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Efficiency of Retaining Wall Structures Incorporating Stress Relieving Shelves

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***Abstract**:* The aim of this study is to optimize the use of relief shelves for minimum lateral pressure and to study the economic aspects of providing shelves. The study is conducted in two parts, first analytical approach by conventional methods and then Finite Element Method of analysis using STAAD Pro. The analytical study shows that the pressure can be reduced to a maximum of 42.53% using single shelf and 62.28% using two shelves. The FEM analysis showed that the deflection of stem slab is reduced by 92.83% using one shelf and 95.18% by providing two shelves. The stresses on shelves increases to very high value if the width of shelf is increased by '0.3h', where 'h' effective height of soil backfill above shelf.

Index Terms **– Retaining wall, stress relief shelves, pressure relief shelves, STAAD pro, FEM analysis.**

I. INTRODUCTION

In today's fast-growing world, it is possible to construct structures which were not affordable in past few years due to lack of knowledge and techniques. For example, roads and buildings can be constructed on the sloping side of a hill without the fear of damaging the structure due to land sliding. Retaining walls are important part of structure constructed to supports the vertical backfill. The most commonly used retaining walls are gravity retaining wall, cantilever retaining wall and counterfort retaining wall. Gravity retaining walls are found to me economical up to 3 m height, cantilever retaining walls are found to be economical up to 6m height beyond that these walls acquire very bulky structure occupying huge space which can be sometimes unaffordable due to constraints in available space. Since the scope of structures is increasing it is necessary to determine a viable solution. The cross-sectional dimensions of the retaining wall mainly depend on the lateral earth pressure due to the backfill soil retained. To reduce the lateral earth pressure geo technical materials were suggested like Expanded Polystyrene (EPS) (Horvath 1997), mixing of glass fibers with soil in backfill (Rehnman and Brans 1972), inclusion of cardboards (Edgar et al. 1989) and also recycled tire chips mixed with sand to reduce the weight of backfill (Reddy and Krishna 2015).
Estimation of lateral earth pressure is also responsible for determination of cost of the project (Goel and Patra 2008; Soon and Drescher 2007). So, to search for a solution to reduce the lateral pressure relief shelves were introduced on the cantilever retaining wall. Retaining walls with pressure relief shelves are not a new concept to the countries like India, China, Russia and Korea (Balwan and Kumbha2011; Tsagareli 1969 and Yakovlev 1974) but due to their complex nature the lack in fully developed mechanism. According to Liu and Chen 2013; the retaining wall with relief shelf saved the time period of construction, excavation and cost by 8.1, 30.8 and 11.4% respectively.
For the walls with greater heights gravity walls are uneconomical solution due to large cross section so relieving platforms can be provided to significantly reduce the lateral earth pressure (Jumikis 1964; Bowels 1997). These shelves can also be provided be on counterfort retaining wall (Jumikis 1964). These shelves were provided along the length of the wall. He explained the stability analysis for counterfort retaining wall with two relief shelves. Tsagareli 1969; theorized zero earth pressure just below the shelf due to void beneath the shelf so that the weight of backfill above the shelf is not transferred below. This theory was disproved experimentally (Yakovlev 1969; Yoo et al. 2012; Moon et al. 2013; Khan et al. 2016) and numerically (Chauhan et al. 2016; Shehata 2016) proving that gap between shelf and below soil is not required for the shelf to bear the load of the soil above it. Chaudhuri (1973), experimentally determined the stability of the wall using coulombs wedge theory but because of a simple model he was not able to determine the pressure behind the wall. Experimental analysis showed that by providing relief shelves the lateral pressure was significantly reduced on the wall (Yoo et al. 2012; moon et al. 2013; Chauhan et al. 2016). When the retaining wall was analyzed by finite element analysis its shows that there was significant reduction in deflection of stem due to addition of a shelf at mid height (Shinde and Watve 2015; Girme et al. 2017)

II. Methodology

2.1 Analytical approach

The following parameters are considered while designing the retaining wall for zero shelf, 1 shelf and two shelves. Provisions from IS456 are considered for cantilever retaining wall. The following are the provisions-

