

Sustainable slope protection: Case study for Retaining wall design for Parashuram Ghat landslide-prone areas

Ast.Prof.V.M.Mali

Ayush V. Chorge, Omkar C. Jadhav, Shreyas R. Khandekar, Omkar S. Sawantdesai

Gharda Institute Of Technology, Lavel

Department of Civil Engineering, Mumbai University

Abstract

Landslides are a recurring problem in hilly terrains, particularly in region of parashuram ghat, which experience intense rainfall, slopes and weak soil Strata. These factors are significantly threaten road safety, minor landslide and human life. This project focus on sustainable slope protection through the design and analysis of retaining wall structure for landslide-prone areas in parashuram Ghat. The study involves detailed site investigation, including soil classification, Premability analysis under varying moisture conditions. Based on these parameters, various retaining wall are analyzed and compared.

Comprehensive stability analysis are carried out, including check for sliding, overturning, and bearing capacity soil, to ensure the safety and reliability of the proposed design under different loading. Additionally, sustainable measures such as proper drainage systems, erosion control techniques. The results demonstrate that the proposed retaining wall system effectively improves slope stability and reduces landslide susceptibility in the Parashuram Ghat region. This study provides a practical and sustainable engineering solution that can be applied to similar landslide-prone areas.

Keywords:Landslides, slope stability, sustainable slope Protection, retaining wall design, soil investigation, permeability test, Geotechnical Engineering, bearing capacity, sliding Stability, overturning stability.

Introduction

The Parashuram Ghat is situated in the ecologically significant of Western Ghats, it is an important mountainous pass that serves as a vital transportation. Despite its strategic importance the region is highly vulnerable to landslides and slope failures due to its steep terrain, weak geological formations, and intense monsoon rainfall. These conditions often result in soil erosion, rockfalls, and blockage of roadways, posing serious risks to traffic safety, infrastructure, and economic activities.

The slope instability in Parashuram Ghat regions is primarily caused due to the imbalance between driving forces and resisting forces acting on the soil mass. The factors such as excessive rainfall infiltration, increased pore water pressure, weathered soil conditions, and human interventions like road cutting and slope modification significantly reduce the stability of slopes. In Parashuram Ghat, repeated landslide occurrences are highlight, the limitations of conventional slope protection measures and need for more reliable and stable designed solutions.

The Retaining walls are among the most widely adopted structural measures for slope stabilization in hilly terrains. The Retaining wall structures are designed to resist lateral earth pressure and provide support to unstable soil masses form preventing slope failure. Retaining wall are that structure type which is used to retain or hold the soil backside and can be constructed with different kind of materials. Retaining wall is to provide lateral support for a mass of earth and hold material that is at higher elevation behind the wall or material in front of the wall. Retaining wall is one of the geotechnical structures and it is generally defined as a vertical structure that holds back earth or prevents retained material from assuming its natural slope.

Types of Retaining wall structures

1. Gravity Retaining Wall
2. Cantilever Retaining Wall
3. Counterfort Retaining Wall
4. Gabion Retaining Wall

1. Gravity Retaining Wall

Gravity retaining wall is a wall that resists the lateral pressure of soil mainly through its own weight. This retaining wall is simplest & oldest one. It is Constructed from materials like store masonry, brick masonry plain Concrete, or gabion. It works on principle of stability of wall that is Sufficient to counter the horizontal earth pressure. This wall used in low 3m to 6m to moderate height.

2. Cantilever Retaining Wall

A cantilever retaining wall is a reinforced concrete structure designed to retain soil by using the principle of cantilever action. These walls are generally economical and efficient for medium heights, typically ranging from about 3 to 8 meters, and require less construction material compared to gravity walls.

3. Counterfort Retaining Wall

A counterfort retaining wall is a type of reinforced concrete retaining structure designed for retaining large heights of soil, where additional support is provided by triangular vertical slabs called counterforts. The counterforts act like tension ties, holding the wall and base together, which makes the structure more stable and economical for heights generally greater than 8 to 10 meters.

4. Gabion Retaining Wall

Gabion retaining wall is a flexible and permeable type of retaining structure constructed using rectangular wire mesh cages filled with stones, gravel, or broken rock fragments. These cages, known as gabions, are stacked and tied together to form a stable mass that resists lateral earth pressure from soil. The Gabion Retaining Wall build upto the height of 5m commonly.

Problem Statement

Slope failure and minor land sliding is the problem in parshuram ghat and retaining wall was constructed and it collapsed due to soil condition , heavy rainfall and leading to minor landslide and soil erosion.

