The Role of Interface Material at the Base of Internal Dumps and Effectiveness of Coal Rib in the Safe Working of Opencast Coal Mines

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ABSTRACT

The challenge to rapidly increasing coal production to meet the ever growing needs of the energy sector in India, has been met by phenomenal increase in coal production from opencast mines. India has reached the forefront of world coal scene, largely due to production from opencast mines which contribute 80% of country's total coal production. But one of the major problems associated with opencast mining is disposal of a large volume of overburden/waste material. Maximum possible waste material has to be accommodated within de-coaled mine due to shortage of space outside mine. Stability of these back-filled dumps, i.e. internal dumps govern the mining cost, safety and environment in the post mining scenario.

Management of opencast coal mines in India applies a new technique of leaving a very small part of coal seam, i.e. termed here as coal rib at the toe of internal dump for improving the stability of dump to some extent. This study attempts to quantify the effect of leaving coal rib and the influence of major geo-technical parameters on the stability of internal dumps.

Keywords: Dump slope stability, waste management , opencast mining, reclamation.

1. INTRODUCTION

In opencast mining rock overburden above coal seam are blasted by explosives and excavated by following two techniques in general to expose coal seam.

- *Overburden rock removal by Shovel-Dumper combination* - The Shovel excavates the rock and dumps back into Dumper. The Dumper moves along the haul road and dumps the waste fragmented rock to the de-

coaled area (the area from where the coal has already been excavated up to floor of Opencast mines) in a suitable place where internal dump mass will not roll back to the mining face.

- *Overburden rock removal by Dragline* - The Dragline excavates the blasted rock and dumps the fragmented rock immediately in the earlier de-coaled area. Dragline can operate only where simultaneous back-filling is possible, i.e. de-coaled area is flat enough to hold back the dump mass against rolling back to the mining face.

The primary objective of this paper is to elucidate, through a fairly extensive numerical evaluation programme, the influence of slope/face angle on its stable height under different geo-technical, geological and hydro-geological parameters for a particular range of factor of safety. The investigation has been carried out for high risk zone and low risk zone which are defined as follows:

- *Low risk zone* - Dump is in such a situation in which failure will lead to no loss of life and moderate damage to property. Factor of safety in this case is taken as 1.15 to 1.20.

- *High risk* zone - Dump is in such a situation in which failure will lead to loss of life and severe damage to property. Factor of safety in this case is taken as 1.3 to 1.35.

In opencast coal mines of India, there is a practice of leaving coal rib at the toe of internal dump for improving the stability by strengthening the dump toe. The coal rib cannot be excavated further in future. This paper also highlights the advantage of leaving coal rib from stability point of view.

2. WASTE DUMP FAILURE MECHANISM

A number of internal waste dump slides were reported from various opencast mines in India. In majority of such opencast mines, there is a practice of leaving coal barrier termed here as coal rib at the toe of internal dump to restrict the movement of dump. Generally, following two types of failure modes were observed from the past failure records (Figs. 1a, b, c) :

- Movement of dump mass above the coal rib without shifting of rib in which case the failure mode is purely circular (Fig. 1a).

- Movement of dump mass with coal rib in which case the failure mode is circular-cum-planar (Fig. 1b).

In absence of coal rib, generally circular-cum-planar failure for dump has been observed (Fig. 1c) and the flow of dump mass is much more than that with coal rib .

