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Slope Stability Analysis

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Abstract
Slope stability issue becomes one of the main problems in construction industry due to nature of the topography and the weather conditions. The wide variety of applications of slope engineering include excavations, hill roads, railway lines, embankments, earth dams, reservoirs, open-cut mines and coastal slope stability. Slope failure has been acknowledged as one of the most frequent natural disaster that can lead to great loss in property and life. The project "Slope Stability Analysis" Provides analysis of Jammu, Himachal and Punjab region soil using Geo Studio 2007 Slope/w software. SLOPE/W has been designed and developed to be a general software tool for the stability analysis of earth structures. In order to undergo the mountainous region project, the most important thing that must be taking care of is the slope stability. The study is focus on slope stability analysis for Jammu, Himachal and Punjab State soil slope using Slope/w. Slope failure has become one of the most frequent geological catastrophes along the road network in the hilly terrain of Himalayan regions that lead to huge loss of life, property and above all the environment. Hence, the analysis of slope stability is very important in order to protect the slopes from fail and minimize the likelihood of slope failure. By using the Geo Studio2007 Slope/w software, the slope stability will be analyzed and the FOS of the slope will be determined.

Keywords*: Topography, Embankment, Excavation*

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I. Introduction

Indian citizens are increasing rapidly year by year. India is the second most populous country in the world, with over 1.27 billion people (2014), more than a sixth of the world's population. Already containing 17.5% of the world's population, India is projected to be the world's most populous country by 2025.As the population growth, we will need more land which mean that more civil engineering project will be carried out in mountainous regions. In order to undergo the mountainous region project, the most important thing that must be taking care of is the slope stability.

Slope stability issue becomes one of the main problems in construction industry due to nature of the topography and the weather conditions. The wide variety of applications of slope engineering include excavations, hill roads, railway lines, embankments, earth dams, reservoirs, open-cut mines and coastal slope stability. Slope failure has been acknowledged as one of the most frequent natural disaster that can lead to great loss in property and life. The stability of slope depends more on the resisting force than the driving force because the driving force is greater than the resisting force which actually causes slope failures.
The state of Himachal Pradesh is inherently prone to disasters, more so as it is a part of the Himalayan mountain system. The state has a long history of disastrous natural events (Chandel and Brar, 2010, 2011, 2012) and frequent natural disasters of varying intensity hamper the development of the state. Slope failure has become one of the most frequent geological catastrophes along the road network in the hilly terrain of Himalayan regions that lead to huge loss of life, property and above all the environment. Hence, the analysis of slope stability is very important in order to protect the slopes from fail and minimize the likelihood of slope failure.

The purpose of this study is to analyze slope stability by using Geo Studio 2007 Slope/w software. SLOPE/W has been designed and developed to be a general software tool for the stability analysis of earth structures. SLOPE/W can be used to assess the sliding stability of a gravity retaining wall, or to find the active earth forces on the wall. SLOPE/W can be used to analyze the stability of a wedge of soil that has been reinforced with a structural component such as a pre-stressed anchor, a soil nail, geo-fabric or some other material. The software will analyze data in order to get slope stability by inserting the data to the software. The data of the slope, which used in analyzing the slope stability using Slope/w, was obtained from laboratory test on soil lab at Lovely Professional University, Punjab by us.

II. Objective Of The Study

The analysis on slope stability using Geo Studio 2007 Slope/w software has three specific objectives which are:

1. To produce slope stability analysis for Jammu, Himachal and Punjab State soil slope using Slope/w.

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2. To determine the factor of safety of slope stability of Jammu, Himachal and Punjab soil slope using Slope/w.

III. Methodology

In this study we have taken soil sample of Jammu, Punjab and Himachal state regions. And study of slope stability done by using the computer based geotechnical software code Slope/w (Geo-slope 2007). The factor of safety (FOS) has been determined using the limit equilibrium within the Morgenstern–Price method along with Mohr-Coulomb expression.We have conducted laboratory test on soil to get the Cohesion, Unit weight and Phi value of all three sample of soil.

The following laboratory test has been conducted:

1) Modified Proctor Test
2) Direct Shear Test
3) Sieve Analysis

IV. Morgenstern-Price Method

This method was developed by N.R. Morgenstern,E. Spencer, which consider not only the normal and tangential equilibrium but also the moment equilibrium for each slice in circular and non-circular slip surfaces. It is solved for the factor of safety using the summation of forces tangential and normal to the base of a slice and the summation of moments about the center of the base of each slice. The equations were written for a slice of infinitesimal thickness. The force and moment equilibrium equations were combined and a modified Newton-Raphsonnumerical technique was used to solve for the factor of safety satisfying force and moment equilibrium. The solution required an arbitrary assumption regarding the direction of the resultant of the interslice shear and normal forces.

V. Results and Discussion

5.1 Laboratory Test Result of Jammu Soil

5.1.1 Modified Proctor Test

Soil sample taken = 5kg , Weight of the mould + base plate = 5.7kg

• TRIAL 1:-
Weight of the mould with base plate + soil = 10.034kg
Weight of soil alone = 10.034- 5.7 = 4.334kg = 4334 g
Weight of the soil sample taken for moisture content = .033kg
Weight of the soil sample after oven dry = .029kg
Moisture content = (.033-.029)/.029 * 100 = 13.79%

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Density = 4334/2250 = 1.92g/cm^3
Dry density = 1.92/(1+0.138) = 1.65g/cm^3

• TRIAL 2:-
Weight of the mould with base plate + soil = 10.452kg
Weight of soil alone = 10.452-5.7= 4.752kg= 4752g
Weight of the soil sample taken for moisture content= .032kg
Weight of the soil sample after oven dry = .028kg
Moisture content = (0.004*100)/.028 = 14.28%
Density = 4752/2250 = 2.11g/cm^3
Dry density = 2.11/1.143 = 1.85g/cm^3

• TRIAL 3:-
Weight of the mould with base plate + soil= 10.226kg
Weight of soil alone = 10.226-5.7= 4.526kg =4526g
Weight of the soil sample taken for moisture content= 0.044kg
Weight of the soil sample after oven dry = .036kg
Moisture content= (0.008*100)/.036= 22.22%
Density = 4526/2250= 2.01g/cm^3
Dry density = 2.01/ 1.222 = 1.64g/cm^3

• TRIAL 4:-
Weight of the mould with base plate + soil= 10.116kg
Weight of soil alone = 10.116-5.7= 4.416kg= 4416g
Weight of the soil sample taken for moisture content= 0.046kg
Weight of the soil sample after oven dry =0.034kg
Moisture content= (0.012*100)/.034= 35.29%
Density = 4416/2250= 1.96g/cm^3
Dry density =1.96/1.363= 1.44g/cm^3

