

# A Stability Classification System for the Dragline Dump Slope

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### 5.1 General

The main issue facing mining engineers is ensuring the stability of the dragline dump, as there have been numerous instances of unstable dump slopes in opencast mines, which have resulted in the loss of personnel and equipment as well as a temporary halt in production (Speck et al., 1993; Kasmer et al., 2006; Singh et al., 2014). As a result, in order to guarantee the security and efficient operation of the mines, an acceptable dump slope profile must be designed. In order to create robust and secure dragline dump profiles, it is important to develop a tool or a system that can be used to identify the vulnerable profiles. Slope stability analysis is crucial in order to prevent the possibility of dump slope failure. It requires a thorough grasp of the factors that control how dump slopes behave. For a geotechnical model used to determine the stability of the dump slope, the factor of safety (FOS) is an index of stability (Manoucherian et al., 2014).

Numerous studies have been conducted to create methods for the analysis and assessment of FOS. The slope stability problems are typically solved using the limit equilibrium method (LEM), despite the fact that it has several assumptions and restrictions (Fellenius, 1936; Morgenstern and Price, 1965; Spencer, 1967; Janbu, 1973; Griffiths and Lane, 1999). Finite element method (FEM) has emerged as one of the efficient ways for accurate slope stability analysis, and numerical simulations are superior at handling the complicated and practical slope stability problems (Rai et al., 2012; Gupta et al., 2014;

Kainthola et al., 2011; Griffiths and Lane, 1999; Cai and Ugai, 2003). Researchers have developed other quick stability evaluation methods, in addition to the ones already stated, to determine the stability of rock or dump slopes, including stability charts, statistical approaches, and categorization methods. The slopes' stability can be quickly estimated using stability charts (Ray et al., 2019; Bharati et al., 2020), while Erzin and Cetin, (2013) and Manouchehrian et al., (2014) both employed statistical approaches to determine the slopes' FOS. Numerous studies have been conducted in order to classify rock slopes, including Romana et al. slope mass rating (SMR), which is based on rock mass rating (RMR), Robertson's slope rock mass rating (SRMR), and Chen's Chinese slope mass rating (CSMR). Very few research has been conducted to create a classification system for the stability of dump slopes, despite the fact that the majority of the effort is devoted to naturally occurring soil or rock slopes. A design guideline for mine waste dump and stockpile design was put forth by Hawley and Cunning, (2017). In order to anticipate the safety factor of a slope as a function of the slope geometry and the soil factor of the soil slope, Kostic et al., (2016) developed an analytical model. The identification and testing of several factors required for the stability study of the dragline dump is a labour-intensive and time-consuming operation that also adds significantly to the overall project cost. Therefore, a classification system has been worked on to aid in the quick and simple identification of vulnerable profiles. The results of numerical simulations were used to develop this classification system, and on the basis of these results, sensitivity analysis for the geometrical and strength parameters was carried out using the two-factor interaction method, and sensitivity indices were calculated for the corresponding parameters. The rating levels for a given parameter are assigned using the sensitivity index. Dragline dump has also been categorised as being very safe, safe, vulnerable, unstable, and highly unstable based on its overall rating. The classification system will be

useful for detecting the stability state as well as for figuring out the best geometrical conditions for creating a secure dragline dump profile.

## **5.2 Dragline Dump**

Draglines are used to side-cast the OB material above the coal seam once the opencast mines have first been established with the aid of a shovel-dumper combination initially. The horizontal tandem technique is typically used, in which two dragline machines work side by side, one digging key cut by chopping down the highwall and the other strip cut by side-casting the OB material. The dragline cut's total width is between 70 and 80 meters, and its depth is between 30 and 40 meters. Figure 5.1 (a) and (b) show schematic diagrams of the horizontal tandem method in cross-sectional and plan views, with both dragline machines set up on the same bench. A key cut is dug toward the highwall side using the leading dragline (Le D/L, no.1). Then, as depicted in Figure 5.1, it excavates the first cut next to the key cut (a). The leading dragline then repositioned itself to key cut for the following cycle, repeating the sequence after completing the two cuts. The second dragline, also known as the lagging dragline (La D/L, no. 2), is set up at least 200 meters behind the leading dragline and is positioned on the extended spoil bench that the leading dragline has dumped. This allows the lagging dragline to side cast OB material farther away. As depicted in Figure 5.1(a), the lagging dragline excavates the first dig next to the first cut of the stripping bench and re-handles the loose OB material to completely uncover the coal seam (Rai et al., 2011). Figure 5.2 displays a representation of a single dragline dump with the geometrical characteristics noted and a list of every geometrical parameter that is used in the simulation:

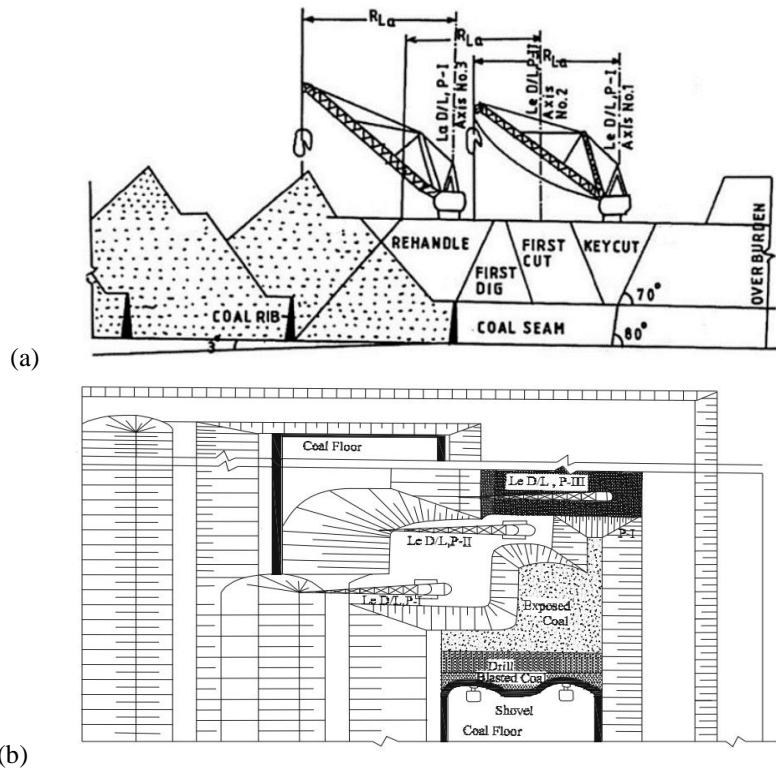


Figure 5. 1 Draglines working in horizontal tandem method. (a) Section view. (b) Plan view

