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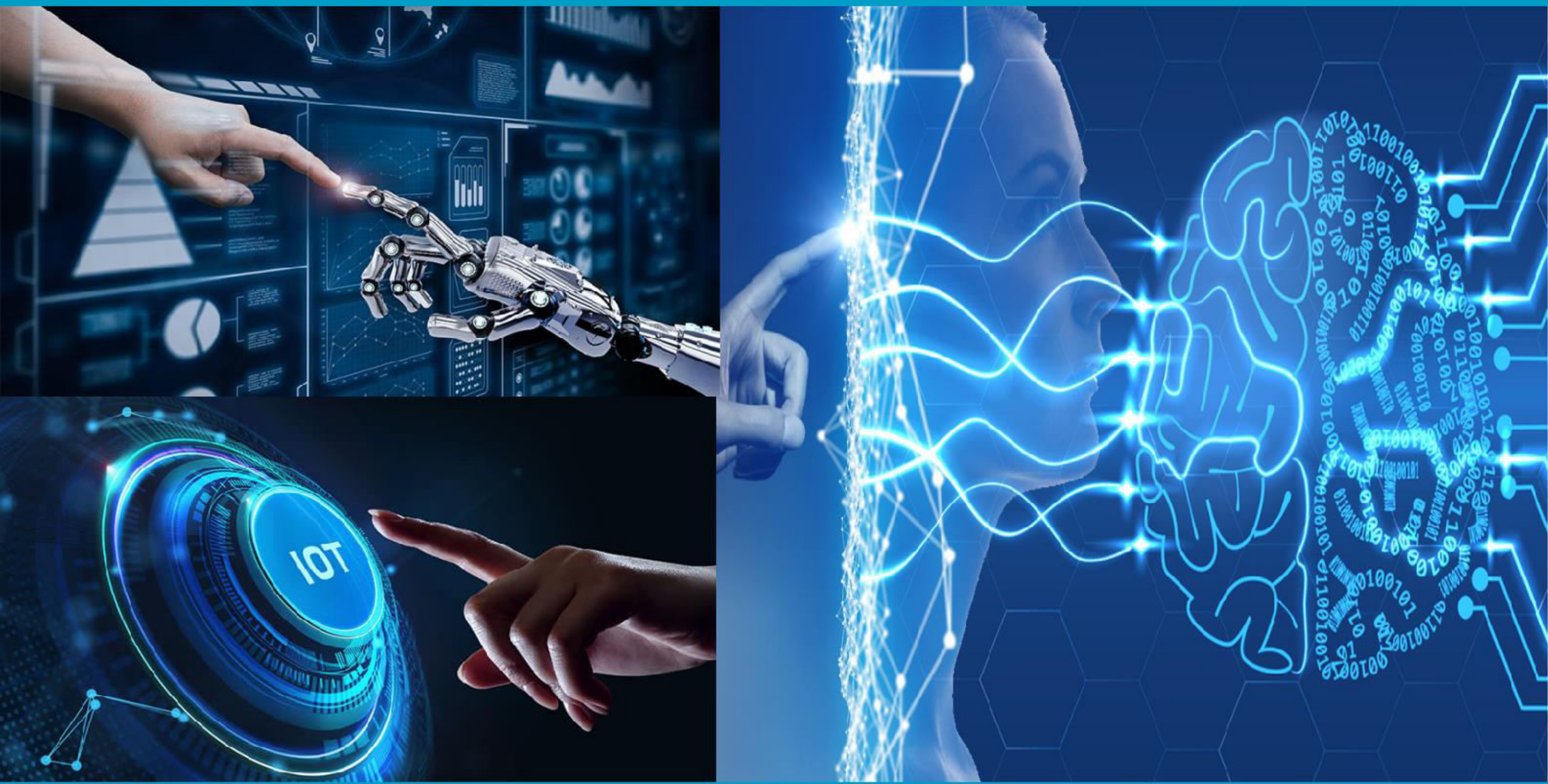

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Seismic Evaluation and Performance Analysis of Cantilever Retaining Walls with Variable Heights

Priyanka Patle[1], Prof. Pallavi Bhende[2], Prof. Kajal Pachdhare[3]

Research Scholar, Department of Civil Engineering Department, Wainganga College of Engineering & Management, Nagpur, Maharashtra, India[1]

Head of Department, Assistant Professor, Department of Civil Engineering Department, Wainganga College of Engineering & Management, Nagpur, Maharashtra, India[2]

Assistant Professor, Department of Civil Engineering Department, Wainganga College of Engineering & Management, Nagpur, Maharashtra, India[3]

ABSTRACT: Cantilever retaining walls are crucial structural elements used to support and stabilize soil in areas with elevation differences. During seismic events, these walls are subjected to significant dynamic forces, making their design and performance evaluation critical, especially for varying wall heights. Seismic evaluation and performance analysis of cantilever retaining walls with variable heights play a crucial role in ensuring structural stability and resilience during earthquake events. This study investigates the dynamic behavior of cantilever retaining walls subjected to seismic loading, considering variations in wall height and associated design parameters. Using numerical modeling and analytical methods, the research examines the impact of height variation on factors such as lateral earth pressure, wall displacement, and base shear. The study incorporates both pseudo-static and dynamic analysis to assess structural performance under different seismic conditions. The results provide valuable insights into the optimal design of cantilever retaining walls, offering guidelines for improved seismic resistance and cost-effective construction practices. The findings contribute to enhancing the safety and reliability of retaining structures in earthquake-prone regions.

KEYWORDS: Cantilever retaining walls, seismic evaluation, performance analysis, variable wall height, dynamic stability, earthquake engineering, finite element analysis.

