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Critical Study of Counterfort Retaining Wall

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Abstract—*Reinforced cement concrete (R.C.C.) Counterfort retaining walls are used for height of backfill more than 6m and for higher earth-pressure magnitudes. In this paper an attempt is made to study critically the counterfort type retaining wall by considering six different models for various parameters and for crucial load cases and combinations. Six models are a) Conventional counterfort Retaining wall without shear key,b) Conventional Counterfort Retaining wall With shear key. c) Conventional counterfort Retaining wall with buttress. d) Conventional counterfort Retaining wall with shear key and buttress. d) 8m counterfort retaining wall with 1 relief shelf e) 8m counterfort retaining wall with 2 relief shelves. Results and suitability is discussed in conclusions.*

Keywords*: Counterfort Retaining wall, earth pressure, seismic force, shear key, buttress, relief shelf.*

1. INTRODUCTION

For critical study of Counterfort retaining wall, the wall is to be study with respect to different aspects. One of the oldest problems in geotechnical engineering is understanding the behavior of earth retaining structures. Earthquake creates more complicated and adverse effect in retaining structure. Analysis of 8m Counterfort Retaining Wall with different backfill properties are carried out without considering seismic effect and with considering seismic effect. Different backfill soils includes GW(well graded gravel),GP(poorly graded gravel)GM(silty gravel),GC(claye gravel),SW(well graded sand),SP(poorly graded sand),SM(silty sand).Cantilever Retaining wall is generally preferred when the height of earth mass to be retained is less than 6 m, beyond which counterfort retaining wall is used because of economy. In present study an attempt is made to reduce the cross section of the counterfort retaining wall by considering six models of counterfort retaining wall with different soils, that six models are briefly explained in following chapters and results, suitability is mentioned in conclusions.

2. LOAD CALCULATIONS

2.1 Dead Load

The dead load coming on to the counterfort retaining wall is mainly due to the self-weight of the members including base slab, stem, counter forts and relief shelves.

2.2 Live Load

Live load includes soil backfill around the wall, due to soil back fill active earth pressure is acting on the wall. Expression for active earth pressure is given below.

$$P_a = \frac{1}{2}\gamma h^2 k_a$$

$$K_a = coefficient\ of\ active\ earth\ pressure = \frac{1-\sin Ø}{1+\sin Ø}$$

Φ=angle of internal friction.

h = height of backfill soil.

γ = unit weight of backfill soil.

2.3 Wind Force

Wind force on structure shall be taken in accordance with IS: 875(Part3)-1987 as applicable. Wind force pressure is given by,

$$P_z = 0.6 \text{ x } V_z^2$$

Where,

$$V_z = V_b.K_1.K_2.K_3$$

P_Z = Design wind pressure in N/m^2 at height z.

V_Z = Design wind speed at any height in m/s

V_b = Basic wind speed at any height in m/s

K_1 = Probability factor (risk coefficient)

K_2 = Terrain height and structure size factor

K_3 = Topographic factor

2.4 Seismic Force

Based on the location where the wall is situated it is subjected to Seismic (EQ) forces, so for the calculation of seismic forces IS1893 –1984, IS1893 (part3)–2002 are followed. The design horizontal seismic coefficient

(α_h) for a structure shall be determined by the following expression:

$$\alpha_h = \frac{z}{2}\frac{I}{R}\frac{S_a}{g}$$

Z= Zone Factor.

I= Importance Factor.

$\frac{S_a}{g}$ = Average response acceleration coefficient.

