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Slope Stability Analysis of the Qalandarabad Landslide

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Abstract- The current study investigates the slope failure at Qalandarabad, Khyber Pakhtunkhwa, Pakistan. The factor of safety (FOS) of the slope is determined using limit equilibrium method (LEM) with the assumption of Morgenstern and Price (MP), ordinary (O), Janbu (J) and Bishop (B) methods in Slope/W software. The analyses are assumed for dry and fully saturated field drainage condition. The values of factor of safety (FOS) for four distinct locations range from 0.344 to 0.383 for gravity loading, 0.287 to 0.332 for seismic loading. The values of FOS indicate relatively unstable slopes. Therefore, slope is strengthened with the strengthening technique (e.g., retaining wall) to increase the FOS values to 1.531 to 1.690 for gravity loading and 1.293 to 1.482 for seismic loading. In addition, the results show that FOS increases with increase in cohesion and internal friction angle, however, increase in the unit weight and overburden pressure result in decrease in FOS.

Keywords- Slope stability, Limit equilibrium method, Finite element method, Laboratory analysis, Shear strength.

I. INTRODUCTION

Background:

Landslide or slope failure is a natural phenomenon that refers to the movement of rock mass, debris or earth down a slope, affected by gravity [1-3]. Landslides pose a severe danger to the population living in the mountainous areas. Landslides involve the forward, sliding and apparent movement of slope constituting resources like rock, soil, artificial fill or arrangement of these under the action of gravity, along a particular observable surface of failure [2, 4]. Varnes [5] separates landslides into five classes; falls, topples slides, spreads and flows. Landslide is one of the seismic perils that are normally seen after ground shaking of the affected zone that can occur from small to large scales. A complete understanding of a complex landslide requires the determination of geometry of slope, slip surfaces, slope angle and soil strength parameters [6]. Remembering the ultimate objective to get this scaling, one has to appreciate the mechanics controlling scaling of landslide geometry in all environmental conditions (i.e., analyzed on both homogeneous and heterogeneous slopes), experimental observation and numerical modeling [7-9].

Engineering geologists and geotechnical engineers are striving to subdue the impacts of this natural hazard, at the global level. With appropriate evaluation, investigation, plan, and development, slope vulnerability issues can be reduced [10]. Landslides are quite recurrent in the northern part of Pakistan, extending over the mountainous regions of Himalayas, Karakorum and Hindukush. The slope failure can cause both direct and indirect expanses [11-12]. The damage caused by the landslide can be reduced by more than 90 percent by utilizing the result of detailed geological and geotechnical studies [13-14].

The first incident of the Kashmir earthquake was created in October 2005, which ultimately passes from Balakot to Bagh along the Balakot-Bagh Fault, affecting more destruction in the surrounding areas. During/after the earthquake, which caused enormous destruction in the region, massive landslides have been triggered in accordance with housing, infrastructure and human damage. The earthquake occurred close to the fault of Muzaffarabad (also called, Balakot-Bagh Fault) within the Hazara Kashmir Syntax, and the extreme vertical movement of fault was around 5m [15-16].

Attabad Lake is a lake in Gojal, Hunza Valley, Gilgit Baltistan, an administrative area of Pakistan. The stream was produced due to an enormous landslide on Attabad City in Hunza Valley, Gilgit Baltistan Province, 14 km northeast (upstream) of Karimabad that happened on Jan 4, 2010 [17]. The slide demolished about twenty individuals and about half a year (five months) jammed the Hunza River movement. The total Hunza and Gojal valley population has been impacted by transferring 6,000 inhabitants from upstream townships up to 25,000 individuals. Because of the problems of access roads and market access and the damage caused by the lake to land, homes and agricultural plants, the Karakoram Highway flooded more than 19 km.

Landslides have blocked the Karakoram Highway (KKH) in many places leaving thousands of people stranded. It is a major trade path and standard tourist destination. The area is considered to be the significant part of the China Pakistan Economic Corridor (CPEC) through which the remote region is supposed to advantageous from developed infrastructure set-up and connectivity.

Slope failure caused vast destruction in Pakistan to various infrastructures on or around the potential landslides during 2005 Kashmir Earthquake. Engineering geologists and geotechnical engineers recognized a deficiency of investigation and stability of slope failures. The present research emphasizes on the evaluation of the impact of rainfall on the slope failure and the correlation with the Qalandarabad landslide. Because it can transmit similar threat to the population or health protection of the individuals and buildings/properties set-up on or nearby the prospective landslides.

In the present study, stability analysis is carried out against gravity and seismic loads. Unstable slope, is stabilized by retaining structures and stability analysis is performed using Geo-studio software (e.g., Slope/W) for limit equilibrium method of slices and Sigma/W package for load deformation analysis or stress deformation history.

Significance of the Research:

Qalandarabad slope or landslide is an important critical slope because there is a road which is passing over the slope and is still being used by all traffic. It connects the public communication line between the main road with the villages/cities laying on the off scoots of Abbottabad District. There are different houses and Government infrastructure lying on the top and toe of the slope. Incase if it failed, it can seriously damage those buildings and also destruct the public communication line between the villages and the main access point which is repeatedly subjected to the live loads. Therefore, a detailed study is needed for its stability analysis for pre–disaster measure and evaluating the effects of geotechnical parameters in triggering a landslide. The results of the study can be used to identify the stability of the slope and its recommendations shall indicate the relevant appropriate strengthening method and thereby preventing a major catastrophe. This work is also very important for the life safety of the people and infrastructure on or around this potential landslide.

II. METHODOLOGY

The detailed field survey includes collecting both disturbed and undisturbed soil samples and conducting the topographical survey using the Topcon-7500 total station. The global positioning system (GPS) recorded the relevant spatial information for the area selected (see Figs. 1-2).

Fig. 1: Qalandarabad landslide or critical slope failure at district Abbottabad

Fig. 2: Schools constructed at the top and bottom of the slope

The total number of twelve disturbed soil samples were collected from the Qalandarabad landslide. These samples were collected with the help of auger and shovels to determine soil index properties at different slope positions i.e., grain size (sieve analysis and hydrometer analysis), Atterberg limits (liquid limit, plastic limit and plasticity index). These samples were collected from field and then unit weight and soil shear strength parameters are obtained.

The undisturbed soil samples were collected using box sampling technique from various site locations. First of all, ground surface was leveled at the position where the block samples need to be achieved and marked the outline of the block face. The soil surface comprising of organic matter or other plant roots is removed from the sample. A dugout was prudently mined to a depth of up to 1 m in the vicinity of the sample, removing an abundance of materials to provide space for safe operation. A backhoe was used to dig the trench, and a large column was first excavated via the backhoe technique. The surplus soil materials were regularly removed on the edges of the block, using hands until and unless the foundation of the required bulk was obtained. The altitude/elevation was measured and recorded at the topmost of the sample. The properties of the soil that is color, moisture, odor, stability or consistency and structure have been noted. The newly exposed sample faces wax paint was melted and enclosed with a soft cloth. For a total of three layers, extra layer of cheesecloth and wax have been applied. When soil samples exposed to fragile then cheesecloth and the wax were useful to specific surfaces of the samples. The underlying soil was carefully cut at the base of a sample by means of spoon and blades in Silty, sandy clayey soil and thin wire in pure clayey soils, to remove the cubic block sample.