I. INTRODUCTION

This study provides a clear understanding of the forces and moments acting on an L-shaped cantilever retaining wall with varying heights. The performance of earth-retaining structures under seismic conditions is a crucial topic due to their wide use in infrastructure projects. One of the main concerns in retaining wall stability is the distribution of earth pressure and how the wall responds, especially under dynamic loading. Soil-wall interaction plays a key role in determining the dynamic behavior of retaining walls. Despite extensive research, this behavior is not yet fully understood. The objective of this study is to analyze the dynamic performance of L-shaped cantilever retaining walls and examine the distribution of earth pressure during seismic events. This research includes a detailed analysis and design process for these walls. The primary dimensions of the retaining wall were estimated and then verified for stability. Factors of safety against sliding, overturning, and bearing capacity were calculated. Additionally, shear resistance at the base, tension stresses in the stem and base, and reinforcement requirements were evaluated. All analyses and designs are based on the Indian Standard Code. The study presents a comparative analysis of cantilever retaining walls, including inverted-T and L-shaped designs, with variations in height. Design calculations and reinforcement details are documented in an Excel sheet. By comparing different types of retaining walls, this study aims to enhance understanding of their behavior under seismic conditions. The first analytical approach to calculating lateral static earth pressures on retaining structures was developed by Coulomb in 1776. He used force equilibrium to determine soil thrust on the wall under active and passive conditions. Since this problem is indeterminate, multiple potential failure surfaces must be analyzed to identify the critical failure surface. Later, in 1857, Rankine introduced a simpler method for calculating earth pressures, assuming general shear failure in the soil behind the wall. His approach allowed for the calculation of static earth pressures for cohesionless soils in a single step. The work of Coulomb and Rankine forms the foundation of static earth pressure analysis, which is widely used in retaining wall design. The study of seismic forces on retaining walls advanced significantly after the Great Kanto Earthquake of 1923. Okabe (1926) and Mononobe & Matsuo (1929) developed the Mononobe-Okabe (M-O) method, which extended Coulomb's theory to include seismic effects. Originally designed for gravity walls with cohesionless backfill, the M-O method remains one of the most commonly used approaches for determining seismic earth pressures.

Retaining walls are structures used to hold back soil when there is a sudden change in ground level. They come in various types, including gravity walls, cantilever walls, counterfort walls, and buttress walls. Among these, cantilever retaining walls are the most commonly used and are economical for heights up to about 8 meters. These walls must resist lateral earth pressure, which can cause bending, sliding, or overturning.

This study focuses on designing an L-shaped cantilever retaining wall to achieve the most economical section while ensuring structural stability. The main considerations include external stability and compliance with Indian Standard (IS) codes. Stability is assessed using a factor of safety, which is the ratio of resisting forces to disturbing forces. For a structure to be safe, the factor of safety must always be greater than one.

A cantilever retaining wall consists of three main components:

1. **Stem** – A vertical cantilever that resists lateral earth pressure.
2. **Heel slab** – A horizontal cantilever extending into the retained soil, resisting upward soil pressure.
3. **Toe slab** – A horizontal cantilever extending in front of the wall, providing additional stability.

The weight of the retained soil helps improve wall stability. Proper reinforcement detailing is essential to ensure structural integrity. This study aims to optimize the design of L-shaped cantilever walls for better performance and cost-effectiveness.

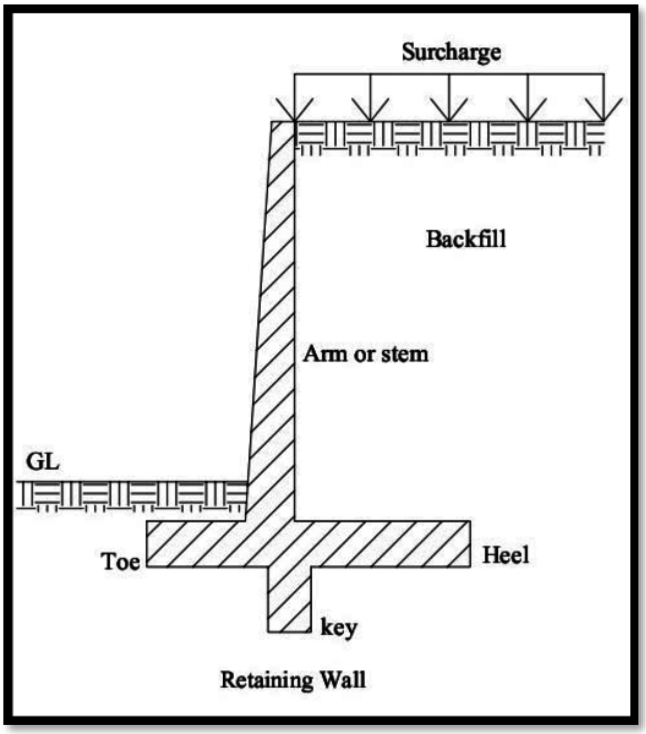

Fig. 1: Cantilever retaining wall

II. LITERATURE REVIEW

2.1 Prediction of Concrete and Steel Materials Contained by Cantilever Retaining Wall by Modeling the Artificial Neural Networks (2018) by U. Gokkus, M.S. Yildirim, A. Yilmazoglu- The use of Artificial Neural Networks (ANNs) for predicting material requirements in civil engineering structures has shown promising advancements, particularly in the accurate estimation of concrete volume and steel reinforcement. In structural design, these predictions play a crucial role in cost estimation, material optimization, and ensuring the structural adequacy of retaining walls. This literature review discusses the application of ANNs in predicting material quantities for cantilever retaining walls, focusing on ANN-based models, the Mononobe-Okabe approach, and the use of optimization algorithms such as Artificial Bee Colony (ABC) in ANN training. Artificial Neural Networks (ANNs) have increasingly been applied in civil engineering for tasks requiring pattern recognition, prediction, and classification. ANNs are particularly useful in scenarios where traditional analytical models may be limited due to the complexity of the data or non-linearity. As illustrated by Ghalehnovi et al. (2016), ANNs can effectively model complex relationships between input and output parameters, such as predicting material quantities for different retaining wall designs based on structural and soil properties.

