



## STATIC ANALYSIS OF RETAINING WALL WITH & WITHOUT SHELF BY USING F.E.M SIMULATION

Mr. Rohan R. Watve<sup>\*1</sup> Prof. Dr. D.N.Shinde<sup>2</sup>

<sup>1\*</sup> Civil Department, PVPIT Budhgaon, India.

<sup>2</sup> Civil Department, PVPIT Budhgaon, India.

**KEYWORDS:** Retaining Wall, Stadd proV8i, Self-weight, Earth Pressure, Stem, Heel, Toe.

### ABSTRACT

The most distinctive feature of the finite element method that separates it from other conventional methods is the division of a given domain into a set of simple sub domains, called finite elements. Any geometric shape that allows computation of the solution or its approximation, or provides necessary relations among the values of solution at selected points, called nodes, of the sub domain, qualifies as finite elements. Other features of the method include seeking continuous, often polynomial, approximations of the solutions over each elements in terms of nodal values, and the assembly of element equations by imposing the inter element continuity of the solution and balance of inter element forces.

### INTRODUCTION

The most Distinctive feature of the finite element method that separates it from other conventional methods is the division of a given domain into a set of simple sub domains, called finite elements.

Steps involved in the finite element analysis of a typical problem are shown below.

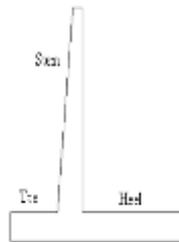
- i. Discretization (or representation) of the given domain into a collection of element formulation of the equation is completed.
  - a. Construct the finite element mesh of the prescribed elements.
  - b. Number the nodes and elements.
  - c. Generate the geometric properties (e.g. coordinates and cross sectional areas) needed for the problem.
- ii. Derivation of the element equations for all typical elements in the mesh.
  - a. Construct the variation of unknown formulation of the given equation over the typical element.
  - b. Assume the typical dependent variable  $u$  is the form of

$$u = \sum_{i=1}^n u_i \psi_i \quad \dots (4.1)$$

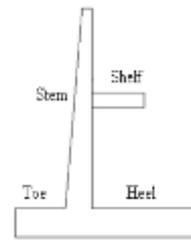
And substitute it into step ii-a to obtain element equations in the form.

- c. Derive or select, if already available in literature, element interpolation function  $\psi_i$  and compute element matrices. Assembly of the element equation to obtain equation of whole problem.
- d. Identify the inter element continuity conditions among the primary variables (relationship between local degrees of freedom and global degrees of freedom – connectivity of the elements) by relating element nodes to global nodes.
- e. Identify the “Equilibrium” conditions among the secondary variables (relationship between the local source or force components and globally specified source components).
- f. Assemble the element equations.
- iii. Imposition of the boundary conditions of the problem
  - a. Identify the specified global primary degrees of freedom. Identify the specified global secondary degrees of freedom.
- iv. Solution of the assembled equations.
  - i) Post processing of the results
    - a. Compute the gradient of the solution or other desired quantities from the Primary degrees of freedom computed in step iii-a.
    - b. Represent the result in tabular and/or Graphical form.

The following figure gives the clear idea about the retaining wall with shelf and without shelf.



1) Retaining wall Without Shelve (Fig no. 1a)



2) Retaining Wall With Shelve (Fig no.1b)

**MATERIALS AND METHODS**

**Introduction to STAAD-Pro**

For finite element modeling, STAAD-Pro V8i software is used. STAAD-Pro V8i is the most popular structural engineering software product for 2D as well as 3D model generation, analysis and multi-material design. It has an intuitive, user-friendly GUI, visualization tools, powerful analysis and design facilities and seamless integration to several other modeling and design software products. The software is fully compatible with all Windows operating systems. For static or dynamic analysis of bridges, containment structures, embedded structures (tunnels and culverts), pipe racks, steel, concrete, aluminum or timber buildings, transmission towers, stadiums or any other simple or complex structure, STAAD-Pro has been the choice of design professionals around the world for their specific analysis needs.