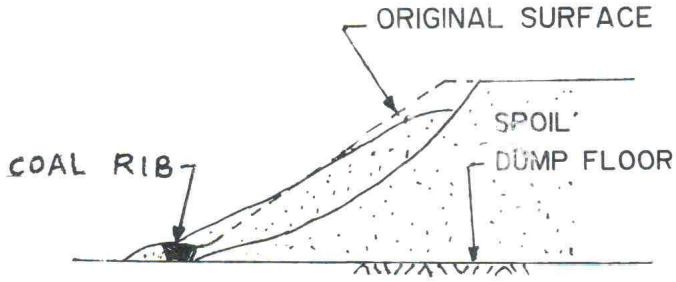


Fig. Ia - CIRCULAR FAILURE WITH NO SHIFTING OF COAL RIB

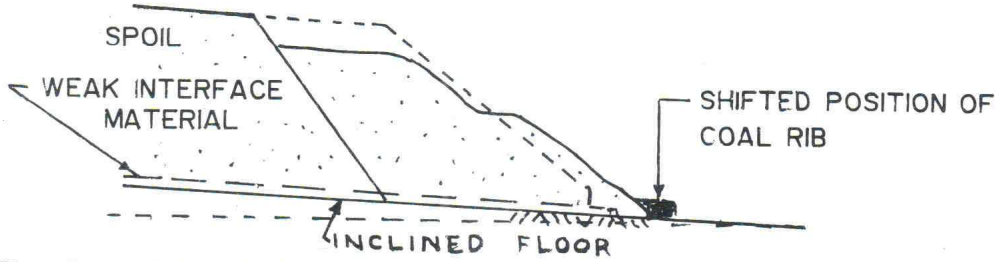


Fig. Ib - CIRCULAR CUM PLANAR FAILURE WITH SHIFTING OF COAL RIB

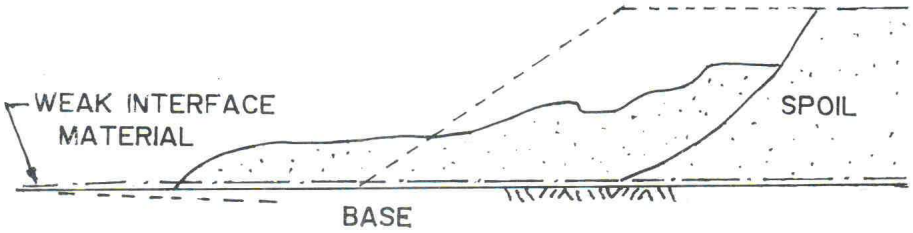


Fig. Ic - CIRCULAR CUM PLANAR FAILURE FOR DUMP WITHOUT COAL RIB

The reason of these failures are given below.

2.1 Circular Mode of Failure

In this case, the low value of shear strength (cohesion and angle of internal friction) of dump material is unable to sustain the excessive height and steep slope of dump. The major controlling parameters, therefore, for such type of failure are as follows:

- Steep height and slope of internal dump
- Angle of internal friction of dump material
- Cohesion of dump material
- Seepage force and upward thrust of water, due to existence of water table above floor of internal dump
- Seismic effect of the mine area

2.2 Circular-cum-Planar Mode of Failure

After the coal is extracted, the waste material is back-filled on the inclined foundation, i.e. de-coaled quarry floor which is hard to medium hard sandstone with cohesion in the range of 1-10 MPa. Inclination of floor of opencast coal mines in Indian condition varies in the range of 2° to 12°. Roof of the de-coaled strata is covered with a mixture of left out crushed coal, crushed rock and water. This slushy mixture covering the roof of the de-coaled area acts as the weak interface material between dump and foundation and termed here as interface material.

The shear strength, particularly angle of internal friction of the interface material, i.e. the mixture of crushed coal, crushed rock and water is generally found to be very low. Due to very low value of shear strength of interface material lying over an inclined plane , it is observed that the probable failure surface of an internal dump standing over a weak interface material is a combination of circular (through dump material) and planar failure (through interface material) [Cambell, 1986]. The major controlling parameters for such type of failure are as follows:

- Steep height and slope of internal dump
- Angle of internal friction of dump material
- Cohesion of dump material
- Seepage force and upward thrust of water, due to existence of water table above floor of internal dump
- Inclination of dump floor
- Angle of internal friction of interface material
- Cohesion of interface material
- Seismic effect of the mine area

It is also experienced in the opencast mining operations that the massive flow of dump mass can be prevented to some extent by putting a resistance at

the toe of the dump through coal rib. Leaving coal rib also prevents spoil toe undercutting of dump during removal of coal. Spoil toe undercutting has been identified as the major cause of internal dump failure at the Paintearth mine, Forestburg, Alberta, Canada. (Hebil, 1986).

3. PROPOSED METHOD OF STABILITY ANALYSIS

A computer program using Fortran 77 language has been developed to evaluate effect of different geo-engineering parameters on the stability of internal dump (Roy, 1999). For numerical evaluation of safe and economic combination of face angle and height of dump, the following computational methods have been adopted.

