Comparative Analysis of Cantilever Retaining Wall and Retaining Wall with Relieving Platform

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Abstract The concept and study of a cantilever retaining wall and a cantilever retaining wall with relieving platform with elevations varying from 5 to 8 meters and having a safe bearing capacity of 160 KN/m2 are presented in this paper. It also depicts relative research such as bending moment, safety against overturning and sliding, expense and economy, between the retaining walls. The cost and optimal cost are calculated as part of the relative analysis. Software and analytical results such as bending moment, deflection, and stresses are also discussed in this paper. Laterally acting total earth pressure is depicted to be reduced due to the provision of relieving platform (RP). The retaining wall with relieving platform (RW with RP) is shown to be cost-effective, more stable, and relieve the BM of the stem and heel portions than cantilever retaining wall (CRW). The findings of this research is drawn based on the results obtained using different models prepared in software , comparison of bending moments , requirement of tension reinforcement and these results are verified by manual analysis. The research shows that the CRW with RP is more economical and is more worthy than CRW.
Keywords- analysis and design, bending moment (BM) cantilever retaining wall (CRW), earth pressure, retaining wall (RW), retaining wall with relieving plate (RW with RP).

1. Introduction

A retaining wall is a kind of assembly that is planned to hold the pressure of the terrain underneath it [6]. It protects a landmass abrupt-faced slant from tearing and helps it resist the slithering downward of the retained material, which applies propel on the assembly, causing them to overturn and slide down [6] [1]. The most common force for retaining wall study, aside from self-weight, is lateral earth constraint [2]. The horizontal constraint exerted by the soil is referred to as lateral earth pressure [6]. The degree and direction of motion of the roots, as well as the inclination of inner rubbing and the tenacious firmness of the retained substance, determine the lateral earth strain [5]. Its distribution is normally triangular, with the lowest concentration at the top of the wall and the highest concentration at the bottom. The earth constraint will cause failure because it will propel the wall, causing it to topple [4].

1.1 Related works & Problem Identification:

Damdhare D. (2018) [1]: The author performed the analysis and design manually and calculated the BM and Cost required for CRW and CRW with RP. In our paper we compared the readings for varying height manually as well as on staad pro. Chougule A. (2017) [4]: The author found the height of relieving platform for cantilever retaining wall. We took this values into consideration and found that the cantilever retaining wall with relieving platform is more economical than cantilever retaining wall. Chauhan V. (2016) [8]: In this paper the author found that reducing the earth pressure reduces width of relieving platforms. The author performed this for 6m height. Taking into consideration the width of the relieving platform we performed our calculations for height varying 5m to 8m. Bhoyar P. (2019) [3]: The author calculated the joint reactions for cantilever retaining wall and cantilever retaining wall with relieving platform. Author also found that the both walls are stable and all the stability checks are safe. Bhuniyan S. (2017) [9]: The author found that the best location for relieving platform is 0.4 to 0.5 the height of wall, for maximum reduction in earth pressure and also for less bending moment and less deflection. Gokkus U. (2017) [15]: In this study, it is aimed that the lateral active earth pressure forces and their overturning moments can be decreased, the weight of double shelves and their protective moments can be increased, double reinforced rectangular section of base on elastic foundation can be equipped well and vertical steel bars in vertical retaining wall designed as cantilever can be placed by stepped and multiple rows reinforcement.

1.2 Cantilever retaining wall :

The most common form of terrain-retaining assembly is a cantilever retaining wall. The main objective of the research is to optimise the requirement of retaining wall such as tension reinforcement, cross sectional area and economy under different loading conditions, in this study two different models have analysed for various loading conditions (Cantilever retaining wall and Relieving platform retaining wall) at different height, the horizontal compulsion at the rear of the wall is converted to vertical compulsion on the deck by these walls [6]. The wall is composed of an adequately thin stem and base slab. The theory of leverage is used to build these barriers [4]. The heel and toe portions are the part of the base slab which are separated. The heel is the portion of the foundation that lies below the backfill. The toe is the segment of the bottom.

1.3 Retaining wall with relieving platform:

Retaining walls of this kind are special, this is a modified version of a cantilever retaining wall. A relieving plate is attached to the stem [8]. Depending on the design requirements, there could be one or more platforms [8] [4]. The idea behind having a relieving platform on the backfill margin of the partition wall is to minimize overall earth pressure on the retaining wall, which decreases the broadness of the partition wall and allows for a more cost-effective design with less BM i.e. bending moment[10] [3]. Therefore it is important to study such a type of retaining wall to observe its performance.

