CHAPTER 6

DEVELOPMENT OF THE STABILITY RATING AND HAZARD CLASSIFICATION SYSTEM

6.1. Introduction

The deterministic stability analysis is most favourable when material properties are predictable, homogeneous and isotropic. However, OB dump materials are rarely homogeneous and isotropic. The uncertainty exists in OB dump material due to the spatial variability of the geotechnical properties, systematic or model errors in properties measurement, and model errors in analytical methods (Oka and Wu 1990). The extent of the uncertainties is magnified with the increase in the dump slope sizes. Thus, determining the exact value of the FoS for OB dump slopes with confidence is challenging. Therefore, performing a probabilistic approach-based study incorporating the uncertainties is preferable over deterministic analysis. Obregon and Mitri (2019) suggested that the probabilistic method of analysis possesses an advantage when (a) the mechanical properties of the parameter or system are insufficient and (b) a significant degree of scattering is observed in the information available.

The stability rating and hazard quantification of the dump slope system and its components using a statistical model, stability state classification, and probabilistic approach based on @RISK software are discussed below.

6.2. Variables and their Range

This study incorporated geometrical (total dump height, bench height, bench slope angle, and bench width) and geotechnical (cohesion, friction angle, and density) parameters of the dump slope structure. The geometry of the dump slopes is controllable as they can be modified, but the dump material's geotechnical properties are uncontrollable. Therefore, the geotechnical parameters were considered as a random variable to accommodate its spatial variability. The range of the random variables was decided by considering the most commonly occurring value and neglecting the exceptional outliers. Table 6.1 shows the range of random variables with mean and standard deviations.

Table 6.1 Distribution of the random variables

	Cohesion (kPa)	**Friction Angle (°)**	**Density (kg/m^3)**
Minimum	10	16	1300
Mean	24.8	29.84	1814
Maximum	90	40	2300
Standard Deviation	5	2	150

6.3. Identification of the Probability Distribution Function

The Normal, Lognormal, Triangle and Program Evaluation and Review Technique (PERT) distribution functions were employed based on the availability of distribution governing parameters, upon the @RISK software's suggestions, and the literature review (Palisade Corporation 2016; Shepheard et al. 2019; Rafiei Renani et al. 2019; Das et al. 2022). The required distributions governing parameters of the selected distribution functions were the mean, the standard deviation, the minimum and the maximum values. The distribution of the factor of safety was obtained through the @RISK software iteration process using the statistical model with due consideration of the random variable range. During the iteration process, the total dump height was 180 m, bench height was 30 m, bench slope angle was 37.5° and bench width was 30 m. The maximum likelihood of the existence of the stable, critically stable, and unstable states for the considered datasets was evaluated using employed distribution functions and summarized in Table 6.2. The normal and lognormal distribution functions determined the highest percentage of the stable state and the lowest chance of failure. On the contrary, the triangle and PERT distribution predicted the highest unstable state and lowest stable state possibilities. The difference between the prediction of the normal and lognormal distribution was negligible. Therefore, the reliability index was used to select the suitable distribution function.

Table 6.2 Stability states based on the distribution functions

Distribution Function	Stability States (%)		
	Stable	Critically Stable	Unstable
Triangle	53.1	37.3	9.6
Lognormal	61.8	38.2	0
PERT	54.1	39	6.9
Normal	61.9	38	0.1

The @RISK software calculated the mean and standard deviation of the considered distribution functions. The reliability index of the distribution functions was determined from Equation 3.7 and is summarized in Table 6.3. The U.S. Army Corps of Engineers (1997) mentioned that the expected performance or reliability of the structure improves and failure probability reduces with the increase in the reliability index. Wang et al. (2010) suggested that the reliability index should be equal to or greater than 2 for the optimal expected performance of the geotechnical design. Thus, the lognormal distribution function was adopted as it provided the highest reliability index.

Table 6.3 Mean, standard deviation, and reliability index for the various distribution functions

Distribution Function	**Mean**	**Standard Deviation**	**Reliability Index**
Lognormal	1.36	0.11	3.37
Normal	1.34	0.11	3.12
PERT	1.26	0.20	1.28
Triangle	1.18	0.21	0.86

6.4. Geometry Parameters for the Stable Dump Slope Structures

The threshold values of the total dump height, bench height, bench slope angle, and bench width were decided for the stable class with due consideration of the uncertainties after identifying the suitable distribution function. The mean value of the random variables as per the lognormal distribution function, deterministic value of the geometrical parameters, and calculated mean FoS based on @RISK software are reported in Table 6.4. The failure possibilities could be reduced by maintaining the geometrical parameters as per the threshold limit for the considered datasets and conditions.

Table 6.4 Stable state based input and output parameters

Total Dump Height (m)	180
Bench Height (m)	30
Bench Slope Angle (°)	37.5
Bench Width (m)	30
Cohesion (kPa)	24.8
Friction Angle (°)	30
Density (kg/m^3)	1807
FoS	1.34

The probability of the stable, critically stable, and unstable states at the threshold value of the geometrical parameters is illustrated in Figure 6.1. The unstable state was almost absent, with a 38.2% chance of the critically stable state, and the stable state had a chance of 61.8%. The maximum FoS was 1.902, and the minimum FoS was 0.948 for the used random variable range. The highest FoS frequency possibilities were also in the stable state region.