Height of backfill supported, H= 9m
Bearing capacity of soil ($Q_{SBC)}$ = 200KN/mm^2
Submerged weight of soil, Q_{sub}= 20KN/m^3
Angle of internal friction, Φ= 30^o
Coefficient of friction, μ=0.8
Unit weight of cement concrete= 20KN/m^3
Grade of concrete, F_{ck}= M20
Grade of steel, F_y = 415
Subgrade base reaction = 40* Q_{SBC}*FOS
= 24000KN/mm^2

The dimensions of the retaining walls are shown in the figures below. All the dimensions mentioned are in meters. In case of single retaining wall, the shelf is provided at the middle of stem, i.e. at H/2 height where 'H' is total height of wall, and in case of two shelves, the shelves are provided at H/3 and 2H/3 from the bottom of the wall

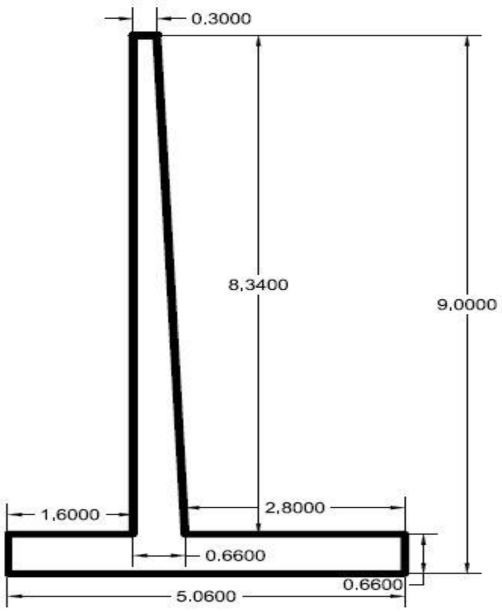

Fig.1. Cantilever retaining wall

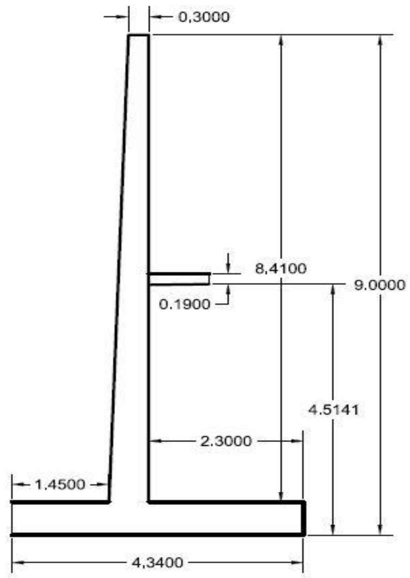

Fig.2. Retaining wall with one relief shelf

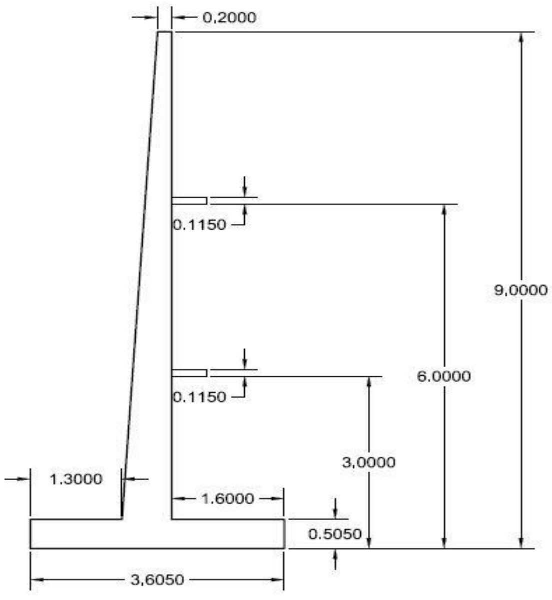

Fig. 3. retaining wall with two shelves

2.1.1 Forces and Moments on structure

Table 1. forces on components of wall

S. No	name of the component	weight/ force (KN) distance from heel(m)		moment (KN-M)
1	stem	W1	b1	W1xb1=M1
2	heel	W2	b2	W2xb2=M2
3	toe	W3	b3	W3xb3=M3
4	shelf	W4	b4	W4xb4=M4
5	soil above shelf	W5	b5	W5xb5=M5
6	soil below shelf	W6	b6	W6xb6=M6
7	remaining soil on heel slab	W7	b7	W7xb7=M7

