

Numerical Evaluation of Slope Stability measures: A Case Study of Birham Landslide, Murree, Pakistan.

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Abstract. Slope failures endanger the public safety and one of major hazard considered in mountainous terrain. In this paper, slope stability measures have been evaluated using the limit equilibrium method (LEM). A case study of slope failure from Birham land slide, Murree, Pakistan has been modelled using SLOPE/W program. In-situ boring tests are performed to collect laboratory test specimens. Geotechnical properties (i.e. shear strength and stiffness parameters) for the idealised slope sections are based on laboratory tests performed on the collected in-situ specimens. Slope stability measures are evaluated in terms of factor of safety (FoS) for static and dynamic loading. Pseudo-static method is used for dynamic analysis, considering the Peak ground acceleration (PGA) from seismic hazard map of Pakistan. Results shows that static and dynamic FoS of original slope are inadequate therefore resistance to slip surface of original unstable slope is provided by slope geometry modification with pile reinforcement. Based on these remedial measures, computed FoS of modified slope are found to be sufficient for static and dynamic slope stability.

Keywords. Stability, birham landslide, numerical evaluation, Murree, Pakistan.

1. Introduction

Murree is a hilly resort town located in northern area of Pakistan. The area of presented case study is located in Murree formation consisting of sandstone, shale and weakly bounded slope forming material. Moreover, it lies in seismically active region due to active Murree Boundary Fault (MBF) Figure 1. Due to highly fragile hilly terrain and seismically active region, this provides a favorable failure zones for faults during seismic event [1, 2].

There are several number of land sliding events along Islamabad Murree Expressway because of rapid urbanization and widening of roads and so on. Menal Z. [1] studied the landslide susceptibility for Murree using Geographic Information System (GIS) and remote sensing techniques. The proposed susceptibility maps depicted in figure 2 shows very low, low, moderate, high and very high landslides with percentage 15%, 27%, 29%, 21% and 8% respectively.

In this paper, a case study of slope failure from Birham land slide that was triggered 10th August, 2012, in Murree, Pakistan has been modelled using Limit Equilibrium (LE). [3] Slope/W program is used to perform LE analysis to calculate static and dynamic Factor of Safety (FoS) for the original and modified improved slopes.