Cantilever retaining wall   Relieving platform retaining wall

Figure. 1 Types of retaining walls

The main objectives of our study are to:

- Study the behavior in various components of the retaining wall at different loading conditions at various height.
- Design the stable and cost-effective retaining wall.
- Study and optimized the different design outputs.
- Cost optimization of both types of retaining wall and propose the best option for a particular height.

1.4 The lateral Earth pressure change due to presence of Relieving Platform:

The wedge is the part of the retaining wall that supports soil that extends beyond the failure plane of the soil type present at the retaining wall site. The wedge can be calculated once the soil friction angle has been determined. If the setback of the retaining wall increases, the size of the slithering wedge shrinks, reducing the load on the retaining wall [14]. Identifying and preventing the slithering down of retained substance because of gravity is the most important aspect of proper retaining wall design and construction. This induces earth constraint laterally at the back of the wall that is evaluated by the internal abrasion angle, cohesive firmness of retained substance, and direction and the magnitude of movement retained material undergoes [14]. The lateral earth constraint in uniform terrain is zero at the tip of assembly and rises proportionally to the highest value at the lowest depth. If the wall is not properly planned and installed, the Earth constraint will force it laterally forward or topple it. The hydrostatic constraint is generated on the wall by groundwater at the back of the wall which is not dissolute by seeping. The cumulative constraint or thrust can be expected to operate at one-third of the lowest bed for longitudinal spans of uniform elevation. Fig. 2 fig. 3 depicts the shift in constraint distribution caused by the presence of a relieving platform.

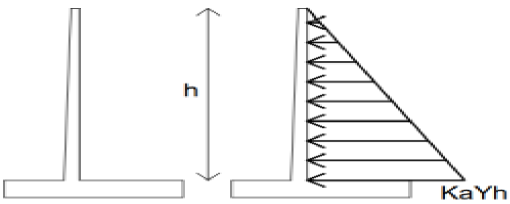

Fig. 2

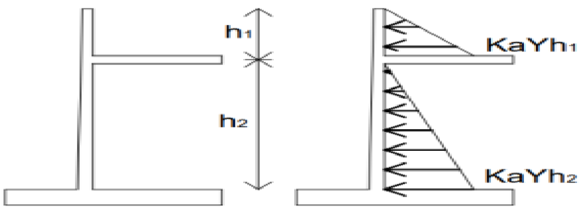

Fig. 3

Figure. 2 Pressure distribution diagram of CRW

Figure. 3 Pressure distribution diagram of CRW with relieving platform

Based on the various literature studied, it appears that the investigation of retaining walls with the relieving platforms is a relatively unexplored field, with only a few studies to date. It's also worth noting that, with the exception of gravity retaining walls, such retaining wall assembly is rarely built [11].

2. Methodology:

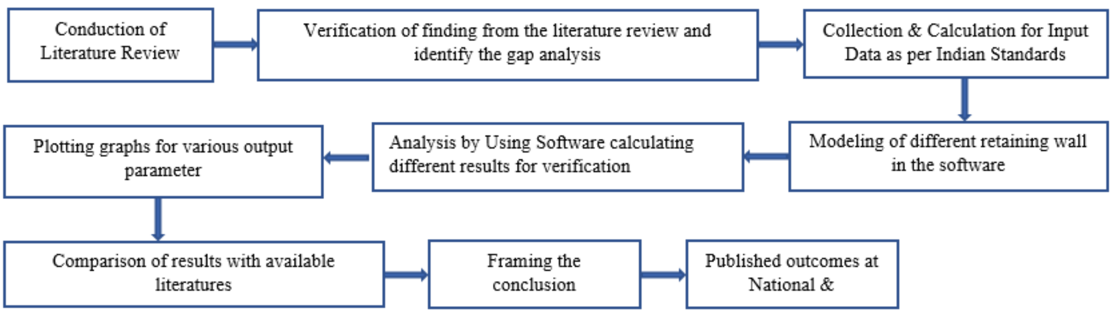

Plate.1 Flow Chart for conduction of Research Work

2.1 Retaining wall Design:

All required limitations and calculations are considered scientifically while planning, and then all feasible result are produced. Then exhaustive scrutiny and calculation are carried out, taking into account all of the constraints, particularly the cost as well as the risks and uncertainties involved. The best solution is then determined to be the one with the lowest cost [12].

