Optimal Design of Cantilever Retaining Wall Using Relief Shelves

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Abstract- *The total active earth pressure acting on the retaining wall mainly decides the cross-sectional dimensions of the retaining wall. To reduce the operative lateral pressure and to implement an enhanced and cost-effective design for retaining walls. Setting up of relief shelves to retaining walls condenses lateral actual stresses acting due to soil, this type of retaining wall is deliberated as an exceptional type of retaining wall. For cantilever walls with maximum height than the normal, there will be a maximum shear force, bending moments, and deflection for which providing relief shelves will be advantageous. For some repair works for already built retaining walls that are having troubles with stability, it is suggested to provide a shelf to these retaining walls. This paper demeanors a parametric study of investigation and performance of cantilever retaining wall with and without relief shelves, observe and study the effects of the provision of relief shelf as a platform in cantilever retaining wall. Retaining walls were analyzed using Staad Pro. and outcomes were studied accordingly. It is found that the addition of shelves had a significant outcome on the distribution of consequential active earth pressure. The arrangement of relive shelves with different combinations of shelf width and locations if shelves were studied.*

Keywords- Cantilever Retaining wall, Relive Shelf, Lateral earth pressure, Economical design, Stability conditions, Staad Pro.

I. INTRODUCTION

Retaining walls are constructed to preserve the earth in a vertical position, at localities where uneven changes arise in the ground levels. It is necessary to have an understanding of the lateral earth pressure acting on the wall which is to be resisted by the wall. The supportive base footing and whole wall assembly have to be analyzed and designed for the lateral pressure exerted due to soil, and also to be checked for stability conditions like sliding, strength, and overturning. There are dissimilar kinds of retaining walls like Gravity wall, Counterfort retaining wall, Cantilever retaining wall, Buttress retaining wall, and Basement wall. These are the most commonly used retaining walls. Walls may be T-type or L-type walls. The T-type wall involves a base slab of a heel and toe slab, whereas the L-type wall has only the heel slab. There were two theories introduced for calculating the earth's pressure on the retaining walls: (a) Coulomb's theory (1773) and (b) Rankine's theory (1857). However, Terzaghi pointed out the legitimacy and boundaries of the above two theories and clarified the important ideologies for the behavior of earth pressures in 1934. The stability conditions of the wall are provided principally by the self-weight of the assembly of the wall and the mass of soil laid on the heel slab. To resist shear forces these retaining walls can be provided with shear keys to resist the lateral forces responsible for sliding. The main force acting on the retaining wall is the force due to earth pressure, tends it to slide, bend, and overturn. Cantilever retaining wall with a relief shelf platform as a part of the whole assembly connected to the stem of the wall is considered as a special type of retaining wall opted for wall with maximum heights. While retaining walls with shelves are now been built at numerous places, their mechanism of working, and calculation method of lateral earth pressure is quiet undeveloped for these types of retaining walls. Therefore, the current study is focused to study and understand the behavior of these walls and observe the efficiency of relief shelves. From the failure of retaining wall with relief shelf platform in Hyderabad. Investigation performed to signifies the thorough study of three-dimensional non-yielding rigid cantilever wall with the mathematical and stagnant analysis that backing cohesionless soil. In this work, it was investigated how the shelf width and location of the shelf and the effect of same on parameters considered while designing the retaining walls. FLAC 3D computer program was used for analysis. Gravity retaining walls are the huge and heavy structure, which is also not that cost-effective by Chauhan and Dasaka (2018) [1]. Researches were conducted on cantilever earth retaining wall structure for stability enrichment by providing pressure relief shelf by soft programming procedure. In the research work, cantilever retaining wall with the height of 4m was considered for analysis with optimal parameters. Lots of restrictions were there for designing retaining wall for optimal individualities by numerical calculation method; which tends to become practice of complex calculations in tactic step and iterative procedure throughout the investigation. Which are more time consuming and difficult method. To overcome with these complications, retaining wall with and without shelf were analyzed using finite element method based programing application SAP 2000. Outcomes tabulated were comparatively acceptable than that of manual calculations. Provision of relief shelf improves the parametric constraints up to 35 percent considered while designing cantilever retaining wall. Defining to the positon of the shelf according to the height of the stem wall is a tedious and complex job by using analytical methods, hence it was identified using a software program by Dharshan and Gowda. (2016) [2]. Cantilever retaining wall with relieving shelf platform have advantages in relation to expenses and constancy, and by putting relive shelf the major force due to lateral earth acting on the wall is deceases. Throughout the study, the pre-eminent circumstances for the retaining wall with a relive shelf were reflected by estimating the outcomes for fall in lateral earth pressure. A mathematical investigation was carried out to study the retaining walls with dissimilar dimensions with adaptable shelf locations, the height of the wall, and base widths. The optimized place of the shelf was found at the dominant point of part of a wall h/H=0.5 and the optimized length of B/L=0.45 was proposed to gratify the design standards premeditated by Moon et al. (2016) [3]. The amount of decrease in overall active earth pressure, overturning moments at the wall base, and its distribution because of the action due to the relief shelf. Effect of putting up shelf for accumulative the resisting moment alongside overturning was also studied. Distribution of pressure underneath the bottom slab, higher bending moment, and shear force on the wall was determined by numerical methods. The mathematical outcomes specified in this paper determined that the occurrence of a relief shelf on the wall caused a reduction in lateral earth pressure. The author studied retaining all of which was exposed to additional loads such as the dynamic lateral earth pressure and unstable wave situations. The decrease in lateral earth pressure, decrease in the overturning moment was observed in dynamic analysis. Various retaining walls were analyzed under the circumstances like cantilever beam like illustration, vertical wall with multi-shelf and doubly bounded rectangular bottom section on flexible foundations, stepwise and three-row strengthening by Gokkus and Tuskan (2017) [4]. Dissemination for the earth pressure overhead and underneath the shelf, as revealed in Figure 1. The difference in pressure distribution due to the presence of the shelf as a part of the wall is described and variations were discussed systematically. The clarification suggested by the author well-defined inclined changeover line two defined points.

