THE RELIABILITY ANALYSIS ON CANTILEVER RETAINING WALL BY USING GEO5 SOFTWARE

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Abstract -*Retaining wall is designed and constructed to "Resist the Lateral Pressure of soil" where there is a desired change in ground elevation that exceeds the Angle of Repose of the soil. Here we are discussing about "Cantilever Retaining Walls" they are most commonly and widely used type of Retaining walls. The cantilever retaining wall should be well designed in order to be safe against the overturning, uplift, sliding. In order to achieve the safety the major factors which causes the failure of the structure should controlled before the construction of retaining wall. The Reliability analysis is carried by using the three sigma rule, in which the variance the each parameters are taken into account and then the varied values as been used in determination of factor of safety. If this factor of safety is well within the required factor of safety then the cantilever retaining is considered as stable and safe if not then the strength of the wall may be increased by taking suitable measures such as soil nailing, increasing the dimensions of wall or by changing the reinforcement details of the wall.*

Key Words: **MDD & OMC, CBR, Liquid Limit**

1. INTRODUCTION

Cantilever retaining walls are the structures which are usually made up of Reinforced cement concrete, they usually consists of two major parts the wall and base slab. The base is usually made into two parts heel and toe. They are best suitable for the height of 20 meters. They can be precast or casted at site. A retaining wall is a structure designed and 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. Retaining walls are usually provided in order to take the lateral earth pressure they are created due to the soil back fill and in such situation where the angle of repose exceeds. These retaining walls are also used where there is a difference in ground elevation and need to be corrected in order to safe guard the life's of the peoples. They are well commonly used as retaining structure at dam sites as a wing wall and in highways in order to support the embankments. They are much useful in the areas which are prone to landslides earthquake etc. Here we are using Geo5 software for the calculation of the resistance of the cantilever retaining wall against the overturning and slip. The software calculates the factor of safety of the wall considering a safety factor of 1.5. the input parameters such as cohesion, earth pressure, surcharge, ground water table, unit weight of the wall material, inclination of backfill with wall, wall friction etc. are taken into consideration in this analysis. . The Reliability analysis mainly refers the percentage of probability of failure of the results provided by the software. They take into account the various uncertainty involved in the input parameters and helps in selecting the correct factor of safety. The reliability analysis is carried by using the three sigma rule, in which the variance the each parameters are taken into account and then the varied values as been used in determination of factor of safety. The variation which provides the minimum factor of safety is considered as critical. If this factor of safety is well within the required factor of safety then the cantilever retaining is considered as stable and safe if not then the strength of the wall may be increased by taking suitable measures such as soil nailing, increasing the dimensions of wall or by changing the reinforcement details of the wall.

2. LITERATURE REVIEW

Harr and Kulhaway, et all (2000):"Probabilistic Back Analysis of Geotechnical Systems"

This thesis is aimed at applying the probabilistic approaches for back analysis of geotechnical systems. In this study the probabilistic back analysis has been used for various observations made at the field. In deterministic study the geotechnical strength parameters were determined by trial and error method, in which the various values where assumed and the analysis is carried out till the factor of safety FS=1.5 is obtained.

Harr has carried out various studies on the recent slope failure case on Freeway No. 3 in Taiwan. This approach takes into account the variations in soil parameters and model bias factors. The efficiency of this analysis is applied for the case and compared with the Markov Chain Monte Carlo (MCMC) simulation.

D K Baidya and A. GuhaRay (2017): "Geotechnical Reliability aspects"

In this study the probabilistic risk factor (Rf) has been derived for various parameters based on their variations. These variations have been selected from based on various studies and they had been used here to determine the reliability aspects. It has been clearly observed from the study the variation in the parameters is cost effective.

3. METHODOLOGY: SOFTWARE USED

The software used for designing is **GEO5**. GEO5 stands for **"The Global Environment Outlook: Environment of the future we want"** It is best and powerful software suite for solving geotechnical related problems. It contains multiple programs for design of retaining walls and supporting structure. These are mainly use to conserving simplicity and clarity of input. It offers number of wall shapes and analyzes reinforced concrete cross sections. Several things make GEO5 a unique software. All modules are easy to use and the printout is highly analytical. The software is also accompanied by extensive supporting manuals and additional documents.

It works on mainly two methods:

1) Analytical Method 2) Finite Element Method

GEO5 gives a matchless system of satisfying safety factor which are different from given structural data

APPLICATION:

GEO5 is a Geotechnical software used to solve geotechnical problems. It also used for analysis of tunnels, damage of building due to tunneling.

The analytical method allow users to design and check the reliability of structure with accuracy.

This designed structure is moved into FEM where the finite element method is used for analysing the whole structure.