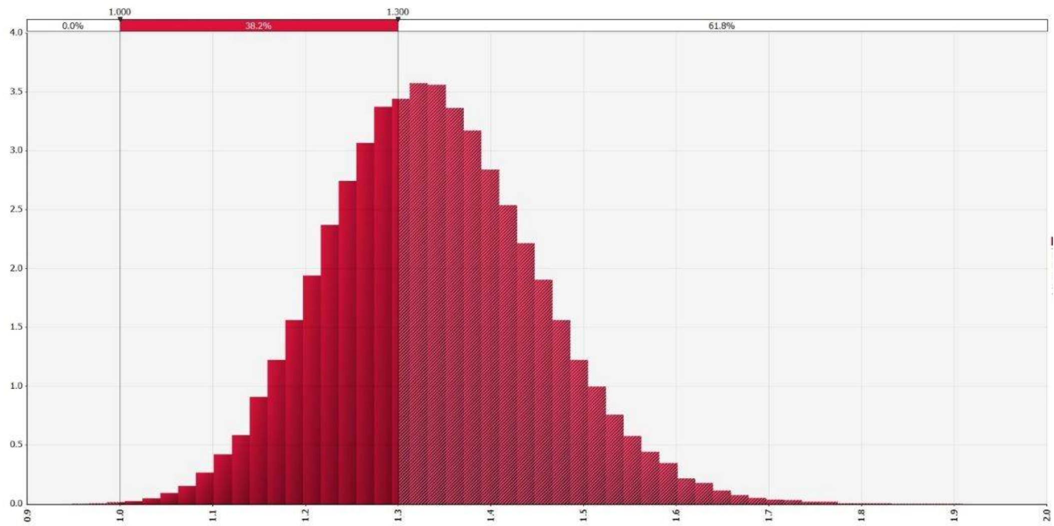


Fig. 6.1 Probability of occurrence of stability states

6.5. Estimation of the Slope Instability Hazard

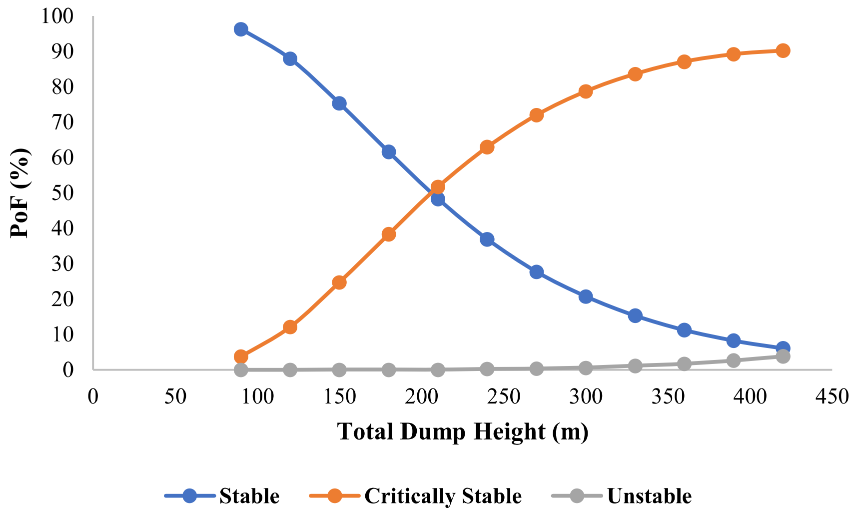
The probability of an unstable state or FoS less than one was considered a hazard in this work. This section evaluated hazards associated with the stability governing parameters using @RISK software. The behaviour of the probability of failure was analyzed throughout the range of the individual input parameter. The extreme points of the geometrical parameters were iterated where the stable state cases were approximately 0 and 100%. The geotechnical parameters range was the same as defined in the random variables. A total of 100000 samples were generated through the Latin Hypercube sampling method based on the lognormal distribution function by varying the random variables in a single iteration. Table 6.5 shows the range and base value of the input parameters. The base value was assigned only to the deterministic parameters. The main aim of the study was to design a stable dump slope structure; therefore, the base values were decided by considering the extreme points of the stable state conditions (FoS>1.30). During hazard quantification of the deterministic parameters, one parameter was varied within a predefined range with the base value of the remaining deterministic parameters and considered random variables range. During the geotechnical parameters hazard quantification, one parameter was varied within a predefined range and the other two were considered random variables with base values of the geometrical parameters.

Table 6.5 Input parameters, range, and base value for hazard quantification

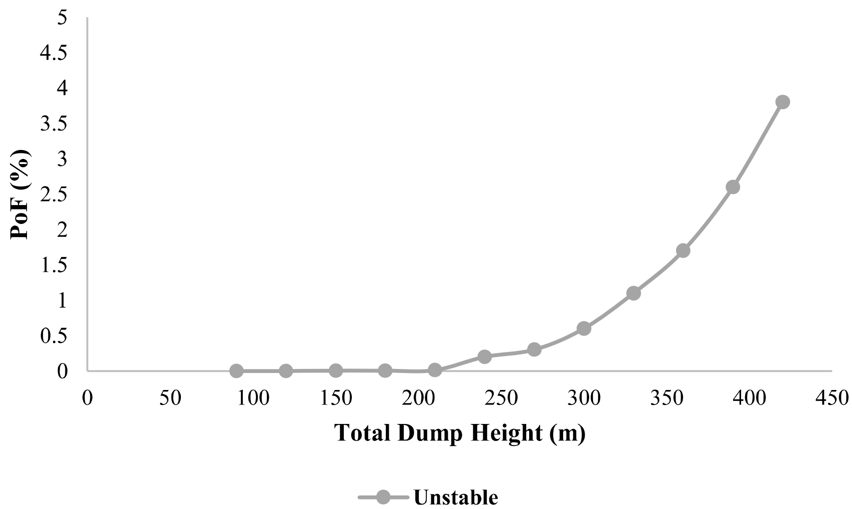
Input Parameters	Range	Base Value
Total Dump Height (m)	90 - 420	180
Bench Height (m)	10 - 50	30
Bench Slope Angle (°)	30 - 50	37.5
Bench Width (m)	5 - 40	30
Cohesion (MPa)	0.01 - 0.09	
Friction Angle (°)	16 - 40	
Density (kg/m^3)	1300 - 2300	

6.5.1. Effect of the Total Dump Height

The stable state condition was 100% at 30 m dump height for the considered uncertainty and stability governing parameters. The hazard quantification of the total dump height was done by varying it from 90 to 420 m in the interval of 30 m. The stable state decreased and the critically stable state increased significantly while increasing the dump height from 90 to 420 m (Figure 6.2 (a)). The unstable state or hazard increased with the succession of the total dump height as shown in Figure 6.2 (b). The PoF was 0% from 90 to 120 m, increased slightly, and reached 0.005% at 150 m dump height. The PoF increased twice from 150 to 210 m dump height, i.e., 0.005 to 0.01%. The PoF enhanced with a moderate rate from 210 to 300 m and accelerated significantly beyond 300 m. It was found that the critically stable and unstable states increased while the stable state condition decreased, and the unstable state condition increased sharply when the critically stable condition started decreasing. The change in the behaviour of stable and critically stable states was more intense against the unstable state.



(a)

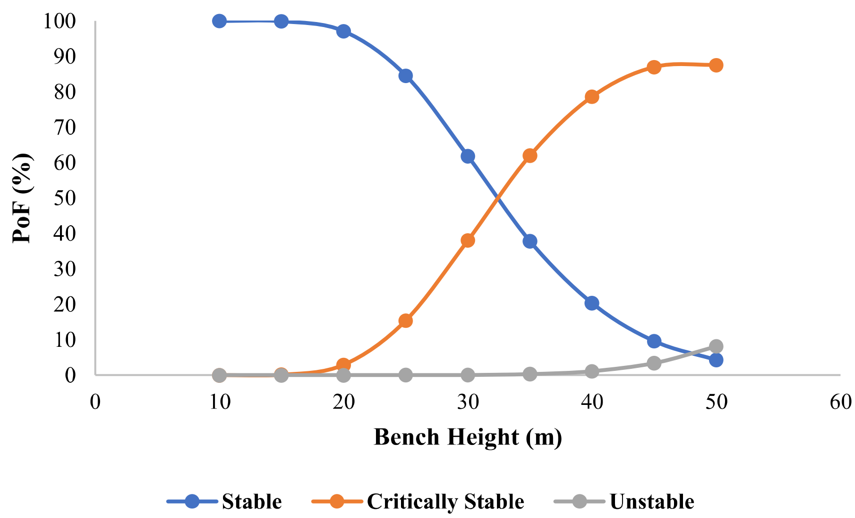


(b)

