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Analysis and Design of Cantilever Retaining Wall with and without Pressure Relief Shelf

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Abstract. Retaining walls are built to retain earth filled of greater height. They are widely used in the construction of basement below ground level, rail and road projects where earth filling is required, wing wall and many more. The cantilever retaining wall with pressure relief shelf in the side of the backfill gives more economical value than the normal cantilever retaining wall. This study aims to analyze and design the cantilever retaining wall with or without pressure relief shelf. The pressure relief shelf is provided at the mid-height of the retaining wall. The analysis and design is done in conventional and soft computing method by using ETABS software. From the study it is found that the effect of lateral active earth pressure exerted on the retaining wall with pressure relief shelf is less than the retaining wall without shelf. The factor of safety against sliding and overturning is more in case of retaining wall with pressure relief shelf and also the area of reinforcement required less for the retaining wall with pressure relief shelf, hence it is more economical.

Keywords: Cantilever retaining wall, Pressure relief shelf, Lateral earth pressure, ETABS.

1 Introduction

1.1 General

A retaining wall is a structure designed to hold back the wedge of soil mass. Retaining walls are constructed in several area of engineering such as dams, tunnels, military fortifications, railroads, mines, roads, subways, etc. The lateral earth pressure and shelf weight are consider for maintaining stability of the retaining wall. Lateral earth pressure plays major role in retain structure, and it depends on the direction and magnitude of movement of the stem, cohesive strength and also the internal friction of retain material. The lateral earth pressure aims to be more in the lowest part of the retaining wall than the top portion of it. Lateral earth pressure will push the wall forward or overturn if not properly design. Pressure relief shelf is provided on the backfill side of the retaining wall to decrease the overall lateral earth pressure and increase the overall stability of the retaining wall. A pressure relief shelf is a horizontal platform provided at the stem of a retaining wall which achieved economic design. This

paper aims to find out how the pressure relief shelf works and its effect on the mid height of retaining wall.

1.2 Objectives

1. To analyze and design the retaining wall with and without pressure relief shelf by conventional method and soft computing method by using ETABS software.
2. To analyze and design the retaining wall with shelf in mid height position of the stem.
3. To compare the results of the analysis.

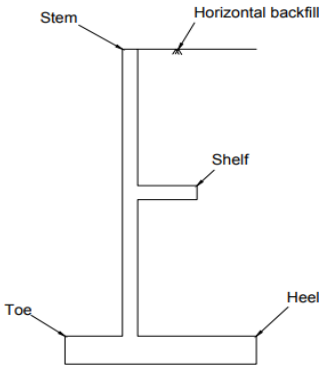

Fig. 1. Retaining wall with pressure relief shelf.

2 Methodology

2.1 Conventional method

The cantilever retaining wall with and without relief shelf is consider for the analysis and design purpose. For the cantilever retaining wall without relief shelf which shows in figure 2.1, wall height of 4.5 m, base width of 2.5 m, toe and base slab thickness of 0.4 m, width of toe slab as 0.75 m and width of heel slab as 1.55 m, stem thickness as 0.2 m throughout the height of the stem and 1 m wall length are considered and the dimension of cantilever retaining wall with pressure relief shelf which shows in figure 2.1 are 4.5 m wall height, 2.5 m base width, toe and heel slab thickness as 0.4 m, width of toe slab as 0.75 m and width of heel slab as 1.55 m, stem thickness as 0.2 m throughout the height of the stem i.e., from top to bottom portion of the stem, 1 m length of the wall and relief shelf of 0.2 m thick (1/2 of thickness of heel slab) and 0.775 m width (1/2 of width of heel slab) is provisioned at the mid height of the stem measured from the bottom portion of the stem.