2.2 Seismic Response and Evaluation of Cantilever Retaining Wall (2018) by Mr. Nasim khan, Mr. Aftab Alam- A Cantilever retaining wall is one of the most important types of retaining structures. It is extensively used in variety of situations such as highway engineering, railway engineering, bridge engineering and irrigation engineering. Reinforced concrete retaining walls have a vertical or inclined stem cast with base slab. For greater heights earth pressure due to retained fill will be higher due to lever arm effect, higher moments are produced at base, which leads to higher section for stability design as well as structural design. This studies the stability and performance for seismic response and evaluation of cantilever retaining wall with the help of a finite element method, STAAD.pro. While the following provisions of the Indian Standard Code, IS 456:2000 and IS 1893: 1984/2002 for the sections.

2.3 Performance-based Optimal Design of Cantilever Retaining Walls (2019) by Mohsen Kalateh-Ahani, Arman Sarani- Performance-based design (PBD) has emerged as a significant approach in structural engineering, particularly in enhancing resilience against seismic activities. Traditional design methodologies often prioritize structural safety under anticipated loads without thoroughly balancing costs associated with structural performance. However, with PBD, engineers and project stakeholders can develop optimized designs that meet specific performance criteria while controlling costs. This literature review explores key developments and studies on the performance-based optimal design of cantilever retaining walls, with a particular focus on seismic resilience, cost optimization, and structural displacement.

2.4 Performance-Based Analysis of Cantilever Retaining Walls Subjected to Near-Fault Ground Shakings (2020) by Milad Aghamolaei, Alireza Saeedi Azizkandi, Mohammad Hassan Baziar, and Sadegh Ghavami- This paper investigates the seismic performance of cantilever retaining walls under near-fault ground shaking, focusing on the unique effects of forward-directivity in near-fault regions. Using finite element modeling, the authors evaluate how near-fault ground motions, characterized by high-intensity velocity pulses, affect cantilever retaining walls compared to far-field earthquake motions.

Key components of the study include:

1. Wavelet approach: Used to extract velocity pulses from near-source ground motions, which were compared with synthetic far-field earthquake records.
2. Seismic performance: A clear distinction in lateral displacement was observed, with up to 85% higher displacement under near-fault conditions compared to far-field excitations, though the forces along the walls were similar.

2.5 Investigation of Seismic Response of Cantilever Retaining Walls: Limit Analysis vs Shaking Table Testing (2020) by Panos Kloukinas, Anna Scotto di Santolo, Augusto Penna, Matthew Dietz, Aldo Evangelista, Armando Lucio Simonelli, Colin Taylor, and George Mylonakis- This paper presents a comprehensive study of the seismic behavior of cantilever retaining walls, focusing on both theoretical and experimental analyses. Conducted at the University of Bristol (EERC - EQUALS), the study compares limit analysis and shaking table testing to evaluate the response of cantilever retaining walls under seismic conditions.

Key Aspects of the Study:

1. Theoretical Analysis: The research employs both limit analysis and wave-propagation methods, which consider multiple factors, including inertia, strength, kinematics, and deformation compatibility. These methods provide exact theoretical solutions for cantilever retaining walls subjected to seismic forces, addressing the fundamental mechanics involved in soil-structure interaction during earthquakes.
2. Shaking Table Testing: The experimental part of the research involves shaking table tests on small-scale models, incorporating different retaining wall geometries, soil configurations, and ground motions. This experimental setup is designed to replicate real seismic conditions and observe the behavior of the retaining walls in a controlled environment.

2.6 Seismic Behavior of Cantilever Wall Embedded in Dry and Saturated Sand (2020) by Sanku Konai, Aniruddha Sengupta, and Kousik Deb- This research article investigates the seismic behavior of embedded cantilever retaining walls in dry and saturated sand, focusing on both experimental and numerical analyses. The study addresses a significant gap in the literature, as most previous studies have concentrated on the static behavior of such walls, leaving their seismic performance underexplored.

Key findings include:

1. In dry sand, the maximum lateral displacement due to seismic loading is less than 1% of the total wall height.
2. In saturated sand, the lateral displacement can be as high as 12.75% of the total wall height, a significant increase attributed to the variation in pore water pressure within the sand.
3. The study highlights the critical influence of soil saturation on the seismic performance of cantilever retaining walls, especially in terms of lateral movement and structural stability. The research underscores the importance of accounting for soil conditions, particularly water content, in the design of retaining structures in seismic zones.

2.7 Displacement based seismic assessment of base restrained retaining walls (2022) by Rohit Tiwari & Nelson Lam- Retaining walls are critical in providing lateral support for soil, particularly in areas prone to seismic activity where lateral forces can induce significant structural demands. Displacement-based seismic assessment (DBSA) has emerged as a valuable approach for evaluating the seismic performance of these structures, focusing on the displacement and deformation patterns under seismic loads rather than only on force-based assessments. This literature review examines recent studies on displacement-based seismic assessment, specifically for base-restrained retaining walls, which face unique challenges due to their structural confinement at the base. Base-restrained retaining walls are particularly sensitive to seismic forces due to the restriction at the base, which limits their capacity to shift or rotate as a response to lateral pressures. Studies such as Mylonakis et al. (2006) demonstrate that base restraint can increase wall rigidity but also lead to greater shear and bending stresses at the wall base, thus increasing vulnerability during earthquakes. These stresses, if not properly managed, can result in structural cracking or even failure. Displacement-based assessment is thus crucial in these walls as it emphasizes allowable deformation levels that can mitigate such risks.

2.8 Dynamic Analysis of Cantilever Retaining Wall (2022) by Prajakta Patil, M. V. Waghmare- This paper explores the seismic behavior of cantilever retaining walls, emphasizing the influence of soil response on the structure's motion. Retaining walls are key for lateral soil support, and the study aims to enhance their seismic design using 3D finite element analysis (FEA) with ANSYS software.

