# Probabilistic and Deterministic analysis of Lungchok landslide, South Sikkim, India

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**Abstract.** The northern part of INDIA is most vulnerable in failure of slopes due to hill region with complex geology, high intensity rainfall and frequently occurrence of earthquakes. The stability of slopes has traditionally analyzed using deterministic methods. But uncertainty plays major role in geotechnical engineering the probabilistic characterization of uncertainties in input variables for the assessment of slope stability is very helpful. In this paper, the safety of slope using deterministic and probabilistic methods under static and pseudo static loads is carried for Lungchok landslide which is in south district of Sikkim state, India. The Factor of safety calculated by deterministic cannot represent the stability of slope exactly as it is limited to the single value of parameters. The stability of slope is independent of single soil parameter but dependent on random process with distribution of soil parameters. Rather than the conventional factor of safety against the sliding failure the probability of sliding failure is most useful. The stability of slope is analyzed using two approaches deterministic and probabilistic analysis under the effects of static and pseudo static forces. The deterministic approach with Morgenstern Price limit equilibrium method and the probabilistic approach with Monte Carlo simulation have been performed for the stability analysis of Lungcok landslide using Geo-Studio Software. The dependence and efficiency of the probabilistic strategies in the investigation of slope stability was highlighted in this paper.

**Keywords:** Slope Stability, Pseudo static analysis, Monte Carlo simulation.

## 1 Introduction

Stability of slopes should be safe by from failure either by collapsing or sliding. The frequency of failures is increasing day by day due to many human inventions especially in hilly areas. The northern part of INDIA is more vulnerable in slope failures due to hill region with frequently occurrence of earthquakes and rainfall. The instability of slope can be occurred due too many reasons which may damage the slope either slowly or rapidly. The better understanding of behavior of the slope helps in proper stabilization.

In general, the stability of slopes is adopted with strong assumptions analyzed using deterministic and probabilistic approaches. In deterministic three approaches were involved analytical approach, limit equilibrium methods and continuum method of slices applied with finite element methods [1] with single value input parameters. The probabilistic analysis differs with deterministic methods mainly due to input random variables of each parameter depend on many input variables. In probabilistic approach three approaches were used First order second moment, Point Estimates and Monte Carlo Simulation. The Monte Carlo Simulation is applied among other probabilistic analyses because of accurate probabilistic method with simple analysis like limit equilibrium analysis that can carry thousands of deterministic analyses depending upon the number of variables in the model in relatively short period of time [2]. The output from probability analysis helps to assess the probability of failure and establish the design process perfectly.

This paper compares the deterministic and probabilistic stability analysis of landslide under static and pseudo static forces. The landslide selected for the analysis is failed during 2011 Sikkim-Nepal earthquake trigged with moment magnitude of 6.9, located near Lungchok village south district of Sikkim state, India. The Sikkim is affected with frequent landslides every year due to the two main primary effects rainfall and earthquake. In the Manson season due to heavy rains the pore pressures increases gradually and reduce the effective normal stresses and these failures are intensified more during earthquakes [3]. The landslide is investigated for fully saturated and dry conditions representing arid and Manson seasons for static and pseudo static effect. The factor of safety of the slope from deterministic approach is employed using Morgenstern price method and probabilistic approach is studied using Monte Carlo Simulation. The current study deals with influence of single and variability of soil parameters of the Lungchok landslide determined using both approaches under static and seismic loads.

## 2 Study area

The slope considered for the analysis is in south district of Sikkim state situated in between the Lungchok and Singtam villages along the roadside. The direction of slope is towards south and located at latitude and longitude of $27^{0}08^{1}01.88^{11}$ North-$88^{0}23^{1}41.46^{11}$ East with elevation of 1686 m (Fig 1). Determination of basic geometry of the slope for the analysis is done using Google earth pro [4]. The slope geometry with boundary conditions considered for the analysis (see Fig. 2). The boundary conditions applied in X-direction is fixed in x and y and along Y-direction x is fixed. The slope is newly activated slope observed during $18^{th}$ September 2011 Sikkim earthquake. The frequency of earthquakes observed was high in the Sikkim state due to the distribution of faults, lineaments, Main Central thrust and Main Boundary thrust with seismic zone IV as per IS (1893-2016). The lungchok landslide is 4.02 Km from Main central thrust and 73kms from epicenter of 2011 Sikkim earthquake.

**Fig.**Error! No sequence specified.**.** Areial photograph of the study area (after 2011 Sikkim earthqauke)

The frequent landslides in south district were observed due to the association of Daling group [5]. The thin phyllites and slaty half-schistose rocks are observed only in the south district when compared with other districts of the Sikkim state [6]. The south district is accumulated with fractured and weathered rocks [7].