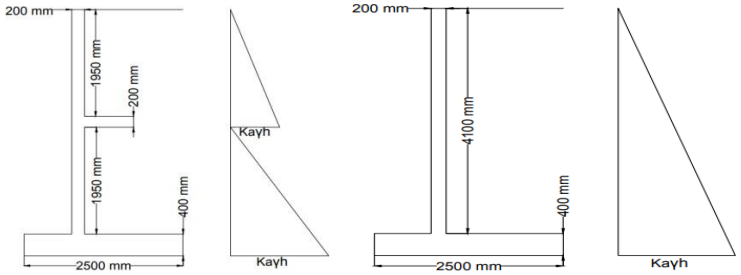

Fig. 2.1 Cantilever retaining wall with and without relief shelf and its pressure distribution.

Both the retaining walls are analyzed to check the stability. There are three checks to be done for stability i.e., check for overturning moment, check for sliding and check for soil earth pressure. Whenever the soil exerts lateral earth pressure on the retaining wall, it tends to overturn the retaining wall about its toe it is due to the unbalanced moments. A minimum factor of safety of 1.4 should be used to check over turning moment. Check for sliding is done when the horizontal force tends to slide the wall away from the backfill, it is there by resisted by the friction between soil and concrete. A factor of safety of 1.4 must be used against sliding. In check for soil earth pressure, checking is done whether the soil can bear the capacity of the load that exerted on the soil. Maximum pressure at the toe of the retaining wall should not exceed the safe bearing capacity of the soil under working conditions and if it exceeds, the soil will fail and the pressure minimum will be zero when the eccentricity exceeds B/6. Design of both the retaining walls is done after the analysis. Design includes fixation of base width, design of stem, design of heel slab, design of toe slab and design of relief shelf. Table 2.1 shows the parameters used for the analysis and design of retaining wall.

Table 2.1 Design parameters

Sl. No.	Parameters	Value
1	Density of earth, γ	23.544 kN/m^3
2	Angle of internal friction, Ø	33°
3	Safe bearing capacity, q_0	149 kN/m²
4	Coefficient of friction, μ	0.5
5	Grade of concrete, M20	20 N/mm^2
6	Grade of steel, Fe415	415N/mm^2

2.2 Soft computing method

ETABS 2016 ultimate 16.2.1 version is used to analyze both the model of retaining wall i.e., retaining wall with and without relief shelf. Then after the analysis the design is done manually. The design codes are assigned as IS456:2000 for concrete and IS800:2007 for steel and the units are assigned as SI unit system. The dimension and design parameter of retaining walls which was used in conventional method is also used for soft computing method. For material properties, M20 grade concrete and Fe

415 grade steel are defined and assigned. The retaining walls are designed as one rigid monolithic structure in which the based slab have been assumed to be fixed in position, so restraints is assign as fixed support. Fig.2.3 and fig.2.4 shows the model of retaining wall with and without relief shelf with the load acting non-uniformly in local-3 directions on the stem portion and the load acting uniformly in the direction of gravity on the heel portion.

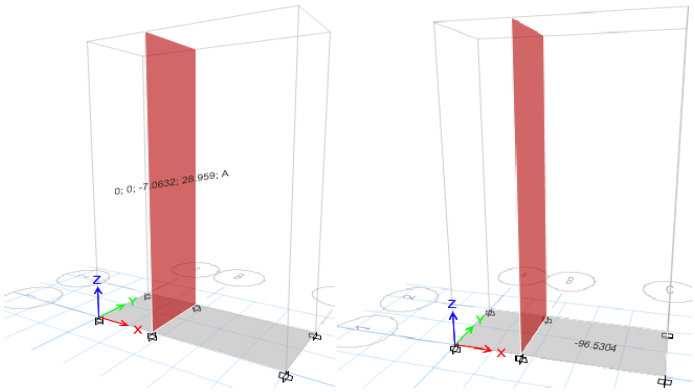

Fig. 2.2. Model of retaining wall without shelf with load acting on its stem and heel portion.