GEO5 SOFTWARE IS USED FOR:

1- Stability Analysis

2- Designing of Retaining walls

3- Design of foundation

4- Design of excavation

5- Scrutinization of soil settlement

6- Analysation of Advanced soil element

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FEATURES OF GEO5:

An Intuitive Tool: GEO5 software code intuitive tool is very easy to operate. The operators mainly don't require any instructions but in case of bluff programs we have to take care while operating.

Maintain Standard: The main approach of GEO5 that they are applicable everywhere. So many countries adopt their own standards and conventions.

Accessibilities of Localizations: GEO5 software area unit is quite inexpensive. According the requirements and budget one can easily purchased the program.

Simple and easy to control: GEO5 is easy to design, check, and modify the structure. Any modification you have done it displayed directly on the screen.

Retaining Wall Design Programs: GEO5 software consist of so many features which made it easy for designing the retaining walls. Every program analysis the structure with respect to geometrical aspects.

SYSTEM REQUIREMENTS: Microsoft Windows 7, Windows 8.1, Windows 10 or later. Display Resolution 1024 x 768 Pixel, Graphics Adapter supporting OpenGL 1.5.

4. TERMS USED IN DESIGNING

Factor of safety: The factor of safety has been in Geotechnical engineering based on the experience which is logical. The factor of safety is the constant which is imposed by standard laws, such that the wall should confirm or exceed this number for the stability of the wall for a long period of life.

$$\textbf{Factor of safety} = \frac{\text{Resisting force}}{\text{Driving force}}$$

Reliability Analysis: Mostly the geotechnical problems are associated with the uncertainty as most the properties of the wall and backfill are most likely to be varied. These reliability concepts are simple and can be applied in simple ways with less efforts, data and time. The mean, standard deviation and probability of failure are the additional factors that are required for the reliability analysis. Here the FOS and the Reliability analysis have been used together to determine the reliability index and probability of failure. This reliability analysis can be determined by various methods such as three sigma rule, graphical three sigma rule, and the also based on the published values. But here use the simple method 3-σ rule. The probability of failure is determined in terms of the percentage. Based on the results provided by Ghaiskarmanand and Abdel kalakEiHami and knowing the reliability index along with the probability of failure the performance of the rock slope can be determined as shown below.

Expected performance	Reliability Index	Probability of failure
High	5	$3X10^{-5}$
Good	4	$3X10^{-3}$
Above average	3	10^{-1}
Below average	2.5	$6X10^{-1}$
Poor	2	2.3
Unsatisfactory	1.5	7
Dangerous	1	16

Table 1: Expected performance based on reliability index

β	P_f	β	P_f	β	P_f
3.00	0.001358	2.00	0.022853	1.00	0.159127
2.95	0.001598	1.95	0.025702	0.95	0.171553
2.90	0.001877	1.90	0.028842	0.90	0.184581
2.85	0.002199	1.85	0.032294	0.85	0.198207
2.80	0.002570	1.80	0.036081	0.80	0.212424
2.75	0.002997	1.75	0.040224	0.75	0.227219
2.70	0.003486	1.70	0.044749	0.70	0.242578
2.65	0.004047	1.65	0.049668	0.65	0.258482
2.60	0.004687	1.60	0.055013	0.60	0.274910
2.55	0.005415	1.55	0.060802	0.55	0.291837
2.50	0.006243	1.50	0.067057	0.50	0.309233
2.45	0.007180	1.45	0.073798	0.45	0.327069
2.40	0.008240	1.40	0.081046	0.40	0.345308
2.35	0.009434	1.35	0.088818	0.35	0.363914
2.30	0.010778	1.30	0.097132	0.30	0.382846
2.25	0.012285	1.25	0.106004	0.25	0.402062
2.20	0.013971	1.20	0.115447	0.20	0.421519
2.15	0.015853	1.15	0.125472	0.15	0.441169
2.10	0.017948	1.10	0.136090	0.10	0.460964
2.05	0.020275	1.05	0.147307	0.05	0.480857
				0.00	0.500798

Table 2: Probability of failure for different values of Reliability Index

Methods to compute reliability:

a) Level I method: The variable parameters are modelled by single habitual value. Ex. Code established on partial coefficient method.

b) Level II method: uncertain parameters are modelled by the mean value, standard deviation and the coefficients of correlation between stochastic variables. The stochastic uncertainties are unconditionally believed to be distributed normally. An instance of level II method is the reliability index method.

c) Level III method: uncertain parameters are modelled by their combined distribution function. The probability of failure is determined as the estimate of reliability.

d) Level IV method: in this method the outcome (cost) of collapse are also taken in to consideration.

The probabilistic strategies of Reliability Analysis include the following:

1. **Monte Carlo Simulation Method (MCS)**
2. **First-Order Second-Moment Method (FOSM)**
3. **First and Second Order Reliability Method (FORM, SORM)**
4. **Point Estimation Methods**

1. **Monte Carlo Simulation Method (MCS)** : One of the mean to evaluate the probability of failure of retaining wall is the utilization of Monte Carlo Simulation method. In this regard distinct values of the constituent random uncertainties are generated according to their probability distribution, and the productivity is calculated, then, for each produced set. The procedure is iterated several times to derive a rough, distinct probability density function of the performance function. This method is simple but time consuming.