The analysis follows three stages:

1. Static Analysis: To assess the initial structural behavior.
2. Modal Analysis: Calculating natural frequencies and mode shapes of the wall.
3. Nonlinear Time History Analysis: Using three distinct earthquake ground motions to simulate real seismic conditions.

The paper highlights that the soil significantly affects the dynamic response of the wall. The study finds maximum displacement occurring at the top of the wall, with no structural failure under the given loading. Additionally, the distribution of equivalent (Von Mises) stress shows lower stress near the ground and higher stress at the base of the wall, especially between the stem and base slab in the soil cover zone. The research provides key insights into how soil dynamics impact the retaining wall, aiding in the safe design of such structures under seismic loading conditions.

2.9 Seismic Behavior of Retaining Walls: A Critical Review of Analytical and Field Performance Studies (2023) by Sabahat Ali Khan, Mourad Karray, and Patrick Paultre- This paper presents a comprehensive review of the seismic behavior of retaining walls, focusing on the complex soil-structure interaction under dynamic loading conditions. Retaining walls are critical in earth retention, and understanding their seismic performance is a vital concern for researchers, industry professionals, and governmental bodies alike.The article evaluates various analytical and field performance studies that address seismically induced lateral earth pressures on retaining walls.

Key points in the review include:

1. Dynamic Earth Pressure: The paper examines how seismic events generate lateral forces on retaining walls, influenced by multiple factors such as soil type, wall geometry, and seismic intensity.
2. Soil-Structure Interaction: The interaction between soil and retaining structures under seismic loading is identified as a complex phenomenon requiring advanced analysis techniques.
3. Design Methodologies: Existing design standards and methodologies are critiqued for their inadequacies in capturing real-world seismic performance, stressing the need for more refined approaches.

2.10 Parametric Analysis and Design of Cantilever Retaining Walls Under Different Soil Conditions (2024) by Kara Naga Sree Vallabh, Asileti Prashanth, Cheera Vamsikrishna, Kallelapola Sankar, Minjuru Kuma, N. Rama Rao- Cantilever retaining walls play a crucial role in construction by supporting soil masses and preventing soil erosion, especially on terrains with significant elevation changes. Designed to withstand lateral pressures, these walls are commonly used in infrastructure projects such as roads, buildings, and terraces. They are constructed without lateral support at the top, relying on their footing to provide stability against earth pressures. This review examines the parametric design considerations of cantilever retaining walls, focusing on the impact of varying soil types on bending moments and reinforcement requirements. Understanding the effects of soil variation on cantilever retaining wall design is critical for safe and cost-effective construction. The parametric analysis conducted in this study highlights the necessity of tailored design approaches for different soil types, specifically regarding bending moment distribution and reinforcement adjustments. This research contributes to the broader knowledge of retaining wall design by offering a framework for engineers to assess and adapt wall specifications according to soil properties, enhancing wall durability and performance in diverse environmental settings.

III. PROPOSED METHODOLOGY

In this study, we have designed three types of cantilevers retaining walls:

1. Inverted T-shaped cantilever retaining wall
2. Standard cantilever retaining wall
3. L-shaped cantilever retaining wall

Each wall is analyzed for heights ranging from 3 meters to 6 meters. The study evaluates their stability against sliding, overturning, and subsidence as per IS code provisions. Additionally, we compare the quantity of steel and concrete required for each design and present the results in graphical form.

3.1 Observation, Data Collection, Design & Calculation

3.1.1 Problem Statement

To design both Inverted T-type and L-shaped cantilever retaining walls, we need to consider stability criteria, structural design, and reinforcement details based on given parameters:

Data:

- Height of wall (H): 3.0m to 6.0m
- Density of soil (γ): 18 kN/m³
- Angle of internal friction (φ): 30°
- Safe bearing capacity (SBC): 200 kN/m²
- Coefficient of friction (μ): 0.5
- Concrete grade: M20 (fck = 20 MPa)
- Steel grade: Fe-415

Design Considerations:

1. Earth Pressure Calculation (Using Rankine's Theory for active pressure)
2. **Stability Checks:**
    - Sliding: Checked using frictional resistance
    - Overturning: Factor of safety against overturning should be >1.5
    - Bearing Pressure: Must not exceed SBC (200 kN/m²)
3. **Structural Design:**
    - Stem Design: Acts as a vertical cantilever
    - Base Slab Design: Includes heel (under retained soil) and toe (in front of wall)
    - Shear and Moment Calculations: To determine reinforcement

3.1.2 Important Step Involved

1. Calculation of Earth Pressure Coefficients

Use Rankine's Theory and Coulomb's Theory to determine:

$Ka=(1-\sin\phi)/(1+\sin\phi)$

$K\mathrm{p}=(1-\sin\phi)/(1+\sin\phi)$

Where:

K_a = Active earth pressure coefficient

K_p = Passive earth pressure coefficient

φ = 30° (given angle of internal friction)

2. Calculation of Lateral Earth Pressure Forces

Compute active earth pressure using:

$Pa= (1/2) \times Ka\gamma H^2$

Determine total lateral force acting on the wall at H/3 from the base.

3. Stability Analysis (As per IS 456:2000)
1. Check for Sliding
Fs=Resisting force/Driving force>1.5
Resisting force = Frictional resistance at the base
Driving force = Lateral earth pressure
2. Check for Overturning
Fo=Resisting moment/Overturning moment>1.5
3. Check for Bearing Capacity
Ensure that the maximum soil pressure under the base does not exceed the SBC of 200 kN/m²
Check for Settlement (Subsidence)

4. Calculation of Seismic Coefficients (IS 1893: Part 3)
Horizontal acceleration coefficient (αh)
Vertical acceleration coefficient (αv)
Consider earthquake zone factor (Z) based on location.