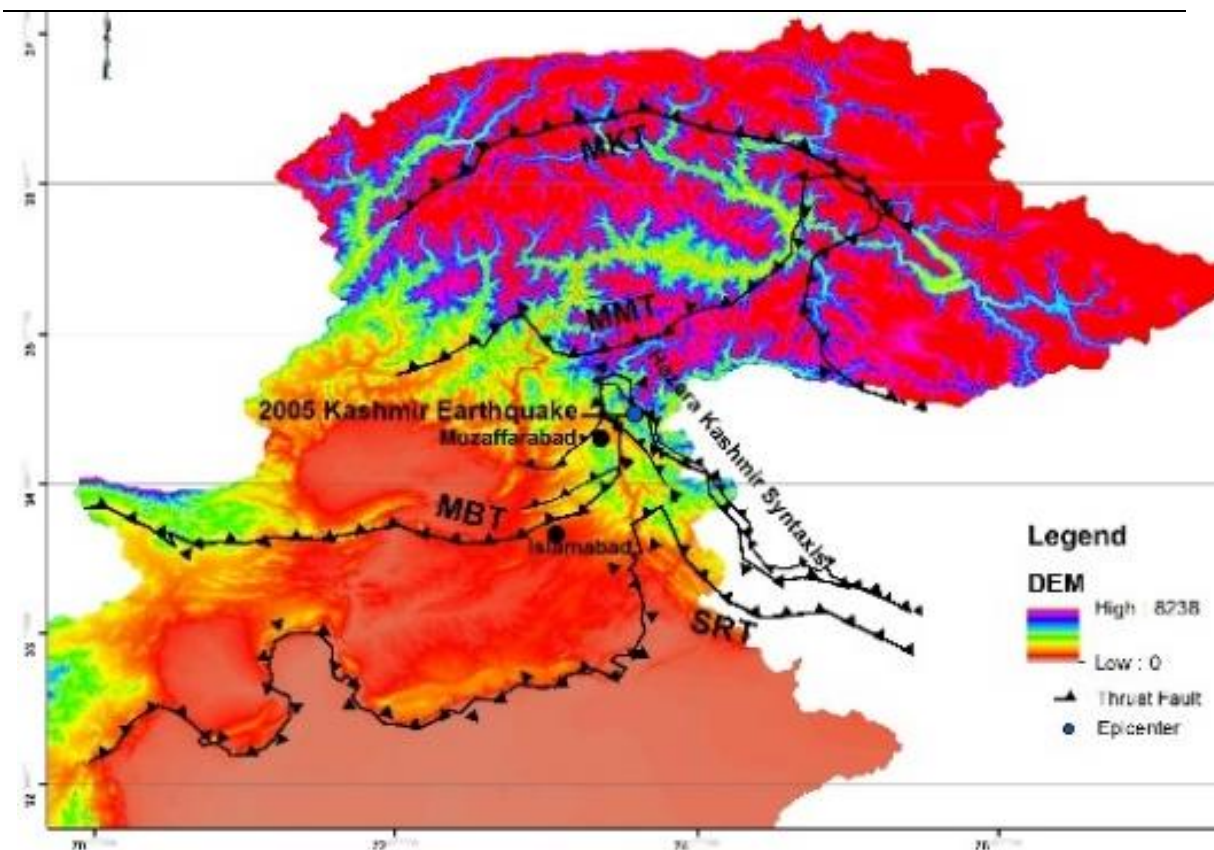


Figure 1. Map showing major fault systems in Northern Pakistan and Kashmir Earthquake, 2005 epicentre location, [2].

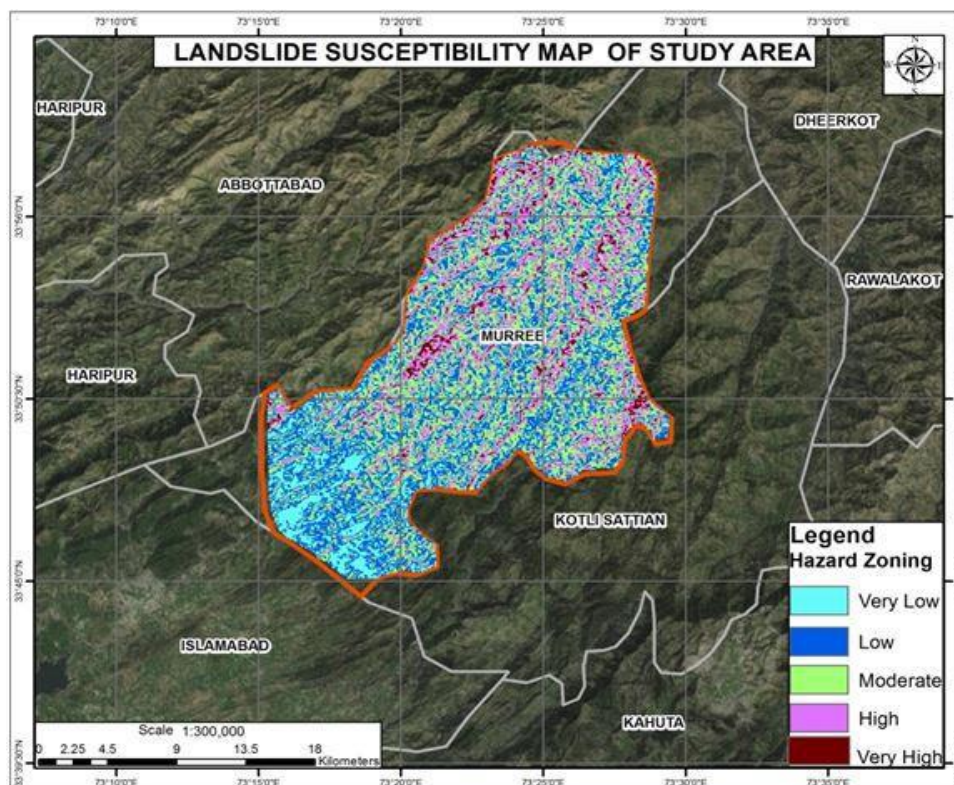


Figure 2. Landslide Susceptibility map, Murree [1].