2. **First-Order Second-Moment Method (FOSM) :** The First Order Second-Moment Method is a notable option to Monte Corlo Simulation method, developed by Cornel (1971). It comprises on a primary sequence Taylor series estimation of the average (mean) and deviation (variance) of the performance function. Fractional by-products of this later calculated at the average values are so required. An easy way of this technique called as the Mean value First Order Second Moment method (MFOSM) was advocated and employed by Hassen et. al. (1999), to find the risky slip circle with minimum reliability index in a probabilistic analysis of slope stability. The approximation of the derivatives is a numerical difficulty of the FOSM method; additionally it is known to loose precision as FOS winds up non-linear and as the variance coefficient of the component expands, which is unluckily a frequent occurrence in the field of geotechnical engineering.

3. **First and Second Order Reliability Method (FORM, SORM) :** The most regularly used methods in geotechnical engineering field are the First and Second Order Reliability Methods; the Hasofer-Lind reliability index yielding is the base for these methods, therefore an invariant type of the reliability method. The First Order Reliability method (FORM) : Involves fitting a tangent hyper plane to the surface of the limit state at the design point, as illustrated in Fig A. Hence the notable step in this method is the search for the design point p*. Several algorithms are suggested for the resolution of this issue. The Second-Order reliability method (SORM): Involves fitting of a hyper-paraboloid to the surface of the limit state at the design point permitting the consideration of

its curvature. As shown in Fig B. The hyper-paraboloid is identical to the hyper plane distant of β_s from the source (origin) of the normalized space. The SORM have the same drawback as in the previous method regarding the difficulty in approximation of partial derivatives.

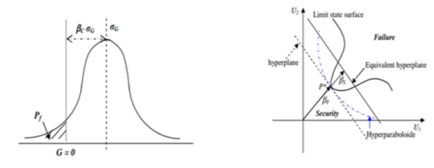


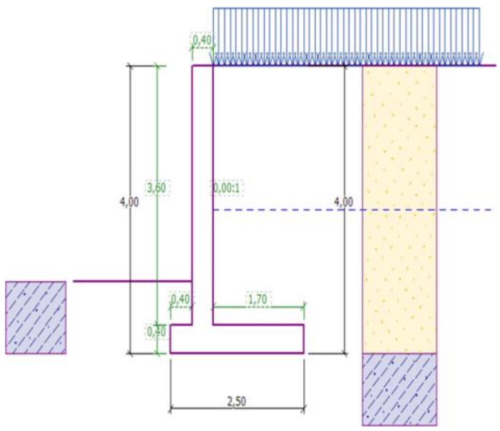
Fig A: Cornel Reliability Index Fig B| Hasofer-Lind Reliability index

4-Point Estimation Methods: This category of techniques involves approximation of integrals which describe the moments relating to the use of statistics of the performance function through a collection of well-defined rules and regulations.

5. DESIGNING AND ANALYSIS

PROBLEM

Design a retaining wall of height 4 meters, and analysis using Geo5 software as per standard. The backfill is horizontal and the water table is 2 meters below the ground level. A surcharge of length 5 meters and magnitude 10kN/m2 acts behind the wall. The wall is founded on Sandy silt (MS), with SBC 175 KPa. The backfill consist of Sand with traces of fines(S-F). The cantilever wall is a concreted of class 20/25.



Soil	Profile	Unit weight	Angle of internal friction	cohesion	Angle of friction Structure-soil	Saturated unit weight
S-F	0,0 -4,0	17.5	28	0	18.5	18
MS	From 4,0	18	26.5	30	17.5	18.5

Table 3: Soil parameters

SOLUTION

The above problem is solved by using Geo5 software and the steps that are involved in the analysis are explained below.

Step1: The first step involves selecting the setting frame and choose the frame No. 3

– “Standard – EN 1997 – DA1”.

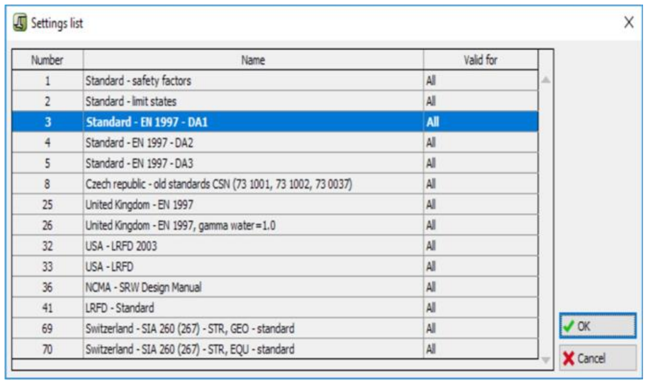


Fig 1: Settings list

Step 2: Select the geometry frame and choose the shape of the wall as shown below for the further analysis.