One of the ways to rectify this problem is by applying the proper retaining wall. A very detail study and analysis need to be conducted in order to determine the proper type of retaining walls to be provided.

Objectives

1. To identify the reasons of pervious retaining wall structure failure
2. To determine the strata, geological and geographical condition of ghat

3. To determine traffic survey of the ghat section
4. To design and analysis of sustainable stable retaining wall

Study Area

This ghat section is part of the Western Ghats, a region known for its complex topography, ecological sensitivity, and high susceptibility to landslides. The terrain in this area is characterized by steep slopes, sharp curves, and deep valleys, making it a challenging location for infrastructure development and maintenance. The area primarily consists of lateritic soil and weathered basalt rock, which are prone to erosion and loss of strength under saturated conditions. The slopes are often highly fractured and jointed, reducing their stability, especially during heavy rainfall. The region experiences intense monsoon precipitation, leading to significant water infiltration into the soil mass. This increases pore water pressure and reduces the effective stress, which is a major cause of slope failure in the area.



Fig 1. Site location

Site Details:

Road: National Highway 66 (NH 66)

Exact Spot: Near Pedhe Baudhawaadi, Chiplun, Ratnagiri district

Coordinates: 17.554788° N, 73.501576° E

Elevation: Approx. 60–80 meters above sea level (hilly terrain)

The site lies in a lateritic and basaltic hill region, typical of the Western Ghats.

The soil and rock composition includes weathered basalt, laterite, and red soil, which are prone to erosion during heavy rainfall. The slope angle is steep (approximately 45–60°) increasing susceptibility to landslides.

Retaining wall:

Gabion retaining walls and reinforced concrete retaining walls are visible along the road cut. These walls provide lateral support and reduce soil pressure on the road. Step-cut slopes (benching) have been implemented to reduce slope height and improve stability.

Slope Protection:

Terracing and benching used to break slope continuity and control erosion. stone pitching and geotextile layers may be applied to prevent surface erosion.

Literature Review

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9. Singla (2015) discovered that the challenge of generating a difference in terrain elevation over an arbitrary horizontal distance is common.
10. Study by Mathur (2017) reported that the properties of soil indexes were analysed.
11. Firoozi et al (2016) reported that the geotechnical properties of the soil such as grain size distribution, the shear strength, softness, the plastic limit, and liquid limit.

Methodology

1. Preliminary study of Parshuram Ghat
2. Collect data slope failure and landslide
3. Data of soil condition and testing result
4. Study on different types of Retaining work
5. Selection of retaining wall according to the parameter
6. Drafting of Retaining wall
7. Design and analyse of returning wall in Staadpro Software

Test on Soil and selection of Retaining Wall Structure

Test on soil

1. Direct Shear test

This test is performed to determine the consolidated-drained shear strength of the given soil. The shear strength is one of the most important engineering properties of a soil, because it is required whenever a structure is dependent on the soil's shearing resistance. The shear strength is needed for engineering situations such as determining the stability of slopes or cuts, finding the bearing capacity for foundations, and calculating the pressure exerted by a soil on a retaining wall.

Shear strength equation:

$$\tau = c + \sigma \tan \phi$$

Final Shear Parameters

Shear strength of soil = 0.022 kg/cm²

Cohesion (c) = 17 kN/m²

Angle of internal friction (ϕ) = 30°

2. Falling Head Premability Test

This standard covers the methods for laboratory determination of coefficient of permeability of soils using falling head method. This test is recommended for soils with coefficient of permeability in the range 10⁻³ to 10⁻⁷ cm/s and maximum particle size of 9.5 mm.

Formula

$$k = aL / At \ln (h_1 / h_2)$$

Calculation

Trial 1

$$k = (1 \times 10 / 50 \times 120) \ln(80/60)$$

$$k = 4.79 \times 10^{-4} \text{ cm/sec}$$

Trial 2

$$k = 4.5 \times 10^{-4} \text{ cm/sec}$$

Trial 3

$$k = 4.7 \times 10^{-4} \text{ cm/sec}$$

Result

The average coefficient of permeability: $k_{avg} = 4.66 \times 10^{-4} \text{ cm/sec}$

The soil shows low permeability. This confirms the presence of clayey/lateritic soil of Parashuram Ghat.

Selection of Retaining Wall Structures

For landslide-prone area in Parashuram Ghat, we have selected the Cantilever Retaining Wall Structure on the basis of properties of soil which is determined through the direct Shear test and falling head permeability test. While considering the shear strength and Permeability characteristics of the soil, the Cantilever Retaining Wall Structure is safe, economical and effective for slope stabilization.

