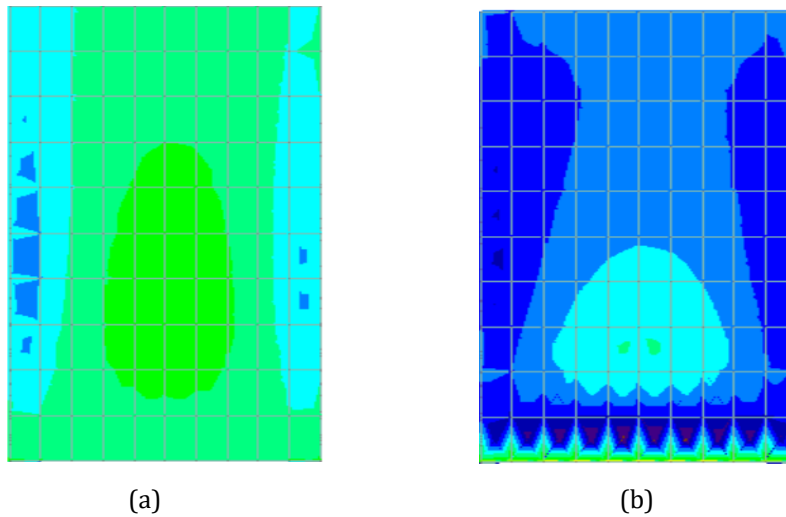


Fig. 8 Stem Moments (a) Short Span ( $M_{sx}$ ) (b) Long Span ( $M_{sy}$ )

Figure 9 shows the midspan moments of stem short span increases linearly and slightly rising up when the height of counterfort retaining wall reached 11m. The support moment demonstrate a linear increasing and following with a exponentially growth when the wall height was 11m.

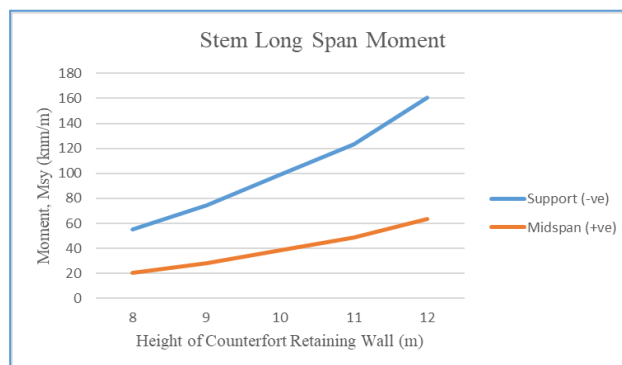
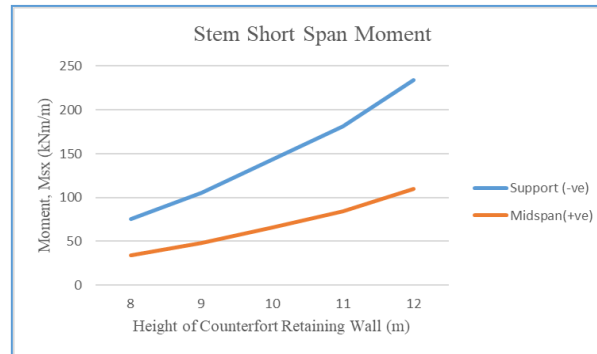


Fig.9 Long Span Stem Moments

Figure 10 shows the midspan moments of stem short span increases linearly and slightly rising up when the height of counterfort retaining wall reached 11m. The support moment demonstrate a linear increasing and

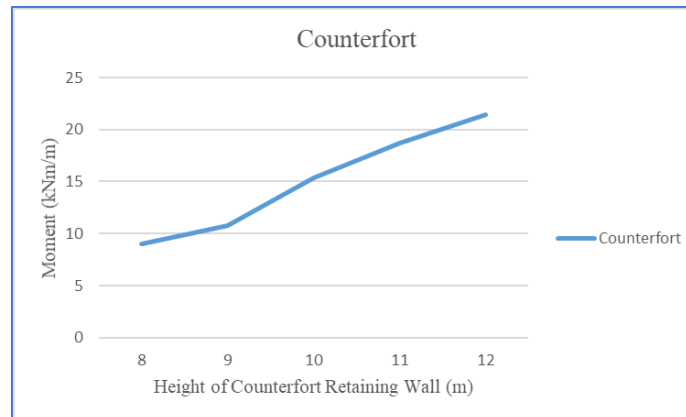
following with an exponentially growth when the wall height was 11m. It can be concluded that the short span moments generally higher than the long span moments. The support moments for both span were always greater than the midspan moments.