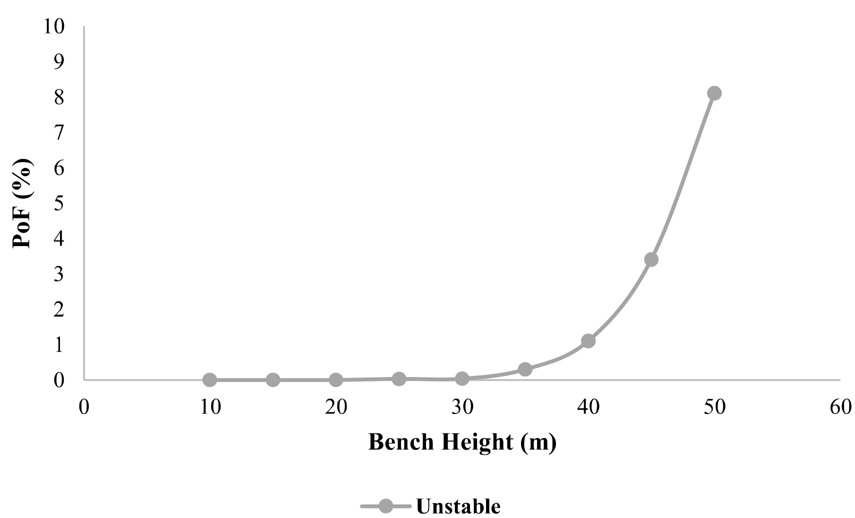
Fig. 6.2 Stability state distribution based on the total dump height

6.5.2. Effect of the Bench Height

The bench height at 10 m possessed a 100% chance of stable state condition. The stability state distribution was analyzed by varying the bench height from 10 to 50 m in the interval of 5 m. The stable state had a low decrement rate from 10 to 20 m and it reduced sharply between 20 to 50 m, as summarized in Figure 6.3 (a). The critically stable state chances magnified with the drop in chances of the stable state and attained maximum likelihood at 50 m bench height. The unstable state increased from 0 to 8.1% with the increment in bench height. The unstable state was absent below 20 m bench height and increased slightly from 20 to 35 m. The PoF accelerated sharply beyond 35 m bench height (Figure 6.3 (b). The increment rate of PoF increased significantly from 35 - 50 m compared to the 10 - 35 m bench height range.



(a)

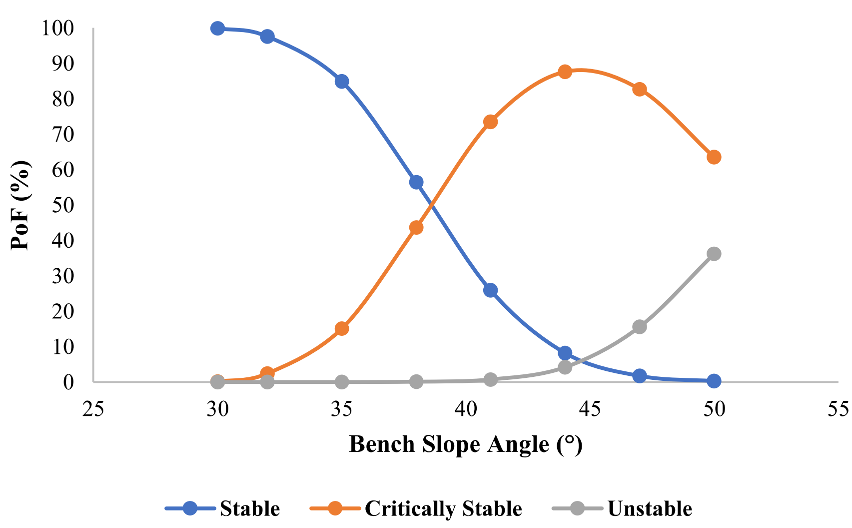


(b)

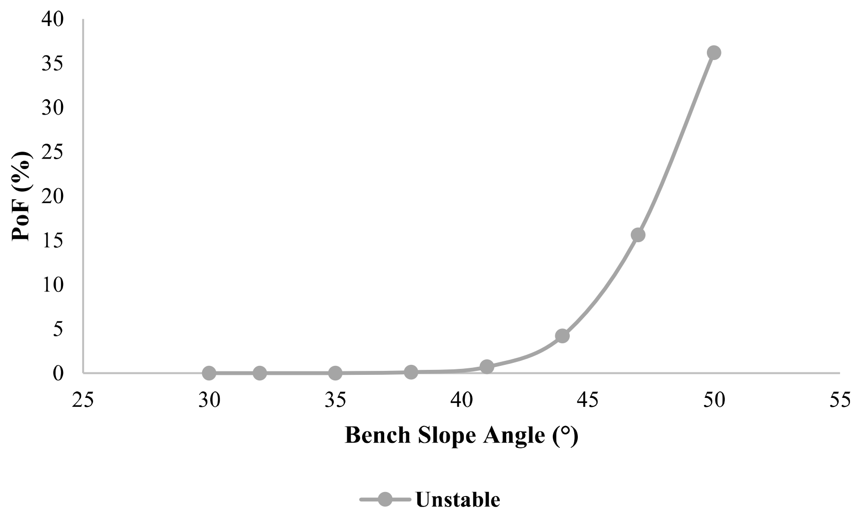
Fig. 6.3 Stability state distribution based on the bench height

6.5.3. Effect of the Bench Slope Angle

The bench slope angle was varied between 30 to 50° to analyse the chances of the stable, critically stable, and unstable states as depicted in Figure 6.4. The distribution of the stable state condition had a nonlinear inverse relationship, and the unstable state condition had a nonlinear direct or positive relationship with the bench slope angle. However, the critically stable state condition increased from 30 to 44° and reduced from 44 to 50° of the bench slope angle (Figure 6.4 (a)). The reduction of the stable state condition was prominent after 32°, and the decrement rate was high from 32 to 47°. The existence chances of the critically stable state were 0 to 87.6% between 30 to 44° and 87.6 to 63.5% between 44 to 50° bench slope angle. The PoF was 0 to 0.1% between 30 to 38° and enhanced from 0.1 to 36.2% between 38 to 50°. The failure chances increased tremendously after the 38° bench slope angle, and the increment rate was also magnified in each step with a high rate (Figure 6.4 (b)).



(a)



(b)

Fig. 6.4 Stability state distribution based on the bench slope angle

6.5.4. Effect of the Bench Width

The distribution of the stability states condition showed a nonlinear positive relationship with stable state conditions and a nonlinear inverse relationship with unstable state conditions when increasing the bench width from 5 to 40 m in the increment of 5 m (Figure 6.5). The critically stable state increased for short intervals and then reduced sharply. The stable state increment rate increased from 15 to 30 m and then diminished from 30 to 40 m, but the overall stable state condition improved. The PoF was 99.5% at 5 m bench width and reduced significantly to 59.7% by increasing the bench width to 10 m. The PoF again dropped sharply from 59.7 to 13.3% in additional increment of bench width from 10 to 15 m. The unstable state chances varied between 13.3 to 0.036% from 15 to 30 m bench width, and further increments in bench width resulted in a 0% chance of instability. The unstable state was approximately zero, the critically stable state decreased, and the stable state increased after crossing the 20 m bench width.