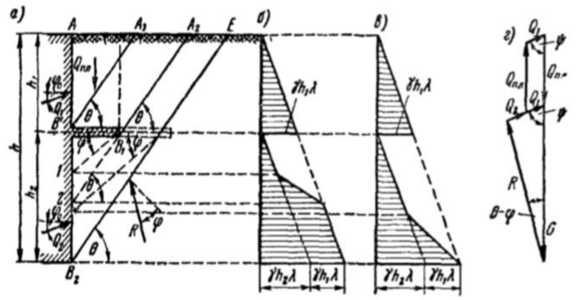


Figure 1: Solution of G.K.Klein, 1964, (a) short shelf, (b) long shelf

The dispersal possibly is also companionable with the finite element solution using more progressive soil prototypes, which were considered for the study. It was established that there were two distributions; a) for the shelf that is not prolonged to the rupture line; b) for the shelf that is prolonged to the rupture line; studied by G. K. Klein (1964) [5]. The practice of providing the relief shelves in retaining walls was briefly discussed. Cantilever walls with relief shelves was taken into account which was one in all the special kinds of retaining walls. The retaining wall is an assembly constructed to preserve the force due to the lateral earth pressure from the backfill. Retaining walls are considered necessary for a number of the field like roads, dams, railroads, tunnels and military foundation, etc. A retaining wall consists of three elements which are stem, toe block and heel slab, the nature of operating of those elements is through cantilever action. Endless work is carried out by the investigators for increasing the improvement in the economy of a wall. The author carried out the comparison of optimum space of strengthened steel and area of concrete between manual computation and soft computing technique of cantilever earth wall studied Shehata (2016) [6]. The perception of providing pressure relief shelves at the backfill side of a retaining wall condenses the entire earth pressure acting on a wall, which effects in dropping down the depth of the wall and ultimately to get a commercially economical design. A parametric study was performed and showed to deliberate the influence of the number of shelves, shelf rigidity, and shelf position on the resulted lateral earth pressure distribution, movement at top of the wall and the bending moment exceedingly acting on the wall. Inadequate elucidations were presented for these types of retaining walls in some of the research works. These wall prototypes investigated using the finite element analysis method in the software program PLAXIS 2D. Effect of decrease in active lateral earth pressure by providing shelf was studied. It was found that the shelves have an astonishing effect on the dispersal of the earth pressure. It was found that it approximately follows the solution given by Klein's, 1964. It was commended to deliver one shelf at one-third of the wall height from top of the wall studied by Farouk (2015) [7].