2.2 Parameters Considered for Design:

- Relieving platform's length: For ease of comparison, it's kept equal to the heel slab's length.
- Relieving platform thickness: Its thickness is half that of the base slab.
- The relieving plate is located at 1/4 times the retaining wall's elevation from the top.
- 30^o is considered as Angle of repose (φ)
- Ka (Coefficient of active earth constraint): 1-sin (φ)/1+sin (φ) = 0.33
- Kp (Coefficient of passive earth constraint): 1+sin (φ)/1-sin (φ) = 3.
- Depth of foundation (Df) is considered to be 1.2m
- Considered 160KN/m^3 as safe bearing capacity (SBC).
- Considered 16 KN/m^3 to be unit mass of soil (ϒs)
- Considered 25 KN/m^3 as the unit weight of concrete.
- M 25 Grade of concrete.
- Fe 415 Grade of steel.

2.3 Checks for Stability:

In the design of the retaining wall the following checks for stability are considered:

- The resulting reaction force's eccentricity should be between 0 and base width/6.
- As a part of safety in case of slithering to be considered greater than 1.5.
- As a part of safety in case of rescinding to be considered greater than 1.5.
- The min and max bearing constraints, respectively, are set higher than 0 and lower than the soil bearing capacity.
- According to the IS456:2000 code, the min and max reinforcement percentages, as well as reinforcement spacing, are used.
- The maximum shear stress constraints in various sections are dependent on the concrete grade as specified by the IS456:2000 code.

2.4 Total Construction Cost:

As previously said, the plan with the lowest amount is considered the better emulsion; the prescription used to calculate this is as follows: Total amount (cost) = steel cost + concrete cost

= (Amount of steel in Kg * Rate of steel per Kg) + (Volume of concrete in m^3 * Cost of concrete per m^3)

2.5 Analysis of retaining wall on Staad pro software:

In 1997, Research Engineers International released STAAD, also known as STAAD Pro, a curriculum for structural analysis and architecture. In late 2005, Bentley Systems acquired Research Engineers International [9].

STAAD Pro is a program for structural analysis and architecture. The product that is used all over the world. Over 90 international steel, concrete, timber, and aluminum construction projects are supported [9].