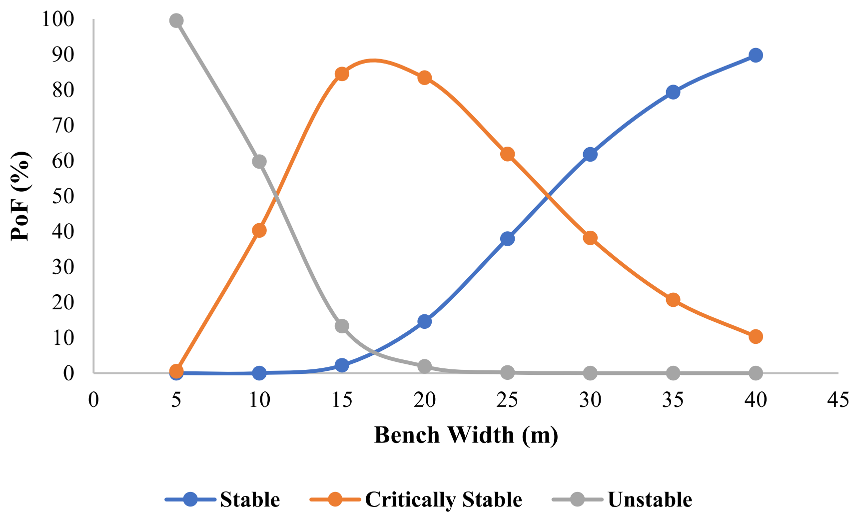
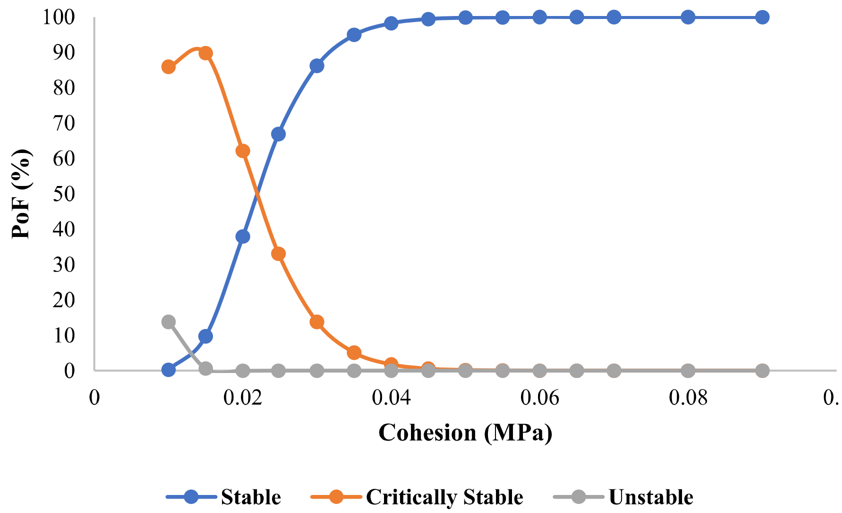


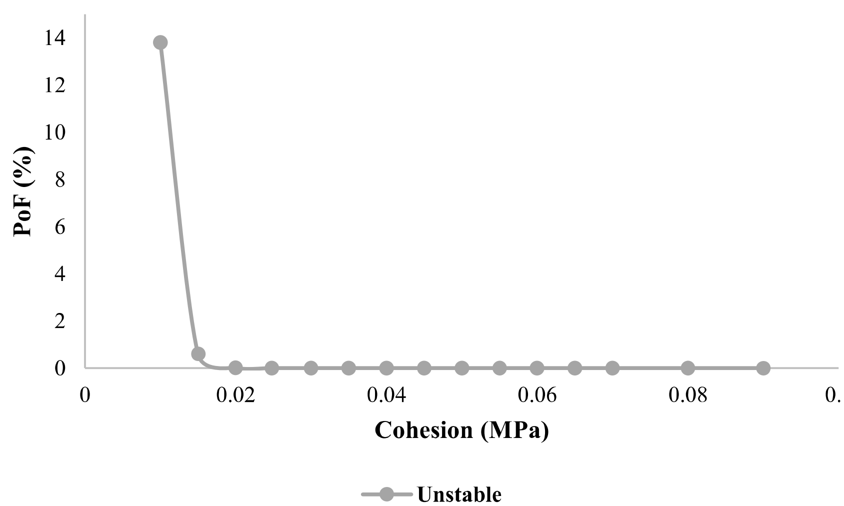
Fig. 6.5 Stability state distribution based on the bench width

6.5.5. Effect of the Shear Strength Parameters

The cohesion was varied from 0.01 to 0.09 MPa to analyze the stability state distribution condition in the interval of 0.005 MPa (Figure 6.6). The stable state condition was approximately absent (i.e., 0.3%) at 0.01 MPa cohesion and changed drastically to 9.7%, 37.9%, 66.9%, and 86.2% at 0.015 MPa, 0.02 MPa, 0.025 MPa, and 0.03 MPa, respectively. The stable state condition also improved from 0.04 to 0.09 MPa but with a low increment rate and reflected 100% stable state condition after 0.065 MPa (Figure 6.6 (a)). The critically stable state attained its maximum magnitude at the initial level (i.e., 0.015 MPa) of 89.7%. The critically stable state dropped sharply from 89.7 to 0.6% while increasing the cohesion from 0.015 to 0.045 MPa. It gradually decreased beyond 0.045 MPa with a low reduction rate. The chances of dump slope instability reduced sharply from 13.8 to 0.01% upon improving the cohesion from 0.01 to 0.02 MPa (Figure 6.6 (b)). The failure chances of the dump slope structure were absent beyond the 0.025 MPa for the adopted deterministic and random variables.



(a)



(b)

Fig. 6.6 Stability state distribution based on the cohesion

The hazard quantification of the friction angle of the OB dump material was done by varying it in a predefined range from 16 to 40° (Figure 6.7). The stable state probability was zero from 16 to 21°, and an intense increment was observed from 0.3 to 97.4% by increasing the friction angle from 24 to 33°. The chances of stability state condition were almost the same between 33 to 40°. The critically stable state distribution followed a curved path like a bell. It started and ended at zero percent probability. No existence of the critically stable state was observed from 16 to 18° and 36 to 40°. It increased tremendously from 0.4 to 94.5% by enhancing the friction angle from 18 to 24°, and reduced sharply from 94.5 to 2.6% by a further increase in the friction angle from 24 to 33°. A small drop was observed between 33 to 36°, i.e., 2.6 to 0.1%. The PoF was approximately 100% between 16 to 18°. It diminished extremely from 99.6 to 0.1% with the improvement of the friction angle from 18 to 27°. The unstable state was zero beyond the friction angle of 27°.