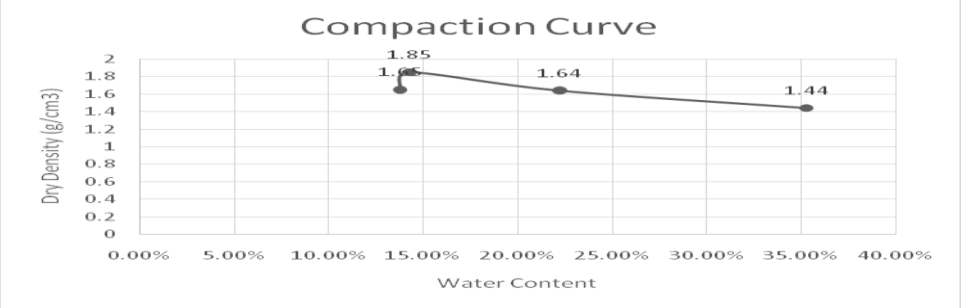

Figure 1.1: Compaction Curve (Jammu region sample)

MDD = 1.85g/cm3 = 16.77kN/m^3

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5.1.2 Direct Shear Test

Dimensions of the soil container = 6cm*6cm

a)

Table 1.1 At 0.05N/mm2:-

Horizontal gauge reading	Proving ring reading	Load (N)	Stress (N/mm^2)
50	2.2	5.5	0.0153
100	4.6	11.5	0.0319

Maximum shear = 0.0319 N/mm^2

b) Table 1.2 At 0.1N/mm^2:-

Horizontal gauge reading	proving ring reading	Load (N)	Stress (N/mm^2)
50	6.2	15.5	0.0431
100	12.6	31.5	0.0875
150	16.1	40.25	0.1118
200	20	50	0.1389
250	20.32	58	0.1411

Maximum shear = 0.1411N/mm^2

c) Table 1.At 0.15N/mm^2:-

Horizontal gauge reading	Proving ring reading	Load (N)	Stress (N/mm^2)
50	13.6	34	0.0944
100	18	45	0.125
150	20.8	52	0.1444
200	27.2	68	0.1889
250	32.4	81	0.225
300	35	87.5	0.2431

Maximum shear = 0.2431N/mm^2

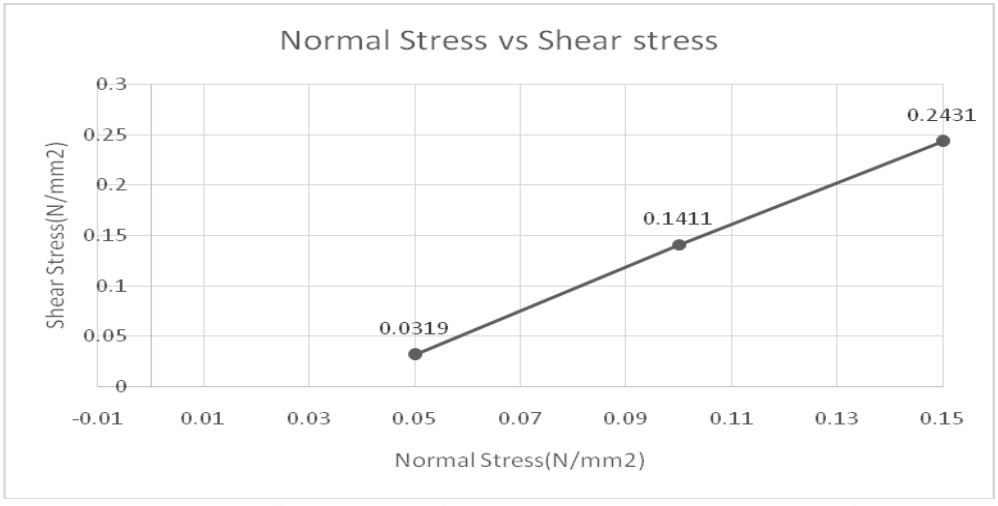

Figure 1.2: Normal Stress Vs Shear stress (Jammu region sample)

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Value Of ϕ = 64.66°
Value Of C= 0.0319 N/mm² =31.9 KPa

1.4.1.3 Table 1.4 Sieve analysis

Sieve size(mm)	Wt retained(kg)	Percent retained	Percent Passing
4.75	.016	3.2	96.8
2	.114	22.8	74
600	.174	34.8	39.2
425	.056	11.2	28
300	.036	7.2	20.8
150	.070	14	6.8
75	.032	6.4	.4
Pan	.001	.4	0

Total Mass taken(Wt) = 0.500 kg
Total Mass retained(Wi) = 0.499kg
Mass lost = (Wt – Wi)/Wt * 100 = 0.2% which is < 2% Hence it is OK.

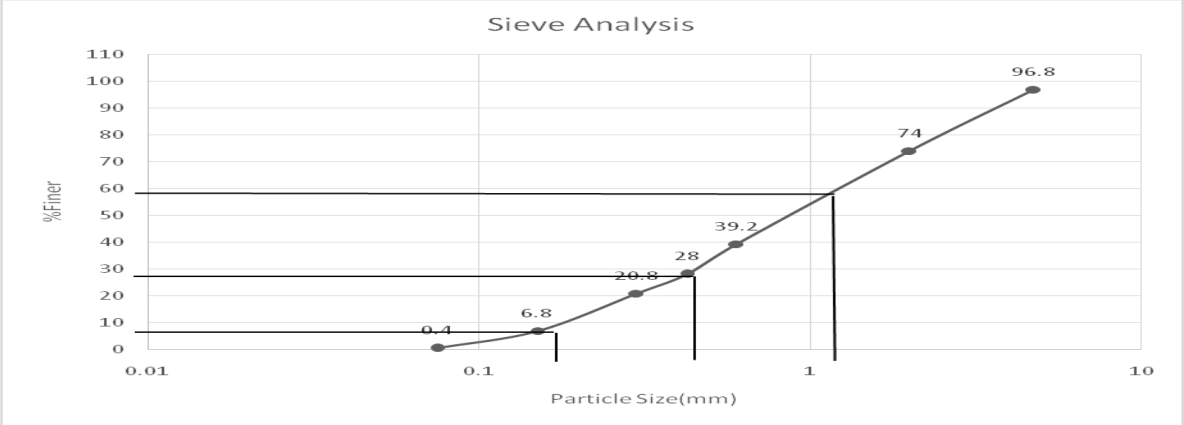

Figure 1.3: Sieve Analysis (Jammu region sample)

Well Graded Soil
D10 = 0.18 D30 = 0.45 D60 = 1.39
CU = 7.72 % Gravel = 3.2 % Fines = 0.4
CC = 0.81 % Sand = 96.4 Unified Classification of Soil: SW