**Model of retaining wall without and with shelf in STAAD-Pro:**

STAAD-Pro is used to perform finite element analyses of retaining wall without and with shelf. The model of the cantilever reinforced concrete retaining wall without and with shelf is generated in Space structure (which is a three-dimensional framed structure with loads applied in any plane) and using four noded plate element. The model of the retaining wall without shelf includes 30 nodes and 14 plates and the wall with shelf includes 32 nodes and 15 plates. Node no. 1 to 6 on toe slab, node no. 5 to 10 on heel slab, node no. 5, 6, 11 to 30 on stem on node no. 31 & 32 on shelf. Node no. 5 & 6 is common for toe, heel and stem. Plate no. 1 & 2 on toe slab, plate no. 3 & 4 on heel slab, plate no. 5 to 14 on stem on plate no. 15 on shelf. Figure no. 4.1 and 4.2 show the Node no. and plate no. for retaining wall without and with shelf.

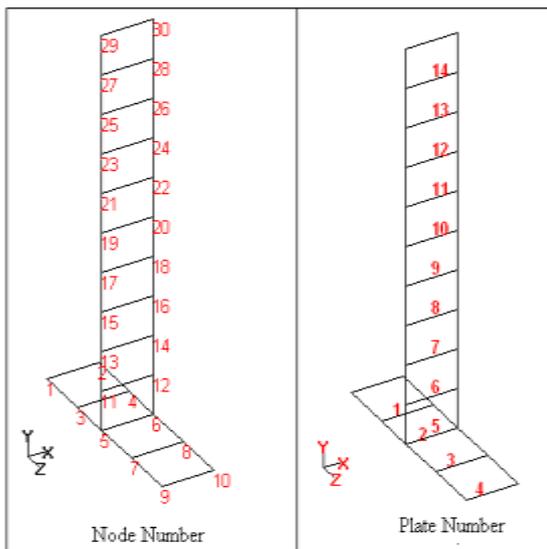


Figure 2.(a) Node no. and plate no. for retaining wall without shelf (Staad Model)

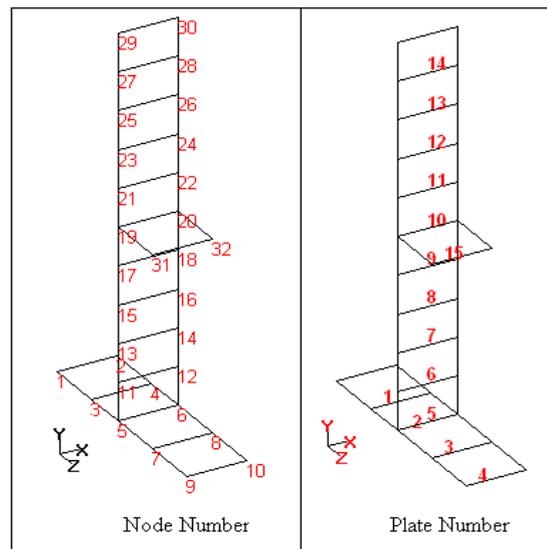


Figure2.(b) Node no. and plate no. for retaining wall with shelf (Staad Model)

Thickness property is given to the plates from commands menu as per thickness of toe, heel, stem and shelf. Fixed support is provided to node no. 5 & 6 which are intersection of toe, heel and stem from support page option. Toe,



heel and stem acts as cantilever member so fix support provide at their intersection joint. Figure no. 4.3 shows the fix support position for retaining wall without and with shelf.

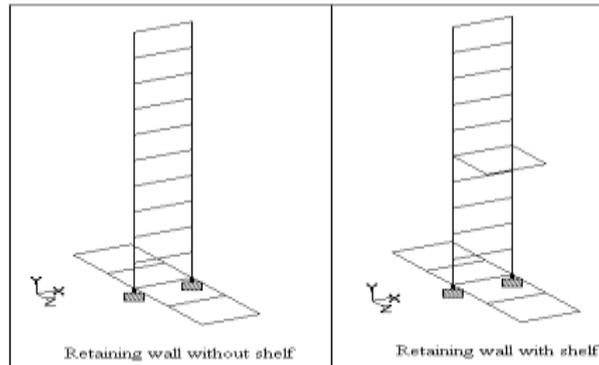


Figure 3 Fix support position for retaining wall (Staad Model fig.)

From load page option Load cases are made for different type loads such as self-weight of wall, earth pressure on stem and heel etc. These load cases are discussed below in details.