5. Calculation of Seismic Earth Pressure Coefficients (As per IRC: 6-2016)
Compute seismic earth pressure coefficient (Kae)
Kae=(1+kh)
Where:
Kae = Seismic active pressure coefficient
kh = Horizontal seismic coefficient

6. Seismic Analysis Using Pseudo-Static Method
- Modify earth pressure forces to include seismic effects.
- Analyze the effect of additional seismic force on wall stability.

7. Structural Design & Reinforcement Detailing
- Stem Design:
1. Consider bending moment due to lateral earth pressure
2. Provide vertical reinforcement
- Base Slab Design:
1. Heel slab: Designed for upward soil pressure
2. Toe slab: Designed for bearing pressure distribution
- Check for Shear and Bending Stresses
- Provide reinforcement as per IS 456:2000 & IS 3370

Table 1: Model Nomenclature

Model Name (L-Shape)	Inv. T	Height (Meter)	Earth Pressure	Foundation Depth (Meter)	Height of Retaining Wall (Meter)
CRL1	CR1	3.0	0.33	1.25	4.25
CRL2	CR2	3.5	0.33	1.25	4.75
CRL3	CR3	4.0	0.33	1.25	5.25
CRL4	CR4	4.5	0.33	1.25	5.80
CRL5	CR5	5.0	0.33	1.25	6.30
CRL6	CR6	5.5	0.33	1.25	6.80
CRL7	CR7	6.0	0.33	1.25	7.30

Table 2: Given data

Model Name (L-Shape)	Inv. T	Symbols	Magnitudes	Units
CRL	CR	H	3.0 to 6.0	Meters
CRL	CR	Y	18	K/M²
CRL	CR	Φ	30	Degree
CRL	CR	B	20	Degree
CRL	CR	SBC	200	KN/M²

CRL	CR	μ	0.5	Unitless
CRL	CR	FCK	20	N/MM²
CRL	CR	FY	415	N/MM²
CRL	CR	I	90	Degree
CRL	CR	Θ	10	Degree
CRL	CR	Δ	90	Degree

Table 3: Inverted T Retaining Wall Dimensions

Model Name	Height of Retaining Wall (Meter)	Width of Wall (Meter)	Toe (Meter)	Length of Heel (Meter)	Thickness of Slab (Meter)
CR1	4.25	2.3	0.675	1.105	0.40
CR2	4.75	2.5	0.75	1.42	0.40
CR3	5.25	2.8	0.825	1.56	0.44
CR4	5.80	3.2	0.93	2.24	0.50
CR5	6.30	3.4	0.99	2.38	0.55
CR6	6.80	3.7	1.05	2.52	0.60
CR7	7.30	3.8	1.14	2.8	0.60

Table 4: Design of Stem

Model Name	Max Moment at Base (KN-m)	Ast Main (MM²)	Ast Distribution (MM²)	Shear Reinforcement
CR1	82.225	706.24	360	No
CR2	123.43	1041	360	No
CR3	167.02	1445.592	360	No
CR4	225.20	2025.27	405	No
CR5	288.61	2723.711	405	No
CR6	362.93	2528.245	480	No
CR7	449.013	3250.961	480	No

Table 5: Model Stability check

Model Name	Total Weight (KN)	Moment (KN-m)	Total Pressure	Overturning Moment (KN-m)	Shear Key
CR1	160.025	232.165	81.93	116.070	Yes
CR2	202.436	309.487	102.343	162.044	Yes
CR3	237.9475	389.53	125.02	218.79	Yes
CR4	299.5555	550.61	152.59	295.009	Yes
CR5	356.9947	684.6868	180.03	378.07	Yes
CR6	403.869	818.2476	209.774	475.421	Yes
CR7	472.5412	1060.6156	241.72	588.194	Yes

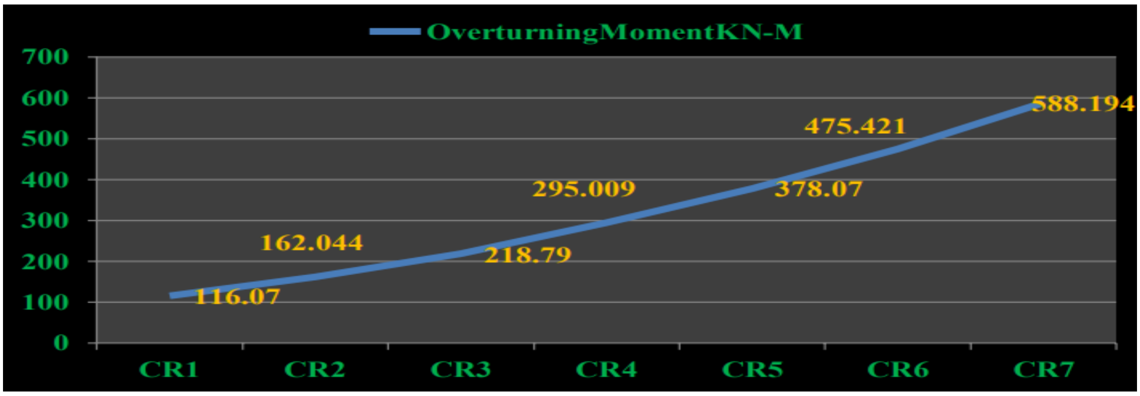

Fig. 2: overturning Moment of" Inverted T" type retaining wall

Table 6: Design of Toe Slab

Model Name	Max Pressure at Face (KN/m²)	Max Moment (KN-m)	Ast Main (mm²)
CR1	50.9	57.815	480
CR2	71.28	8.3526	480
CR3	89.241	58.5120	600
CR4	93.616	185.4937	620
CR5	165.505	291.2928	640
CR6	225.806	404.9702	640
CR7	129.97	395.6149	640

Table 7: Design of Heel Slab

Model Name	Total Downward Load (KN/m)	Max Moment (KN-m)	AST Main (mm²)
CR1	78.4	57.06	380
CR2	88.3	85.581	707
CR3	96.625	115.69	936
CR4	105	371.68	1335.38
CR5	113.9	480.92	1842.10
CR6	122.2	612.36	4856.56
CR7	130.45	442.176	4954.30

3.2 RCC L-Shape Retaining Wall

Design L- Shape retaining wall to retain on earth embankment with a horizontal top (height) 3.5 meter to 6 meter above ground level. Density of earth, ϒ= 18 KN/m3. Angle of intern friction φ = 30ºand SBC of soil is 200 KN/m2. Take coefficient of friction between soil and concrete = 0.5 Adopt M20 grade concrete and fe-415 steel.