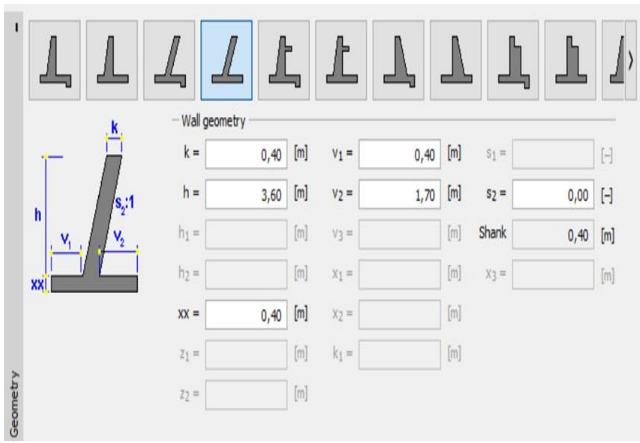


Fig 2: Geometry

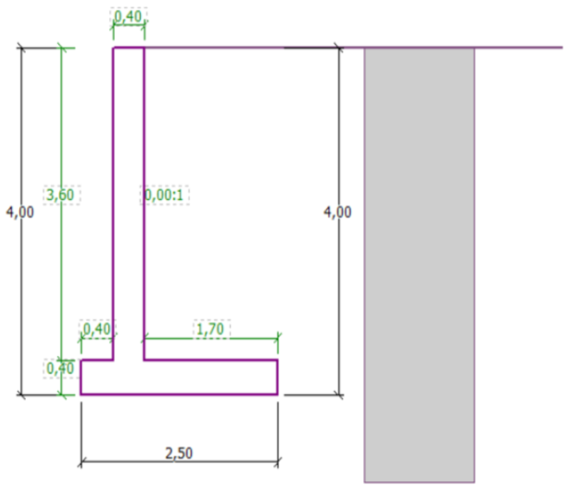


Fig 3 : Geometry Frame

Step3: Select the frame Material, enter the material of the wall and enter the details of the wall which is made of concrete of C 20/25and steel of class B 500.

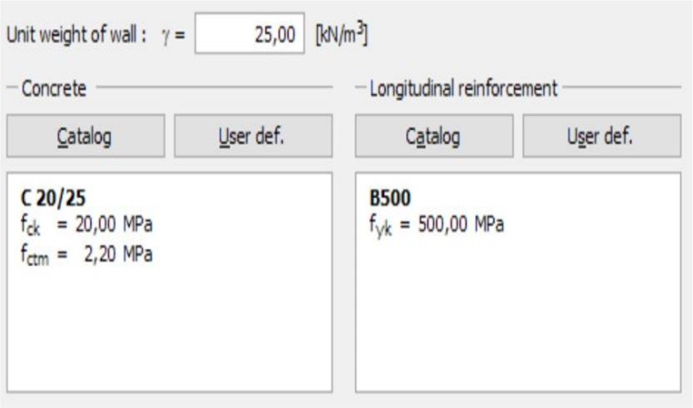


Fig 4: Material

Step4: Input the details of the materials and define the interface depth 4 mts by using add button.

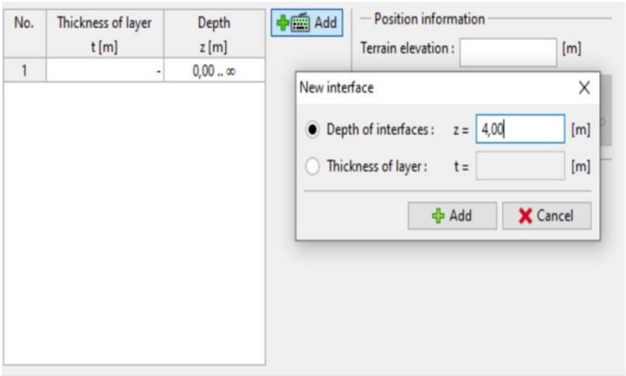


Fig 5: Profile

Step 5: Select the Soil frame and the details of the parameters of the soil behind the wall that is S-F soil and then later add the soil which makes the foundation MS soil.