Drainage system

The drainage system in a cantilever retaining wall is a critical component, especially in landslide-prone and high rainfall in Parashuram Ghat, as it helps in relieving hydrostatic pressure that develops behind the wall due to water in the backfill soil. Without proper drainage system, the increase in pore water pressure can reduce soil strength and lead to instability, sliding, or even failure of the Cantilever retaining structure. Due to drainage system the stability and durability gets improved under environmental conditions.

Weep Holes = 80 mm to 90 mm

Spacing= 1m to 1.5m

Perforated drain pipe= 120–130 mm PVC perforated pipe (at heel area)

Drafting of Cantilever Retaining Wall

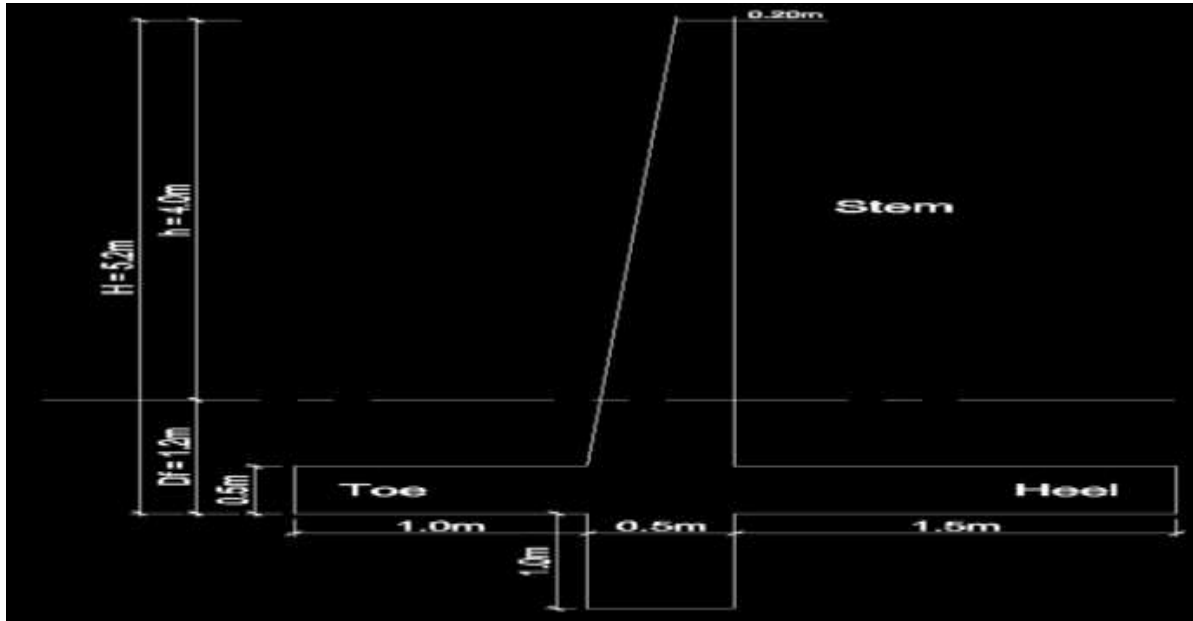


Figure 2. Autocad drafting of Cantilever Retaining Wall

Analysis in STAADPRO Software

Details of discription of model

Type of structure= Rcc frame structure

Concrete (f_{ck})= M30

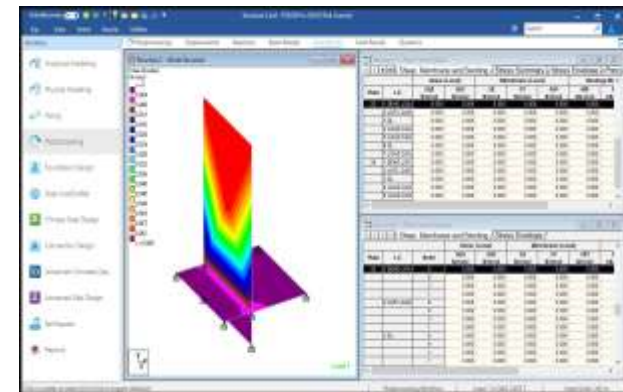
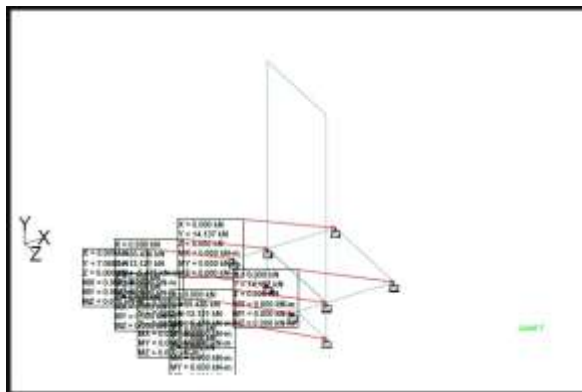
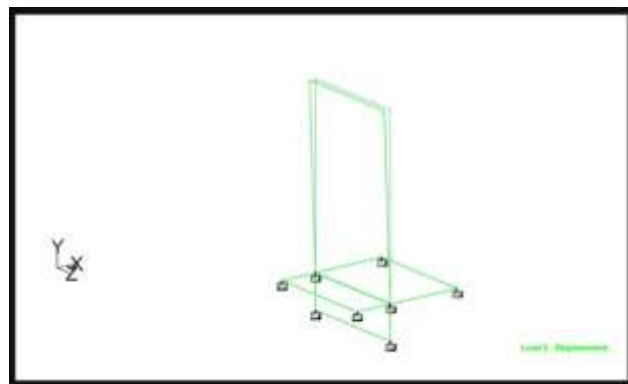
