CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter reviews significant case studies and research works relating to dump slope structures to identify critical stability governing parameters. Studies in conjunction with stability rating and hazard classification based on the design of the general dump slope structure (Figure 2.1) are also summarized in this chapter. Analysis of the dump slope stability through a robust rating and hazard system is one of the best alternatives to overcome the limitations of numerical simulation. Significant gaps are identified for improving the stability rating and hazard classification system.

Fig. 2.1 The general layout of the dump slope structure (DMT Group 2020)

2.2. Parameters Governing Dump Slope Stability

Several factors at various levels trigger instabilities within operating dump slopes. Depending upon its levels; the factors impact the intensity and scale of the failure.

Cho and Song (2014) categorized these triggering factors into external and intrinsic. The coupling of the intrinsic factors with external factors causes instability. The instability may occur due to external factors like rainfall and seismicity if a slope is on the verge of failure due to vulnerable shear strength or geometry. Zhigang et al. (2018) suggested external force, physical and mechanical properties of dump material, physical and mechanical properties of the base, and the effect of water as major instability contributing factors. It was also observed that the geological, hydrological, and physical and mechanical properties of OB dump materials significantly influence the stability condition (Peng et al. 2013; Zhang et al. 2017; Amarsaikhan et al. 2018; Gupta et al. 2018; Igwe and Chukwu 2019). Hawley and Cunning (2017) reported that the dumping method and the floor shape also influence the stability of the resulting dump slope. The bottom-up and top-down construction method affects the density, homogeneity, material settlement, and permeability (Caldwell and Moss 1985; Spitz and Trudinger 2008; Zevgolis 2018). Zhou et al. (2020) concluded that as rock content increases in rock-soil dump material, the cohesion decreases and friction angle increases. The presence of clay hinders the water movement and increases the pore water pressure with more plasticity to the dump material (Igwe et al. 2013; Xing et al. 2019; Gupta et al. 2021). The spontaneous combustion due to dry and hot summers also causes instability of dump slopes (Carras and Leventhal 2000; Hajra et al. 2009; Jelínek et al. 2015).

In most scientific studies, geotechnical, geometrical, and external parameters were observed as considerable instability accelerating factors (Gupta et al. 2021). The primary geotechnical characteristics are grain size, density, moisture content, permeability, porosity and void ratio, friction angle, Young's modulus, Poisson's ratio, cohesion, dilation angle, Atterberg limit, floor competency, and interface geotechnical properties. The prime geometrical parameters include overall slope angle, bench slope angle, total dump height, bench height, number of benches, bench width, topographical conditions, and floor inclination. Rainfall, surcharge loading, and seismicity are notable external parameters.

2.3. Classification of Dump Slope Stability and Hazards

Currently, limit equilibrium and numerical simulation methods are used to analyze the stability of dump slope structures, but both methods have some limitations. The limit equilibrium method does not consider the effect of stress and strain (Cheng et al. 2007). Numerical simulation with strength reduction method considers the stress-strain relationship and assess the critical slip surface, satisfy rotational and translational equilibrium conditions. However, it is time-consuming, expensive, and requires a high degree of technical skills for analysis (Abdalla et al. 2015; Koopialipoor et al. 2019). In addition, ready-to-use tools were also proposed to analyze the stability of dump slopes. Generally, it was done by classifying the stability of dump slope structures into different stability states through stability rating, hazard classification, and safety factor. This section reviews the literature on the dump slope stability state classification designed by various researchers.

2.3.1. Stability Rating

Initially, only qualitative waste dump slope classification was done based on the dump configuration, overall foundation characteristics, failure mechanisms, and stability controls (MESA 1975; Wahler 1979; USBM 1982; OSM 1989; Hawley and Cunning 2017). The first comprehensive stability and hazard classification of the waste rock dump slope structure was introduced by the British Columbia Mine Waste Rock Pile Research Committee (BCMWRPRC) (BCMWRPRC 1991; Hawley 2000). BCMWRPRC developed a Dump Stability Rating (DSR) considering 11 factors, as shown in Table 2.1.

