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Finite Element Analysis of RCC Cantilever Retaining Wall with and without Pressure Relief Shelf using Staad Pro: A Case Study on Construction of AANSON Building Project, Sinamangal, Kathmandu

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Abstract

A project named "Construction of AANSON Building at Sinamangal" is taken as a case study for the stability analysis of RCC Cantilever Retaining Wall with and without Pressure Relief Shelves. Modelling is done using Finite Element Method (STAAD Pro) using plate and 4 noded models. The earth pressure exerted by the back-fill soil and the underlaying soil is applied on the model after calculation of parameters. The investigations are carried out on some of the major factors like displacement of stem, heel and toe, bending moments, reactions etc. The result reveals that the pressure relief shelves could be used in RCC Cantilever retaining walls to make the structure more stable.

Keywords

Pressure Relief Shelf, STAAD Pro, Earth Pressure(P), Stem, Toe, Heel, Earth Pressure above Shelf(P1), Earth Pressure below shelf(P2), Coefficient of active earth pressure(ka)

1. Introduction

It is also possible to consider retaining walls with relief shelves as a special type of retaining walls. Some engineering studies have reported that using shelves is the most cost-effective method of building high walls.

According to the study scenario, high cantilever retaining walls can also be the most economical solution when relief shelves are attached to the backfill side of stem. [1] These walls are labeled as retaining wall with relief shelves.If there is a construction near the wall and it is not possible to apply the soil reinforcement, the use of this type of wall can be the most efficient tool to reduce costs and improve overall safety.

2. Research Objectives

The overall objective of the present thesis is to contribute to the Finite Element Method analysis of RCC Cantilever Retaining wall with and without pressure relief shelves. For being operationalized, this objective has to be split up into smaller and more specific objective in order to achieve the overall objective.

1. To use the analytical method for the stability analysis of RCC Cantilever Retaining wall with and without pressure relief shelves.
2. To use Finite Element Method tool using the parameters obtained from analytical method for calculation of displacement, moments, support reactions among the nodes and plates of retaining wall.

3. Literature Review

A pressure relief shelf is a thin horizontal cantilever platform of finite width, extending into the backfill at right angles, throughout the length of the retaining wall, constructed monolithically with the stem of the retaining wall. Number of such shelves is constructed at regular spacing along the height of the wall.

When designing retaining walls, an engineer must assume some of the dimensions, called proportioning, which allows the engineer to check trial sections for stability. If the stability checks yield undesirable results, the sections can be changed and rechecked.

Jumikis [2] found that the relief shelves decrease the lateral earth pressure on the wall and increase the stability of the overall retaining structure.

P. R. and et all [3] 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.

Yakovlev [4] experimentally investigated the earth pressure distribution on a wall with two relief shelves.

Padhye R.D., Bhoye H.N. [5], 2012 carried out the FEM analysis of RCC Cantilever retaining wall with and without shelves and carried out the factors like displacement of stem, heel and toe, bending moments, reactions etc. He observed that the deflection of stem is reduced due to provision of shelf at mid height by about 47.5% at top and bending moment in X direction by about 55% than the deflection and bending moment given without shelf.

Shinde , Watve [6], 2015 carried out the FEM analysis of RCC Cantilever retaining wall with and without shelves and also compared the result by changing the locations and width of shelf.

Fuchen, Shile [7] predicted the earth pressure for shorter relief shelves for analytical calculation of RCC Retaining wall with pressure relief shelf. He formulated the active earth pressure distribution for the shorter relief shlef using Feng Goudung's theory.

4. Materials and Methodology

The research work started with the study of article related to the RCC Retaining wall. Primary and secondary data are collected using literature and lab test reports, then these data are used in model. Analytical Method is used for stability analysis of the retaining wall (with and without shelf) with proportioning based upon several literatures and codes.

4.1 Location

Study area considered in this research is the project for the building project for Civil Aviation Authority of Nepal. The project area lies near Tribhuvan International Airport. Geographically the site is located at 27o 41' 51.28" N/85o 21' 19.31"E at an elevation of 1323 meter from mean sea level. It is in the left side of Sinamangal-Airport road, partly attached to the road and partly just behind Nepal World Peace Stupa located in front of Tribhuvan International Airport.