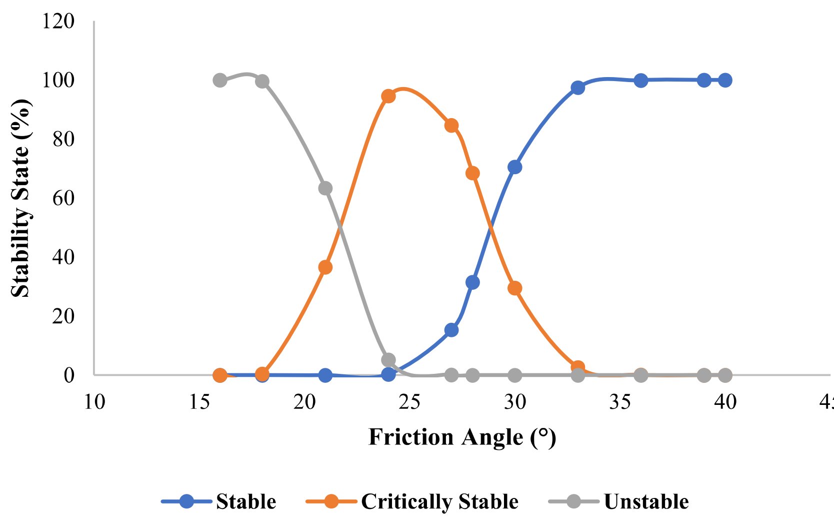
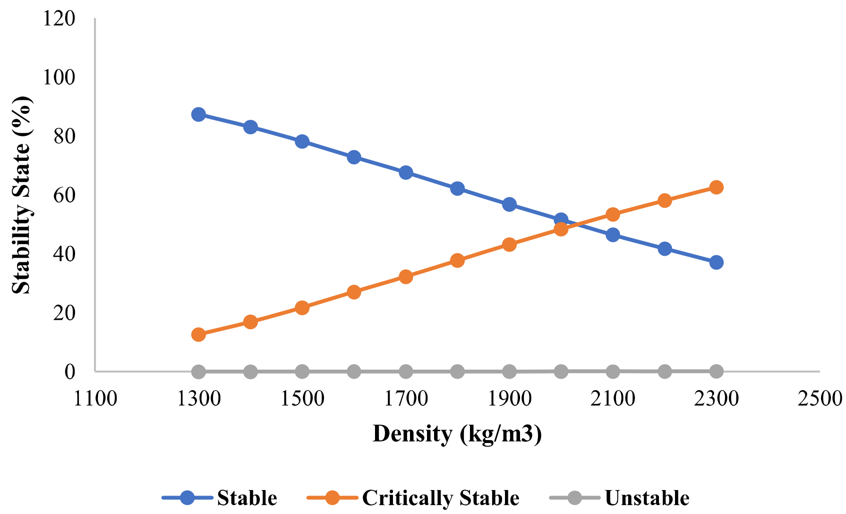


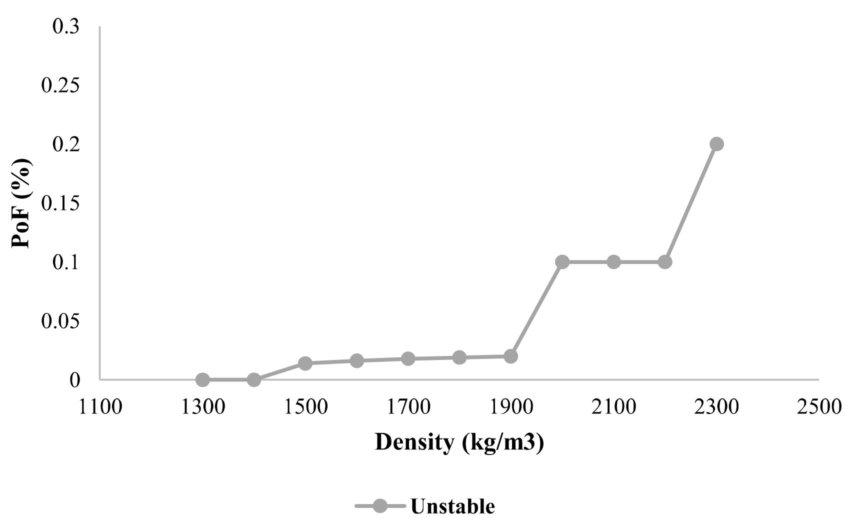
Fig. 6.7 Stability state distribution based on the friction angle

6.5.6. Effect of the Unit Weight of the dump material

The density varied between 1300 to 2300 kg/m^3 as per the general existence range of the OB dump material in the gap of 100 kg/m^3 to quantify the hazard (Figure 6.8). The stable state was 87.4% at 1300 kg/m^3 and 37.2% at 2300 kg/m^3. A gradual decrement in the stable state and increment in the critically stable state with a nearly constant rate was observed during the study, as depicted in Figure 6.8 (a). The PoF accelerated from 0 to 0.2% on increasing the density, as illustrated in Figure 6.8 (b). The overall change in the PoF was minimal compared to other stability states. The unstable state was absent from 1300 to 1400 kg/m^3, raised slightly after 1400 kg/m^3 and maintained a nearly constant value till the density of 1900 kg/m^3. The PoF rose from 0.02 to 0.1% on increasing the density from 1900 to 2000 kg/m^3 and attained a constant value up to 2200 kg/m^3. In the last stage, the PoF increased to 0.2% by increasing the density to 2300 kg/m^3. The stability state distribution of the density significantly differed from the other stability governing parameters.



(a)



(b)

Fig. 6.8 Stability state distribution based on the density

6.6. Slope Instability Rating

The ranking and weightage of each stability governing parameter were done through regression coefficients. The coefficient of each parameter was divided by the sum of the coefficients, and the percentage of this ratio was assigned as weightage. The weightage and ranking of each parameter are presented in ascending order in Table 6.6. The bench slope angle had the highest weightage hence 1st rank, while total dump height possessed the lowest weightage with the last rank. The weightage of each parameter was allocated as a maximum rating to the respective parameter where it owned 100% stable state stability condition.

Table 6.6 Weightage and ranking of input parameters

Parameters	Weightage	Ranking
Total Dump Height	6	7
Density	7	6
Cohesion	8	5
Bench Width	9	4
Bench Height	11	3
Friction Angle	29	2
Bench Slope Angle	30	1

The distribution of the stable, critically stable, and unstable states was deduced throughout the range of each parameter as described in the previous section. The FoS was calculated at each point within the predefined range of the parameter and was divided by the FoS of 100% stable state stability condition of the corresponding parameter to determine the reduction factor. The reduction factor of each value was multiplied by the weightage of the related parameter, and the obtained value was assigned as a rating to the individual value of the considered parameter. Table 6.7 illustrates the rating calculation of the friction angle using the stability state distribution. In the friction angle case, a 100% stable condition was observed at 39°, and the corresponding FoS was 1.69. The FoS of each value of the friction angle was divided by 1.69, and the obtained ratio was taken as the reduction factor. The reduction factor was multiplied by the weightage of the friction angle (i.e., 29), and the acquired value was allotted as a rating to the respective friction angle. The rating of each point is organized in Figure 6.9. The rating increased linearly with the increase in friction angle.