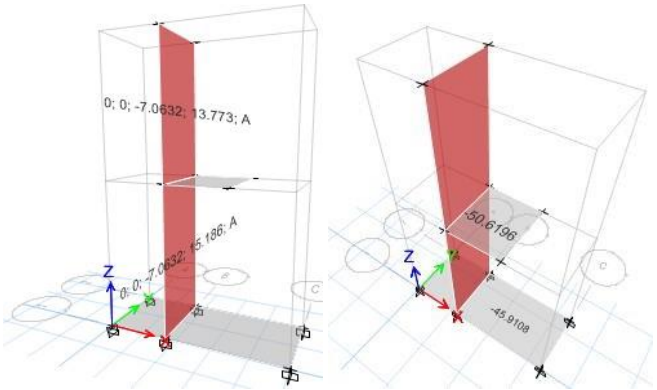

Fig. 2.3. Model of retaining wall with relief shelf with load acting on its stem and heel portion.

3 Results and Discussion

3.1 Analysis and design results of conventional method

The analysis and design results of cantilever retaining wall with and without relief shelf are compared. The following table 3.1 shows the analysis and design results of cantilever retaining wall with and without relief shelf.

Table 3.1. Theoretical analysis results of cantilever retaining wall with and without relief shelf

Descriptions	Retaining wall without pressure relief shelf.	Retaining wall with pressure relief shelf.
Active earth pressure	71.5149 kN	35.828 kN
FOS against overturning	2.57	4.67
FOS against sliding	1.22	2.72
Eccentricity from toe	0.22 m	0.019 m
P max (Pressure intensity at toe)	120.674 kN/m^2	81.832 kN/m^2
P min (Pressure intensity at heel)	35.423 kN/m^2	74.446 kN/m^2
Volume of concrete		
1. Base slab	1 m^3	1 m^3
2. Stem	0.82 m^3	0.82 m^3
3. Relief shelf	—	0.355 m^3
Total volume of concrete required	1.82 m^3	2.175 m^3
Area of reinforcement		
a) Toe of base slab		
• Longitudinal reinforcement	383.33 mm^2	275.257 mm^2
• Distribution reinforcement	480 mm^2	480 mm^2
b) Heel of base slab		
• Longitudinal reinforcement	801.46 mm^2	370.59 mm^2
• Distribution reinforcement	480 mm^2	480 mm^2
c) Stem		
• Longitudinal reinforcement	2177.16 mm^2	1633.87 mm^2
• Distribution reinforcement	240 mm^2	240 mm^2
d) Relief shelf		
1. Longitudinal reinforcement	—	328.807 mm^2
2. Distribution reinforcement	—	240 mm^2
Total area of reinforcement required	4561.95 mm^2	4048.524mm^2

It is observed that the active earth pressure is reduced in case of the retaining wall with pressure relief shelf due to the provision of pressure relief shelf in the mid height. Retaining wall with pressure relief shelf is more stable than retaining wall without shelf. For the retaining wall without relief shelf, shear key is provided due to the failure in sliding but in case of retaining wall with pressure relief shelf there is no need to provide shear key, since it was safe in sliding. It is also observed that the factor of safety against overturning and sliding is more in retaining wall with shelf. The eccentricity is decreased in retaining wall with relief shelf hence it is more economical than the retaining wall without shelf. The area of reinforcement required is also reduced in case of retaining wall with relief shelf when comparing with retaining wall without relief shelf.

3.2 Analysis and design results of soft computing method

The following figures show the ETABS analysis results of cantilever retaining wall with and without pressure relief shelf. ETABS analysis produced the design moment and shear forces of cantilever retaining wall with and without pressure relief shelf.

