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Cost Optimization of Cantilever Retaining Wall

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Abstract: *This study researches optimal design in provisions of minimum cost of reinforced concrete cantilever retaining walls. For the optimization practice, the process which is a combination of genetic algorithm and local search method was executed. Evolutionary method was utilizes in this study as it can efficiently resolve extremely nonlinear problems and problems that characteristic irregular functions as demonstrated by numerous works available in the literature. The main objective was to reduce the total cost of the wall, which covers costs of concrete, steel, and excavation. Material strength and soil characteristics are treated as design parameters where they are consider as constants during solution of the problem. This study is about analysis and design of relieving platform and cantilever retaining wall with height changing from 3m to 10m and SBC 160KN/m². It also gives comparative study such as economy, cost and bending moment of both the retaining wall. In this study it is also concluded that the relieving platform retaining wall is efficient than cantilever retaining wall.*

Keywords: Cantilever Retaining Wall.

I. INTRODUCTION

Retaining walls are designed to resist lateral earth and water pressures and for a service life based on concern of the probable long–term effects of material deterioration on all of the material components comprising the wall. Permanent retaining walls are considered for a minimum service life of 50 years. Temporary retaining walls are designed for a minimum service life of 5 years.

Retaining walls are structures that are used to resist earth (or any other backfill material) in a place where the ground level changes quickly. They can be of various types such as gravity wall, cantilever wall, counterfort wall and buttress wall amongst others. The 'cantilever wall' is the most frequent form of retaining wall and is economical heights up to about 8 m. The lateral force because of earth stress is the major force that will develop on the retaining wall which has the leads to failure like slide and overturn.

The structure is designed on a trial–and–error basis. Provisional design must satisfy the limit states given by various concrete codes. By employing this procedure tends to safe designs, but the cost of the concrete retaining walls is majorly reliant upon the practice and experience of the designer. Therefore, to reduce the cost of the concrete retaining walls within design limitation, it is helpful for designer to design the issues as an optimization difficulty.

The present study focuses on designing the cantilever type of wall giving the most economic section. The main considerations are the external stability of the section and the accordance to the guidelines of IS 456:2000. The ratio of resisting forces to the disturbing forces is the factor of safety, and this factor of safety should always be greater than one for the structure to be safe against failure w. r. t. that given criteria.

II. CANTILEVER RETAINING WALL

The cantilever walls generally having members of a base slab and vertical stem, made up of two important sections, viz. a heel slab and a toe slab. All three members act as one-way cantilever slabs: the 'stem' acts as a vertical cantilever below the lateral earth pressure; the 'heel slab' and the 'toe slab' acts as a horizontal cantilever below the action of the resulting soil pressure. The reinforcement detailing is given in fig1.

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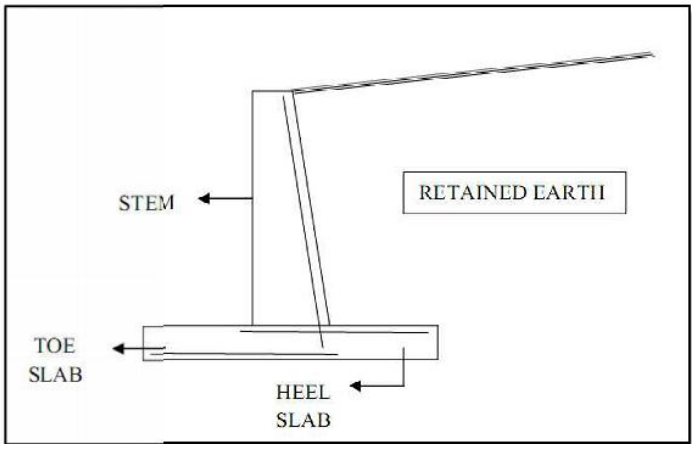

Fig.1 Cantilever Retaining Wall

2.1 Relieving Platform Retaining Wall

This type of wall is modified type of cantilever retaining wall with provision of relieving platform. This platform is given at stem. This platforms changes total pressure distribution diagram and also provides economical design as well as less bending moments.

- Can be precast or fin-situ
- Economical than cantilever retaining wall
- Can be utilize for any height.(more than 8m and less than 8m)
- Retaining wall with relieving platform can also be considered as a unique form of retaining walls. Some researchers have concluded that using reinforced walls is the most economical method for constructing high. The relive platform has the advantages of deceasing the acting lateral earth pressure and increasing the overall stability of the retaining wall.