**Loading on Retaining wall without shelf:**

- Load case 1: Self-weight of retaining wall.
- Load case 2: Earth pressure on stem.
- Load case 3: Earth pressure on heel.
- Load case 4: Upward soil pressure on toe.
- Load case 5: Upward soil pressure on heel.

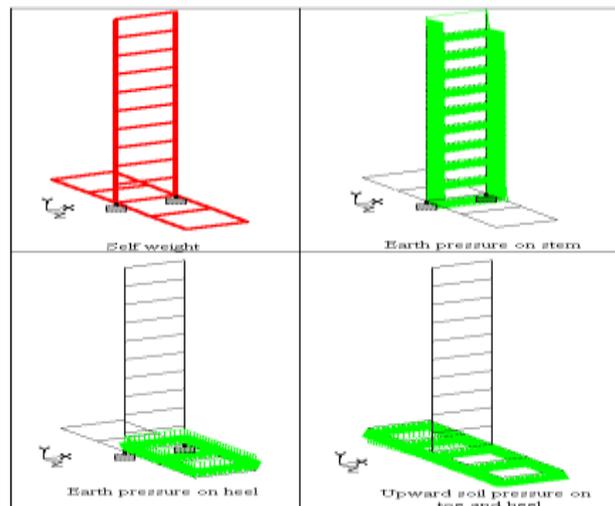


Figure 4: Loading on Retaining wall without shelf (Staad Model)

**Loading on Retaining wall with shelf at mid span:**

- Load case 1: Self-weight of retaining wall.
- Load case 2: Earth pressure on stem above shelf.
- Load case 3: Earth pressure on stem below shelf.
- Load case 4: Earth pressure on shelf.
- Load case 5: Earth pressure on heel below shelf.
- Load case 6: Earth pressure on heel.
- Load case 7: Upward soil pressure on toe.
- Load case 8: Upward soil pressure on heel.

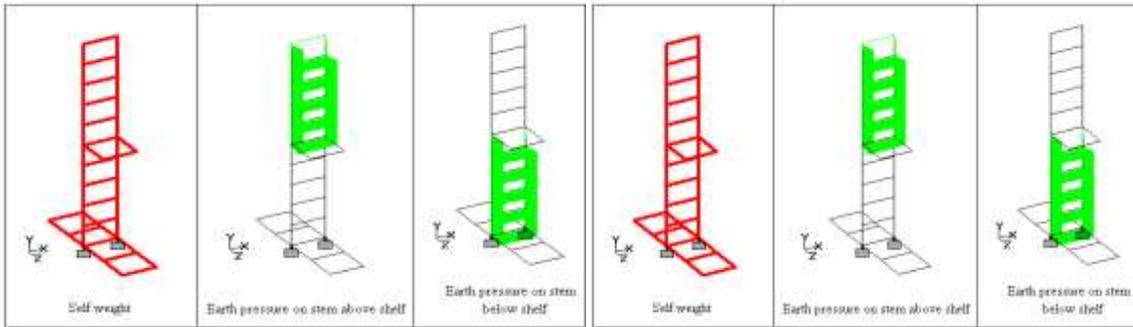


Figure5: Loading on Retaining wall with shelf

**RESULTS AND DISCUSSION**

**Modeling of the retaining wall and analysis in STAAD-Pro**

A four node plate element model is prepared for cantilever reinforced concrete retaining wall without and with shelf.

**Modeling of Retaining wall without shelf**

Figures shows the cross section and finite element model of retaining wall without shelf respectively. The model is prepared for the following geometry of wall.

Stem height	7 m
Heel	2 m
Toe	1 m
Top width of stem	0.4 m
Bottom width of stem	0.8 m
Toe/heel slab depth	0.8 m
Base width	3.8 m

