Study on Comparative Design of Retaining Wall Structures and Analysis it in ANSYS APDL Software

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Abstract - *This research concerned typical representation of retaining wall with the development of an approach which can be used in reduction of c/s area and material cost. It's however applied a retaining wall are going to replace it with a cantilever retaining wall structure because as we all know cantilever retaining wall requires a smaller c/s than the gravity retaining wall and hence make it safe and We have also done all important required stability checks under the static loading condition for the same location. So, the aim of this project is to developed a structurally efficient profile of retaining wall by compared it with a cantilever retaining wall structure of the same height and properties, where is further analyzed by finite element method by using ANSYS software under static loading condition. The finite element method (FEM) is a numerical method for solving problems and mathematical physics. This gravity retaining wall is located on Bendse-wave- Bridges, Karjat city of Maharashtra state of India. Then a modeled in the finite element software (ANSYS) is the developed and the deformation and displacement behavior of retaining wall is estimated for static load. Finally the results obtained from the numerical and the finite based analysis is compared.*

Key Words: **Cantilever retaining wall, Gravity retaining wall, ANSYS software.**

1. INTRODUCTION -

Retaining walls are used to retain earth or other loose material. The outline design of earth retaining wall involves the choice of wall, while detailed design concerns with the numerical calculation necessary to allow for safe chosen wall. However, wall sections forms a crucial part of the overall design process and hence should be given much greater attention. This Project focuses on comparative design of rigid retaining wall which is located on bendse Wave Bridge, Karjat by detailed numerical calculation and analysis in ANSYS software and comparing it with cantilever retaining wall and calculating and comparing results of both manually and in ANSYS software. This comparative design procedure should lead to economics of selection as a more informed comparison of alternative retaining wall types can be made.

ANSYS software helps in solving complex structural engineering problems with Finite Element Analysis (FEA) simulation software for implicit structural engineering problems and makes better, faster design decisions With finite element analysis (FEA) tools available in the suite, we can customize and Automate solutions for structural mechanics problems. ANSYS Structural analysis software is used throughout the industry to enable engineers to optimize their product designs means specialized service that requires engineering knowledge so as to reduce weight of the product and still enhances its strength and reduce the costs of physical testing.

1.1 Original site pictures and location on map –

Figure 1.1 Bridge site

Figure 1.2 Gravity wall cross section on site

Figure 1.3 Location of site on Google map

1.2 Standard section size of retaining wall from PWD department -

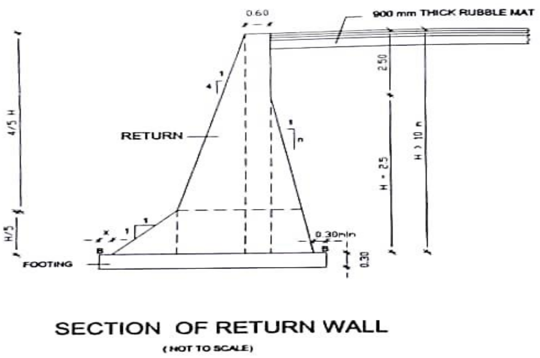

Figure 1.4 section of retaining wall

From the above section we have designed gravity retaining wall and some of the properties are also used in the design of cantilever retaining wall by using limit state method (LSM). As we all know masonry can be saved in the retaining wall by using steel but this cross section is generally used by PWD department.

1.3 Relevance –

Conventionally, retaining walls are broadly classified as –

1. Gravity retaining wall,
2. Semi gravity retaining wall,
3. Cantilever retaining wall and
4. Counter fort retaining wall.

A gravity retaining wall utilizes entirely its own weight to produce the necessary stability. Cantilever and counter fort retaining walls utilize the weight of the soil itself to produce stability. Semi-gravity retaining walls are intermediate between the cantilever and gravity types walls. Among the concrete retaining walls, the cantilever retaining walls are most widely used as it is economical. This wall increases the weight of the soil itself to produce stability. Cantilever retaining walls are used in basement of buildings, as abutments of bridges, as a flood walls in irrigation works as well as for retaining ores, minerals and other granular materials. Therefore, considering the importance of cantilever retaining structures, the estimation of earth pressure is found to be essential for the safe design of retaining wall under the static conditions.

2. LITERATURE REVIEW –

Bharat Shah and P.P.Tapkire (Optimization of gravity retaining wall profile by introducing cavity) (2015) etc. in which the main aim of this paper is to develop a cost effective and structurally efficient profile of gravity retaining wall by introducing cavity in the section. For this, various section sizes of gravity retaining wall are analyzed and accordingly profile is selected and then after selection of an appropriate profile of gravity retaining wall stability calculations are carried out for various heights using 'C' programming by strength of material approach then section is further analyzed by finite element method by using software ANSYS.

A.sadrekarimi (Gravity retaining walls: Reinvented) (2015) etc. Stated that Gravity Retaining wall are indispensable element of most important infrastructure, however many of these structures have experienced large displacements during past earthquakes, resulting in damage to the structures built on their backfill. In this published paper the study carried out using limit equilibrium analysis to investigation the effect of wall back faces geometry on seismic lateral earth thrust and overturning moment. This can be simply accomplished by modifying the back face shape of the wall. One particular approach for reducing lateral earth pressure is to minimize the size of the failure wedge developed behind the wall.