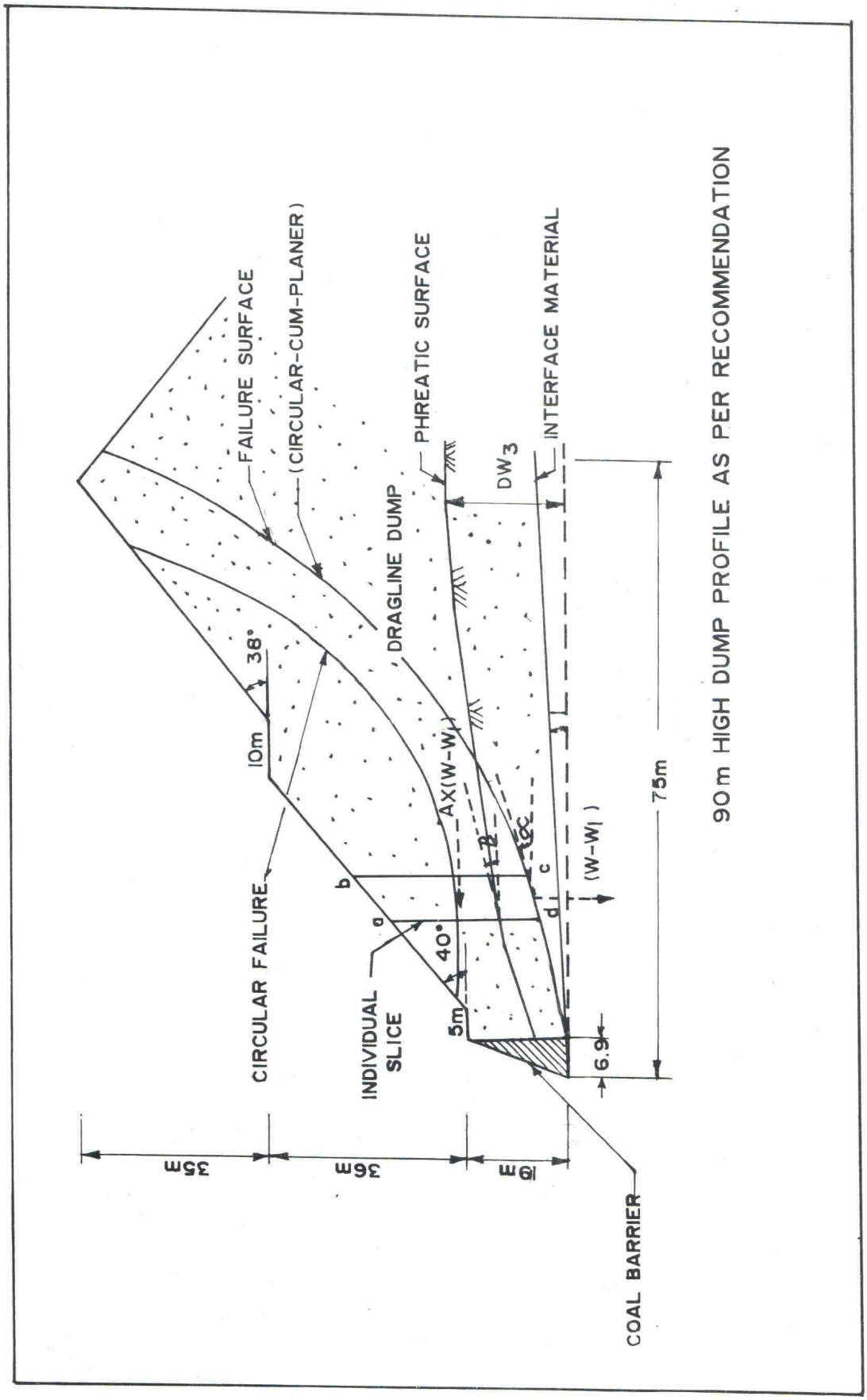
For an assumed section, a trial surface is considered for arbitrarily selecting the centre for the first iteration method and it is divided into suitable number of blocks or sectors depending on the geometrical shape of the section and each block is subsequently sub-divided into hundred number of individual slices of equal thickness (Fig. 2). Each slice is subjected to following forces (Fig. 3):

- Dead load of the dump mass (W)
- Upward thrust (W_1) due to water table within dump mass
- Seepage force due to water table within dump mass
- dynamic force due to seismicity of the area.

All these forces acting on each slice are resolved to determine disturbing and frictional forces on individual slice. They are suitably added for all the slices to determine cumulative disturbing force and resisting force (considering cohesive force of the whole failure surface). The ratio of the cumulative resisting force to the cumulative disturbing force is the Factor of safety of 1st trial surface. The process is repeated by selecting several trial surfaces in a systematic manner around the first one to find the absolute minimum Factor of safety (Fig. 4). With this value of Factor of safety by Fellinius method, Bishop's simplified method is applied to determine Factor of safety.