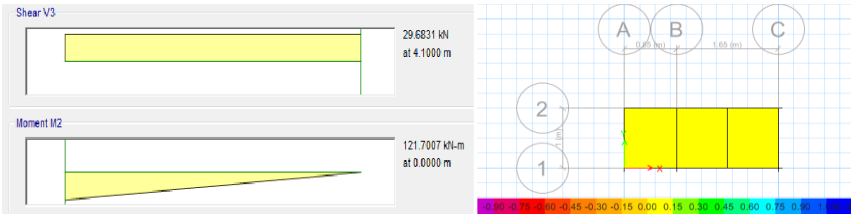

Fig. 3.1. Shear force and moment diagram of stem and base portion of cantilever retaining wall without shelf.

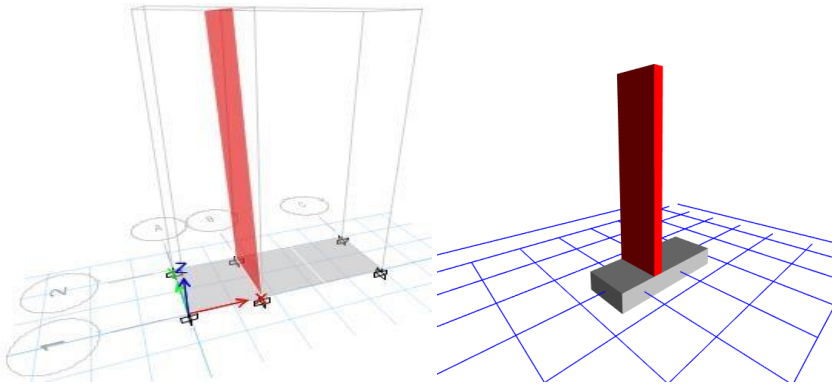

Fig. 3.2. Deformed shape after adding load and rendered view of retaining wall without shelf.

Fig.3.1 and fig.3.2 shows the shear forces diagram, moment diagram, deformed shaped and rendered view of cantilever retaining wall without relief shelf. These design moment and shear force values of stem portion are obtained after the analysis and it is observed that the moment at the base portion of slab is zero.

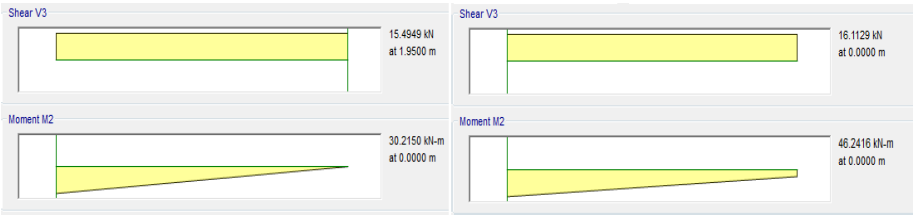

Fig. 3.3. Shear force and moment diagram of stem portion above and below the relief shelf.

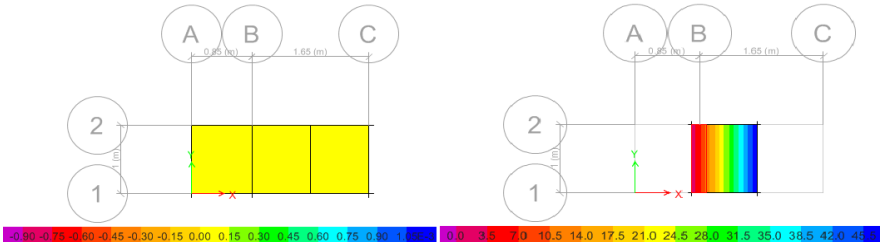

Fig. 3.4. Soil pressure diagram for the base and pressure relief shelf portion.