The range of each parameter was subdivided into different categories as per their influence. The rating and weightage of each parameter were assigned according to the perception of the authors. The DSR value was inversely proportional to the stability of dump slope structure and subdivided into 4 different dump slope stability classes (Table 2.2). The DSR value varied from 0 to 1800. In class I, failure hazard was negligible with DSR<300. Failure hazard was low in class II and DSR varied between 300 to 600. Failure hazard increased from low to moderate in class III with DSR value between 600 to 1200. The class IV had DSR>1200 with high potential of dump slope failure. However, no explicit reference was included to measure the consequence of failure, and no calibration of DSR system was done due to lack of funding.

Table 2.1 Dump stability parameters and their rating (BCMWRPRC 1991; Hawley 2000)

Parameters	**Range**	**Number of Categories**	**Rating**
Dump height (m)	<50 to >200	4	0 to 200
Dump volume (bank cubic meter)	$< 1 \times 10^6$ to $> 5 \times 10^7$	3	0 to 100
Dump slope (°)	<26 to >35	3	0 to 100
Foundation slope (°)	<10 to >32	4	0 to 200
Degree of confinement	Confined to Unconfined	3	0 to 100
Foundation type	Competent to Weak	3	0 to 200

Dump material quality	High to Poor	3	0 to 200
Method of construction	Favourable to Unfavourable	3	0 to 200
Piezometric and climatic conditions	Favourable to Unfavourable	3	0 to 200
Dumping rate	Slow to High	3	0 to 200
Seismicity	Low to High	3	0 to 100

Table 2.2 Classification of hazards based on dump stability rating (BCMWRPRC 1991; Hawley 2000)

Dump stability rating	Dump stability class	Failure hazard
<300	I	Negligible
300-600	II	Low
600-1200	III	Moderate
>1200	IV	High

The waste dump and the stockpile stability rating and hazard classification (WSRHC) system ameliorated the BCMWRPRC study to upgrade the insight related to the stability analysis of the spoil piles (Hawley and Cunning 2017). The WSRHC system added 11 more stability affecting parameters in the DSR system and categorized all 22 parameters into 7 groups. The seven groups were Regional Setting (Seismicity and Precipitation), Foundation Conditions (Foundation Slope, Foundation Shape, OB Type, OB Thickness, Undrained Failure Potential, Foundation Liquefaction Potential, Bedrock, and Groundwater), Material Quality (Gradation, Intact Shear Strength and Durability, Material Liquefaction Potential, and Chemical Stability), Geometry and Mass (Height, Slope Angle, and Volume and Mass), Stability Analysis (Static, and Dynamic Stability), Construction (Construction Method, and Loading Rate) and Performance (Stability Performance). The waste dump and stockpile stability rating (WSR) is illustrated in Table 2.3. In WSR, the rating of each parameter and consequences of dump slope instability were based on the experience and suggestions from the field practitioner to refine and improve the system. The maximum value of WSR was 100 and subdivided into 5 waste dump and stockpile hazard classes (WHCs) qualitatively (Table 2.4). WHC I (WSR>80) presented a very low potential for instability and WHC V (WSR<20) showed a very high potential to dump slope instability, and intermediate potential for instability was represented by intermediate classes (WHC II, III, and IV).

Table 2.3 Waste dump and stockpile stability rating (Hawley and Cunning 2017)

S No	Parameters	Range	Number of Categories	Rating
1	Seismicity	Very High to Very Low	5	0 to 2
2	Precipitation	Very High to Very Low	5	0 to 8
3	Foundation Slope (°)	>32 to <5	5	0 to 5
4	Foundation Shape	Convex on Very Steep slopes to Planar or Concave on Flat or very irregular slopes	5	0 to 2
5	Overburden Type	Type I to Type V	5	0 to 4
6	Overburden Thickness (m)	> 5 to < 0.3	5	0 to 2
7	Undrained Failure Potential	Very High to Negligible	5	-20 to 0