Karan yadav and Dr. Raghvendra Singh (stability assessment of earth retaining structure) (2018) etc. stated a failure of a recently constructed R.C.C. counter fort retaining wall of 5.0 high and 230 m length constructed in 2003 which is located near sangli city of Maharashtra state of India is analyses with analytical and finite element based software distressed under static loading condition. The wall could not sustain the flood impact and there was a sliding, collapse and even rotational failure at some portion of wall was observed and this wall was constructed to protect a village road about 1800 m along a stream from flood water and it seems that the wall failed due to heavy flood and backwater in the stream from river Krishna and the improper design criteria.

3. METHODOLOGY –

The purpose of this chapter is to present design methods required for the manual calculations of both (Gravity and cantilever) retaining wall with all required checks and also this chapter includes analysis of gravity retaining wall and cantilever retaining wall in ANSYS APDL software. The method we are using in manual calculations is limit state method (LSM).

3.1 Manual calculations of gravity retaining wall –

Given –

Height=5m, Safe bearing=200KN/m^2

Angle of Internal friction=30^o, Cohesion=0

M20 grade Fe415, Soil coefficient=0.5

Unit weight=18KN/m^3

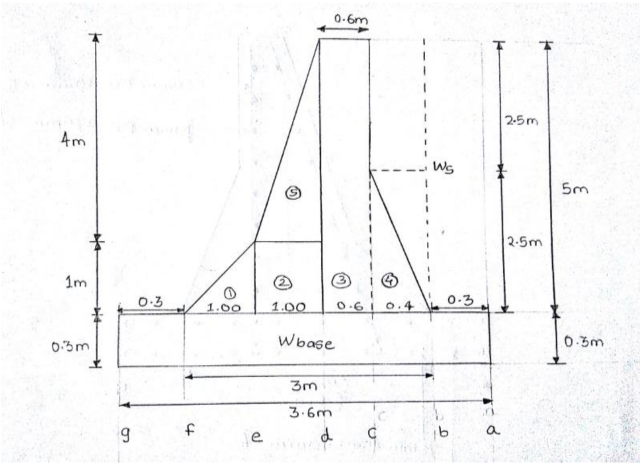

Figure 3.1 cross section of gravity wall

Table 3.1 Load calculation table for gravity retaining wall

Load due to	Vertical	Horizontal	$\bar{x}$ from toe	Moment restoring	Moment overturning
1)Stem 1)25×0.5×1×1	12.5		0.9667	12.083	
2)25×1×1×1	25		1.8	45	
3)25×0.6×5×1	75		2.6	195	
4)25×0.5×0.4×2.5×1	12.5		3.0333	37.916	
5) 25×0.5×1×4×1	50		1.9667	98.333	
2)Base =3.6×0.3×25×1	27		1.8	48.6	
3)Backfill 1)18×0.5×0.4×2.5×1	9		3.1667	28.5	
2)18×0.3×5×1	27		3.45	93.15	
3) 18×0.4×2.5×1	18		3.1	55.8	
4)Earth pressure $\frac{k_a\gamma H^2}{2}=\frac{0.33\times18\times5.3^2}{2}$		83.427	1.7667		147.387
5)Surcharge k_aQH=0.33×3.83×5.3	6.698		2.65	17.7497	
6)Water pressure $Y_w\times$ h= 9.81×3.3		32.373	1.1		35.6103
	ΣV= 262.698 KN	ΣH= 115.8 KN		ΣMR= 632.131KN.m	ΣM0= 182.997 KN.m

Check :-

Overturning = $\frac{\Sigma MR}{\Sigma Mo}$= **3.45 > 1.55** **Safe**

Sliding = $\frac{\mu\Sigma V}{\Sigma H}$= **1.47 < 1.55** **so fail in sliding**

So shear key provide

This less than 1.55 hence we will provide a factor of safety 1.55 the wall should be same for the horizontal pressure force 1.55

1.55×pH = 1.55×115.8 = **179.49KN**

Maximum available friction = **170.7537KN**

Unbalanced horizontal friction = 179.49-170.7537

= **8.74KN**

Safe horizontal soil reaction = 0.7×200 = **140KN\m²**

Let the height of shear key be 'y'

Safe horizontal reaction × y = unbalanced horizontal force

140×a×y = 8.74

y = **0.0624m ≅ 0.1m ≅ 100mm**

Moment = 8.74×0.1 = **0.874KN.m**Ultimate moment

= **1.311KN.m**

Calculation of steel:-

$m_u = 0.138 \times f_{ck} \times bd^2$

$$d = \sqrt{\frac{1.311\times10^6}{0.138\times15\times1000}} = 25.16mm$$

Add cover = 20mm D = 25.16+20= 45.16 ≅ 50mm

$$A_{st} = \frac{0.5 f_{ck} bd}{f_y}\left[1-\sqrt{1-\frac{4.6 m_u}{f_{ck} bd^2}}\right] = 138.80mm^2$$

