DESIGN AND ANALYSIS OF RETAINING WALL

D.R. Dhamdhere[1], Dr. V. R. Rathi[2], Dr. P. K. Kolase[3]

Department of Civil engineering, PREC, Loni, University of Pune, Maharashtra, India

[1] Post Graduate Student, Pravara College of Engineering, Loni, Maharashtra, [2] Professor and Head, Civil Engineering Department, Pravara College of Engineering, Loni, Maharashtra India.

[3]Professor, Civil Engineering Department, Pravara College of Engineering, Loni, Maharashtra

Abstract

This paper consist of analysis and design of cantilever and relieving platform retaining wall with varying height from 3m to 10m and SBC 160KN/m^2. It also shows comparative study such as cost, economy, bending moment, stability against overturning &sliding between both the retaining wall. The comparative study is carried out along with the cost and optimum or least cost estimate is chosen as the best option. In this paper it is also shown that the relieving platform retaining wall is economical, more stable than cantilever retaining wall and it also relives the bending moment of heel portion.

Keywords- Retaining wall, cantilever retaining wall, relieving platform retaining wall, design and analysis.

I.INTRODUCTION

A retaining wall is a structure designed to sustain the earth behind it. It retains a steep faced slope of an earth mass against rupture of slopes faced slopes in cuts and fills and against sliding down. The retained material exerts a push on structures and this tends to overturn and slide it.

Besides the self-weight, the main predominant force for analysis and design of the retaining wall is lateral earth pressure. The lateral earth pressure behind the wall depends on the angle of internal friction and the cohesive strength of the retained material, as well as the direction and magnitude of movement of the stems. Its distribution is typically triangular, least at the top of the wall and increasing towards the bottom. The earth pressure could push the wall forward or overturn it if not properly addressed. Retaining walls are encountered and constructed in various fields of engineering such as roads, harbors, dams, subways, railroads, tunnels, mines and military fortifications.

This research is generally focusing on the the following types of retaining walls,

1.1 Cantilever retaining wall:

The wall consists of a relatively thin stem and base slab. The base is also divided into two parts, the heel and the toe. The heel is the part of base under the backfill. The toe is the other part of base.

- Use much less concrete than monolithic gravity walls, but requires more design and careful construction.
- Generally economical up to 8m to 9m in height
- Can be precast in a factory or formed on site

1.2 Counterfort Retaining walls:

Counter fort retaining walls are similar to cantilever walls except they have thin vertical concrete webs at regular intervals along the backside of the wall. These webs are known as counterforts.

- The counterfort tie the slab and base together, and the purpose of them is to reduce the shear force and bending moments imposed on the wall by the soil.
- Can be precast or formed on site
- Counterfort retaining walls are more economical than cantilever walls for heights 8m.

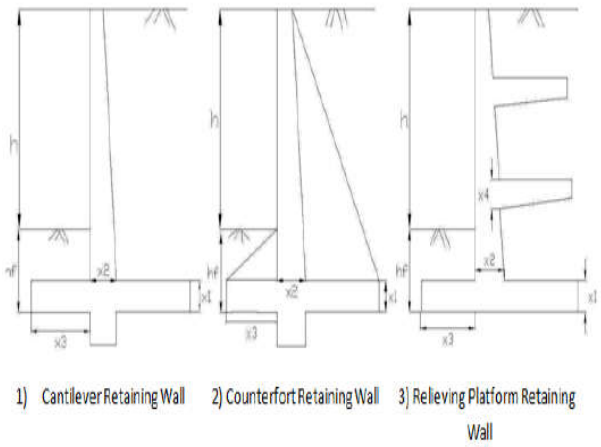

Fig. 1 Types Of Retaining Wall

1.3Relieving platform retaining wall:

This type of wall is modified form of cantilever retaining wall with added relieving platform. The platform is provided at stem. The one can provide one or more platform as design demands. This platforms changes entire pressure distribution diagram. This platform gives economical design as well as less bending moments.

- Can be precast or formed on site
- Economical than cantilever retaining wall
- Can be used for any height.(more than 8m and less than 8m)

Retaining wall with relieving platform or relief shelves can also be considered as a special type of retaining walls. Some researchers have stated that using reinforced walls is the most economical method for constructing high walls with relieve platforms in their reports. The relive platform have the advantages of deceasing the acting lateral earth pressure and increasing the overall stability of the retaining wall.

1.4 Change in pressure due to presence of shelf:

When the relieving platform is provided to the retaining wall, the setback of the wall increases and the sliding wedge is reduced. This reduction lowers the pressure on the retaining wall.

The most important consideration in proper design and installation of retaining wall is recognize and counteract the tendency of the retained to move down slope due to gravity. This creates lateral earth pressure behind the wall which depends on the angle of internal friction and the cohesive strength of the retained material, as well as the direction and magnitude of movements the retaining structure undergoes.

Lateral earth pressure are zero at the top of the wall and in homogeneous ground increase proportionally to a maximum value at the lower depth. Earth pressure will push the all forward or overturn it if not properly designed. Also, any groundwater behind the wall causes hydrostatic pressure.

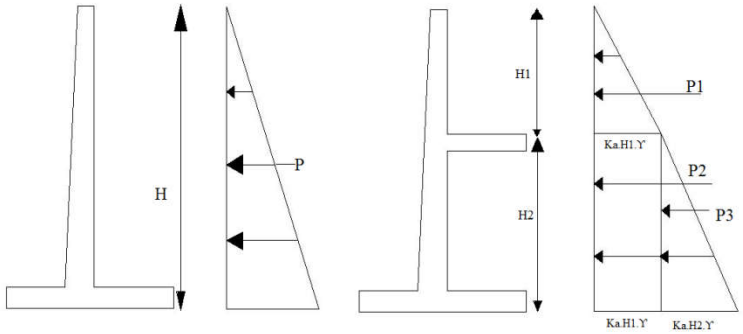

Fig. 2. Pressure distribution diagram for cantilever wall and the wall with relieving platform

II. LITERATURE REVIEW:

Donkadaet. al[1], found that at developing an understanding of optimal design solutions for three types of reinforced concrete retaining walls, namely, cantilever retaining walls, counterfort retaining walls and retaining walls with relieving platforms. Using genetic algorithms, parametric studies were carried out to establish heuristic rules for proportioning the wall dimensions corresponding to the minimum cost points. Optimal cost-estimates of the retaining walls types were compared to establish the best design alternative for a given height. Also, the advantages of retaining walls with relieving platforms, which are relatively new in India, are discussed.