4.2 Laboratory Test Results

It includes collection of technical information and facts regarding soil data underlaying the retaining wall and back fill soil. Five no. of boreholes (percussion drilling) were drilled at the site previously for the similar scope of works. Standard Penetration Tests were conducted. The test represents the overall area of the site since several boreholes were drilled. From the borehole data, the data representing the real position of RCC Retaining wall to be placed was taken.

1. Geotechnical Parameters like angle of internal friction, cohesion, safe bearing capacity were adopted from conducted laboratory test results.

2. Angle of repose of backfill soil=27;Bulk Density of soil(Y)=13.5 KN/m3; Safe Bearing Capacity=90 KN/m2 were adapted from the laboratory tests conducted at the site.

4.3 Analytical Method

1. Fixation of base width, heel and toe length, height of stem, depth of foundation, thickness of stem.

2. Stability Analysis using above mentioned parameters

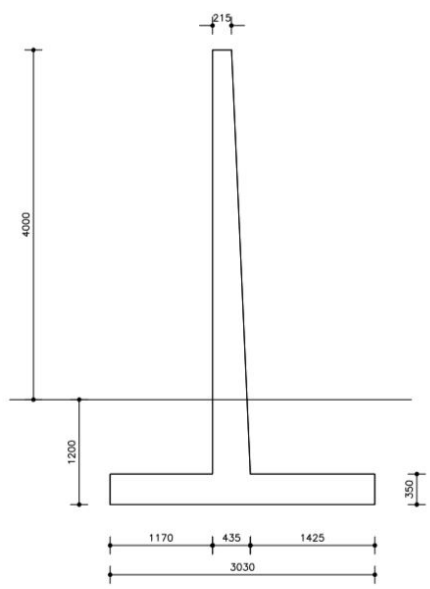

Figure 1: Fixation of base widths, heights and other parameters from different criteria

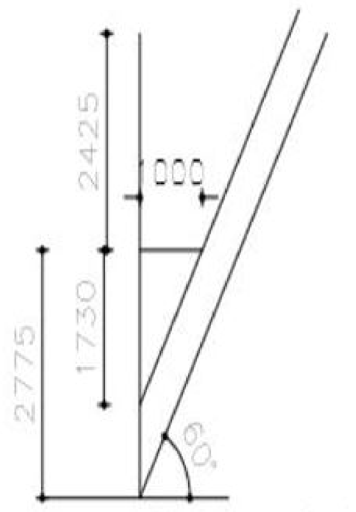

Figure 2: Application of Feng Guodung's theory for the calculation of earth pressure for the model(1 m shelf @ 0.5 H from top)

Table 1: Calculation of earth pressure applying Feng Guodung's theory

Description	1m shelf at middle	Without Shelf
Y	13.5 KN/m3	13.5 KN/m3
ka	0.376	0.376
H1	2.425 m	
H2	2.775 m	
H3	1.735 m	
H		5.2 m
P1	14.925 KN/m2	
P2	32.346 KN/m2	
P		53.22 KN/m2

Table 2: Calculation of upward soil pressure as per analytical method

Description	Without Shelf	1m shelf at middle
Pmax at heel	73.76 KN/m2	66.04 KN/m2
Pmax at toe	31.72 KN/m2	45.22 KN/m2
Eccentricity	0.2	0.09

4.4 Finite Element Model

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 node plate elements. 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.

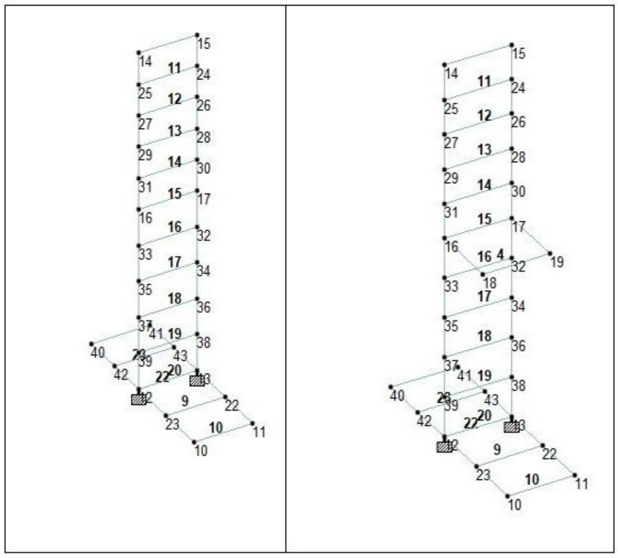

Figure 3: Node and plates of RCC cantilever retaining wall with and without shelf