$A_{st\,min}$ = 0.12%×bD= **60mm²**

$A_{st} > A_{stmin}$

Main steel:-

Distribution steel:-

Use 10mm ϕ bars

Use 6mm ϕ bars

$$Spacing = \frac{\frac{\pi}{4}\times10^2}{138.88}\times1000 \cong 550mm$$

Provide 10mm ϕ at 550mm c/c

$$Spacing = \frac{\frac{\pi}{4}\times6^2}{60}\times1000 \cong 450mm\ c/c$$

Provide 6mm ϕ at 450mm c/c

Check for pressure:-

$\bar{X} = \frac{\Sigma MR - \Sigma Mo}{\Sigma V}$ = **1.709m** $e = \frac{B}{2} - \bar{X}$ = **0.091** < $\frac{B}{6}$ or 0.6

$$P = \frac{\Sigma V}{B}\left[1+\frac{6e}{B}\right]$$

P_{max}= **84.039KN/m²** P_{min}= **61.904KN/m²**

$$m = \frac{84.039-61.904}{3.6} = 6.148$$

P_a = **61.904KN/m²** P_b = **63.7484KN/m²**

P_c =**66.207KN/m²** P_d = **69.896KN/m²**

P_e = **76.044KN/m²** P_f = **82.192KN/m²**

P_g = **84.039KN/m²**

Design of stem:-

D = 3000mm d=2400mm

$m_{u\,max} = 0.138 \times f_{ck} bd^2$ = **17892252×10³KN.m**

m_u = 17892252×10³×1.5 = **282.310KN.m**

Calculation of steel:-

$$A_{st} = \frac{0.5 f_{ck} bd}{f_y}\left[1-\sqrt{1-\frac{4.6 m_u}{f_{ck} bd^2}}\right] = 266.7597mm^2$$

A_{stmin} = 0.12%bD = **3600mm²**

$A_{st} > A_{stmin}$

Main steel:

Provide 20mm ϕ bar

$$Spacing = \frac{\frac{\pi}{4}\times20^2}{3600}\times1000 \cong 80mm\ c/c$$

$$A_{st}provided = \frac{\frac{\pi}{4}\times20^2}{80}\times1000 = 3926.99mm^2$$

Provide 20mm ϕ 80mm c/c-----------main steel

Distribution steel:

$A_{st\,min}$ = **266.75mm²** Use 10mm ϕ bar

Spacing = $\frac{\frac{\pi}{4}\times10^2}{266.75}\times1000 \cong$ **275mm c/c**

Provide 10mm ϕ 275mm c/c

Check for Shear:

P_a = 98.195 V_{uD} = 1.5×98.195 = **147.29KN**

pt% = $\frac{A_{stp}}{bd}\times100$ = **1.33%**

(By interpolation) Γ_{uC}= **0.686N/mm²**

$V_{uC} = \Gamma_{uC}\times bd$ = **2016.8×10³KN >V_{uD}** **Safe**

Design of Toe:-

w_1 = **2.25KN** v_1 = **24.6576KN** v_2= **0.277KN**

m @ d $w_1\times x_1+v_1\times x_2+v_2\times x_3$=**4.09154KN.m**

m_u @ d = 1.5×4.09154 =**6.02931KN.m**

Calculation of steel:-

Main steel:

$$A_{st}=\frac{0.5f_{ck}bd}{f_y}\left[1-\sqrt{1-\frac{4.6m_u}{f_{ck}bd^2}}\right] = \textbf{70.18mm}^2$$

$A_{st\ min}$ = 0.12%×Bd = **360mm²**

A_{st}< $A_{st\ min}$ ------So take $A_{st\ min}$

Use 16mm ϕ bars

Spacing = $\frac{\frac{\pi}{4}\times16^2}{360}\times1000 \cong$ **550mm**

Provide 16mm ϕ at 550mm c/c

Distribution steel:-

$A_{st\ D}$ = **70.18mm²**

Use 10mm ϕ bars

Spacing = $\frac{\frac{\pi}{4}\times10^2}{70.18}\times1000 \cong$ **1100mm c/c**

A_{st} provided = $\frac{\frac{\pi}{4}\times16^2}{550}\times1000$ = **365.56mm²**

Provide 10mm ϕ at 1100mm c/c

Design of heel:-

w_1 = **2.25KN** w_2= **27KN**

w_3 = **9KN** w_4= **18KN**

v_1= 18.57KN v_2 = **0.2766KN**

m=**14.443KN.m** m_u= **21.665KN.m**

v_D= **-37.4024KN (↓)** v_{uD}= **56.1036KN**

Calculation of steel:-

$$A_{st}=\frac{0.5f_{ck}bd}{f_y}\left[1-\sqrt{1-\frac{4.6m_u}{f_{ck}bd^2}}\right] = \textbf{705.0936mm}^2$$

$A_{st\ min}$ = 0.12%×bD= **360mm²**

A_{st}>A_{stmin}

Main steel:-

Use 16mm ϕ bars

Spacing = $\frac{\frac{\pi}{4}\times16^2}{705.0936}\times1000 \cong$ **275mm**

A_{st}provided = $\frac{\frac{\pi}{4}\times16^2}{275}\times1000$ = **731.134mm²**

