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Parametric Analysis and Design of Cantilever Retaining Walls Under Different Soil Conditions

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Abstract— **The project deals with the parametric analysis of cantilever retaining walls and how it is going to react by varying in bending moment and difference in reinforcement which proportionally varies accordingly while changing the type of soils, all among the types of soils and get our requirements i.e., (bending moment and reinforcement). Here we selected the constant height for the retaining wall as 3m.Here we use different types of soils such as Intact clay, calcareous clay, silt, sand and gravel.**
KeyWords: **Retaining wall, moment, stem, heal, toe, reinforcement.**

1. INTRODUCTION

A retaining wall is a structure designed to hold back soil or other materials and prevent erosion or collapse in areas where there is a change in ground elevation. They serve various purposes, including creating usable space on sloped terrain, preventing soil erosion, and providing structural support for roads, buildings, or other infrastructure. Retaining walls come in different types, such as gravity walls, cantilever walls, and reinforced walls, each with its own construction methods and design considerations. Proper engineering, including analysis of soil properties, drainage systems, and loading conditions, is essential for the successful construction and long-term stability of retaining walls. Additionally, factors such as aesthetics, environmental impact, and local regulations play a role in the design and implementation of retaining wall projects. Overall, retaining walls are critical elements of infrastructure and land development, providing both functional and aesthetic benefits in various landscapes.

A retaining wall is designed to hold in place a mass of earth or the like, such as the edge of a terrace or excavation. The structure is constructed to resist the lateral pressure of soil when there is a desired change in ground elevation that exceeds the angle of repose of the soil.

A basement wall is thus one kind of retaining wall; however, the term usually refers to a cantilever retaining wall, which is a freestanding structure without lateral support at its top. These are cantilevered from a footing and rise above the grade on one side to retain a higher level grade on the opposite side. The walls must resist the lateral pressures generated by loose soils or, in some cases, water pressures.

2. LITERATURE REVIEW

Following literature represents the works conducted on analysis and design cantilever retaining wall.

Dembicki et al (1989) Systematic analysis methodologies to evaluate the structural behavior and performance of cantilever retaining walls. Through rigorous calculations and simulations, we investigate factors such as soil properties, loading conditions, and wall geometry to optimize design parameters.

Kerisel (1993) Project deals with history of retaining wall design. In Retaining structures retaining walls are the most useful structure where this retaining wall is founded first nothing but the origin of retaining wall.

Goh (1993) Analyze the behavior of cantilever retaining walls through empirical observation and mathematical modeling. By examining factors such as soil properties, wall geometry, and loading conditions.

Bentler et al (2006). We assess its ability to withstand lateral earth pressure and maintain stability. This involves analyzing factors like deflection, settlement, and potential structural distress. Through monitoring and periodic inspections.

Guler et al (2007) Conduct numerical analyses to evaluate the performance of reinforced soil-retaining wall structures. By considering various backfill materials, including cohesive and granular types, we assess factors such as stability, deformation, and load-bearing capacity to inform design optimization.

Sivakumar et al (2008) It was an optimum design of cantilever retaining walls we chose that to make a upper limit of economical target using target reliability approach.

Fenton, et al (2008) project deals with the Reliability of the traditional retaining wall and the design particulars what we have used the design first time.

Lee et al (2008) Investigate deformation patterns in earth retaining walls through advanced analytical techniques and field observations. By analyzing factors such as soil mechanics, wall material properties, and external loads.

Liu, et al. (2008) Project deals with the complete structural design of cantilever retaining wall with revealing platform which includes the surcharge for the components.

Abood et al. (2011) We design the cantilever retaining wall with constant height as 4m according to the ACI318 standard for the slab design.

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Pei (2012) In this method they have chosen to design of reinforced cantilever retaining walls using heuristic optimization algorithms.

Kaveh et al (2014) In this method they used to design a cantilever retaining walls using ray optimization method.

Moon and Ku. (2016) the project deals with empirical estimation of soil unit weight and undrained shear strength from shear wave velocity measurements.

Kumar et al. (2017) Using the differential evolution algorithm, we optimize the dimensions and reinforcement of the cantilever retaining wall for stability and cost-effectiveness. This involves iteratively refining parameters such as wall height, base width, and reinforcement distribution to achieve optimal performance under varying soil conditions.