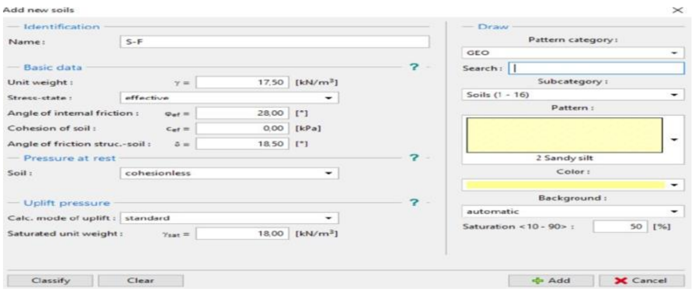


Fig 6: S-F soil frame

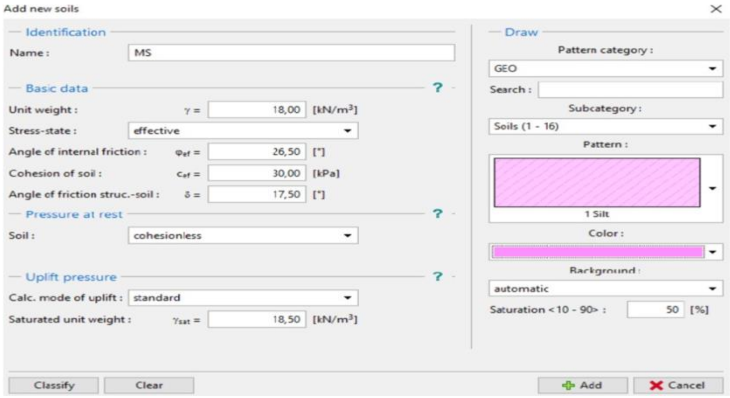


Fig 7: MS soil frame

Note: The active earth pressure depends on the friction between the wall and the soil. The angle of internal friction and the material of the wall decides the

Friction angle which is normally entered in the interval $\delta = (\frac{1}{3}+\frac{1}{2})*\varphi_{efc}$

Step 6: Select the assignment frame and add the geological layers of the soil.

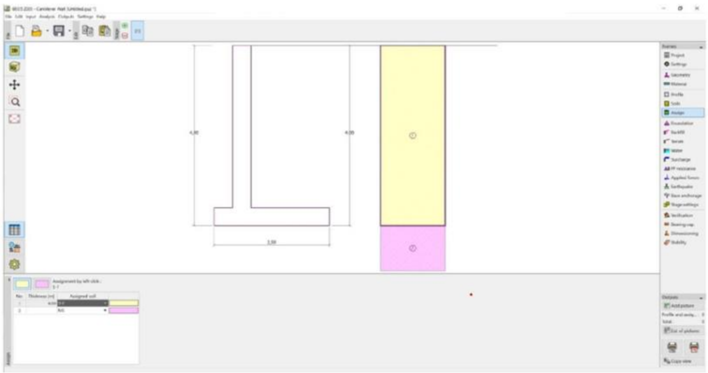


Fig 8: Assignment

Step 7: Choose the horizontal slope in the terrine frame

Fig 9: Terrain

Step 8: Select the frame water and then add the details of the water near to the surroundings of the wall

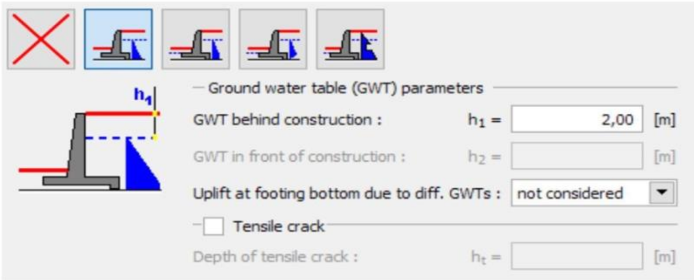


Fig 10: Water Frame

Step 9: Select the surcharge frame and add the surcharge with a magnitude of 10 KN/m3which acts as a dead load for a length of 5 meters.

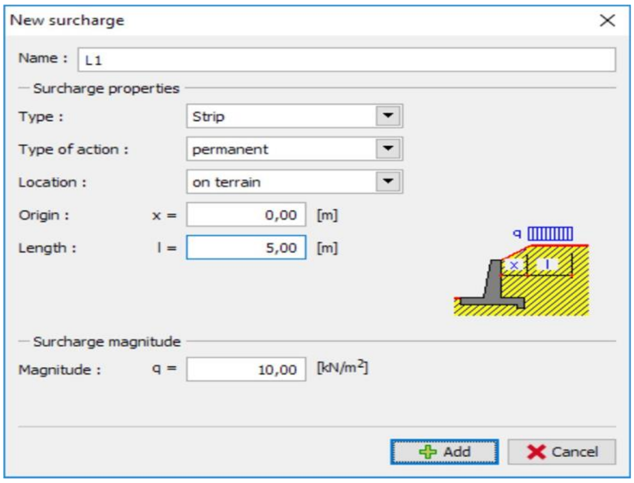


Fig 11: New surcharge

Step10: Select the tab FF resistance and then enter the details of the face resistance of the wall.