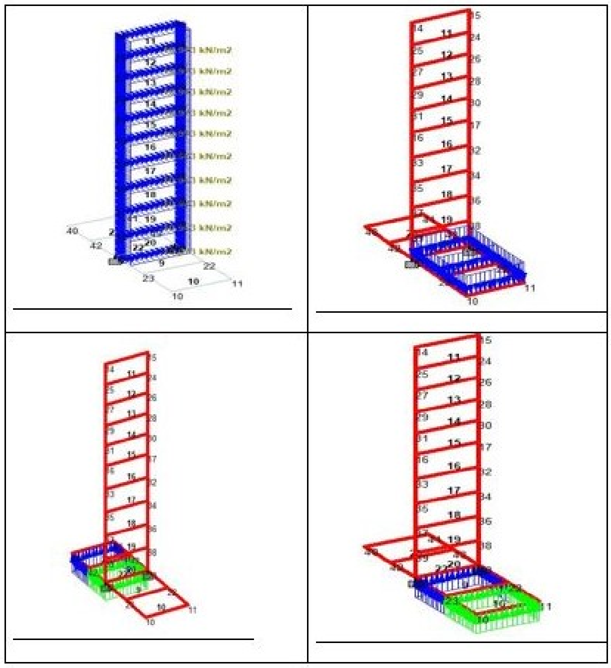

Figure 4: Loading Assigned along the elements RCC wall without shelf

Figure 3 shows the node number and plate number for retaining wall without and with shelf. 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. 12 and 13 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. The several load cases are formulated like Self Weight, Earth Pressure at stem above shelf, Eath Pressure at stem below shelf, Earth Pressure on Heel, Upward Soil Pressure on Toe, Upward Soil Pressure on heel. The load envelopes are created in the STAAD Pro. Then the loadings are applied as per calculated from the analytical method. Then the static analysis is done on the basis of applied load parameters and load envelopes. The obtained results from the software are tabulated and comparative analysis among the nodal displacements, bending moments among the plates is made.

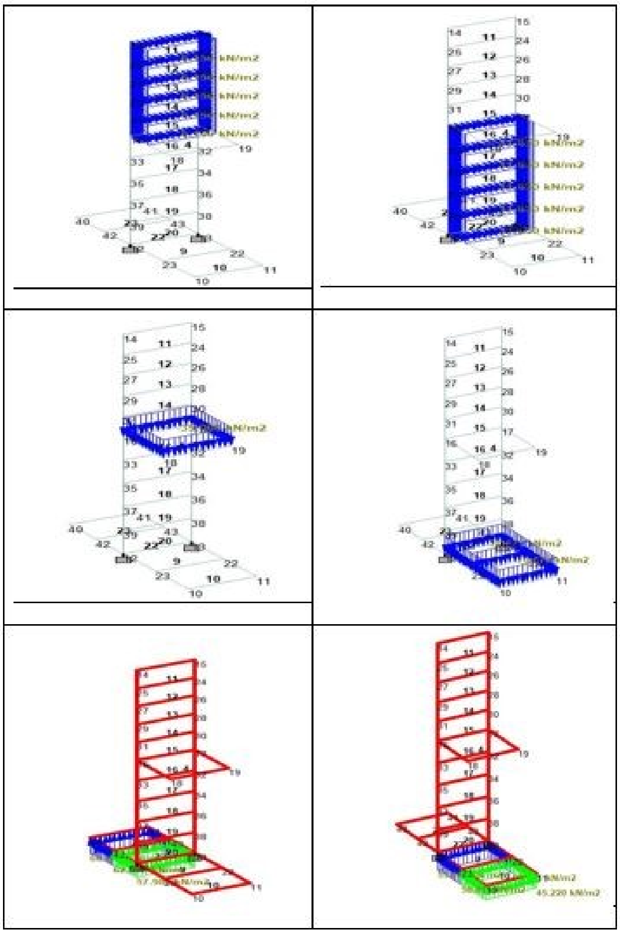

Figure 5: Loading Assigned along the elements RCC wall with shelf

5. Results and Discussions

Comparative study of analysis of retaining wall with and without shelves were made.