2. Case Study

The town of Murree in Himalayan foothills lies about 50km to Northeast of Islamabad at an elevation of approximately 2200m. The lithology comprised of shale, siltstone and sandstone belonging to the Oligocene-Miocene Murree and Kuldana formations.

Slope stability analysis requires the stiffness and strength properties of soil/intact rock to be known. Geotechnical investigations were performed at the three locations as shown in layout plan in Figure 3, to collect the samples from top, middle and bottom of slope, details of sample and laboratory test results are presented in Table 1. The slope strata mainly comprise of shale, siltstone and sandstone. Based on careful extrapolation of boreholes, slope stratigraphy is idealized as shown in Figure 4.

Table 1 Summary of Geotechnical properties

Borehole No.	Run No.	Depth (m)	Rock type	Point load strength (MPa)	Specific gravity	Bulk Density (kPa)	Moisture content (%)
BH-1	R-1	10.7-11.1	Claystone	-	2.63	22.9	2.02
	R-2	13.5-13.7	Siltstone	4.4	2.72	23.9	4.54
BH-2	R-3	5.4-5.6	Sandstone	8.1	2.75	25.1	1.37
	R-4	6.0-6.4	Shale	-	2.67	25.8	1.19
	R-5	14.1-14.2	Claystone	-	2.65	24.6	3.45
	R-6	15.9-16.1	Sandstone	16.1	2.74	24.3	0.30
BH-3	R-7	17.3-17.4	Shale	-	2.62	24.2	5.98
	R-8	21.5-21.6	Claystone	2.8	2.69	22.1	6.22
	R-9	26.9-27.2	Shale	-	2.63	23.1	4.80

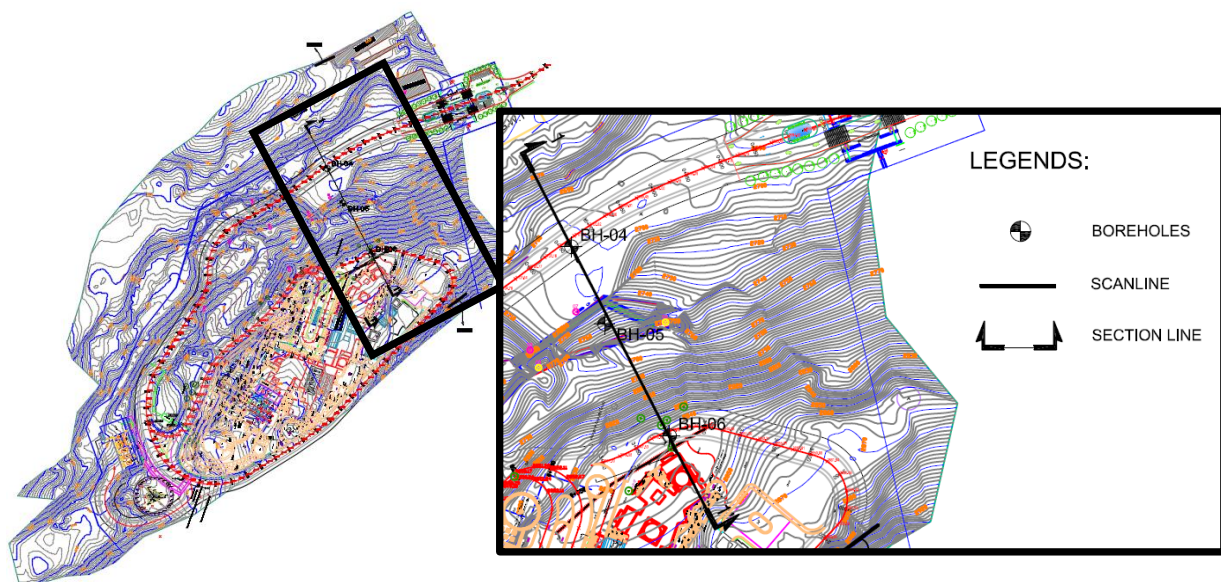


Figure 3. Layout plan showing the selected slope borehole locations (geotechnical investigation).