8	Foundation Liquefaction Potential	Very High to Negligible	5	-20 to 0
9	Bedrock (Competency)	Very weak to Very competent	5	0 to 4
10	Groundwater	High to Low	3	0 to 3
11	Gradation	Very Fine Grained to Very Coarse Grained	5	0 to 7
12	Intact Strength and Durability	Type I to Type V	5	0 to 8
13	Material Liquefaction Potential	Very High to Negligible	5	-20 to 0
14	Chemical Stability	Highly Reactive to Neutral	5	-5 to 5
15	Height	Very High to Very Low	5	0 to 4
16	Overall Slope Angle (°)	> 35 to < 15	5	0 to 4
17.1	Volume (m^3)	$> 1 \times 10^9$ to $< 1 \times 10^6$	5	0 to 2
17.2	Mass(te)	$> 2 \times 10^9$ to $< 2 \times 10^6$	5	0 to 2
18	Static Stability			
18.1	Factor of Safety or Strength Reduction Factor	< 1.1 to > 1.5	5	0 to 7
18.2	Probability of Failure (%)	> 20 to < 1	5	0 to 7
18.3	Other criteria	Non-convergent Numerical Model, No Supporting Stability Analysis,	3	0 to 3.5

		Convergent numerical model		
19	Dynamic Stability			
19.1	Factor of Safety or Strength Reduction Factor	< 1.0 to > 1.15	5	0 to 3
19.2	Other criteria	Non-convergent Numerical Model, No Supporting Stability Analysis, Convergent numerical model	3	0 to 1.5
20	Construction method	Method I to Method V	5	0 to 8
21	Loading Rate	Very High to Very Low	5	0 to 7
22	Stability Performance	Very Poor to Very Good	5	-15 to 15

Table 2.4 Waste dump and stockpile stability rating based hazard classification (Hawley and Cunning 2017)

Rating	Class	Hazard
80–100	I	Very Low Hazard
60–80	II	Low Hazard
40–60	III	Moderate Hazard
20–40	IV	High Hazard
< 20	V	Very High Hazard

Fattahi (2017) proposed a new approach for risk assessment and FoS prediction through a Rock Engineering System (RES) for circular failure slopes. The unit weight, pore pressure ratio, height, angle of internal friction, cohesion, and slope angle were considered pertinent parameters. The final outcome of the study was achieved in three steps. In the first step, the weightage of parameters was evaluated using RES based interaction matrix. The assigned rating of the range of each parameter is presented in Table 2.5. The vulnerability index (VI) was calculated through the assigned weightage of parameters in the second step. Risk level was classified into three levels based on the rating from lower to higher vulnerability, as depicted in Table 2.6. In the third step, FoS was assessed using a relationship with VI as established in Equation 2.1. However, the datasets used in this study were obtained from different research work, and the study was partially dedicated to mining dump slopes. The quantification of the corresponding levels of risk was absent.

$$FoS = 3.77EXP(-0.028VI) \tag{2.1}$$

Table 2.5 The range and the ratings of the parameters (Fattahi 2017)

Parameter					
Unit weight (kN/m^3)	<18	18-20	20-26	>26	-
Rating	0	1	2	3	-
Cohesion (kPa)	-	0-5	5-25	25-40	>40
Rating	-	1	2	3	4
Angle of internal friction (°)	0-10	10-20	20-30	30-38	>38
Rating	0	1	2	3	4
Slope angle (°)	>45	40-45	30-40	25-30	<25
Rating	0	1	2	3	4
Height (m)	-	>180	120-180	50-120	<50

Rating	-	1	2	3	4
Pore pressure ratio	>0.5	0.4-0.5	0.3-0.4	0.05-0.3	0-0.05
Rating	0	1	2	3	4

Table 2.6 Vulnerability index (VI) and the associated risk (Fattahi 2017)

Vulnerability Index (VI)	**Risk**
0-33	Low - Medium
33-66	Medium - High
66-100	High - Very High

Sharma et al. (2017) designed the Dump Slope Rating (DSR) for an Indian coal mine using numerical modelling and principal component analysis. Principal component analysis revealed that the overall slope angle had the highest influence and the number of benches had the least influence among the total dump height, overall slope angle, number of benches, groundwater, cohesion and friction angle of dump material. The range, number of categories, and the ratings of each parameter are illustrated in Table 2.7. Stability class and hazard were classified into 4 categories based on the summation of the rating of parameters (Table 2.8). Class A had negligible failure hazard with a total rating greater than 80, and Class D was more prone to failure as it had a total rating of less than 40. Class B and C were in the intermediate stability state and possessed total stability ratings between 61-80 and 41-60, respectively. The study was conducted for the moderate size of the dump structures. However, mega opencast projects are currently planning for a giant dump slope structure (beyond the 300-400 m dump height), and DSR assigned the same rating after 160 m total dump height, which is not appropriate. In DSR, the number of benches had been considered instead of bench height, which would be geotechnical inaccurate.