Net force, W= ∑w=W1+W2+W3+W4+W5+W6+W7
Net resisting moment MR=∑M »∑M=M1+M2+M3+M4+M5+M6+M7
Active earth pressure = $\frac{1}{2}k\gamma H^2$
Where, K= $\frac{1-\sin\Phi}{1+\sin\phi}$
K= Rankine's coefficient
φ= angle of friction
ϒ= unit weight of backfill
h= height of soil section

The wall has an overturning moment due M_O due to active earth pressure which is in opposite direction of resisting moment M_R

I. For cantilever retaining wall of height H M_O= $\frac{1}{6}k\gamma H^3$

II. For retaining wall with single shelf at height h from base with a total height of wall H

$$M_O = \frac{1}{2}k\gamma h^2 + \frac{1}{6}k\gamma(H-h)^2[H-2h]$$

2.2 STAAD Modelling

STAAD pro is a perfect software to analyze the deflection of a member up to 3 decimal places of a millimeter. The shelf bear the complete load of the soil above it. The model in STAAD is as follows. A wall of constant height is considered – 7m, 9m and 11m the position of shelf is at optimum state where we get minimum earth pressure with varying its width difference between deflection for one and two shelves retaining wall.

The width of shelves are taken at 0.2h, 0.3h 0.4h 0.5h and 0.6h where 'h' stands for effective height of soil above the shelf. The mesh is generated at the base and shelf to account subgrade base reaction due to soil below underneath. The loads applied on the walls are uniformly varying load due to Rankins Earth pressure in horizontal direction of the stem, dead load of the soil on the retaining side and support reactions as subgrade base reaction by generating a mesh on base slab and shelf slab.

Lateral earth pressure on the basis of Rankin's earth pressure theory is P.

Therefore,

$$P = k\gamma h \text{ KN/m}^2$$

Where, h-height of soil above the shelf

Pressure P varies from 0 to $k\gamma h$ in horizontal direction varying about vertical axis.

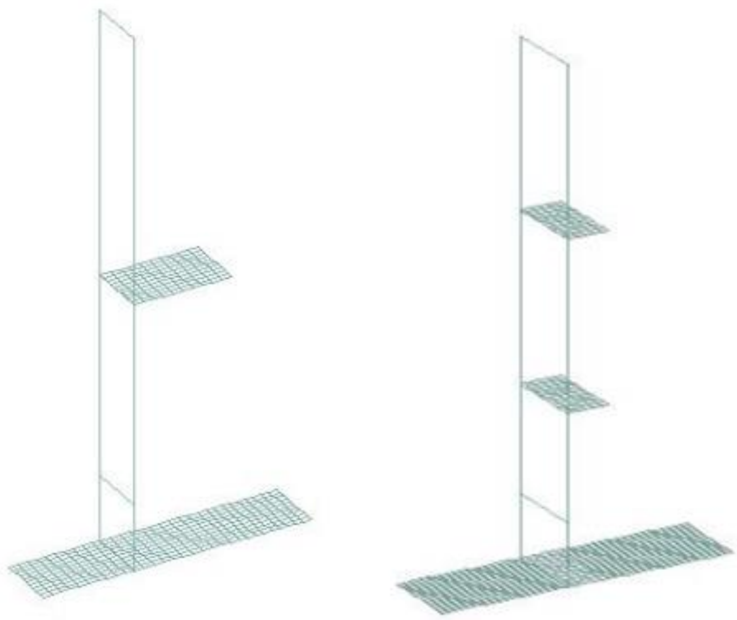

Figure 4 STAAD model for wall with 1 shelf and two shelves

III.Results and Discussion

3.1Numerical approach

The following observations were made by numerical analysis of the three retaining walls namely cantilever retaining wall, retaining wall with one shelf and retaining wall with two shelves.