5.2 Laboratory Test Result of Himachal Soil

5.2.1 Modified Proctor Test

Soil sample taken = 5kg
Weight of the mould + base plate = 5.7kg

• TRIAL 1:-
Weight of the mould with base plate + soil= 10.400kg

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Weight of soil alone = 10.400-5.7= 4.700kg= 4700g
Weight of the soil sample taken for moisture content= 0.156kg
Weight of the soil sample after oven dry =0.150kg
Moisture content= (0.006*100)/0.150= 4%
Density = 4700/2250= 2.09g/cm3
Dry density =2.09/1.04= 2.009g/cm3

• TRIAL 2:-
Weight of the mould with base plate + soil = 10.700kg
Weight of soil alone = 10.700- 5.7 = 5 Kg
Weight of the soil sample taken for moisture content = 0.200kg
Weight of the soil sample after oven dry = 0.192kg
Moisture content = (0.200-0.192)/0.192 * 100 = 4.16%
Density = 5000/2250 = 2.22g/cm3
Dry density = 2.22/(1+0.42) = 2.13g/cm^3

• TRIAL 3:-
Weight of the mould with base plate + soil = 10.534kg
Weight of soil alone = 10.5342-5.7= 4.834kg= 4834g
Weight of the soil sample taken for moisture content= 0.246kg
Weight of the soil sample after oven dry = 0.232kg
Moisture content = (.014*100)/0.232 = 6.03%
Density = 4834/2250 = 2.15g/cm^3
Dry density = 2.15/1.06 = 2.02g/cm^3

• TRIAL 4:-
Weight of the mould with base plate + soil= 10.272kg
Weight of soil alone = 10.272-5.7= 4.572kg =4572g
Weight of the soil sample taken for moisture content= 0.256kg
Weight of the soil sample after oven dry = 0.240kg
Moisture content= (0.016*100)/0.240= 6.67%
Density = 4572/2250= 2.032g/cm^3
Dry density = 2.032/ 1.067 = 1.90g/cm^3

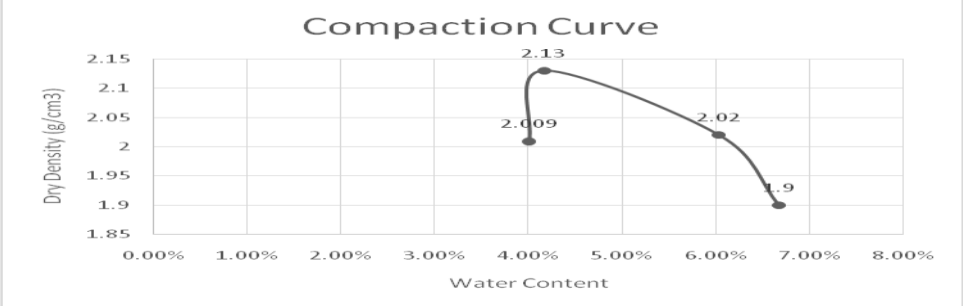

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Figure 1.4: Compaction Curve (Himachal region sample)

MDD = 2.13g/cm^3 =19.31kN/m^3

5.2.2 Direct Shear Test

Dimensions of the soil container = 6cm*6cm

a) Table 1.5 At 0.05N/mm2

Horizontal gauge reading	Proving ring reading	Load (N)	Stress (N/mm^2)
50	4.2	10.5	0.0291
100	6	15.0	0.0416
150	7.4	18.5	0.0514

Maximum shear = 0.0514N/mm^2

b) Table 1.6 At 0.1N/mm2

Horizontal gauge reading	proving ring reading	Load (N)	Stress (N/mm^2)
50	9.2	23	0.0639
100	12.0	30	0.0833
150	15.0	37.5	0.1042
200	15.32	38.3	0.1064
250	15.68	39.2	0.1089

Maximum shear = 0.1089 N/mm^2

c) Table 1.7 At 0.15N/mm2

Horizontal gauge reading	Proving ring reading	Load(N)	Stress(N/mm2)
50	12.6	31.5	0.0875
100	15.4	38.5	0.1069
150	17.4	43.5	0.1208
200	19.0	47.5	0.132
250	20.6	51.5	0.1431
300	21.8	54.5	0.1514
350	23.4	58.5	0.1625

Maximum shear = 0.1625N/mm^2

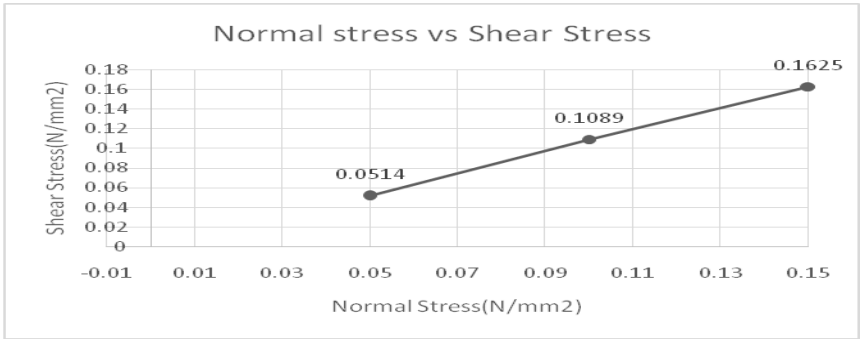

Figure 1.5: Normal Stress Vs Shear stress (Himachal region sample)

Value Of ϕ = 48^o

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Value Of C= 0.0514 N/mm^2 =51.4 KPa

1.6.1 Table 1.8 Sieve analysis

Sieve size(mm)	Wt retained(kg)	Percent retained	Percent Passing
4.75	.012	2.4	97.6
2.36	.036	7.2	90.4
2	.022	4.4	86
1	.058	11.6	74.4
600	.078	15.6	58.8
425	.064	12.8	46
300	.000	0	46
150	.026	5.2	40.
75	.176	35.2	5.6
PAN	.026	5.6	0

Total Mass taken(Wt) = 0.500 kg
Total Mass retained(Wi) = 0.498kg
Mass lost = (Wt – Wi)/Wt * 100 = 0.4% which is < 2% Hence it is OK.

