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Enhancing Retaining Wall Stability: A Comparative Study Of Counter-Fort Retaining Walls Versus Counter-Fort Retainingwalls With Relief Shelves Using E-TABS

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Abstract: This project examines the design and analysis of two types of retaining walls: the Counter-fort Retaining Wall and an innovative variation with Relief Shelves. Retaining walls are essential for slope stabilization and preventing soil erosion. The study investigates the structural efficiency and stability of these designs under different loading conditions. The Counter-fort Retaining Wall is analyzed using standard engineering principles, while Relief Shelves are introduced to enhance stability and aesthetics by reducing lateral earth pressure. Analytical methods and computer simulations are used to assess performance under two conditions as Retaining wall with and without Relief Shelve. The results aim to provide insights into the advantages and limitations of each design, offering practical recommendations for optimal design parameters in geotechnical engineering and retaining wall construction. This research contributes to the field by informing better decision-making and promoting sustainable infrastructure development.

***Index Terms* -** Retaining walls, Counter-fort Retaining Wall, Relief Shelves, Slope stabilization, Soil erosion prevention, Lateral pressure resistance, Soil properties, Structural efficiency, Stability analysis

I. Introduction

Retaining walls are structures built to resist the lateral pressure of soil when there is a change in ground elevation that exceeds the soil's angle of repose. Commonly used in civil engineering and landscaping, they stabilize and support soil, preventing collapse and erosion. Applications include road and railway embankments, bridge abutments, waterfront structures, and terraced gardens. Retaining walls help prevent erosion and runoff, critical for water quality and environmental protection. The primary forces acting on retaining walls are earth pressure and self-weight, influenced by soil properties like internal friction and cohesive strength. Proper analysis and design are essential to prevent structural failure.

Key Components and Considerations:

Types of Retaining Walls:

- Gravity Walls: Depend on mass and weight, suitable for low to moderate heights.
- Cantilever Walls: Use a horizontal cantilever section and vertical stem, typical for medium to high walls.
- Counterfort Walls: Similar to cantilever walls but with additional vertical slabs for stability.
- Gabion Walls: Wire baskets filled with stones, allowing water flow and reducing pressure.
- Segmental Walls: Made of precast blocks, often used for decorative purposes.

Components:

- Stem: Vertical section bearing soil pressure.
- Base: Distributes load to the foundation.
- Toe: Provides stability at the base.
- Heel: Extends horizontally, providing counterweight.
- Backfill: Material placed behind the wall for resistance.
- Drainage System: Manages water to prevent hydrostatic pressure.
- Reinforcement: Increases strength and stability.
- Facing: Adds aesthetic appeal and protection.
- Anchors (Optional): Provide extra support.

Design Considerations:

- Soil Properties: Crucial for design and stability.
- Wall Height: Influences wall type selection.
- Surcharge Loads: Additional loads near the wall top affecting stability.
- Drainage: Essential to prevent water accumulation and pressure.

Construction Materials:

Materials: Include timber, gabions, segmental blocks, reinforced concrete, and masonry.

Counter-fort Retaining Wall:

A Counter-fort retaining wall, used to retain soil and prevent erosion on slopes, includes vertical concrete members (counterforts) for additional support. Key components are the base, stem, toe, and counterforts, which act as braces against lateral pressure. The construction process involves excavation, foundation building, formwork setup, reinforcement placement, concrete pouring, curing, and backfilling. Design considerations include load calculations, drainage, and material selection. These walls offer stability and flexibility for higher loads and taller heights compared to traditional cantilever walls.

Failure in a Counter-fort Retaining Wall:
The failure of a Counter-Fort retaining wall can occur due to various factors, including design flaws, construction defects, inadequate maintenance, or unforeseen environmental conditions.