5.1 Stability Analysis

Table 3: Comparison of stability of retaining wall with and without shelf

S.N.	Description	Without shelf	With shelf
1	FOS(Sliding)	1.36	1.96
2	FOS(Overturning)	2.81	3.98

5.2 Finite Element Method Analysis from STAAD Pro

Table 4: Comparison of support reactions of retaining wall with and without shelf

S.N.	Load Case	Without Shelf		Shelf Length =1m 0.5H	
		Fy	Fz	Fy	Fz
1	Self-Wt.	-78.038	0	-86.285	0
2	Earth Pressure at Stem above Shelf	0.000	-57.06	0.000	-14.914
3	Earth Pressure at Stem below Shelf			0.000	-32.329
4	Earth Pressure on Shelf	0.000	0.000	-35.000	0.000
5	Earth Pressure on heel	-115.900	0.000	-115.900	0.000
6	Upward soil pressure on toe	90.350	0.000	86.193	0.000
7	Upward soil pressure on heel	67.240	0.000	82.100	0.000

Table 5: Comparison of moment of supports of retaining wall with and without shelf

S.N.	Load Case	Without Shelf		Shelf Length =1m 0.5H	
		My	Mz	My	Mz
1	Self-Wt.	0.000	-39.019	0.000	-43.142
2	Earth Pressure at Stem above Shelf	28.530	0	7.457	0
3	Earth Pressure at Stem below Shelf			16.164	0
4	Earth Pressure on Shelf	0.000	0.000	0.000	-17.500
5	Earth Pressure on heel	0.000	-57.950	0.000	-57.950
6	Upward soil pressure on toe	0.000	45.175	0.000	43.096
7	Upward soil pressure on heel	0.000	33.620	0.000	41.050

Table 6: Comparison of moment of plates of retaining wall with and without shelf

S.N.	Plate No.	Without Shelf		Shelf Length =1m 0.5H	
		Mx	My	Mx	My
1	9	-10.537	-59.399	-10.537	-59.399
2	10	-6.180	-11.88	-6.180	-11.88
3	11	-0.937	-0.645	-0.525	-0.362
4	12	-0.937	-3.226	-0.525	-1.808
5	13	-0.937	-8.389	-0.526	-4.702
6	14	-0.934	-16.132	-0.508	-9.041
7	15	-1.001	-26.457	-0.911	-14.828
8	16	-1.011	-40.493	-0.705	-22.222
9	17	-0.948	-58.642	-1.405	-30.499
10	18	-1.047	-80.17	-1.040	-38.776
11	19	0.018	-105.078	-0.753	-47.053
12	20	-12.018	-133.366	-4.608	-55.330
13	22	41.178	8.091	38.413	7.657
14	23	8.493	5.972	7.812	5.581

Table 7: Comparison of nodal displacements at plates at retaining wall with and without shelf

S.N.	Node	Without Shelf		Shelf Length =1m 0.5H	
		Y	Z	Y	Z
1	40	0.452	-	0.421	-
2	41	0.452	-	0.421	-
3	42	0.162	-	0.152	-
4	43	0.162	-	0.152	-
5	12	0.000	-	-	-
6	13	0.000	-	-	-
7	23	-0.312	-	-0.312	-
8	22	-0.312	-	-0.312	-
9	10	-0.888	-	-0.888	-
10	11	-0.888	-	-0.888	-
11	14	-0.016	-6.837	-0.018	-3.153
12	15	-0.016	-6.837	-0.018	-3.153
13	24	-0.014	-5.989	-0.017	-2.751
14	25	-0.014	-5.989	-0.017	-2.751
15	26	-0.014	-5.144	-0.017	-2.350
16	27	-0.014	-5.144	-0.017	-2.350
17	28	-0.014	-4.306	-0.017	-1.953
18	29	-0.014	-4.306	-0.017	-1.953
19	30	-0.013	-3.486	-0.015	-1.566
20	31	-0.013	-3.486	-0.015	-1.566
21	16	-0.012	-2.699	-0.014	-1.198
22	17	-0.012	-2.699	-0.014	-1.198
23	32	-0.010	-1.862	-0.012	-0.811
24	33	-0.010	-1.862	-0.012	-0.811
25	34	-0.008	-1.127	-0.010	-0.481
26	35	-0.008	-1.127	-0.010	-0.481
27	36	-0.006	-0.536	-0.007	-0.223
28	37	-0.006	-0.536	-0.007	-0.223
29	38	-0.003	-0.136	-0.004	-0.054
30	39	-0.003	-0.136	-0.004	-0.054