Dhamdhere et al. (2018) a comprehensive analysis of retaining wall designs, focusing on structural integrity, stability, and cost-effectiveness. Our research explores various construction materials, techniques, and environmental factors to optimize performance and mitigate risks. Through innovative methodologies and empirical studies.

Yadav et al. (2018) we conduct analytical and experimental analyses of retaining walls under both static and seismic conditions. By integrating theoretical models with real-world testing, we assess structural performance, deformation patterns, and failure mechanisms.

POUR et al. (2019) Conduct a parametric analysis of back-to-back reinforced earth retaining walls, exploring variations in factors like reinforcement type, soil characteristics, and wall geometry.

Uray et al. (2019) In the design for concrete cantilever retaining walls in various soils, we analyze soil properties to determine bearing capacity and potential lateral pressures. We explore structural configurations, considering factors such as wall height, base width, reinforcement, and drainage systems, to optimize stability.

Mittal et al. (2021) Focus on the analysis and design of retaining walls incorporating reinforced cohesive frictional backfill. Through comprehensive investigations, we evaluate the interaction between the reinforcement, cohesive soil, and frictional backfill.

Varga et al. (2021) Conduct a multi-parametric analysis of gravity retaining walls. By examining multiple design parameters such as wall height, soil characteristics, and loading conditions, we assess the structural performance and stability of the wall under various scenarios.

3. DIFFERENT TYPES OF SOILS USED IN DESIGN OF CANTILEVER RETAINING WALL

Table- 1 Unit weights of different types of soils

SOILS	**UNIT WEIGHT (kN/m^3)**
Intact clay	15.5
Calcareous clay	17
Silts	18
Sand	20
Gravel	21.5

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4. ANALYSIS AND DESIGN OF CANTILEVER RETAINING WALL

Following analysis and design is conducted for silty soil with the unit weight of 18 kN/m^3 and same procedure is followed for remaining types of soil.

4.1 DESIGN CONSTANTS

M 20 CONCRETE (σ_{cbc} =7 N/mm^2)

Fe 415 STEEL (σ_{st}=230 N/mm^2)

m = 13.33

Height of wall = 3 m

K_c= 0.289

J_c = 0.904

R_c = 0.914

γ = 18 kN/m^3

$\emptyset = 30^0$

SBC = 100 kN/m^2

$\mu = 0.5$

4.2 DEPTH OF FOUNDATION

$$Y_{min} = \frac{q_0}{\gamma}\left(\frac{1-\sin\emptyset}{1+\sin\phi}\right)^2 = 0.62 \text{ m}$$

Assume 1 m as foundation. We need to design retaining wall of height 3 m, so total height is 3+1 = 4 m

4.3 DIMENSIONS OF BASE

$$a = 1 - \frac{q0}{2.2gH} = 0.37$$

For the base width of retaining wall

$$b = 0.95H\sqrt{\frac{k_a}{(1-\alpha)(1+3\alpha)}} = 1.90 \text{ m}$$

Where $\mathbf{k_a} = \frac{\mathbf{1-\sin\emptyset}}{\mathbf{1+\sin\phi}} = 0.33$

Base width as per consideration of sliding

$$b = \frac{0\cdot 7Hk_a}{(1-\alpha)\mu} = 2.96\ m$$

This width is excessive. Normal practice is to provide b between 0.4 to 0.6 H Take maximum value of 0.6 H

b = 0.6 H = 2.4 m

It is not sufficient hence provide shear key

Let the thickness of toe be $\frac{1}{12}H = 0.3$ m

4.4 THICKNESS OF STEM

$$B = k_a\gamma\frac{H^3}{6} = 50.65 \text{ x } 10^6 \text{ N-mm}$$

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Table -2 Table Showing Moments According To the Different Loadings

S no	Designation	Force (kN)	Lever arm (m)	Moment about roe (kN-m)
1	W_1	1 X 0.2 X 3.7 X 25 = 18.5	1.1	20.35
2	W_2	½ X 0.1 X 3.7 X 25 = 4.63	0.9 7	4.49
3	W_3	1 X 2.4 X 0.3 X 25 = 18.0	1.2	21.60
4	W_4	1 X 1.2 X 3.7 X 18 = 79.97	1.8	143.86
Σ W = 121.05			**MR = 190.30**	