Table 6.7 Rating calculation based on a reduction factor of friction angle

Friction Angle (°)	Stability States (%)			FoS	Reduction Factor	Rating
	Stable	Critically Stable	Unstable			
16	0	0	100	0.77	0.46	13.21
18	0	0.4	99.6	0.856	0.51	14.69
21	0	36.6	63.4	0.98	0.58	16.82
24	0.3	94.5	5.2	1.1	0.65	18.94
27	15.3	84.6	0.1	1.224	0.72	21.00
28	31.5	68.5	0	1.264	0.75	21.69
30	70.5	29.5	0	1.344	0.80	23.06
33	97.4	2.6	0	1.46	0.86	25.05
36	99.9	0.1	0	1.578	0.93	27.08
39	100	0	0	1.69	1	29
40	100	0	0	1.7	-	-

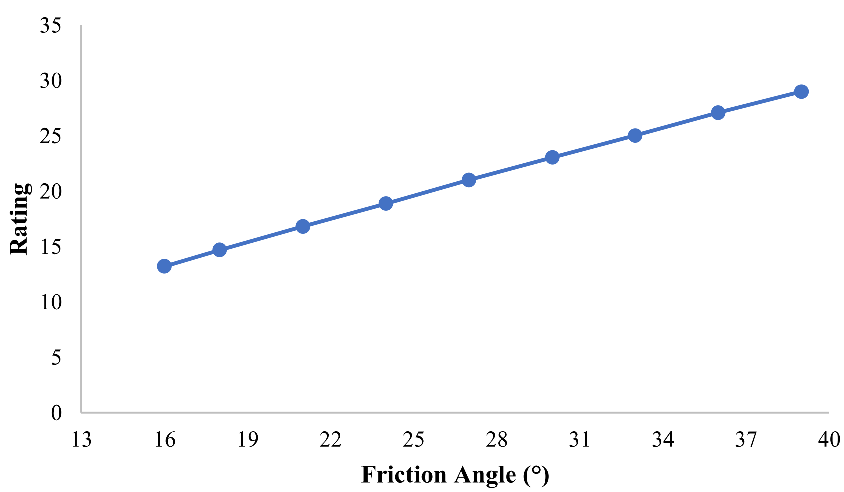


Fig. 6.9 Rating variation of friction angle

The ratings of the remaining parameters were calculated by following the same procedure and compiled in Figures 6.10 to 6.15. The rating dropped from 4.95 to 3.78 on increasing the dump height from 90 to 420 m in the succession of 30 m (Figure 6.10). The decrement rate of rating was high from 90-270 m compared to the remaining increment of the dump height. A minor drop was observed from 270 to 420 m dump height.

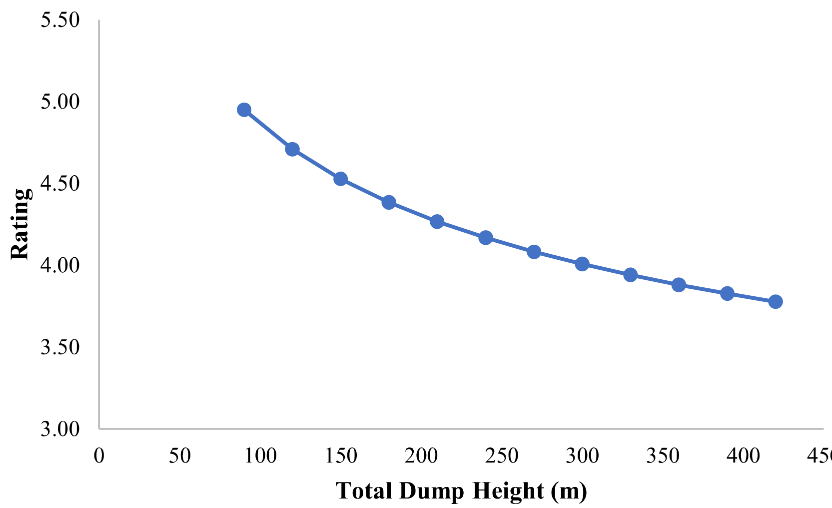


Fig. 6.10 Rating variation of total dump height

The bench height reflected an inverse relationship with the rating, as shown in Figure 6.11. The rating reduced from 11 to 6.37 during the increment of the bench height from 10 to 50 m in the interval of 5 m. The decrement rate was significant between 10 to 30 m and after that the corresponding rate of change reduced as it is evident from the slope of the curve.

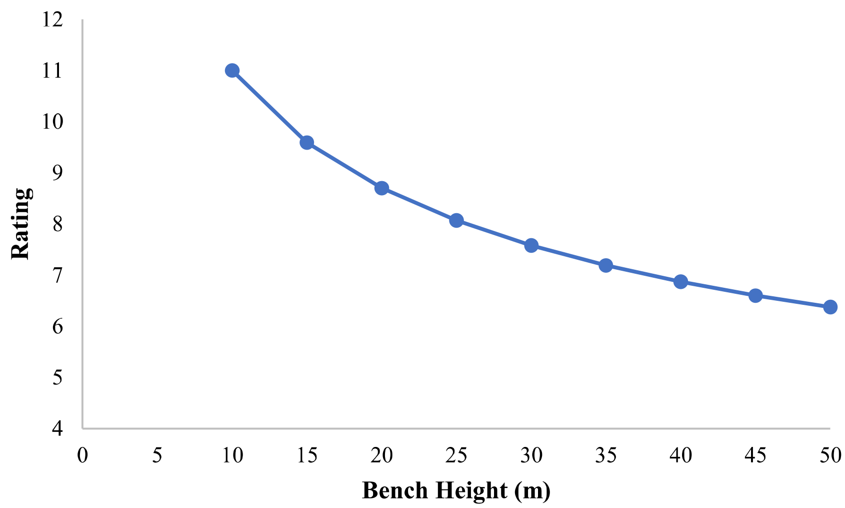


Fig. 6.11 Rating variation of bench height

Figure 6.12 depicts the bench slope angle rating behaviour from 30 to 50° in the step of 3°. The rating changed nonlinearly against the bench slope angle. The rating decreased from 26.3 to 16.7 on increasing the bench slope angle for the considered range. The rating at 50° reduced to approximately 37% of the 30° bench slope angle. The fluctuation in the rate of decrement was less throughout the range.