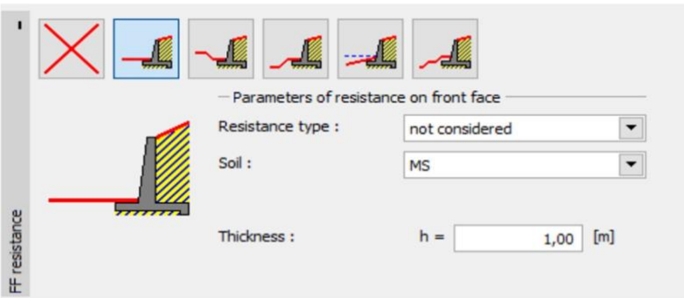


Fig 12: FF resistance

Note: Here we don't take into account the front face resistance. The resistance of the wall depends upon the type of the soil and its quality and also on the allowable displacement of the wall. We take into account the at rest pressure of original or compacted soil.

Next select the stage setting frame and then choose the design situation as permanent and the pressure acting on the wall as wall can deflect.

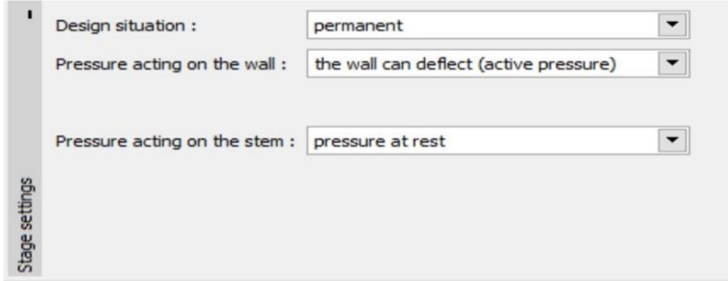


Fig 13: Stage setting

Now the task looks like this:

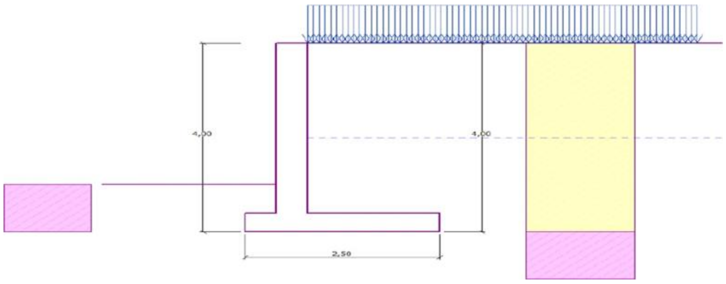


Fig 14: Analyzed structure

Next by select the frame of verification we can see the satisfactory results for slip and overturning.

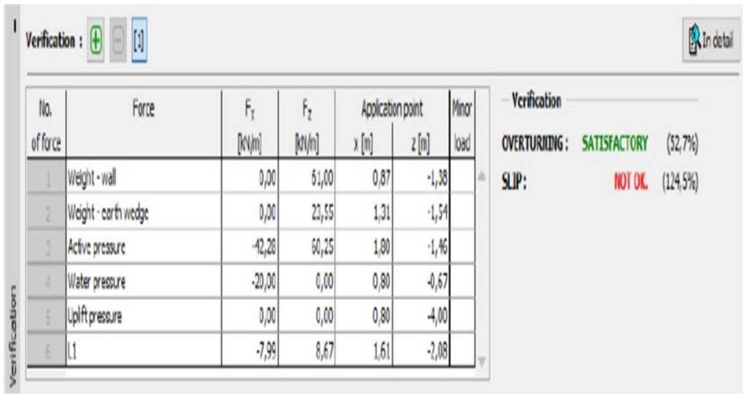


Fig 15: Verification

Note: By clicking on the in detail button we get the detailed information about the results of the analysis.

ANALYSIS:

The results are not satisfactory for the slip.

Check for overturning stability
Resisting moment M_{res} = 208,17 kNm/m
Overturning moment M_{ovr} = 109,75 kNm/m
Wall for overturning is SATISFACTORY

Check for slip
Resisting horizontal force H_{res} = 65,74 kN/m
Active horizontal force H_{act} = 81,83 kN/m
Wall for slip is NOT SATISFACTORY