**Fig. 10** Short Span Stem Moments

### 3.3 Counterfort Moments

The counterfort was subjected to the ultimate load which the combination load cases of lateral earth pressure, horizontal surcharges and selfweight during the structure analysis in StaadPro. Figure 11 shows the counterfort moments for counterfort retaining wall. The counterfort moments increased linearly and growth exponentially when it reached 10 m height.



**Fig. 11** Counterfort Moments

### 3.4 Design Spreadsheet

The Excel spreadsheet created for counterfort retaining wall design serves as a comprehensive tool. It is organized into three parts: selecting dimensions, performing stability checking, and generating design output. Accurate input of dimensions enables proper calculations and design considerations. Overall, it is a user-friendly tool for analyzing and designing counterfort retaining wall structural components. The application of Excel spreadsheet to analysis and design counterfort retaining wall had been shown in Appendix C.

### 3.5 Standard Design Table and Detailing

A standard design table has been developed after the analysis and design of structural components of counterfort retaining wall. All the structural elements which consist of base, stem and counterfort were analysed and designed. The dimensions of structural components of counterfort retaining wall and the reinforcements provided were tabulated in the design table. Table 3 shows the standard design table of counterfort retaining wall with 11m height and characteristics strength of concrete,  $f_{ck} = 25 \text{ N/mm}^2$ .

The standard detailing of the counterfort retaining wall has been drawn in AutoCAD software and the structural elements were labeled. Figure 12 show the detailing drawing of counterfort retaining wall with 11m height. Other tables and for different concrete grade and detailing drawing are shown in Appendix B and A respectively.

**Table 3** Standard Design Table of Counterfort Retaining Wall of 11m height,  $f_{ck} = 25 \text{ N/mm}^2$

Height, H (m)	Dimension (m)					Base Reinforcement (mm <sup>2</sup> /m)					
	B1	B2	h <sub>B</sub>	h <sub>S</sub>	h <sub>C</sub>	Sc	BB1	BB2	TB1	TB2	TB3
11	1.10	6.21	0.55	0.42	0.42	5.5	H16-200	H16-200	H16-200	H16-200	H16-200

Height, H (m)	Stem Reinforcement (mm <sup>2</sup> /m)				Counterfort Reinforcement (mm <sup>2</sup> /m)	
	S1	S2	S3	S4	C1	C2
11	H20-150	H20-150	H20-300	H20-150	H12-200	H12-200