A total station (7500 Topcon) is used to carry out the topographic survey of Qalandarabad Landslide. The major purpose of the survey is to measure the horizontal angle, the vertical angle and the slope distance from the set-up point of the total station to the foresight point. The geometry of the slope is determined with the assistance of the total station from the topographic survey. The angle (horizontal or vertical) accuracy of the total station varies from 2″ (0.0005°) to 5″ (0.0014°). The distance range measurement of this model (7500 Topcon) once there is prism at a distance up to 3 km and in mirror type a range of 2 km and a short-range accuracy of 5-10 mm, which is reduced to about 10- 20 mm at 1 km and so on. The accuracy mainly depends on leveling of the instrument and type of instrument. Two leveling bubbles are approved on the apparatus for this precision/accuracy determination and are called the circular level and the 2nd one is called plate level. Just beneath the total station scope, the circular level adjusted on the top of tripod (tri brake) whereas plate level adjusted on horizontal axis of the device/apparatus.

The overall total station was then carefully smoothed and oriented to the north and then concentrated on the survey point in the field. The occupied/ base and the back (reflection) points were fixed by the Global Positioning System (GPS) coordinates. The survey was then started by obtaining maximum points at a distance of 5-15 m. During the survey, the main hurdle was dense vegetation, landslide trees and steep topography in Qalandarabad landslide, Abbottabad. The results obtained were later plotted in Arc-GIS software to create slide surfaces and contour lines.

Many samples are analyzed/evaluated in the laboratories to perform the index properties and soil materials type such as natural moisture content (ω), grain size analysis, hydrometer analysis, Atterberg Limits (liquid limit, plastic limit, and plasticity index), specific gravity (Gs), and the unit weight (γ) in order to investigate several geotechnical properties of the soil. Direct shear box test is performed to determine the shear strength parameters i.e., cohesion (c) and angle of internal friction (ϕ).

All tests were conducted in accordance with American Society for Testing Materials (ASTM) standard at National Center of Excellence in Geology, University of Peshawar in the Geotechnical Engineering laboratory. The below mentioned tests were carried out on collected samples to measure the engineering properties that influence the behaviour of landslide.

1. Unit weight of soil samples in accordance with ASTM D-7263 [18].
2. Analysis of the hydrometer and grain size analysis in accordance with ASTM D-7928 [19].
3. Atterberg Limits according to ASTM D- 4318 [20]. Liquid limit & plastic limit test are carried out on ash form of samples achieved and PI value from these tests were determined.
4. Specific gravity for all samples were determined as per ASTM C-127 [21].
5. Direct shear tests were conducted for undisturbed samples as per ASTM D – 3080 [22].
6. Numerical simulation/Modeling with Geo-studio software package (SLOPE/W) to assume the slope stability and (SIGMA/W) for Stress/ Load deformation analysis.

The sieve analysis (see Table 1) is carried out to classify the soil for engineering purpose or properties to classify the soil grain size distribution whether the soil can consist of predominantly sand, gravel, silt or clay size limited extent. Grain size distribution was performed on both the surface/disturbed and the subsurface/undisturbed soil samples. Samples collected from site were placed in oven to dry up to 24 hours at 1100 C to remove moisture content. The sieves used in stack were #4, 10, 20, 30, 40, 60, 140 and 200. To obtain mass retained, for 10-15 minutes, the sieves were located in auto sieves shaker device. Then, the soil materials retained on sieve No. 4 is considered as gravel while soil materials which is retained on sieve No. 200 and passed from sieve No. 4 is categorized as Sand whereas passed from sieve No. 200 is classified as clay and silt.

Table 1: Results of sieve analysis of all disturbed soil samples

Sieve #	Sieve Opening Size (mm)	% Passing											
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
		91.28	78.16	90.96	76.05	94.27	85.15	99.42	72.61	95.69	98.17	99.79	99.33
No. 4	4.75	70.75	51.44	75.04	55.73	77.29	58.93	94.22	47.58	77.61	90.1	91	85.34
No. 10	2	49.7	35.69	62.02	42.88	54.02	38.78	80.91	28.99	57.44	68.72	71.96	66.09
No. 20	0.85	41.15	29.79	56.17	37.55	45.03	31.96	73.47	22.47	49.81	59.5	64.07	59.16
No. 30	0.595	35.14	25.48	49.18	31.54	38.92	27.1	67.65	17.85	44.21	53.97	58.35	54.54
No. 40	0.425	26.01	19.48	34.16	21.27	31.59	20.87	53.1	11.98	37.14	46.19	50.51	47.56
No. 60	0.25	15.38	11.24	19.48	11.24	22.97	12.71	22.79	6.03	28.25	37.16	37.21	37.02
No. 140	0.106	11.56	9.09	14.87	8.74	19.85	9.12	14.9	3.97	23.95	33.51	31.36	32.11

Hydrometer analysis is conducted in a soil for the fraction that is smaller than #200 sieve (0.075 mm size). A glass hydrometer is typically made of a cylinder-shaped stem and a bulb weighed with lead or mercury to float vertical. A graduated tube-like cylinder is often dropped/sinks down, as the tested liquid is tipped into a high flask/container and the hydrometer somewhat placed in the liquid until and unless it floats freely/spontaneously. The point at which touches the hydrometer stem on the surface of the fluid is noted again and again after the selected time. The hydrometer test was performed to calculate the amount of colloids and the clay content in the soil for complete disturbed soil samples collected from the site passing at #200 sieve (see Table 2).

Table 2: Table showing the variation of effective depth (L) with Hydrometer readings

Sample 3												
Elapsed Time (min)	Hydrometer Reading	Temperature (°C)	Ft	Corr. Hyd. Reading	Hyd. Corr. Only for meniscus	Eff. Depth, L (cm)	L/t	K	% Finer	Adjusted % Finer	Diameter (mm)	Percentage of Fine (%)
0												
0.25	41	29	2.4	37.4	42	9.4078	37.6312	0.012	73.304	37.367	0.074	100.000
0.5	39	29	2.4	35.4	40	9.736	19.472	0.012	69.384	35.369	0.053	94.652
1	38	29	2.4	34.4	39	9.9001	9.9001	0.012	67.424	34.370	0.038	91.979
2	30	29	2.4	26.4	31	11.2129	5.60645	0.012	51.744	26.377	0.028	70.588
4	25	29	2.4	21.4	26	12.0334	3.00835	0.012	41.944	21.381	0.021	57.219
8	18	29	2.4	14.4	19	13.1821	1.64776	0.012	28.224	14.387	0.015	38.503
15	15	29	2.4	11.4	16	13.6744	0.91163	0.012	22.344	11.390	0.011	30.481
30	11	29	2.4	7.4	12	14.3308	0.47769	0.012	14.504	7.393	0.008	19.786
60	9	29	2.4	5.4	10	14.659	0.24432	0.012	10.584	5.395	0.006	14.439
120	7	29	2.4	3.4	8	14.9872	0.12489	0.012	6.664	3.397	0.004	9.091
240	6	29	2.4	2.4	7	15.1513	0.06313	0.012	4.704	2.398	0.003	6.417
480	5	29	2.4	1.4	6	15.3154	0.03191	0.012	2.744	1.399	0.002	3.743
1440	5	29	2.4	1.4	6	15.3154	0.01064	0.012	2.744	1.399	0.001	3.743
2880	4	29	2.4	0.4	5	15.4795	0.00537	0.012	0.784	0.400	0.001	1.070

For analysis, both the disturbed and undisturbed soil samples natural moisture content was calculated at field and laboratory as well. Liquid limit defines the moisture content from liquid to plastic state of the soil. To carry out this test, take 50g soil sample and pass from #40 sieve. Adjust Casagrande apparatus and place the soil sample in china dish and mix with water and make a uniform paste. Place 50g sample in liquid limit (brass cup) apparatus and level the surface of soil via using spatula that has a maximum depth of approximately 8 mm. Cut a soil along the central line with the grooving tool. Then turn on/switch on the liquid limit device at a speed of about two revolutions per second. Count/total the number of blows (N) to close the groove in the device at 13 mm distance. The test is repeated three times and the sample was then placed in oven for at-least 16 hours to dry and the moisture content measurements are recorded for N = 25-35, N = 20-25 and N = 15-20. Now plot moisture content (w) against the number of blows (N). The water content at N = 25 is termed as the liquid limit of the soil.