Patilet. al[2]], found that a retaining wall is one of the most important types of retaining structures. It is extensively used in variety of situations such as highway engineering, railways engineering, bridge engineering and irrigation engineering. Reinforced concrete retaining walls have a vertical or inclined stem cast with base slab. These are considered suitable upto a height of 6m. it resist lateral earth pressure by cantilever action of stem, toe slab and heel slab. The tendency of wall to slide forward due to lateral earth pressure should be investigated and the factor of safety of 1.5 shall be provided against sliding. Cantilever retaining walls are found best up to a height of 6m. for greater heights earth pressure due to retained fill will be higher due to lever arm effect, higher moments are

produced at base, which leads to higher section for stability design as well as structural design. This proves to be an uneconomical design. As an alternative to this, one may go for counter for retaining wall, which demands greater base area as well as steel. As a solution to this difficulty, a new approach that is to minimize effect of foeces coming from retained fill, short reinforced concerete balance the locally appearing forces and will result into lesser moment and shear forces along the stem. Also it will reduce the bending action that is pressure below the base.

Patilet. al[3], have found that a retaining wall is a structure designed and constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil. The most important consideration in proper design and installation of retaining walls is to recognize and counteract the tendency of the retained material to move down slope due to gravity. This creates lateral earth pressure behind the wall which depends on the angle of internal friction (ø) and the cohesive strength (c) of the retained material, as well as the direction and magnitude of movement the retaining structure undergoes. In many cases we have to come across the retaining wall of 7m, 8m, 9m height. So we will consider these heights for noncohesive soil conditions for different spacing of counter-forts. We studied, by changing the spacing of counter-forts what will be the change in thickness of stem as well as heel slab, what is the optimum spacing of the counter-forts, what is the effect of changing spacing of counter-forts on bending moments, and plotted a graph of optimum spacing of counter-forts vs height of wall. The data presented here in following sections clearly indicates that changing spacing of counter-forts for retaining wall results in, reduction of spacing of counter forts will result in reduction in bending moments in heel slab and stem wall, reduction of spacing of counter forts will result in reduction in thickness of heel slab and stem wall. It is also observed that for 1m, 1.5m, 2m, 3m, 3.5m, 4m spacing of counter-forts the concrete and steel quantities per meter length of retaining wall is more than at 2.5m spacing. So optimum spacing of counter-forts for 7m, 8m, 9m height retaining wall is observed to be 2.5m.

TamadherAboodet. al[4], has found that retaining structures hold back soil or other loose material where an abrupt change in ground elevation occurs. The retained material or backfill exerts a push on the structure and thus tends to overturn or slide it, or both. The cantilever is the most common type of retaining wall and is used for walls in the range of 3to 6m in height. This study presents analyses and design of cantilever retaining wall which is made from an internal stem of steel-reinforced, cast-in-place concrete (often in the shape of an inverted T). In this work a detailed analyses and design for this type of walls which include estimation of primary dimensions of the wall, then these dimensions were checked.The factor of safety against sliding, overturning and bearing were calculated.the shear resistance for the base, the tension stresses in the stem and the tension stresses for the base were checked. Calculation of reinforcement for each part of the wall were done. All analysis and design are based on the ACI code

Inder Kumar et al[5], found that the analysis for the behaviour & optimal design of counter fort retaining wall and gravity wall in concrete dam. Cost analysis against each design of wall is evaluated by using volume of concrete and amount of steel. A comparative study is carried out & alternative with the least cost estimate is chosen as the best design solution.

Prof. SaritaSingla et al[6], has discovered that during development of land, one often comes across with the challenge of creating a difference in terrain elevation over an arbitrary horizontal distance. This can often be done by creating slopes or by constructing retaining walls. Retaining walls are structures that are constructed to retail soil or

any such materials which are unable to stand vertically by themselves. In this paper the study of the behaviour and optimal design of three types of reinforced concrete walls of varying heights namely cantilever retaining wall, counterfort retaining wall and retaining wall with relieving platforms is done. Cost against each optimal design of wall for particular height is calculated by using the volume of concrete and the amount of steel. Amidst the cost estimates of all the three optimal designs for particular height, a comparative study is carried out and the alternative with the least cost estimate is chosen as the best design solution.

YashChaliawala et al[7], has found that the behavior and optimal design of two types of reinforced concrete walls of varying heights namely cantilever retaining wall, counter fort retaining wall. Cost against each optimal design of wall foe particular height is calculated using the volume of concrete and the amount of steel. Amidst the cost estimate is chosen as the best design solution.

III METHODOLOGY:

3.1Design of retaining wall:

Technically while designing, all the necessary parameters and requirements are considered and all the possible solutions are generated. Then a thorough analysis and calculations are carried out considering all the parameters especially cost involved and the risk and uncertainties involved. Then the solution with the optimal cost is chosen as the best solution. Thus, it is overall a rigorous decision making process.

The design of retaining will includes the following steps:

- Fixation of the base width and the other dimensions of retaining wall
- Performing stability checks and computation of maximum and minimum bearing pressure.
- Design of various parts like stem, toe slab, heel slab, relieving platform.

For the analysis purpose three reinforced concrete retaining walls namely cantilever retaining wall, counterfort retaining wall and retaining wall with relieving platforms with height ranging from 3m to 10m with interval of 0.5m are considered. Safe bearing capacity is ranging from 100KN/m^3 to 200 KN/m^3 with interval of 10 KN/m^3. Length of relieving platform is kept equal to length of heel slab for analysis purpose.