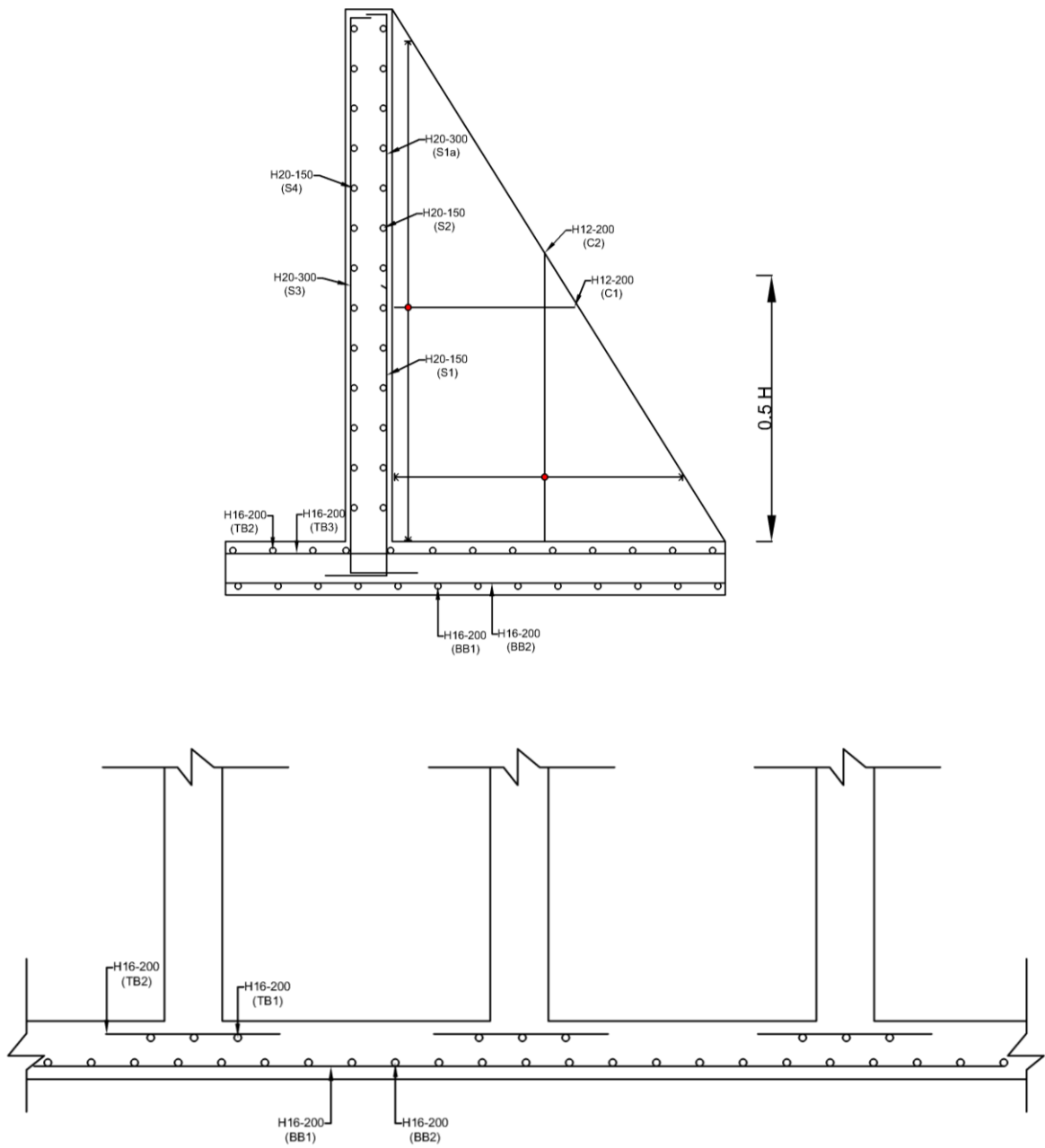


Fig. 12 Detailing Drawing of Counterfort Retaining Wall of 11m height

#### 4. Conclusion

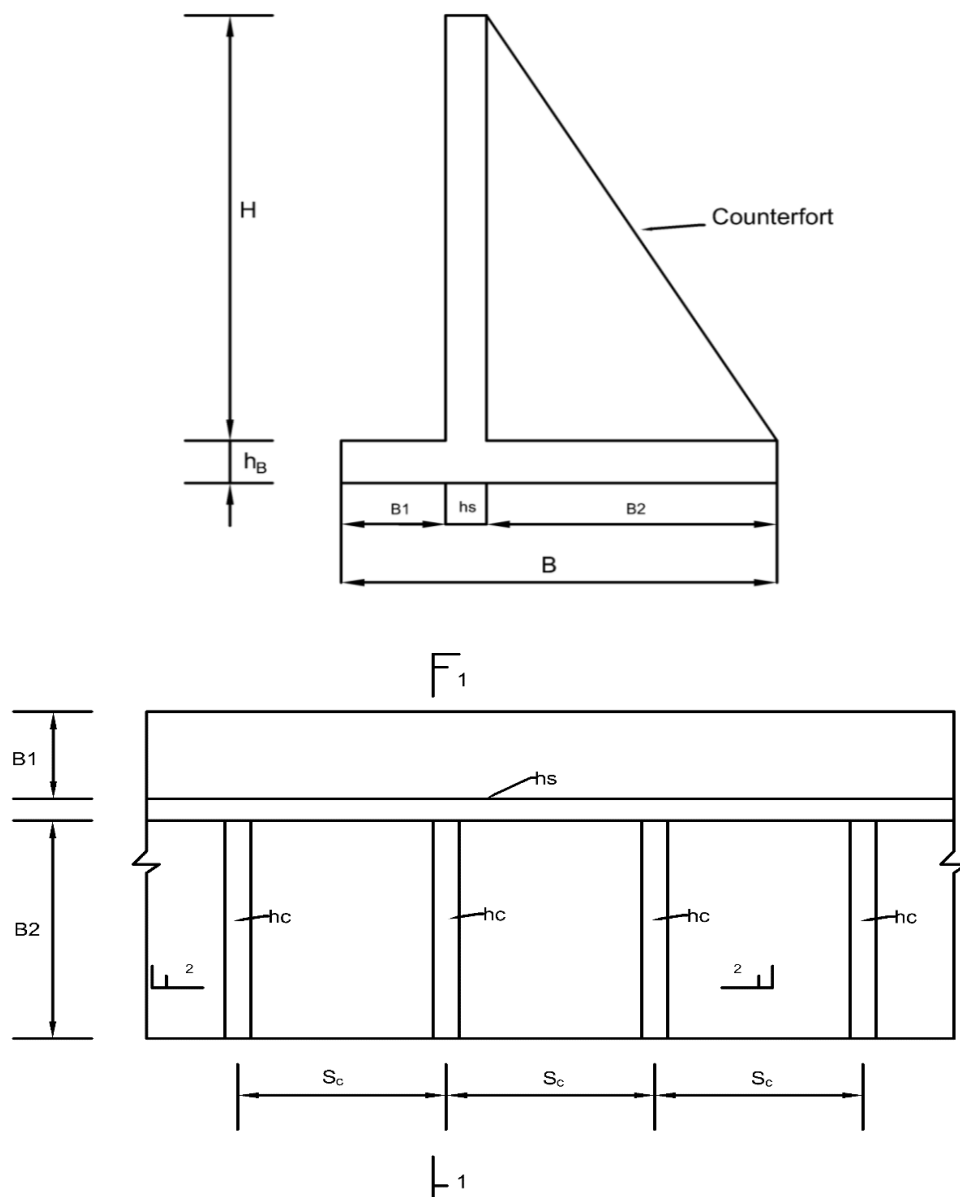
In conclusion, this study successfully achieved its objectives of analysis and design of counterfort retaining wall, and producing a standard design table. Counterfort retaining wall with height ranging from 8m to 12m was analysed. The analysis revealed that support and midspan moments increase as the height of counterfort retaining wall increase. The support moments typically larger than the midspan moments for both short and long spans. The counterfort moments increased linearly and growth exponentially when it reached 10 m height.