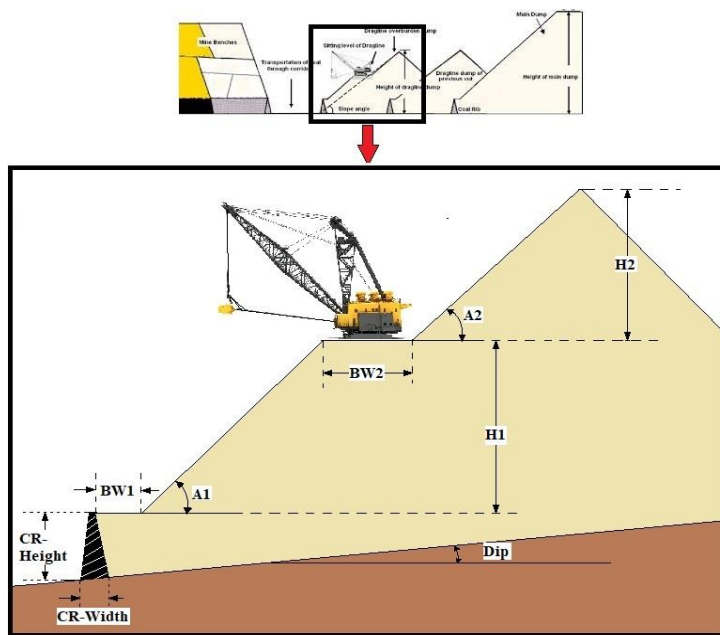


Figure 5. 2 Geometrical parameters of the dragline dumps

## 5.3 Methodology

### 5.3.1. Geotechnical properties of OB material

Samples are taken from each of the four mines of NCL, as was previously noted, in order to reveal the geotechnical characteristics of waste material. The collected samples are dried in an oven, and the geotechnical tests are carried out in accordance with the relevant ASTM laboratory testing standards. To examine the grain size distribution, compaction, and shear strength of the OB material, three tests are carried out: sieve analysis, proctor compaction, and tri-axial test.

#### 5.3.1.1. Sieve Analysis

The dragline dump samples are subjected to sieve examination in accordance with ASTM standard practice (ASTM-C 13606 2006). A 500g oven-dried sample is taken in a mechanical sieve shaker in accordance with the process. The percentage of particles has ranged from 1 to 5 percent, whereas the percentage of medium and fine size sand ranges from 32 to 53 percent and 28 to 43 percent, respectively. Figure 5.3 displays the size distribution graph for the four mines.

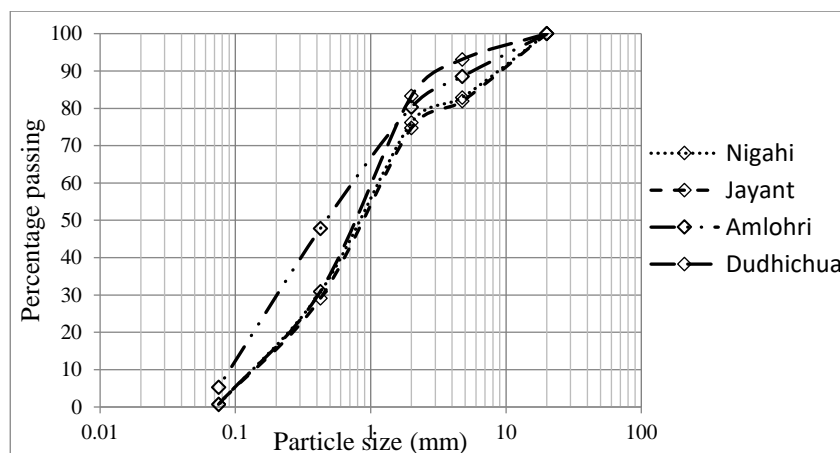


Figure 5. 3 Grain size distribution of the four mines

### 5.3.1.2. Proctor Compaction

The maximum density of soil occurs at a particular water content. Maximum Dry Density (MDD) is the name given to this density, and Optimum Moisture Content (OMC) is the name given to the particular water content. To determine the MDD and OMC of the dragline dump material, a modified proctor compaction test is carried out (ASTM (2007) ASTM D698-07). Dragline dump samples from the four mines were subjected to a proctor compaction test, the results of which are displayed in Figure 5.4 and given in Table 5.1. Table 5.1's values indicate that the OMC ranges from 7.8 to 9.7 percent and the MDD ranges from 1.98 to 2.14 g/cc.

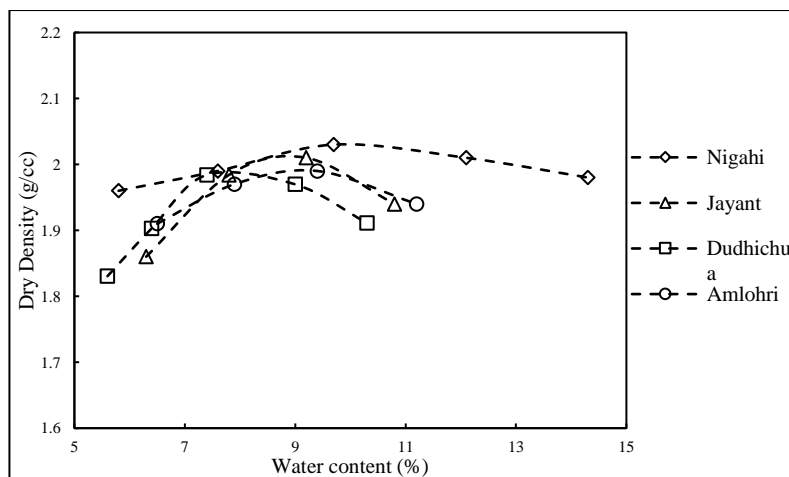


Figure 5. 4 Proctor compaction curves of dump material from the four mine sites

### 5.3.1.3. Tri-axial test

Shear strength criteria are crucial in assessing the stability of dump slopes. In order to determine the shear strength property of the dump material, the Unconsolidated Undrained triaxial test (ASTM (2003) D2850-03) is utilized, and the tri-axial samples are

prepared at the appropriate MDD of the mines. Findings from the triaxial test show that cohesion values range from 28 to 56 kPa and that friction angles range from 23 to 31°. The strength parameters that were established for each sample are listed in Table 5.1.