EARTH PRESSURE =>

$P = k_a \gamma \frac{H^2}{2} = 48$ kN/m

OVERTURNING

$Mo = P \text{ X } \frac{4}{3} = 64$ kN -m

Factor of safety against overturning = $\frac{190.3}{64} = 2.97$ > 2 hence safe

SLIDING

$F \cdot S = \frac{\mu \Sigma W}{P} = 1.26 < 1.5$

HENCE UNSAFE

We should provide shear key

4.5 PRESSURE DISTRIBUTION

Net moment = ΣM = 190.3 – 64 = 126.3 kN-m

$\bar{x} = \frac{\Sigma M}{\Sigma W} = 1.04$ m

ECCENTRICITY $e = \frac{b}{2} - \bar{x} = 0.16$ m

Should not be less than $\frac{b}{6} = 0.4$ m

Pressure p_1 at toe = $\frac{\Sigma W}{b}\left(1 + \frac{6e}{b}\right)$ = 70.61 kN/ m^2 < 100(SBC), hence safe

Pressure p_2 at heel = $\frac{\Sigma W}{b}\left(1 - \frac{6e}{b}\right)$ = 30.26 kN/ m^2

Pressure p at junction of stem with toe slab

$p = p_1 - \frac{p_1 - p_2}{b} X \alpha b$ = 55.48 kN/ m^2

Pressure p' at the junction of stem with heal slab

$p = p_1 - \frac{p_1 - p_2}{b}$ X width of heel slab = 50.44 kN/ m^2

4.6 DESIGN OF TOE SLAB

Downward weight of slab = 7.5 kN/ m^2

Hence net pressure = 70.61-7.5 = 63.11 kN/m^2

Whereas at junction 55.48 - 7.5 = 47.98 kN/ m^2

Total S.F = ½ X (63.11+ 47.98) 0.9 = 50 kN

$\bar{x} = \left[\frac{47.98+2(63.11)}{47.98+63.11}\right]\frac{0.9}{3} = 0.47$ m

B.M = 50 X 0.47 = 23.52 kN-m

Depth of toe slab as per its moment

$d = \sqrt{\frac{B}{1000 \times R_C}}$ = 161 mm

Take depth as 200 mm and overall depth as 260 mm

$A_{st} = \frac{BM}{\sigma_{cbc} \cdot J_C \cdot D}$ = 566 mm^2

Half of the reinforcement of stem has been bent up into the toe

Check for development length L_d = 45 x dia of bar
= 45 x 12
= 540 mm

Take cover 50 mm = 900-50 = 850 > L_d

Hence safe

DISTRIBUTION STEEL

$\frac{0.12}{100}$X1000 $\left[\frac{260+200}{2}\right]$ = 276 mm^2

Use 8 dia bars spacing = $\frac{1000 \times 50.3}{276}$ = 182 ~ 180 mm c/c

4.7 DESIGN OF HEEL SLAB

Weight of soil = 1.2 x 3.7 x 1 x 18 = 80 kN

Weight of heel slab = 1.2 x 0.26 x 1 x 25 = 7.8 kN

Total upward soil reaction = ½ X (50.44+ 30.26) 1.2 = 48.42 kN

$\bar{x} = \left[\frac{50.44+2(30.26)}{50.44+30.26}\right]\frac{1.2}{3} = 0.55$ m

B.M (80 x 0.6) + (7.8 x 0.6) – (48.42 x 0.55) = 26.05 kN-m

$d = \sqrt{\frac{B}{1000 \times R_C}}$ = 169 mm

Hence keep the depth of stem 260 mm and effective depth as 200 mm

4.8 REINFORCEMENT IN STEM

Earlier we have assumed thickness of toe slab as 0.3m so reduce the height as 4 – 0.3 = 3.7 m

$M = k_a \gamma \frac{H^3}{6}$ = 52.31 kN-m

$d = \sqrt{\frac{B}{1000 \times R_C}}$ = 239 mm

Keep d and 250 mm and D as 310 mm

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$A_{st} = \frac{BM}{\sigma_{Cbc} \cdot J_C \cdot D}$ = 1007 mm^2, use 12 dia bars ,one bar area = 113 mm^2
Spacing = a_{st} / A_{st} = 112 mm
Provide 12 dia bars @ 90 mm c/c
A_{ST} provided = 1000 x 113/90 = 1256 mm^2