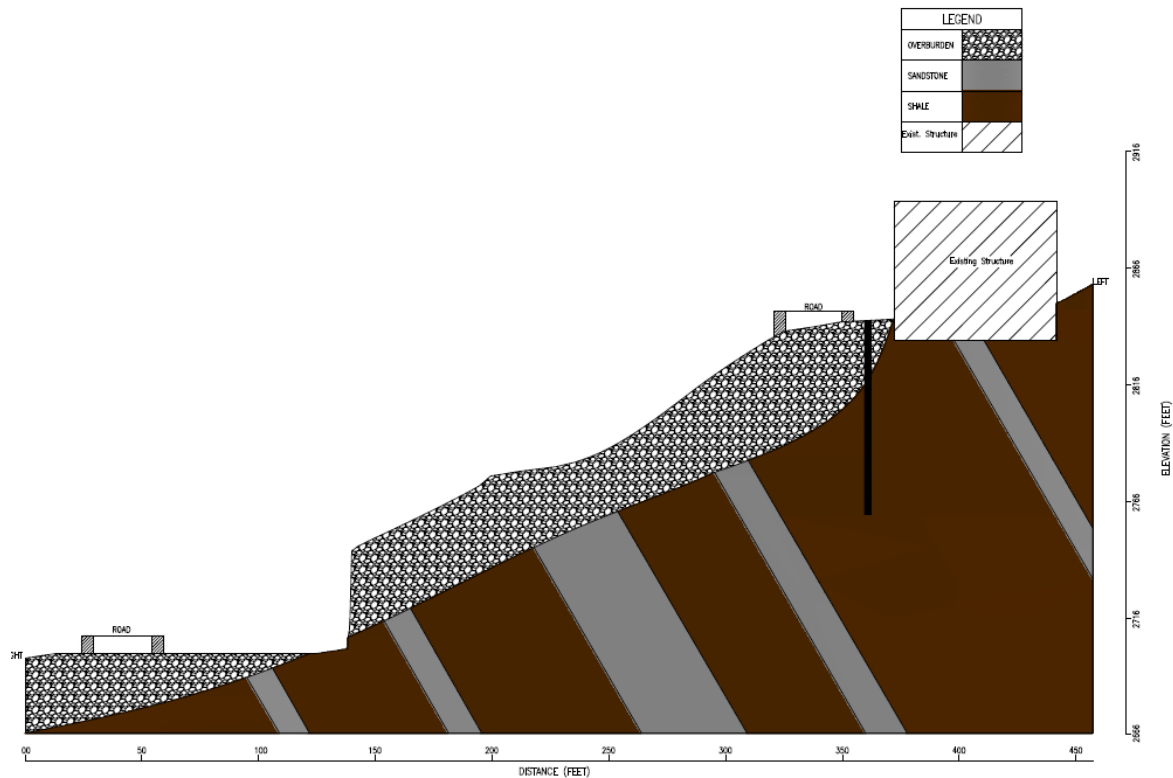


Figure 4. Idealized slope geometry and stratigraphy of selected slope section 1-1'.

3. Numerical modelling

Based on layout plan and selected section 1-1' shown in Figure 3 and idealized slope geometry and stratigraphy shown in Figure 4, two dimensional plane strain (2D) static and pseudo static analysis to calculate factor of safety (FoS) are performed using SLOPE/W program. The soil and rock properties used for simulations are summarized in Table 2. The constitutive behaviour of soil and rock both are simulated using the elastic-perfectly plastic assumption of Mohr-Coulmn model. The boundary conditions in numerical model were applied such that the vertical face was fixed in horizontal direction and base was fixed in both horizontal and vertical directions.