The geo-engineering parameters which have an impact on the stability of internal dump are documented below:

- Angle of internal friction at the contact layer between coal rib and mine floor
- Cohesion at the contact layer between coal rib and mine floor
- Angle of internal friction of dump material (ϕ_2)
- Cohesion of dump material (c_2)
- Cohesion of interface material (c_3)
- Angle of internal friction of interface material (ϕ_3)
- Height of water table within internal dump (Dw_3)
- Height of water table at the toe of internal dump (Dw_4)
- Inclination of mine floor (I)
- Seismic acceleration of mine area (A_g)



90 m HIGH DUMP PROFILE AS PER RECOMMENDATION

Fig. 2

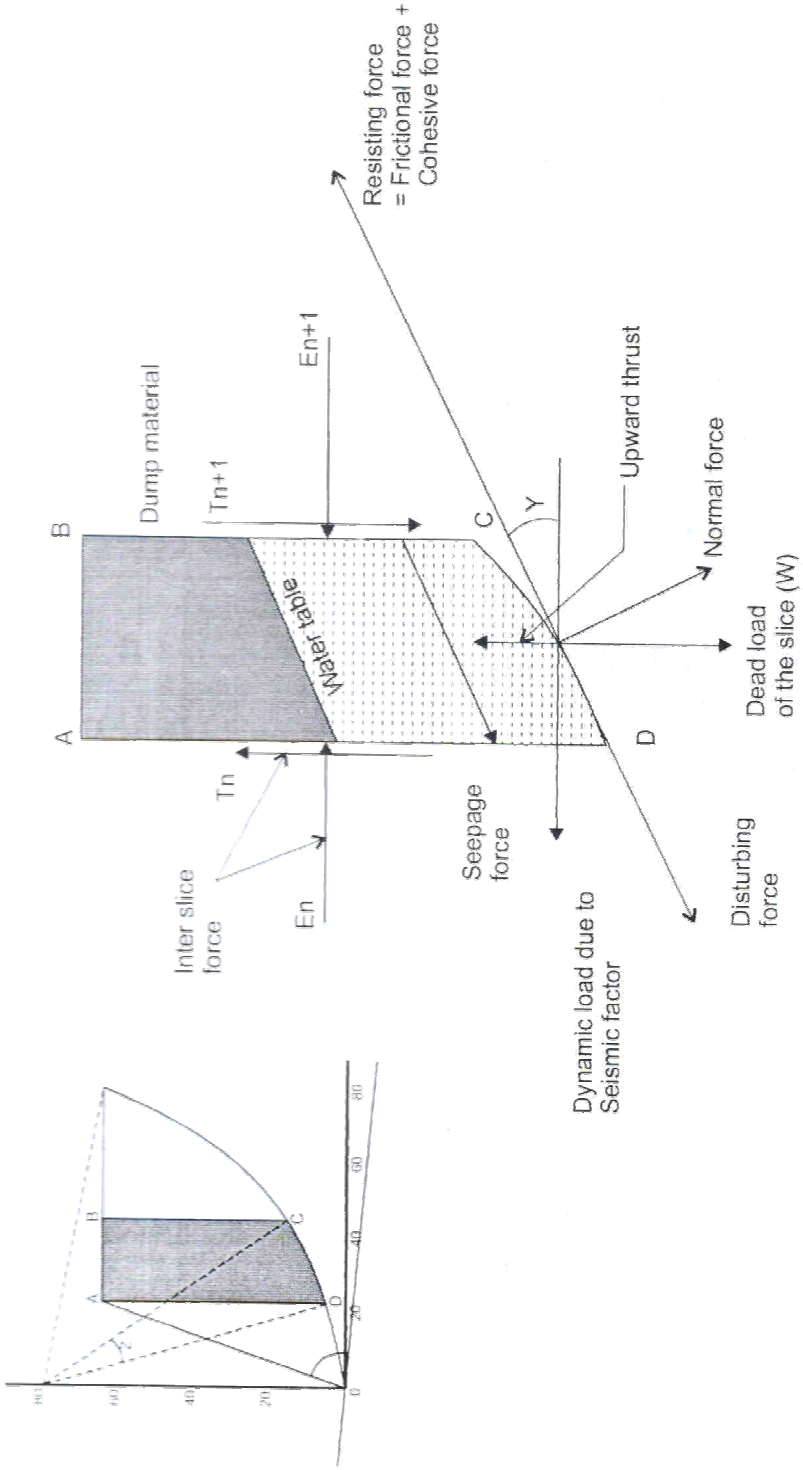


Fig. 3 - Free body diagram of an individual slice