Plastic limit is used to determine the plastic nature/limit of soil. To perform this test, the remaining/residual soil sample (1/4 part) was taken from the Casagrande apparatus and added filtered water until and unless the soil for the required test reached a consistency limit where it might be rolled neither penetrating to the fingers. Between the compliment and the cut-glass plate ellipsoidal soil mass was prepared and rolled. To move the soil mass to a 3 mm diameter thread appropriate stress was applied. Thus, this procedure was constant and continues until and unless the fractures were created in a sample and then the sample was located for 16 hours to dry in the oven. After drying the sample in oven, the moisture content of every cans was calculated and the average weight was referred to plastic limit of the soil sample. Now plasticity index was actually calculated to determine the difference among the liquid limit moisture content and plastic limit, giving us an understanding of the clay content of the soil and the moisture content collection through which it stays in plastic condition.

Specific gravity of soil is the ratio between the solid material unit weight and the water unit weight. The 100 g dry soil sample was dry in the oven for 16.0 to 24.0 hours passed from #200 sieve (0.075 mm). A dry soil sample was put in the flask and fully filled with water. The flask weight with soil sample was measured and shaken for 10-20 minutes until and unless the sample completely remove the air. Then the sample was placed in the oven for 24 hours to dry. Thus, dry sample was weighed and specific gravity is determined.

Under three different vertical load conditions, the four same samples were tested/sheared and in each case the extreme/maximum shear stress was measured. By plotting the maximum shear stress compared to normal stress, cohesion and the internal friction angle as the shear strength parameters of a soil were calculated. The soil sample was extracted with a sampler and a geological hammer from the sampling box. The extruded sample was cut and leveled on the sampler sides using a cutter. The sample was weighed and the sampler on shear box was placed. By pushing the sample extruder on its top of the surface, the sample was then gradually extruded/come out into the shear box machine. All porous plates were placed below and above the sample in the shear box, the screws were pressed and the box was finally sited in the machine. Earlier the test was started, two screws of the four screws were removed and completely the equipment was set accordingly. This test was performed on four samples of all undisturbed samples of the soil. This instrument was used to determine the shear strength of cohesionless soil (e.g., internal friction angle). The result was that the maximum shear stress for a specific vertical confining stress was achieved by locating the shear stress versus horizontal displacement. From the plot of peak shear stress versus vertical confining stresses (normal) repeated several times for all the test, various vertical confining stresses were produced after the experiment.

Slope/W software is one of the leading slope stability software packages used for soil and rock stability. For different slip/slide surfaces, pore water pressure, soil properties and loading conditions, it analyzes both the simple and complicated difficulties by using various limit equilibrium methods. With this wide range of characteristics, SLOPE/W could be used to explore nearly every issues of slope stability you will experience in your geotechnical, mining and civil engineering tasks/ projects. The CAD shape is available to define the geometry of the problem simply by picture it on the screen. Slope/W has a few instruments to display the outcomes of minimum and maximum safety factor (FOS), free body graph diagram (Chart) and the all-slice force polygon. It also constructs/produces all input data and outcomes or result in detail for finding the stability problems. Based on the parameters of shear strength (i.e., cohesion and internal angle friction) obtained from direct shear test. In order to recognize the landslide category, the SLOPE/W model was created to calculate the safety factor (FOS) for the region investigated and slip surfaces. This was performed on the basis of the slope angle which was obtained using topographic survey.

Sigma/W is also one of the leading software for the Finite Element Method (FEM), a product for the stress and deformation analysis in earth and structural materials. Linear flexible, non-linear flexible, elastic-plastic, came and clay, revised came and clay, stress-strain reinforcing/ strengthening deformation analysis can be performed in this software. It has the ability to display stress state at each finite element mesh node like the Mohr circle. In addition, shear and the moment distribution can be displayed along the structural elements such as beams and bars. Various fundamental soil models encourage a broad range of soils or structural materials to be characterized. Moreover, in response to additional or external loads SIGMA/W modeled the change in pore-water pressure and dispersion. With SIGMA/W you can evaluate almost every settlement, permanent stress and deformation analysis problems you will experience in your geotechnical, mining and civil engineering tasks/ projects.

III. TESTED MATERIALS

In accordance with ASTM D-2487 [23], the soil samples in Qalandarabad landslide at 1m depth are dropped by more than 50 percent in coarse grained soil classification having greater than 50% retained on sieve No. 200 or passing from No. 200 sieve is less than 50% whereas the surface sample from No. 200 sieve passed greater than 90% were considered as fine-grained soils (see Fig. 3). These were non-plastic soil with 0-5 plasticity index (P.I) with limited shear strength. Under the Unified system of soil classification (USCS), the four samples of Qalandarabad landslide fields were categorized as Silty Clayey Sand (SC-SM) while the three samples from Qalandarabad landslide were classified as Silty sand with gravel (SM), and the three samples were categorized as Silty Sand (SM) and the remaining samples are Clayey Sand (SC) and Non-Plastic Sandy soil. Similarly, the Subsurface Undisturbed soil samples were categorized as Silty clayey sand (SC-SM), Silty sand with gravel (SM) and coarse grained gravely soil. All these classifications/categorizations are based on evaluation of grain size, hydrometer analysis (see Fig. 4), specific gravity and Atterberg limits (liquid and plastic limit) and the finding are listed in Table 3.

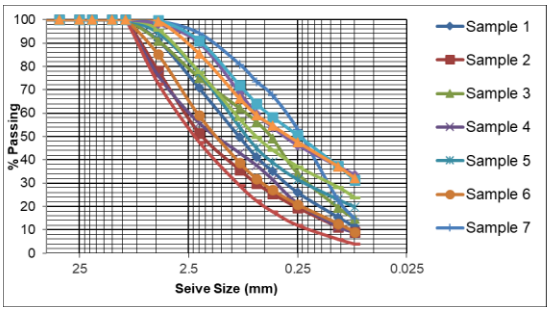

Fig. 3: Particle size distribution of soil samples from sieve analysis of Qalandarabad Landslide

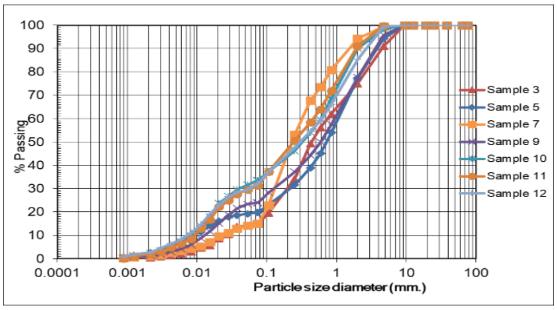

Fig. 4: Particle size distribution of soil samples of Qalandarabad Landslide from Hydrometer reading

Table 3: Soil type of Qalandarabad Landslide according to Unified soil classification system (USCS)