Provide 16mm ϕ at 275mm c/c

Distribution steel:-

$A_{st\ D}$ = **360mm²**

Spacing = $\frac{\frac{\pi}{4}\times10^2}{360}\times1000 \cong$ **215mm c/c**

Provide 10mm ϕ at 215mm c/c

Check for shear:-

Pt% = $\frac{A_{st}}{bd}\times100$ = **0.30**

(By interpolation) Γ_{uc}= **0.384**

$V_{uC} = \Gamma_{uc}\times bd$= **92.16KN >$v_{uD}$** **Safe in shear**

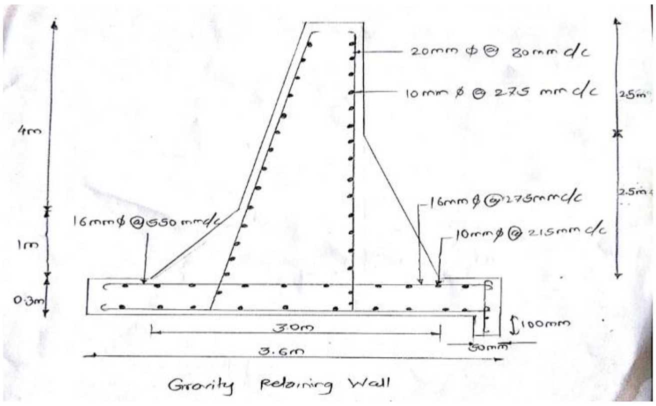

Figure 3.2 Detailed drawing of gravity wall section

3.2 Manual calculations of cantilever retaining wall:

Given –

Height=5.75m, Safe bearing=200KN/m^2

Angle of Internal friction=30^o, Cohesion=0

M20 grade Fe415, Soil coefficient=0.5

Unit weight=18KN/m^3

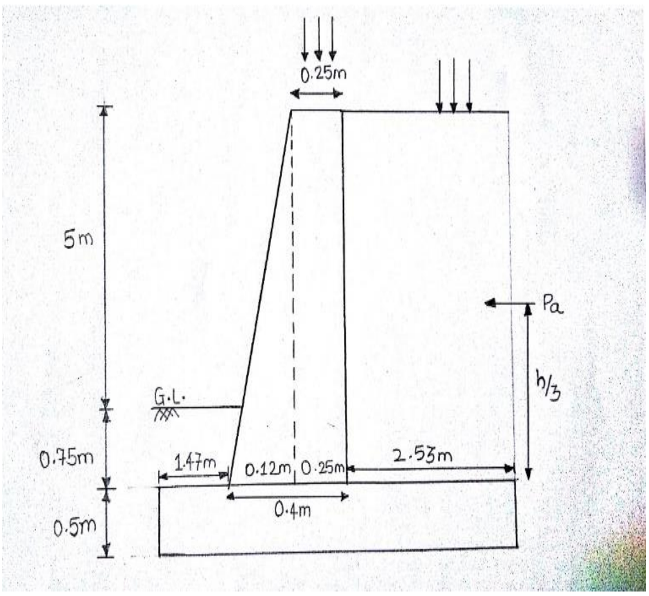

Figure 3.3 section of cantilever wall

$Df_{min}=\frac{\gamma_{BC}}{\gamma}(Ka)^2 \cong$ **1.25m** $Ka = \frac{1-\sin 30}{1+\sin 30}$ = **0.33**

H = 5+1.25 = **6.25m**

Base slab:

Width of base slab = 0.6H or 0.7H = **4.37 ≅ 4.4m**

Depth of base slab = 0.06H or 0.07H = **0.4375 ≅ 0.5m**

Toe projection = $\frac{1}{3}\times$B**= 1.47m**

Stem:-

Top projection = 250mm (Assume 200mm to 400mm)

Bottom projection:

Pa = $\frac{1}{2}\times Ka\times\gamma h_s\times h_s$= **98.2KN**

Moment at base of stem = $Pa\times\frac{h_s}{3}$

= **188.20KN.m**

Ultimate moment at stem = 1.5×188.20

= **282.310KN.m**

m_{umin} = m_u at stem = 0.138×bd^2

d **= 319.82mm**

Table 3.2 Load calculation table for cantilever wall

Sr. No.	Height	Vertical	Horizontal	$\bar{x}$ from toe	Moment of Resistance	Moment of overturning
1.	**Stem**					
	w_1	35.937		1.745	62.71	
	w_2	10.781		1.57	16.926	
2.	**Base**	55		2.2	121	
3.	**Backfill**	261.85		3.135	820.91	
4.	**Earth pressure**		116.015	25/12		241.699

5.	**Surcharge** $=K_aqH$ $=0.33\times3.83\times6.25$	7.899		13/4	25.671	
6.	**water pressure** $=\gamma_w\times h$ $=9.81\times4.25$		41.6925	17/12		59.064
		ΣV = 371.45	ΣH = 157.708		ΣMR = 1047.2	ΣMo = 300.763