2.2 Objective of Present Study

1. Study the existing literature on retaining walls, its analysis and economics along with the performance of reinforced earth walls in order to ascertain the need for the study.
2. To compute the forces acting on the dam and study different modes of failure.
3. To carry out the stability analysis of the retaining walls for different stability criterion.
4. Study the behavior in various components of the retaining wall at different loading conditions at various heights.
5. Cost optimization of both types of retaining wall and propose the best option for a particular height.
6. Conduct parametric studies to examine the effect of variation of geometric and material properties on the load - deformation behavior of retaining walls using the finite element code.
7. Develop design charts based on the limit state method of design.

III. LITERATURE REVIEW

M. A. A. Sadman, A.Hossain, M. Ashikuzzaman (2019)

Researched about the seismic Stability of Slopes in Cohesive Soils exploitation using GEO5 computer software tool. LEM module of GEO5 software tool has been familiar to analyze a uniform slope model with clay soil. From the study it had been concluded that: a) For all ratios of Kv/Kh, this safety factor decreases with increment of horizontal seismic constant Kh, in view of all ways of examine. b) For all ratios of Kv/Kh, issue of safety will increase with the increment in of cohesion.

Ali Asghar Firoozi, Mojtaba Shojaei Baghini, Ali Akbar Firoozi: (2016)

In this study, developed a review on the clayey soils. The geotechnical properties of soil like its grain size distribution, shear strength, plastic limit, liquid limit and shrinkage limit was estimated by laboratory testing. Also, at the location

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where determination of strength and other properties of soil samples were taken, as a result of this process avoids disturbing samples all over field test. Two main processes could include physical and chemical change or decomposition and recrystallization. And also the most important property of colloids is their minute size and massive area. It was found that, the clay particles play a really required within the chemical process.

Yash Chaliawala and Gunvant Solanki (2015)
Researcher provides a comparative study of cantilever and counter fort wall. Cost against each optimum style of wall for clear height was computed by use of quantity of concrete and the amount of steel. It was concluded that Cantilever retaining walls are economically suitable for all heights up to 6 meter and Counter fort walls are suitable for retaining wall of height about 8 meter to 10 meter for the conventional conditions assumed.

IV. METHODOLOGY

4.1 Design of Retaining Wall

Technically while designing, every required parameters and requirements are considered and all the possible solutions are computed. Then a comprehensive analysis and calculations are carried out considering all the parameters especially cost involved and the risk and uncertainties involved. Then the situation with the optimal cost is considered as the best solution. Therefore, it is entire a careful judgment making process.
For the analysis purpose three reinforced concrete retaining walls namely cantilever retaining wall, counterfort retaining wall and retaining wall relieving platforms with height ranging from 3
-10 m with interval of 0.5m are considered. Safe bearing capacity is ranging from 100 KN/m3 to 200 KN/m3 with interval of 10 KN/ m3.

4.2 Design Parameters

- Length of relieving platform: It is considered as same as to the length of heel slab (for easy analysis purpose).
- Thickness of relieving platform: It is assumed as a ¼ th of the thickness of base slab.
- Location of relieving platform: It is provided at the mid height of the retaining wall.
- Angle of friction(ϕ) : 35º
- Coefficient of active earth pressure(Ka): = 0.271
- Coefficient of passive earth pressure(Kp) : = 3.70
- Depth of foundation: ranging from 3-10m with interval of 0.5m is considered.
- Soil bearing capacity: varying from 100KN/m3 to 200 KN/m3 with interval of 10 KN/m3
- Unit weight of soil (Υs): 18 KN/m3
- Unit weight of concrete: 25 KN/m3
- Grade of concrete: M25
- Grade of steel: Fe500

4.3 Stability Checks

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

- Eccentricity of the resultant force should lie between 0 and the base width/6
- FOS against sliding is taken greater than 1.5
- FOS against overturning is also taken greater than 1.5
- Maximum and minimum reinforcement percentage and reinforcement spacing is given as per IS456:2000 code.
- Restrictions on maximum shear stress in different member are based on concrete grade as per IS456:2000 code

4.4 Total Cost of Construction

As stated in the above, the design with the optimal cost is taken as a best; the formula applied in computation is given as follows,
Total cost: = cost for steel + cost for concrete