3.2. Design parameters:

- Length of relieving platform: It is kept equal to the length of heel slab for easy analysis purpose.
- Thickness of relieving platform: It is considered as a one fourth of the thickness of base slab.
- Location of relieving platform: It is considered at the mid height of the retaining wall.
- Angle of friction(ϕ) : 35º
- Coefficient of active earth pressure(Ka): $\frac{1-\sin\phi}{1+\sin\phi} = 0.27$
- Coefficient of passive earth pressure(Kp) : $\frac{1+\sin\phi}{1-\sin\phi} = 3.69$

- Depth of foundation: Height or depth of foundation ranging from 3m to 10m with interval of 0.5m is considered.
- Soil bearing capacity: SBC is ranging from 100KN/m^3 to 200 KN/m^3 with interval of 10 KN/m^3
- Unit weight of soil (ϒs): 18 KN/m^3
- Unit weight of concrete: 25 KN/m^3
- Grade of concrete: M25
- Grade of steel: Fe500

3.3 Stability Checks:

The following stability checks are used in the design of retaining wall

- Eccentricity of the resultant reaction force should lie between 0 and the base width/6
- Factor of safety against sliding is taken greater than 1.5
- Factor of safety against overturning is also taken greater than 1.5
- The maximum and minimum bearing pressure is taken greater than 0 and less than soil bearing capacity
- Maximum and minimum reinforcement percentage and reinforcement spacing is taken as per IS456:2000 code.
- Restrictions on maximum shear stress in different parts are based on concrete grade as per IS456:2000 code

3.4. Total Cost of construction:

As mentioned in the above, the design with the optimal cost is taken as a best solution, the formula involved in calculation is as follows,

Total cost: = cost for steel + cost for concrete

=

$$(amount\ of\ steel\ in\ kg\ X\ rate\ of\ steel\ per\ kg) + (volume\ of\ concrete\ in\ m^3\ X\ cost\ of\ concrete\ per\ m^3)$$

IV RESULTS AND DISCUSSION

4.1 Variation of bending moments:

Table 1: bending moment variation

height of retaining wall	Cantilever retaining wall			retaining wall with relieving platform			
	bending moment(KN-m)			bending moment(KN-m)			
	steam	heel	toe	steam	heel	toe	relieving platform
3	30.52	26.8	12.73	20.2	5.85	7.18	15.71
3.5	44.85	39.99	18.42	29.68	8.26	10.46	20.19
4	63.07	56.93	25.61	41.75	11.24	14.61	25.24
4.5	85.67	78.08	34.45	56.71	14.85	19.72	30.85
5	113.11	103.91	45.14	74.87	19.15	25.90	37.02
5.5	145.85	134.9	57.83	96.54	24.19	33.24	43.76
6	184.38	171.51	72.71	122.04	30.03	41.85	51.06
6.5	229.16	214.21	89.95	151.68	36.74	51.82	58.92
7	280.65	263.47	109.71	185.76	44.38	63.26	67.34
7.5	339.33	319.76	132.19	224.61	52.99	76.26	76.33
8	405.67	383.54	157.54	268.52	62.64	90.93	85.88
8.5	480.14	455.28	185.94	317.81	73.39	107.36	95.99
9	563.20	535.47	217.56	372.79	85.3	125.65	106.66
9.5	655.33	624.55	252.59	433.77	98.43	145.92	117.90
10	757.00	723	291.19	501.06	112.83	168.24	129.69

As we can see the bending moment for heel and toe is less in retaining wall with the relieving platform as relieving wall is relieving some BM. From above table values we can plot the graphs and can see the variation of bending moment.