Table 2. Summary of soil and rock properties used in numerical modelling

Layer	Soil/rock type	Unit weight (kN/m ³)	Cohesion (kPa)	Friction angle (Deg.)
1	Overburden	19.66	32.60	20.0
2	Shale	23.96	369.2	23.5

Pseudo static analysis is one of simplest methods of idealizing the slope stability problem subjected to dynamic loading. Although earthquake force is dynamic, however if the strength is reduced less than 15 percent by cyclic loading, pseudo static analysis of the seismic loading can be used [4]. In pseudo static analysis, the Peak Ground Acceleration (PGA) generated by earthquake shaking is considered to create inertial forces. These inertial forces act in horizontal and vertical directions [5].

Building code of Pakistan (BCP) [6], provides the seismic hazard level in terms of horizontal Peak Ground Acceleration (PGA) for the four seismic zones of Pakistan Figure 5, the level of PGA corresponding to each zone is presented in Table 3. The selected site shown in Figure 5 is

located in Zone 2B, level of hazard in terms of horizontal PGA is 0.2g. Dynamic FoS is calculated by performing pseudo static analysis, in which 0.2g PGA value is used to introduce the seismic loading.

Table 3. Peak horizontal acceleration for different seismic zones

Zone	1	2A	2B	3	4
PGA (g)	0.075	0.15	0.20	0.30	0.40

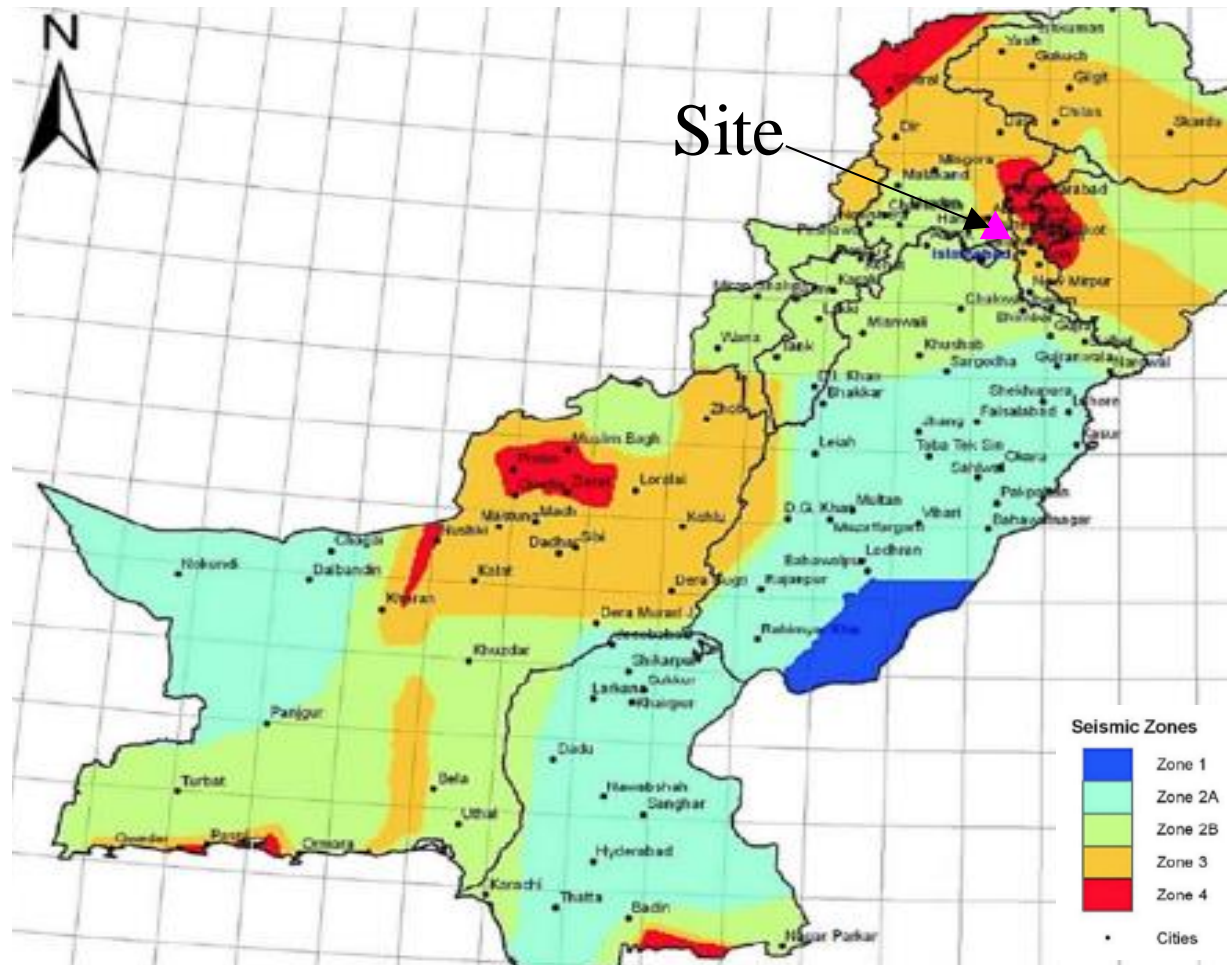


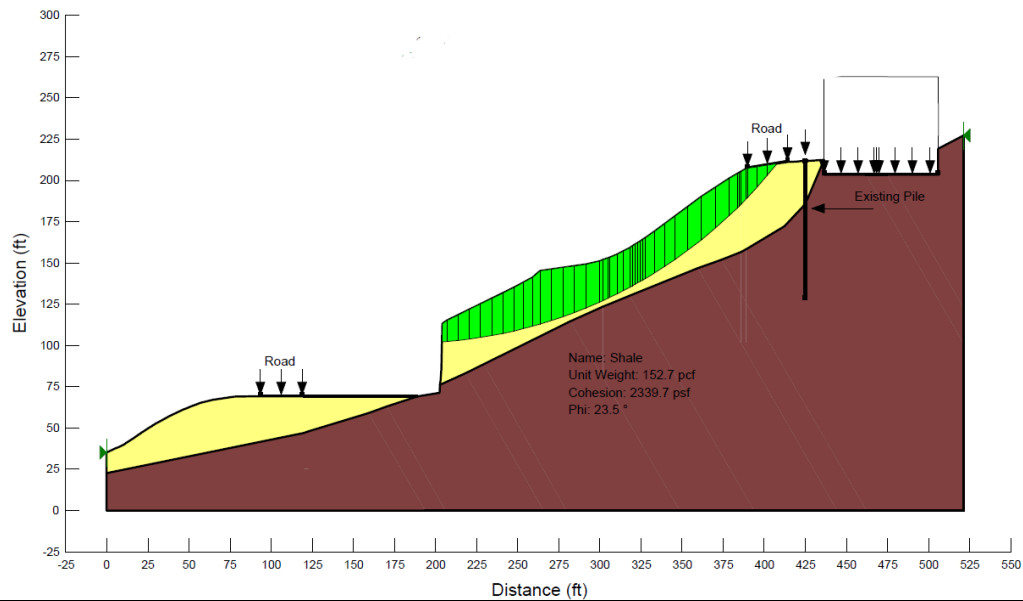
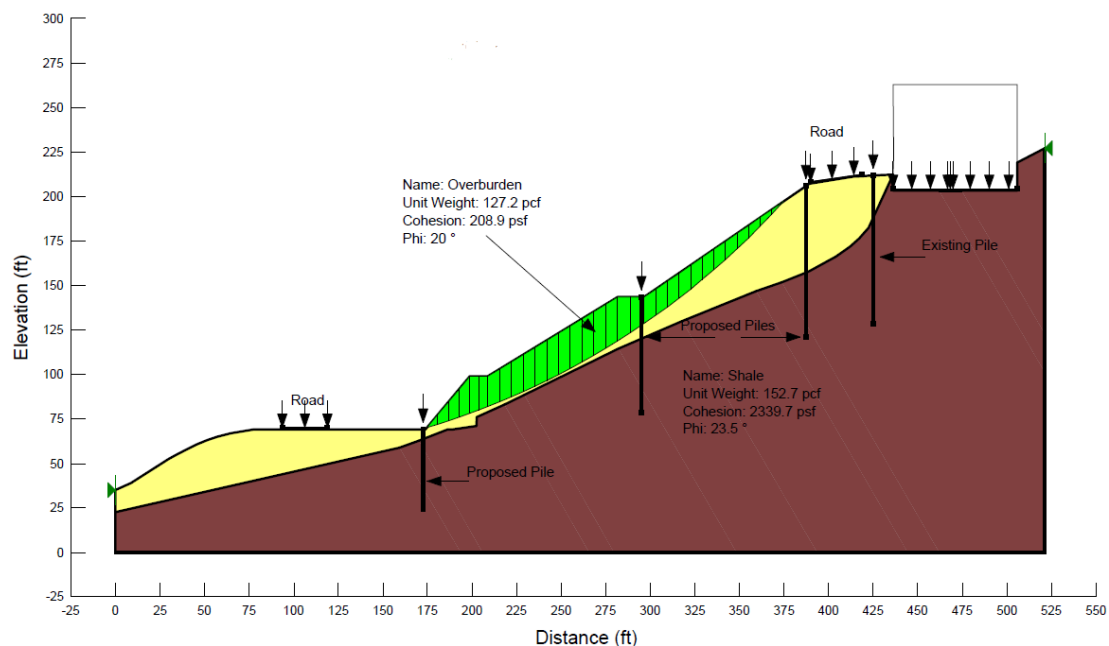
Figure 5. Seismic zonation of Pakistan, Building code of Pakistan (BCP) [6]