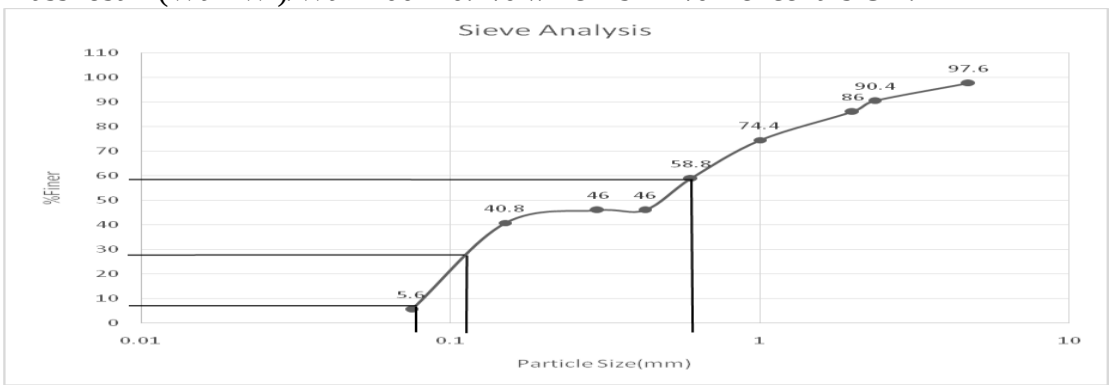

Figure 1.6: Sieve Analysis (Himachal region sample)

Well Graded Soil
D10 = 0.082 D30 = 0.115 D60 = 0.162
CU = 1.97 % Gravel = 2.4 % Fines = 5.6
CC = 0.995 % Sand = 92 Unified Classification of Soil: SW

5.3 Laboratory Test Result of Punjab Soil

5.3.1 Modified Proctor Test

Soil sample taken = 5kg
Weight of the mould + base plate = 5.7kg

• TRIAL 1:-
Weight of the mould with base plate + soil= 10.216kg
Weight of soil alone = 10.216-5.7= 4.516kg= 4516g
Weight of the soil sample taken for moisture content= 0.042kg

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Weight of the soil sample after oven dry =0.038kg
Moisture content= (0.004*100)/0.042= 9.52%
Density = 4516/2250= 2.01g/cm3
Dry density =2.01/1.095= 1.83g/cm3

• TRAIL 2:-
Weight of the mould with base plate + soil = 10.646kg
Weight of soil alone = 10.646- 5.7 = 4.946kg = 4946g
Weight of the soil sample taken for moisture content = 0.026kg
Weight of the soil sample after oven dry = 0.022kg
Moisture content = (0.026-.022)/0.022 * 100 = 18.18%
Density = 4946/2250 = 2.2g/cm2
Dry density = 2.2/(1+0.1818) = 1.86g/cm2

• TRIAL 3:-
Weight of the mould with base plate + soil = 10..40kg
Weight of soil alone = 10.40-5.7= 4.7kg= 4700g
Weight of the soil sample taken for moisture content= 0.018kg
Weight of the soil sample after oven dry = 0.014kg
Moisture content = (.004*100)/0.014 = 28.57%
Density = 4700/2250 = 2.08g/cm3
Dry density = 2.08/1.2857 = 1.62g/cm3

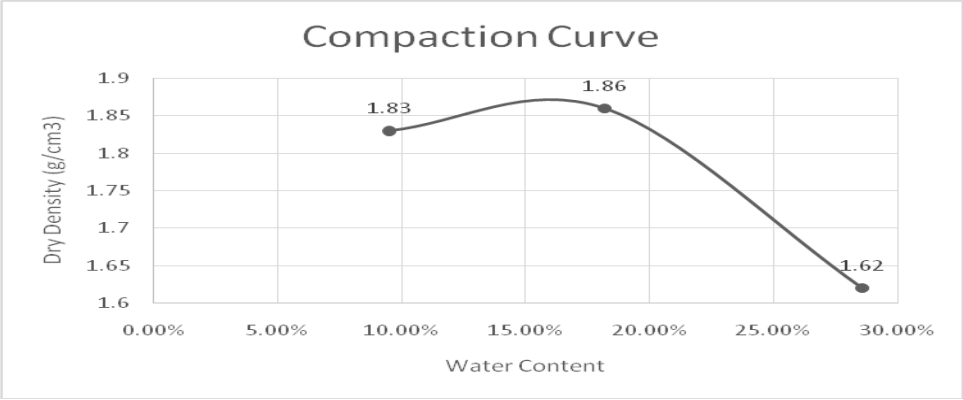

Figure 1.7: Compaction Curve (Punjab region sample)
MDD = 1.86g/cm3 =18.24kN/m3

5.3.2 Direct Shear Test

Dimensions of the soil container = 6cm*6cm

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a) Table 1.9 At 0.05 N/mm2:-

Horizontal gauge reading	Proving ring reading	Load (N)	Stress (N/mm2)
50	30	75	0.021
100	53	132.5	0.037
150	64	160	0.044
200	75	187.5	0.052
250	76	190	0.053

Maximum shear = 0.053 N/mm2

b) Table 2.1 **At 0.10 N/mm2:-**

Horizontal gauge reading	proving ring reading	Load	Stress
50	12	30	0.008
100	37	92.5	0.026
150	48	120	0.033
200	53	132.5	0.037
250	89	222.5	0.061
300	131.04	327.6	0.091

Maximum shear = 0.091N/mm2

c) Table 2.2 **0.15 N/mm2:-**

Horizontal gauge reading	Proving ring reading	Load	Stress
50	60	150	0.042
100	95	237.5	0.066
150	125	312.5	0.087
200	138	345	0.096
250	150	375	0.104
300	157	392.5	0.109
350	166	415	0.115
400	172	430	0.119
450	177	442.5	0.123
500	179	447.5	0.124
550	182	455	0.126
600	185	462.5	0.128
650	187	467.5	0.128

Maximum shear = 0.128N/mm2

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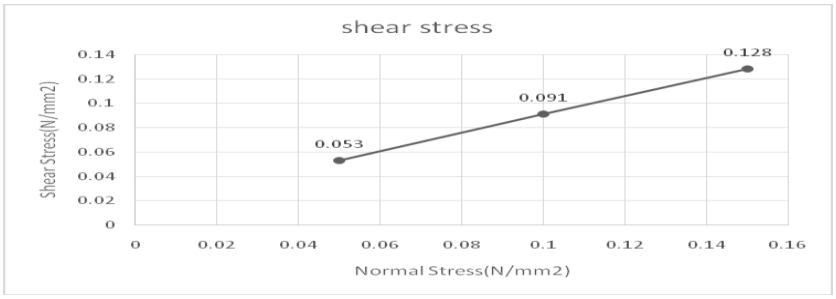

Figure 1.8: Normal Stress Vs Shear stress (Punjab region sample)

Value Of ϕ = 36.86o
Value Of C= 0.053 N/mm2 =53 KPa

1.7.3 Table 2.1 **Sieve analysis**

Sieve size(mm)	Wt retained(kg)	Percent retained	Percent Passing
4.75	.042	8.4	91.6
2.36	.036	7.2	84.4
1	0.66	13.2	71.2
0.60	0 .046	9.2	62
0.30	0 .042	8.4	53.6
0.21	2 .080	16	37.6
0.15	0 .066	13.2	24.4
0.07	5 .078	15.6	8.8
PAN	.040	8.8	0

Total Mass taken(Wt) = 0.500 kg
Total Mass retained(Wi) = 0.496kg
Mass lost = (Wt – Wi)/Wt * 100 = 0.8% which is < 2% Hence it is OK.