Table 2.7 Dump slope rating (Sharma et al. 2017)

S. No.	Parameters	Range	Number of Categories	Rating
1	Overall height of dump (m)	≤40 to >160	5	20 to 0
2	Overall Slope angle (°)	<18 to >38	7	30 to 0
3	Number of benches	2-4 to >4	2	5 to 10
4	Cohesion of dump material (kPa)	<1 to >70	6	0 to 10
5	Friction angle of dump material (°)	<10 to >32	6	0 to 15
6	Ground water conditions (% of height)	0 to >40	5	15 to -5

Table 2.8 Dump slope rating based hazard classification (Sharma et al. 2017)

Dump stability class	Failure hazard	Range of dump rating
A	Negligible (long term stable)	>80
B	Low (Stable)	61-80
C	Moderate (Short term stable)	41-60
D	High (Unstable)	<40

2.3.2. Factor of Safety

The uncertainty related to the geometry or strength of waste rock material may cause FoS fluctuation of about 10%. The waste rock slope structure was observed to have a low risk of failure with an FoS of 1.10 to 1.15. Therefore, the dump slope structure has a high risk of instability with FoS less than 1.10 (Miller et al. 1979; Khandelwal and Mozumdar 1992; Hustrulid et al. 2009). Gupta et al. (2019) introduced a critically stable state along with stable and unstable states to determine the threshold value of FoS of different stability conditions. The critically stable state was introduced to identify the dump slope structure with FoS>1 but it is prone to failure. The critically stable state varied between FoS of 1 to 1.28. The slope was stable with FoS>1.28 and unstable when FoS<1.

Several studies have provided the minimum value of FoS based on the hazard and life of dump slope structures. In 1975, the US Mine Enforcement and Safety Administration (MESA) proposed the first minimum acceptance criteria for dump slope structures (MESA 1975). The range of FoS value depended on certain key assumptions related to shear strength, seismicity and hazard level (Table 2.9). In 1977, the Canadian Centre for Mining and Metallurgy (CANMET) also suggested a minimum FoS value for the design of waste rock dumps based on the assumed shear strength properties, earthquake, and consequences (Table 2.10) (CANMET 1977).

Table 2.9 MESA 1975 stability acceptance criteria (MESA 1975)

Assumptions	**High hazard**	**Moderate hazard**	**Low hazard**
Designs based on shear strength parameters measured in the laboratory	1.5	1.4	1.3
Designs that consider the maximum seismic acceleration at the site	1.2	1.1	1.0

Table 2.10 CANMET 1977 stability acceptance criteria (CANMET 1977)

Assumptions	**High Consequences**	**Low Consequences**
Peak shear strength parameters	1.5	1.3
Residual shear strength parameters	1.3	1.2
100-year return period earthquake	1.2	1.1

The MESA (1975) guidelines were modified by the US Bureau of Mines (USBM) in 1982. The USBM included the tailing dams and waste rock dumps along with the coal refuse dumps and the suggested range of FoS, as described in Table 2.11 (USBM 1982). The British Columbia Mine Waste Rock Pile Research Committee (BCMWRPRC) developed the first stability acceptance criteria specifically for mine waste rock dumps in 1991 (BCMWRPRC 1991; Hawley and Cunning 2017). The BCMWRPRC considered the potential scale of instability, consequence of instability, design basis, confidence in input parameters, and stability analysis methods to recommend the minimum FoS criteria (Table 2.12) based on cases A and B.

