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Effective Use of Shelves in Cantilever Retaining Walls

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Abstract - *Reinforced concrete cantilever retaining walls (RCCRW) are used in a variety of engineering fields such as roads, dams, tunnels and mines. RCCRWs are usually favored due to their economic benefits when compared to counterfeited walls. When considering retaining walls of greater height, the RCCRW can be effectively used if shelves are provided in the stem. If the shelves are extended up to rupture surface, the effective lateral earth pressure on the wall decreases considerably (which is advantageous for stability of the wall) as compared to cantilever retaining wall without shelves. This paper conducts a thorough analysis of the design measures taken of RCCRWs with 1) Single and Double shelves, and 2) Without Shelves. The paper concludes that the best location for a shelf for single shelf retaining walls is at 7/12th of stem height from top and the best locations for two shelves for double shelf retaining wall is at 4/12th of stem height and 7/12th of stem height from top.*

***Key Words*: Retaining Wall, Effective lateral earth pressure, rupture surface, double shelf, best location**

1. INTRODUCTION

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. A. R. Jumikis[1], P. C. Varghese[3] suggested that the stability of counterfort wall can be considerably increased by providing one or more relief platforms or shelves in cross section of such a wall and by extending them up to rupture surface. The relief shelves have an advantage of decreasing lateral earth pressure on wall and increasing overall stability of the structure. This results in an economical design since less material has to go into the wall as compared with massive structure or cantilever, and even counterforted walls without shelves. Bhaskarai, P. R. and et all[2]stated that as the total active earth pressure on a retaining wall with relief shell is lower in magnitude than that of conventional type only if the shelf is extended upto the rupture surface.

Retaining walls may be used economically by providing relief shelves on the back fill side of the wall. Such walls are termed as the retaining wall with relief shelf. One or more relief platforms or shelves extended to the rupture surface may have an advantage of decreasing the overall lateral earth pressure on the wall and increasing the stability of the structure. This will be an economical design because less material goes into the wall as compared to massive structure of cantilever or even counterfort retaining walls without shelves. The study of such type of retaining wall is therefore important to see its performance.

1.1 Change in pressure due to presence of shelf

Retaining wall supports a "wedge" of soil. The wedge is defined as the soil which extends beyond the failure plane of the soil type present at the wall site, and can be calculated once the soil friction angle is known. As the setback of the wall increases, the size of 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 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 and the cohesive strength of the retained material, as well as the direction and magnitude of movement the retaining structure undergoes.

Lateral earth pressures are zero at the top of the wall and in homogenous ground increase proportionally to a maximum value at the lowest depth. Earth pressures will push the wall forward or overturn it if not properly designed. Also, any groundwater behind the wall that is not dissipated by a drainage system causes hydrostatic pressure on the wall. The total pressure or thrust may be assumed to act at one-third from the lowest depth for lengthwise stretches of uniform height. Figure 1.1 and Figure 1.2 shows the change in pressure distribution due to presence of shelf

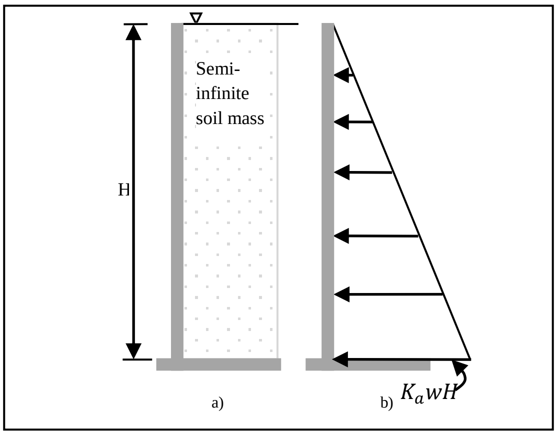

Fig -1.1: Stem of Cantilever type of retaining wall without shelf

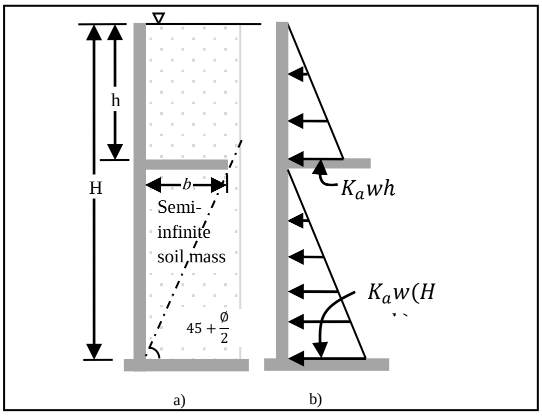

Fig -1.2: Stem of Cantilever type of retaining wall with shelf

From above literature review, it is observed that the study of retaining wall with relief shelf is somewhat an un-noticed area and very few studies have been carried out so far on this topic. It is also observed that rarely such retaining wall structures are constructed except gravity retaining wall. The study of this type of retaining wall is therefore important to see performance of such wall. The analytical and practical solutions regarding reduction in the sections of wall due to reduction in earth pressure is interesting to observe. In this project the efforts have been taken to perform the study of such type of wall from structural point of view.