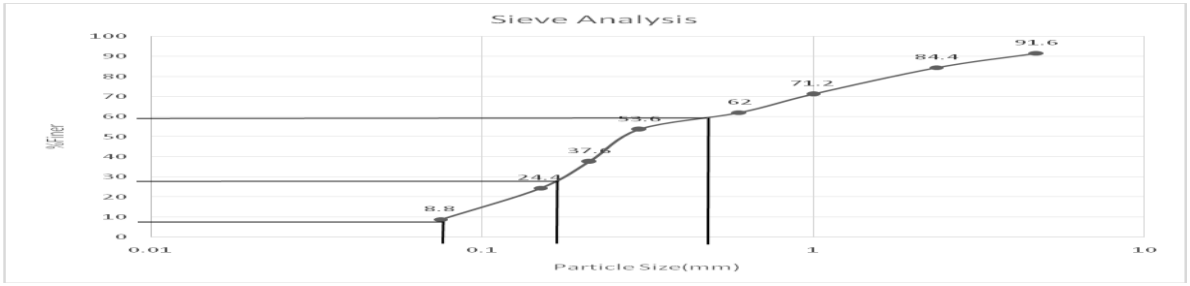

Figure 1.9: Sieve Analysis (Punjab region sample)

Well Graded Soil
D10 = 0.081 D30 = 0.18 D60 = 0.52
CU = 0.642 % Gravel = 8.4 % Fines = 8.8
CC = 0.77 % Sand = 82.8 Unified Classification of Soil: SW

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5.4 Slope/W Analysis

5.4.1 Slope/W Analysis Of Jammu Region Soil

File Information

Revision Number: 6
Date: 4/26/2015
Time: 2:57:37 AM
File Name: jammu region soil.gsz
Directory: E:\capastone\geo studio work\
Last Solved Date: 4/26/2015
Last Solved Time: 3:09:59 AM

Project Settings

Length(L) Units: meters
Time(t) Units: Seconds
Force(F) Units: kN
Pressure(p) Units: kPa
Strength Units: kPa
Unit Weight of Water: 9.807 kN/m³
View: 2D

Analysis Settings

SLOPE/W Analysis

Description: jammu soil analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
Apply Phreatic Correction: No
Side Function
Interslice force function option: Half-Sine
PWP Conditions Source: Piezometric Line
Use Staged Rapid Drawdown: No
Slip Surface
Direction of movement: Left to Right
Use Passive Mode: No
Slip Surface Option: Entry and Exit
Critical slip surfaces saved: 1
Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
FOS Distribution

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FOS Calculation Option: Constant
Advanced
Number of Slices: 30
Optimization Tolerance: 0.01
Minimum Slip Surface Depth: 0.1 m
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

X (m)	Y (m)
0	10
22.444444	7
34	7

Materials

upper soil layer

Model: Mohr-Coulomb
Unit Weight: 16.77 kN/m³
Cohesion: 31.9 kPa
Phi: 64.6 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Table 2.3 Regions

	Material	Points	Area (m²)
Region 1	upper soil layer	1,2,3,4,5,6	332

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (0.7, 14) m
Left-Zone Right Coordinate: (1, 14) m
Left-Zone Increment: 4
Right Projection: Point
Right Coordinate: (33, 5) m
Right-Zone Increment: 4
Radius Increments: 4

Table 2.4 Points

	X (m)	Y (m)
Point 1	0	14
Point 2	10	14
Point 3	26	5
Point 4	34	5
Point 5	34	0
Point 6	0	0

Slip Surface Limits

Left Coordinate: (0, 14) m
Right Coordinate: (34, 5) mPiezometric Lines

Piezometric Line 1

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Table 2.2 Coordinates

	Slip Surface	X (m)	Y (m)	PWP (kPa)	Base Normal Stress (kPa)	Frictional Strength (kPa)	Cohesive Strength (kPa)
1	23	1.4829265	13.303515	-34.341517	3.2661932	6.8785869	31.9
2	23	2.448779	11.998745	-22.811899	19.199076	40.43316	31.9
3	23	3.4146315	10.851725	-12.828567	33.637064	70.839493	31.9
4	23	4.380484	9.831465	-4.0892621	46.905358	98.782454	31.9
5	23	5.377069	8.89091	3.8283937	60.317559	118.96591	31.9
6	23	6.404387	8.020236	11.020087	73.687529	131.97733	31.9
7	23	7.431705	7.238684	17.338319	85.980685	144.56049	31.9
8	23	8.459023	6.5362725	22.880079	97.460965	157.06698	31.9
9	23	9.486341	5.9052745	27.722161	108.31665	169.7316	31.9
10	23	10.51852	5.337204	31.940015	114.69727	174.28637	31.9
11	23	11.555555	4.8277085	35.577263	116.42052	170.2555	31.9
12	23	12.59259	4.375704	38.650305	117.43695	165.92429	31.9
13	23	13.62963	3.9778795	41.192341	117.72353	161.1743	31.9
14	23	14.66667	3.631529	43.230442	117.26648	155.91953	31.9
15	23	15.703705	3.3344425	44.784568	116.01558	150.01216	31.9
16	23	16.74074	3.084825	45.872675	113.89266	143.24976	31.9
17	23	17.77778	2.8812345	46.510104	110.81072	135.41678	31.9
18	23	18.814815	2.722538	46.707349	106.70366	126.35193	31.9
19	23	19.85185	2.607879	46.472138	101.46151	115.80735	31.9
20	23	20.88889	2.5366515	45.810923	95.00262	103.59747	31.9
21	23	21.925925	2.508485	44.72841	87.266973	89.586006	31.9
22	23	23.037035	2.527575	43.861269	81.381241	79.016878	31.9
23	23	24.22222	2.600625	43.145019	77.093737	71.495834	31.9
24	23	25.407405	2.73036	41.872403	70.916381	61.166474	31.9
25	23	26.5	2.898827	40.219956	63.720727	49.492509	31.9
26	23	27.5	3.098655	38.260053	60.152931	46.106294	31.9
27	23	28.5	3.341352	35.880812	55.495669	41.308793	31.9
28	23	29.5	3.6282225	33.067207	49.777071	35.190892	31.9
29	23	30.5	3.960879	29.804725	43.044779	27.88349	31.9
30	23	31.5	4.3412915	26.074399	35.366821	19.569796	31.9
31	23	32.5	4.7718535	21.851684	26.824469	10.472659	31.9