4. Results and Discussion

The stability of slope is evaluated in terms of FoS. The computed static and pseudo static FoS for both the original Figure 6 and improved slopes Figure 7 are presented in Table 4. The calculated minimum FoS of original slope for both static and pseudo static analysis is less than the required [6] code guidelines. Slope geometry modification and pile reinforcements are the remedial methods usually used for improvement of unstable slopes in Pakistan. Pile shear strength and arching between the rows of these piles are two type of resistances provided to critical slip surface of unstable slope. Pile location, length, diameter and centre to centre spacing are selected based on parametric study (not presented here for brevity). Calculated FoS of modified slope Figure 7 are adequate and slope is stable under static and dynamic loading.

Table 4 Calculated Factor of Safety

Slope	Analysis	Factor of Safety (FoS)	Comments
Original	Static	1.000	<1.5 (Unstable)
	Dynamic	0.718	<1.1 (Unstable)
Improved	Static	1.807	>1.5 (Stable)
	Dynamic	1.184	>1.1 (Stable)

**Figure 6.** Slope stability analysis for original section under static and dynamic loading.**Figure 7.** Slope stability analysis for the modified geometry and proposed shoring (RCC pile walls) under static and dynamic loading

5. Conclusions

Murree, Pakistan is susceptible to major landslide events due to its location in seismically active region and weak loosely bound slope forming material. A case study of slope failure from Birham land slide has been numerically modelled using SLOPE/W program. Slope stability in terms of FoS is evaluated for original and modified slope under static dynamic loading. Dynamic loading is considered as a pseudo-static by defining horizontal PGA of 0.2g from seismic hazard map of Pakistan. Results shows that static and dynamic FoS of original slope are inadequate therefore resistance to slip surface of original unstable slope is provided by slope geometry modification with pile reinforcement. Based on these remedial measures, computed FoS of modified slope are found to be sufficient for static and dynamic slope stability.

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