R= Response reduction factor.

$$C_a = \frac{(1 \pm \alpha_v)\cos^2(\emptyset - \lambda - \alpha)}{\cos\lambda \cos^2\alpha \cos(\delta + \alpha + \lambda)} X \left[\frac{1}{1 + (\frac{\sin(\emptyset + \delta)\sin(\emptyset - i - \lambda)}{\cos(\alpha - i)\cos(\delta + \alpha + \lambda)})^{0.5}}\right]^2$$

$$C_p = \frac{(1 \pm \alpha_v)\cos^2(\emptyset + \alpha - \lambda)}{\cos\lambda \cos^2\alpha \cos(\delta - \alpha + \lambda)} X \left[\frac{1}{1 \pm (\frac{\sin(\emptyset + \delta)\sin(\emptyset + i - \lambda)}{\cos(\alpha - i)\cos(\delta - \alpha + \lambda)})^{0.5}}\right]^2$$

C_a = Coefficient of active earth pressure in dynamic condition.

C_p = Coefficient of passive earth pressure in dynamic condition.

$$\lambda = \tan^{-1}(\frac{\alpha_h}{1 \pm \alpha_v})$$

$\alpha_v=(2/3)\alpha_h$

α = angle which earth face of the wall makes with the vertical.

i = slope of earth fill.

δ = angle of friction between the wall and earth fill .

Φ = angle of internal friction of soil,

$$P_a = \frac{1}{2}\gamma h^2 C_a$$

P_a=Dynamic active earth pressure acting on the wall.

$$P_p = \frac{1}{2}\gamma h^2 C_p$$

P_p= Dynamic passive earth pressure acting on the wall.

γ =unit weight of soil backfill

3. UPLIFT FORCE

In rainy seasons there is change in water table levels if water table reaches to the ground level then there is problem for the structure. So to take care of this water table changes, uplift pressure force is considered in load combinations.

$U= c\gamma_w h$

U=Uplift pressure

C=uplift coefficient

γ_w=unit weight of water

h=height of uplift water

Table 1: Load combinations

Cases	Description
Case 1	Construction stage(D.W+ wind)
Case 2	D.W + soil(backfill)+uplift force
Case 3	D.W+ soil(backfill)+ uplift + EQ force

4. APPROACH TO STABILITY CHECKS

a) Stability checks: Stability checks are performed for wall for all expected loads such as dead load, soil pressure, wind load, earthquake load, uplift etc. and their combinations.

b) Expected loads: Expected loads are the loads which are generally acts on wall which includes dead load i.e. self weight of wall, live load i.e. soil pressure present outside of wall.

C) Critical loads: Critical loads include the wind load and earthquake loads, according to wall situated in load is considered when wall is under construction and there is no soil fill is there, while earthquake is considered at the time of construction and after soil fill.

5. PARAMETERS CONSIDERED FOR ANALYSIS

a)Safe bearing capacity 250kN/m^2, coefficient of friction between soil and concrete =0.5, unit weight of water =10 KN/m^3, angle of internal friction for different soils below foundation , unit weight of different backfill soils, intensity of wind=1.4 KN/m^2,horizontal seismic coefficient=0.15, friction angle δ= 2/3φ,height of wall=8m

b) Soil properties around the wall are listed in table 2.

Table 2: Properties of soil around the wall

Soil Type	γ	ϕ	δ=2/3ϕ	i	c	K_a
GW	21	37	25	0	0	0.249
GP	19	36	24	0	0	0.260
GM	20	34	23	0	0	0.283
GC	20	33	22	0	0	0.295
SW	20	34	23	0	0	0.283
SP	18	34	23	0	0	0.283

6. CRITICAL STUDY OF COUNTERFORT RETAINING WALL

For critical study of counterfort retaining wall six models of walls are considered and studied for all load combinations, for different types of soils mentioned above for six models analysis done with all the load cases and critical load case is observed. Analysis includes finding F.O.S for sliding, overturning(O.T) and calculation of concrete quantity per 1m run. Here critical load case observed is combination of Dead load, soil force (earth force), uplift force, earthquake force. For different types of soils for different load cases different sizes of cross sections of counterfort retaining wall are coming.