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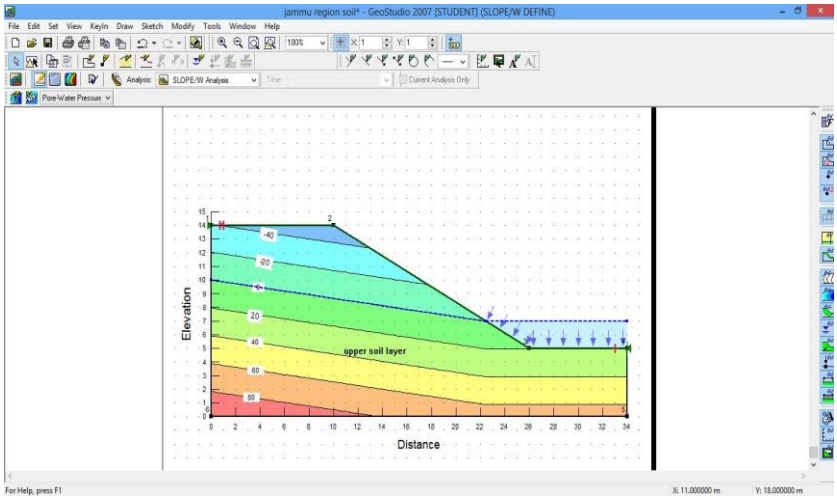

Figure 2.0: Slope/w Analysis (Jammu region sample)

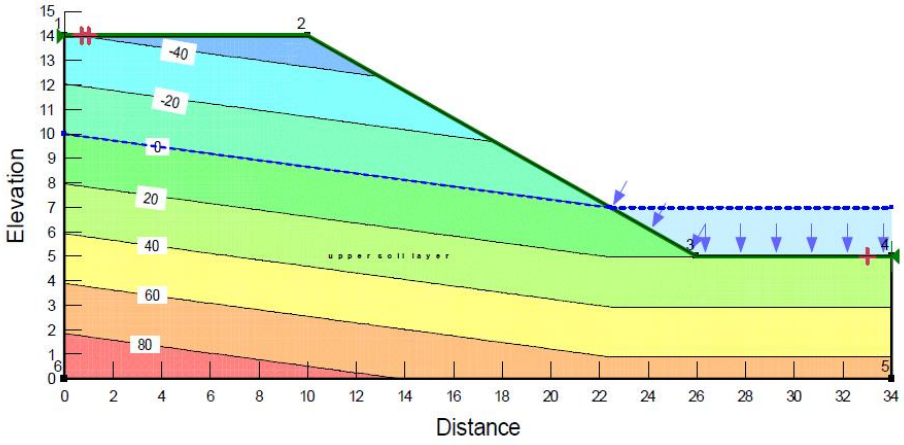

Figure 2.1: Pore pressure from a piezometric line (Jammu region sample Slope/W Analysis)

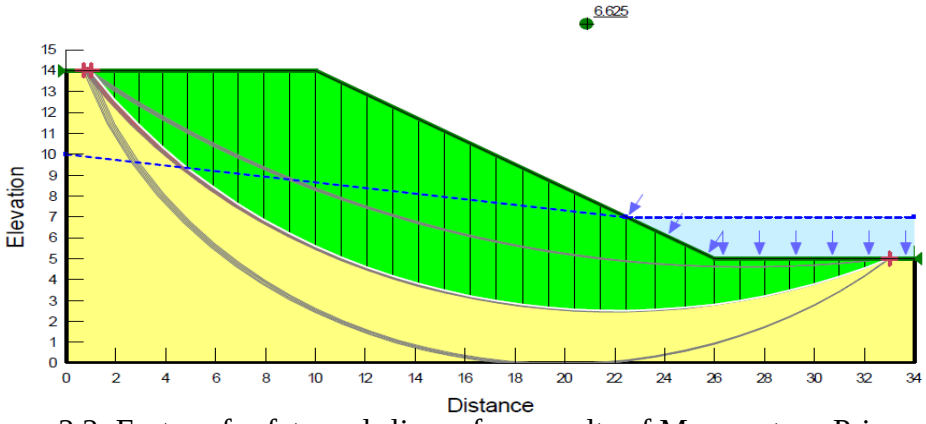

Figure 2.2: Factor of safety and slip surface results of Morgenstern-Price analysis computed by SLOPE/W

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5.4.2 Slope/W Analysis Of Himachal Region Soil

File Information

Revision Number: 5
Date: 4/26/2015
Time: 3:02:07 AM
File Name: HIMACHAL REGION SOIL.gsz
Directory: E:\capastone\geo studio work\
Last Solved Date: 4/26/2015
Last Solved Time: 3:02:12 AM

Project Settings

Length(L) Units: meters
Time(t) Units: Seconds
Force(F) Units: kN
Pressure(p) Units: kPa
Strength Units: kPa
Unit Weight of Water: 9.807 kN/m³
View: 2D

Analysis Settings

SLOPE/W Analysis

Description: HIMACHAL SOIL
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Apply Phreatic Correction: No
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: Piezometric Line
    Use Staged Rapid Drawdown: No
Slip Surface
    Direction of movement: Left to Right
    Use Passive Mode: No
    Slip Surface Option: Entry and Exit
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack
        Tension Crack Option: (none)
FOS Distribution
    FOS Calculation Option: Constant
Advanced
    Number of Slices: 30

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Optimization Tolerance: 0.01

Coordinates

Minimum Slip Surface Depth: 0.1 m
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Table 2.5

X (m)	Y (m)
0	10
22.8	6
34	6

Materials

UPPER SOIL LAYER

Model: Mohr-Coulomb
Unit Weight: 19.31 kN/m³
Cohesion: 51.4 kPa
Phi: 48 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Table 2.6 Regions

	Material	Points	Area (m²)
Region 1	UPPER SOIL LAYER	1, 2, 3, 4, 5, 6	316

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (0.96, 14) m
Left-Zone Right Coordinate: (1, 14) m
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (32.82, 4) m
Right-Zone Right Coordinate: (33, 4) m
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 14) m
Right Coordinate: (34, 4) m

Piezometric Lines Piezometric Line 1

Table 2.7 Points

	X (m)	Y (m)
Point 1	0	14
Point 2	10	14
Point 3	26	4
Point 4	34	4
Point 5	34	0
Point 6	0	0

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Table 2.8 Critical Slip Surfaces

	Slip Surface	FOS	Center (m)	Radius (m)	Entry (m)	Exit (m)
1	103	4.552	(22.805, 27.758)	25.782	(1, 14)	(32.82, 4)