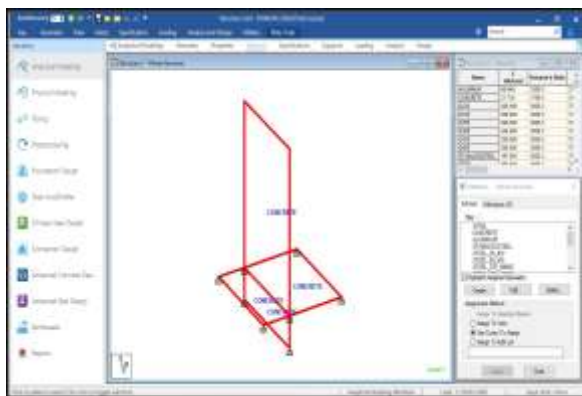
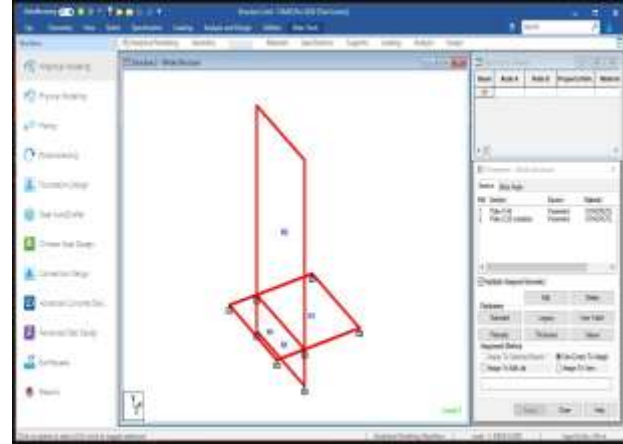
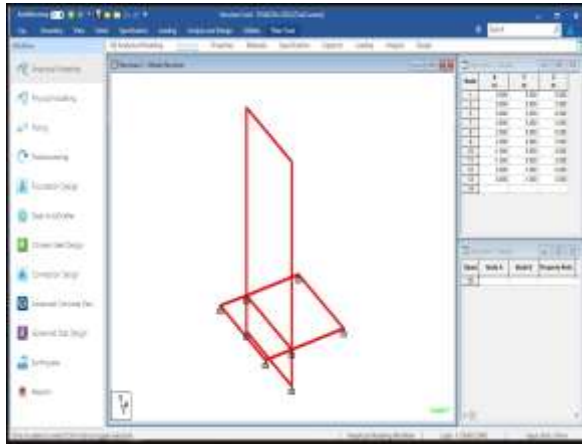
Steel (f_y)= Fe500

Angle of repose(ϕ) = 30°

Safe bearing capacity (SBC) = 220 kN/m^2

Active Earth Pressure Coefficient (k_a)= 0.33

Unit weight of soil (γ) = 19 kN/m^3



Results

Node Displacements

Node	L/C	X (mm)	Y (mm)	Z (mm)	Resultant (mm)	rX (rad)	rY (rad)	rZ (rad)
1	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
3	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
5	1:DEAD LOAD	0	-0.019	-0.007	0.020	-0.000	0	0
	2:live load	-176.272	0	0	176.272	0	0.001	0.056
7	1:DEAD LOAD	0	-0.019	0.007	0.020	0.000	0	0
	2:live load	-176.272	0	0	176.272	0	-0.001	0.056
8	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
9	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
10	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
11	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
12	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0
13	1:DEAD LOAD	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0