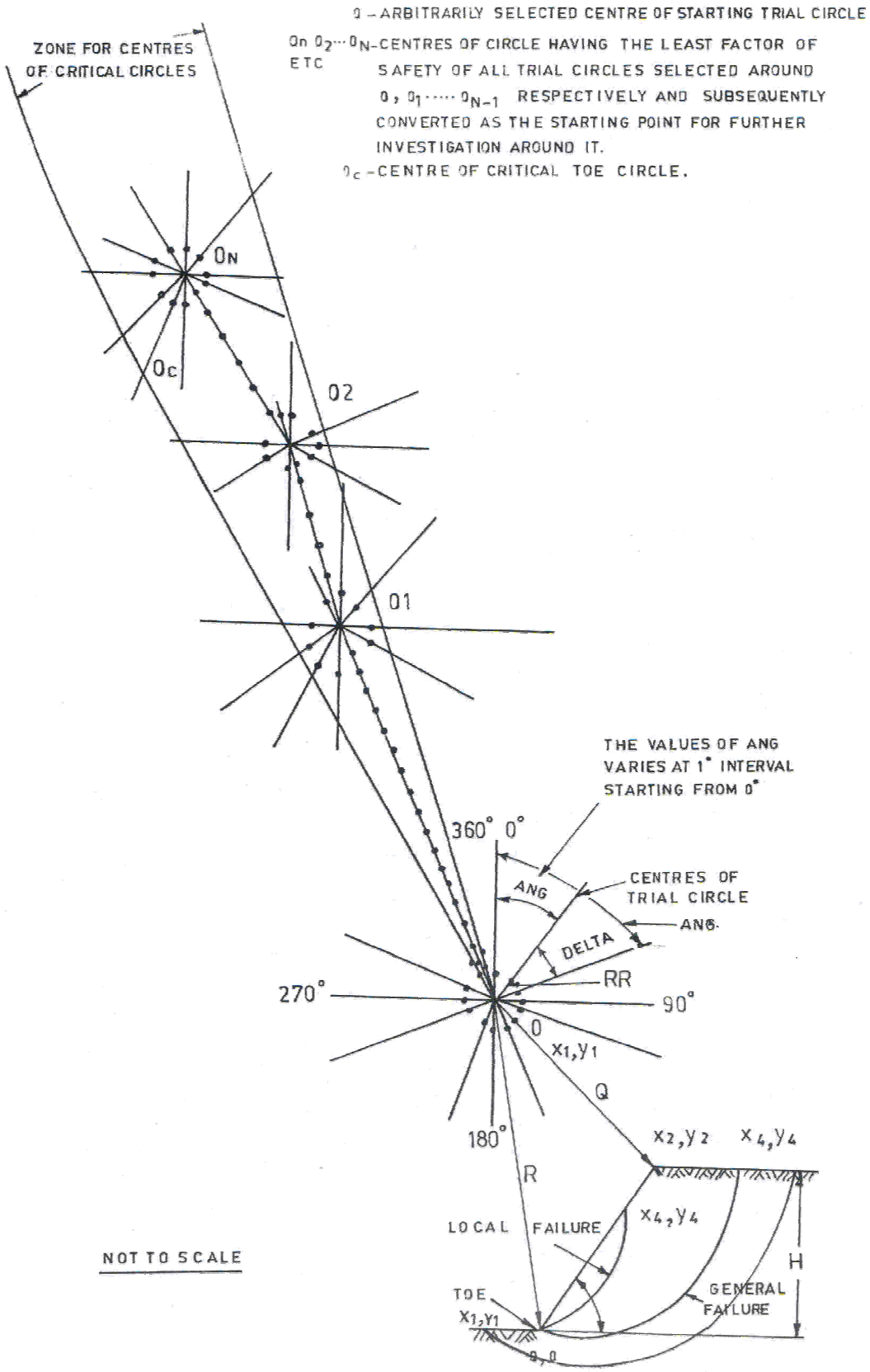


Fig. 4 Scheme adopted for selection of centre of trial circles to probe the location of the centre of critical toe circle

- Unit weight of dump material (γ_2)

4. RESULTS OF ANALYSIS

The influence of all the major geo-engineering parameters are studied numerically and discussed below.

4.1 Impact of Angle of internal friction of Interface Material (ϕ_3) and Cohesion of Dump Material (c_2) on the Height and Slope Angle of Dump (Fig. 5)

To present the influence of above two parameters, i.e. angle of internal friction of interface material (ϕ_3) and cohesion of dump material (c_2) on the height and slope angle of dump, the values of other controlling parameters have been kept constant as given below.