In this paper best location of shelf for optimum design of reinforced concrete cantilever retaining wall "with single and double shelf" is found out and analysis, design and comparison of reinforced concrete cantilever retaining wall "without shelf", "with single shelf" and "with double shelf" is done, which will be of great practical use.

2. ANALYSIS OF MODELS

The following analytical models were analyzed and designed:

Model 1: Cantilever Wall Without Shelf (CWWS)
Model 2: Cantilever Wall with Single Shelf (CWSS)
Model 3: Cantilever Wall with Double Shelf (CWDS)
Manual and software analysis is done. Software

Analysis is done by using STAAD Pro V8i software. Analysis and design [4][5][6] of cantilever wall is done for per meter length of the wall. Analysis of stem, shelf, heel slab and toe slab is done as cantilever beam [4][5][6] and designed likewise.

All models are having same data and c/s dimensions for the parametric study. The data are listed in table 1.

Table -1: Assumed data for all models

Height of stem (h)	6 m	The density of soil (w)	18 kN/m³
Safe bearing capacity of soil is(q_o)	200 kN/m²	Co-efficient of friction between concrete and soil(μ)	0.5
The angle of repose (Φ)	30°	Active Earth Pressure (K_a)	0.3333
Depth of foundation	1.25m	Use M20 concrete and Fe415 steel.	
The backfill is horizontal.			

2.1 Analysis of CWWS

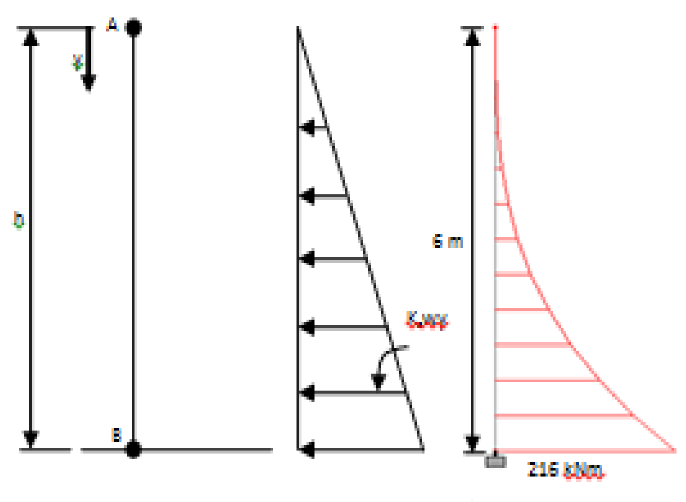

Fig -2: Analysis and BMD from STAAD-Pro software of stem of CWWS

The analysis of stem of CWWS is shown in figure 2. The Bending Moment Diagram (BMD) of stem from STAAD Pro software is also shown on right side of figure 2. The results are given in table 2.

The equation of BM at any level 'y' from top of the stem is

$$M_y = \frac{wy^3}{18}$$

Table -2: Assumed data for all models

BM at the base of stem(BM at 6 m)	216 (kNm)
Area BMD	324 (kNm^2)

2.2 Analysis of CWSS

The model of CWSS and pressure distribution of stem of CWSS is as shown in figure 3.1. The figure 3.2 shows BMD of stem of CWSS from STAAD Pro software.

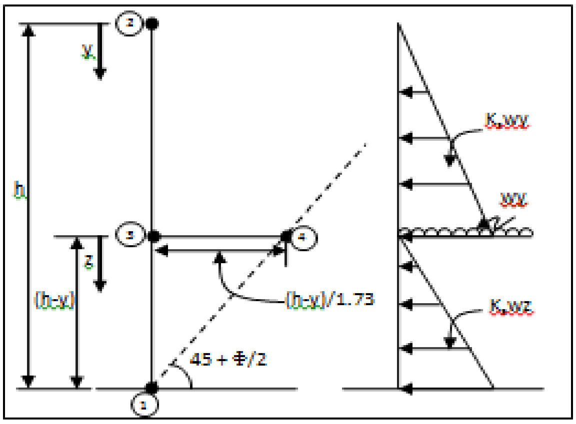

Fig -3.1: Model of CWSS and pressure distribution of stem of CWSS.