Check:-

Overturning $=\frac{\Sigma MR}{\Sigma Mo}=$ **3.48 > 1.55** **Safe**

Sliding $=\frac{\mu\Sigma V}{\Sigma H}=$ **1.529 ≅ 1.53** **Ok**

Check for pressure:-

$\bar{x}=\frac{\Sigma MR-\Sigma Mo}{\Sigma V}=$ **2.009mm**

$e=\frac{B}{2}-\bar{x}=$ **0.919** $<\frac{B}{6}$ or 0.735

$P=\frac{\Sigma V}{B}\left[1+\frac{6e}{B}\right]$

$P_{max}=$ **106.408KN/m²** $P_{min}=$ **62.433 KN/m²**

$m=\frac{106.408-62.433}{4.4}=$ **9.994**

$P_a=$ **62.433KN/m²** $P_b=$ **87.707KN/m²**

$P_c=$ **90.2052KN/m²** $P_d=$ **93.703KN/m²**

$P_e=$ **106.408KN/m²**

Design of stem:-

D=**400mm** d=400-60 = **340mm**

$m_u=$ **282.310KN.m**

Calculation of main steel: -

$A_{st}=\frac{0.5f_{ck}bd}{f_y}\left[1-\sqrt{1-\frac{4.6m_u}{f_{ck}bd^2}}\right]=$ **2768.744mm²**

$A_{stmin}=\frac{0.12}{100}\times1000\times400=$ **480mm²**

$\mathbf{A_{st}>A_{stmin}}$

Provide 20mm ϕ bar

Spacing $=\frac{\frac{\pi}{4}\times20^2}{2768.744}\times1000\cong$ **100mm c/c**

$A_{st}provided=\frac{\frac{\pi}{4}\times20^2}{100}\times1000=$ **3141.592mm²**

Provide 20mm ϕ 100mm c/c

Calculation of distribution steel:-

$A_{st\ min}=480mm^2$

Use 10mm ϕ bar

Spacing $=\frac{\frac{\pi}{4}\times10^2}{480}\times1000\cong$ **150mm c/c**

Provide 10mm ϕ 150mm c/c

Check for Shear:-

$P_a=$ **98.195KN** $V_{uD}=1.5\times98.195=$ **147.29KN**

$pt\%=\frac{A_{stp}}{bd}\times100=$ **0.923%** $\Gamma_{uC}=$ **0.601N/m²**

(By Interpolation)

$V_{uC}=\Gamma_{uC}\times bd=$ **204.34KN >V_{uD}** **Safe**

Design of Toe:-

D = **500mm** d = **440mm**

cover = **60mm**

$w_1=$ **18.975KN** $v_1=$ **137.434KN** $v_2=$ **9.084KN**

m @ d $w_1\times x_1+v_1\times x_2+v_2\times x_3=$ **96.637KN.m**

m_u @ d = 1.5×96.637 = **144.956KN.m**

Calculation of steel:-

Main steel:-

$A_{st}=\frac{0.5f_{ck}bd}{f_y}\left[1-\sqrt{1-\frac{4.6m_u}{f_{ck}bd^2}}\right]=$ **956.0256mm²**

$A_{st\,min}$ = 0.12%×bD= **600mm²**

Use 16mm ϕ bars

Spacing = $\frac{\frac{\pi}{4}\times16^2}{956.0236}\times1000 \cong$ **200mm**

A_{st}provided = $\frac{\frac{\pi}{4}\times16^2}{200}\times1000$ = **1005.309mm²**

Provide 16mm ϕ at 200mm c/c

Distribution steel:-

$A_{st\,D}$ = **600mm²**

Spacing = $\frac{\frac{\pi}{4}\times10^2}{600}\times1000 \cong$ **125mm c/c**

Provide 10mm ϕ at 125mm c/c

Check for shear:-

P_f = 62.433+9.99×(2.53+0.4+1.06) = **102.293KN/m²**

w = **13.25KN** V_1 = **99.325KN** V_2 = **4.552KN**

$V_D = V_1+V_2-w$ = **90.627KN**

V_{uD} = 1.5×90.627 = **135.940KN**

Pt% = $\frac{A_{st}}{bd}\times100$= **0.22** Γ_{uc}= **0.336N/mm²**

$V_{uC} = \Gamma_{uc}\times bd$= **147.84KN > 135.940KN** **Safe in shear**

Design of heel:-

w_1= **31.625KN** w_2 = **261.855KN** v_1 = **157.955KN**

v_2 = **31.97KN**

m@b = **144.583KN.m** m_u@b = **216.875KN.m**

v_D = **-103.254KN (103.254 ↓)** v_{uD}=**154.881KN**

Calculation of steel :-

$A_{st}=\frac{0.5f_{ck}bd}{f_y}[1-\sqrt{1-\frac{4.6m_u}{f_{ck}bd^2}}]$ = **1024.97mm²**

$A_{st\,min}$ = 0.12%×bD= **600mm²** $A_{st}>A_{stmin}$

Main steel:-

Use 16mm ϕ bars Spacing = $\frac{\frac{\pi}{4}\times16^2}{1024.97}\times1000 \cong$ **175mm**