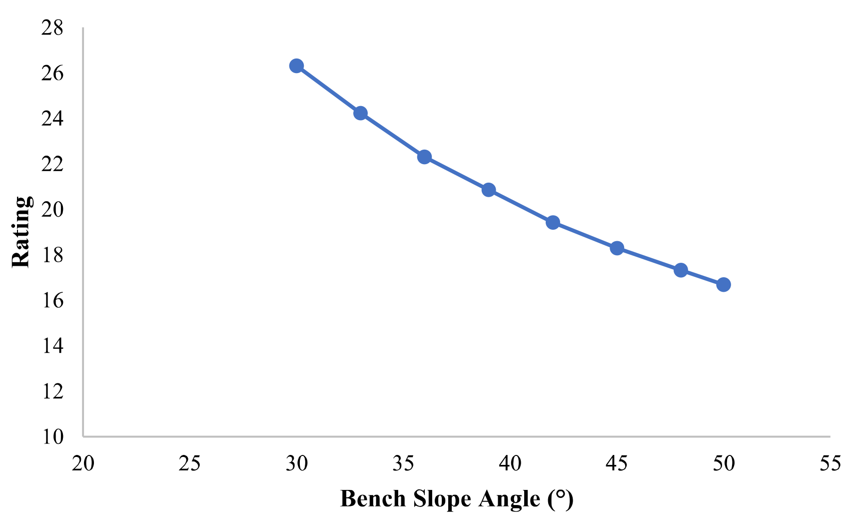


Fig. 6.12 Rating variation of bench slope angle

The rating depicted a nonlinear relationship with the bench width (Figure 6.13). The rating behaviour was observed from 5 to 40 m in the interval of 5 m. The rating improved from 4.14 to 7.26 on increasing the bench width. The rating reflected nonlinear behaviour from 5 to 25 m and then attained an approximately linear trend from 25 to 40 m. The rate of change of rating was also different in both ranges.

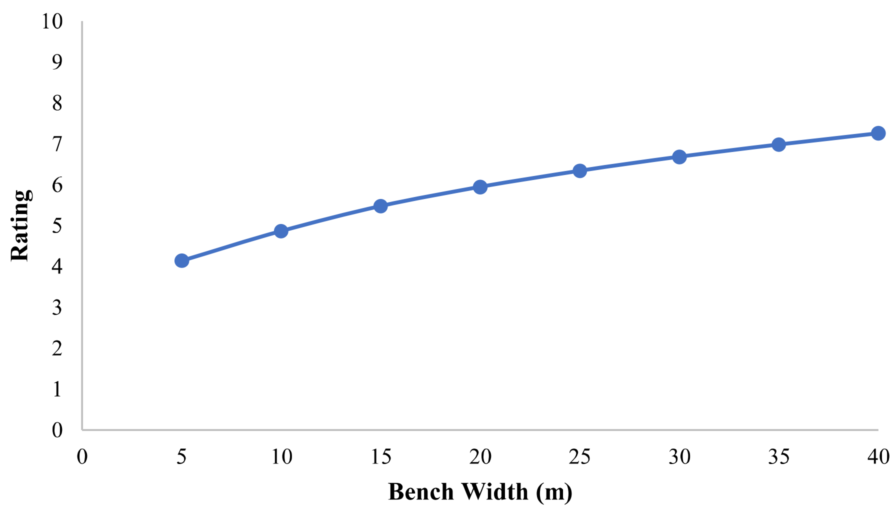


Fig. 6.13 Rating variation of bench width

The rating increased from 4.98 to 8 with the increase in the cohesion of OB dump material from 0.01 to 0.065 MPa in the gap of 0.005 MPa (Figure 6.14). The change in rating was high from 0.01 to 0.03 MPa, and then the increment rate was almost constant throughout the range. The stable state cases were 100% above 0.065 MPa cohesion, therefore, the rating would be same (i.e., 8) up to 0.09 MPa.

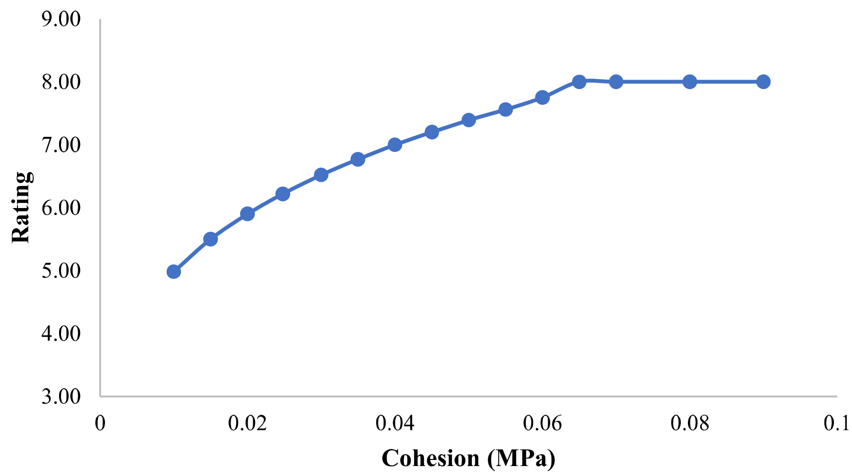


Fig. 6.14 Rating variation of cohesion

The change in the rating of the density from 1300 to 2300 kg/m^3 in the interval of 100 kg/m^3 is depicted in Figure 6.15. The rating was inversely proportional to the density of OB dump material. The rating reduced from 7 to 6.2 with the increase in density. Since the effect of density was low on the safety factor for the considered range; therefore, a minor fluctuation was observed in the reduction ratio. Thus, the rating was reduced by only 11.43% on increasing the density from 1300 to 2300 kg/m^3. The decrement rate of the rating was nearly constant.

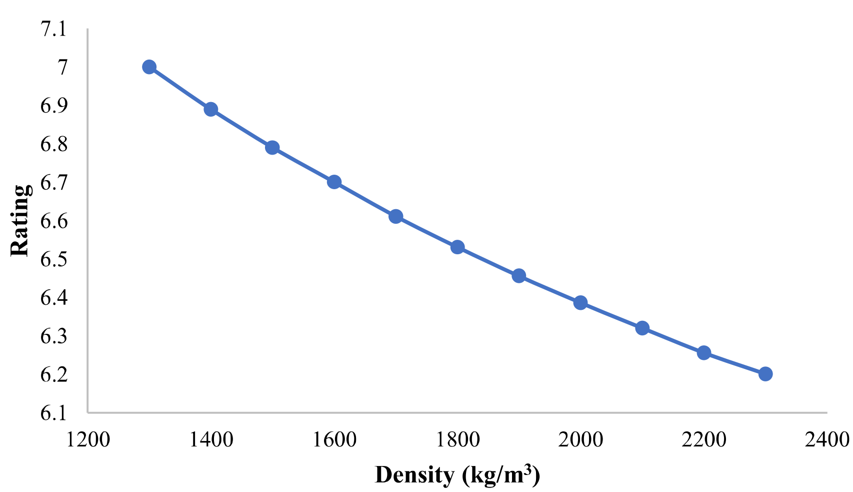


Fig. 6.15 Rating variation of density

In this work, the total dump height (T), bench height (H), bench slope angle (A), bench width (W), cohesion (C), friction angle (φ), and density (ρ) were incorporated to examine the stability rating and hazard of the dump slope structures. The FoS guided the classification of the range of the stability governing parameters related to the stable, critically stable, and unstable stability states. Similarly, the characterization of the rating and PoF of each input feature was done corresponding to the different stability states as described in Table 6.8. The rating was assigned zero when the safety factor was less than one. Table 6.8 communicates insightful information related to the threshold magnitude of the stability governing parameters for the adopted uncertainty. The notable inferences were drawn based on the outcomes of the hazard quantification and rating sections.