Table 8: Model Dimensions

Model Name	Height of Retaining Wall (m)	Width of Wall (m)	Toe Projection (m)	Thickness of Base Slab (m)
CRL1	4.25	2.3	1.9	0.40
CRL2	4.75	2.5	2.1	0.40
CRL3	5.25	2.8	2.4	0.44
CRL4	5.80	3.2	2.8	0.50
CRL5	6.30	3.4	3.0	0.55
CRL6	6.80	3.7	3.0	0.60
CRL7	7.30	3.8	3.0	0.60

Table 9: Model Stability check

Model Name	Total Weight (KN)	Moment (KN-m)	Total Pressure	Overturning Moment (KN-m)	Shear Key
CRL1	157.406	179.101	81.93	116.070	Yes
CRL2	191.546	257.13	102.343	162.044	Yes
CRL3	232.925	402.94	125.024	218.791	Yes
CRL4	283.238	618.18	152.591	295.009	Yes
CRL5	330.344	808.79	177.187	369.141	Yes
CRL6	396.675	1031.83	209.745	475.421	Yes
CRL7	457.425	1224.66	241.724	588.194	Yes

Table 10: Design of stem

Model Name	Max Moment at Base (KN-m)	AST Main (mm²)	AST Distribution (mm²)	Shear Reinforcement
CRL1	88.207	729.51	360	No
CRL2	123.345	1040.188	360	No
CRL3	165.72	1433.188	360	No
CRL4	223.09	2003.343	540	No
CRL5	277.51	2595.414	600	No
CRL6	362.92	2528.54	660	No
CRL7	449.013	3251.11	720	No

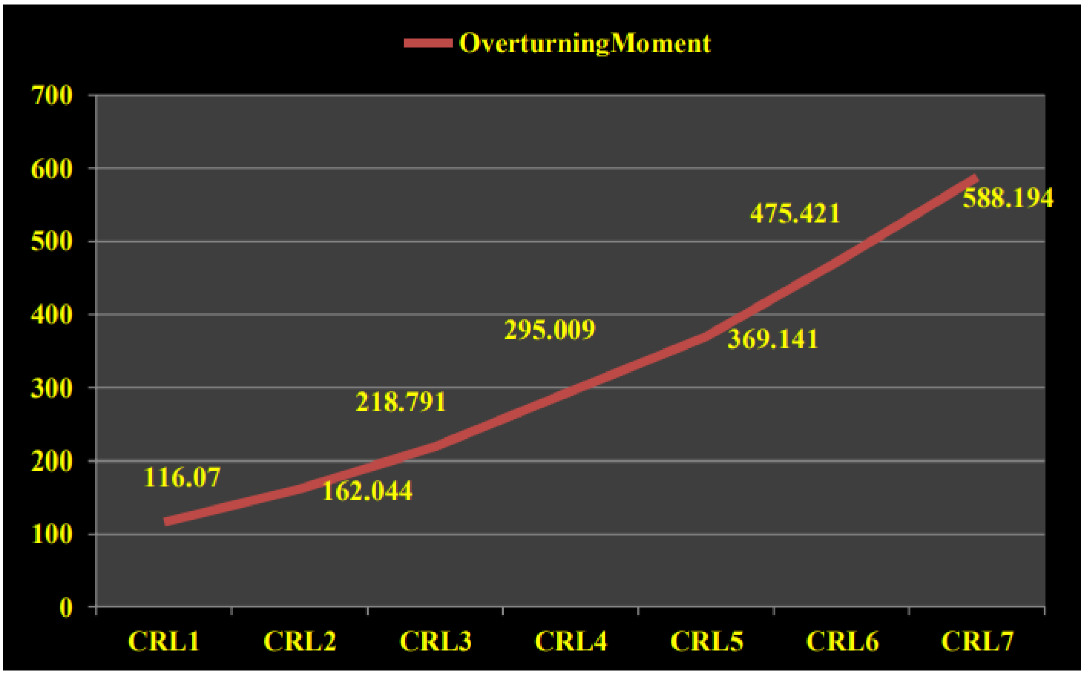

Fig. 3: overturning Moment of “L Shape" type retaining wall

Table 11: Design of Toe Slab

Model Name	Max Pressure at Face (KN/m²)	Max Moment (KN-m)	AST Main (mm²)
CRL1	178.446	966.234	7646.21
CRL2	170.843	902.923	2410.85
CRL3	160.784	1320.336	2817.54
CRL4	145.647	1453.665	2345.68
CRL5	145.549	1552.014	2483.37
CRL6	155.546	1749.89	1710.13
CRL7	176.339	2060.28	1462.89

IV. RESULTS & DISCUSSION

The retaining wall is a crucial component of soil reinforcement, designed to support ground loads vertically or stabilize slopes. Steep slopes or cliffs increase the driving forces acting on the wall, making stability a key concern. Ground conditions are influenced by natural erosion caused by rivers, springs, seawater, and wind. Additionally, external loads such as buildings on slopes and vehicular movement contribute to increased driving forces, potentially leading to landslides. This study focuses on the parametric analysis and design of cantilever retaining walls. A failure in retaining walls can lead to catastrophic consequences, affecting the surrounding areas. Therefore, a well-engineered design is essential to ensure stability. The results obtained from the parametric study align with previous investigations on the stability of cantilever retaining walls. In this paper, two types of cantilevers retaining walls—"Inverted T" and "L-

Type"—are considered. Using Excel-based computer programming, all components of these walls were designed. The study indicates that for practical cantilever walls, with typical factors of safety, the active and passive pressures in the design can be assumed to follow theoretical limiting values as per established methods. The factor of safety was calculated and verified in accordance with IS 456:2000 to ensure compliance with design standards.