**Table 5. 1** Shear strength and compaction test results

S. No.	Mine	Cohesion (kPa)	Friction Angle (°)	OMC (%)	MDD (g/cm <sup>3</sup> )
1.	Amlohri	28	31	9.2	1.99
2.	Nigahi	45	26	9.7	2.14
3.	Jayant	53	28	8.8	2.01
4.	Dudhichua	56	23	7.8	1.98

### 5.3.2. Finite Element Modelling of Dragline Dump

In this study, complex dragline dumps geometrical features such as dragline dump slope angle, the influence of coal rib, hydrological circumstances, and the effect of foundation are simulated using FEM-based software. It can model progressive failures and calculate deformations at various sites without making any prior assumptions about the orientation and shape of crucial slip surfaces. The factor of safety (FOS) of the dragline dump model is calculated using the shear strength reduction (SSR) method (Bowman and Gilchrist, 1978; Sharma et al., 2011; Chakraborty and Goswami, 2016). The FOS value of the dragline dump model is given by SSR as a factor F, which is a ratio of the dump's real shear strength to its new shear strength at the point where the slope of the dump is barely at a stable equilibrium (Duncan 1996). The dragline dump model is simulated using this method in a series of increasing  $F^{\text{trial}}$ , and the actual shear strength properties—friction angle ( $\phi$ ) and cohesion ( $c$ )—decrease with each trial as shown in the equation below:

$$c^{\text{trial}} = \frac{1}{F^{\text{trial}}} c$$

$$\varphi^{\text{trial}} = \tan^{-1} \left[ \frac{1}{F^{\text{trial}}} \tan \varphi \right]$$

Where  $c^{\text{trial}}$  and  $\varphi^{\text{trial}}$  are the reduced value of cohesion and friction angle on each trial, respectively, the  $F^{\text{trial}}$  at which the dragline dump model fails are the FOS of the model (Mbarka et al., 2010).

Using Rocscience's RS2 V9.0 FEM-based software, numerical simulations are performed to analyse the stability of the dragline dump. It includes an SSR method that is used to calculate the FOS of the dump slope model. It also aids in figuring out the slope's deformation parameters. A number of previous studies studying slope stability have also used the FEM analysis (Griffiths and Lane 1999, Dawson et al. 1999).

The dragline dump models have uniform type meshing and triangular components with six nodes. Furthermore, as recommended by (Kanungo, 2013), boundaries are fixed in the dragline dump model's lateral sides and bottom side in both the x and y directions. Because there was only a small change in FOS below the chosen element size, the mesh element size is chosen based on optimization technique and is taken as 1m for the dump and 0.5m for the coal-rib.

### **5.3.3. Sensitivity Analysis**

The main benefit of the sensitivity analysis is that it helps to determine how much the input parameters affect the stability of the dump slope. Two general categories are used to classify these input parameters: (1). Geometrical parameters that include parameters like coal rib height and thickness. (2). Cohesion and angle of friction of the dump material are strength parameters. Sensitivity analysis allows for the identification of the more

important/critical parameters, which is useful for constructing the required dragline dump profiles (Rai et al., 2012; Siddque and Pradhan, 2018).

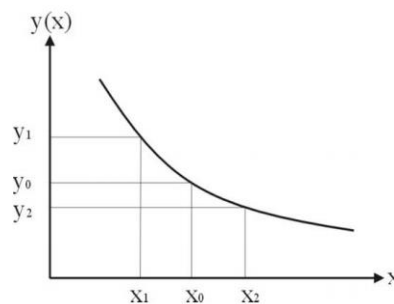
The sensitivity of a parameter, while all other parameters are held constant, is the ratio of the change in output to the relative change in the input parameter (Hamby, 1994; Lenhart et al., 2002; Saltelli et al., 2006; Choo et al., 2019). Lenhart, (2002) said that a dimensionless index known as the "sensitivity index" is used to indicate the sensitivity of input parameters (I). The following formula is used to determine the sensitivity index:

$$I = \frac{(y_2 - y_1)/y_0}{2\Delta x/x_0} \quad \dots (1)$$

Here,  $2\Delta x = (x_2 - x_1)$

$$I = \frac{(y_2 - y_1)/y_0}{(x_2 - x_1)/x_0} \quad \dots (2)$$

Mathematically, x stands for the input variables, also known as the slope parameters, and y for the output variable, also known as the FOS. Whereas,  $y_0$  is the result obtained for a parameter x's initial value of  $x_0$  (Figure 5.5). If  $\pm\Delta x$  is added to the initial input value, then  $x_1 = x_0 + \Delta x$  and  $x_2 = x_0 - \Delta x$  is produced, with  $y_1$  and  $y_2$  being the corresponding output values. The sensitivity index's sign indicates whether or not the relationship between the input and output variables is codirectional (that is, if the output increases as the input parameter increases or vice versa).



**Figure 5. 5** Schematic of a relation between output (y) and input (x) parameters

## 5.4 Result and discussion

### 5.4.1. Sensitivity Analysis of Geometrical Parameters

For the sensitivity analysis, nine dragline dump geometrical factors are taken into account, as illustrated in Figure 5.2. As part of Kostic et al. (2016) two-factor interaction method, the sensitivity analysis of the slope angle with modifying bench height or vice versa for a particular bench is carried out. The two-factor interaction method takes into account the impact on the response by altering two parameters at once; this approach is used in the study because the combined impact of two parameters contributes differently to the FOS than the individual effects do, and because it is useful in solving practical issues (Kostic et al. 2016). Similar to this, the sensitivity tests for CR-Height and BW1 are conducted, and the tests for the remaining geometrical parameters, such as CR-Width, Dip, and BW2, are run separately while maintaining the values of the other parameters constant. Table 5.2 lists the base values of nine geometrical parameters used to conduct the sensitivity analysis, and Table 5.3 displays the geotechnical characteristics of the dump material. Table 5.4 contains a list of all the parameters' derived sensitivity indices.