Reactions

Node	L/C	Horizontal	Vertical	Horizontal	Moment		
		FX (kN)	FY (kN)	FZ (kN)	MX (kN'm)	MY (kN'm)	MZ (kN'm)
1	1:DEAD LOAD	0	60.436	13.121	-5.475	0	0
	2:live load	117.000	22.500	0	0	104.745	-304.200
3	1:DEAD LOAD	0	60.436	-13.121	5.475	0	0
	2:live load	117.000	22.500	0	0	-104.745	-304.200
8	1:DEAD LOAD	0	14.137	0	0	0	0
	2:live load	0	22.500	0	0	0	0
9	1:DEAD LOAD	0	14.137	0	0	0	0
	2:live load	0	22.500	0	0	0	0
10	1:DEAD LOAD	0	7.068	0	0	0	0
	2:live load	0	0	0	0	0	0
11	1:DEAD LOAD	0	7.068	0	0	0	0
	2:live load	0	0	0	0	0	0
12	1:DEAD LOAD	0	7.068	0	0	0	0
	2:live load	0	0	0	0	0	0
13	1:DEAD LOAD	0	7.068	0	0	0	0
	2:live load	0	0	0	0	0	0

Statics Check Results

L/C		FX (kN)	FY (kN)	FZ (kN)	MX (kN'm)	MY (kN'm)	MZ (kN'm)
1:DEAD LOAD	Loads	0	-177.419	0	266.128	0	-42.411
1:DEAD LOAD	Reactions	0	177.419	0.000	-266.128	0	42.411
	Difference	0	0	0.000	0	0	0
2:live load	Loads	-234.000	-90.000	0	135.000	-351.000	518.400
2:live load	Reactions	234.000	90.000	0	-135.000	351.000	-518.400
	Difference	-0.000	0	0	0	0.000	-0.000

Plate Corner Stresses

Plate	L/C	Node	Shear (Local)		Membrane (Local)			Bending Moment (Local)		
			SQX (N/mm ²)	SQY (N/mm ²)	SX (N/mm ²)	SY (N/mm ²)	SXY (N/mm ²)	MX (kN ² /m)	MY (kN ² /m)	MX ² (kN ² /m)
21	1:DEAD LOAD	5	0	0	0.032	-0.037	-0.012	0	0	0
		7	0	0	0.032	-0.037	0.012	0	0	0
		3	0	0	-0.075	-0.098	0.012	0	0	0
		1	0	0	-0.075	-0.098	-0.012	0	0	0
21	2:live load	5	-0.066	0.309	0	0	0	30.317	71.162	-63.512
		7	0.066	0.309	0	0	0	30.317	71.162	63.512
		3	0.088	0.108	0	0	0	29.509	111.218	30.379
		1	-0.088	0.108	0	0	0	29.509	111.218	-30.379
22	1:DEAD LOAD	10	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		11	0	0	0	0	0	0	0	0
22	2:live load	10	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		11	0	0	0	0	0	0	0	0
23	1:DEAD LOAD	8	0	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
23	2:live load	8	0	0	0	0	0	0	0	0
		9	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
24	1:DEAD LOAD	13	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
		12	0	0	0	0	0	0	0	0
24	2:live load	13	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0
		1	0	0	0	0	0	0	0	0
		12	0	0	0	0	0	0	0	0

Plate Center Stresses

Plate	L/C	Shear (Local)		Membrane (Local)			Bending Moment (Local)		
		SQX (N/mm ²)	SQY (N/mm ²)	SX (N/mm ²)	SY (N/mm ²)	SXY (N/mm ²)	MX (kN ² /m)	MY (kN ² /m)	MX ² (kN ² /m)
21	1:DEAD LOAD	0	0	-0.015	-0.065	-0.000	0	0	0
	2:live load	-0.000	0.223	0	0	0	15.258	106.505	-0.000
22	1:DEAD LOAD	0	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0	0
23	1:DEAD LOAD	0	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0	0
24	1:DEAD LOAD	0	0	0	0	0	0	0	0
	2:live load	0	0	0	0	0	0	0	0

Conclusion

The present study on sustainable slope protection in the landslide-prone regions of Parashuram Ghat demonstrates that the adoption of a cantilever retaining wall is an effective and practical solution for ensuring slope stability and roadway safety. Based on geotechnical investigations and analysis, the selected wall type satisfies both structural and economic requirements for hilly terrain conditions.

The design approach incorporated soil parameters obtained from field and laboratory tests, ensuring realistic consideration of site conditions such as shear strength, permeability, and bearing capacity. Further validation using STAAD.Pro 2024 provided detailed insight into stress distribution, bending moments, shear forces, and deformation behavior of the retaining wall.

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