II. LITERATURE REVIEW

2.1.1 Arun Maher, Ashwini Korade, Ashish Deshmukh, Karuna Pawar, Asst. Prof. Uday A. Kakde(Dec 2022 This research paper is about analysis and design of counterfort retaining wall. There are many types of retaining walls but selected the counterfort retaining wall. We chose the counterfort retaining wall because it is more reliable and strong type of retaining wall. In this type of retaining wall the counterforts are provided at suitable intervals i.e. H/2, H/3 and 2H/3 resp. Generally the 2H/3 distance corresponding to height is most widely used for counterforts. Counterfort retaining wall with counterforts or pressure relief shelf are very strong as compared to conventional cantilever retaining wall.

2.1.2 Vicharapu Balaji, S. Shameem Banu(March 2022): An Earth retaining wall is a structure which is used to counteract the lateral earth pressures or to sustain the soil behind it. Cantilever Retaining wall structures are usually constructed to the height of 6m by analyzing the various parameters that need to applied in the design of retaining structures. Counterfort retaining walls are another type of retaining wall where specially designed counterforts are used to resist lateral earth pressure. Stability analysis plays an important role in the design of retaining wall.

2.1.3 Karthik Thipparthi, Srikanth Kandalai, Kastro Kiran (Feb 2020): Retaining walls are used with tying with more than one wall at perpendicular joints to retain liquids, water storage and materials storages such as dyke walls and tanks. Retaining walls excessively used in culverts and as well as in the bridges i.e., construction of abutments, wing walls supposed to resist soil pressures, applied perpendicular to the axis of the walls. Due to in-sufficient land and based on the present construction scenario followed in the construction of retaining structures, the wall height is often increased, thereby increasing the cost of construction of sub structure.

2.1.8 Dr. G. D. Awachat and Prachi S. Bhoyar (5/MAY2019): The findings of the static analysis and the design of retaining walls with and without shelves are presented in this study. One unique kind of retaining wall is the cantilever retaining wall with pressure-relieving shelves. By reducing the overall earth pressure on a R.C.C. retaining wall, the idea of installing pressure relief shelves on the backfill side of the wall leads to a reduction in wall thickness and, eventually, an economical cantilever wall design. The addition of shelves causes significant modifications to the pressure distribution diagram. To ensure the stability of the structure, the pressure relief shelves have been extended to the failure plane. In actuality, utilizing more shelves is limited, although upward.

2.1.4 Naveena N (July 2018): The transportation sector involves a number of activities which are mainly depending on the financial aspect. In the planning and design of highways there is increasing need for analysis to indicate justification of the expenditure required and the comparative worth of proposed improvements, particularly when various alternatives are being compared. In roadway or railway sector the alignment will be passing through cutting or filling. In this portion a number of structures like masonry retaining wall, RCC retaining wall, Mechanically Stabilized Earth Wall etc. will be provided to retain the earth, depending upon the site condition and funds availability.

2.1.5 D.R. Dhamdhere (2018) have worked for optimal solution. He has chosen optimal cost as best solution. He fixed base width and other dimensions of retaining wall then performed stability check and determined minimum and maximum bearing pressure and then accordingly designed all portions of retaining wall. He has taken reliving platform length equal to heel slab length and reliving platform's length is considered one fourth of base slab thickness

2.1.6 Karthik Babu and Keerthi Gowda B (17 December 2016): Analyzed an 8m high counterfort retaining wall using soft computing techniques (SAP-2000) versus traditional methods. Parameters like pressure relief shelf position and width were optimized. Soft computing proved more efficient than manual design, making it beneficial for less experienced engineers.

2.1.7 Kusum Sahu, Dolendra Patel (2014): One of the important retaining structures used in civil engineering is retaining wall. It finds application in highway engineering, irrigation and bridge engineering. The current research reviews the existing work in the field of retaining wall design and analysis. The existing analysis are based on use of experimental and numerical techniques. The results obtained from these techniques are evaluated with analytical methods. The extensive review on shelves, material type and design of retaining wall is presented.