The graph is plotted between location of relief shelf in terms of fraction of total height in x-axis and with lateral earth pressure on y-axis. A smooth upward parabola is formed shown in the fig 4. As the location shelf is switched from 0.1H to 0.9H creating an apex at 0.5H, the point of minimum lateral earth pressure. In case of two shelves initially the shelves were located at extreme ends then gradually brought closer to the mid of stem forming the above graph in fig 4. The two shelves behave as a single shelf at the center. The point of minimum earth pressures is at H/3 and 2H/3.

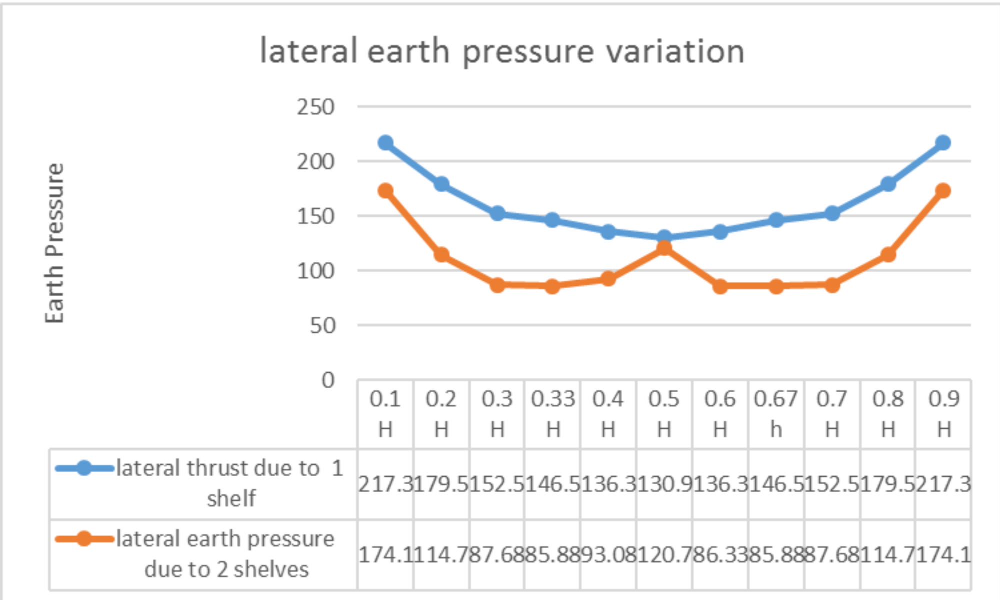

Fig. 5. lateral earth pressure variation on the stem with respect to location of shelf/ shelves

When the eccentricity of the net force on the wall is plotted against the location of relief shelf, we get the above graph for 1 and 2 relief shelves as shown in fig.5. For the case of single shelf as the location of the shelf is shifted upwards eccentricity gradually decreases up to 0.6H then increases, but still it is very less till 0.7H. In case of two shelves the pattern is similar to that of earth pressure in a double concave upward graph. A sudden hike in eccentricity signifies that the two shelves are very close and behave as a single unit.