- Angle of internal friction of dump material (ϕ_2) = 40°
- Cohesion of interface material between dump and foundation (c_3) = 30 kN/m^2
- Height of water table within internal dump (Dw_3) = 0 m
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Inclination of dump floor (I) = 3°
- Seismic acceleration of mine area (A_g) = 0 m/sec^2
- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonnes

Dump is considered to be in low risk zone, i.e. the failure will lead to no loss of life and moderate damage to property. Factor of safety in this case is taken as 1.15 to 1.20. The analysis has been carried out without considering the coal rib/barrier.

Using Fig. 5, the influence of c_2 and ϕ_3 is explained as below.

(a) For angle of internal friction of interface material (ϕ_3) = 20° and slope angle of dump (β) = 30°, variation of allowable Height (H) for different values of cohesion of dump material (c_2) is tabulated below:

c_2 (kN/m^2)	15	20	25	30
H(m)	35	55	80	90

(b) For cohesion of dump material (c_2) = 25 kN/m^2 and for slope angle of dump (β) = 30°, variation of allowable Height (H) for different values of angle of internal friction of interface material (ϕ_3) is tabulated below :

ϕ_3 (deg.)	20	10
H(m)	80	25

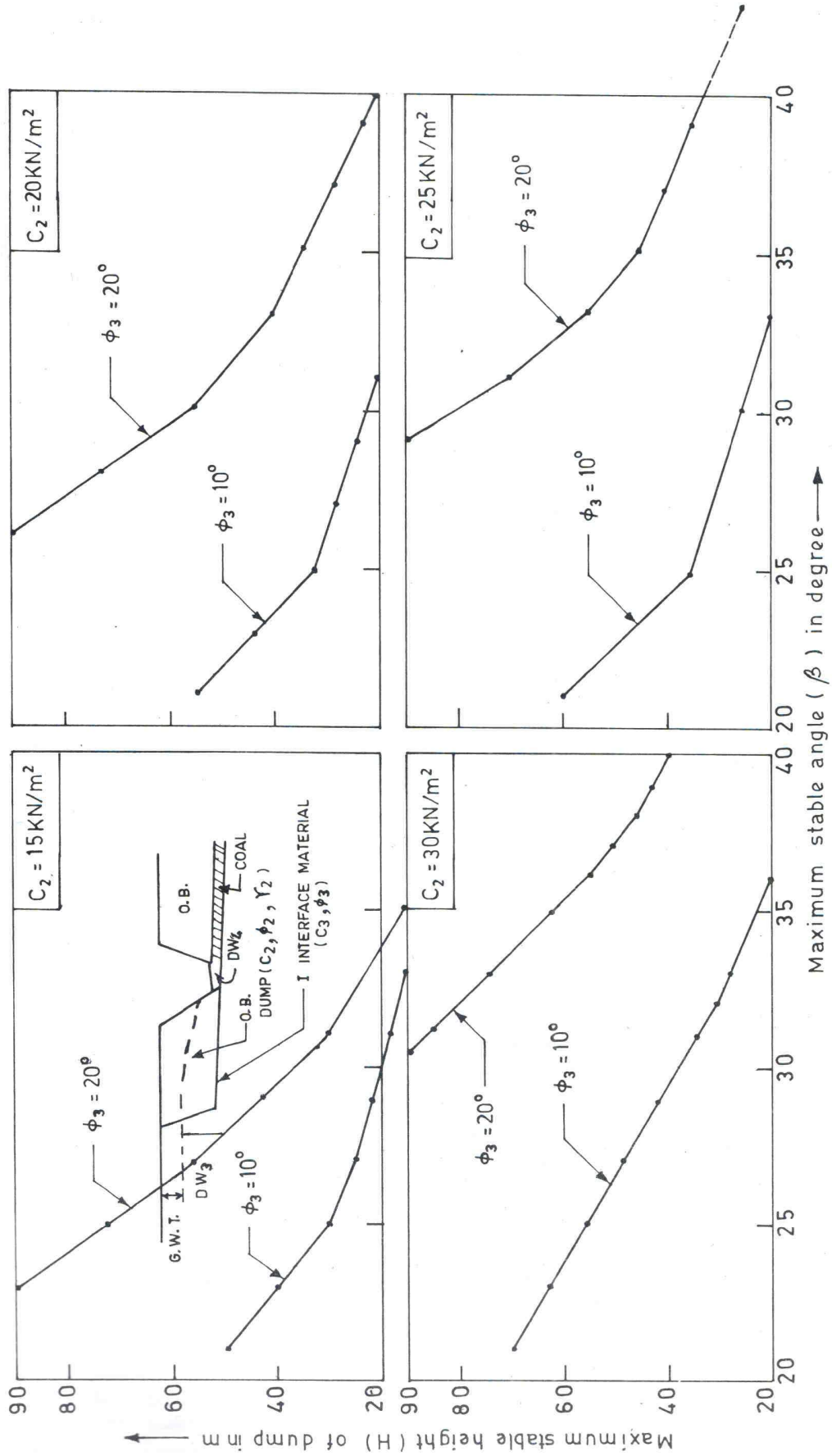


Fig. 5 Influence of face angle of internal dump on its stable height in low risk zone (F.S.=1.15 to 1.20) for different values of cohesion (C_2) of dump material and angle of internal friction (ϕ_3) of interface material between dump and foundation. ($\phi_2 = 40°$, $C_3 = 30\ KN/m^2$, $DW_3 = 0\ m$, $DW_4 = 0\ m$, $I = 3°$, $Ag = 0$, $\gamma_2 = 21\ KN/m^3$, Cap = 50 T)

To avoid mining operational hazards, height of dump is restricted to 90m.

Hence, cohesion of dump material (c_2) and angle of internal friction of interface material (ϕ_3) both have immense impact on the stability of dump.