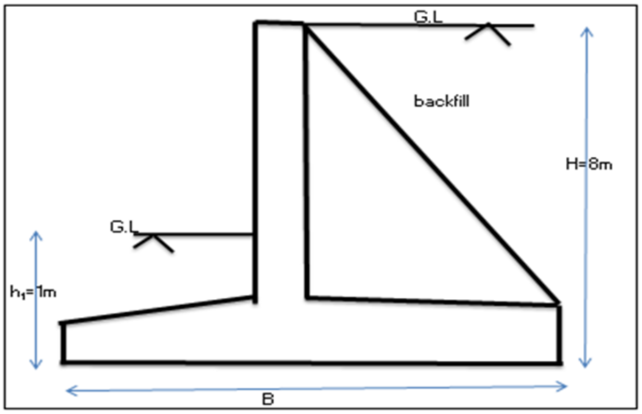


Fig. 1: General counterfort retaining wall

Following models are defined according to different cases.

a) Conventional 8m counterfort Retaining wall without shear key.

b) Conventional 8m Counterfort Retaining wall

with shear key

c) Conventional 8m counterfort Retaining wall with buttress.

d) Conventional 8m counterfort Retaining wall with shear key and buttress.

e) 8m counterfort retaining wall with one relief shelf.

f) 8m counterfort retaining wall with two relief shelves.

By using relief shelf at some height of the stem, soil pressure variation s is changing , it is shown in fig.2 and it is different from soil pressure variation in conventional type counterfort retaining wall. There is reduction in soil pressure because of shelf, by reducing the soil pressure moment coming on to the structure decreases and it results in reduction of various components of counterfort retaining wall.

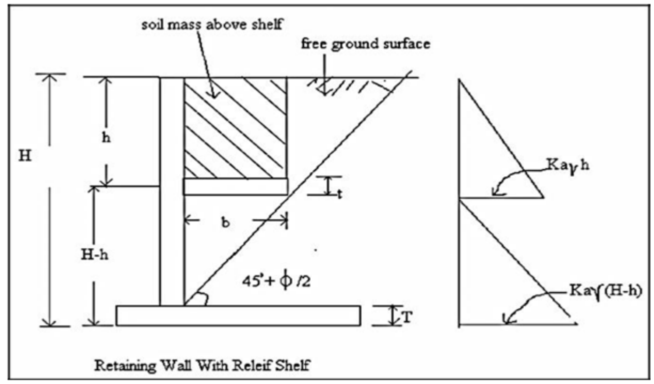


Fig. 2: Cross section of counterfort retaining wall with one relief shelf and soil pressure variation