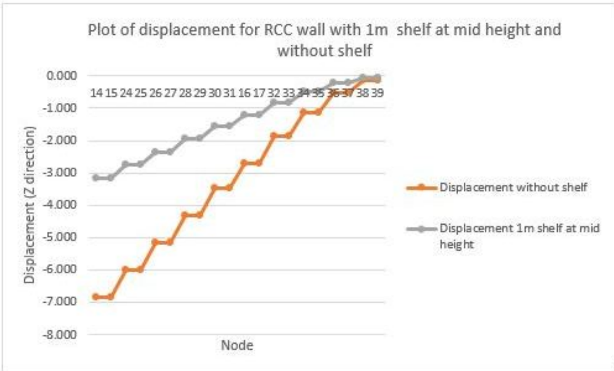

Figure 6: Plot of Displacement(Y) vs nodes for retaining wall with and without shelf above shelf

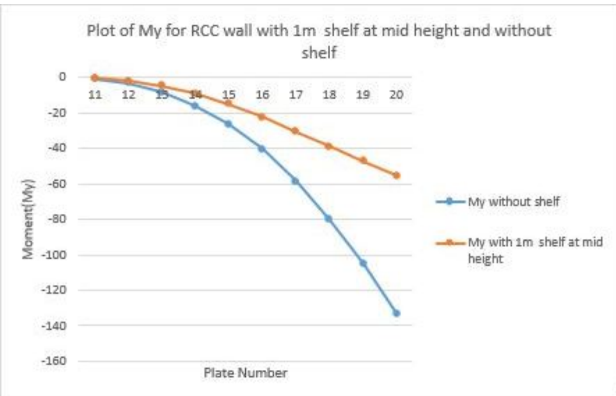

Figure 7: Plot of Moments(Y) vs nodes for retaining wall with and without shelf below shelf

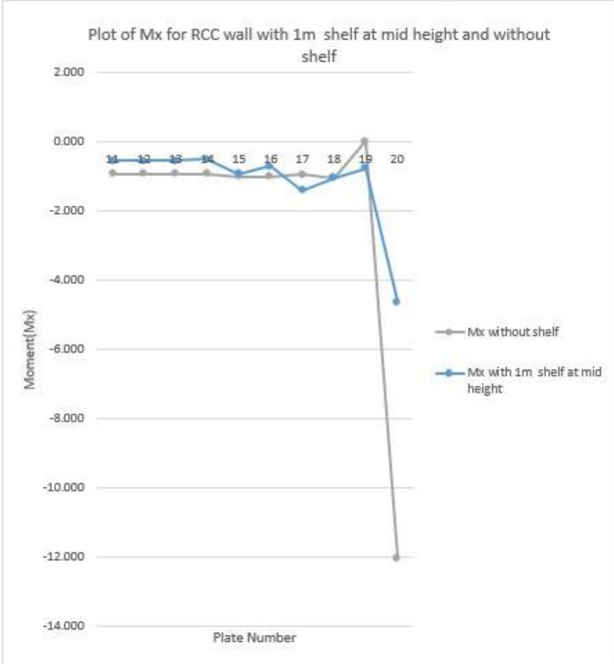

Figure 8: Plot of Moment(X) vs plates for retaining wall with and without shelf below shelf

6. Conclusions

1. FOS of RCC Cantilever Retaining wall against sliding increased from 1.36 to 1.96 by introducing 1 m shelf at mid height of stem.

2. FOS of RCC Cantilever Retaining wall against sliding increased from 2.81 to 3.98 by introducing 1 m shelf at mid height of stem.

3. Self-weight of retaining wall with shelf increases due to which stability force increases and retaining wall become more stable.

4. The top deflection of the stem is reduced by 53.88 percentage (highest) by adding 1m shelf at mid height.

5. The plate moments along stem is reduced by about 52.85 percentage in average by adding 1m shelf at mid height.

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