Sample	# 200 Passing	Liquid Limit	Plastic limit	Plasticity index	Specific Gravity	Moisture Content (%)	Soil Type	Description
1	11.56	18.39	16.72	1.67	2.73	4.6%	SM	Silty Sand
2	9.09	18.55	16.66	1.9	2.77	5.1%	SM	Silty Sand with Gravel
3	14.87	0	0	NP	2.68	3.5%	NP	Non-Plastic Sandy Soil
4	8.74	18.03	16.01	2.03	2.68	10.49%	SM	Silty Sand with Gravel
5	19.85	29.19	24.57	4.62	2.67	8.76%	SC-SM	Silty, Clayey Sand
6	9.12	21.81	18.55	3.26	2.64	5.6%	SM	Silty Sand
7	14.9	17.15	0	17.15	0	9.75%	SC	Clayey Sand
8	3.97	17.48	15.45	2.03	2.65	8.11%	SM	Silty Sand with Gravel
9	23.95	30.89	27.87	3.02	2.69	7.6%	SM	Silty Sand
10	33.51	27.99	23.89	4.10	Nil	10.26%	SC-SM	Silty, Clayey Sand
11	31.36	30.43	24.79	5.63	2.69	9.78%	SC-SM	Silty, Clayey Sand
12	32.11	26.57	22.48	4.08	2.68	11.02%	SC-SM	Silty, Clayey Sand

A direct shear box test is performed in this research to determine the soil drained shear strength (see Figs. 5-9). Parameters of shear strength are determined either (e.g., cohesion or internal friction angle). The peak shear stress is acquired from the shear stress plot versus horizontal displacement for a specific vertical confining stress (see Tables 4-7). Tests are carried out numerous times at rising perpendicular/vertical confining pressures and the highest shear stress plot is generated for all experiments relative to vertical confining stresses (normal).

The shear resistance/strength is the capacity of the soil to shear stresses and according to Abramson et al., [24] varies on ordinary load (normal), internal friction angle and cohesion. The conclusion is that the internal friction angle and cohesion is dependent on the variety of soil. Soil cohesion reduces the moisture content as eventually rises which leads to a slope failure. The shear strength alongside the catastrophe surface is due to effective stress measured indirectly when the water pressure of the pore is well-known (within undrained test or investigation). If the pressure of the pore-water is determined, the effective stress theory or principle with drained strength parameters is used for analysis. On this occasion, pressure of pore water is unidentified and therefore total stress or deformation analyses are used for short term stability harms as long as the pore water stress is degenerated completely. The strength parameter for total stress assessment is Cu and $\phi u=0$ is used. For assessment of the stability of the slope, the slope shear strength is important/ necessary and relies on the degree of saturation.

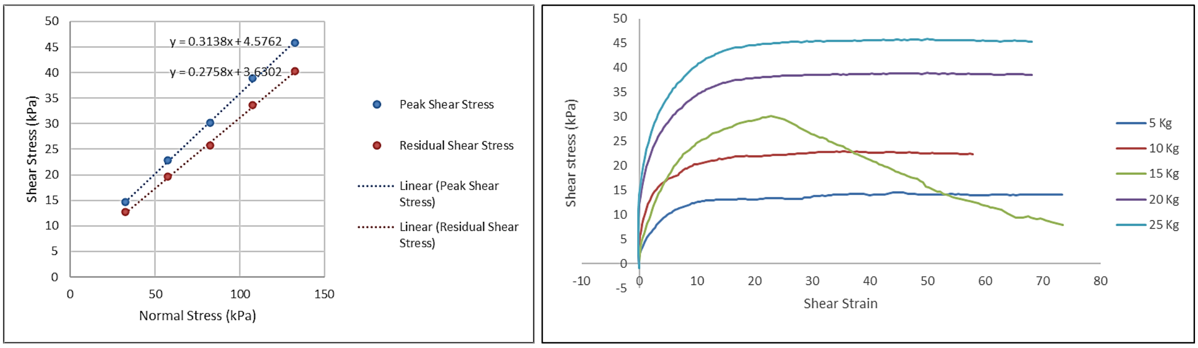

Fig. 5: Direct shear test result of Sample No. 1

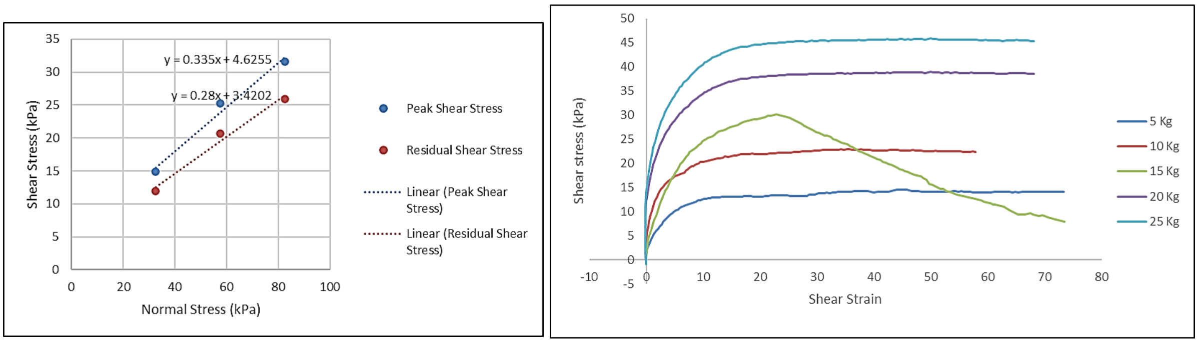

Fig. 6: Direct shear test result of Sample No. 2

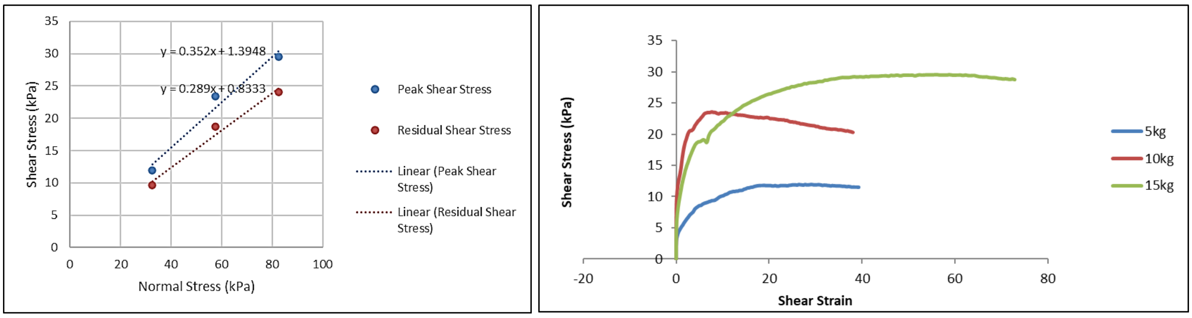

Fig. 7: Direct shear test result of Sample No. 3

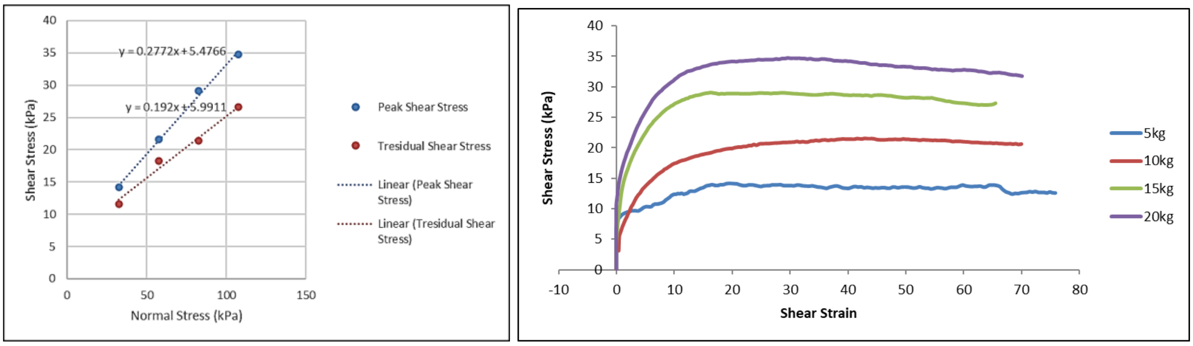

Fig. 8: Direct shear test result of Sample No. 4

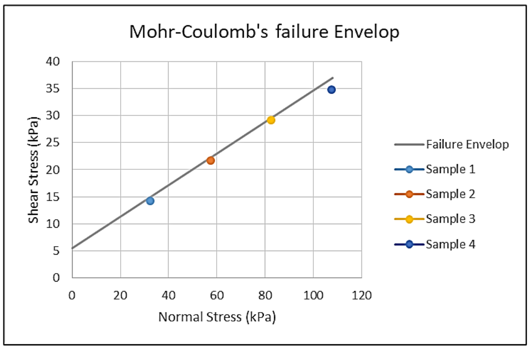

Fig. 9: Mohr-Coulomb Failure Envelope constructed from direct shear box test results of the undisturbed soil samples