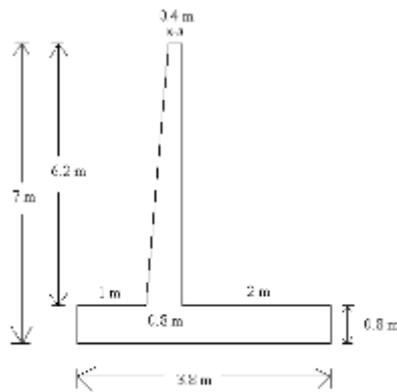


Figure 6.(a) Cross Section of Retaining wall without shelf

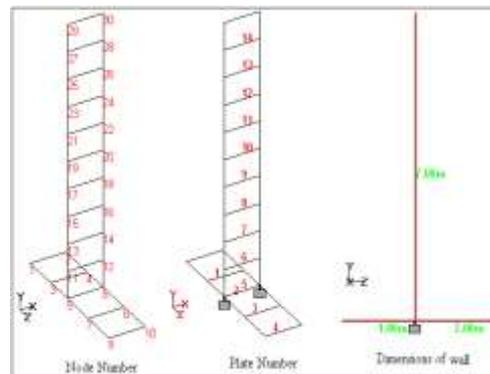


Figure 6.(b) Finite Element Model of Retaining wall

**Analysis result:**

**Support reaction:**

Table 1: Support reaction for retaining wall without shelf

Load Case	Fx kN	Fy kN	Fz kN
Load case 1: Self-weight of retaining wall.	0	-169	0
Load case 2: Earth pressure on stem.	0	0	-163.345
Load case 3: Earth pressure on heel.	0	-248	0



Load case 4: Upward soil pressure on toe.	0	274.674	0
Load case 5: Upward soil pressure on heel	0	142.322	0

**Support moments:**

*Table 2: Support Moment for retaining wall without shelf*

Load Case	Mx kNm	Mz kNm
Load case 1: Self-weight of retaining wall.	-	-238.92
Load case 2: Earth pressure on stem.	381.138	0
Load case 3: Earth pressure on heel.	-	-372
Load case 4: Upward soil pressure on toe.	-	412.011
Load case 5: Upward soil pressure on heel	-	213.483

**Displacement:**

(Node 1-4 on toe, Node 7-10 on heel, Node 11- 30 on stem, Node 5&6 common for toe, heel and stem)

*Table 3: Displacement for retaining wall without shelf*

Node	Horizontal	Vertical	Horizontal
	X mm	Y mm	Z mm
1	0	0.251	0
2	0	0.251	0
3	0	0.08	0
4	0	0.08	0
5	0	0	0
6	0	0	0
7	0	-0.083	0
8	0	-0.083	0
9	0	-0.227	0
10	0	-0.227	0
11	-0.001	-0.006	-0.306
12	0.001	-0.006	-0.306
13	-0.001	-0.01	-1.141
14	0.001	-0.01	-1.141
15	0	-0.015	-2.323
16	0	-0.015	-2.323
17	0	-0.018	-3.742
18	0	-0.018	-3.742
19	0	-0.021	-5.31
20	0	-0.021	-5.31
21	0	-0.024	-6.963
22	0	-0.024	-6.963
23	0	-0.026	-8.661
24	0	-0.026	-8.661
25	0	-0.027	-10.377
26	0	-0.027	-10.377
27	0	-0.028	-12.099
28	0	-0.028	-12.099
29	-0.001	-0.029	-13.821
30	0.001	-0.029	-13.821

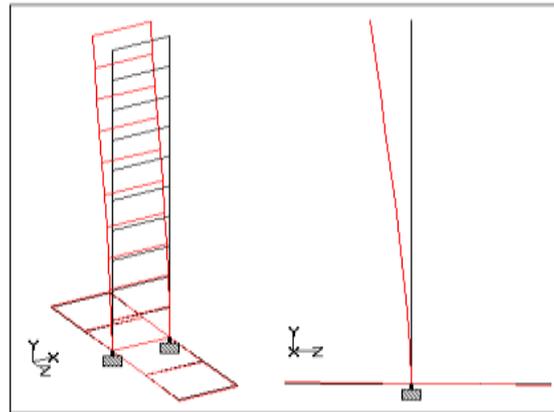


Figure 7. Displacement of retaining wall without shelf

**Modeling of Retaining wall with shelf at mid span of stem**

The modeling is done on Retaining wall with shelf. The shelf is provided at the mid height of the stem. Figure 5.8 and figure 5.9 shows the cross section and finite element model of retaining wall with shelf respectively. The model is prepared for following geometry of wall.