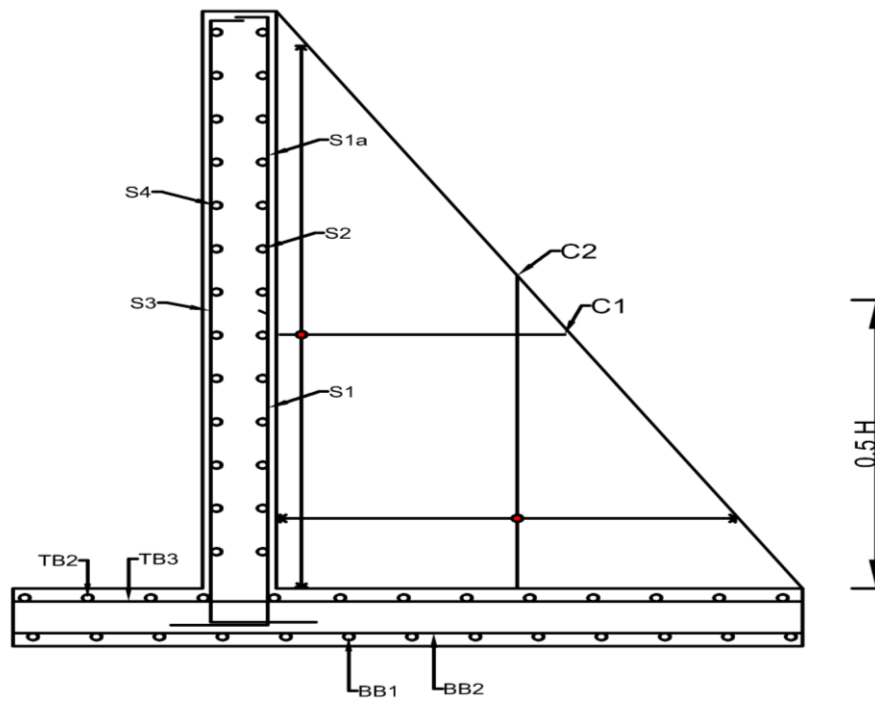
Standard design tables were developed, encompassing dimension of counterfort retaining wall, rebar sizing and grades of concrete. The tables serve as a quick reference for engineers to select appropriate dimensions and reinforcement for counterfort retaining wall. Additionally, a standard detailing drawing was created using AutoCAD software to aid in the design process. This study provides valuable insights and tools for engineers designing counterfort retaining wall. The standard design table offer efficient solutions, considering specific requirements.