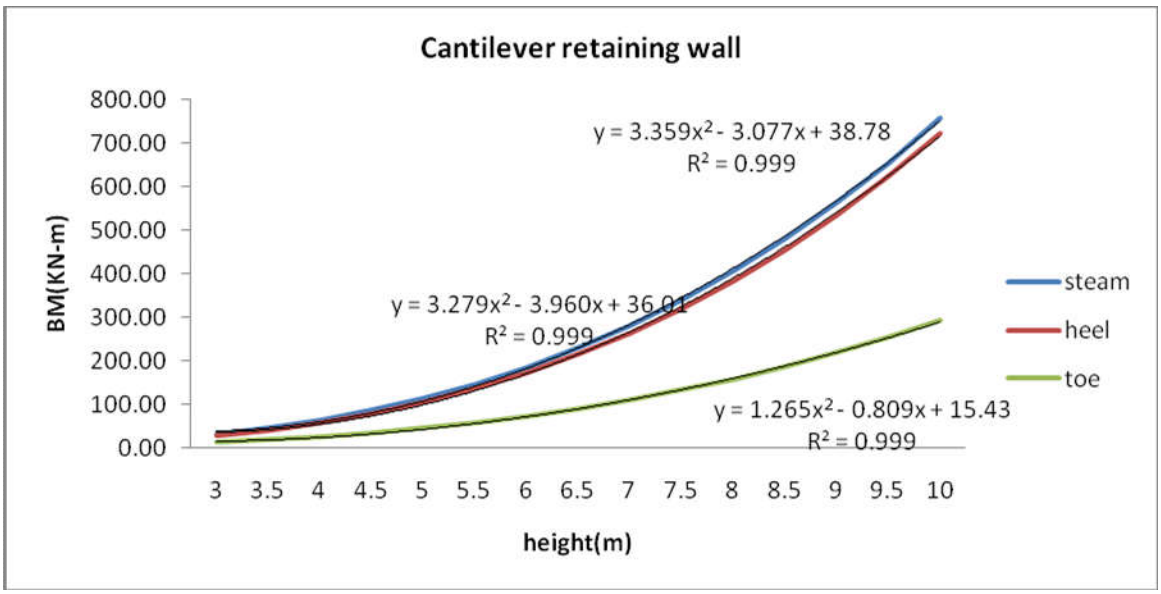

Figure 3: BM vs. height of wall for cantilever retaining wall

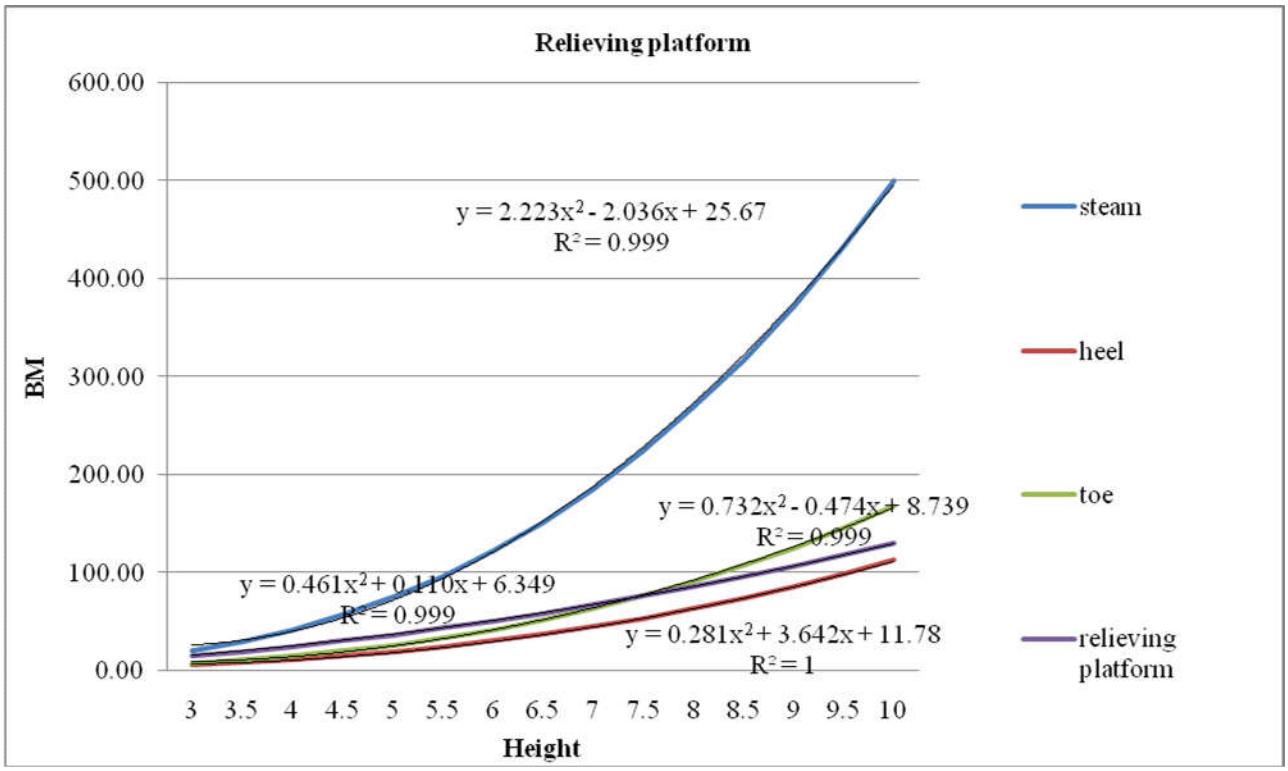

Figure 4: BM vs. height of wall for retaining wall with relieving platform

From graph 1 and 2 we can see that as height of wall is increases, the bending moment of stem, toe and heel is also increases in both the cases. But bending moment of heel and toe decreases in retaining wall with relieving platform than cantilever retaining wall.

From graph, the equation for bending moment of different part of retaining wall is as follows,

- For cantilever retaining wall:
  Stem BM: $y = 3.3593x^2 - 3.0778x + 38.785$
  Heel BM: $y = 3.2762x^2 - 3.9969x + 35.912$
  Toe BM: $y = 1.2652x^2 - 0.8141x + 15.411$
- For retaining wall with relieving platform:
  Stem BM: $y = 2.2235x^2 - 2.0372x + 25.672$
  Heel BM: $y = 1.1908x^2 - 1.6134x + 19.89$
  Toe BM: $y = 1.1656x^2 - 0.7622x + 14.083$
  Relieving platform: $y = 0.3562x^2 + 4.6133x + 14.925$

  Where x = height of wall

4.2 Variation of Area of steel:

Table 2: area of steel variation

Cantilever retaining wall				retaining wall relieving platform				
height of retaining wall	Area of steel (mm2)			height of retaining wall	area of steel (mm2)			
	steam	heel	toe		steam	heel	toe	relieving platform
3	436.28	425.69	377.14	3	323.63	377.14	377.14	321.17
3.5	588.99	545.78	419.05	3.5	439.27	419.05	419.05	412.90
4	766.12	681.06	471.43	4	574.01	452.57	471.43	516.13
4.5	967.85	831.51	565.71	4.5	728.04	514.29	565.71	630.86
5	1194.34	997.14	595.49	5	901.53	670.48	595.49	757.10
5.5	1445.67	1177.93	670.48	5.5	1094.58	670.48	670.48	894.84
6	1721.93	1373.88	693.60	6	1307.28	670.48	693.60	1044.08
6.5	2023.17	1584.98	744.97	6.5	1539.7	804.57	744.97	1204.82
7	2349.45	1811.25	773.63	7	1791.89	804.57	773.63	1377.07
7.5	2700.81	2052.67	838.10	7.5	2063.91	914.29	838.10	1560.81
8	3077.27	2309.24	874.53	8	2355.79	942.86	874.53	1756.06
8.5	3478.87	2580.97	957.82	8.5	2667.56	1028.57	957.82	1962.82
9	3905.62	2867.85	1005.71	9	2999.24	1131.43	1005.71	2181.07

9.5	4357.54	3169.88	1117.46	9.5	3350.86	1257.14	1117.46	2410.83
10	4834.65	3487.07	1183.19	10	3722.43	1340.95	1183.19	2652.09

As we can see the area of steel for heel and toe is less in retaining wall with the relieving platform. But the total area of steel for both cases is almost equal. From above table values we can plot the graphs and can see the variation of area of steel.