	Slip Surface	X (m)	Y (m)	PWP (kPa)	Base Normal Stress (kPa)	Frictional Strength (kPa)	Cohesive Strength (kPa)
1	103	1.498052	13.267645	-34.623254	-1.5552208	-1.7272477	51.4
2	103	2.494156	11.897485	-22.900179	19.804641	21.995283	51.4
3	103	3.49026	10.69587	-12.82952	38.631456	42.904578	51.4
4	103	4.486364	9.6288005	-4.0785601	55.562225	61.708102	51.4
5	103	5.4859745	8.670451	3.6001477	71.632337	75.557401	51.4
6	103	6.4890915	7.805221	10.359607	86.895992	85.002266	51.4
7	103	7.492208	7.024649	16.288894	100.97462	94.053031	51.4
8	103	8.4953245	6.319438	21.479245	114.15798	102.93016	51.4
9	103	9.4984415	5.682333	26.001081	126.66712	111.80096	51.4
10	103	10.533335	5.0912615	30.017453	133.6564	115.10271	51.4
11	103	11.6	4.545072	33.538354	134.93353	112.61076	51.4
12	103	12.666665	4.0594645	36.465126	135.40175	109.88026	51.4
13	103	13.733335	3.6307705	38.834721	135.04181	106.8488	51.4
14	103	14.8	3.255995	40.674562	133.80552	103.43241	51.4
15	103	15.866665	2.93269	42.010069	131.62457	99.526983	51.4
16	103	16.933335	2.658862	42.860299	128.39285	94.99352	51.4
17	103	18	2.432903	43.241386	124.0034	89.695308	51.4
18	103	19.066665	2.253538	43.164413	118.35104	83.503213	51.4
19	103	20.133335	2.119787	42.640961	111.30661	76.260935	51.4
20	103	21.2	2.0309375	41.677115	102.79394	67.877115	51.4
21	103	22.266665	1.986524	40.277477	92.721054	58.244493	51.4
22	103	23.333335	1.986317	39.362034	84.927139	50.605175	51.4
23	103	24.4	2.0303155	38.930866	79.371956	44.914381	51.4
24	103	25.466665	2.118747	38.063258	72.060865	37.758168	51.4
25	103	26.568335	2.25799	36.697799	64.029891	30.355364	51.4
26	103	27.705	2.4519125	34.795933	60.061549	28.06031	51.4
27	103	28.841665	2.6988695	32.373888	54.58598	24.669027	51.4

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28	103	29.978335	3.0004515	29.416487	47.665322	20.267385	51.4
29	103	31.115	3.358689	25.903077	39.400925	14.990879	51.4
30	103	32.251665	3.7761275	21.809419	29.923695	9.0118165	51.4

Slices of Slip Surface: 103

Factor of Safety (Himachal Soil) =4.552 (Morgenstern-Price Method)
Factor of Safety (Himachal Soil) =4.225 (Ordinary)
Factor of Safety (Himachal Soil) =4.552 (Bishop)
Factor of Safety (Himachal Soil) =4.270 (Janbu)

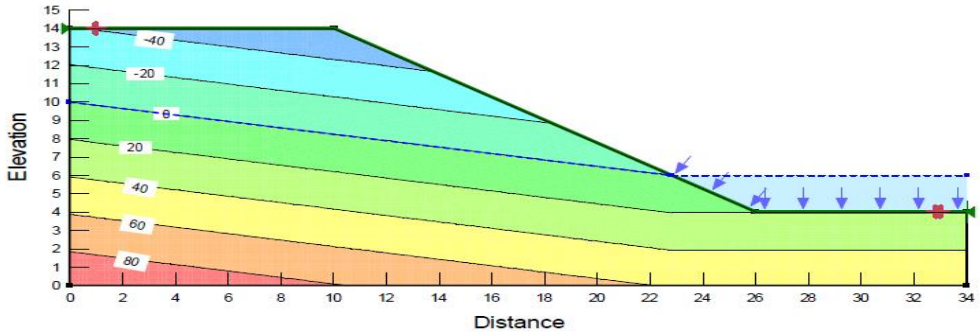

Figure 2.3: Pore pressure from a piezometric line (Slope/w Analysis Himachal sample)

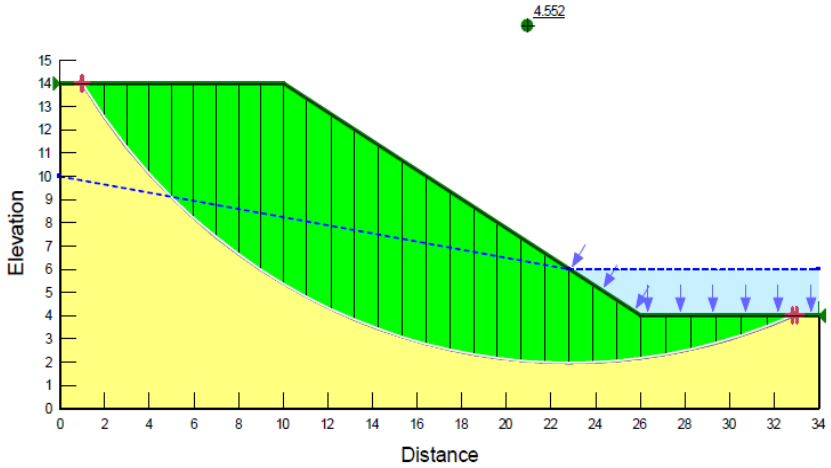

Figure 2.4: Factor of safety and slip surface results of Morgenstern-Price analysis computed by SLOPE/W Slope/w Analysis Himachal sample

5.4.3 Slope/W Analysis Of Punjab Region Soil

File Information

Revision Number: 9

ISSN: 2348 9510
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Date: 4/27/2015
Time: 1:42:38 AM
File Name: PUNJAB region soil.gsz
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Last Solved Date: 4/27/2015
Last Solved Time: 1:42:42 AM

Project Settings

Length(L) Units: meters
Time(t) Units: Seconds
Force(F) Units: kN
Pressure(p) Units: kPa
Strength Units: kPa
Unit Weight of Water: 9.807 kN/m³
View: 2D

Analysis Settings

SLOPE/W Analysis

Description: PUNJAB soil analysis
Kind: SLOPE/W
Method: Morgenstern-Price
Settings
    Apply Phreatic Correction: No
    Side Function
        Interslice force function option: Half-Sine
    PWP Conditions Source: Piezometric Line
    Use Staged Rapid Drawdown: No
Slip Surface
    Direction of movement: Left to Right
    Use Passive Mode: No
    Slip Surface Option: Entry and Exit
    Critical slip surfaces saved: 1
    Optimize Critical Slip Surface Location: No
    Tension Crack
        Tension Crack Option: (none)
FOS Distribution
    FOS Calculation Option: Constant
Advanced
    Number of Slices: 30
    Optimization Tolerance: 0.01

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Minimum Slip Surface Depth: 0.1 m
Optimization Maximum Iterations: 2000
Optimization Convergence Tolerance: 1e-007
Starting Optimization Points: 8
Ending Optimization Points: 16
Complete Passes per Insertion: 1
Driving Side Maximum Convex Angle: 5 °
Resisting Side Maximum Convex Angle: 1 °