**Table 5. 2** Base values of geometrical parameters used in numerical simulation

S. No.	Geometrical Parameter	Base Value (Unit)
1	A <sub>1</sub>	38°
2	H <sub>1</sub>	36m
3	A <sub>2</sub>	38°
4	H <sub>2</sub>	24m
5	CR-Height	15m
6	CR-Width	7m
7	BW <sub>1</sub>	10m
8	BW <sub>2</sub>	15m
9	Dip	4°

**Table 5. 3** Geotechnical properties of the dump material used in numerical simulation.

Material	Geotechnical Parameter	Value (Unit)
Dragline Dump	Cohesion	45.5 kPa
	Friction Angle	27 °
	Unit Weight	19.91 KN/m <sup>3</sup>

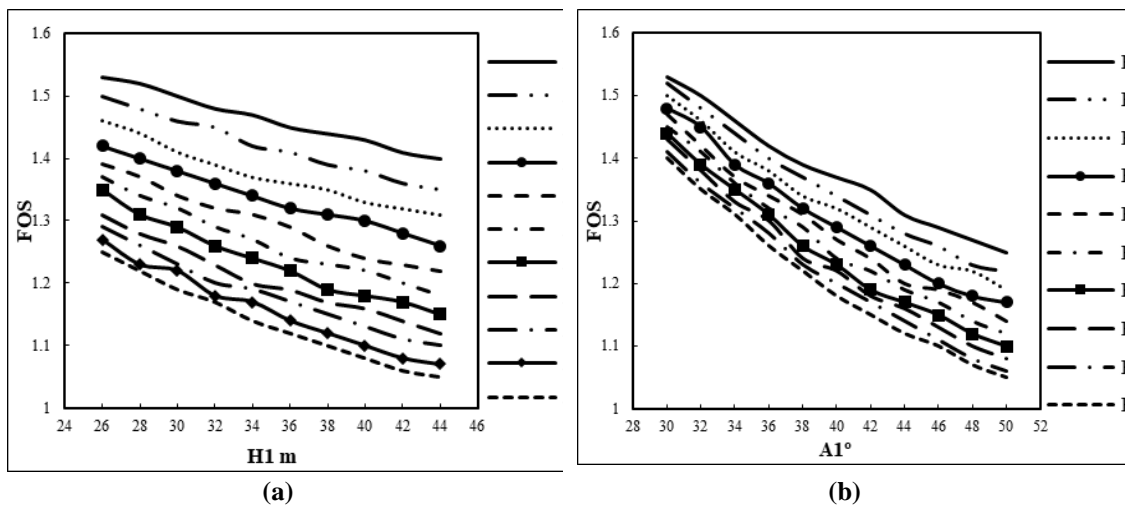
**Table 5. 4** Sensitivity index and rating assigned for all the geometrical and strength parameters

S. No.	Parameter	Sensitivity Index (I)	Positive Value of I (II)	Percentage = $\frac{ I }{2.55} \times 100$	Rating Assigned
1.	A1	-0.52	0.52	20.39	20
2.	H1	-0.28	0.28	10.98	11
3.	A2	-0.17	0.17	6.67	6
4.	H2	-0.14	0.14	5.49	6
5.	BW1	0.07	0.07	2.75	3
6.	BW2	0.12	0.12	4.71	5
7.	CR-Height	-0.17	0.17	6.67	7
8.	CR-Width	0.09	0.09	3.53	3
9.	Dip	-0.03	0.03	1.18	1
10.	Cohesion	0.24	0.24	9.41	10
11.	Friction Angle	0.72	0.72	28.24	28
Total			2.55	100.00	100

#### 5.4.1.1. A<sub>1</sub> and H<sub>1</sub>

The dragline bench's slope angle and height below the dragline sitting level are A<sub>1</sub> and H<sub>1</sub>, respectively. Compared to other geometrical factors, these two geometrical parameters are extremely dependent on one another in order to guarantee the stability of the dragline dump. For the analysis, A<sub>1</sub>'s range is kept between 30 and 50 degrees, and H<sub>1</sub>'s range is 26 to 44 meters for each value of A<sub>1</sub> and their intervals are 2 degrees and 2 meters, respectively. As a result, different combinations of A<sub>1</sub> and H<sub>1</sub> are used to create dragline dump slope models, while the rest of the parameters are left at their base value. The graph between the two parameters and their corresponding FOS is displayed in Figure 5.6 (a) and (b) following the simulation of all 110 models. Using Eq. (2), the sensitivity

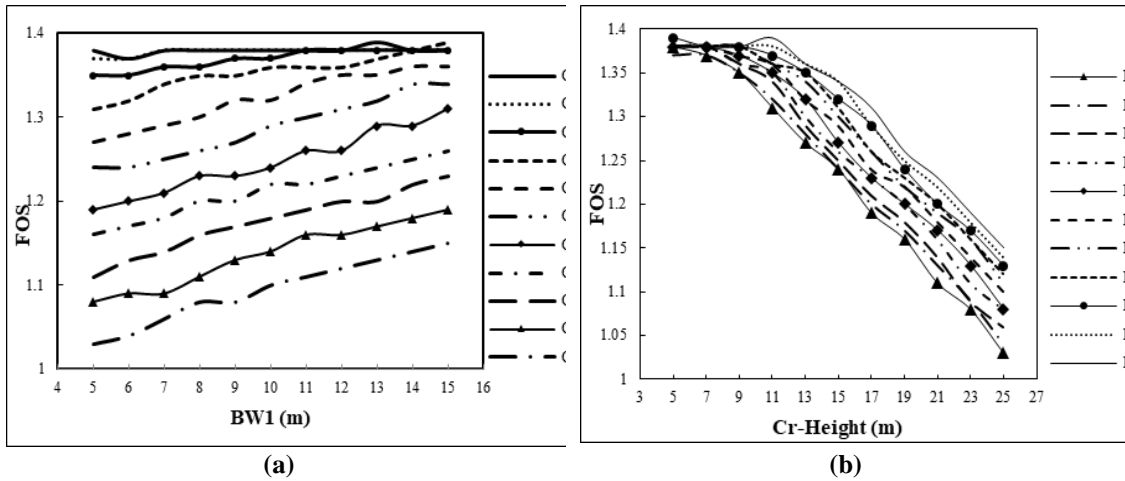
index is determined for A1 and H1 and is 0.52 and 0.28, respectively. This index measures how sensitive one parameter is to changes in the values of the other parameter.