Table 12: Cantilever Retaining Wall's factor of safety

Model	FOS For Overturning	FOS For Sliding	FOSF for Subsidence
CR1	1.6 > 1.2	1.75 > 1.4	1.43 > 0.75 (B/3)
CR2	1.60 > 1.2	1.44 > 1.4	1.47 > 0.83 (B/3)
CR3	1.55 > 1.2	1.41 > 1.4	1.61 > 0.91 (B/3)
CR4	1.5 > 1.2	1.44 > 1.4	1.78 > 1.0 (B/3)
CR5	1.54 > 1.2	1.46 > 1.4	1.81 > 1.1 (B/3)
CR6	1.47 > 1.2	1.42 > 1.4	1.97 > 1.16 (B/3)
CR7	1.48 > 1.2	1.41 > 1.4	2.1 > 1.26 (B/3)

Table 13: L-Shape Retaining Wall's factor of safety

Model	FOS for Overturning	FOS for Sliding	FOS for Subsidence
CRL1	1.29 > 1.2	1.49 > 1.4	1.13 > 0.76 (B/3)
CRL2	1.27 > 1.2	1.42 > 1.4	1.34 > 0.83 (B/3)
CRL3	1.26 > 1.2	1.65 > 1.4	1.72 > 0.91 (B/3)
CRL4	1.26 > 1.2	1.88 > 1.4	2.18 > 1.06 (B/3)
CRL5	1.26 > 1.2	1.97 > 1.4	2.44 > 1.13 (B/3)
CRL6	1.28 > 1.2	1.95 > 1.4	2.60 > 1.233 (B/3)
CRL7	1.28 > 1.2	1.87 > 1.4	2.67 > 1.266 (B/3)

Table 14: Comparison in steel between cantilever and L-shape retaining wall

Sr. No	Height	Cantilever Retaining Wall AST (Kg/m³)	L-Shape Retaining Wall AST (Kg/m³)	Difference in AST (Kg/m³)
1	3 m	32.31	33.26	0.95
2	3.5 m	34.63	41.14	6.51
3	4 m	38.52	42.73	4.21
4	4.5 m	43.14	45.20	2.06
5	5 m	64.02	47.69	16.33
6	5.5 m	58.26	69.88	11.62
7	6 m	70.33	77.13	6.80

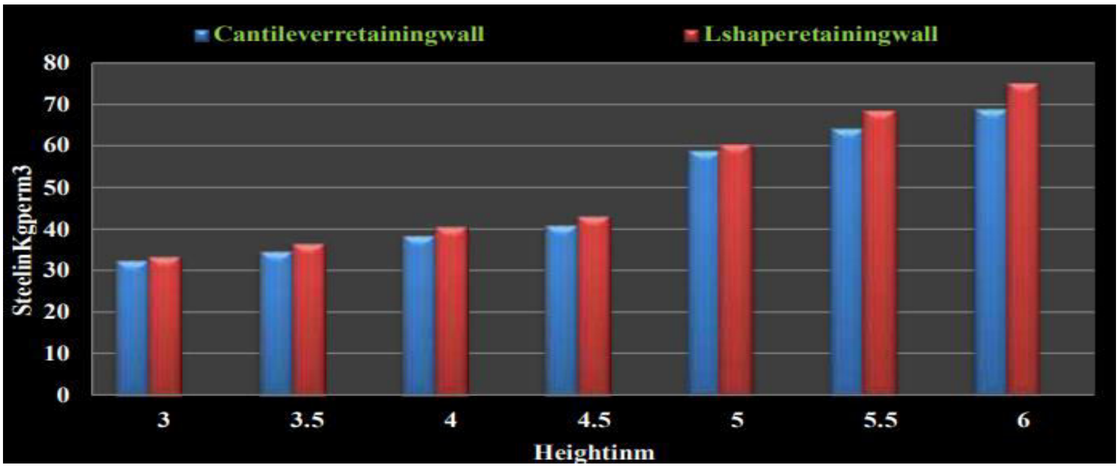

Fig.4: comparison of quantity of steel between Inverted T and L shape wall

Table 15: comparison in concrete between cantilever and L-shape retaining wall

Sr. No	Height	Cantilever Retaining Wall Concrete (cum)	L-Shape Retaining Wall Concrete (cum)	Difference in Concrete (cum)
1	3 m	5.83	5.50	0.33
2	3.5 m	7.90	6.58	1.32
3	4 m	9.75	9.21	0.54
4	4.5 m	13.01	12.75	0.26
5	5 m	13.19	15.12	1.93
6	5.5 m	16.99	16.18	0.81
7	6 m	20.16	17.83	2.33