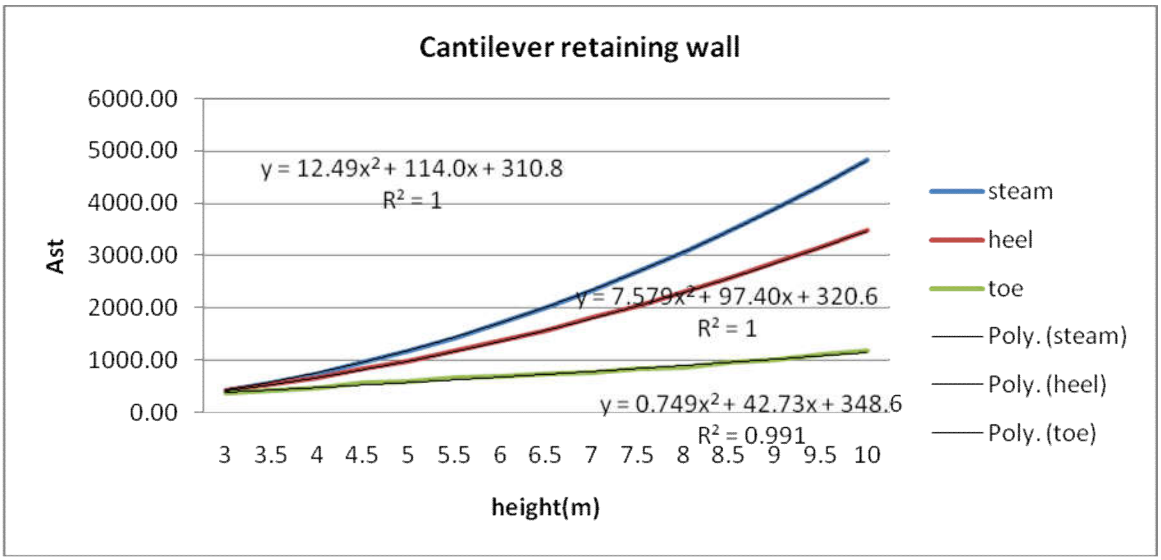

Figure 5: Ast vs. height of wall for cantilever retaining wall

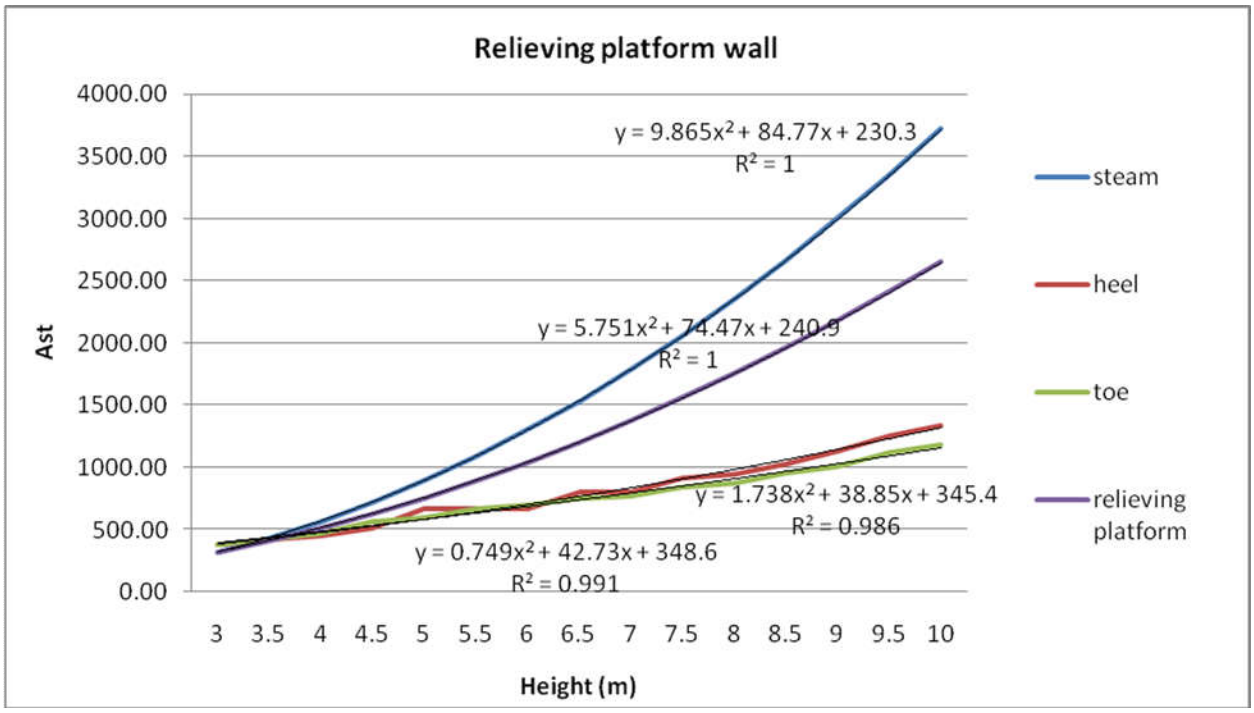

Figure 6: Ast vs. height of wall for retaining wall with relieving platform

- For cantilever retaining wall:

  Stem Ast: $y = 12.497x^2 + 114.08x + 310.86$

  Heel Ast: $y = 7.5794x^2 + 97.097x + 318.71$

  Toe Ast: $y = 2.8109x^2 + 40.885x + 158$

- For retaining wall with relieving platform:

  Stem Ast: $y = 9.8651x^2 + 84.77x + 230.3$

  Heel Ast: $y = 7.2849x^2 + 94.335x + 305.19$

  Toe Ast: $y = 4.0678x^2 + 92.977x + 164.67$

  Relieving platform Ast: $y = 3.4906x^2 + 17.743x + 244.73$

  Where x = height of wall

4.2 Cost comparison:

Table 3 cost comparison

height	Cantilever retaining wall			Retaining wall with relieving platform		
	steel cost	concrete cost	total cost	steel cost	concrete cost	total cost
3	2915	7274	10189.96	3428.14	6302	9729.93
3.5	3558	9166	12723.45	3995.33	7911	11905.92
4	4631	11272	15903.74	4818.09	9699	14517.17
4.5	5415	13595	19009.75	5776.68	11667	17443.94
5	6377	16133	22509.56	6697.40	13815	20512.52
5.5	6826	18887	25712.95	6173.16	16143	22315.84
6	8185	21856	30040.81	6781.53	18650	25431.45
6.5	9795	25041	34835.85	7339.28	21337	28676.13
7	10678	28442	39119.15	8281.68	24203	32485.15
7.5	12692	32058	44749.69	8969.05	27250	36218.83
8	14542	35890	50431.54	9385.63	30476	39861.40
8.5	14918	39937	54855.29	10488.32	33881	44369.77
9	16992	44200	61191.87	11584.58	37467	49051.40
9.5	18372	48679	67050.81	12352.61	41232	53584.48
10	20537	53373	73910.51	12994.94	45177	58171.55

As we can see the cost for steel in both the cases are almost same. But the cost for concrete is less for retaining wall with relieving platform than cantilever retaining wall. This is happened because when we provide platforms to the retaining wall the thickness of the base and the steam is reduces, and the volume of concrete is also reduces.