1. Model creation
2. Property and Support assignment
3. Load assignment
4. Analysis

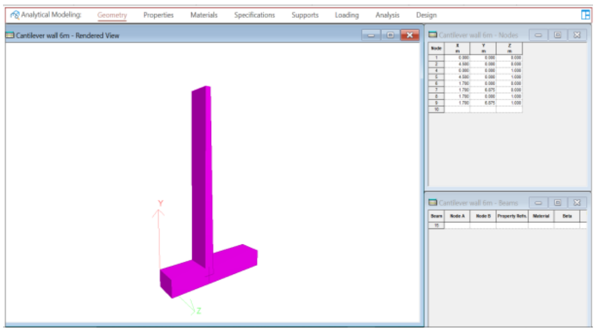

Figure. 5 3D rendered view of CRW

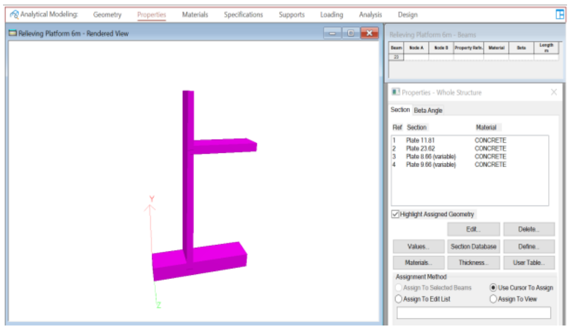

Figure. 6 3D rendered view of RW with RP

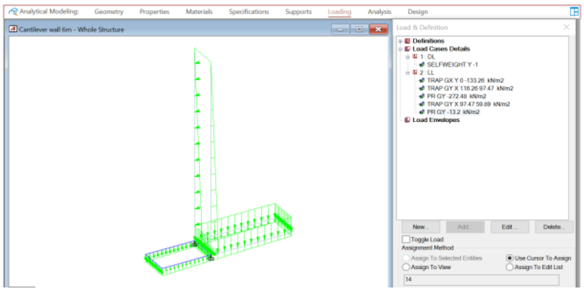

Figure. 7 Loading diagram of CRW

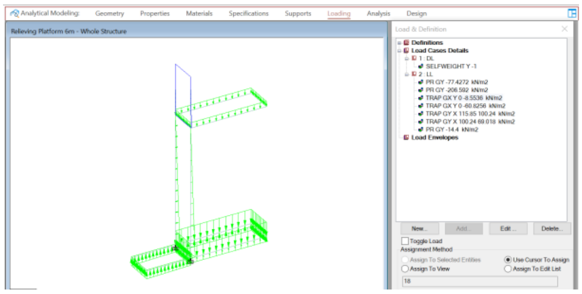

Figure. 8 Loading diagram of RW with RP

3. Results and Discussion:

After doing the design manually and on the software of CRW and RW with relieving plates and results that were obtained were compared relatively. Elevations considered for analysis and design were 5m, 6m, 7m, and 8m. For the study of both the retaining wall, the results are tabulated and graphed. The cost comparison is done for varying elevations.

3.1 Variation of bending moment with elevation:

Elevation Retaining wall (m)	CRW Bending Moment (KN.m)			RW with RP Bending Moment (KN.m)			
	Stem	Toe	Heel	Stem	Toe	Heel	Relieving platform
5m	158.71	69.04	104.32	91.45	60.80	19.99	87.94
6m	247.28	105.46	170.02	143.51	96.80	48.66	122.30
7m	365.34	158.19	247.94	212.30	148.14	92.28	194.62
8m	532.84	224.44	346.09	302.42	207.20	105.4	294.89

Table 1. Bending Moment in various components of retaining walls

As can be seen from table 1.the B.M. for stem, heel, and toe is least in the RW with relieving plates since the relieving platform relieves some of the bending moment.
We can plot graphs based on the values in the table above to see how the bending moment varies.

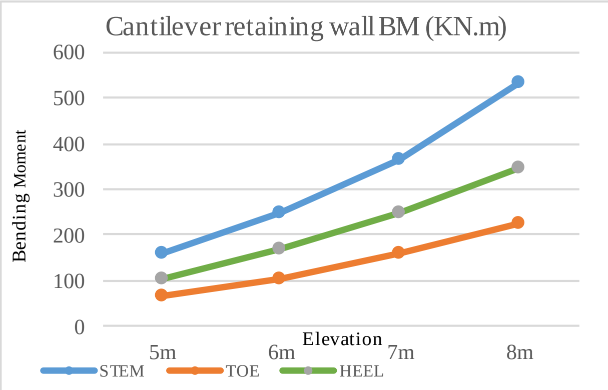

Figure. 8 BM VS. Height Of CRW

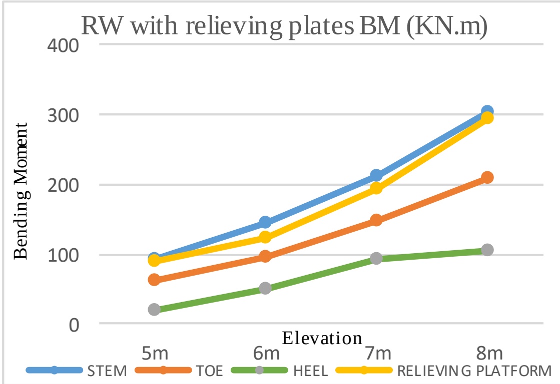

Figure. 9 BM VS. Height of RW with RP

We can see the findings from figures 8 and 9 that as the elevation of the wall rises, the BM of the stem, toe, and heel rises as well. However, in a retaining wall with relieving plates, the bending moment of the heel and toe is reduced compared to a cantilever retaining wall. These above results are compared and verified with the manual calculations and it was observed that these values are nearly same i.e, ranging +-8%.

3.2 Stability Check

Elevation RW (m)	CRW		RW with Relieving Plates	
	FOS against repeal > 1.5	FOS against Slithering > 1.5	FOS against repeal > 1.5	FOS against Slithering > 1.5
5	3.64	1.64	3.7	1.69
6	3.42	1.60	3.61	1.67
7	3.51	1.61	3.57	1.63
8	3.72	1.66	3.79	1.68

Table 2. Stability Comparison

The above table number 2 indicates the comparison between CRW and RW with relieving platform on the basis of the factor of safety against overturning and factor of safety against sliding.