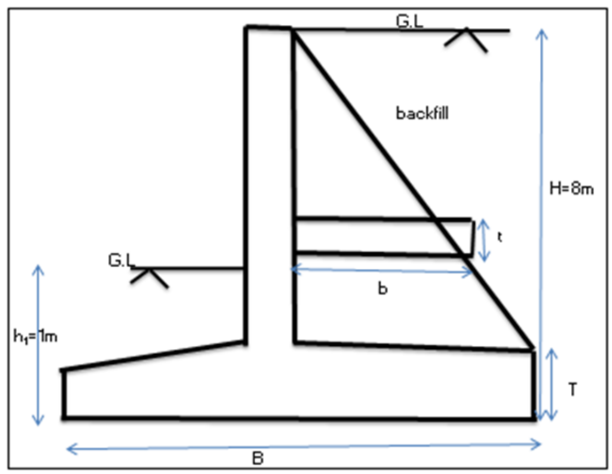


Fig. 3: Counterfort retaining wall with one relief shelf

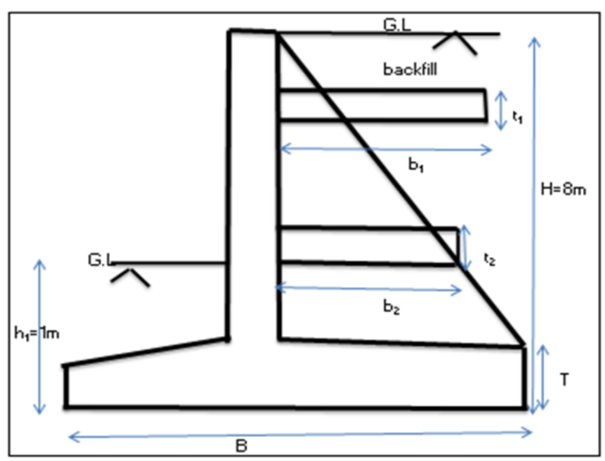


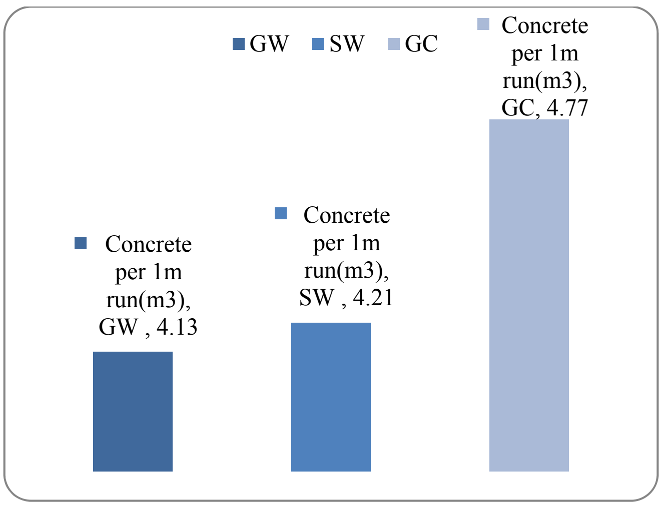
Fig. 4: Counterfort retaining wall with two relief shelves

7. RESULTS

From above load combinations critical load combination is (D.W+ soil+ uplift+ EQ). Stability analysis is carried out for seven types of soils such as GW,GP,GM,GC,SW,SP,SM among all this soils 3 types of soils(GC,SW,GW) which are giving high concrete quantity, medium concrete quantity, low concrete quantity are selected for comparison of results. For this 3 types of soils, for critical load combinations results mentioned below in the form of tables and graphs.

Table 3: Results for counterfort retaining wall with different types of soils, without shear key

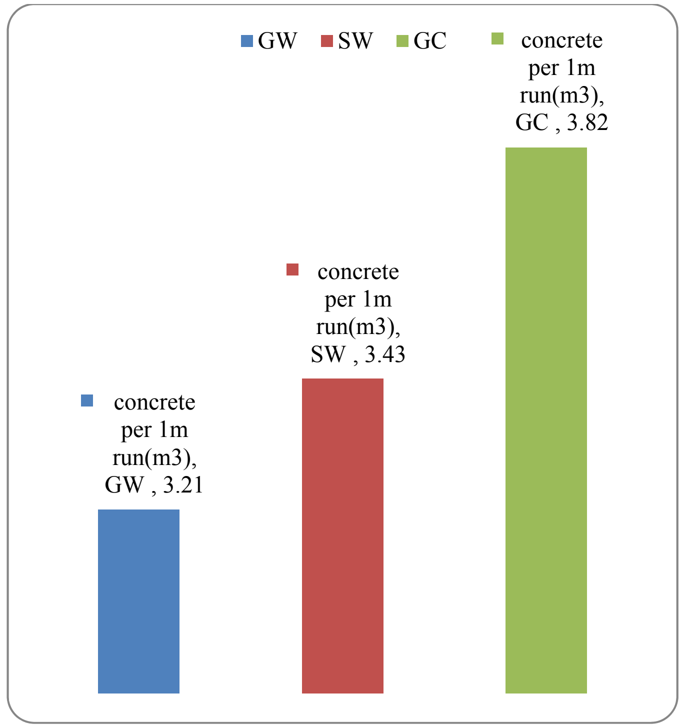
Soil type	F.O.S for O.t	F.O.S for sliding	P_{max} (KN/m^2)	P_{min} (KN/m^2)	Concrete (m^3)
GW	2.64	1.56	220.57	54.70	4.13
SW	2.99	1.53	204.01	56.80	4.21
GC	2.72	1.52	221.54	50.71	4.77