Stem height	7 m
Heel	2 m
Toe	1 m
Top width of stem	0.4 m
Bottom width of stem	0.8 m
Toe/heel slab depth	0.8 m
Base width	3.8 m
Shelf width	1.0 m
Shelf thickness	0.4 m

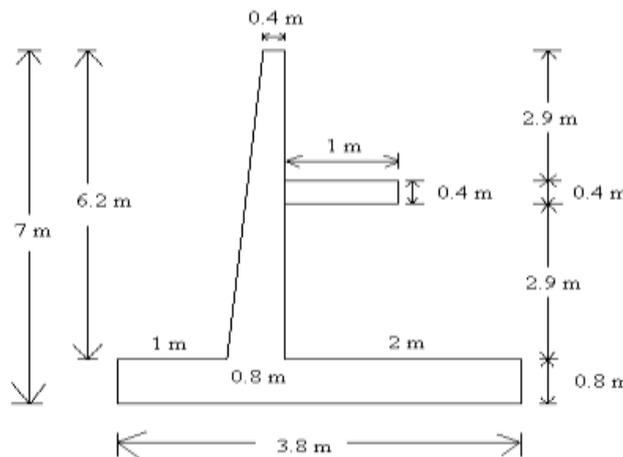


Figure 8. Cross Section of Retaining wall with shelf at mid span

**Analysis result:**  
**Support reaction:**

Table 4: Support reaction for retaining wall with shelf at mid span

Load Case	Fx kN	Fy kN	Fz kN



Load case 1: Self-weight of retaining wall.	0	-179	0
Load case 2: Earth pressure on stem above shelf.	0	0	-36.167
Load case 3: Earth pressure on stem below shelf	0	0	-36.167
Load case 4: Earth pressure on shelf.	0	-62	0
Load case 5: Earth pressure on heel below shelf.	0	-62	0
Load case 6: Earth pressure on heel	0	-124	0
Load case 7: Upward soil pressure on toe.	0	210.025	0
Load case 8: Upward soil pressure on heel.	0	209.046	0

**Support moment:**

*Table 5: Support moment for retaining wall with shelf at mid span*

Load Case	Mx kN	Mz kN
Load case 1: Self-weight of retaining wall.	0	-268.5
Load case 2: Earth pressure on stem above shelf.	-168.781	0
Load case 3: Earth pressure on stem below shelf	-42.195	0
Load case 4: Earth pressure on shelf.	0	-93
Load case 5: Earth pressure on heel below shelf.	0	-93
Load case 6: Earth pressure on heel	0	-186
Load case 7: Upward soil pressure on toe.	0	315.038
Load case 8: Upward soil pressure on heel.	0	313.568

**Displacement:**

(Node 1-4 on toe, Node 7-10 on heel, Node 11- 30 on stem, Node 31&32 on shelf, Node 5&6 common for toe, heel and stem)

*Table 6: Displacement for retaining wall with shelf at mid span*

Node	Horizontal	Vertical	Horizontal
	X mm	Y mm	Z mm
1	0	0.167	0
2	0	0.167	0
3	0	0.054	0
4	0	0.054	0
5	0	0	0
6	0	0	0
7	0	-0.025	0
8	0	-0.025	0
9	0	-0.076	0
10	0	-0.076	0
11	-0.001	-0.01	-0.141
12	0.001	-0.01	-0.141
13	-0.001	-0.019	-0.527
14	0.001	-0.019	-0.527
15	-0.001	-0.028	-1.075
16	0.001	-0.028	-1.075
17	-0.001	-0.036	-1.732
18	0.001	-0.036	-1.732
19	-0.001	-0.043	-2.445
20	0.001	-0.043	-2.445
21	0	-0.046	-3.201
22	0	-0.046	-3.201
23	0	-0.048	-3.998
24	0	-0.048	-3.998
25	0	-0.049	-4.811
26	0	-0.049	-4.811
27	0	-0.05	-5.628



28	0	-0.05	-5.628
29	-0.001	-0.051	-6.447
30	0.001	-0.051	-6.447
31	-0.001	0.879	-2.446
32	0.001	0.879	-2.446