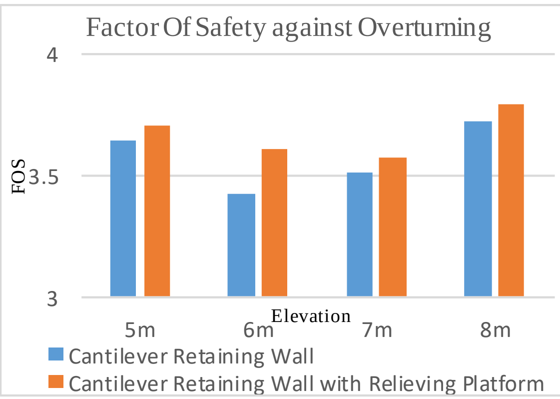

Figure. 10 FOS VS. Height of CRW

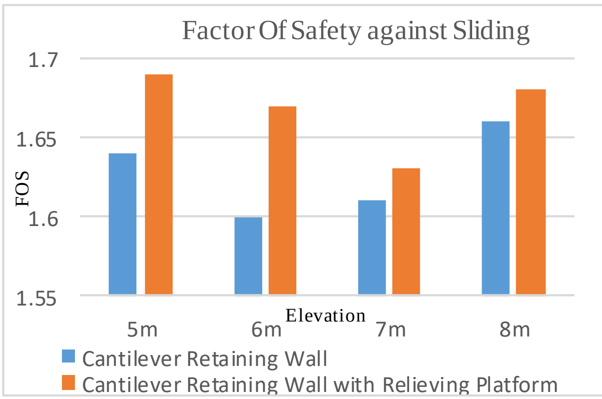

Figure. 11 FOS VS. Height of RW with RP

Figure 10 and 11 depicts a graphical contrast between the two walls based on the table 2 values for factor of safety against overturning and sliding. As it can be seen clearly from the graphs that both the walls are safe against overturning and slithering i.e. values are greater than 1.5. However, RW with relieving plates is much safer than the CRW in both aspects. The values of figure 10 and figure 11 were obtained through manual calculations.

3.3 Variation of the requirement of steel with elevation.

Elevation RW (m)	CRW Area of steel (Main + Distribution) (mm^2)			RW with Relieving Plates Area of steel (Main + Distribution) (mm^2)			
	Stem	Toe	Heel	Stem	Toe	Heel	Relieving Platform
5	3106.95	1257.48	1572.71	2377.42	1187.08	790.08	2545.12
6	4164.32	1525.61	1998.37	3342.96	1482.62	971.54	2648.66
7	5098.50	1878.4	2463.40	3940.61	1836.60	1444.96	3890.33
8	6075.80	2257.25	2829.87	4393.81	2195.68	1542.41	4912.176

Table 3. Area of steel with varying elevation

The area of steel for the heel and toe is less in the retaining wall with the relieving platform, as can be seen from the above table 3. However, the total area of steel for a retaining wall with the relieving platform is significantly larger than for a cantilever retaining wall. We can frame graphs and see the difference in steel area using the value from the table above

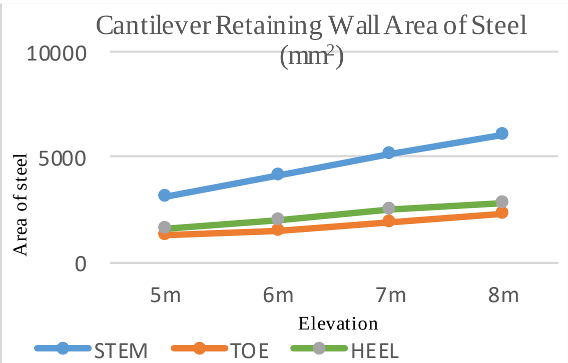

Figure. 12 Area of steel VS. Elevation of CRW

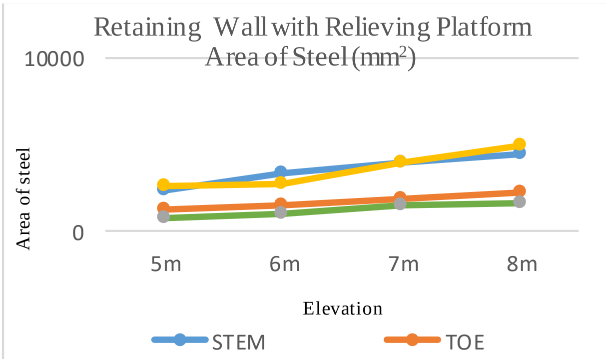

Figure. 13 Area of steel VS. Elevation of RW with RP

From figures 12 and 13 it is evident that as the elevation of the wall increases, the requirement of the steel in both the cases increases but the overall area of steel in the retaining wall with relieving platform is slightly greater due to the involvement of the steel area of relieving platform. . We compared manual calculations with staad pro results of reinforcement requirements and it was observed that these values are nearly same i.e, within the range of +-15%.