2.1.8 Sanjei(2015) selected various retaining wall's shape by performing preliminary calculations. He conducted finite element Analysis, for that he used PLAXIS. He considered two ways of construction first one is Backfilling after the wall construction and other is backfilling parallel to wall construction. He generated finite element model for his analysis. He selected three different shapes with constant height and cross-sectional area. He used trial method to adopt stable section as per BS 8002. He estimated exerted force on retaining wall first by using Coulomb's method of analyze and wedge method. He assumed few basic properties of soil and designed wall as mass concrete, and calculated optimal base size for three walls.

2.1.9 Indrajit Chowdhury (2013) evaluated the performance of gravity type of retaining wall for earthquake loading: He has taken simplest case of retaining wall in which back fill considered is dry and cohesion less. Backfill soil is sandy and ground is not having any slope. He proposed mathematical model for same case. His model is based on few assumptions that Active pressure is mobilized already so it cannot induce any stiffness to overall dynamic response and inertial effect contribution will be there. Also, as thickness of wall is sufficient, he has considered stiffness contribution, thus wall is considered as contributing in stiffness and inertia.

III. METHODOLOGY

This study employs a mixed-method research design, combining quantitative and qualitative approaches to analyze and design a counterfort retaining wall. Data collection involves an extensive literature review to establish a theoretical foundation, along with site-specific geotechnical data gathering, including soil properties and environmental conditions. A representative site reflecting typical engineering challenges is selected for the study.

Geotechnical analysis is conducted to determine key parameters such as friction type, bearing capacity, cohesion, and angle of internal friction. Load calculations include surcharge loads, self-weight, and water pressure. The structural design is developed using site-specific data and load requirements, and E-Tab software is utilized for modeling the retaining wall, applying loads, and analyzing structural responses. Iterative analyses are performed to optimize the design.

Results of the geotechnical analysis, structural design, and E-Tabs simulations are presented, highlighting insights from the optimization process. The study concludes with a summary of key findings, their implications, and suggestions for future research in retaining wall design and analysis.

Design Conditions for Retaining Wall
For the site conditions:

- Height above ground level: 8m
- Sub charge angle (□): 30º
- Coefficient of friction (μ): 0.5
- Grade of concrete: M25
- Grade of steel: Fe500
- Safe bearing capacity (SBC): 200 KN/m²
- Soil density: 17 KN/m³
- Seismic zone: IV
- A counterfort retaining wall is designed for heights above 6m.

Determining the Dimensions of counterfort Retaining wall:

- Depth of Foundation: Calculated as 1.3m.
- Spacing of Counterfort: Adopted as 3m.
- Thickness of Counterfort: Calculated as 300mm.
- Thickness of Base Slab: Calculated as 558mm.
- Toe Projection: Calculated as 1.5m.
- Height of Stem: Calculated as 8.742m.
- Stem Thickness: Calculated as 250mm.

Forces:

- Active Earth Pressure (Pa): 242.60 KN/m²
- Stem Weight (W1): 54.63 KN
- Heel & Toe Weight (W2): 83.7 KN
- Soil Pressure: 6.31 KN

These calculations and design parameters form the basis for the structural integrity and performance of the counterfort retaining wall