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V. RESULTS AND DISCUSSION

5.1 Variation of Bending Moments

Table 1: bending moment variation

Height of retaining wall	Cantilever retaining wall			Retaining wall with relieving platform			
	B.M. (KN.-M)			B.M. (KN.-M)			
	Steam	Heel	Toe	Steam	Heel	Toe	Relieving platform
3	30.51	26.82	12.73	20.3	5.86	7.19	15.81
3.5	44.78	40.00	18.44	29.79	8.63	10.48	20.20
4	63.09	56.94	25.63	41.77	11.22	14.61	25.28
4.5	85.66	78.00	34.46	56.73	14.81	19.70	30.89
5	113.13	103.90	45.16	74.88	19.16	25.93	37.08
5.5	145.89	134.90	57.81	96.55	24.20	33.21	43.79
6	184.36	171.53	72.72	122.00	30.00	41.88	51.01
6.5	229.19	214.25	89.59	151.98	36.79	51.86	58.93
7	280.59	263.46	109.81	185.86	44.48	63.28	67.39
7.5	339.33	319.79	132.30	224.91	52.99	76.36	76.36
8	405.77	383.52	157.51	268.62	62.6	90.99	85.84
8.5	480.19	455.68	185.89	317.84	73.40	107.46	96.00
9	563.65	535.40	217.55	372.77	85.32	125.60	106.86
9.5	655.23	624.57	252.59	433.88	98.44	145.32	117.80
10	757.08	723.00	291.1	501.04	112.84	168.24	129.69

From above table we can concluded that the bending moment for heel and toe is less in retaining wall with the relieving platform. From above table values we can draw the graph that shows the variation of bending moment.