Table 2.11 USBM 1982 stability acceptance criteria (USBM 1982)

Assumptions	**High hazard**	**Moderate hazard**	**Low hazard**
Shear strength parameters from representative testing	1.5	1.4	1.3
Based on maximum expected seismic acceleration	1.2	1.2	1.1

Table 2.12 BCMWRPRC 1991 stability acceptance criteria (BCMWRPRC 1991)

	Suggested minimum design values for factor of safety	
Stability condition	**Case A**	**Case B**
Stability of spoil surface		
Short-term (during construction)	1.0	1.0
Long-term (reclamation – abandonment)	1.2	1.1
Overall stability (deep-seated stability)		
Short-term (static)	1.3-1.5	1.1-1.3
Long-term (static)	1.5	1.3
Pseudo-static (earthquake)	1.1-1.3	1.0

Case A

- Low level of confidence in critical analysis parameters
- Possibly unconservative interpretation of conditions, assumptions
- Severe consequences of failure
- Simplified stability analyses method (chart, simplified method of slices)
- Stability analysis method poorly simulates physical conditions
- Poor understanding of potential failure mechanism(s)

Case B

- High level of confidence in critical analysis parameters
- Conservative interpretation of conditions, assumptions
- Minimal consequences of failure
- Rigorous stability analysis method
- Stability analysis method simulates physical conditions well
- High level of confidence in critical failure mechanism(s)

2.3.3. Probability of Failure vis-a-vis Factor of Safety

Nguyen and Chowdhury (1984) provided PoF for a specific value of FoS by considering the shear strength of the dump and floor material as a random variable. The FoS was calculated using the Bishop method, assuming two-wedge failure mode. The study was performed for dump slope heights of 38-80 m. Simmons (1995) also classified PoF into four classes against FoS and defined the range of FoS and PoF instead of specific values. Similarly, Hawley and Cunning (2017) suggested the range of PoF as per the stability acceptance criteria in five classes. In all cases, it was observed that the chances of consequence were low when FoS was greater than 1.30 and significant in the range of 1-1.30. The quantification and classification of the PoF regarding FoS were done based on the experience of the field practitioners and through the limit equilibrium method (LEM). Adriansyah et al. (2021) analyzed the stability of the in-pit dump slope structure through FoS and PoF using the Morgenstern-Price method. Here, the cohesion and friction angle of the material were taken as a random variable. The stability state was categorized into three states. The slope was safe when FoS > 1.05 and PoF varied between 0-1%. It transferred to the marginal state as PoF placed between 1-12% and FoS < 1.05. The slope was unstable when FoS < 1.05 and PoF > 12%. Igwe et al. (2022) considered the dump slope structure of Lead–Zinc mines at Enyigba, Iron-Steel mines at Itakpe, and Tin–Columbite in Jos, Nigeria. The cohesion, the friction angle and the density of the dump material were treated as a random variable and deployed Morgenstern-Price's general limit equilibrium method to determine FoS and PoF. The validation of the results was done by the Spencer method. The FoS and PoF ranged from 0.58 to 2.80 and 2 to 100%, respectively, for the Enyigba mine. In Itakpe mine, the FoS varied between 0.63 to 2.11 with PoF from 2 to 100%. The Jos mine had the same PoF range as the previous two mines for the variation of FoS from 0.84 to 3.06. The consequence of dump slope instability is evaluated using probabilistic criteria, i.e. the probability of failure (PoF). Table 2.13 illustrates the maximum tolerable value of PoF according to stability acceptance criteria based on FoS.

Table 2.13 Probability of failure against safety factor for waste rock dump slopes

Factor of Safety	Probability of Failure (%)	Reference
1.15	15	Nguyen and Chowdhury (1984)
1.20	10	
1.25	5	
1.35	2.5	
≤1.0	>80	Simmons (1995), Hiung (2016)
1.0-1.1	20-80	
1.1-1.2	0.1-20	
1.2-1.5	<0.1	
<1.1	>20	Hawley and Cunning (2017)
1.1-1.2	10-20	
1.2-1.3	5-10	
1.3-1.5	1-5	
>1.5	<1	
>1.05	0-1	Adriansyah et al. (2021)
<1.05	1-12	
<1.05	>12	
0.58-2.80	2-100	Igwe et al. (2022)
0.63-2.11	2-100	
0.84-3.06	2-100	

Hawley et al. (2017) suggested a risk matrix (Figure 2.2) based on the hazard intensity and confidence over stability governing parameters. The product of the consequence and confidence provided an indirect risk index. The requirement of the FoS would be low and the PoF would be high (more tolerable) when the low rating of consequence combined with a high confidence rating. It was due to an overall low risk condition. Conversely, high risk would occur when a high consequence rating would be combined with a low confidence rating. It would result in the need of higher FoS with lower tolerable PoF. Thus, minimum acceptable values of FoS and PoF were suggested for stability acceptance criteria, as shown in Figure 2.2. It was observed that PoF varies widely and depends on the statistical treatment and reliability of input parameters and analysis technique. Currently, no consensus has been arrived at among the field practitioners related to risk matrix application. Therefore, it was recommended that the primary static stability acceptance criteria should be based on FoS, and PoF being used as a supplementary criterion only.