Graph 1 Concrete quantity required for different types of soils without shear key

4. Results for counterfort retaining wall with different types of soils, with shear key

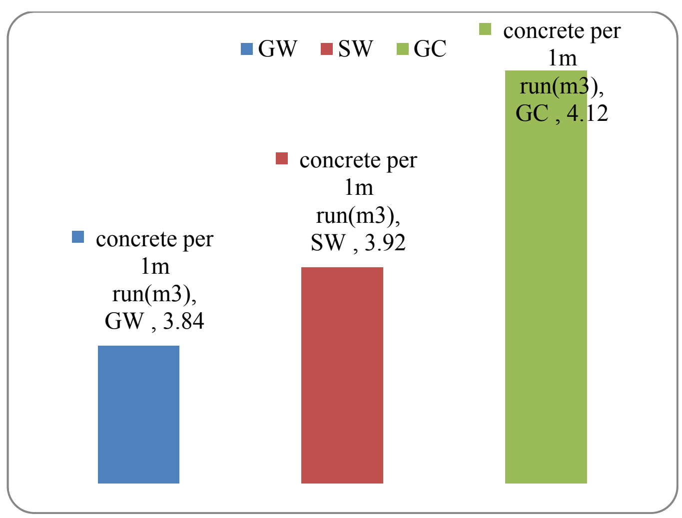
Soil type	F.O.S for O.T	F.O.S for sliding	Pmax (KN/ m2)	Pmin (KN/ m2)	Concrete (m3)
GW	1.91	1.52	210.51	3.77	3.21
SW	2.19	1.60	205.77	21.33	3.43
GC	1.93	1.61	225.26	11.82	3.82



Graph 2: Concrete quantity required for different types of soils with shear key

Table 5: Results for counterfort retaining wall with different types of soils, with buttress

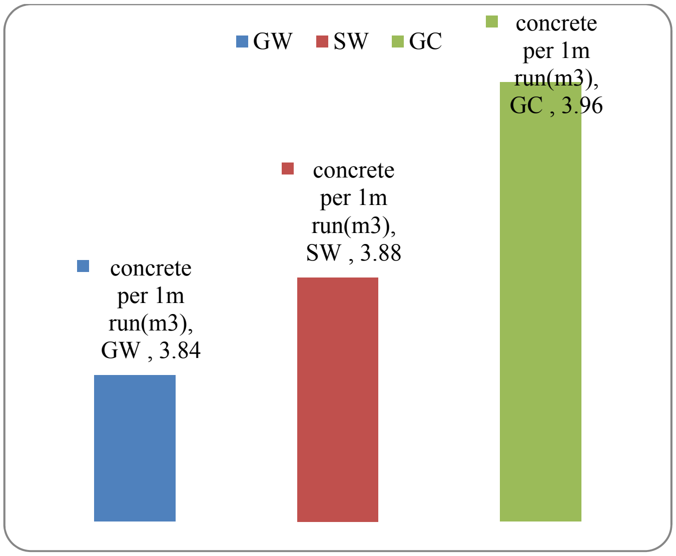
Soil type	F.O.S for O.T	F.O.S for sliding	P_{max} (KN/ m^2)	P_{min} (KN/ m^2)	Concrete (m^3)
GW	2.31	1.57	238.33	21.07	3.84
SW	2.45	1.56	241.84	21.39	3.92
GC	2.60	1.53	217.02	38.11	4.12