**Figure 5. 6** Effect of H1 and A1 on FOS of the dragline dump (a) H1 Vs FOS and (b) A1 Vs FOS

#### 5.4.1.2. BW1 and Cr-Height

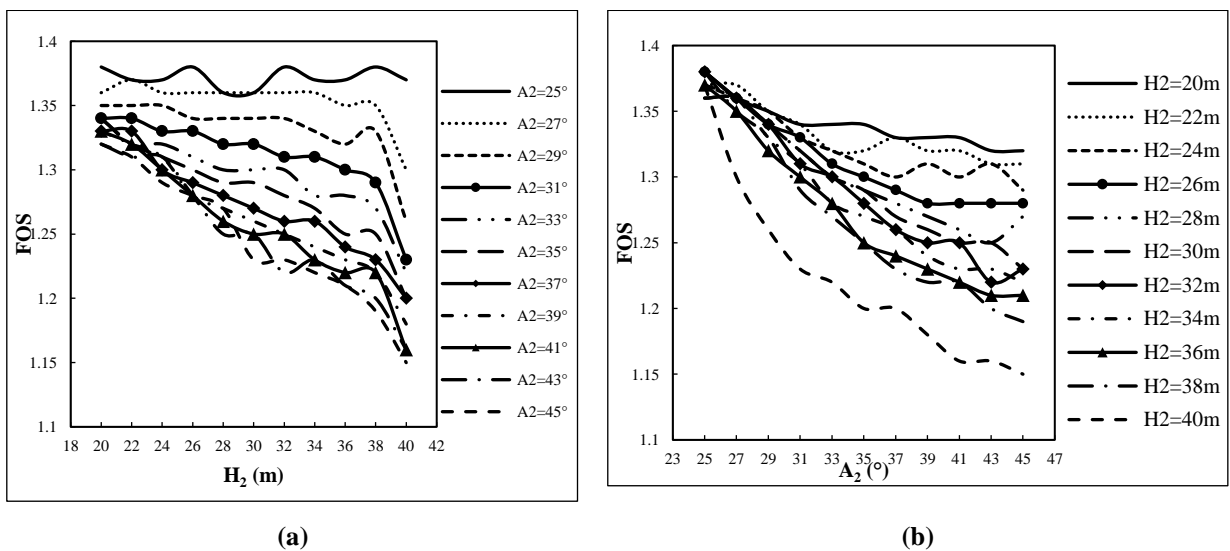
BW1 is the berm width at the coal-rib roof level, and CR-Height is the coal-rib height as well as the coal seam thickness. As seen in Figure 3, these two parameters are close to one another and have contributed to the stability of the dragline dump. As a result, these two factors are combined to perform the sensitivity analysis. The models are made with a variable range of BW1 from 5 to 15 meters and CR-Height from 5 to 25 meters, respectively, with intervals of 1 and 2 meters. The change in FOS is plotted with changing BW1 and CR-Height parameters for a total of 121 models, as shown in Figure 5.7 (a) and (b). BW1 and CR-Height have average sensitivity indices of 0.07 and 0.17, respectively.



**Figure 5.7** Effect of BW1 and Cr-Height on FOS of the dragline dump (a) BW1 Vs FOS and (b) Cr-Height Vs FOS

### 5.4.1.3. H2 and A2

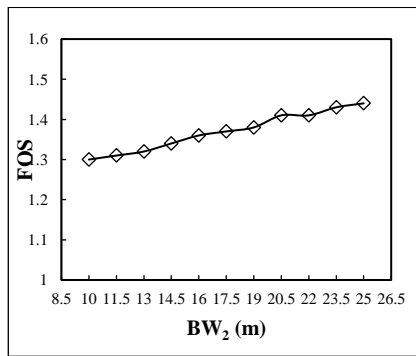
As indicated in Figure 3, H2 is the height of the dump at dragline sitting level and A2 is the slope angle. These two factors are combined to do a sensitivity study, and the range of H2 is changed from 20 to 40 meters at intervals of 2 meters. A2 is simultaneously changed from 25° to 45° at 2° intervals. As a result, 121 models in total are simulated, and the graph between FOS and the two parameters is plotted, as seen in Figure 5.8 (a) and (b). H2 and A2 have average estimated sensitivity indices of 0.14 and 0.17, respectively.



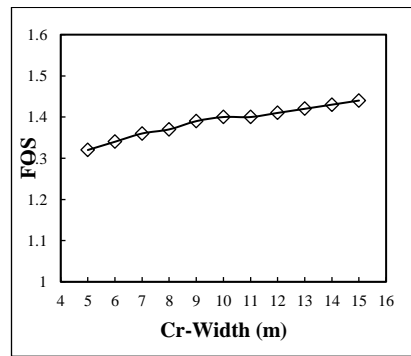
**Figure 5. 8** Effect of H2 and A2 on FOS of the dragline dump (a) H2 Vs FOS and (b) A2 Vs FOS

#### 5.4.1.4. BW<sub>2</sub>, CR-Width, and Dip

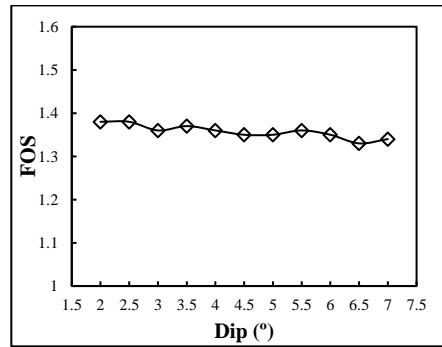
Each of the three parameters is subjected to a sensitivity analysis while the rest of the parameters remain constant. BW<sub>2</sub>, which ranges from 10 to 25 meters at 1.5-meter intervals, refers to the berm width at the dragline sitting level. The coal rib that supports the dump slope has a bottom width called CR-Width that ranges from 5 to 15 meters at 1-meter intervals. Dip, which runs from 2° to 7° at an interval of 0.5°, depicts the dipping of the strata at which the dump material is put. There are a total of 11 models created for the three factors, and the simulation results are displayed in Figure 5.9 (a), (b), and (c), which illustrate how they affect the FOS. The parameters BW<sub>2</sub>, CR-Width, and Dip have sensitivity indices of 0.12, 0.09, and 0.03, respectively. As a result, Dip has the lowest sensitivity index value of any parameter and has essentially little impact on the stability of the dragline dump within the limits of its prescribed range.