3.4 Cost Comparison

Elevation of retaining wall (m)	CRW			RW with Relieving Plates		
	Steel Cost Per m.	Concrete Cost Per m.	Total Cost Per m.	Steel Cost Per m.	Concrete Cost Per m.	Total Cost Per m.
5	2265.6	6841.35	9160.95	2632.80	6453.45	9086.25
6	2933.86	8875.06	11808.92	3271.20	8462.20	11733.40
7	3602.40	11781.00	15383.40	4240.32	10680.00	14920.32
8	4260.00	14843.40	19103.40	4977.60	13520.10	18497.60

Table 4. Cost comparison of different Retaining Wall

As can be shown, the cost of steel in a RW with relieving plates is higher than the cost of steel in a CRW. However, the cost of concrete for a RW with relieving plates is lower than for a CRW. This occurs by providing a relieving platform for retaining the wall which ultimately leads to a decrease in the thickness of the base slab and the stem as well as a reduction in concrete volume. Based on the above table 4, few graphs are plotted showing the graphical comparison for steel cost, concrete cost, and total cost separately between both the walls for ease of comprehension.

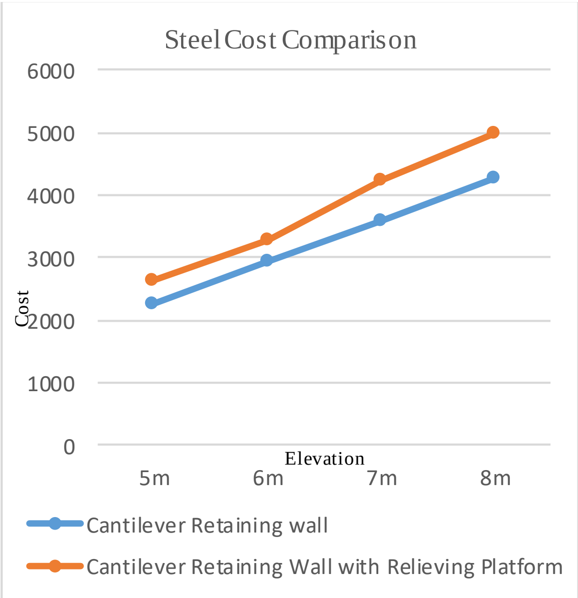

Figure. 14 Comparison in cost of steel between CRW and RW with RP

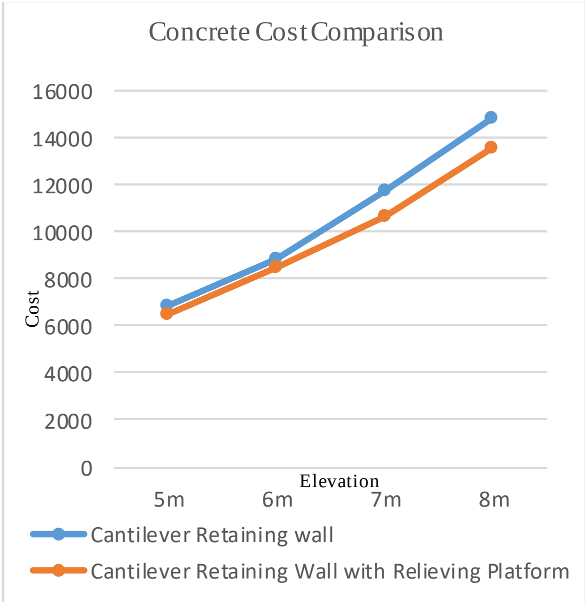

Figure. 15 Comparison in cost of concrete between CRW and RW with RP