A_{st}provided = $\frac{\frac{\pi}{4}\times16^2}{175}\times1000$ = **1148.925mm²**

Provide 16mm ϕ at 175mm c/c

Distribution steel:-

$A_{st\,D}$ = 600mm²

Spacing = $\frac{\frac{\pi}{4}\times10^2}{600}\times1000 \cong$ **125mm c/c**

Provide 10mm ϕ at 125mm c/c

Check for shear:-

Pt% = $\frac{A_{st}}{bd}\times100$= **0.26** Γ_{uc}= **0.384** **(**By interpolation)

$V_{uC} = \Gamma_{uc}\times bd$= **168.46KN > 154.881KN** **Safe in shear**

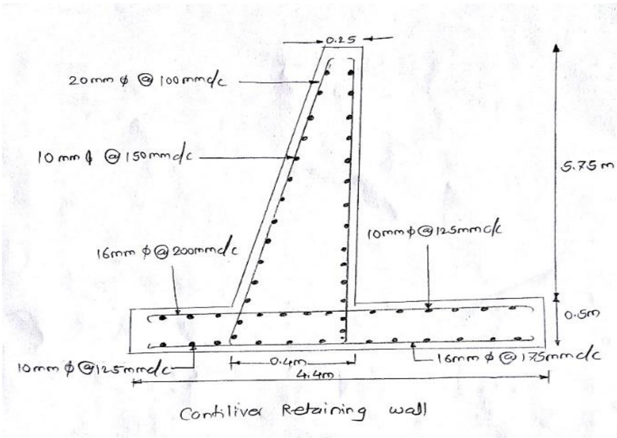

Figure 3.4 Detailed drawing of cantilever retaining wall

3.3 ANSYS APDL analysis results of gravity retaining wall:

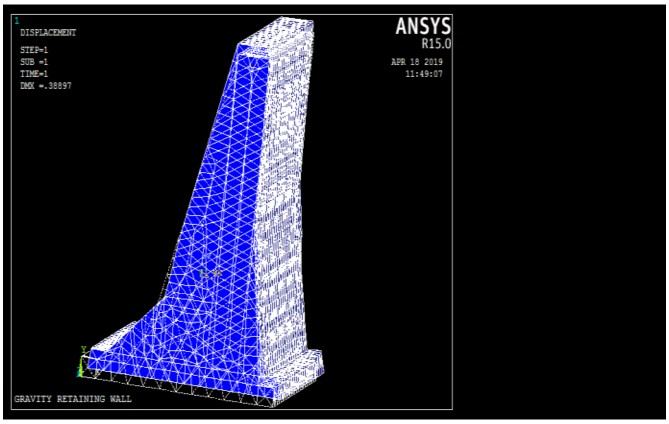

Figure 3.5 displacement of gravity retaining wall deformed plus undeformed shape

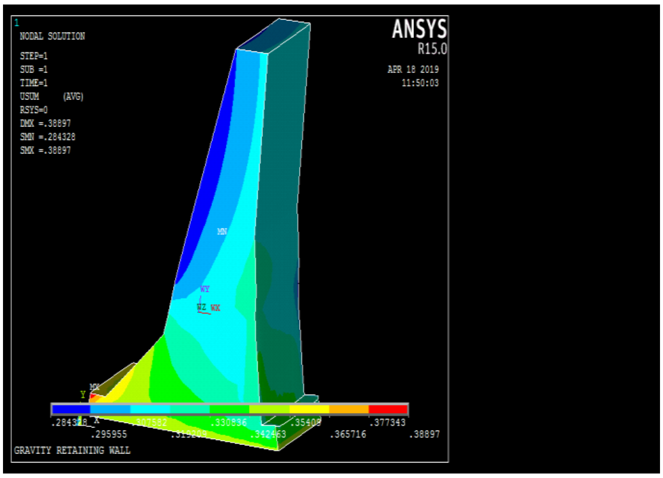

Figure 3.6 DOF solution displacement vector sum

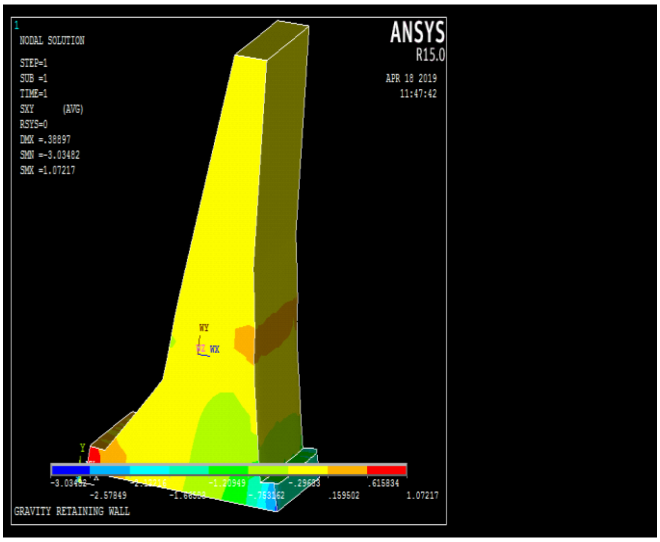

Figure 3.7 Shear stress in XY plane

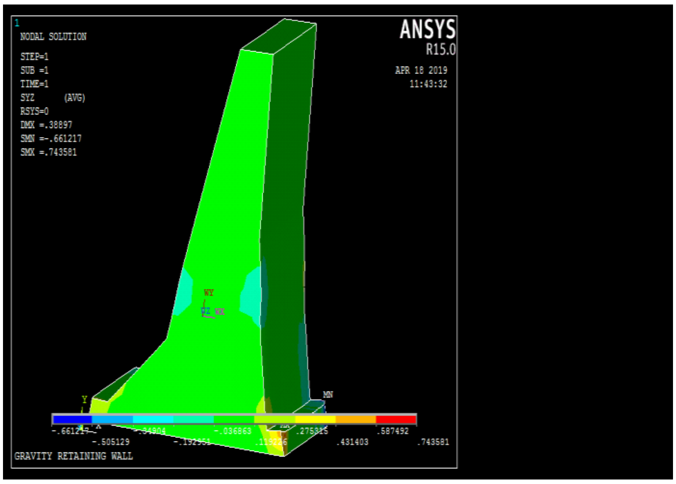

Figure 3.8 Shear stress in YZ plane

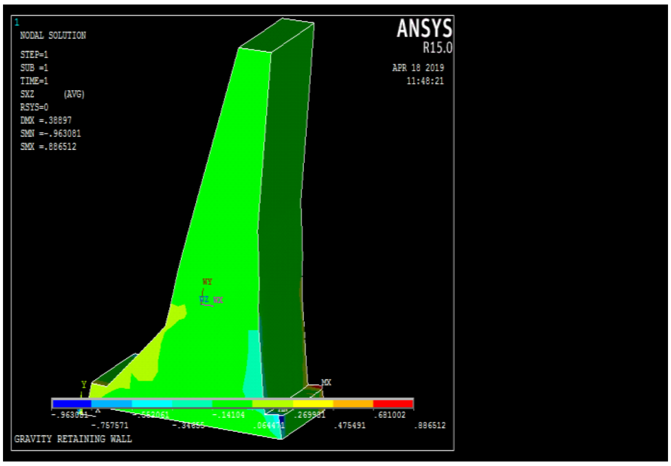

Figure 3.9 Shear stress in XZ plane