(a)



(b)

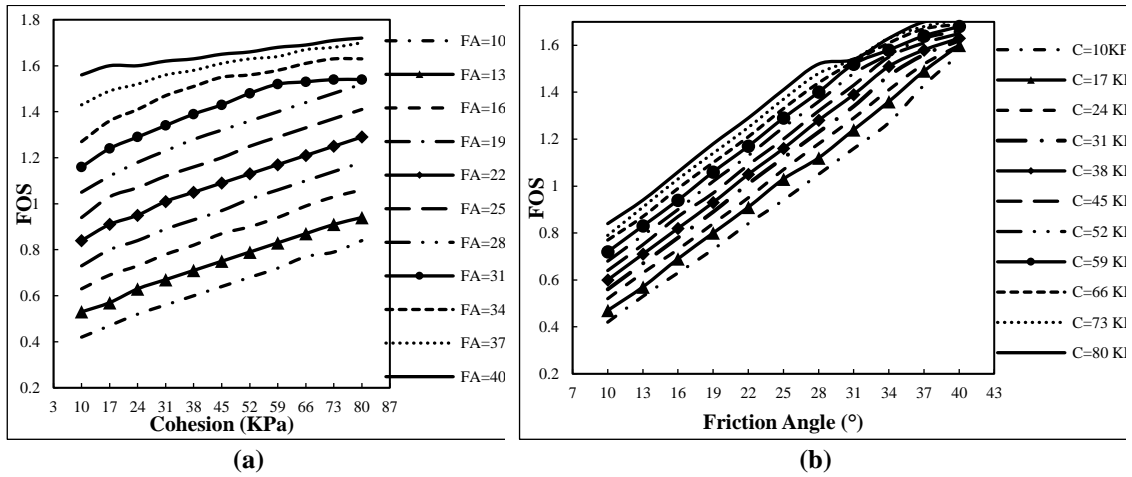


(c)

**Figure 5. 9** Effect of BW2, Cr-BW and Dip on FOS of the dragline dump (a) BW2 Vs FOS and (b) Cr-BW Vs FOS (c) Dip Vs FOS

#### 5.4.2. Sensitivity Analysis of Strength parameters

The most important factors in determining the stability of the dragline dump slope are those related to shear strength. It is often expressed by two elements, namely the friction angle and the cohesion. Cohesion is varied from 10-80 kPa with an interval of 7 kPa, and for each cohesion value, friction angle is varied from 10° to 40° at an interval of 3°. This combination of parameters is subjected to sensitivity analysis. The remaining parameters are maintained at their current values except from these two variables. As a result, 121 models in total are created, and following their simulation, Figure 5.10 (a) and (b) exhibit the behaviour of the two parameters with the FOS. Cohesion and friction angle's computed average sensitivity indices are 0.24 and 0.72, respectively. The friction angle is found to have the greatest sensitivity index out of all the parameters taken into consideration. As a result, it determines the stability of the dragline dump slope and is the most sensitive and important parameter.



**Figure 5. 10** Effect of cohesion and friction angle on FOS of the dragline dump (a) Cohesion Vs FOS and (b) Friction angle Vs FOS

### 5.3. Rating Assigned and its Distribution

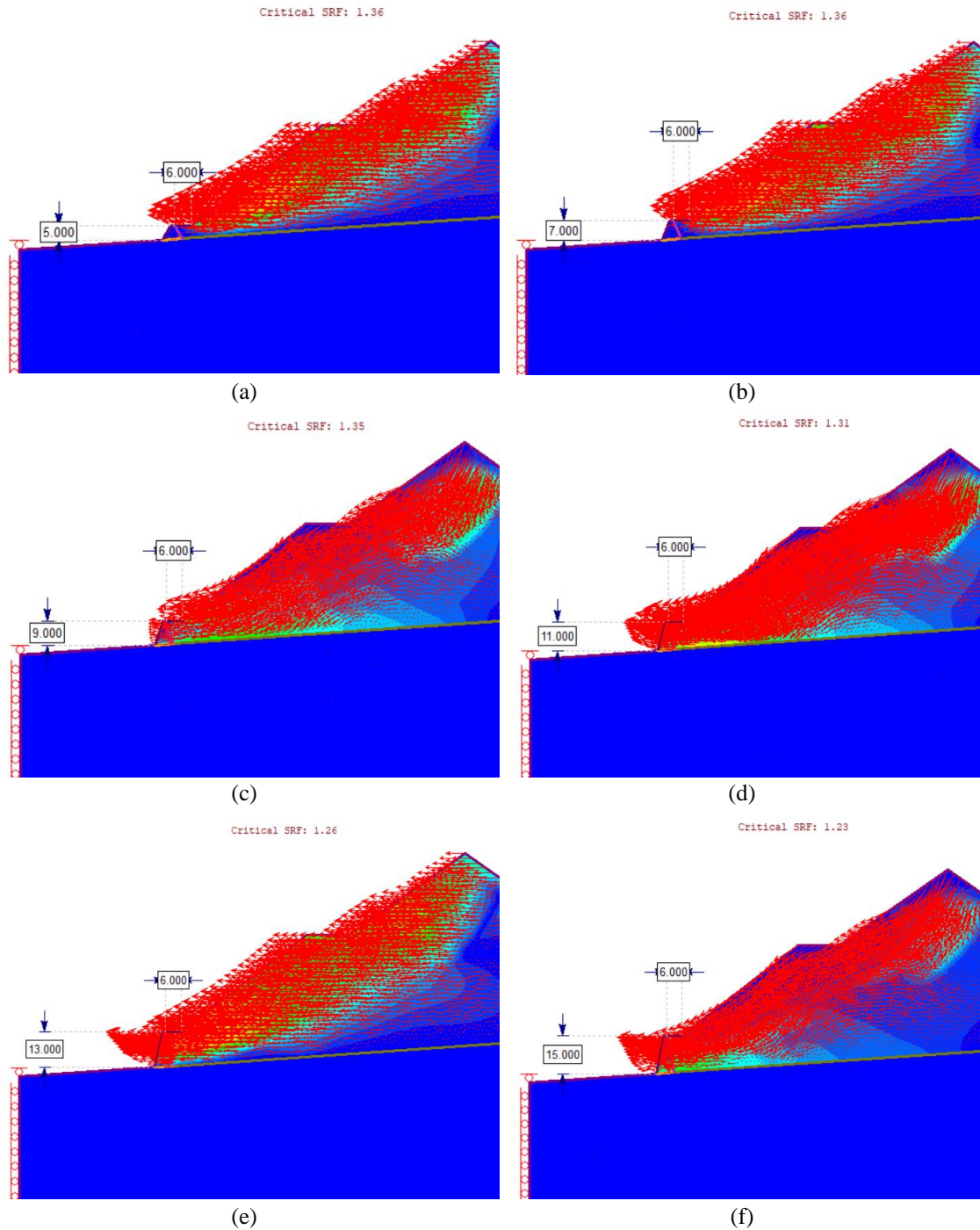
The distribution of each parameter rating value within its stated range follows the next stage. By adopting the two-factor interaction technique, the sensitivity index of each parameter has taken into account the interdependency of their neighbouring parameters. In order to rate the parameters, the sensitivity index is employed to reflect the cumulative effect on the stability of dragline dumps. Additionally, the overall impact on stability is determined by adding together the absolute values of each parameter's sensitivity index. The total sum of the sensitivity index is then used to calculate the percentage of each parameter's influence on stability, as shown in Table 5.4. Following that, the rating is distributed as follows within the specified range of each parameter:

#### 5.3.1. Geometrical Parameters

Geometrical parameter  $A_1$  shows a linear relationship with FOS for different values of  $H_1$ , and the latter shows a similar relation with FOS for different values of  $A_1$ , as shown in Figure 5.6. Thus, the rating is distributed uniformly within the defined range of both  $A_1$  and  $H_1$ . As shown in Table 5.4,  $A_1$  and  $H_1$  are assigned with rating values of 20 and

11, respectively.  $A_1$  ranges from  $30^\circ$  to  $50^\circ$ , and  $4^\circ$  interval is taken to uniformly distribute the rating as shown in Table 5.5. The maximum rating of 20 is assigned for  $A_1 < 30^\circ$ , while the minimum rating of 0 is assigned for  $A_1 > 50^\circ$ . The parameter  $H_1$  has a range of 26 to 44 meters and 4 meters interval is taken for uniform distribution of rating, as shown in Table 5.5. In this case,  $H_1 < 26$  meters and  $H_1 > 44$  meters are assigned the maximum (11) and minimum (0) rating, respectively.

$BW_1$  and CR-Height show a linear relation with FOS except for the lower values of the CR-Height, as shown in Figure 5.7. CR-Height for the values 5,7 and 9 meters is showing almost constant FOS for different values of  $BW_1$ , which demonstrates that there is almost negligible impact on the stability of slope while going below the 9-10 meters of CR-Height. A simulation result of some of the models showing deformation vector of maximum shear strain is depicted in Figure 5.11, which illustrates that in the case of CR-Height less than 9 meters, deformation vectors are either not passing through the coal-rib or if passing, the density is significantly less in comparison to CR-Height above 9-10 meters. Consequently, there is negligible change is found in FOS due to the variation of  $BW_1$  for CR-Height less than 9 meters. However, FOS decreases drastically with increasing CR-Height above 9-10 meters, as seen in Figure 5.7 due to an increase in density and magnitude of the deformation vector of maximum shear strain (Figure 5.11). Therefore, the rating distribution is not uniform in the case of CR-Height. The CR-Height has a range of 5-25 meters, and the total rating assigned to it is 7. The maximum rating of 7 is assigned for 5-10 meters, which is showing constant FOS values, and the rest of the range (11-25 meter) is distributed uniformly at an interval of 3 meters with 1 rating interval. However, the rating is distributed uniformly for  $BW_1$ , which ranges from 5-15 meters, and a 0.5 rating is added at every interval of 2.5 meters.



**Figure 5.11** Simulation results with maximum shear strain with deformation vector for the models with (a) CR-Height = 5m, (b) CR-Height = 7m, (c) CR-Height = 9m, (d) CR-Height = 11m, (e) CR-Height = 13m and (f) CR-Height = 15m

In the case of  $A_2$  and  $H_2$ , both shows linear relation with FOS. It is clearly observed that with the increase in both the parameters, FOS is decreasing. However, for the lower values of  $H_2$ , there is a marginal decrease in FOS with the increase in values of  $A_2$ . Whereas there is a negligible decrease in FOS with the increase in  $H_2$  for lower values of

$A_2$ . This has happened because the sensitivity index of  $H_2$  is lower than  $A_2$ , as it is also evident from the stability of lower angle slopes of different slope heights at the sites. The range of  $A_2$  for rating distribution is  $25^\circ$  to  $45^\circ$  at an interval of  $5^\circ$ . The maximum rating of 6 and a minimum rating of 0 has been assigned to  $A_2 < 25^\circ$  and  $A_2 > 45^\circ$ , respectively. The parameter  $H_2$  is varying from 20 - 40 meters, and the rating is distributed uniformly from 0 to 6 with a range of 4 meters intervals.

Parameter  $BW_2$ , CR-Width, and Dip show an almost constant relationship with the FOS; therefore, the rating is distributed within the defined range with a fine increment for each interval for all three parameters. These parameters have the least sensitivity index; hence they have the least rating allocated. The rating distribution of these parameters is shown in Table 5.5.

### **5.3.2. Strength Parameters**

Cohesion and Friction angle are the two strength parameters whose sensitivity index is calculated and based on that rating is assigned. These two parameters are analysed in combination, and their result shows almost a linear variation with the FOS (Figure 5.10 (a) and (b)). Thus, the rating is distributed uniformly within their defined range. The range of cohesion is 10-80 kPa, and 1 rating value is added for an interval of 10 kPa each. Maximum rating value of 10 and minimum rating value of 2 is assigned to cohesion  $>80$  kPa and 1-10 kPa, respectively. The friction angle is varying from  $10^\circ$ - $40^\circ$ , and the rating of 4 is incremented for each interval of  $5^\circ$  friction angle. The maximum rating value of 28 and the minimum rating value of 0 are assigned to friction angle  $> 40^\circ$  and  $< 10^\circ$ , respectively, as shown in Table. 5.6.

**Table 5. 5** Rating distribution within the defined range of geometrical parameters

<b>A<sub>1</sub></b> (°)	< 30°	30°-34°	34°-38°	38°-42°	42°-46°	46°-50°	≥ 50°
Rating	20	18	16	12	8	4	0
<b>H<sub>1</sub></b> (m)	< 26	26-30	30-34	34-38	38-42	42-44	≥ 44
Rating	11	9	7	5	3	1	0
<b>A<sub>2</sub></b> (°)	< 25°	25°-30°	30°-35°	35°-40°	40°-45°	≥ 45°	
Rating	6	5	4	3	2	0	
<b>H<sub>2</sub></b> (m)	< 20	20-24	24-28	28-32	32-36	36-40	≥ 40
Rating	6	5	4	3	2	1	0
<b>BW<sub>1</sub></b> (m)	< 5	5-7.5	7.5-10	10-12.5	12.5-15	≥15	
Rating	0	1	1.5	2	2.5	3	
<b>BW<sub>2</sub></b> (m)	< 10	10-13	13-16	16-19	19-22	22-25	
Rating	0	1	2	3	4	5	
<b>Cr-Height</b> (m)	5-10	10-13	13-16	16-19	19-22	22-25	
Rating	7	5	4	3	2	1	
<b>CR-Width</b> (m)	< 5	5-7.5	7.5-10	10-12.5	12.5-15		
Rating	0	1	2	3	4		
<b>Dip</b> (°)	< 2°	2°-4°	4°-6°	6°-7°			
Rating	1	0.75	0.5	0			