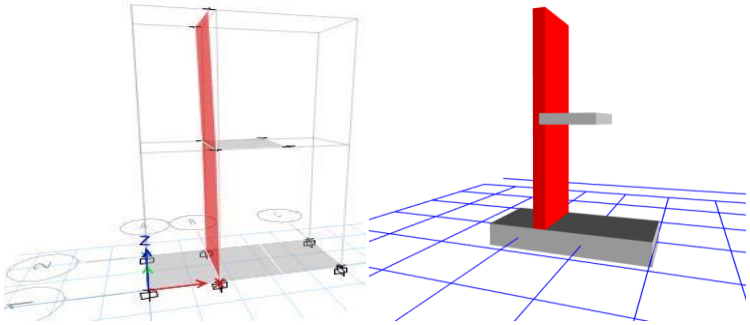

Fig. 3.5. Deformed shape after adding load and rendered view of retaining wall with shelf.

Fig. 3.4, 3.5 and 3.6 shows the moment diagram, shear force diagram, soil pressure and rendered view of the stem portion of retaining wall with pressure relief shelf. These design moment, shear force and soil pressure values are obtained after the analysis. The moment obtained at the base slab is zero and soil pressure on the relief shelf is obtained as 45.5kN/m^2. The moment and shear force that obtained after the analysis is used for the design of stem and relief shelf portion of cantilever retaining wall with and without pressure relief shelf. After the analysis and design, the results of both the analysis are compared. Table 3.2 shows the analytical results of cantilever retaining wall with and without pressure relief shelf.

Table 3.2. Analytical results of cantilever retaining wall with and without pressure relief shelf.

Descriptions	Retaining wall with-out pressure relief shelf.	Retaining wall with pressure relief shelf.
Active earth pressure	-7.0632, 28.959	(-7.0632, 13.773) Above shelf (-7.0632, 15.186) Below shelf
FOS against overturning	2.57>1.4	4.67 >1.4
FOS against sliding	1.22<1.4	2.72>1.4
Eccentricity from toe	0.22 m	0.019 m
P max (Pressure intensi-ty at toe)	120.674 kN/m^2	81.832 kN/m^2
P min (Pressure intensity at heel)	35.423 kN/m^2	74.446 kN/m^2

Volume of concrete		
4. Base slab	1 m^3	1 m^3
5. Stem	0.82 m^3	0.82 m^3
6. Relief shelf	—	0.355 m^3
Total volume of concrete required	1.82 m^3	2.175 m^3
Area of reinforcement		
e) Toe of base slab		
• Longitudinal reinforcement	383.33 mm^2	275.257 mm^2
• Distribution reinforcement	480 mm^2	480 mm^2
f) Heel of base slab		
• Longitudinal reinforcement	801.46 mm^2	370.59 mm^2
• Distribution reinforcement	480 mm^2	480 mm^2
g) Stem		
• Longitudinal reinforcement	2177.16 mm^2	1210.92 mm^2
• Distribution reinforcement	240 mm^2	240 mm^2
h) Relief shelf		
3. Longitudinal reinforcement	—	245.28mm^2
4. Distribution reinforcement	—	240 mm^2
Total area of reinforcement required	4561.95 mm^2	3542.047mm^2

It is observed that the active earth pressure is assigned in different position of the stem for retaining wall with pressure relief shelf due to the provision of relief shelf in the mid height position. Retaining wall with pressure relief shelf is safe in overall stability since the factor of safety is more than 1.4 when compared to retaining wall without relief shelf and there is no need to provide shear key. The eccentricity is decreased in retaining wall with relief shelf hence it is more economical than the retaining wall without relief shelf. The total area of reinforcement required is much more less in case of retaining wall with relief shelf when comparing with retaining wall without relief shelf.

4 Conclusion

In a retaining wall with pressure relief shelf, the total active earth pressure is decreased due to the provision of shelf in the mid height of the retaining wall. The design moment of the stem portion obtained from soft computing method is less than

conventional method. The overturning moment obtained for retaining wall with relief shelf is less than the retaining wall without relief shelf. The design moment of pressure relief shelf obtained from soft computing method is less than the conventional method. Factor of safety against overturning and sliding is more in retaining wall with pressure relief shelf. Also the retaining wall with pressure relief shelf is safer against overturning and sliding than retaining wall without pressure relief shelf, so there is no need for shear key in retaining wall with shelf. Retaining wall with pressure relief shelf attains overall stability when comparing with retaining wall without relief shelf. The area of reinforcement required for toe and heel slab is less in retaining wall with pressure relief shelf than the retaining wall without relief shelf. It is also obtained that the total area of reinforcement required for retaining wall with pressure relief shelf is less than the total area of reinforcement required for retaining wall without pressure relief shelf.