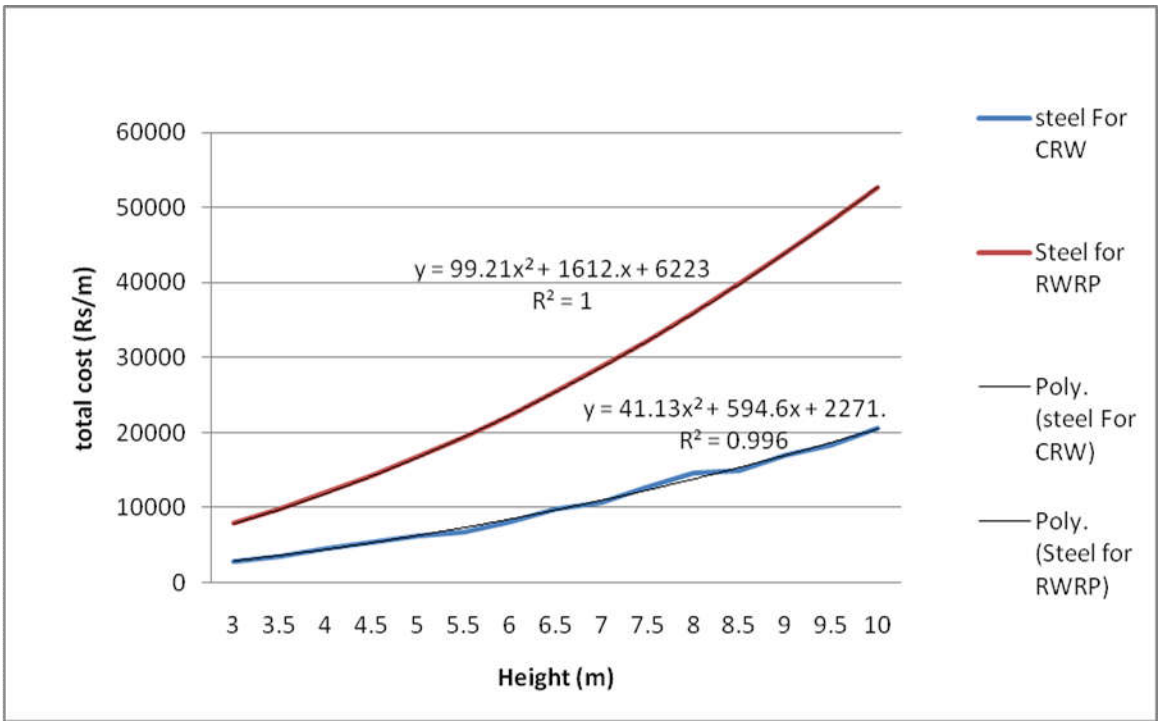

Figure 7: Steel Cost vs. height

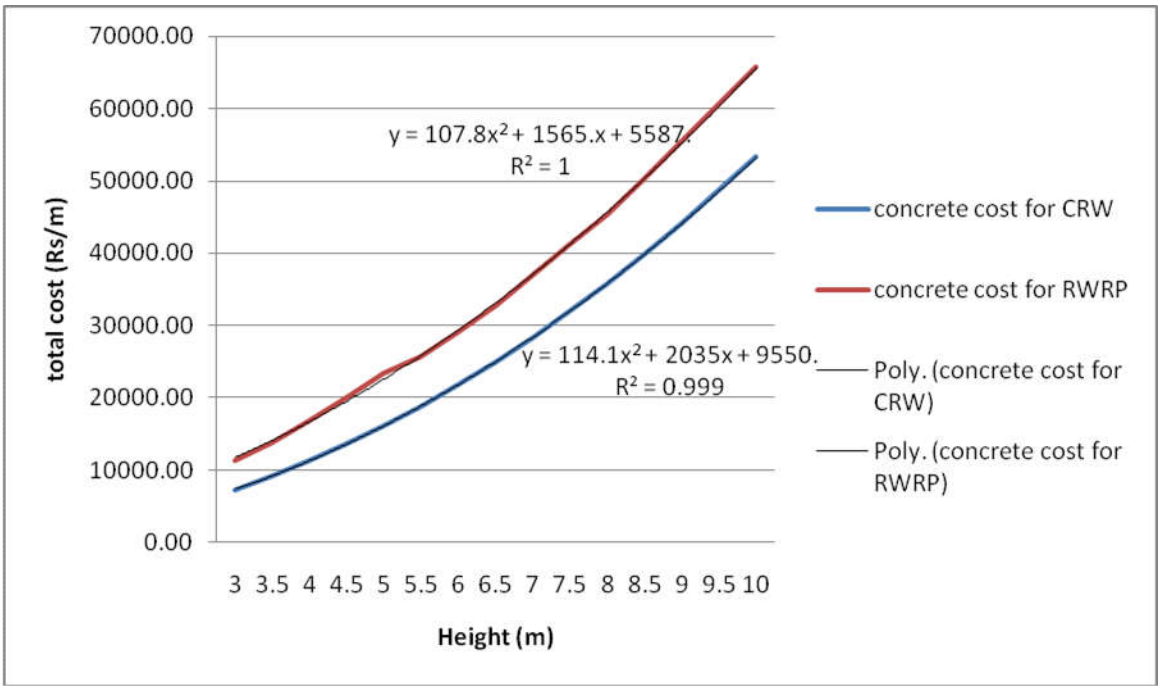

Figure 8: Concrete Cost vs. height of wall

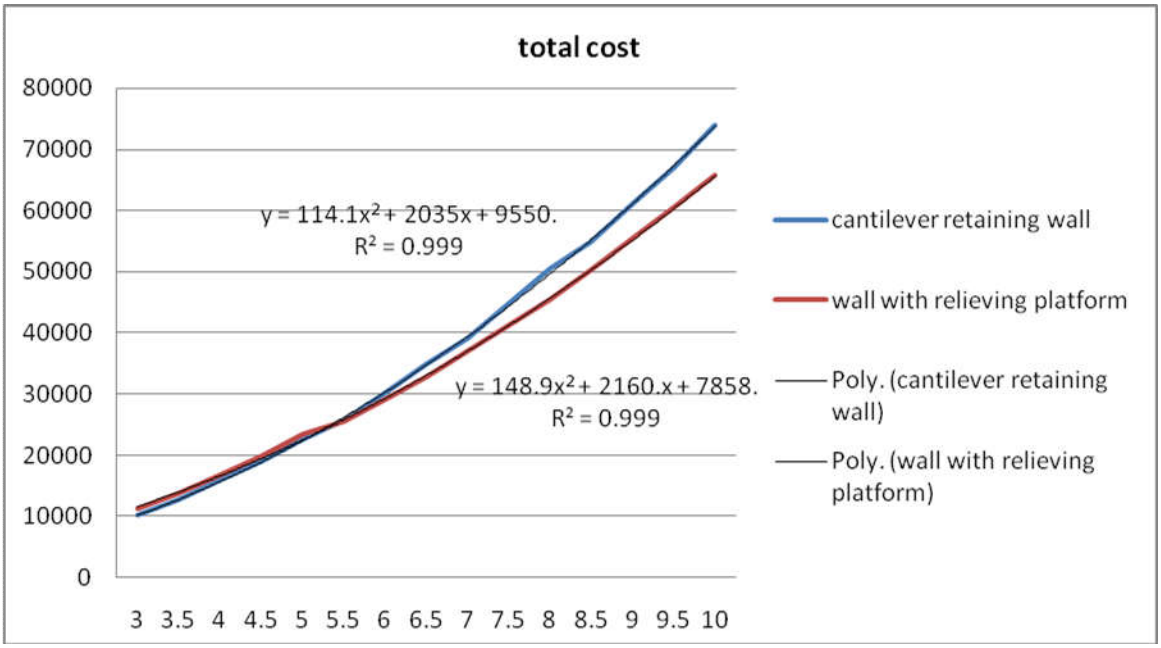

Figure 9: Cost comparison

From Graph 8, we can see than the as height increases the cost for construction is also increases. But the cost for retaining wall with relieving platform is more than the cantilever retaining wall up to height 5.5-6m and after that it is starting decreases.

- For cantilever retaining wall:
  Steel cost: $y = 41.134x^2 + 594.63x + 2271.4$
  Concrete cost: $y = 114.1x^2 + 2035x + 9550.9$
  Total cost: $y = 114.1x^2 + 2035x + 9550.9$
- For retaining wall with relieving platform:
  Steel cost: $y = 99.219x^2 + 1612.5x + 6223$
  Concrete cost: $y = 107.81x^2 + 1565.9x + 5587.1$
  Total cost: $y = 148.95x^2 + 2160.5x + 7858.5$

Where x = height of wall

4.4 Percentage cost:

$$= \frac{cost\ for\ cantilever\ wall - cost\ for\ retaining\ wall\ with\ platform}{cost\ for\ cantilever\ wall}$$

Table 4. Percentage profit

height	total cost for cantilever retaining wall	total cost for retaining wall with relieving platform	percentage cost
3	10189.96	9729.928	4.73
3.5	12723.45	11905.92	6.87
4	15903.74	14517.17	9.55
4.5	19009.75	17443.94	8.98
5	22509.56	20512.52	9.74
5.5	25712.95	22315.84	15.22
6	30040.81	25431.45	18.12
6.5	34835.85	28676.13	21.48
7	39119.15	32485.15	20.42
7.5	44749.69	36218.83	23.55
8	50431.54	39861.4	26.52
8.5	54855.29	44369.77	23.63
9	61191.87	49051.4	24.75
9.5	67050.81	53584.48	25.13
10	73910.51	58171.55	27.06

From table 4, we can say that the retaining wall with the relieving platform retaining wall is slightly costlier than cantilever retaining wall up to height 5.5m but after 5.5m its economical than cantilever retaining wall.