4.2 Impact of Angle of internal Friction(ϕ_3) and Cohesion of Interface Material (c_3) on the Height and Slope Angle of Dump (Fig. 6)

Following other controlling parameters are considered to be constant.

- Angle of internal friction of dump material (ϕ_2) = 40°
- Cohesion of dump material (c_2) = 25 kN/m^2
- Height of water table within internal dump (Dw_3) = 0 m
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Inclination of dump floor (I) = 6 degree
- Seismic acceleration of mine area (A_g) = 0 m/sec^2
- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonnes

Dump is considered to be in such a situation in which failure will lead to no loss of life (low risk zone) and moderate damage to property. Factor of safety in this case is taken as 1.15 to 1.20. The analysis has been carried out without considering the coal rib/barrier. The influence of c_3 and ϕ_3 is explained in following manner (Fig. 6).

(a) For angle of internal friction of interface material (ϕ_3) = 20° and for slope angle of dump (β) = 21°, variation of height (H) for different values of cohesion of dump material (c_3) is tabulated below:

c_3 (kN/m^2)	5	13	21	30
H(m)	45	55	70	90

The influence of angle of internal friction of interface material (ϕ_3) on stability of dump has already been explained.

Hence, shear strength of interface material plays an important role in the stability of internal dump.

4.3 Impact of Angle of Internal Friction (ϕ_2) of Dump Material and Dump Floor Inclination (I) on the Height and Slope Angle of Dump (Fig. 7)

Following other controlling parameters are considered to be constant.

- Angle of internal friction of interface material (ϕ_3) = 20°
- Cohesion of dump material (c_2) = 25 kN/m^2
- Cohesion of interface not dump material (c_3) = 30 kN/m^2