II. METHODOLOGY

Objective

1. To study and determine the effect of relieving shelf in cantilever retaining wall.
2. To determine the optimized and economical section of cantilever retaining wall.
3. Results are compared in terms of the position of the shelf, number of shelves, factors affecting stability, bending moments, and deflection at top of the wall.

Preliminary data

Table 1: Preliminary data for analysis

Type of Retaining wall	Cantilever Retaining wall	The angle of internal friction	30^0
Height of wall	12 m	Coefficient of friction	0.55
Density of Steel	78.5 kN/m^3	Density of Concrete	25 kN/m^3
Unit weight of concrete	25 kN/m^3	Unit weight of soil(γ)	18 kN/m^3
Grade of Concrete	M25	Grade of Steel	Fe500
Bearing Capacity of soil(qf) = 300 kN/m^2			

Grouping of Prototypes

Table 2: Prototypes to be analyzed

Group of Prototypes	Prototypes
Group 1	a) Retaining wall without shelves. Total number of model = 1
Group 2	Retaining wall with single shelf, position of shelf : a) 0.25h, b) 0.5h, c) 0.65h. With shelf width = 3m; 3.5m; 4m. Total number of models = 9
Group 3	Retaining wall with two shelves, position of shelves: a) 0.30h & 0.50h, b) 0.40h & 0.60h, c) 50h & 0.70h With shelf widths = 3m & 3.5m; = 3.5m & 4m. Total number of models = 6

The prototypes mentioned in above Table 2 are to be considered for the study. The height of cantilever retaining wall with shelves is taken as 12m. Retaining walls analyzed in the study area.

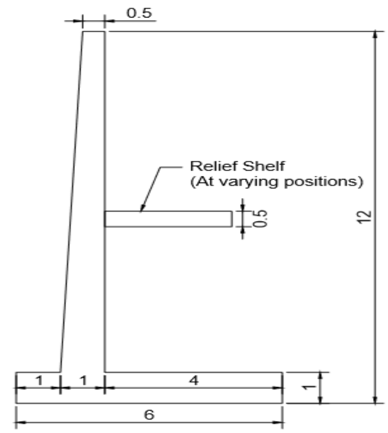


Figure 2: Typical cross-sectional detail for Cantilever retaining wall with shelf

III. RESULTS AND DISCUSSIONS

This segment describes the outcome results for the diverse prototypes analyzed to conclude the parameters such as base pressures, top node displacement, the bending moment at bottom of the stem, and bending moment at the end of the shelf.

A. Results For Group 1 Prototype:

Here, a retaining wall without shelves with cross-sectional dimensions of wall analyzed using Staad pro. The results tabulated are as mention below in Table 3. The factor of safety against sliding is beneath 1.4 for considered cases. Maximum pressure below base slab Pmax exceeds the bearing capacity of the soil and minimum pressure Pmin value is negative which will cause both compression and tension at the foundation. Therefore this retaining wall does not fulfill the stability conditions.

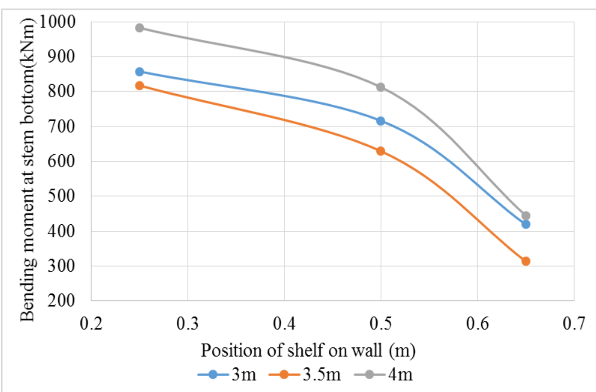
Table 3: Results for Group 1 Prototype

Base width (m)	6 m
Node displacement of the top node (mm)	32.20
Bending moment at the stem bottom(kN-m)	2287.52
Bending moment at toe end(kN-m)	2535.33
Bending moment at the heel end(kN-m)	1091.99
Pmax (kN/m^2)	508.99
Pmin (kN/m^2)	-122.42
FOS against Overturning	1.40
FOS against Sliding	1.07