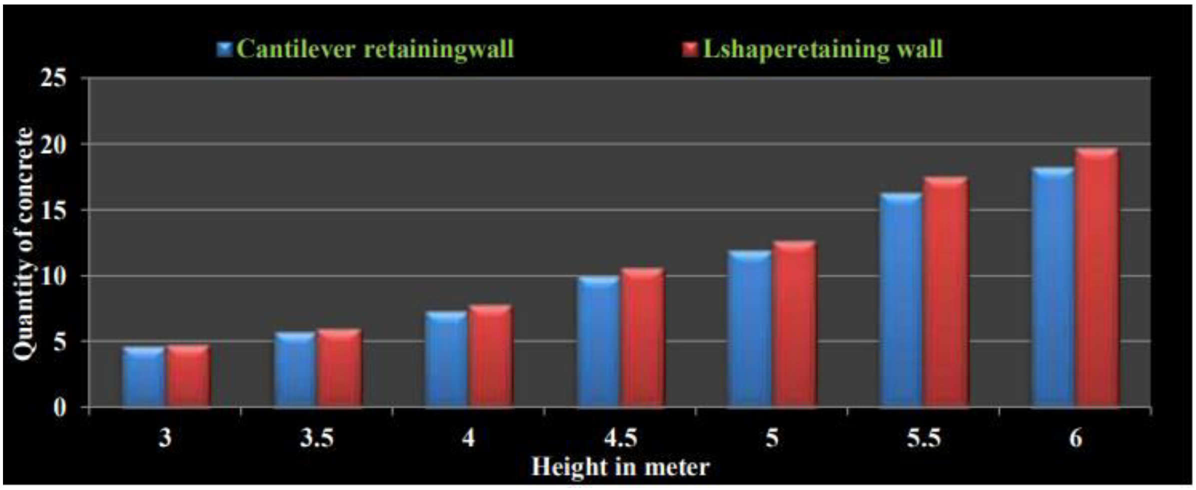

Fig.5: comparison of quantity of concrete between Inverted T and L-shape retaining wall

V. CONCLUSION

From the analysis, it is evident that the variation in steel increases with an increase in height due to the corresponding increase in the area of steel reinforcement. The L-shaped retaining wall requires more steel compared to the cantilever retaining wall, primarily because of its greater stem thickness. Additionally, the L-shaped retaining wall also consumes more concrete due to its larger dimensions, leading to a significant difference in concrete quantity as the height increases. The study reveals that the quantity of steel required for the L-shaped RCC retaining wall is approximately 7.61% greater than that of the cantilever RCC retaining wall, mainly due to the increase in reinforcement bar diameter and the reduction in bar spacing. Furthermore, the concrete consumption for the L-shaped RCC retaining wall is about 11.84% higher than that of the cantilever RCC retaining wall, attributed to the larger structural dimensions. These findings highlight the impact of structural configuration on material consumption, emphasizing the importance of selecting an appropriate retaining wall type based on project requirements and material efficiency.

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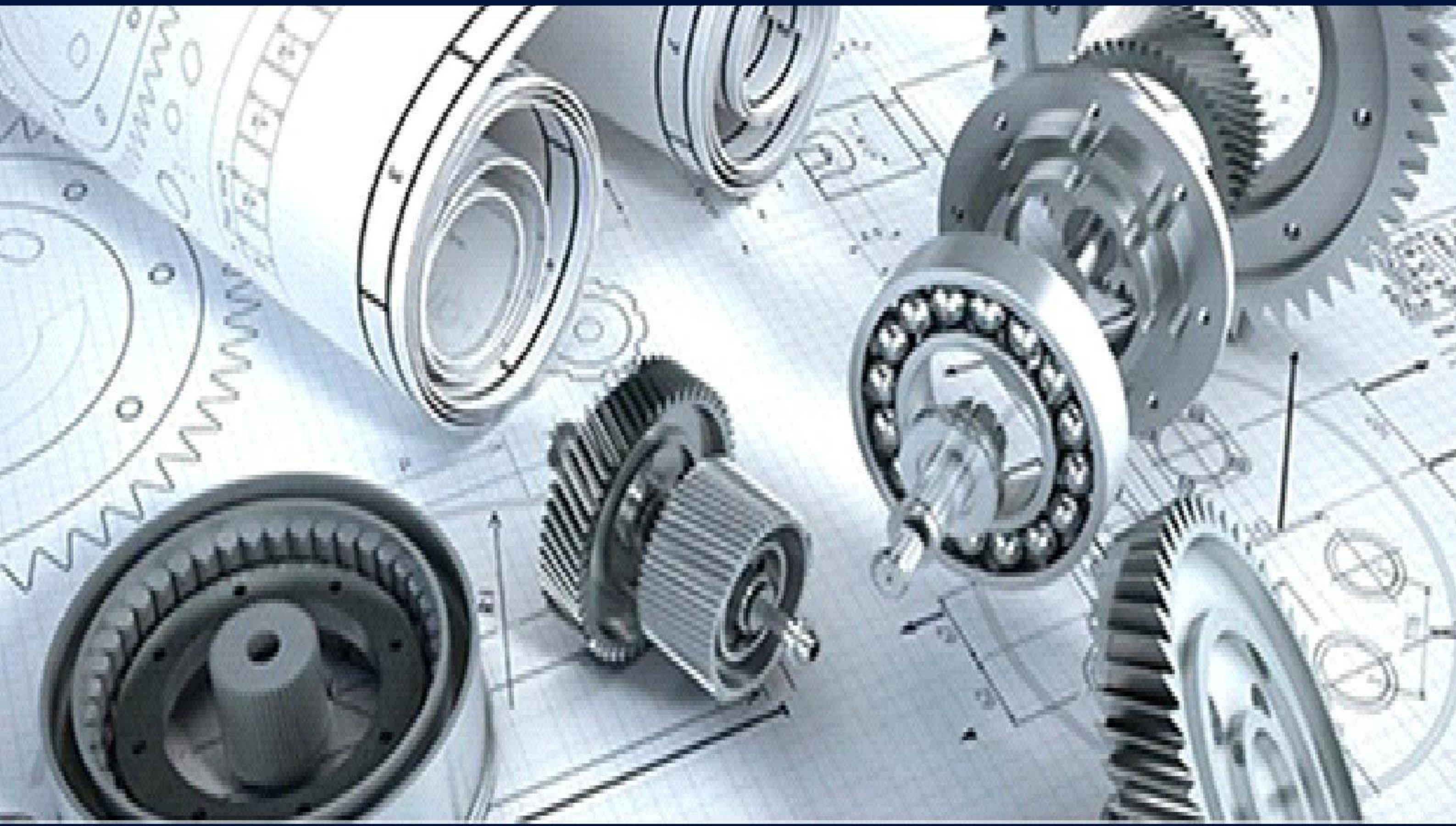

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+91 99405 72462 +91 63819 07438 ijmrsetm@gmail.com