#### Acknowledgement

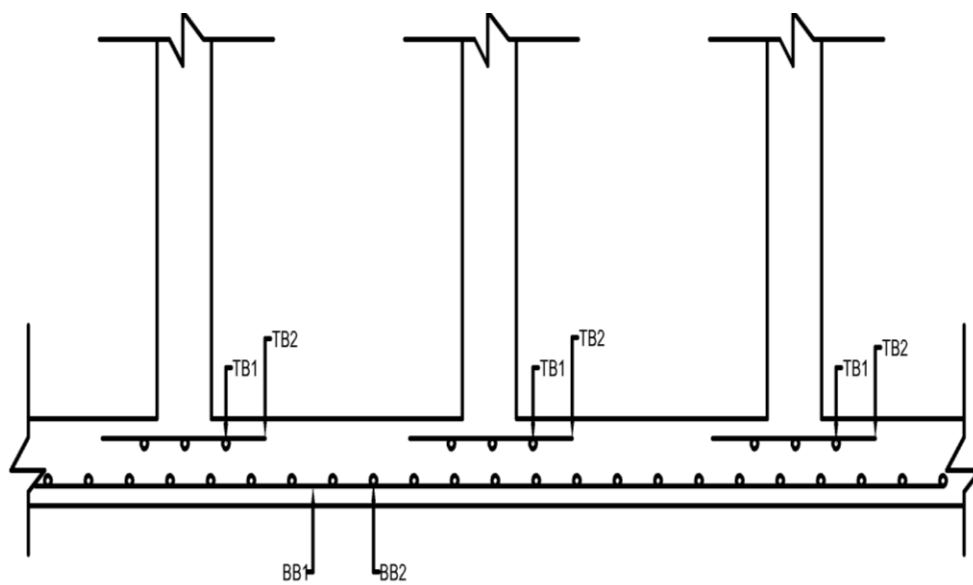
This research was made possible by the Faculty of Civil Engineering and Built Environment, University Tun Hussein Onn Malaysia for providing me with the opportunity to complete this Final Year Project. I would also like to thank my supervisor, Mr Koh Heng Boon for his invaluable guidance, assistance, and contribution to stimulating insightful suggestions and encouragement to assist me to complete this study smoothly.

#### Appendix A Detailing Drawing of Counterfort Retaining Wall





Section 1-1



Section 2-2

## Appendix B Standard Design Table

### Characteristics Strength of Concrete, $f_{ck} = 25 \text{ N/mm}^2$

Height, H (m)	Dimension (m)						Base Reinforcement ( $\text{mm}^2/\text{m}$ )				
	B1	B2	$h_B$	$h_S$	$h_C$	Sc	BB1	BB2	TB1	TB2	TB3
8	0.79	4.46	0.455	0.35	0.35	4.0	H16-225	H16-225	H16-225	H16-225	H16-225
9	0.89	5.06	0.455	0.35	0.35	4.5	H16-225	H16-225	H16-225	H16-225	H16-225
10	0.99	5.61	0.52	0.40	0.40	5.0	H16-225	H16-225	H16-225	H16-225	H16-225
11	1.09	6.19	0.546	0.42	0.42	5.5	H16-200	H16-200	H16-200	H16-200	H16-200
12	1.19	6.76	0.585	0.45	0.45	6.0	H16-200	H16-200	H16-200	H16-200	H16-200

Height, H (m)	Stem Reinforcement ( $\text{mm}^2/\text{m}$ )				Counterfort Reinforcement ( $\text{mm}^2/\text{m}$ )	
	S1	S2	S3	S4	C1	C2
8	H20-225	H20-225	H20-300	H20-300	H12-200	H12-200
9	H20-200	H20-200	H20-300	H20-200	H12-200	H12-200
10	H20-175	H20-175	H20-300	H20-175	H12-200	H12-200
11	H20-150	H20-150	H20-300	H20-150	H12-200	H12-200
12	H20-125	H20-125	H20-125	H20-125	H12-175	H12-175

### Characteristics Strength of Concrete, $f_{ck} = 30 \text{ N/mm}^2$

Height, H (m)	Dimension (m)						Base Reinforcement ( $\text{mm}^2/\text{m}$ )				
	B1	B2	$h_B$	$h_S$	$h_C$	Sc	BB1	BB2	TB1	TB2	TB3
8	0.79	4.46	0.455	0.35	0.35	4.0	H16-200	H16-200	H16-200	H16-200	H16-200
9	0.89	5.06	0.455	0.35	0.35	4.5	H16-200	H16-200	H16-200	H16-200	H16-200
10	0.99	5.61	0.52	0.40	0.40	5.0	H16-200	H16-200	H16-200	H16-200	H16-200
11	1.09	6.19	0.546	0.42	0.42	5.5	H16-200	H16-200	H16-200	H16-200	H16-200
12	1.19	6.76	0.585	0.45	0.45	6.0	H16-175	H16-175	H16-175	H16-175	H16-175