6. RESULTS AND DISCUSSION

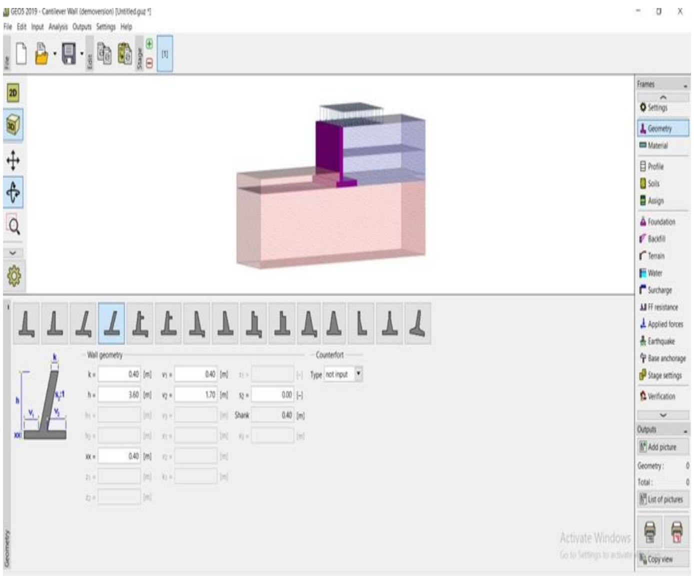


Fig16: 3D view

SOIL	UT WT(KN/m³)	Φcf-(°)	COHESION(Cef)	δ=(°)	γsat-(KN/m³)	FOS OVT	FOS SLIP
SF							
	VARIED						
	–3σ=15.75	σ=28	σ=0	σ=18.5	σ=18	2.037	1
	σ=17.5	σ=28	σ=0	σ=18.5	σ=18	2.017	0.995
	3σ=19.25	σ=28	σ=0	σ=18.5	σ=19.25	2.055	1
		VARIED					
	σ=17.5	–3σ=25.2	σ=0	σ=18.5	σ=18	1.84	0.821
	σ=17.5	σ=28	σ=0	σ=18.5	σ=18	2.017	0.995
	σ=17.5	3σ=30.8	σ=0	σ=18.5	σ=18	2.21	1.197
			VARIED				
	σ=17.5	σ=28	–3σ=0	σ=18.5	σ=18	2.017	0.995
	σ=17.5	σ=28	σ=0	σ=18.5	σ=18	2.017	0.995
	σ=17.5	σ=28	3σ=0	σ=18.5	σ=18	2.017	0.995
				VARIED			
	σ=17.5	σ=28	σ=0	–3σ=1.65	σ=18	2	0.99
	σ=17.5	σ=28	σ=0	σ=18.5	σ=18	2.017	0.995
	σ=17.5	σ=28	σ=0	3σ=20.35	σ=18	2.03	1.01
					VARIED		
	σ=17.5	σ=28	σ=0		–3σ=16.2	2	0.91
	σ=17.5	σ=28	σ=0		σ=18	2.017	0.995
	σ=17.5	σ=28	σ=0		3σ=19.8	2.076	1.01
MS							
	VARIED						
	–3σ=16.2	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	σ=18	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	3σ=19.2	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
		VARIED					
	σ=18	–3σ=23.85	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	σ=18	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	σ=18	3σ=29.15	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
			VARIED				
	σ=18	σ=26.5	–3σ=24	σ=17.5	σ=18.5	2.017	0.995
	σ=18	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	σ=18	σ=26.5	3σ=29.15	σ=17.5	σ=18.5	2.017	0.995
				VARIED			
	σ=18	σ=26.5	σ=26.5	–3σ=15.75	σ=18.5	2.017	0.995
	σ=18	σ=26.5	σ=26.5	σ=17.5	σ=18.5	2.017	0.995
	σ=18	σ=26.5	σ=26.5	3σ=19.25	σ=18.5	2.017	0.995

For overturning

SUM = 64.656

MEAN (μ) = 2.0205

STANDARD DEVIATION (σ) = 0.048943

RELIABILTY INDEX (β) = $\frac{MEAN\ FOS-1}{SD}$ = 20.85

For the β obtained the corresponding Pf from the table given by Ghaiskarmannd is 3x10-5.from table its clear that the given cantilever wall has high performance against the overturning

For slip

SUM = 31.818

MEAN (μ)= 0.994313

STANDARD DEVIATION (σ) = 0.50422

RELIABILTY INDEX (β) = $\frac{MEAN\ FOS-1}{SD}$ = -0.011=0

For the β obtained the corresponding From the table given by Ghaiskarmannd is 0.5.hence from the table for the given probability of failure the cantilever retaining wall is under dangerous condition hence we need to take care to overcome the slip of the wall.

FOS FOR OVERTURNING FOS FOR SLIP

FOS	DENSITY	FOS	DENSITY
0-0.5	0	0–0.25	0
0.5-1	0	0.25– 0.5	0
1-1.5	0	0.5-0.75	0
1.5-2	3	0.75–1	27
2-2.5	27	1.25-1.5	3

As the slip is not satisfactory we have to change the design. And this can be achieved by doing some changes some parameters. For example, we can:

– Use of good quality soil

– Base anchorage

– Increasing the friction

– Stem anchorage

As the mentioned changes requires high technology and coasty, we can change the geometry of the wall by providing the in order obtain required standard

Changing wall geometry

Return the geometry frame and change the geometry of the wall. In order to increase the resistance introduce wall jump by changing the values of x1 and x2.

Fig 17: Rearranging Geometry

Note: A wall jump is usually analysed as an inclined footing bottom. If the influence of the base jump is evaluated as front face resistance, the program will analyse it with a straight footing bottom, but the FF resistance of the construction is going to be analysed up to the depth of the bottom part of the wall jump.