4.9 DESIGN OF SHEAR KEY

$P_p = k_p\, p$ = 3 x 55.48 = 166.4 kN/m^2
Total passive pressure P_p = 166.4a (here a is height of shear key)

Sliding force 3(4+a^2)
Weight of soil between base = 2.4a x 18 = 42.3 a
Total force = 121.05 + 42.3 a

$1.5 = \frac{\mu \Sigma W + P_P}{P_H} \Rightarrow a^2 - 33 \cdot 8a + 2 \cdot 54 = 0$

We get a as 0.09 m ≅ 90 mm so provide minimum as 300 mm shear key

5. RESULTS AND DISCUSSIONS

The moments in the different types of retaining walls in which in different soil properties changes there will be change in heel stem and to slabs accordingly whereas the reinforcement in the above slabs will be changing accordingly.

Table 3 Moments for Different types of Soil

Moments in components of retaining wall under different soils (kN-m)					
Type of slab	**Intact clay**	**Calcarreous clay**	**Silts**	**Sand**	**Gravel**
Stem	45.1	49.4	52.31	58.1	62.5
Toe	15.18	22.49	23.52	32.19	38.22
heel	31.61	37.52	26.05	21.23	19.5

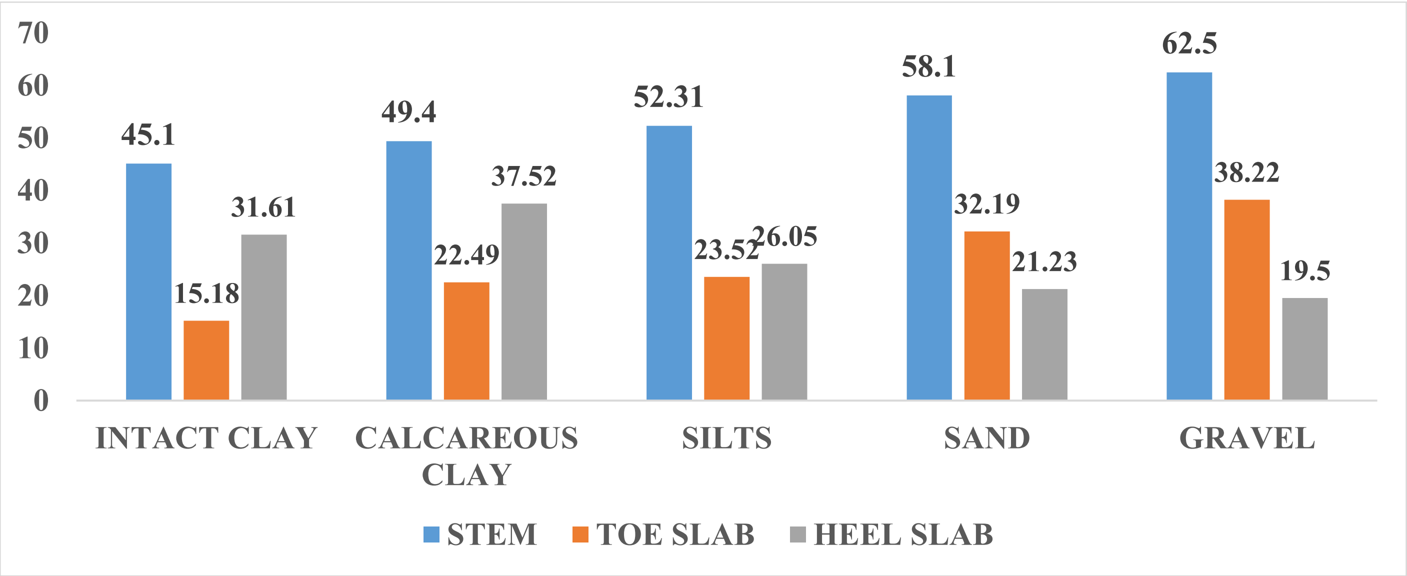

Figure -1 Moments Graph in Different Soils

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Table-4 Reinforcement Variation in Different Types of Soils