Height, H (m)	Stem Reinforcement ( $\text{mm}^2/\text{m}$ )				Counterfort Reinforcement ( $\text{mm}^2/\text{m}$ )	
	S1	S2	S3	S4	C1	C2
8	H20-250	H20-250	H20-300	H20-300	H12-200	H12-200
9	H20-200	H20-200	H20-300	H20-200	H12-200	H12-200
10	H20-175	H20-175	H20-300	H20-175	H12-175	H12-175
11	H20-150	H20-150	H20-300	H20-150	H12-175	H12-175
12	H20-125	H20-125	H20-125	H20-125	H12-175	H12-175

**Characteristics Strength of Concrete,  $f_{ck} = 35 \text{ N/mm}^2$**

Height, H (m)	Dimension (m)						Base Reinforcement (mm <sup>2</sup> /m)				
	B1	B2	h <sub>B</sub>	h <sub>S</sub>	h <sub>C</sub>	Sc	BB1	BB2	TB1	TB2	TB3
8	0.79	4.46	0.455	0.35	0.35	4.0	H16-200	H16-200	H16-200	H16-200	H16-200
9	0.89	5.06	0.455	0.35	0.35	4.5	H16-200	H16-200	H16-200	H16-200	H16-200
10	0.99	5.61	0.52	0.40	0.40	5.0	H16-200	H16-200	H16-200	H16-200	H16-200
11	1.09	6.19	0.546	0.42	0.42	5.5	H16-200	H16-200	H16-200	H16-200	H16-200
12	1.19	6.76	0.585	0.45	0.45	6.0	H16-175	H16-175	H16-175	H16-175	H16-175

Height, H (m)	Stem Reinforcement (mm <sup>2</sup> /m)				Counterfort Reinforcement (mm <sup>2</sup> /m)	
	S1	S2	S3	S4	C1	C2
8	H20-250	H20-250	H20-300	H20-250	H12-175	H12-175
9	H20-200	H20-200	H20-300	H20-200	H12-175	H12-175
10	H20-175	H20-175	H20-300	H20-175	H12-175	H12-175
11	H20-150	H20-150	H20-300	H20-150	H12-150	H12-150
12	H20-150	H20-150	H20-300	H20-150	H12-150	H12-150

**Appendix C Excel Spreadsheet**

**SPECIFICATION**

**Dimension:**  
 Height, H = 8 m  
 Width, B = 5.6 m  
 Spacing Counterfort, S<sub>c</sub> = 4 m  
 Toe Slab Length, B1 = 0.79 m  
 Heel Slab Length, B2 = 4.46 m

**Thickness:**  
 h<sub>s</sub> = 0.35 m  
 h<sub>b</sub> = 0.455 m  
 h<sub>c</sub> = 0.35 m

**Dimension & Soil Pressure**

Surcharge (kN/m<sup>2</sup>)

Counterfort

Active Soil Pressure

$$P = \frac{(\gamma H + w) K_a}{(1 - \sin \phi)(1 + \sin \phi)}$$

$$P = \frac{(20 H + 10) \times 0.406}{8.12 H + 4.06}$$

H (m)	P (kN/m <sup>2</sup> )
0	4.06
8	69.00
8.455	72.69

<b>(i) Stability against overturning</b>			
Overturning Moment =	$1.10 \times 3270.80 +$	$1.5 \times 580$	
	$= 4468.29$		kNm
Restraining Moment =	$0.9 \times 11527.94 +$	$0 \times 601$	
	$= 10375.15$		kNm
Overturning moment	<	Restraining Moment	OK!
<b>(ii) Stability against sliding</b>			
Sliding force =	$1.35 \times 1160.545 +$	$1.5 \times 137$	
	$= 1772.63$		kN
Friction Force =	$\mu V_k$		
	$= 1835.97$		kN
Sliding force	<	Friction Force	OK!
<b>(iii) Stability against settlement</b>			
$V_k =$	$3671.938 +$	$178.50$	
	$= 3850.44$		kN
$\Delta M =$	$11527.94 +$	$601.32 -$	$3271 - 580$
	$= 8278.19$		kNm
$x = \frac{\Delta M V_k}{V_k^2}$	$= 2.13$		m
Eccentricity,	$a = (B/2) - x$	$0.65$	< $B/6 = 0.93$ m
Bearing Pressure, $q = N/A \pm My/I$			
$q_{ed} =$	$171.8945 \pm$	$119.7244$	
$q_{edmin} =$	$52.17012$		$kN/m^2$
$q_{edmax} =$	$291.6189$		$kN/m^2$
	>	Soil Bearing Capacity, $q_{sd} =$	$200$ $kN/m^2$