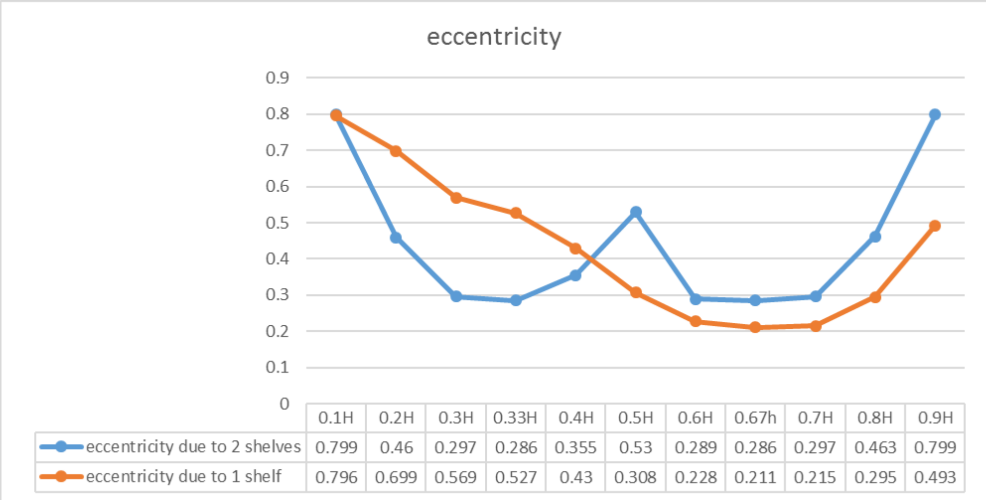

Fig. 6. eccentric behavior of wall with respect to location of shelf/shelves

Factor of safeties in sliding against the location of shelf/shelves are plotted for wall with 1 and 2 shelves. When in one shelf as the height of the shelf is increased the safety increase. After the mid-point sliding factors starts decreasing having maximum value at midway. While in two shelves graph shows two downward parabolas with maximum safety at H/3 and 2H/3.

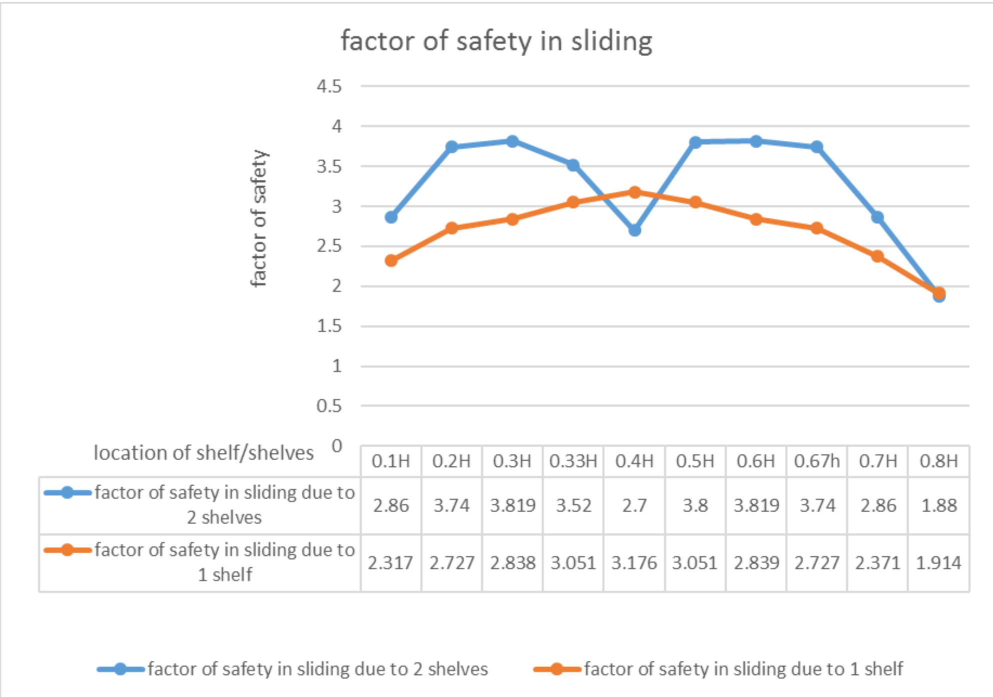

Fig. 7. factor of safety in sliding against location of shelf/shelves

The above explanations are formulated in a table 2 for most optimum locations of shelves

Table 2 comparative analysis of wall with zero, 1 and 2 shelves on various criteria

S. No.	Number of shelves / components	0 shelf	1 shelf	2 shelf
1	shelf width(m)	0	0.9	0.5
2	shelf thickness(m)	0	0.19	0.115
3	stem thickness(m)	0.66	0.59	0.505
	% reduction		10.61	23.48
4	base width(m)	5.06	4.34	3.605
	% reduction		14.2	28.75

5	lateral earth pressure (KN/m^2)	227.73	130.88	85.88
	% reduction		42.53	62.28
6	net moment (KN-m)	1494.09	1075.29	690.97
	% reduction		28.04	53.76
7	Eccentricity(m)	0.32	0.31	0.28
	% reduction		4.32	11.15
8	FOS overturning	2.99	2.81	2.63
	% reduction		5.81	11.92
9	FOS sliding	2.14	3.17	3.81
	% increase		48.50	78.56
10	concrete required(m^3)	167.46	153.14	116.87
	% reduction		8.55	30.21
11	Area of steel (mm^2)	10121.61	9823.49	8310.65
	% reduction		2.95	17.89