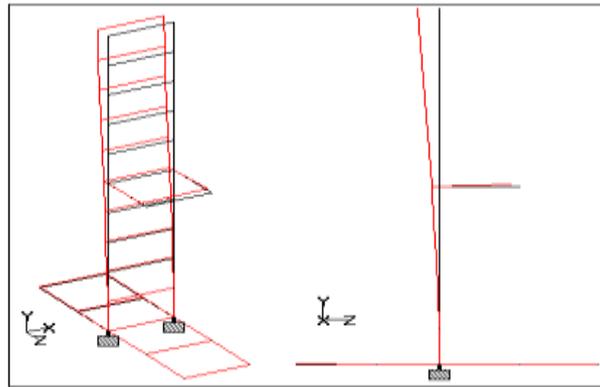


Figure 9: Displacement of retaining wall with shelf at mid span

- Same modeling and analysis done for varying the position of shelf also width of shelf the following table Give clear idea about varying the position

**Combination of location and width**

Table No7): Combination of location factor and shelf factor

Combination	Shelf width	Shelf location from top				
		0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
Combination 1	0.25 m	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
Combination 2	0.50 m	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
Combination 3	0.75 m	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
Combination 4	1.0 m	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h

- The Following Observations are done after all Work is completed

**Support reaction**

**Self-weight of retaining wall:**

Table 8: Self-weight of retaining wall

Shelf width	Shelf position (Load in kN)				
	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
0.25 m	129.688	129.688	129.688	129.688	129.688
0.50 m	130.625	130.625	130.625	130.625	130.625
0.75 m	131.563	131.563	131.563	131.563	131.563
1.0 m	132.5	132.5	132.5	132.5	132.5

Table (8) gives the values of self-weight of retaining wall. The values of self-weight are increases with increasing the width of shelf and it same for particular location. Self-weight of retaining wall with shelf increases due to which stability force increases and retaining wall become more stable.



**Support Moment:  
Moment due to self-weight**

*Table 9: Moment due to self-weight*

Shelf width	Shelf position (Moment in kN.m)				
	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
0.25 m	194.53	194.53	194.53	194.53	194.53
0.50 m	195.94	195.94	195.94	195.94	195.94
0.75 m	197.344	197.344	197.344	197.344	197.344
1.0 m	198.75	198.75	198.75	198.75	198.75

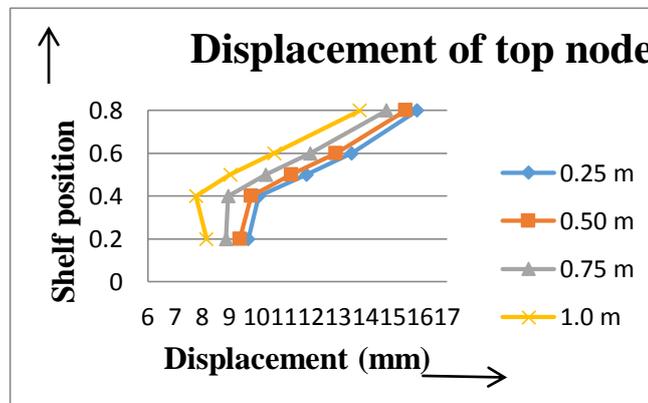
Table (9) gives the values of moment due to self-weight of retaining wall. The values of moment are increases with increasing the width of shelf and it same for particular location.

**DISPLACEMENT**

**Displacement of top node**

*Table10: Displacement of top node*

Shelf width	Shelf position (Displacement in mm)				
	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
0.25 m	9.699	10.076	11.838	13.494	15.902
0.50 m	9.390	9.806	11.278	12.925	15.480
0.75 m	8.876	8.959	10.345	11.977	14.776
1.0 m	8.156	7.773	9.038	10.651	13.792