Table 4: Direct shear test result of Sample No. 1

Sample 1									
Load (kg)	Peak Shear Load (kN)	Residual Load (kN)	Normal Stress (kPa)	Peak Shear Stress (kPa)	Residual Shear Stress (kPa)	Peak Friction Angle (deg)	Peak Cohesion (kPa)	Residual Friction Angle (deg)	Residual Cohesion (kPa)
5	2.92	2.55	32.53	14.61	12.76	17.42	4.57	15.42	3.63
10	4.57	3.92	57.55	22.87	19.62				
15	6.03	5.14	82.58	30.18	25.72				
20	7.78	6.73	107.60	38.93	33.68				

Table 5: Direct shear test result of Sample No. 2

Sample 2									
Load (kg)	Peak Shear Load (kN)	Residual Load (kN)	Normal Stress (kPa)	Peak Shear Stress (kPa)	Residual Shear Stress (kPa)	Peak Friction Angle (deg)	Peak Cohesion (kPa)	Residual Friction Angle (deg)	Residual Cohesion (kPa)
5	2.97	2.39	32.53	14.86	11.96	18.52	4.62	15.64	3.42
10	5.04	4.13	57.55	25.22	20.67				
15	6.32	5.19	82.58	31.63	25.97				

Table 6: Direct shear test result of Sample No. 3

Sample 3									
Load (kg)	Peak Shear Load (kN)	Residual Load (kN)	Normal Stress (kPa)	Peak Shear Stress (kPa)	Residual Shear Stress (kPa)	Peak Friction Angle (deg)	Peak Cohesion (kPa)	Residual Friction Angle (deg)	Residual Cohesion (kPa)
5	2.39	1.92	32.53	11.96	9.60	19.39	1.39	16.12	0.83
10	4.68	3.74	57.55	23.42	18.71				
15	5.91	4.81	82.58	29.58	24.07				

Table 7: Direct shear test result of Sample No 4

Sample 4									
Load (kg)	Peak Shear Load (kN)	Residual Load (kN)	Normal Stress (kPa)	Peak Shear Stress (kPa)	Residual Shear Stress (kPa)	Peak Friction Angle (deg)	Peak Cohesion (kPa)	Residual Friction Angle (deg)	Residual Cohesion (kPa)
5	2.83	2.32	32.53	14.16	11.61	15.50	5.47	10.87	5.99
10	4.31	3.64	57.55	21.57	18.21				
15	5.81	4.27	82.58	29.07	21.37				
20	6.95	5.31	107.61	34.78	26.57				

IV. Results and Discussions

In order to secure a slope from failure or fall, slope stability assess the basic requirement before developing any earth retaining structures. It is therefore necessary to carry out the slope stability analysis before developing a retaining wall to assess whether the slope is stable or not and to check the equilibrium situation. Slope stability analysis is mostly performed to evaluate the slope against failure and collapse. The fundamental requirement for slope stability is to maintain the equilibrium situation, the shear strength of the soil should be larger than the shear stress. This situation can be achieved by reducing or decreasing the shear strength of the soil or increasing the shear stress of the soil in two forms/directions.

Ordinary, Morgenstern-Price, Spencer, Simplified Bishop, Simplified Janbu are the Limit Equilibrium method (LEM) of slices are used for carrying out the stability analysis of slope in order to get the Factor of Safety (FOS) whereas the Finite element method for carrying out the stresses/deformation analysis. The technique based on finite elements (FEM) stresses first calculated and includes safety factor computations. Linear-elastic soil model is used to evaluate finite elements.

Fully Dry and Saturated environmental situation/ conditions are supposed for the analysis. The loads of materials acting on slope soil are also assumed such as Government School constructed at the slope bottom, Government building constructed at the slope top field measurement/ observation and itself weight of road and vehicles transportation are to be considered in the analysis according to the AASHTO standard. Fig. 10 shows bearing slope model. Fig. 11 shows FOS of bearing slope for gravity loadings in dry condition. Fig. 12 show FOS of bearing slope for gravity loadings in saturated condition.

As the FOS is 0.380 for dry condition and 0.379 for saturated condition, which is smaller than critical factor of safety which is equal to 1.5 for gravity loading, so it is unsafe. Findings of the pseudo-static analysis depends on the seismic coefficient (k_h) value which is assumed in the analysis. The most tough and essential features of pseudo-static slope stability assessment is the selection of appropriate pseudo-static coefficient. The pseudo-static force measured by seismic coefficient on the failure mass. Therefore, its value would be associated to some amount of the influenced amplitude of inertial force in the probably unbalanced materials. The inertial force would be the outcomes of the definite horizontal acceleration and the weight of unbalanced materials influenced on potential slide, if the slope materials were inelastic. When the horizontal acceleration extends beyond its extreme value then the inertial forces would touch its extreme value. Terzaghi [25] suggested that the usage of k_h = 0.1 for the "severe" earthquakes, k_h = 0.2 for its "violent, destructive" earthquake (Rossi-forel X) and k_h = 0.5 for the "Catastrophic" earthquake (Rossi-forel 1X). In accordance with building code of Pakistan (BCP), Abbottabad fall in seismic zone-3 seismic provision-2007. Hence, Abbottabad having severe earthquake that's why we consider the Horizontal pseudo-static coefficient, k_h = 0.1. Fig. 13 shows bearing slope model. Fig. 14 shows FOS of bearing slope for gravity and seismic loadings in dry condition. Fig. 15 shows FOS of bearing slope for gravity and seismic loadings in saturated condition.