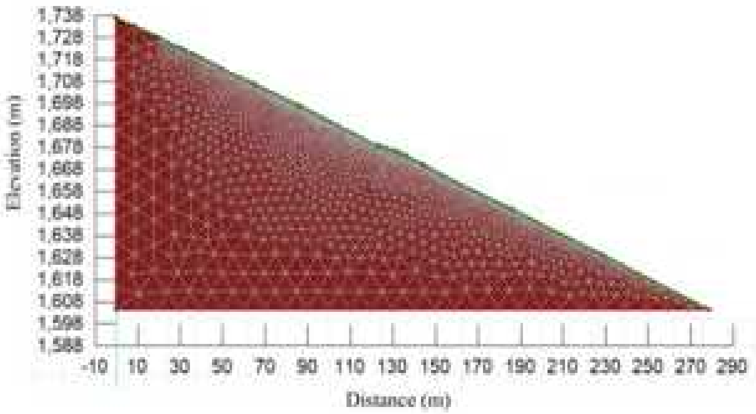


**Fig.2.** Finite element model of the slope

## 3 Methodology

The main purpose of the study is to understand the future earthquakes and to assess the nature. The study is analyzed using probabilistic and deterministic analysis with combination of finite element method using SLOPE W software. The hundred years of earthquake data (1997-2017) is involved in the analysis using appropriate ground motion prediction equation. The three node triangular plane strain elements are used in the entire model. The stability of the slope was examined for dry and saturated slope for static and pseudo static conditions. The horizontal coefficient $K_h$ 0.156 and vertical coefficient $K_v$ 0.201 of the 18$^{th}$ September 2011 Sikkim earthquake was used for the pseudo static analysis.

### 3.1 Deterministic approach

In deterministic approach to analyze the slope stability the single valued parameters are used and the output from the analysis yields single value of factor of safety. The variables adopted are summarized in the Table 1. There are many methods which are used to calculate the slope stability depending upon their assumptions. In the present study the Morgenstern method [8] is used as it is commonly employed method in stability analysis. The entry and exit method is used to find the critical slip surface.

**Table 1.** Geotechnical properties used in the Deterministic analysis

| Variable | Value |
|---|---|
| Cohesion (kN/m$^2$) | 0.1 |
| Friction angle (°) | 23 |
| Unit weight (kN/m$^3$) | 17.65 |

**Probabilistic approach.** The uncertainties in the soil parameters are taken in to consideration in probabilistic analysis. The probabilistic slope stability analysis is performed using Monte Carlo Simulation. For minimum factor of safety slip surface calculated by deterministic method is then used for probabilistic analysis by recomputing using Monte Carlo trials. This trial value "N" is dependent on the number of variables considered with respect to standard deviation and on their confidence level. The unit weight, cohesion and friction angle with different random input variables are selected based on mean value and adopted normal probabilistic distribution in the analyses is summarized in Table 2. The random value for each parameter is assigned according to the considered probability distribution function. If the input random variables are normally distributed the probability density function of the safety factors tends to be normally distributed [9].

**Table 2.** Geotechnical properties used in the Probabilistic analysis

| variable | Mean value | Standard deviation | Distribution adopted |
|---|---|---|---|
| Cohesion (kN/m$^2$) | 0.1 | 2 | Normal |
| Friction angle (°) | 23 | 2 | Normal |
| Unit weight (kN/m$^3$) | 17.65 | 2 | Normal |

## 4 Results

The factors of safety for the four different cases are calculated with the help of deterministic method namely Morgenstern method summarized in the Table 3.

**Table 3.** Factor of safety's calculated in different cases (deterministic).

| Cases considered | Factor of safety |
|---|---|
| Dry | 1.582 |
| Dry + Pseudo static | 0.781 |
| Saturated | 1.012 |
| Saturated + Pseudo static | 0.588 |

From the results, the slope is safe in saturated and dry condition but critically unstable when the pseudo static forces are applied. The factors of safety of slope under four different conditions using probabilistic analysis were presented in the Table 4. The slope with reliability index less 3 is unstable and requires stabilization [10]. In the present probabilistic analysis the slope at dry condition was perfectly safe and the reliability index was decreased from 5.08 to 1.192 during saturated condition. The slope under pseudo static condition was not reliable and more vulnerable to failure. From the results, the maximum factor of safety value of the slope at dry and saturated conditions is stable but the minimum factor of safety of saturated slope indicates the slope is unstable. Thus observed that the slope is safe in dry condition and the failure was initiated during rainy season. The increase in pore pressures dragged the soil downwards and created the failure plane channel and thus failed during 2011 Sikkim earthquake event. When compared to deterministic the probabilistic analysis is more realistic corresponding to factor of safety.

**Table 4.** Factor of safety's calculated in different cases (probabilistic)

| Variable | Mean factor of safety | Maximum factor of safety | Minimum factor of safety | Reliability Index | Standard deviation |
|---|---|---|---|---|---|
| Dry | 1.633 | 2.027 | 1.368 | 5.085 | 0.124 |
| Dry + Pseudo static | 0.821 | 0.836 | 0.783 | -17.83 | 0.010 |
| Saturated | 1.112 | 1.412 | 0.925 | 1.192 | 0.925 |
| Saturated + Pseudo static | 0.688 | 0.703 | 0.671 | -51.92 | 0.006 |

## 5 Conclusion

The slope profile selected for the present analysis is located in south district of Sikkim state. The stability analysis of the slope was determined using deterministic and probabilistic approaches. The results from the two approaches are compared for the better efficiency of slope stability. The slope under dry and saturated condition for with and without pseudo static forces was examined using SLOPEW software. The stability of slope under deterministic approach was analyzed using Morgenstern price method and probabilistic approach using Monte Carlo Simulation. In deterministic approach single valued input parameters are assigned which provided the single valued factor of safety. In probabilistic approach the random input variables based on normal probabilistic distribution were assigned are used to establish the probability of failure with mean, maximum and minimum factor of safety with risk criterion. From the deterministic approach the slope is safe in dry and saturated conditions but is unstable in both conditions when the pseudo static forces are applied. The slope is stable in two cases and unstable in two cases. But in the probabilistic approach, the slope is unstable in three cases with reliability index less than 3. From the whole analysis the slope failure is initiated during rainy season and disrupted and failed during earthquake with 100% probability of failure.

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