References

1. Chadhuri, P. R., Garg, A. K., Bhaskarai, P. R. R., Sharma, R. N., & Satija, P. D. (1973), "Design of Retaining Walls With Relieving Shelves". In Journal of the Indian Roads Congress (Vol. 35, No. 2).
2. Chauhan, V. B., Dasaka, S. M., & Gade, V. K. (2016), "Investigation of Failure of a Rigid Retaining Wall With Relief Shelves". Japanese Geotechnical Society Special Publication, 2(73), 2492-2497.
3. Chougule, A. C., Patankar, J. P., & Chougule, P. A. (2017), "Effective Use of Shelves in Cantilever Retaining Walls". International Research Journal of Engineering and Technology (IRJET) e-ISSN, 2395-0056.
4. Conti, R., Viggiani, G. M. B., & Burali d'Arezzo, F. (2015), "Some Remarks on The Seismic Behaviour of Embedded Cantilevered Retaining Walls". In Geotechnical Earthquake Engineering: Géotechnique Symposium in Print 2015 (pp. 137-147). ICE publishing.
5. Dhamdhere, D. R., Rathi, V. R., & Kolase, P. K. (2018), "Design and Analysis of Retaining Wall". International Journal of Management, Technology and Engineering, 8(9), 1246-1263.
6. Hany F Shehata (2016), "Retaining Walls With Relief Shelves" Innovative Infrastructure Solutions, 1(1), 4.
7. Hitesh Rathi, Dr. G.N. Ronghe (2019), "Optimize Positioning of Relief Shelf Cantilever Retaining Wall". GRD Journal of Engineering , e-ISSN:2455-5703
8. J. P. Bhusari, & Ghodke, R. S.(2019), "Structural Behaviour of Cantilever Retaining Wall With Pressure Relieving Shelves". International Journal of Engineering Research & Techology (IJERT).
9. Karthik Babu C and Keerthi Gowda B S (2016), " Analysis of Counterfort Retaining Wall With or Without Pressure Relief Shelf Using Soft Computing Technique". Science insights: An International Journal.
10. Padhye, R. D., & Ullagaddi, P. B. (2011), "Analysis of Retaining Wall With Pressure Relief Shelf by Coulomb's Method". In Proceedings of Indian Geotechnical Conference (pp. 671-673).
11. Patil, S. S., & Bagban, A. A. R. (2015), "Analysis and Design of Stepped Cantilever Retaining Wall". International Journal of Engineering Research & Technology (IJERT), 4(02).

12. Prachi S. Bhoyar, Dr. G. D. Awachat (2019), " Static Analysis and Design of Retaining Wall With and Without Shelve Using Software". International Journal of Engineering Research & Techology (IJERT).
13. Prof. Dr. D.N.Shinde(Guide), Mr.Rohan R. Watve(Student) (2015), "Optimum Static Analysis of Retaining Wall With or Without Shelf at Different Level Using Finite Element Analysis". International Journal of Engineeering Research and Journal Science.
14. Singla, S., & Gupta, S. (2015), "Optimization of Reinforced Concrete Retaining Walls of Varying Heights Using Relieving Platforms". International Journal of Engineering Research and Technology, 4(06), 1071-1077.
15. V. B. Chauhan and S. M. Dasaka (2016), "Behaviour of Rigid Retaining Wall With Relief Shelves With Cohesive Backfill". Research Gate.