3.2 Finite element approach

Table 3. deflection of components of retaining wall with zero, 1 and two shelves in millimeters

number of shelves / component of wall	0	1	2
stem	99.791	7.153	4.8
heel	25.04	11.376	7.267
shelf		2.868	3.086

The above table shows the deflection in stem heel and shelf of the three retaining walls of 9m height. This shows that addition of a single shelf reduces the deflection in each component by large amount. When the deflection of base was calculated with respect to the changing width of shelf the following graph was observed. The width of shelf is denoted in the ration of total width of base 'B' to the height of soil retained over the shelf 'h'. Hence the shelves are of width 0.2h, 0.3h, 0.4h, 0.5h and 0.6h. The deflection decreases as the shelf width is increased to 0.5h and beyond that it increases. The graph has a similar pattern for wall with all heights.

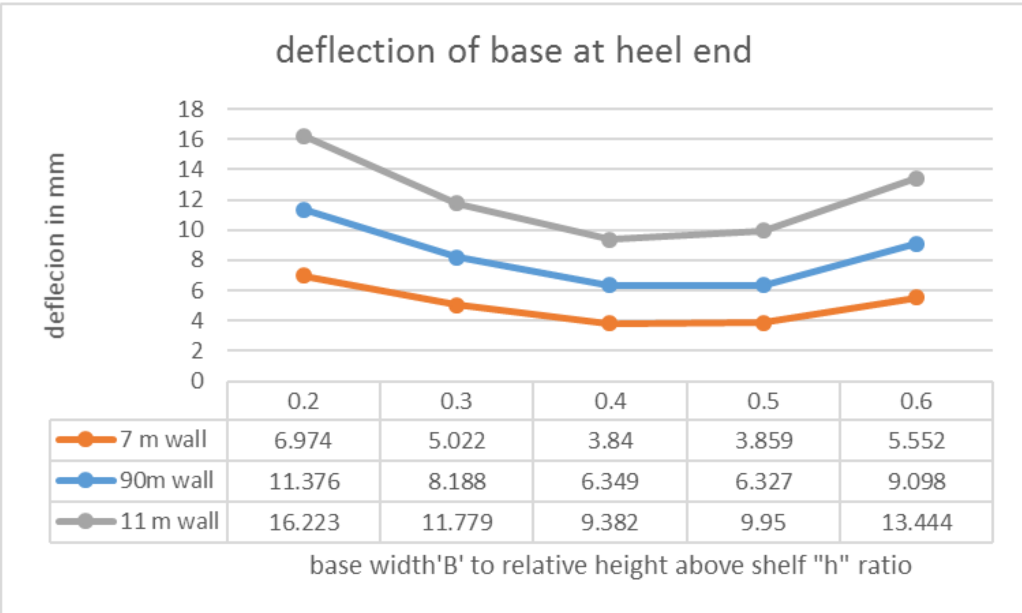

Fig 8. Deflection of base slab at heel for different width of shelf

IV.Conclusion

The introduction of relief shelves to the retaining walls is an effective solution economically and structurally. The following conclusions are derived from the above paper.

- The shelf location best suited for a wall with one shelf is between 0.4H to 0.6H. The lateral pressure is minimum at 0.5H, where 'H' is total height of the retaining wall. While providing two shelves the locations are H/3 and 2H/3.
- The requirement of base width is reduced by 14.2% by providing 1 shelf and by 28.75% by providing 2 shelves.
- The lateral pressure is reduced by 42.53% by using 1 shelf and reduction of 62.28% by using 2 shelves.
- Safety in sliding is increased by 42.53% in 1 shelf and 78.56% in 2 shelves.
- Reduction in concrete requirement is decreased by 8.55% by one shelf and reduced by 30.21% by 2 shelves.
- Provision of single shelf reduced the deflection in stem by 92.83% and by providing two shelf it is reduced by 95.18%.
- Shelf with width of 0.3h to 0.5h, where 'h' is height of soil above shelf, reduces the deflection on base by 44.38%

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