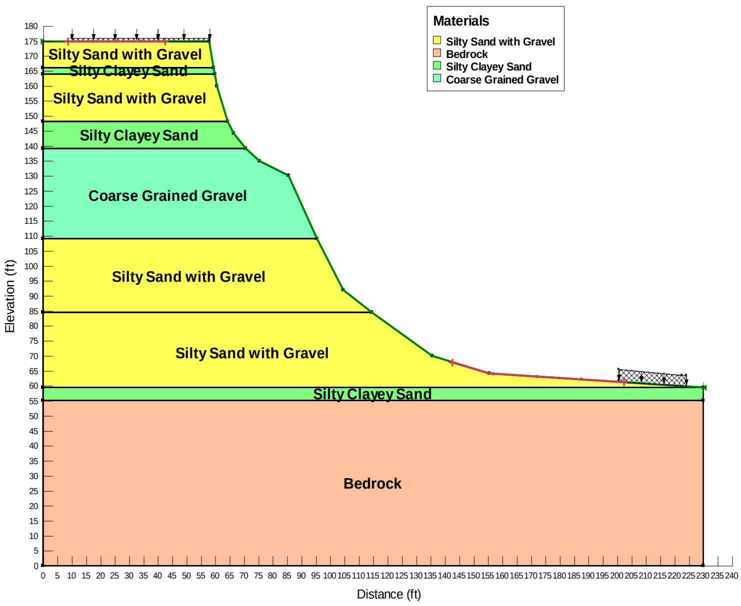

Figure 10: Bearing Slope Model

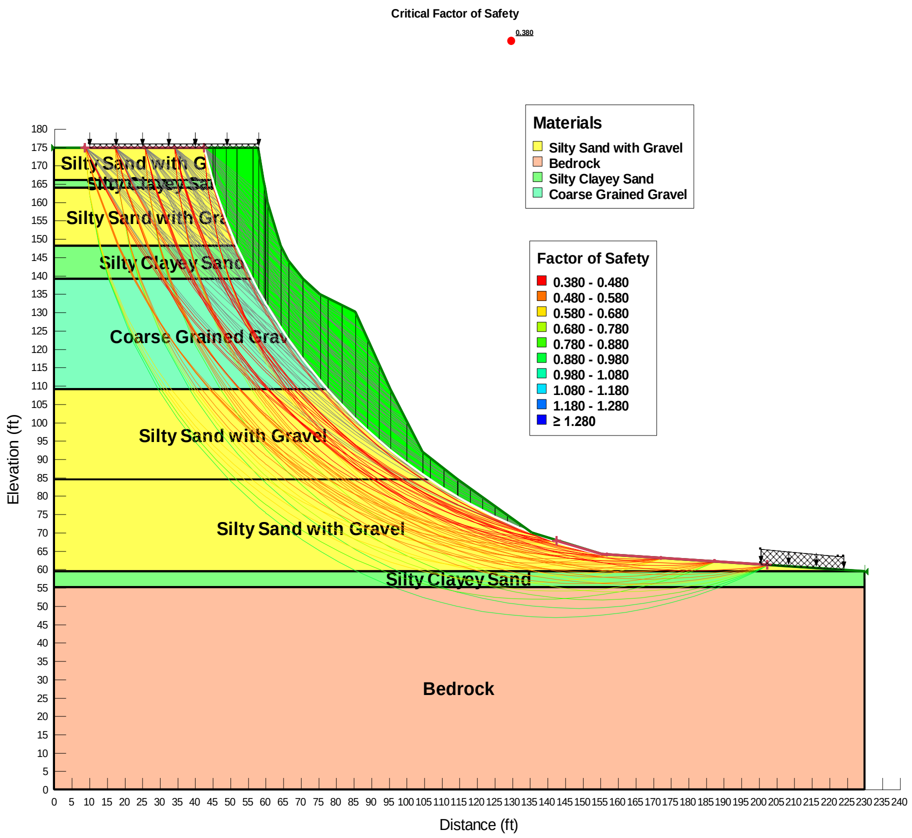

Figure 11: FOS of Bearing Slope for Gravity Loadings in Dry Condition

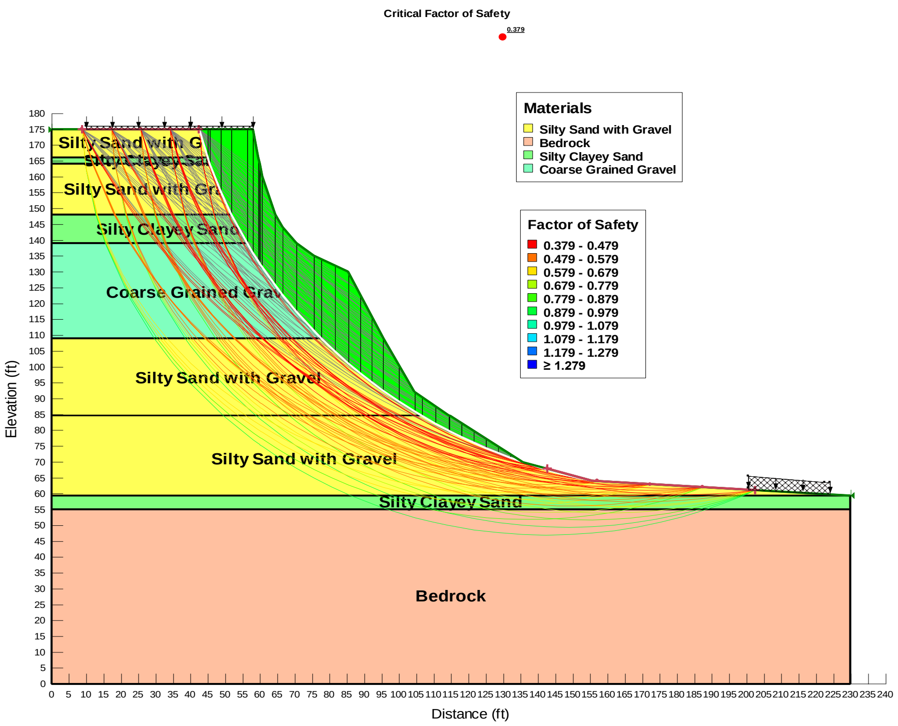

Figure 12: FOS of Bearing Slope for Gravity Loadings in Saturated Condition

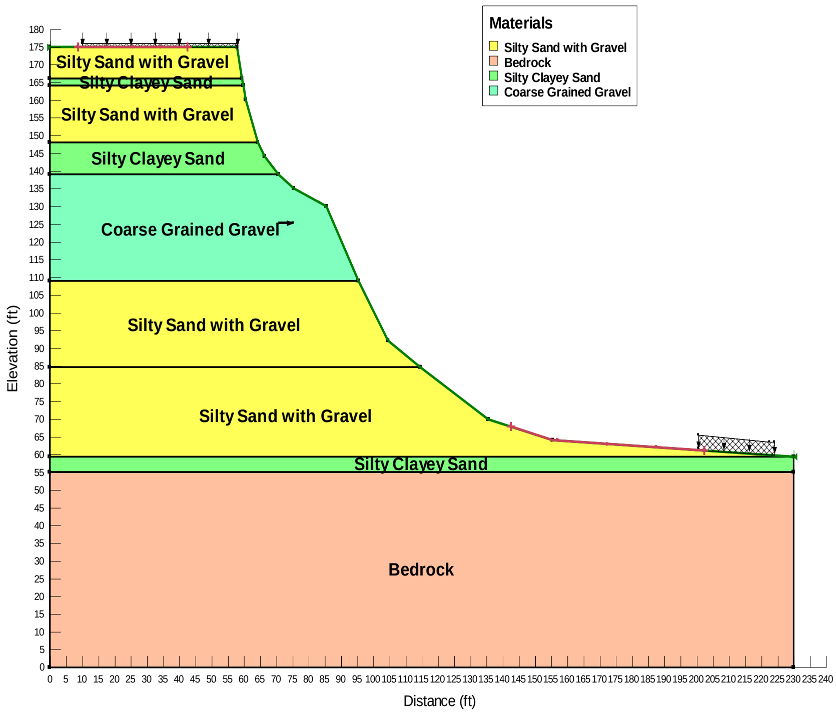

Figure 13: Bearing Slope Model

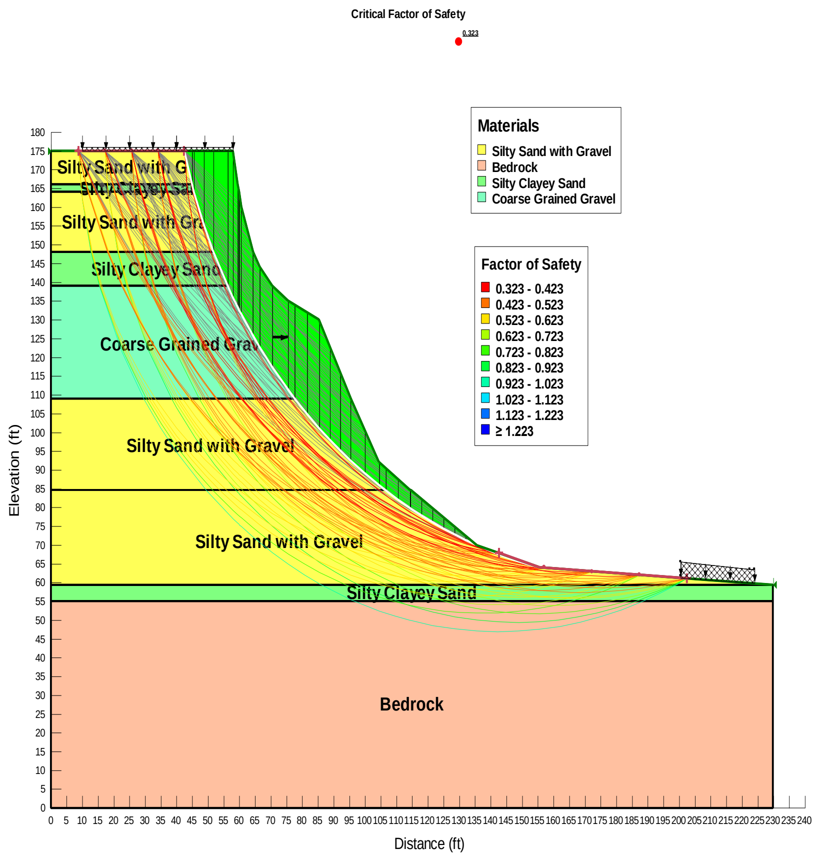

Figure 14: FOS of Bearing Slope for Gravity and Seismic Loadings in Dry Condition

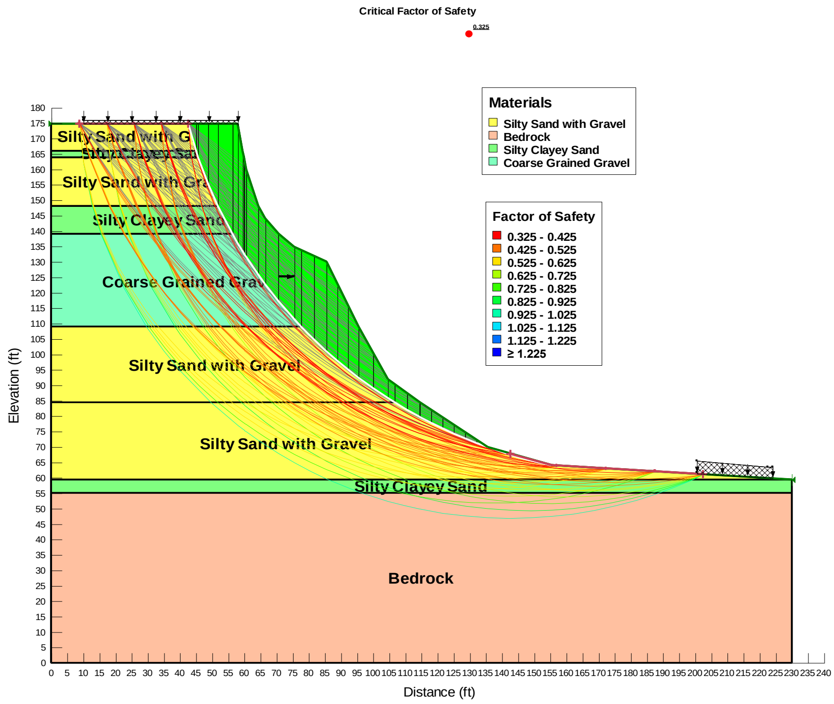

Figure 15: FOS of Bearing Slope for Gravity and Seismic Loadings in Saturated Condition

As the FOS is 0.323 for dry condition and 0.325 for saturated condition, that is less than a critical factor of safety (FOS) equivalent to 1.0 for gravity and seismic loading, so it is unsafe. The summary of the FOS stability assessment results of the only bearing slope against gravity and seismic loadings are presented in Table 8.

Table 8: Summary of FOS of only bearing slope against both gravity and seismic loadings

Methods	F.O.S of Bearing Slope for Gravity Loading		F.O.S of Bearing Slope for Gravity and Seismic Loading	
	Dry Condition	Saturated Condition	Dry Condition	Saturated Condition
Bishop Simplified	0.380	0.379	0.323	0.325
Janbu Simplified	0.344	0.343	0.287	0.289
Morgenstern-Price	0.383	0.382	0.332	0.333
Ordinary	0.348	0.347	0.289	0.291
Spencer	0.381	0.380	0.331	0.332

To provide lateral opposition to earth mass or other material, retaining wall is typically used to support and accommodate transportation or maintain earth mass for the structural safety and protection. These walls are used in a variety of application including security or safety of current buildings/ infrastructure that are necessary persevere in the area, widening of highways, slopes stabilization, separations of grade (class, school etc.), fresh roads and highways embankment manufacture, limitation of the correct way of the roads, security and safety of naturally sensitive areas. It is possible to categorize the retaining walls into gravity, non-gravity and hybrid wall program. In the current studies, we proposed the gravity retaining wall in the assessment for the stabilization of the Qalandarabad landslide slope.