**Table 5. 6** Rating distribution for the strength parameters of dump material

<b>Cohesion (C)</b> (kPa)	1-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	>80
Rating	2	3	4	5	6	7	8	9	10
<b>Friction Angle (f)</b> (°)	< 10°	10°-15°	15°-20°	20°-25°	25°-30°	30°-35°	35°-40°	>40°	
Rating	0	4	8	12	16	20	24	28	

#### 5.4. Dump Slope Classification

To classify the stability of the dragline dump slope, the overall rating must be distributed in accordance with the individual rating of each geometrical and strength parameter. The total rating obtained from the addition of rating of all the individual parameters is 100. It has to be divided into various classes ranging from highly unstable to very safe states for identification of stability. In this regard, the most important factor is the identification of

the range of rating for the unstable slopes. Therefore, the rating of the two most important parameters based on sensitivity analysis is considered to cover the instability range. The friction angle and the geometrical parameter A1 are the two most crucial parameters with maximum individual ratings of 28 and 20, respectively. They are combinedly used to classify the unstable state of the dragline dump. Thus, a rating less than 50 implies an unstable condition. The rest of the stability states are assigned accordingly. The rating 0-30 is considered as a highly-unstable state and 31-50 as an unstable state for the dragline dump slope. Apart from the unstable state, the rest of the rating is divided as vulnerable, safe, and very-safe, as shown in Table 5.7. The vulnerable state, which is a transition state between unstable and safe, needs to be taken good care of, lies within 51 to 60. However, the safe and very-safe state has been distributed within the range 61-80 and 81-100, respectively.

**Table 5. 7** Overall stability classification of the dragline dump

Stability	Highly-unstable	Unstable	Vulnerable	Safe	Very-safe
Rating	≤ 30	31-50	51-60	61-80	81-100

## 5.5. Validation

The developed classification system is validated by the previous research works, and it has shown similar results. The first three data Jayant 1, Jayant 2, and Jayant 3 listed in Table 5.8 are taken from Sharma and Roy, (2015), wherein Jayant 1 and Jayant 2 dragline dump profiles are proposed by the authors with FOS 1.11, and Jayant 3 is a case of dragline dump failure and the classification system has shown the first two as vulnerable and the Jayant 3 as unstable, as shown in Table 5.8. Similarly, Amlohri 1 and Amlohri 2 are the two dragline dump profiles proposed by Sengupta et al., (2016) holding an

optimum volume of OB material with safety, and both the profiles are vulnerable by the proposed classification system. However, Amlohri 3 to Amlohri 8 are the dragline dump profiles taken from the mine site, and all have shown the safe stability status. The profiles of Nigahi and Dudhichua are analyzed by Roy and Sengupta, (2014), both have shown vulnerable status by the classification system.

**Table 5. 8** Validation results of the classification of dragline dump

<u>Parameters</u> Mines	A1	H1	A2	H2	BW1	BW2	Cr-Height	Cr-Width	Dip	c	$\phi$	Total rating	FOS	Classification System
Jayant 1	45	35	37	32	15	15	18	7	3	52.7	32.0	52.75	1.11	Vulnerable
Jayant 2	45	35	37	41	10	12	9	7	3	52.7	32.0	54.75	1.11	Vulnerable
Jayant 3	50	35	38	32	0	0	18	17	3	52.7	32.0	44	0.94	Unstable
Amlohri 1	40	35	37	30	9	15	15	6.3	3	68.9	29.6	56.25	1.2	Vulnerable
Amlohri 2	40	42	37	30	9	20	15	6.3	3	68.9	29.6	54.25	1.1	Vulnerable
Amlohri 3	40	33	30	12	10.2	18.7	14	10	3	68.9	29.6	65	Working slope profile	Safe
Amlohri 4	37.5	25.5	37.5	30.2	12	15	14	6	3	68.9	29.6	67.5	-do-	Safe
Amlohri 5	34	33.9	33	20.5	13.44	17.93	14	8	3	68.9	29.6	67.5	-do-	Safe
Amlohri 6	37.5	35.5	32	17.5	14.61	18.05	14	7.5	3	68.9	29.6	67	-do-	Safe
Amlohri 7	41	33.2	34.5	25.3	11	15	14	8	3	68.9	29.6	62	-do-	Safe
Amlohri 8	33	33.8	34	21.4	12	18	14	8	3	68.9	29.6	70	-do-	Safe
Nigahi	40	35	38	19	8	15	15	8	3	78.7	28.6	59	1.08	Vulnerable
Dudhichua	41	37	37	28	10	15	20	7.5	3	57.4	34.3	56	1.2	Vulnerable

## 5.6. Summary

The present study proposes a classification system in terms of rating to classify the stability of internal dragline dumps, wherein geometrical and strength parameters are considered for the classification. Initially, the sensitivity analysis is performed by incorporating the two-factor interaction method; after that, the rating is calculated for each parameter, and consequently, the classification system is defined. The stability analysis of individual dragline dump slope is significantly a time-consuming process, whereas the devised classification system is handy in the quick identification of stability of the dragline dumps, and this also helps in designing a stable dragline dump profile. Some of the conclusions are highlighted below:

- According to the sensitivity analysis, friction angle from the strength parameters and  $A_1$  and  $H_1$  from geometrical parameters are the three topmost sensitive among all the parameters with the sensitivity index of 0.72, -0.52, and -0.28, respectively.
- The least significant parameters are Dip,  $BW_1$ , and CR-Width with the sensitivity index -0.03, 0.07 and 0.09, respectively.
- Based on the sensitivity analysis, rating for individual parameters is obtained wherein the friction angle has the maximum rating of 28 and Dip has the minimum rating of 1.
- The sum of the individual rating of the parameters is used to obtain the stability status for the investigated slope, which ranges from highly unstable to very safe.
- The developed classification system will be handy in the quick estimation of the stability of the dump slopes. If the stability status of the dump slope is vulnerable, the slope profile needs to be redesigned. This system helps in the pre-estimation of geometrical parameters to design a safe dragline dump profile for a particular strength parameter and the thickness of coal.