3.4 ANSYS APDL analysis results of cantilever retaining wall:

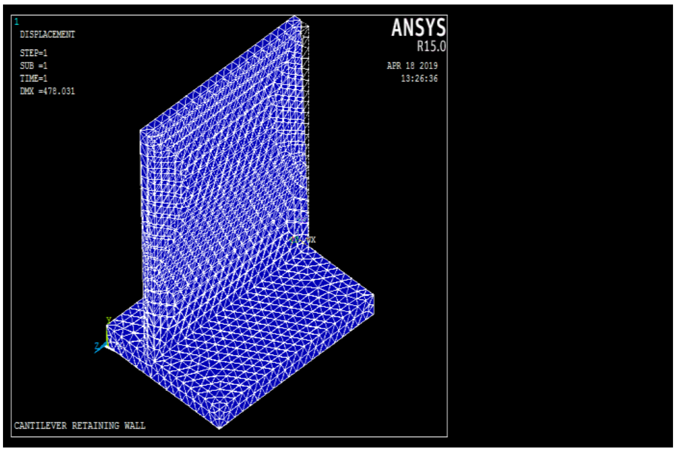

Figure 3.10 Displacement of cantilever wall deformed and undeformed shape

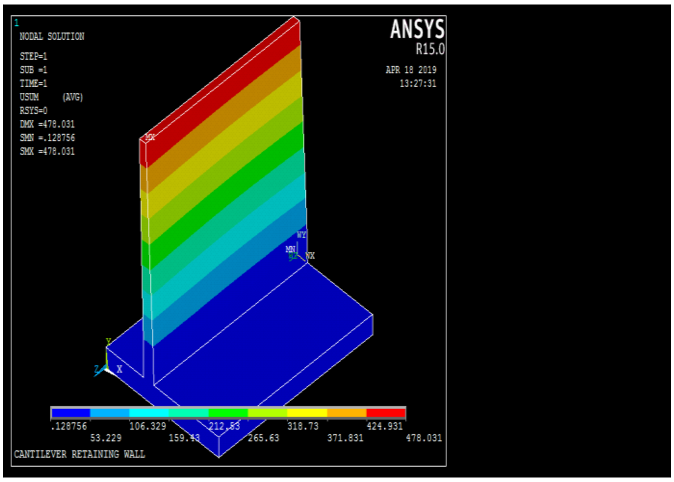

Figure 3.11 cantilever wall nodal solution displacement vector sum

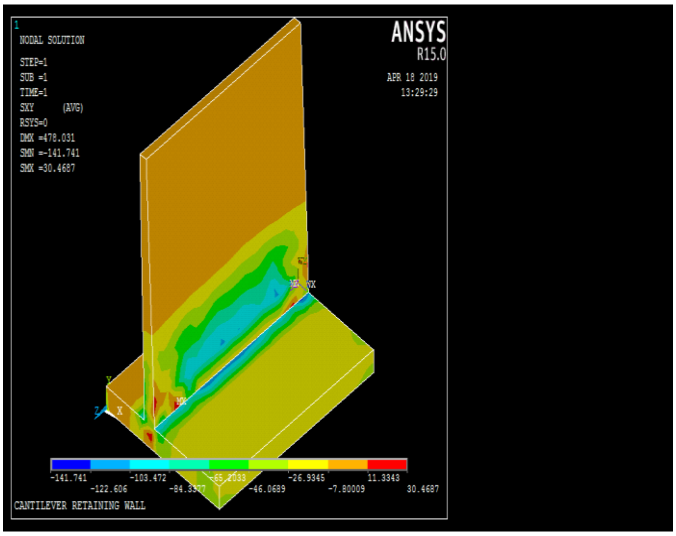

Figure 3.12 Shear stress in XY plane

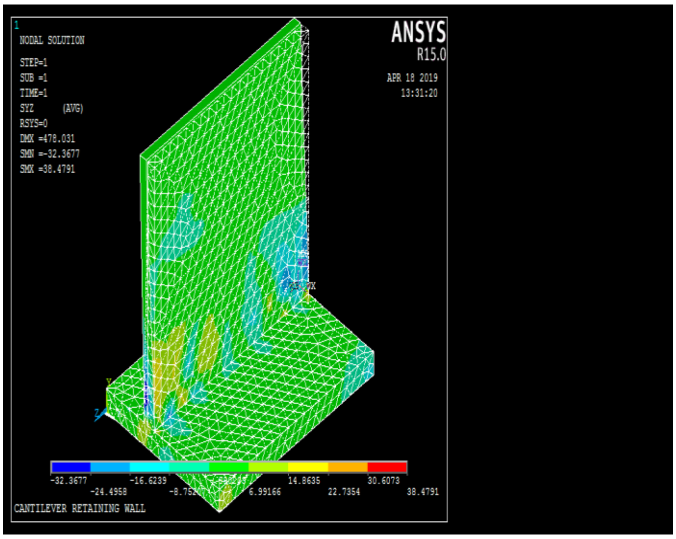

Figure 3.13 Shear stress in YZ plane

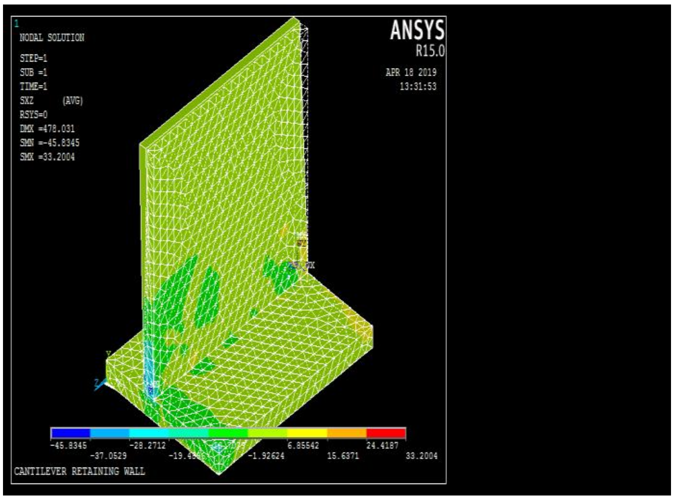

Figure 3.14 Shear stress in XZ plane

4. RESULTS

4.1 Manual calculation results –

SR. No.	Checks	Gravity retaining wall	Remark	Cantilever retaining wall	Remark
1.	Overturning	3.45 > 1.55	**Safe**	3.48 > 1.55	**safe**
2.	Sliding	1.47 < 1.5	**Unsafe (added shear key)**	1.53 > 1.5	**Safe**
3.	Pressure	0.091 < 0.6 (B/6)	**Safe**	0.191 < 0.735 (B/6)	**Safe**

Table 4.1 Checks for retaining wall

4.2 Total volume calculations –

SR. NO.	Type of wall	Component	Area (m^2)	Volume(m^3)
1.	Gravity wall	Stem	7.45	44.7
		Base	1.08	6.48
TOTAL			**8.53**	**51.18**
2.	Cantilever wall	stem	1.86875	11.212
		Base	2.2	13.2
TOTAL			**4.06875**	**24.412**

Table 4.2 Total volume calculation

Volume Reduction in cantilever retaining wall **= 26.767m³**

5. SCOPE

On this basis any type of comparison of retaining wall structure and also by finding all required checks we will decide accurately either structure is safe or unsafe for static stability condition and deflection, stresses in X, Y,Z direction of components also checked by Finite Element Software (ANSYS) quickly as compared to any other software because all kinds of design can solve internally by this software by putting given values and also adding pressure in it. This software is new in market but according to facilities provided for the result of any structure demand of ANSYS increases in better way.

6. CONCLUSION

The actual location is made with the help of gravity retaining wall but from all aspects we have finally concluded that for that location cantilever retaining wall is the best option.

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