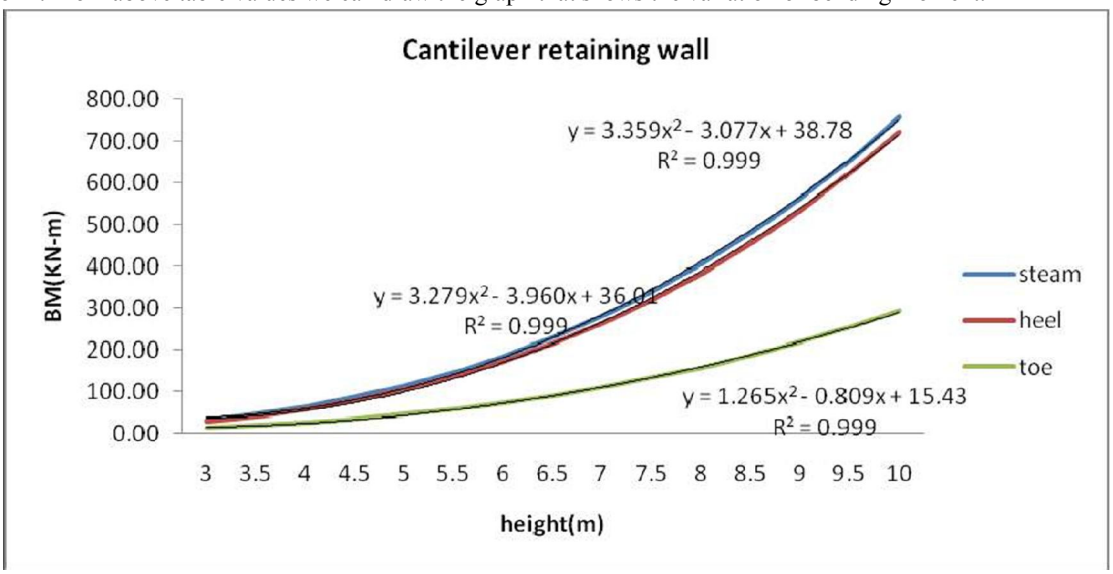

Figure 2: BM vs. height of wall for Cantilever Retaining Wall

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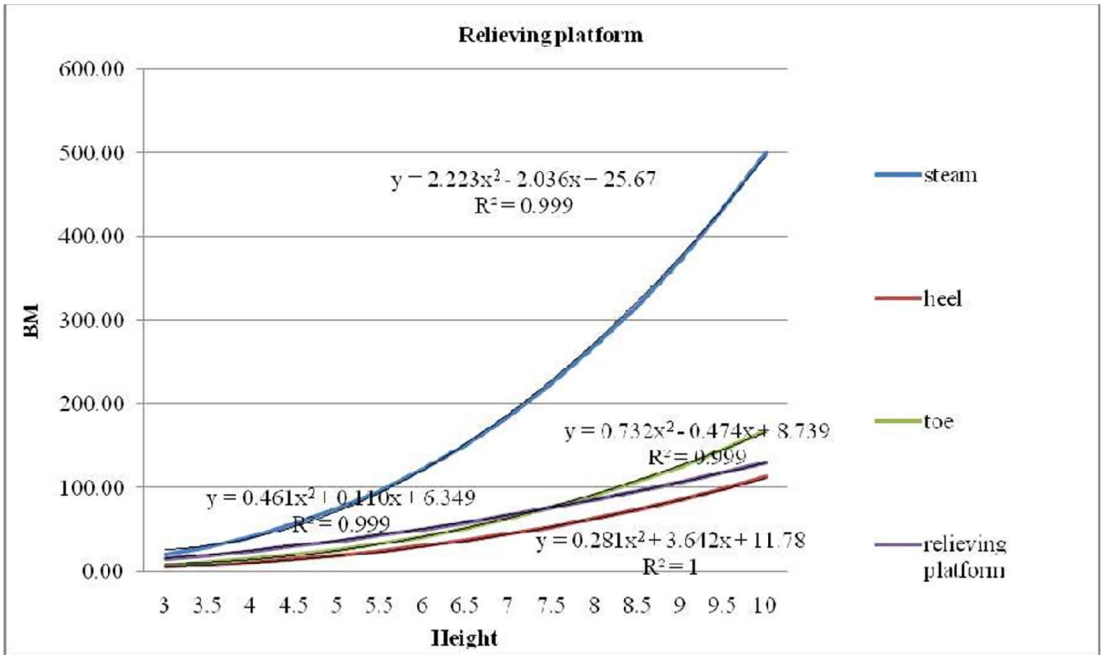

Figure 3: BM vs. height of Wall with Relieving Platform

From graph 2 and 3, as height of wall is increases, the BM of stem, toe and heel is also increases in both the examples. But bending moment of heel and toe less in retaining wall with relieving platform than cantilever retaining wall. From graph, the equation for BM of different locations of retaining wall is as follows,

For cantilever retaining wall:

Stem BM: $y = 3.3594x^2 - 3.0779x + 38.786$

Heel BM: $y = 3.2762\ x^2 - 3.9969x + 35.912$ Toe BM: $y = 1.2652\ x^2 - 0.8141x + 15.411$

For retaining wall with relieving platform:

Stem BM: $y = 2.2235\ x^2 - 2.0372\ x + 25.672$ Heel BM: $y = 1.1908\ x^2 - 1.6134x + 19.89$

Toe BM: $y = 1.1656\ x^2 - 0.7622x + 14.083$

Relieving platform: $y = 0.3562\ x^2 + 4.6133x + 14.925$ Where x = height of wall

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5.2 Cost Comparison

Table 2 Cost Comparison

Height of retaining all	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	30010.81	6781.53	18650	28676.13
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 concluded that the cost for steel in both the cases are approximately equal. But the cost for concrete is less for retaining wall with relieving platform than cantilever retaining wall. This is occurs because of providing platforms to the retaining wall the thickness of the base and the steam is reduces, and the volume of concrete is also decreased.