Table 2.9Coordinates

	X (m)	Y (m)
	0	10
	22.444444	7
	34	7

Materials

Table 3.0 Regions

	Material	Points	Area (m²)
Region 1	upper soil layer	1, 2, 3, 4, 5, 6	332

upper soil layer

Model: Mohr-Coulomb
Unit Weight: 18.24 kN/m³

Cohesion: 53 kPa

Phi: 36.86 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Table 3.01Points

	X (m)	Y (m)
Point 1	0	14
Point 2	10	14
Point 3	26	5
Point 4	34	5
Point 5	34	0
Point 6	0	0

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (0.7, 14) m
Left-Zone Right Coordinate: (1, 14) m
Left-Zone Increment: 4
Right Projection: Point
Right Coordinate: (33, 5) m
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (0, 14) m
Right Coordinate: (34, 5) m
Piezometric Lines
Piezometric Line 1

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Critical Slip Surfaces

	Slip Surface	FOS	Center (m)	Radius (m)	Entry (m)	Exit (m)
1	24	4.279	(19.861, 19.672)	19.695	(1, 14)	(33, 5)

	Slip Surface	X (m)	Y (m)	PWP (kPa)	Base Normal Stress (kPa)	Frictional Strength (kPa)	Cohesive Strength (kPa)
1	24	1.4827335	12.723295	-28.65114	-6.1428531	-4.605482	53
2	24	2.448201	10.527416	-8.3816007	29.187754	21.882938	53
3	24	3.435868	8.8424335	6.8484414	58.046047	38.384387	53
4	24	4.4457345	7.4402895	19.275394	83.051121	47.814583	53
5	24	5.455601	6.2615695	29.511307	103.89481	55.76755	53
6	24	6.4654675	5.250195	38.106329	121.94228	62.85434	53
7	24	7.475334	4.372447	45.390105	138.02132	69.448414	53
8	24	8.4852005	3.6061675	51.581401	152.65269	75.776192	53
9	24	9.495067	2.935908	56.830896	166.20436	82.000578	53
10	24	10.556625	2.3246275	61.434458	174.53978	84.79847	53
11	24	11.669875	1.771384	65.401087	177.51934	84.058428	53
12	24	12.783125	1.302221	68.542685	179.40979	83.120404	53
13	24	13.896375	0.91079785	70.922095	180.22437	81.947208	53
14	24	15.009625	0.59230865	72.58643	179.92952	80.478346	53
15	24	16.122875	0.3431335	73.57059	178.43205	78.617796	53
16	24	17.236125	0.16060691	73.901497	175.63758	76.274602	53
17	24	18.349375	0.04286321	73.59661	171.39464	73.322129	53
18	24	19.383475	0	72.661609	167.30768	70.95901	53
19	24	20.338425	0	71.409184	158.17628	65.051909	53
20	24	21.223035	0.028230145	69.973087	152.78817	62.088964	53

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23	24	24. 22222	0. 47539125	63. 987079	130. 60048	49. 942076	53
24	24	25. 407405	0. 78403285	60. 959645	120. 56084	44. 684808	53
25	24	26. 5	1. 1371392	57. 496889	110. 2132	39. 523004	53
26	24	27. 5	1. 5267265	53. 676349	103. 04119	37. 010308	53
27	24	28. 5	1. 981387	49. 217111	94. 126421	33. 669863	53
28	24	29. 5	2. 5063145	44. 069588	83. 460346	29. 532438	53
29	24	30. 5	3. 108224	38. 166404	71. 042973	24. 648554	53
30	24	31. 5	3. 795926	31. 422539	56. 899619	19. 100934	53
31	24	32. 5	4. 5812395	23. 720612	41. 062011	13. 001369	53

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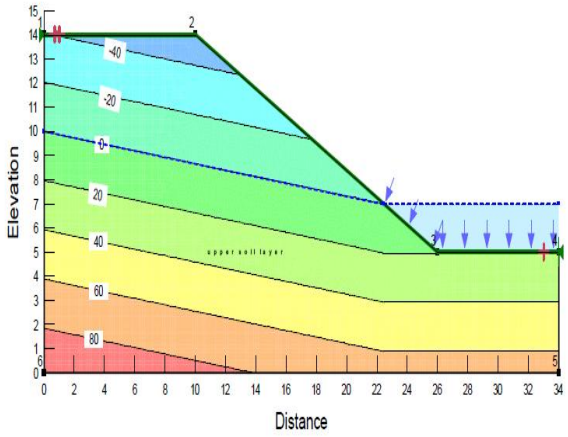

Figure 2.5: Pore pressure from a piezometric line (Slope/W Analysis Punjab region sample)

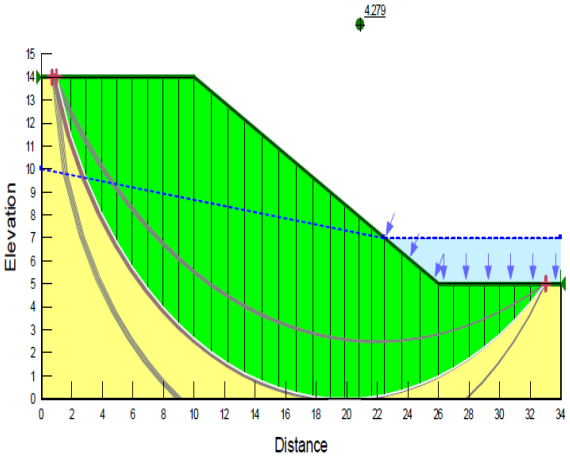

Figure 2.6: Factor of safety and slip surface results of Morgenstern-Price analysis (Slope/W Analysis Punjab region sample)

VI. Conclusion

	PUNJAB SOIL	HIMMACHAL SOIL	JAMMU SOIL
ϕ	**36.86°**	**48°**	**64.66°**
F.O.S.(Morgenstern-Price Method)	**4.279**	**4.552**	**6.625**

- The results show that the factor of safety of the slope stability increases with an increase in cohesion and internal friction angle
- Since the value of F.O.S. > 1.5, So all the structures are safe.
- Jammu Region soil is having greater stability as compare to Punjab and Himachal region as FOS and internal friction are maximum as compare to others.
- The study of slope stability problems by using the computer based geotechnical software code Slope/w provides more understanding viewing all the detailed forces on each slice, to understand failure mechanisms, and the distribution of a variety of parameters along the slip surface with respect to the factor of safety.

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- Morgenstern-Price Method consider not only the normal and tangential equilibrium but also the moment equilibrium for each slice in circular and non-circular slip surfaces. It is solved for the factor of safety using the summation of forces tangential and normal to the base of a slice and the summation of moments about the center of the base of each slice.

- SLOPE/W is the leading software product for computing the factor of safety of earth and rock slopes. With SLOPE/W, both simple and complex problems can be analyzed for a variety of slip surface shapes, pore-water pressure conditions, soil properties, analysis methods and loading conditions. Using limit equilibrium, SLOPE/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure conditions using a large selection of soil models.

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