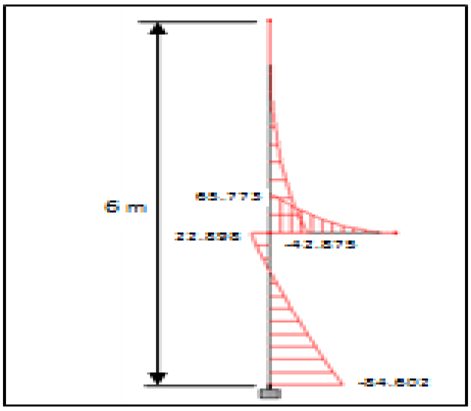

Fig -3.2: BMD (kNm) of CWSS from STAAD-Pro software, Shelf is at 7h/12 from top of the stem)

The manual analysis is done and general equations are derived. The equations are given below,

$$M_{y23} = \frac{wy^3}{18}$$

$$M_{yb3} = \frac{wy^3}{18} - \frac{wy(h-y)^2}{5.9858}$$

$$M_{y31} = \frac{wz^3}{18} + \frac{wy^3}{18} - \frac{wy^2 z}{6} - \frac{wy(h-y)^2}{5.9858}$$

Where (Refer figure 3.1),

M_{y23}= BM above shelf (BM between node 2 to 3)
M_{yb3}= BM just below shelf (BM just below node 3)
M_{y31}= BM below shelf (BM between node 3 to 1)
y = distance of a point under consideration from top of the stem(Maximum upto shelf) is Varies from 0.5 m to 5.5 m with an interval of 0.5 m each.
z = distance of a point under consideration from shelf (Maximum upto bottom of stem)is Varies from 5.5 m to 0.5 m with an interval of 0.5 m each.
Angle of rupture surface with heel slab = 45 + ϕ/2 = 60°
Length of loft = (h-y)/1.73 = Varies from 3.179 m to 0.289 m for each loft position.

The analysis of CWSS for stem height of 6m is done by using above general equations. The analysis is done for various location of shelf. The range of location of shelf is from h/12 to 11h/12 measured from top of stem and area of BMD is calculated. The values obtained from the analysis are given in table 3.

Table -3: Values of BM(kNm) and area of BMD(kNm^2) for CWSS

Position of shelf from top of stem	BM at node 3 due to soil wt above shelf (kNm)	BM at node 3 (kNm)	BM just below node 3 (kNm)	BM at node 1 (kNm)	Area of BMD (kNm^2)
h/12	45.48	-0.13	45.36	-125.14	229.11
2h/12	75.18	-1	74.18	-65.82	310.47
3h/12	91.34	-3.38	87.97	-33.53	345.81
4h/12	96.23	-8	88.23	-23.77	317.15
5h/12	92.09	-15.63	76.47	-32.03	244.11
6h/12	81.18	-27	54.18	-53.82	158.17
6.75h/12	69.9	-38.44	31.46	-76.33	122
7h/12	65.77	-42.88	22.9	-84.6	119
7.25h/12	61.5	-47.64	13.87	-93.16	122.65
8h/12	48.116	-64	-15.884	-115.88	163.41

9h/12	30.45	-91.13	-60.68	-155.18	234.8
10h/12	15.04	-125	-109.96	-185.96	285.04
11h/12	4.14	-166.38	-162.24	-207.74	312.79

2.3 Analysis of CWDS

The model of CWDS and pressure distribution of stem of CWDS is as shown in figure 4.1. The figure 4.2 shows BMD of stem of CWDS from STAAD Pro software.

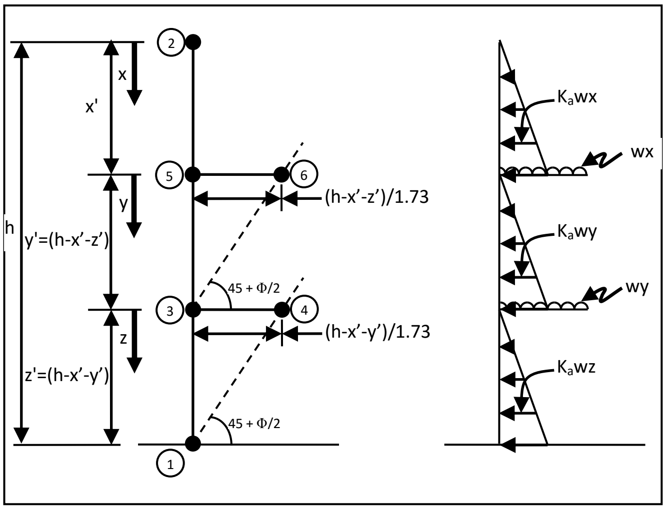

Fig -4.1: Model of CWDS and pressure distribution of stem of CWDS.