B. Results For Group 2 Models

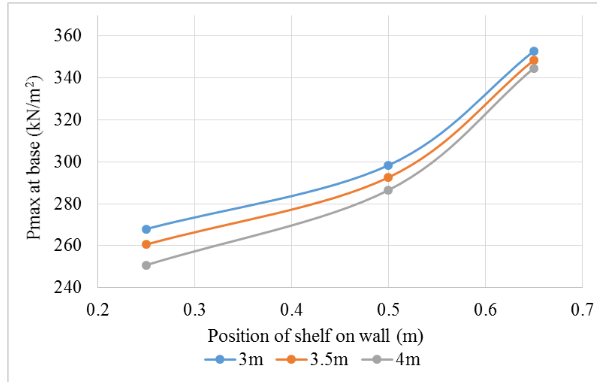
Retaining wall with relief shelves are having unlike shape associated with the nominal retaining wall and accumulation of flat horizontal relief shelves have greater than before the weight of wall and center of gravity of the whole assembly will be shifted towards backfill. The decrease in lateral thrust is observed proportionally in the variation of contact pressure at the foundation base. Whole contact pressure below the foundation slab is considered in study and results were tabulated with respect to different shelf width and varying positions of a shelf. It can be determined that the appropriate choice of relief shelves width can minimize total contact pressure below the foundation base slab ominously and afterward increase in the factor of safety against bearing capacity failure.

The cantilever retaining wall with a single shelf located at varying locations is analyzed. Locations of the shelf were varied 0.25, 0.5 & 0.65 times the total height of the stem. The results were interpreted and tabulated below.



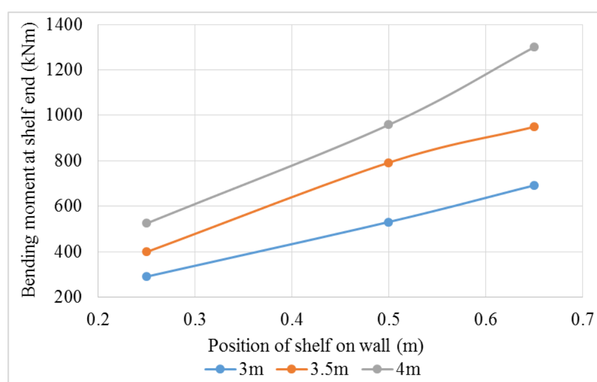
Graph 1: Bending moment at the stem end of Group 2 Prototypes.

The graph for bending moment at the stem with respect to the location of the shelf is contrived as presented in Graph 1. It is observed that for varying shelf widths, the least bending moment at bottom of the stem of retaining wall is attained for the position of the shelf at 0.65h. The bending moment for 3.5 m shelf width, located at 0.65h is the minimum amongst other cases considered. The graph plotted above represents the interpretations of results for shelf width of 3m, 3.5m & 4m as a part of cantilever retaining wall. For 0.25h position of the shelf the bending maximum bending moment observed for all cases considered for analysis as the height remained below the shelf is proportionately more hence the lateral earth pressure acting on this part of the stem also will be more and hence bending moment at stem will be increasing by an increment in the height below the shelf. The graph plotted above interprets same the increment in bending moments with an increase in height below the shelf.



Graph 2: Pressure Pmax at base of Group.2 Prototypes.

The graph of the location of the shelf corresponding to the height of the stem of the wall with respect to maximum base pressure due to soil Pmax is plotted as shown in Graph.2. As shelf localities diverge from 0.25h to 0.65h, the value Pmax increases proportionately. The retaining wall having a shelf located at 0.65h from top of stem does not satisfy the stability conditions for any of the opted shelf widths. Retaining wall with shelf positioned at 0.65h are the ones which do not satisfy the stability conditions as value for Pmax exceeds the bearing capacity of the soil. Other retaining walls with shelf situated at 0.25h and 0.5h with respect to the height of stem satisfies the stability conditions. Considering the width of the shelf, the contact pressure at the bottom of the foundation is not affected.