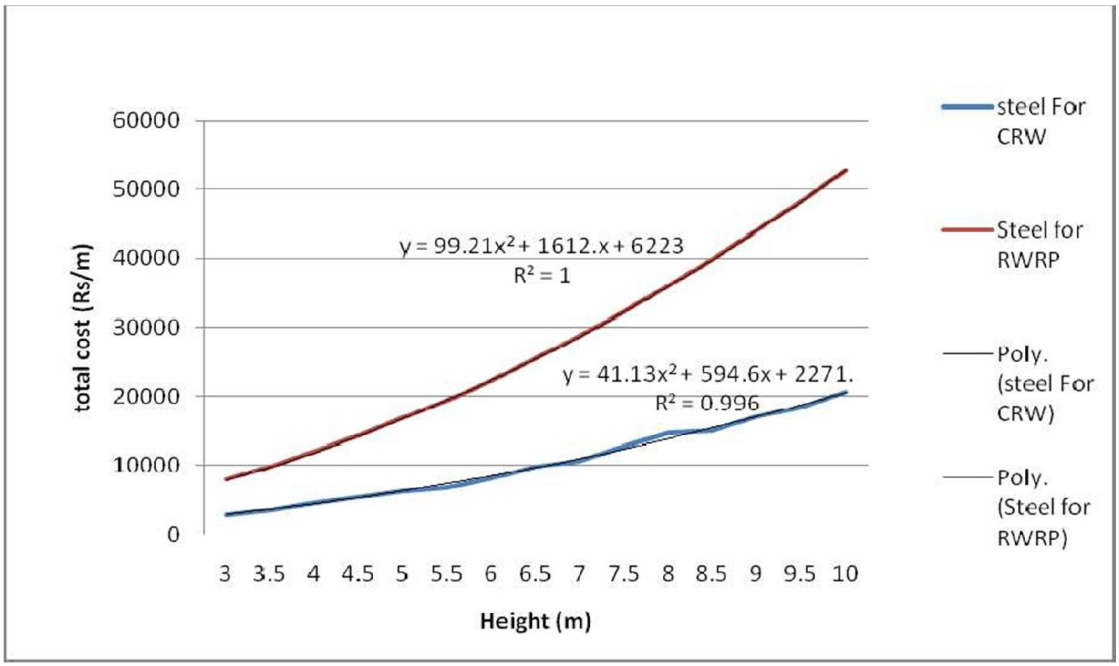

Figure 4: Steel Cost vs. height

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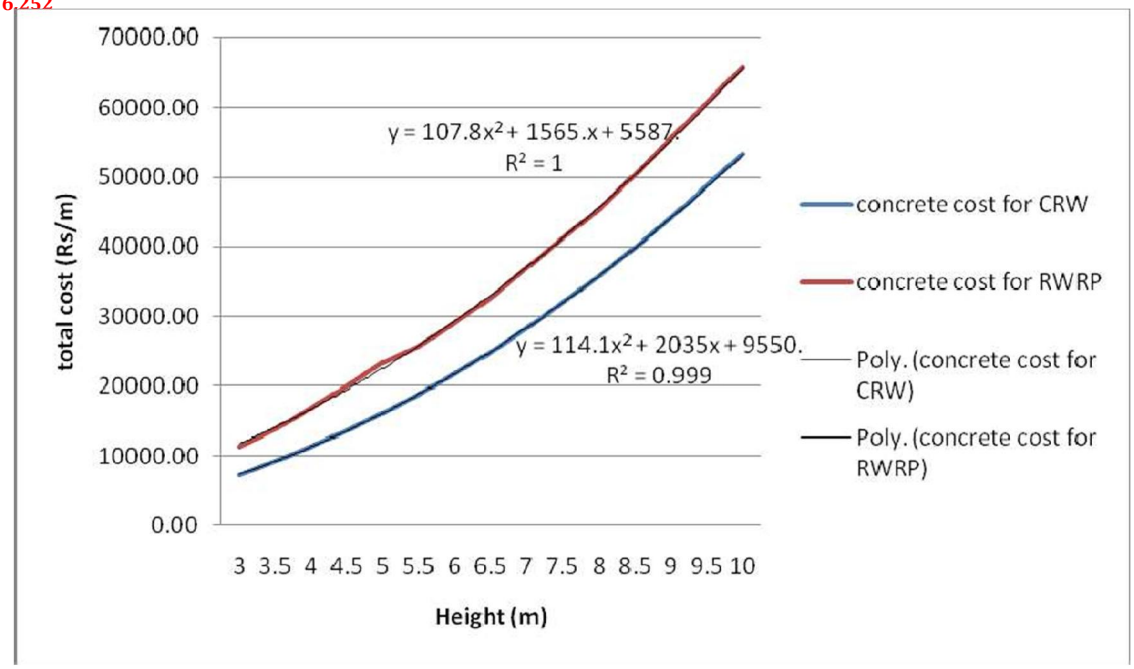