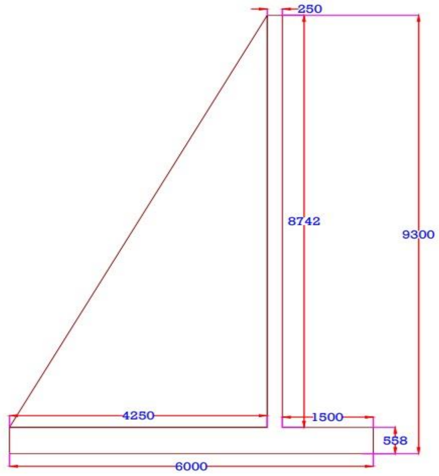

Fig 1: Calculated Dimensions of Retaining Wall

IV. RESULT

Sr.no	Name	Retaining Wall Without Relief Shelve		Retaining Wall with Relief Shelve	
1	Moment	Base	2630KNm	Base	250KNm
		Stem	115KNm	Stem	25KNm
2	Shear Force		18400KN		4400KN
3	Displacement	Base Bottom	0.5m	Base Bottom	0.2m
		Base Top	0	Base Top	0
		Stem Top	8.5m	Stem Top	0.85m
				Stem Relief Shelve	0.88m
4	Drift	Base Bottom	0	Base Bottom	0
		Base Top	0.95	Base Top	0.22
		Stem Top	0.95	Stem Relief Shelve	1.9
				Stem Top	0.1
5	Story Shear	Base Bottom	0	Base Bottom	0
		Base Top	14000-18000KN	Base Top	7500KN
		Stem Top	1500KN	Stem Relief Shelve	1500KN
				Stem Top	0KN
6	Overturning Moment		8000KNm		500KNm

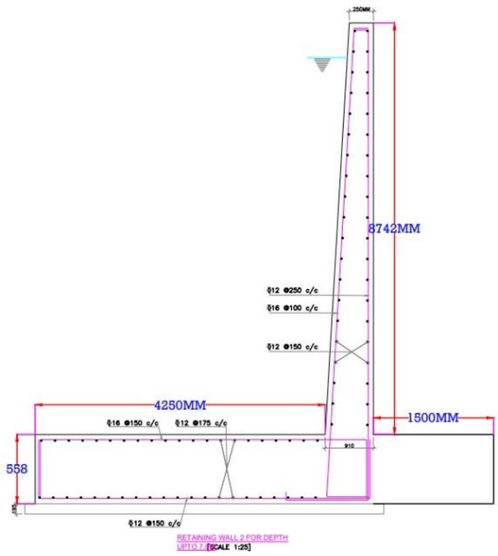

Fig 2: Retaining wall with Relief Shelve

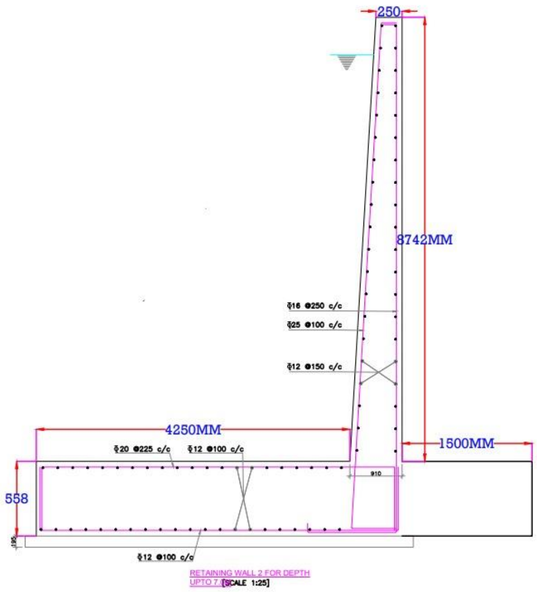

Fig 3: Retaining wall without Relief Shelve

CONCLUSION

In conclusion, the comparative study between Counterfort Retaining walls and Counterfort Retaining walls with relief shelves using E-TABS software demonstrates that incorporating relief shelves significantly enhances retaining wall stability. This suggests that integrating relief shelves is a beneficial design modification for improving the structural performance and longevity of retaining walls, especially in challenging geological or loading conditions.

The addition of relief shelves effectively redistributes loads and reduces stresses, improving overall structural performance.

In the event of failure, a Counterfort Retaining wall without relief shelves may experience greater vulnerability to structural instability, especially in conditions of excessive lateral pressure or inadequate reinforcement. Conversely, a Counterfort Retaining wall with relief shelves offers improved resistance to failure by distributing loads more effectively and reducing stress concentrations, thereby enhancing overall structural integrity and mitigating the risk of catastrophic collapse.

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