The primary stability is modeled by providing the retaining wall in the slope resistance studies. They are set up as a components/ element of beams. Soil slope model was first generated and loads are then implemented in the assessments to be considered. The gravity loads from Government infrastructure like School and other buildings lying on the top and toe of the slope are used as point loads and communication forces pending from the vehicle transportation are to be considered. The self-weight of soil materials is measured by the identification of the unit load in the direction of gravity, whereas the horizontal pseudo-component is indicated as the unit load performing away from the slope in parallel direction. As a key element of SIGMA/W software package, the self-weight & seismic loads are mechanically produced. All filling and drainage condition are constructed and give results in gravity and seismic loading for saturated particular condition providing the maximum possible movement in the slope. Retaining wall is chosen to show/ constructed as beams that require cross-sectional area, moment of inertia and type of

materials modulus of elasticity. The basic foundation and stem are presented/ remodeled in the software as beams with various structural rigidity.
Gravity retaining wall could be advance categorized as soil nail wall, earth wall, semi gravity, mass gravity and mechanically stabilized rock walls. Gravity retaining wall is measured as internally stabilized wall as they resist lateral/ horizontal earth pressures by using their individual self-weight. Fig. 16 shows bearing slope with retaining wall model. Fig. 17 shows FOS of slope with retaining wall for gravity loading in dry condition. Fig. 18 shows FOS of slope with retaining wall for gravity loading in saturated condition. While Table 9 shows finite element analysis for Gravity loading under dry and saturated conditions.