4.5 Stability Consideration:

Table 5: Stability checks

height of retaining wall	Cantilever retaining wall		Retaining wall with relieving platform	
	FOS against overturning>1.5	FOS against sliding>1.5	FOS against overturning>1.5	FOS against sliding>1.5
3	3.42	1.97	3.87	3.37
3.5	3.40	1.95	3.84	3.33
4	3.38	1.94	3.81	3.29
4.5	3.37	1.92	3.79	3.27
5	3.35	1.91	3.77	3.24
5.5	3.34	1.90	3.76	3.23
6	3.33	1.90	3.74	3.21
6.5	3.33	1.89	3.73	3.20
7	3.32	1.89	3.72	3.18
7.5	3.31	1.88	3.71	3.17
8	3.31	1.88	3.71	3.16
8.5	3.30	1.87	3.70	3.16
9	3.30	1.87	3.69	3.15
9.5	3.30	1.87	3.69	3.14
10	3.29	1.86	3.68	3.14

From above table we can evident that FOS against overturning and sliding for both the wall decreases as the height of wall increases. But for the same height, both the safety factors are almost 2 times greater in relieving tform retaining wall as compared to the cantilever retaining wall. So we can conclude that the relieving platform retaining wall is more stable and safe as compared to cantilever one.

V CONCLUSION

A retaining wall is one of the most important types of retaining structures. It is extensively used in variety of situations such as highway engineering, railway engineering, bridge engineering and irrigation engineering. This research aims at developing an relationship between various parameter of retaining wall and showing their comparative study.

- The bending moment in toe and heel is less for retaining wall with relieving platform than cantilever retaining wall.

- The area of steel for toe and heel is less for retaining wall with relieving platform than cantilever retaining wall.
- The construction cost for the retaining wall with relieving platform is more than cantilever retaining wall up to height 5.5m and less after that.
- The retaining wall with relieving platform is economical after 5.5m
- By providing platform, the stability against sliding in increases much more. And the FOS against sliding and overturning is almost double in retaining wall with relieving platform than cantilever retaining wall.
- The retaining wall with relieving platform is much more safer against overturning and sliding than cantilever retaining wall.
- And we also get inter-relationship between height of wall and various parameters of retaining wall like dimensions, area of main steel, bending moments for different part of retaining wall and cost of construction.

Parameter	component	Cantilever retaining wall	Retaining wall with relieving platform
Dimension	Height of wall	x	x
	Total height	H	H
	Base width	0.6H	0.6H
	Base depth	H/12	H/12
	Steam top width	200mm	200mm
	Steam bottom width	H/10	H/12
	Toe width	0.2H	0.2H
BM	Stem	$y = 3.3593x^2 - 3.0778x + 38.785$	$y = 2.2235x^2 - 2.0372x + 25.672$
	Heel	$y = 3.2762x^2 - 3.9969x + 35.912$	$y = 1.1908x^2 - 1.6134x + 19.89$
	Toe	$y = 1.2652x^2 - 0.8141x + 15.411$	$y = 1.1656x^2 - 0.7622x + 14.083$
	Relieving platform		$y = 0.3562x^2 + 4.6133x + 14.925$
Ast main	Stem	$y = 12.497x^2 + 114.08x + 310.86$	$y = 9.8651x^2 + 84.77x + 230.3$
	Heel	$y = 7.5794x^2 + 97.097x + 318.71$	$y = 7.2849x^2 + 94.335x + 305.19$
	Toe	$y = 2.8109x^2 + 40.885x + 158$	Toe Ast: $y = 4.0678x^2 + 92.977x + 164.67$
	Relieving platform		Ast: $y = 3.4906x^2 + 17.743x + 244.73$
Cost	Steel	$y = 41.134x^2 + 594.63x + 2271.4$	$y = 99.219x^2 + 1612.5x + 6223$
	Concrete	$y = 114.1x^2 + 2035x + 9550.9$	$y = 107.81x^2 + 1565.9x + 5587.1$
	Total cost	$y = 114.1x^2 + 2035x + 9550.9$	$y = 148.95x^2 + 2160.5x + 7858.5$

REFERENCES

1. Shravya Donkada and Devdas Menon, “Optimal design of reinforced concrete retaining walls”, The Indian concrete journal. April 2012, page 9-18
2. S. S.Patil and A. A. R. Babgan, “analysis and design of reinforced concrete stepped cantilever retaining wall”, IJRET, vol. 04, Feb-2015, page 46-67
3. Rupa B. Patil, G. R. Patil, “Design and detailing of counter fort retaining walls for construction site”, International journal of informative & fururistic research, Vol. 3, September 2015, page 61-71
4. Tamadher abood, Haten E. Younis Eldawi, Faeza R. Elnaji Abdulrahim, “Design of Cantilever retaining wall with 4m height ”, Imternational journal of civil and structural engineering research, vol. 3, April 2015, pp 318-326
5. Inder kummar Lilani, Dr. Rakesh Patel, “Analysis of counterfort retaining wall in non over flow section of gravity dam” , IJSRD, Vol. 5, May 2017, pp. 920-924
6. Sarita Singla and Er. Sakshi Gupta, “Optimisation of reinforced concrete walls of varing heights using relieving platform”, IJERT, Vol. 4, June 2015, pp 1071-1077
7. Yash Chaliawala, Gunvant Solanki, Anuj K. Chandiwala, “Comparative study of cantilever and counter fort retaining wall”, International journal of advanced engineering and research development, Vol. 2, Dec. 2015, pp. 221-224
8. S. Tatahari, R. Sheikoleslami, M. Shadfaran and M. Pourbaba, “Optimum Design of gravity retaining walls using charged system search algorithm”, Hindawi Publishing corporation, sep. 2012,
9. Su Yang, Amin Chegnizadeh and Hamid Nikraz, “Review of studies on retaining walls behavior on dynamic/ seismic condition”, vol. 3, Nov 2013, pp. 1012-1021
10. Swati Nagare, Rutuja Shinde, Sushma Ladkat and Komal Mahisare, “Case study of retaining wall”, April 2017
11. IS 14458 (1998): Guidelines for retaining wall for hill area, part-1: selection of type of wall
12. IS 14458 (1998): Guidelines for retaining wall for hill area, part-2: Design of retaining/ breast walls
13. IS 14458 (1998): Guidelines for retaining wall for hill area, part-3: Construction of Dry stone walls