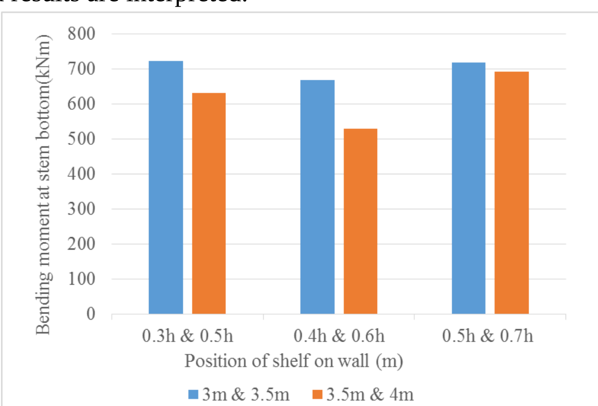
Graph 3: Bending moment at shelf end of Group 2 Prototypes.

As shown in Graph.3, it is observed that for every retaining wall with different opted shelf width, with an increase in width of the shelf there will be more soil weight on the shelf which will increase the value for bending moment at end of the shelf and hence as the position of shelf varies from 0.25h to 0.65h the bending moment varies accordingly. Bending moment values for retaining wall with a shelf width of 3m are less than that of the shelf with 3.5m and 4m. After observing and comparing both graphs for bending moment at the stem and bending moment at shelf end it shows exactly opposite behavior, correlating with the location of the shelf and the width of the shelf. As the position of shelf varies the bending moment decreases at the stem and bending moment at the shelf end increase with the varying position of shelf i.e. 0.25h to 0.65h.

Considering these four constraints, the suitable location of the shelf can be considered as 0.5h. The results of these walls are compared to models of cantilever retaining wall without shelves and it is observed that for retaining wall of height 12m, providing shelf enhance the overall stability conditions compared to that of the wall without shelf. Displacement at top of the stem is also less than that of retaining wall without shelf.

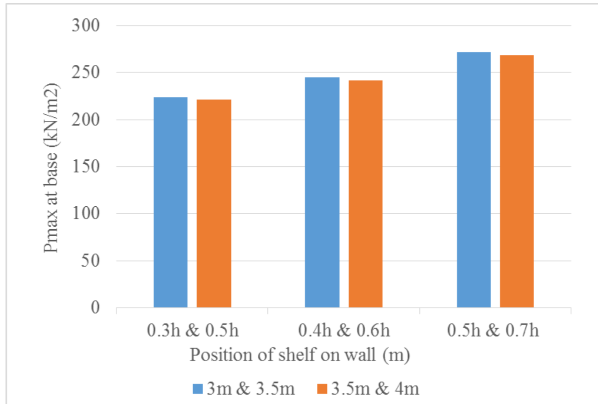
C. Results for Group 3 Prototypes:

In this group of prototypes, the retaining wall with two shelves at different locations and varying shelf widths were analyzed and studied. Retaining wall with two shelves 3m, 3.5m, and 4m width situated at heights 0.3h and 0.5h, 0.4h and 0.6h, 0.5h, and 0.7h. Considering the discrepancy in bending moment at stem bottom, base pressure, as well as displacement at top of stem and base pressure were studied and results are interpreted.



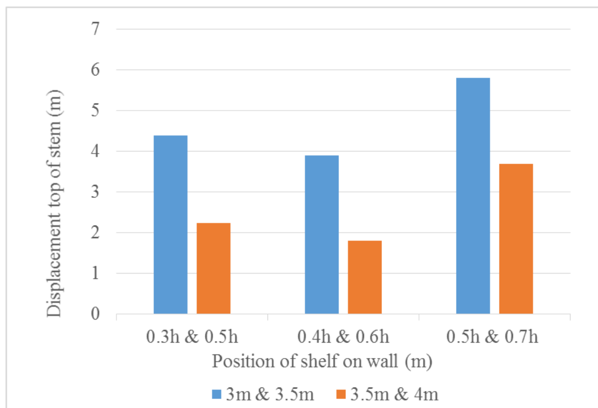
Graph 4: Bending moment at stem of Group 3 Prototypes.