STATIC ANALYSIS

CONSEQUENCE	LOW	MODERATE	HIGH
HIGH	FoS ≥ 1.5 PoF ≤ 1%	FoS 1.4-1.5 PoF 1-2.5%	FoS 1.3-1.4 PoF 2.5-5%
MODERATE	FoS 1.4-1.5 PoF 2.5-5%	FoS 1.3-1.4 PoF 5-10%	FoS 1.2-1.3 PoF 10-15%
LOW	FoS 1.3-1.4 PoF 10-15%	FoS 1.2-1.3 PoF 15-25%	FoS 1.1-1.2 PoF 25-40%

CONFIDENCE

Fig. 2.2 Risk matrix for the design and stability acceptance criteria (Hawley et al. 2017)

2.4. Dump Material Characterization

In this study, grain size analysis, proctor compaction and triaxial compression tests were performed to determine the OB dump material particle size distribution, density and shear strength properties. These geotechnical properties were enriched from the scientific reports and research articles to cover the majority of the Indian coal mines (Annexure I). Although the OB dump material is heterogeneous and particles vary from micrometre to meter. In the analysis of 87 cases (Annexure I), it was observed that clay, silt, sand and gravel were the major constituents of dump material. Figure 2.3 shows the variation in the percentage of Clay was 0-15, Silt was 0-79, Sand 10-100 and Gravel 0-90. The statistical distribution of the geotechnical properties is depicted in Figure 2.4. It may be noted that the minimum value of the density was 1129 kg/m^3 and the maximum was 2480 kg/m^3 with a mean of 1862 kg/m^3 and a standard deviation (SD) of 320 kg/m^3 (Figure 2.4 (a)). The cohesion of the dump material varied from 1.56-125 kPa with mean and SD of 29 kPa and 31 kPa, respectively (Figure 2.4 (b)). The friction angle of the dump material was in the range of 6 to 49° with a mean of 30° and SD of 10° (Figure 2.4 (c)).

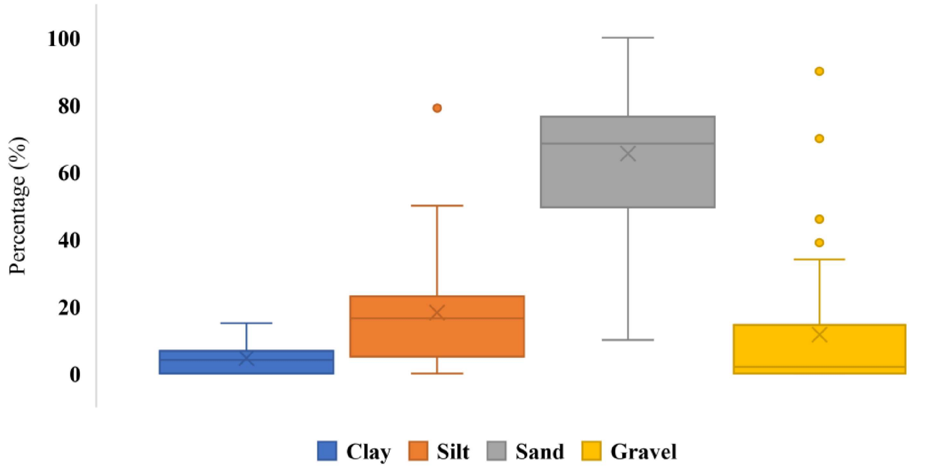
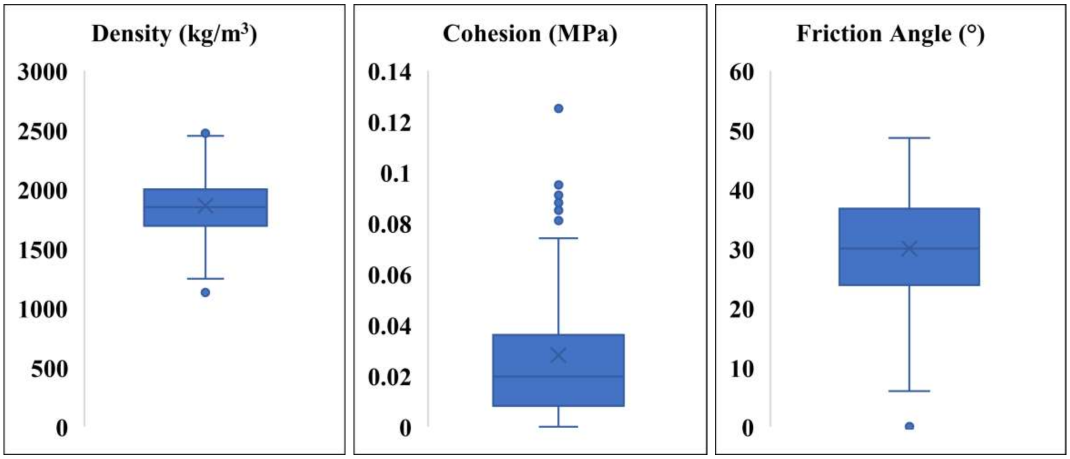