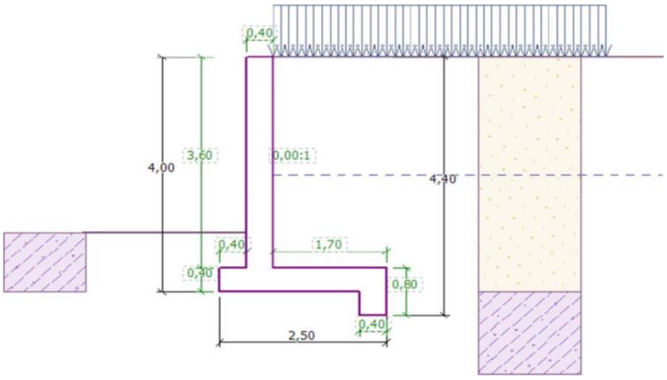


Fig 18: The new shape of the structure

Now we can analyse the newly designed structure

Verification : [1]

No. of force	Force	F_x [kN/m]	F_z [kN/m]	Application point x [m]	Application point z [m]	Minor load
1	Weight - wall	0,00	65,00	0,95	-1,28	
2	Weight - earth wedge	0,00	23,55	1,31	-1,54	
3	Active pressure	-42,28	60,25	1,80	-1,46	
4	Water pressure	-28,80	0,00	0,80	-0,40	
5	Uplift pressure	0,00	0,00	0,80	-4,00	
6	L1	-7,99	9,06	1,65	-2,08	

Verification
OVERTURNING: SATISFACTORY (49,4%)
SLIP: SATISFACTORY (64,9%)

Fig 19: Re-Verification

In the Bearing capacity frame an analysis for the bearing capacity is to be done by considering the bearing capacity of the foundation soil as 175 kPa

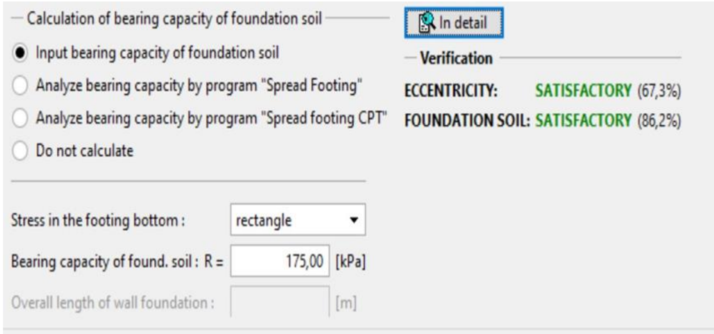


Fig 20: Bearing capacity Frame

Note; the bearing capacity of the soil is considered as an input value, this value is available from the geological survey of India.

Next in the dimension frame enter the details of the details of the reinforcements for the stem as 12 mm ϕ, 10 pieces which satisfies the design criteria's.

Fig 21: Dimensioning

Fig 22: Detailed Results

Then in the frame stability we are going to analyse the slope stability by Bishop method which uses the optimum slip surface for the calculation of the stability and the results provided are conservative.

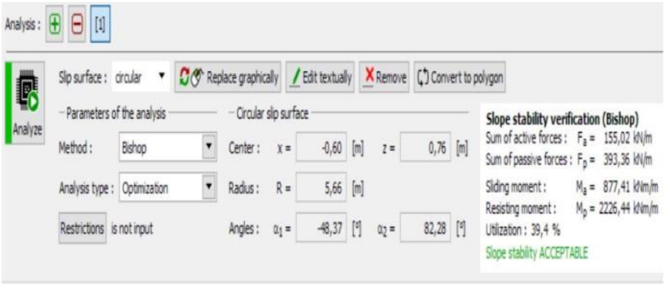


Fig 23: Slope stability

Analysis and Results:

- Resisting moment(218.35KN-m)>

  Overturning moment=107.94

  Hence safe (49.4%)

- Slip Hres=99.26 >Hovr=64.38

Hence safe (64.9%)

- Bearing capacity Rd=175>140.31

  Hence safe(86.2%)

- Overall stability as per Bishop method is 39.4%

  Satisfactory

The Design of the wall is satisfactory.

7. CONCLUSION

From the reliability analysis carried out using the Geo5 software for various variances of the parameters such as cohesion, unit weight and angle of internal friction, we obtain a various number of results for various combinations. For any changes made in the parameters of the MS soil there is no change in the FOS of the soil is observed. From the its clear that the highest factor of safety is 2.21>1.5 against overturning and the lowest FOS against overturning is 1.84>1.5 hence the wall is safe against overturning. Further by considering slip into account the lowest FOS is 0.821<1.5 hence the wall is not safe in slip. Hence in order to make the wall safe against the slip the geometry of the wall has changed and the wall has been made safe in both slip and overturning.

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