Graph 3: Concrete quantity required for different types of soils with buttress

6. Results for counterfort retaining wall with different types of soils, with shear key and buttress

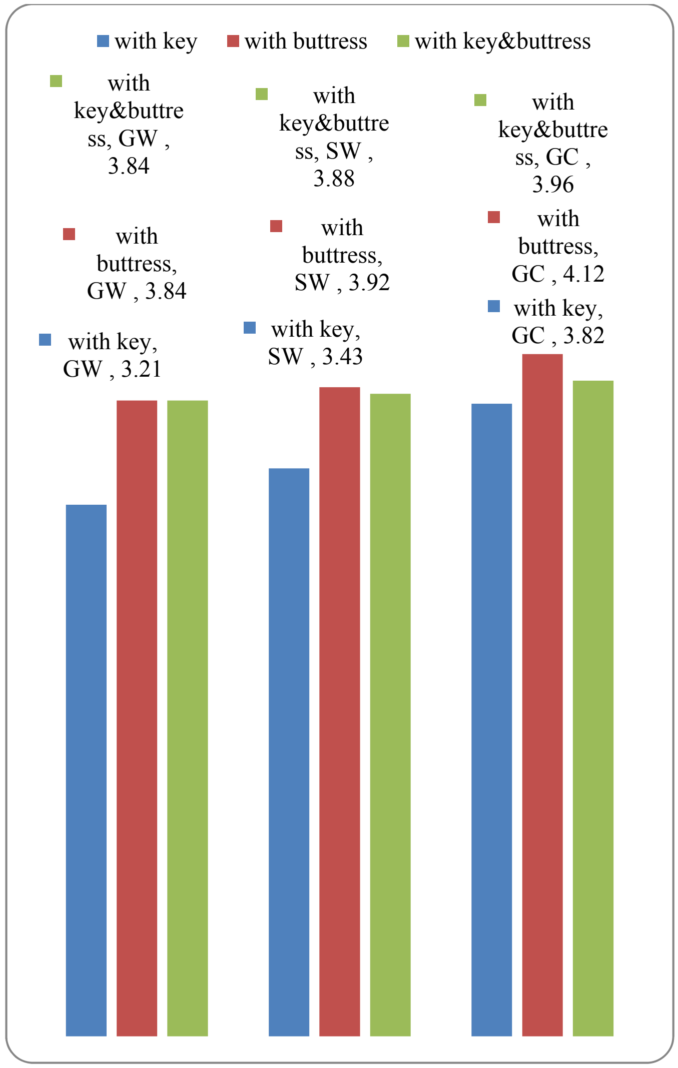
Soil type	F.O.S for O.T	F.O.S for sliding	P_{max} (KN/ m^2)	P_{min} (KN/m^2)	Concrete (m^3)
GW	2.02	2.15	240.63	1.93	3.84
SW	2.11	2.04	247.67	0.75	3.88
GC	2.21	1.99	241.93	8.71	3.96



Graph 4: Concrete quantity required for different types of soils with shear key and buttress

7. Results for comparison of with shear key, buttress and combined shear key and buttress

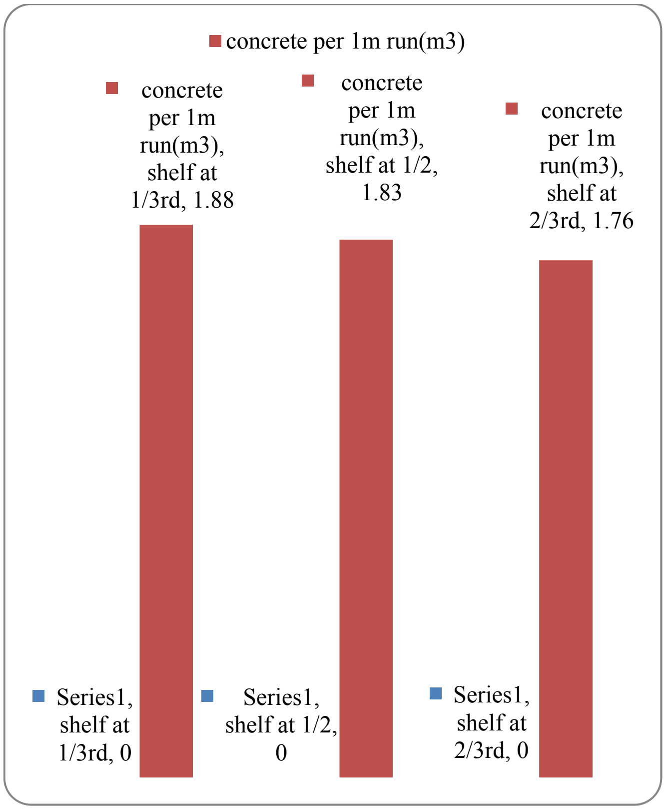
Case	Type of soil	F.O.S against overturning	F.O.S against sliding	P_{max}(KN/m^2)	P_{min}(KN/m^2)	Concrete (m^3)
Withshear key	GW	1.91	1.52	210.51	3.77	3.21
	SW	2.19	1.60	205.77	21.33	3.43
	GC	1.93	1.61	225.26	11.82	3.82
With buttress	GW	2.31	1.57	238.33	21.07	3.84
	SW	2.45	1.56	241.84	21.39	3.92
	GC	2.60	1.53	217.02	38.11	4.12
With shear key and buttress	GW	2.02	2.15	240.63	1.93	3.84
	SW	2.11	2.04	247.67	0.75	3.88
	GC	2.21	1.99	241.93	8.71	3.96