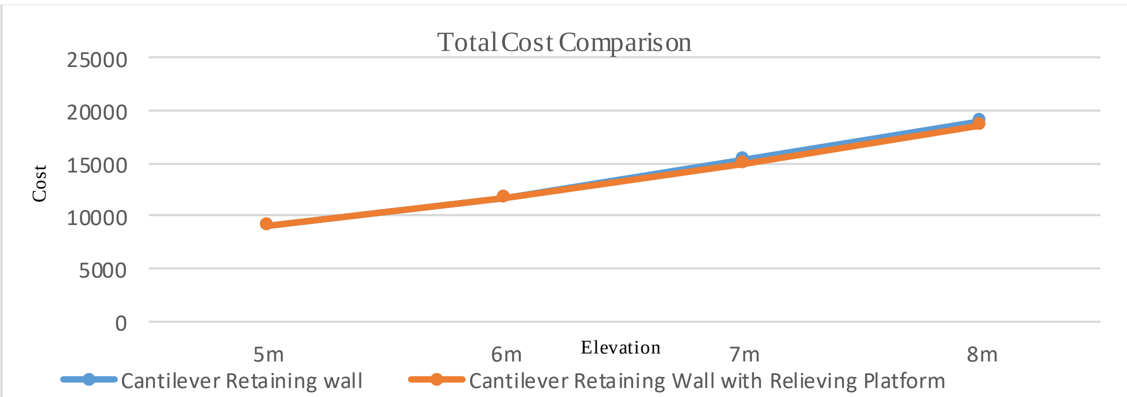

Figure 16 Comparison of total cost between CRW and RW with RP

We can see from Figure 16 that as the elevation of a wall rises, so does the cost of construction rises. However, the cost of both the walls is almost identical up to an elevation of 6 meters, after which the cost of the retaining wall with relieving platform begins to decrease. . We compared manual calculations with staad pro calculations and it was observed that these values are nearly same i.e, ranging +-10%.

3.5 Software Analysis

3.5.1 Deflection Diagram

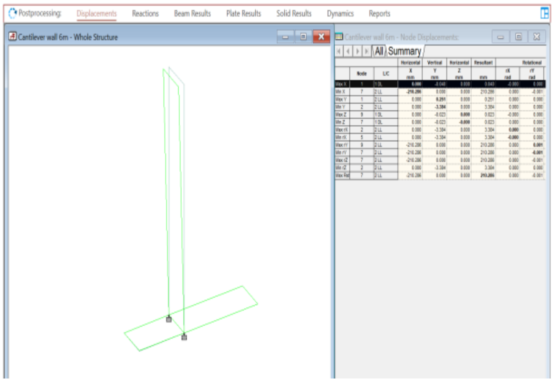

Figure. 17 Deflection diagram of CRW

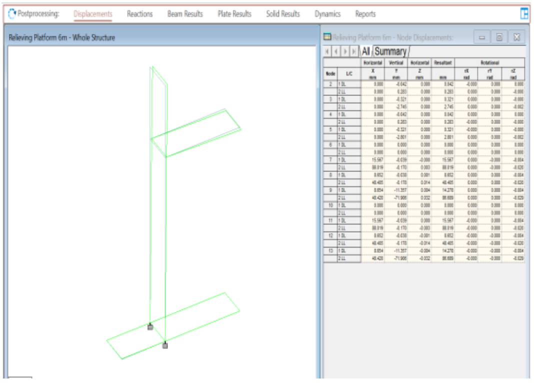

Figure. 18 Deflection diagram of RW with RP

Figure 17 and 18 shows the deflection diagram of both the walls obtained from Staad. pro software. It is seen that relieving platform reduces the deflection in the retaining wall to maximum extend.

3.5.2 Stress Diagram

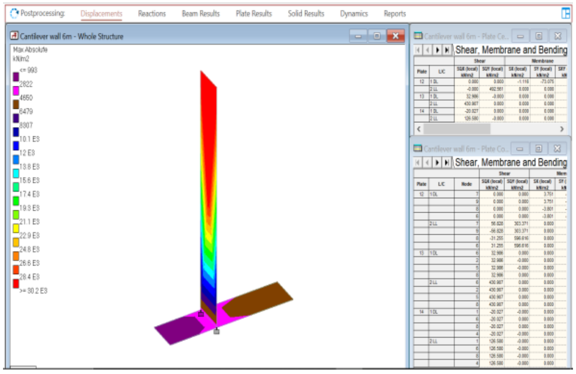

Figure. 19 Stress diagram of CRW

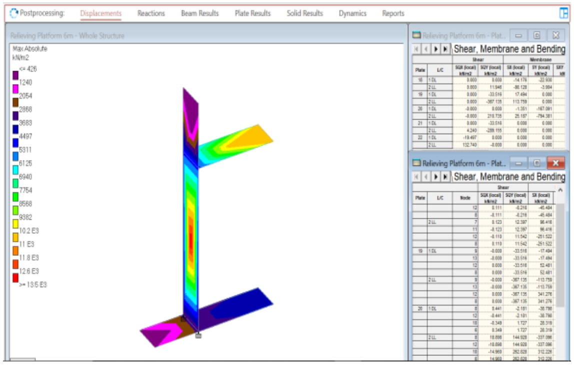

Figure. 20 Stress diagram of RW with RP

Fig 19 and fig 20 depict the stress diagram of both the walls. From the figures, it is clear that using relieving platform reduces stress at the stem and base slab of the retaining wall.