Reinforcement in components of retaining wall under different soils (kN-m)					
Type of slab	**Intact clay**	**Calcarreous clay**	**Silts**	**Sand**	**Gravel**
Stem	942	957	1256	1340	1675
Toe	470	628	628	941	840
heel	941	754	754	628	470

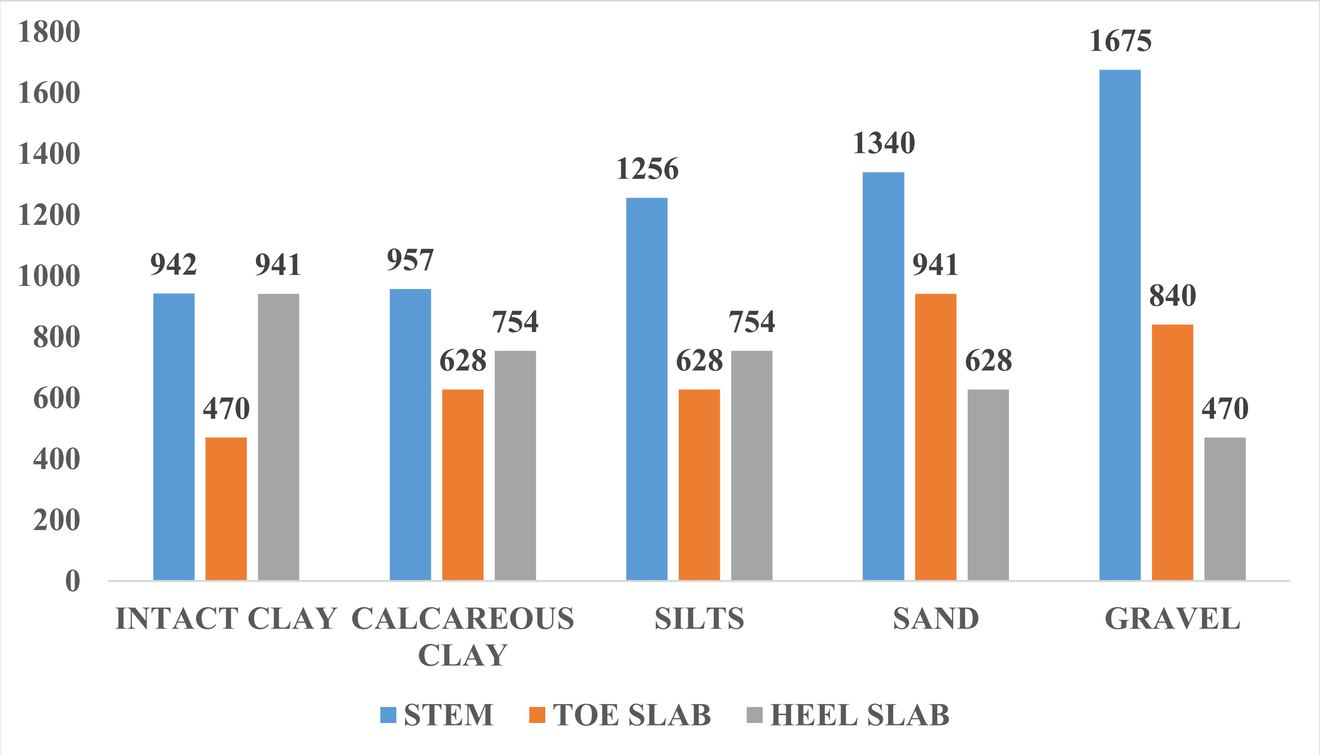

Figure- 2 Reinforcement Graph In Different Soils

CONCLUSIONS

- Ultimately, the application of parametric analysis empowers engineers to create sustainable and effective retaining wall designs that balance safety, functionality, and cost-effectiveness. By leveraging insights gained from this study, stakeholders retaining wall systems, thereby contributing to the resilience and sustainability of infrastructure worldwide.
- There will be the periodic increase of steel provided in the stem and toe slabs in all the retaining walls.
- There will be an optimum point for the heal slabs reinforcement in the retaining walls
- The only reason is after application of different soils even though the slab is small the moment which comes through the soil will be transferred to heel slab in the process of overturning.

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