Fig. 2.3 Grain size distribution of OB material



(a) (b) (c)

Fig. 2.4 Statistical distribution of geotechnical parameters (a) density (b) cohesion (c) friction angle based on case studies

2.5. @RISK software

@RISK is a software application developed by Palisade Corporation. It is used for risk analysis and decision-making. In @RISK software, a model is created in Microsoft Excel that represents a system. The model generally contains formulas that calculate outputs based on the input variables. @RISK allows users to define probability distributions for input variables. These distributions represent uncertainty in the data used for analysis. Thousands or millions of simulations are run using a statistical technique. In each simulation, it randomly samples values from the specified input distributions and calculates the corresponding output. After running simulations, @RISK provides a range of statistical results. This includes probability distributions for the output variables, as well as summary statistics like mean, standard deviation, and percentiles. This software assesses uncertainties and potential outcomes in complex models or situations. @RISK helps users understand the potential impact of different variables on their projects or decisions. The software provides a user-friendly interface and integration with tools like Microsoft Excel. It allows users to define uncertain variables, create distributions, and perform simulations to gain insights into the likelihood of different outcomes. However, running complex simulations in @ RISK can be computationally intensive and time-consuming. @RISK can be integrated with Microsoft Excel, but it may not seamlessly integrate with other software tools or platforms.

2.6. Research Gaps

Based on the findings of the literature review, the major shortcomings in existing stability rating and hazard classification norms can be summarized as follows:

- Most of the analyses are qualitative. The quantifiable rating was designed only for small-scale and site-specific dump slope structures. The quantification of hazard was also missing.
- Stability state classification was done only through FoS.
- The FoS and PoF were utilized for the stability and hazard classification, but the effect of change in various stability governing parameters on these outcomes has not been quantified.
- The hazard quantification was based on the single bench or small-scale dump slope with an assumed probability distribution function of the random variables.

2.7. Summary

This chapter covers all literature related to the dump slope stability governing parameters and stability state classification with associated hazards. It was found that many factors influence the stability of the dump slope structure, and they have been broadly classified into two categories internal and external factors. The instability of the dump slope structure occurs due to the coupling of external and internal factors. The stability state classification of the dump slope is achieved through stability rating and hazard classification, FoS, and PoF.

In stability rating and hazard classification, ratings were assigned to each stability governing parameter, and the summation of the rating of each parameter provided the stability state of the dump slope structure. Hazard was assigned based on the different ranges of total ratings. In FoS based classification, assumptions were made about the shear strength, type of analysis (static and seismic), and life of dump slope. The FoS was suggested for the assumed associated hazard with due consideration of assumptions made. In probabilistic related classification, the hazard was quantified using PoF. The tolerable PoF was provided for the different stability acceptance criteria based on FoS.

The existing stability state classification and acceptance criteria had some limitations that were also chronicled in this chapter. Therefore, the current stability state analysis system requires up gradation to improve it.