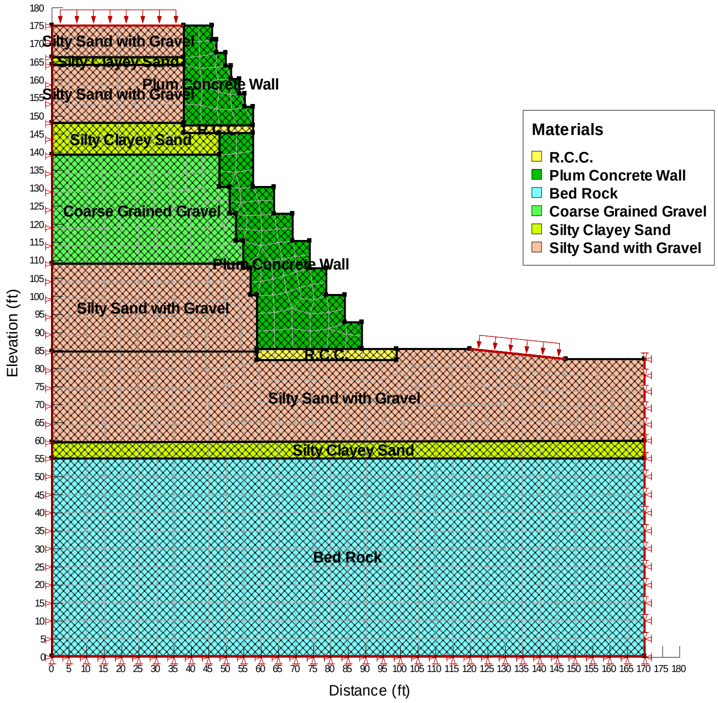

Figure 16: Bearing Slope with Retaining Wall Model

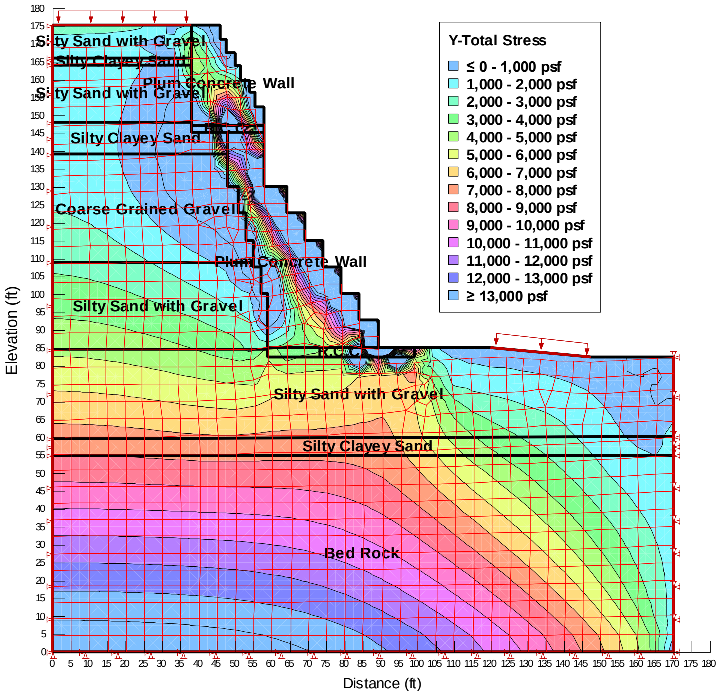

Figure 17: FOS against Sliding and Overturning for Gravity Loading in Dry Condition

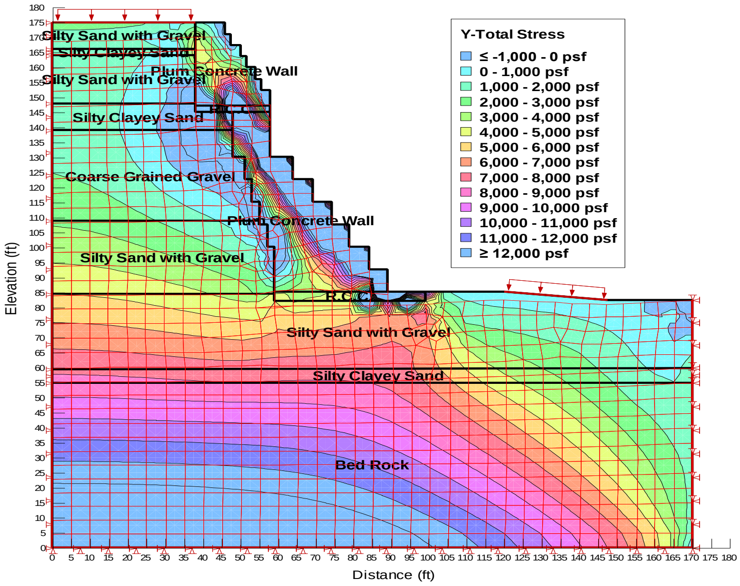

Figure 18: FOS against Sliding and Overturning for Gravity Loading in Saturated Condition

Table 9: Finite element analysis for Gravity loading

Finite Element Analysis for Gravity Loadings		
Methods	Dry Condition	Saturated Condition
F.O.S against Sliding	1.680	1.590
F.O.S against Overturning	2.440	2.310

Qalandarabad landslide, District Abbottabad retaining wall is safe in sliding, overturning and bearing pressure. It is also safe against slope failure as factor of safety of slip critical surface is 1.69 that is greater than the critical factor of safety equal to 1.5.

V. CONCLUSIONS

The purpose of this study was to determine soil slope stability analysis against the gravity and seismic loads and conduct a topographic survey of Qalandarabad landslides for geometry of the slope. To assess the effects of rainfall on the Qalandarabad landslide and its relationship to the geotechnical properties. The topographic survey showed that the study area has an irregular topography with 80% of the moderately steep slopes in the range of 120-300 in northwest and northeast directions.

The material properties exposed the soil composition as Silty clayey sand, Silty sand, Silty sand with gravel and were found to be non-plastic sandy soil. Furthermore, the rocks were very fragile overlain by non-plastic silty sand. The cohesion is ranged from 1.39 kPa to 5.48 kPa whereas the angle of internal friction from 15.5° to 19.39°. The tension cracks were found in all the areas with depth of 2.4-3.0m. The tension cracks or fissures that are likely to raise the soil's tendency to become unstable since they are filled with surface water (owing to rainfall) and excess energy owing to water stress in a crack/ fissure improves the tendency of slide to occur. The presence of tension cracks can be imports of initiation of progressive shear failure.

The factor of safety values calculated for four distinct locations in Qalandarabad in SLOPE/W modeling ranged from 0.344 to 0.383 for Gravity loading and 0.287 to 0.332 for seismic loading that indicates relative unstable areas. So, it is strengthened with the strengthening techniques as Retaining Wall which eventually increases the FOS values being 1.531 to 1.690 for gravity loading and 1.293 to 1.482 for seismic loading.

The Qalandarabad active landslide was identified as most critical and geotechnically unstable in the pre-existing condition for both gravity and seismic load under dry and fully saturated condition as modeled by Geo-Studio software Slope/W. The shear strength parameters and factor of safety (FOS) value also indicate that Qalandarabad landslide is unstable as the FOS for all method of slices is less than 1.

The factor of safety being 0.383 in dry condition and 0.383 in saturated condition for Gravity loading which is less than 1.5. The factor of safety being 0.332 in dry condition and 0.333 in saturated in condition for seismic loading which is less than 1. So, it’s considered to be an unstable slope.

Therefore, it is strengthened with most suitable, effective and economical strengthening techniques (e.g., retaining wall) for its stability of the slope.
The geological processes are although very slow but consistent; thus, they have intense result on stability of slope. The occurrence of outcrop in the slipping area as Government building like School at both the top (heel) and bottom (toe) of the slope also resists the complete failure of the slope. The valley present in the landslide is irrigated by a water channel and the water seeps down the soft sediments and rocks where the channel is open and as a result there is a noticeable soil movement and rock falls. Additionally, rainwater surface overflow further harms the situation. Conclusively, Abbottabad lies in the area of an active fault zone and there is a possibility of triggering of landslides as a result of seismic activities in the said area.
In the present study, the factors like geological conditions, human intervention, ground water and surface conditions, permafrost, earthquake and influence of vegetation were not studied in detail. Proper drainage system should be developed, channelization for water must be ensured throughout the area and water penetration to the slope must be controlled. Drainage pipes can be used in Qalandarabad landslide area and constructing Gabion wall along roads may reduce the damage as a result of landslide movement. In addition, proper bio-engineering remediation procedures need to be undertaken; fresh trees (plants) need to be planted to further reduce the slope movement; thus, the tress should not be cut down in the sliding areas.

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