Retaining wall with two shelves divides the stem wall into three parts and it is observed that there is variation in the bending moment values at the stem end. Bending moment at the stem with respect to two shelves located at varying observed and plotted in Graph.4. As two shelf placed at different combinations along the height of stem this will reduce the lateral earth pressure and the bending moment induced due to this will also reduce. It is observed that for retaining wall with shelves located at 0.4h and 0.6h of the total stem height represents lesser values for bending moment values compare to the remaining two walls. The bending moment at the stem in two remaining walls is almost the same. Considering pressure Pmax which should not be more than 300 kN/m^2 (SBC) all three combinations satisfies the condition. The pressure at base Pmax varies along with the three combinations of retaining wall. For retaining wall with one shelf located 0.5h and other at 0.7h shows maximum base pressure amongst all. Due to the reduction of lateral earth pressure acting on the wall the deflection at the top node varies along with the different combinations. The deflection at top of the node with respect to the different combinations considered of the location of shelves is interpreted in above Graph 6.



Graph 5: Pressure Pmax at base of Group 3 Prototypes.

It is observed that compare to retaining wall without shelf and retaining wall with a single shelf the pressure at the base is less than that of retaining wall with two shelves. This means that providing shelves will also upturn the stability, particularly when providing two shelves at 0.5h and 0.7h height of the stem.



Graph 6: Displacement at top of Group 3 Prototypes.

It is observed that the displacement at top of retaining wall with shelves located at 0.4h and 0.6h compare to the other two types of retaining wall. Also, the variations were observed with the change in the width of shelves. A combination of shelf width of 3.5m and 4m shows fewer displacement values than that of a combination of shelves width 3m and 3.5m.

It can be concluded by observing above results that considering parameters like bending moment at the stem, base pressure at bottom, stability conditions and displacement at top of the wall, retaining wall with two shelves one which is located at 0.4h and a second one located at 0.6h with the combination of shelf width 3.5m and 4m is effective than that of other combinations. For a long height wall, it is preferable to provide two shelves by considering all the parameters. Even though for high retaining walls with shelves the material and construction cost is more than that of the usual wall, but for stability and other parameters point of view, it is an economical solution.

IV. CONCLUSION

This paper describes the study of the end product of providing shelves to a retaining wall, cost-effective and enhanced solution for the design of cantilever retaining wall. It was observed that few academics have considered this special type of wall for a brief study. Observing the results carried out in parametric study considering provision shelf as relieving platform in cantilever retaining wall the conclusion was computed as follows:

1. Providing shelves as a part of retaining wall, minimizes the forces due to lateral earth pressure acting on them. This leads to improvements in stabilizing conditions and lowering down the net bending moments.
2. For cantilever retaining wall with a single shelf it is observed that amongst all prototypes considered for analysis, the wall with shelf provided at 0.5h found out to be optimized solution.
3. The bending moment at the stem end reduces from shelf location 0.25h to 0.65h. Also with a varying width from 3m to 4m, the bending moment values slightly increase.
4. It is observed retaining wall with a shelf located at 0.65 times the total stem height from top reductions in the resultant bending moment.
5. By increment in the width of the shelf, the displacement at the free end and the bending moment at shelf end rise beside the bending moment at stem end decreases primarily.
6. Permissible width of the shelves should be amplified from top to bottom of the wall, and it is also noted that the permissible width of the relief shelf at any height is a role of the width of the relief shelf located above it.
7. Provision of two shelves for the wall of height 12m primes to stabilize the wall assembly in an enhanced way. The pressure at the base will be acting uniform as stabilizing moment decreases and tend to the stable whole retaining structure.
8. Considering material required for cantilever retaining wall with shelf is more than that of usual walls but for retaining wall with long height, retaining wall with shelves is preferable as per stability parameters.

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