Figure 5: Concrete Cost vs. height of wall

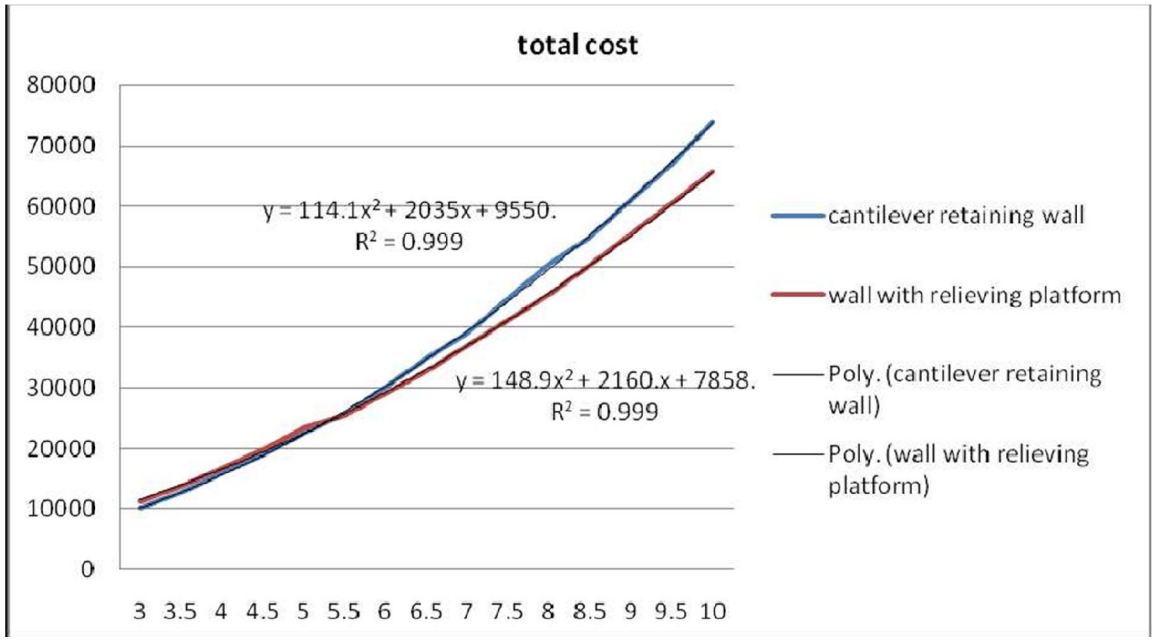

Figure 6: Cost comparison

From Graph 5, 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: $y = 41.14x^2 + 594.66x + 2271.49$ Concrete cost: $y = 114.1x^2 + 2035x + 9550.9$ Total cost: $y = 114.15x^2 + 2035x + 9550.9$

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For retaining wall with relieving platform:

Steel cost: $y = 99.22x^2 + 1612.52x + 6223$ Concrete cost: $y = 107.81x^2 + 1565.9x + 5587.1$ Total cost: $y = 148.96x^2 + 2160.51x + 7858.53$

Where x = height of wall

Percentage Cost:

$$\text{Percentage cost} = \frac{Cost\ for\ Cantilever\ Wall - Cost\ for\ Retaining\ Wall\ with\ Platform}{Cost\ for\ Cantilever\ Wall}$$

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.

VI. CONCLUSION

A retaining wall is one of the mainly significant forms of retaining structures. It is widely employed in range of conditions such as highway engineering, railway engineering, bridge engineering and irrigation engineering.

- The BM in toe and heel is smaller as compared to retaining wall with relieving platform than cantilever retaining wall.
- The construction cost required for the retaining wall with relieving platform is higher than cantilever retaining wall up to height 5.5m and then reduced after that.
- The retaining wall with relieving platform is efficient and reasonable subsequent to 5.5m

And we also find co relationship between height of wall and different variables of retaining wall like size, area of main steel, BM for different element of retaining wall and cost of construction are given as below:

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Parameter	Component	Cantilever retaining wall	Retaining wall with relieving platform
Dimension	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	$y = 3.3594x^2 - 3.0779x + 38.786$	$y = 2.2235x^2 – 2.0372x + 25.672$
	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	$y = 7.5796x^2 + 97.098x + 318.71$	$y = 7.2867x^2 + 94.335x + 305.19$
	Toe	$y = 2.8109x^2 + 40.885x + 158$	Toe Ast: $y = 4.0678x^2 + 92.977x + 164.67$
	Relieving platform		Ast: $y = 3.4905x^2 + 17.744x + 244.73$
Cost	Steel	$y = 41.14x^2 + 594.66x + 2271.49$	$y = 99.22x^2 + 1612.52x + 6223$
	Concrete	$y = 114.1x^2 + 2035x + 9550.9$	$y = 107.81x^2 + 1565.9x + 5587.1$
	Total cost	$y = 114.15x^2 + 2035x + 9550.9$	$y = 148.96x^2 + 2160.51x + 7858.53$

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