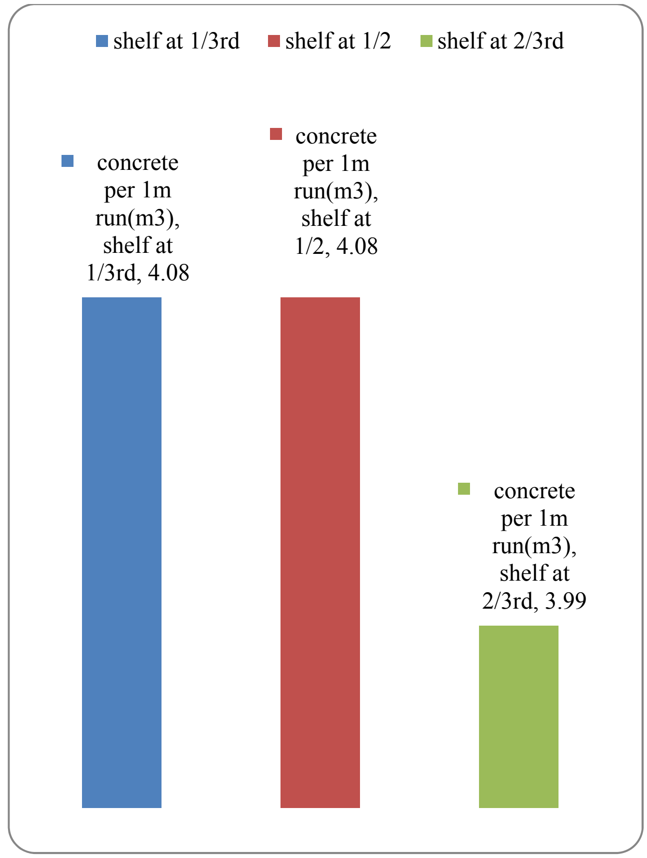
Graph 5: Comparison of concrete with shear key, buttress, combined shear key and buttress

8. Results for 8m counterfort retaining wall with one shelf at different locations of wall

Sr.no.	Desription	P_{max} (KN/m^2)	P_{min} (KN/m^2)	F.O.S for sliding	F.O.S for over turning	Concrete (m^3)
1	Shelf at 1/3rd height of stem	131.19	129.20	2.78	5.20	1.83
	With uplift	121.19	119.20	2.56	3.93	1.83
	with uplift and shear key	121.94	119.07	5.40	3.93	1.88
	with uplift and shear key&EQ	218.82	22.19	3.74	2.20	1.88
2	Shelf at 1/2 height of stem	141.55	118.21	3.11	4.67	1.78
	With uplift	132.61	109.65	2.90	3.65	1.78
	with uplift and shear key	133.37	109.52	6.35	3.65	1.83
	with uplift and shear key&EQ	228.45	11.93	4.06	1.89	1.83
3	Shelf at 2/3rd height of stem	165.87	93.02	2.84	3.77	1.71
	With uplift	155.87	83.02	2.62	3.05	1.71
	with uplift and shear key	155.37	83.51	5.89	3.05	1.76
	with uplift and shear key&EQ	217.85	21.66	3.80	2.20	1.76