4. Conclusion

This research paper mainly aimed to study two types of retaining walls that are widely used and to compare the CRW and the RW with relieving plates. Both the retaining walls were compared based on the elevation of the retaining wall B.M., firmness against overturning and sliding, and cost and economy. A retaining wall along with a relieving platform is a unique type of retaining wall. In their papers, some researchers claim that using the relieving platform is the most cost-effective approach for building a high raised retaining wall. This reliving platform has the advantage of minimizing acting earth constraint working laterally on retaining wall and improving overall retaining wall stability.

- In the case of a RW with relieving plates, the RW is more stable because of discontinuous laterally acting soil constraint.
- Relieving platform reduces the BM in heel, toe and stem for retaining wall.
- As compared to a CRW, steel requirement is less in heel and stem of RW with relieving plates.
- Cantilever retaining walls are much more vulnerable to overturning and slithering than RW with relieving plates.
- Reducing the area of cross-section of a RW with relieving plates decreases the construction material requirement, such as concrete volume and steel, lowering the total cost.
- The cost of constructing a RW with relieving plates is almost the same as a CRW up to an elevation of 6 meters and then drops.

5. References

[1] Dhamdhere D., Rathi V. and Kolase P., September 2018 "Design and analysis of retaining wall", International Journal of management, technology, and engineering, Volume 8, Issue 9.

[2] Tapkire P.and Karkare B. November 2019, "Assessment of Rectangular Cavity in Concrete Gravity Retaining Wall Using Finite Element Method", International Journal of Recent Technology and Engineering (IJRTE) ISSN: 2277-3878, Volume-8 Issue-4.

[3] Bhoyar P., Awachat G., May 2019 "Static analysis and design of retaining wall with and without shelve using software", International research journal of engineering and technology, volume 06, issue 05.

[4] Chougule A, Patankar J.,Chougule P. , July 2017 "Effective use of shelves in cantilever retaining wall", International research journal of engineering and technology, volume 04, issue 07.

[5] Puri S. and Salgude R., September 2018 "Study of Geogrid Reinforced Soil Retaining Wall & Its Comparison with R.C.C. Retaining Wall with Respect To Cost & Time", IJRET, volume 05, issue 3.

[6] Retaining wall - Wikipedia.

[7] IS 456 - 2000 Plain reinforced concrete - code of practice is an Indian standard code of practice for general structural use of plain and reinforced concrete.

[8] Chauhan V., Dasaka S. (2016), "Behaviour of Rigid retaining wall with Relief Shelves with Cohesive Backfill".

[9] Bhuniyan S., Girme B., Lambe B.,Agrawal A., (2017), "Study of Stress Reliving Shelf at Different Levels of retaining wall by using STAAD-Pro" , International Journal Of Innovative Research In Technology, Volume 4 Issue 1, ISSN: 2349-6002.

[10] Babu K., Gowda K., (2016), "Analysis of Counter fort retaining wall with and without Constraint Relief Shelf using Soft Computing Technique", Science Insights: An International Journal, ISSN 2277–3835.

[11] Chauhan V. B. and Dasaka, S. M., 2018,"Performance of a Rigid Retaining Wall with Relief Shelves" Journal of Performance of Constructed Facilities, 32, 3, pp.211–219.

[12] Koopialipoor M., Muidhar B., Hedayat A., Armaghani D., Gordan B., and Mohamad E., ''The use of new intelligent techniques in designing retaining walls,'' Eng. Comput., pp. 1–12, Jan. 2019.

[13] Chouksey S. and Fale A., 2017, "Reliability Analysis of Counterfort Retaining Wall", International Journal of Civil Engineering and Technology.

[14] Yadav P., Padade A.,Dahale P., Meshram V.,February 2018 "Analytical and experimental analysis of retaining wall in static and seismic conditions: a review" International Journal of Civil Engineering and Technology (IJCIET) Volume 9, Issue 2.

[15] Gokkus U. and Tuskan Y., 2017, "Cantilever beam-like design of retaining wall with multiple pressure relief shelves and elastic foundation". IJAR.