<b>Base</b>									
Effective depth,	$d_x = h - C_{nom} - 0.5\phi_{bar}$	$= 455$	-	$50$	-	$8$	$= 397$	mm	
	$d_y = h - C_{nom} - 1\phi_{bar}$	$= 455$	-	$50$	-	$24$	$= 381$	mm	
Minimum and maximum reinforcement area									
$A_{s,min} = 0.26 (f_{ctm} / f_{yk}) b d$	$= 0.26$	x	$3.2$	$500$	$1000$	$397$	$= 661$	$mm^2/m$	
$A_{s,max} = 0.04 A_c$	$= 0.04$	x	$1000$	$x$	$455$	$= 18200$	$mm^2/m$		
<b>Short Span:</b>									
MidSpan, $M_{sx} =$	$1.35$	x	$14.64$	$=$	$19.76$	$kNm/m$			
$K = \frac{M}{b d^2 f_{ck}}$	$=$	$19.76$	$10^6$	$=$	$1000$	$x$	$397$	$x$	$35$ $= 0.0036$ < $K_{bal} = 0.167$
									Compression reinforcement is not required
$z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right]$	$= 0.997$	$d$	$< 0.95d$						
$A_s = \frac{M}{0.87 f_{yk} z}$	$= 120.47$	$mm^2/m$							Use H16-300 (670mm <sup>2</sup> /m)
<b>Support, <math>M_{sx} =</math></b>									
$K = \frac{M}{b d^2 f_{ck}}$	$= 1.35$	x	$33.02$	$=$	$44.58$	$kNm/m$			
	$=$	$44.58$	$10^6$	$=$	$1000$	$x$	$397$	$x$	$35$ $= 0.0081$ < $K_{bal} = 0.167$
									Compression reinforcement is not required
$z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right]$	$= 0.993$	$d$	$< 0.95d$						
$A_s = \frac{M}{0.87 f_{yk} z}$	$= 271.71$	$mm^2/m$							Use H16-300 (670mm <sup>2</sup> /m)
<b>Stem</b>									
Effective depth,	$d_x = h - C_{nom} - 0.5\phi_{bar}$	$= 350$	-	$50$	-	$8$	$= 292$	mm	
	$d_y = h - C_{nom} - 1\phi_{bar}$	$= 350$	-	$50$	-	$24$	$= 276$	mm	
Minimum and maximum reinforcement area									
$A_{s,min} = 0.26 (f_{ctm} / f_{yk}) b d$	$= 0.26$	x	$3.2$	$500$	$1000$	$292$	$= 486$	$mm^2/m$	
$A_{s,max} = 0.04 A_c$	$= 0.04$	x	$1000$	$x$	$350$	$= 14000$	$mm^2/m$		
<b>Short Span:</b>									
MidSpan, $M_{sx} =$	$1.35$	x	$34.01$	$=$	$45.91$	$kNm/m$			
$K = \frac{M}{b d^2 f_{ck}}$	$=$	$45.91$	$10^6$	$=$	$1000$	$x$	$292$	$x$	$35$ $= 0.0154$ < $K_{bal} = 0.167$
									Compression reinforcement is not required
$z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right]$	$= 0.986$	$d$	$< 0.95d$						
$A_s = \frac{M}{0.87 f_{yk} z}$	$= 380.49$	$mm^2/m$							Use H20-300 (1047mm <sup>2</sup> /m)
<b>Support, <math>M_{sx} =</math></b>									
$K = \frac{M}{b d^2 f_{ck}}$	$= 1.35$	x	$75.41$	$=$	$101.80$	$kNm/m$			
	$=$	$101.80$	$10^6$	$=$	$1000$	$x$	$292$	$x$	$35$ $= 0.0341$ < $K_{bal} = 0.167$
									Compression reinforcement is not required
$z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right]$	$= 0.969$	$d$	$< 0.95d$						
$A_s = \frac{M}{0.87 f_{yk} z}$	$= 843.66$	$mm^2/m$							Use H20-225 (1396mm <sup>2</sup> /m)
<b>Counterfort</b>									
$b =$	$1000$	mm		$\phi_{bar} =$	$12$	mm			
$h =$	$350$	mm							
Eff. depth, $d =$	$350$	-	$50$	-	$12$	-	$12.50$	$= 276$	mm
Med									
$K = \frac{M}{b d^2 f_{ck}}$	$=$	$8.99$	$kNm$		$1000$	$x$	$276$	$x$	$35$ $= 0.0093$ < $K_{bal} = 0.167$
	$=$	$8.99$	$10^6$						Compression reinforcement is not required
$z = d \left[ 0.5 + \sqrt{0.25 - \frac{K}{1.134}} \right]$	$= 0.992$	$d$	$< 0.95d$						
$A_s = \frac{M}{0.87 f_{yk} z}$	$= 103.71$	$mm^2/m$							Use H12-225 (503mm <sup>2</sup> /m)
Minimum and maximum reinforcement area									
$A_{s,min} = 0.26 (f_{ctm} / f_{yk}) b d$	$= 0.26$	x	$3.2$	$500$	$1000$	$276$	$= 458$	$mm^2/m$	
$A_{s,max} = 0.04 A_c$	$= 0.04$	x	$1000$	$x$	$276$	$= 11020$	$mm^2/m$		