Graph 6: Concrete quantity required for 8m counterfort retaining wall with one shelf



Graph 7: Concrete quantity required for 8m counterfort retaining wall with one shelf

9. Results of 8m counterfort retaining wall with two shelves at different locations of wall

Desription	$P_{max}(KN/m^2)$	$P_{min}(KN/m^2)$	F.O.S for sliding	F.O.S for over turning	Concrete (m^3)
Shelf at 1/3, 2/3rd height of stem					
With uplift	160.01	120.68	5.04	4.89	1.77
with uplift and shear key	153.40	131.89	11.64	5.75	1.89
with uplift and shear key&EQ	245.86	39.44	6.46	2.81	1.89

10. Results for 10m counterfort retaining wall with one shelf at different locations of wall.

Sr.no.	Desription	$P_{max}(KN/m^2)$	$P_{min}(KN/m^2)$	F.O.S for sliding	F.O.S for over turning	Concrete (m^3)
1	Shelf at 1/3rd height of stem	180.53	176.89	3.53	7.19	3.98
	With uplift	170.53	166.89	3.33	5.34	3.98
	with uplift and shear key	171.76	166.52	5.89	5.34	4.08
	with uplift and shear key&EQ	268.90	57.44	3.85	2.95	4.08
2	Shelf at 1/2height of stem	186.77	172.31	4.12	6.97	3.98
	With uplift	178.37	162.71	3.92	5.23	3.98
	with uplift and shear key	179.58	162.34	6.93	5.24	4.08
	with uplift and shear key&EQ	263.46	76.46	4.20	2.73	4.08
3	Shelf at 2/3rd height of stem	207.29	151.04	3.79	5.64	3.89
	With uplift	197.29	141.04	3.58	4.43	3.89
	with uplift and shear key	198.50	140.67	6.49	4.43	3.99
	with uplift and shear key&EQ	254.28	84.89	3.96	3.17	3.99

11. Results of 10m counterfort retaining wall with two shelves at different locations of wall.

Sr.no.	Desription	$P_{max}(KN/m^2)$	$P_{min}(KN/m^2)$	F.O.S for sliding	F.O.S for over turning	Concrete (m^3)
1	Shelf at 1/3, 2/3rd height of stem					
	with uplift	202.98	135.32	5.82	6.70	3.37
	with uplift and shear key	203.23	135.48	10.62	6.71	3.42
	with uplift and shear key&EQ	249.63	89.08	5.11	3.22	3.42

8. CONCLUSIONS

a) From above results it can be concluded that cohesive soil around the wall leads to increase in cross section of the wall when compared to non cohesive soil around the wall.

b) From table3&4, it is observed that concrete quantity will be reduced by providing shear key in counterfort retaining wall.

c) From table3&5, it can say that by providing buttress in counterfort retaining wall we can reduce the concrete quantity.

d) From table7, it can say that effect of shear key is advantageous over buttress and combined effect of shear key and buttress.

e) From table4& 8 it can be conclude that effect of one shelf is advantageous compared to effect of shear key.

f) From table 8&9 it can be conclude that for 8m counterfort retaining wall 1shelf at 2/3rd height of stem is effective than two shelves at different position.

g)From table 8, it can say that better location of shelf is at 2/3rd height from the top of the wall.

h) From table 10&11 it can be conclude that for 10m counterfort retaining wall 2 shelves at different positions is effective than one shelf at 2/3rd height of stem.

i) Above study can also say that provision of two shelves is advantageous for height of wall more than 8m

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