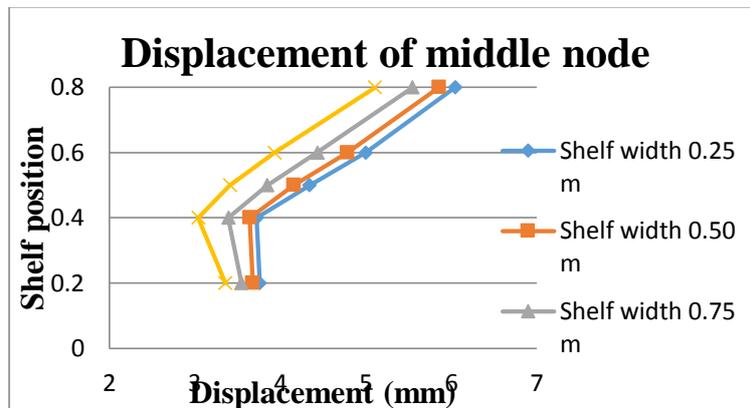


*Graph 1. Displacement of top node for shelf location*

**Displacement of middle node**

*Table11: Displacement of middle node*

Shelf width	Shelf position (Displacement in mm)				
	0.2 h	0.4 h	0.5 h	0.6 h	0.8 h
0.25 m	3.757	3.723	4.341	4.999	6.045
0.50 m	3.677	3.643	4.155	4.786	5.857
0.75 m	3.544	3.392	3.845	4.431	5.545
1.0 m	3.057	3.040	3.410	3.934	5.108



Graph 2. Displacement of top node for shelf location

## CONCLUSION

The retaining wall with relief shelf is proved to be advantageous over the cantilever and counterfort retaining wall. The finite element analysis of 2-D model of retaining wall by using STAAD-Pro is performed in this work. The software STAAD-Pro can be suitably applied for the structural analysis of such type of wall. The study of deflections, bending moment, support reactions, etc. on various components of retaining wall can be performed by this software.

Following are the concluding remarks.

1. The best location for the single shelf is observed to be in between 0.4 h to 0.5 h for the maximum reduction in earth pressure, less bending moments and less deflection.
2. The deflection of the stem is reduced by about 41.50% by providing shelf at 0.5 h than the deflection given without shelf.
3. The deflection of the stem depends mainly on the shelf location and it increases for the shelf located from 0.2 h to 0.8 h.
4. The deflection reduces by increasing the width of the shelf but the variation is less.
5. The pattern of occurrence of bending moment on toe for all the shelves (0.25 m, 0.50 m, 0.75 m, 1.0 m) is same in X & Y direction.
6. Displacement of shelf reduces as the width of shelf increases at a particular location.
7. Self-weight of retaining wall with shelf increases due to which stability force increases and retaining wall become more stable.

## REFERENCES

1. Suliman B.A.Mohamed, Kuo-Hsing Yang. (2014): Finite element analyses of two-tier geosynthetic reinforced soil wall comparison involving centrifuge test and limit equilibrium results.
2. Padhye R. D. (2010), Ph.D. thesis on "Analysis and Design of Retaining Walls with Pressure Relief Shelves".
3. Syed Mohd. Ahmad and P. K. Basudhar, (2008) "Behaviour of reinforced soil retaining wall under static loading using finite element method" The 12<sup>th</sup> International Conference
4. Kevin Abraham (2007), "Three dimensional behavior of retaining wall systems," A Dissertation for the degree of Doctor of Philosophy. The Department of Civil and Environmental Engineering. M.S., Mississippi State University.
5. P.E. Pinto and C.G. Lai (2006) "Numerical Modelling & Seismic Behavior of Earth Retaining Walls".
6. Padhye R. D. & Ullagaddi P. B., (2005), "Retaining Walls with Pressure Relief Shelf – A Review Study", All India Seminars on, "Advances in Geotechnical Engineering". National Institute of Technology, Rourkela. pp 62
7. Varghese P.C. (2005), "Foundation Engineering", Prentice Hall of India Pvt. Ltd. New Delhi.
8. Seung-Hoon Lee, Buhm soo Chang (2004) Two-Parameter Beam-column model and back analyses for flexible Earth retaining walls.
9. J.R. Blake, J.P. Renaud, M.G. Anderson, (2003) Prediction of rainfall-induced transient Water pressure behind a retaining wall using a high resolution finite element model.



10. Ray Chaudhuri P. et al (1973), Paper No. 295. "Design of Retaining Walls with relieving shelves" IRCJournal, Volume 35, part 2, pp 289 - 325.
11. G. Wayne Clough and James M. Duncan, (1971) "Finite Element Analyses of Retaining Wall Behavior" Vol. 97, No. 12, pp.1657-1673.
12. Jumikis A. R. (1964), "Mechanics of Soils", D. Van NostrandCompanInc, PrincetonNJ.