<b>Shear Stem</b>					
Max. design shear force, $V_{ed}$ =	0.336	$N/mm^2$			
$p1 = A_{s1}/bd < 0.02$	=	0.0029			
$k = 1 + \left(\frac{200}{d}\right)^2 \leq 2.0$	=	1.828			
$V_{min} = [0.035k^2f_{ck}]^{\frac{1}{3}}$	=	0.5116	$N/mm^2$		
$V_{rd,c} = [0.12k(100\rho1f_{ck})^{\frac{1}{3}}]$	=	0.474	$N/mm^2$		
$V_{rd,c}$	=	0.5116	$N/mm^2$	>	$V_{ed} = 0.336 N/mm^2$ <b>OK!</b>
<b>Base</b>					
Max. design shear force, $V_{ed}$ =	0.124	$N/mm^2$			
$p1 = A_{s1}/bd < 0.02$	=	0.0017			
$k = 1 + \left(\frac{200}{d}\right)^2 \leq 2.0$	=	1.710			
$V_{min} = [0.035k^2f_{ck}]^{\frac{1}{3}}$	=	0.4629	$N/mm^2$		
$V_{rd,c} = [0.12k(100\rho1f_{ck})^{\frac{1}{3}}]$	=	0.369	$N/mm^2$		
$V_{rd,c}$	=	0.4629	$N/mm^2$	>	$V_{ed} = 0.124 N/mm^2$ <b>OK!</b>
<b>Counterfort</b>					
Max. design shear force, $V_{ed}$ =	0.024	$N/mm^2$			
$p1 = A_{s1}/bd < 0.02$	=	0.0017			
$k = 1 + \left(\frac{200}{d}\right)^2 \leq 2.0$	=	1.852			
$V_{min} = [0.035k^2f_{ck}]^{\frac{1}{3}}$	=	0.5219	$N/mm^2$		
$V_{rd,c} = [0.12k(100\rho1f_{ck})^{\frac{1}{3}}]$	=	0.400	$N/mm^2$		
$V_{rd,c}$	=	0.5219	$N/mm^2$	>	$V_{ed} = 0.024 N/mm^2$ <b>OK!</b>

## Acknowledgement

This project paper is supported by Universiti Tun Hussein Onn Malaysia. The author would like to thank the Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia for providing necessary research facility for this study.

## References

- Bowles, J. E. (1996). *Foundation Analysis and Design*. McGraw-Hill 5th ed, Singapore.
- Ching, F. D., Faia, R., S., & Winkel, P. (2006). *Building Codes Illustrated: A Guide to Understanding the 2006 International Building Code*. New York, Wiley Association.
- Das, B. M. (2011). *Principles of Foundation Engineering*. 7th ed. International Thomson Publishing Asia.
- Shoeb Mohammed Sayeed., & K. Mythili (2014). Seismic Analysis And Design of Cantilever Retaining Walls, *International Journal of Science Engineering and Advance Technology (IJSEAT)*, 2(10), 2321- 6905.
- S. S Patil (2015). The Analysis And Design Of Stepped Cantilever Retaining Wall, *International Journal of Engineering Research & Technology (Ijert)* ,4 (2).
- S. P. Parmar (2012). *Lateral Earth Pressure*. Department Of Civil Engineering Dharmasinh Desai University Nadiad.
- Tonne V.R., & Mohite P.M. (2015). Optimization and Improvement in Stability of Counterfort Retaining Wall with Relief Shelf, *International Journal of research in Engineering and Technology*, 4(4), 447-451.
- V.N.S. Murthy (2007). *Advanced Foundation Engineering*. CBS Publishers and Distributors.
- Yash Chaliawala., Gunvant S Olanki., & Anuj.K.Chandiwala (2015). Comparative Study of Cantilever and Counterfort Retaining wall, *International Journal of Advance Engineering and Research Development*, 2 (12).