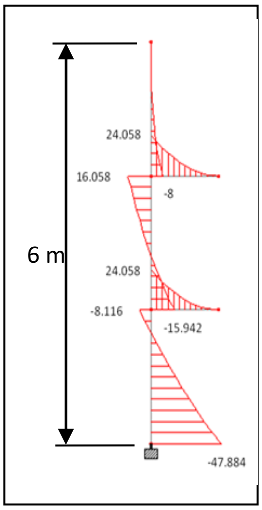

Fig -4.2: BMD (kNm) of CWDS from STAAD-Pro software, Shelves are at 4h/12 and 7h/12 from top of the stem)

The manual analysis is done and general equations are derived in same manner as derived for single shelf.
The notation used in figure 4.1 are as follows,

x = distance of a point under consideration from top of the stem(Maximum upto 1st shelf)
y = distance of a point under consideration from 1stshelf(Maximum upto 2nd shelf)
z = distance of a point under consideration from 2nd shelf (Maximum upto bottom of stem)
$45 + \phi/2$ = angle of the rupture surface with heel slab.

The analysis of CWDS for stem height of 6m is done by using general equations. The analysis is done for various location of shelf. The range of location of upper shelf is h/12 to 10h/12 and that of lower shelf is from 2h/12 to 11h/12 measured from top of stem and area of BMD is calculated. The values obtained from the analysis for the most a particular location of shelves is given in table 4.

Table -4: Values of BM(kNm) and area of BMD(kNm^2)for CWDS

Description	position of shelves from top of stem, 1st Shelf at 4h/12 2nd Shelf at 8h/12
BM at node 5 due to soil wt above 1st shelf(kNm)	24.0569 (kNm)
BM at node 5	8.0000 (kNm)
BM just below node 5(kNm)	-16.0569 (kNm)
BM at node 3 just above 2nd shelf(kNm)	24.0569 (kNm)
BM at node 3(kNm)	15.9431 (kNm)
BM just below node 3(kNm)	-8.1139 (kNm)
BM at node 1(kNm)	47.8861 (kNm)
Area of BMD(kNm^2)	62.1122 (kNm^2)

4. RESULTS AND DISCUSSIONS

From the analysis of CWWS, CWSS and CWDS for various shelf locations the results are found out and the comparison of steel quantity and stability are shown in the table 5 and table 6 respectively

Table -5: Comparison of steel quantity for different cantilever retaining wall models (Height H = 6m)

Quantities	Model 1: CWWS	Model 2: CWSS	Model 3: CWDS
Economic shelf location: (Distance from top of stem)	-------	7H/12	Upper shelf: 4H/12 Lower shelf: 7H/12
Steel in Kg	282.04	150.66	147.24
Concrete in m^3	3.24	3.6	3.63

Comparison of steel with Model 1	-------	46.58 % less	47.79 % less
Comparison of steel with Model 2	-------	-------	2.27 % less

Table -6: Stability for same dimensions of cantilever retaining wall in all models (Height H = 6m)

Quantities	**Model 1:** **Cantilever wall without shelf**	**Model 2:** **Cantilever wall with single shelf**	**Model 3:** **Cantilever wall with two shelves**
Economic Loft Location: (Distance From Top of Stem)	-------	7H/12	2ndLoft: 4H/12 1stLoft: 7H/12
Stability against overturning	2.83	3.86	3.36
Stability against sliding	1.55	2.6	3

5. CONCLUSIONS

“Retaining walls with shelves” are economical compared to conventional “retaining wall without shelves”.

The economic shelf location for cantilever retaining wall with single shelf is at 7H/12 from top of the stem, where H is height of stem.

The economic shelves locations for cantilever retaining wall with two shelves are, the 1st shelf at 7H/12 from top of the stem and the 2nd shelf is at 4H/12 (7/12 of 7H/12).

In a retaining wall with shelves, as the height of the wall increases, percentage saving of material increases.

Cantilever Retaining walls with two shelves are economical as compared to cantilever wall with single shelf.

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