The total dump height was stable when it was less than 180 m and unstable while crossing the 420 m dump height, and the remaining range lay in the critically stable state condition. The rating of the stable state ranged from 6 to 4.38, with less than 0.005% of failure. The rating decreased (4.38 to 3.78) further with the increment of PoF (0.005 to 3.8%) for the critically stable state condition. The unstable state had a PoF greater than 3.8% with a zero rating.

The dump slope structure was situated in a stable state condition by maintaining the bench height up to 30 m, and it moved to a critically stable state condition upon increasing the bench height from 30 to 50 m. The FoS was approximately one when the bench height was close to 50 m. The rating reduced from 11 to 7.58 and 7.58 to 6.37 for the stable and critically stable state conditions, respectively. The PoF increased significantly while moving from stable to critically stable state conditions.

The dump slope structure had a failure probability of less than 0.03% with FoS greater than 1.30 when the bench slope angle was less than 37.5°. The PoF increased to 7%, and FoS reduced to 1 on increasing the bench slope angle to 45°, and beyond this instability was observed. The stability rating of the bench slope angle varied between 30 to 21.46 in stable state conditions and reduced to 18.14 at the transition point of the critically stable to an unstable state.

The large-size dump slope structure would remain in a critically stable or unstable state while providing the bench width less than the bench height and collapse by keeping the bench width less than half of the bench height. The dump slope was unstable when the bench width was less than 14 m with a PoF greater than 19%. In the critically stable state, the PoF declined from 19 to 0.036% by increasing the bench width from 14 to 30 m, and the rating improved from 5.56 to 6.92. The bench width transferred from the critically stable to a stable state while keeping the bench width greater than 30 m. The stability rating varied between 6.92 to 9 in the stable state condition.

A cohesion of less than 11.2 kPa resulted in instability, the critically stable state was generated by elevating the cohesion to 24.8 kPa, and the minimum requirement of the cohesion was 24.8 kPa to design the stable dump slope structure for the considered uncertainty. The PoF was zero in the stable state condition, ranged from 0 to 6.9% in the critically stable state, and was greater than 6.9% in the unstable state. The rating was 8 at 100% stable state condition and varied between 6.21 to 8 when FoS was greater than 1.30. The rating decreased from 6.21 to 5.11 as FoS dropped from 1.30 to 1.

The stable state had a PoF of 0% and the stability rating varied between 29 to 22.36 when the friction angle was greater than 29°. In the critically stable state condition, the PoF increased to 5.2%, and the stability rating reduced to 18.94 upon the reduction of the friction angle to 24°. The unstable state was initiated below the friction angle of 24°. The PoF was greater than 5.2%, and the stability rating was zero in the unstable state.

Table 6.8 Stability ratings and hazards of input parameters

Parameters	Stability States		
	Stable	**Critically Stable**	**Unstable**
T (m)	**<180**	**180 - 420**	**>420**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0-0.005	0.005-3.8	>3.8
Rating	6-4.38	4.38-3.78	0
H (m)	**<30**	**30 - 50**	**>50**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0-0.035	0.035-8.1	>8.1
Rating	11-7.58	7.58-6.37	0
A (°)	**<37.5**	**37.5 - 45**	**≥45**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0-0.03	0.03-7	>7
Rating	30-21.46	21.46-18.14	0
W (m)	**>30**	**30 - 14**	**<14**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0-0.036	0.036-19	>19
Rating	9-6.92	6.92-5.56	0
C (kPa)	**≥24.8**	**24.8-11.2**	**<11.2**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0	0-6.9	>6.9
Rating	8-6.21	6.21-5.11	0
Φ (°)	**>29**	**29-24**	**≤24**
FoS	>1.30	1.30-1.00	<1.00
PoF (%)	0	0.0-5.2	>5.2
Rating	29-22.36	22.36-18.94	0
ρ (kg/m^3)	**<1800**	**1800-2300**	
FoS	>1.30	1.30-1.24	
PoF (%)	0-0.019	0.019-0.2	
Rating	7-6.53	6.53-6.20	

Only stable and critically stable state conditions were present in the deployed range of the density. The stable state ranged from 1300 to 1800 $kg/m^{3,}$ and the critically stable state varied from 1800 to 2300 kg/m^3. A minor change occurred in PoF and rating when the stability state transformed from stable to critically stable. The PoF changed from 0 to 0.019% and the rating changed from 7 to 6.53 in the stable state, and the PoF changed from 0.019 to 0.2% with the decrement of rating from 6.53 to 6.20 in the critically stable state condition.

The stability rating and PoF of each stability governing parameter were determined for the considered range. All seven parameters significantly governed the stability of the dump slope structure. Shifting any stability governing parameter from stable to critically stable or unstable state would make it prone to or lead to failure. Thus, all the stability governing components were linked in a series system to control the stability of the dump slope structure. The total sum of ratings of each parameter was classified into stable, critically stable, and unstable states based on the series system. Adding the upper limit rating of each parameter of the stable state provided the upper limit rating of the dump slope system i.e., 100. The rating sum was 75.4 while adding the stable state lower limit rating of each parameter. Similarly, adding the lower limit rating of each stability governing parameter of the critically stable state produced 64.1. The total ratings 75.4 and 64.1 were transition ratings from stable to critically stable and critically stable to unstable state, respectively. The PoF of the upper and lower limit of each stability state was evaluated using Equation 3.8. The PoF of the transition state from stable to critically stable and critically stable to the unstable state were 0.12% and 41.3%, respectively. Table 6.9 interpreted the range of summation of rating and PoF of the dump slope structure corresponding to the different stability state conditions.

Table 6.9 Stability rating and hazard of dump slope structure

Stability State	Summation of Rating	PoF (%)
Stable	75.4 - 100	0 - 0.12
Critically Stable	64.1 - 75.4	0.12 – 41.3
Unstable	0 – 64.1	41.3 – 100

6.7. Summary

This chapter discussed the procedure to obtain the influence of the spatial variability of the geotechnical parameters on the stability of the dump slope structure. The first section explained the assignment of random and deterministic variables among the input parameters. The selection of the probability distribution function to generate the trial samples during the iteration process was summarized in the next section. The threshold values of geometrical parameters were identified to design a stable dump slope structure for the adopted geotechnical uncertainty. The PoF and rating related to each stability governing parameter as well as for the dump slope structure were evaluated through @RISK software. In the last section, the range of the input features, rating, and PoF were classified into stable, critically stable, and unstable states.