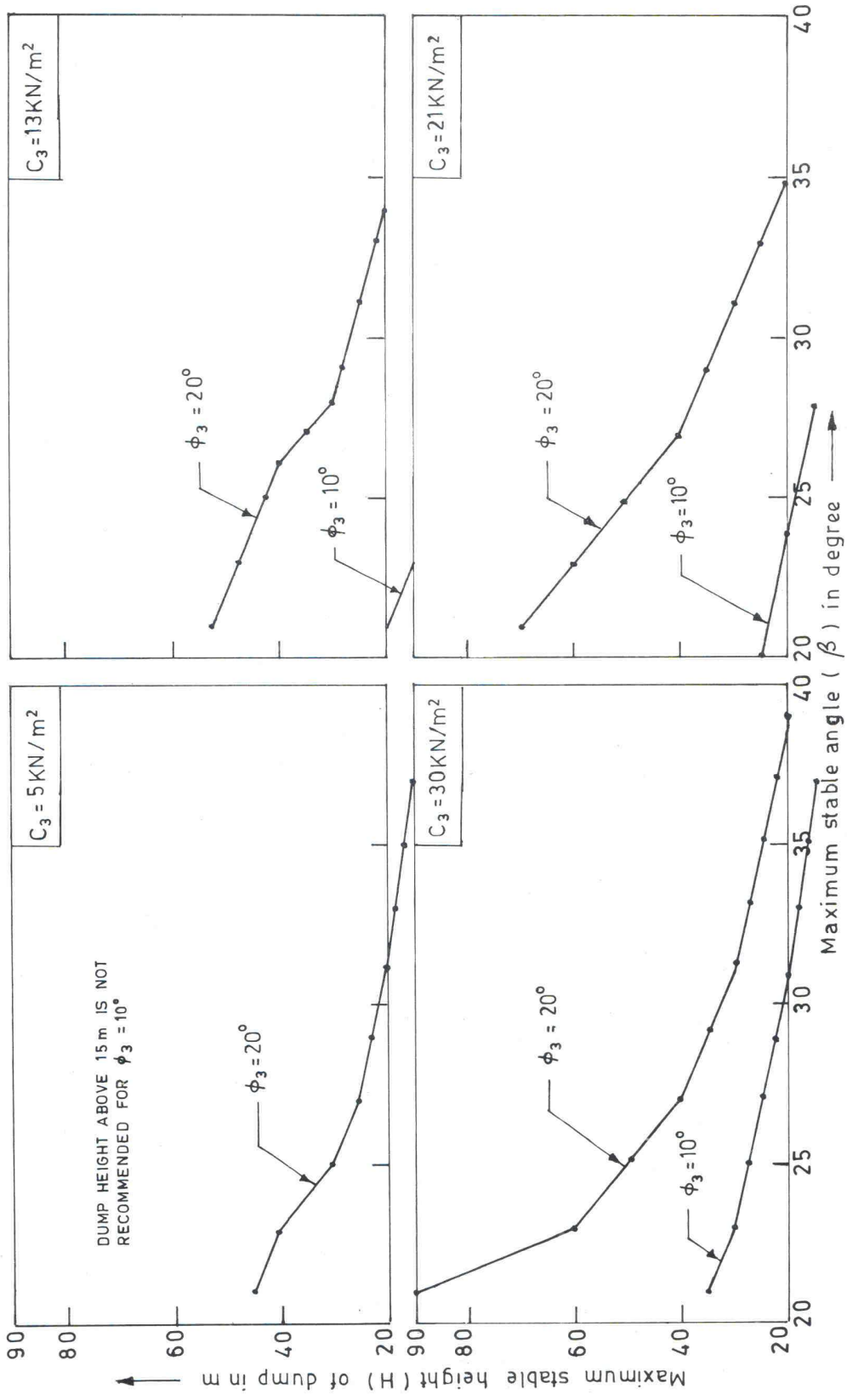


Fig. 6 Influence of face angle of internal dump on its stable height in low risk zone (F.S. = 1.15 to 1.20) for different values of cohesion(C_3) and angle of internal friction(ϕ_3) of interface material between dump and foundation. ($\phi_2 = 40°$, $C_2 = 25 KN/m^2$, $I = 6°$, $Ag = 0$, $DW_3 = 0 m$, $DW_4 = 0 m$, $\gamma_2 = 21 KN/m^3$, Cap = 50 T)

- Height of water table within internal dump (Dw_3) = 0 m
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Seismic acceleration of mine area (A_g) = 0 m/sec^2
- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonnes

Dump is considered to be in such a situation in which failure will lead to no loss of life and moderate damage to property. Factor of safety in this case is taken as 1.15 to 1.20. The analysis has been carried out without considering the coal rib/barrier. Influence of I and ϕ_2 is explained in following manner (Fig. 7).

(a) For angle of internal friction of interface material (ϕ_2) = 40° and for slope angle of dump (β) = 30°, variation of Height (H) for different values of floor Inclination (I) is tabulated below.

I(degree)	3	6	9	12
H(m)	80	35	30	20

Due to change in inclination of floor from 3 to 6 degree, there is an abrupt decrease in allowable height due to presence of weak interface material. The most probable failure mode will have tendency to pass through interface material. Hence, the failure surface will be circular-cum-planar instead of circular failure for an increase in floor inclination.

(b) For floor inclination (I) = 3 degree and slope angle of dump (β) = 25°, variation of allowable Height (H) for different values of angle of internal friction of dump material (ϕ_2) is tabulated below :

ϕ_2(degree)	40	20
H(m)	90	20

To avoid mining operational hazards, height of dump is restricted to 90m. Angle of internal friction of dump material (ϕ_2) is one of the most controlling parameters in the stability of internal dump.

4.4 Impact of Angle of Internal Friction (ϕ_2) of Dump Material and Height of Water Table within Internal Dump (DW_3) on the Height and Slope Angle of Dump (Fig. 8)

Following other controlling parameters are considered to be constant.

- Angle of internal friction of interface material (ϕ_3) = 20°
- Cohesion of dump material (C_2) = 25 kN/m^2
- Cohesion of interface material (C_3) = 30 kN/m^2
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Inclination of mine floor (I) = 3°

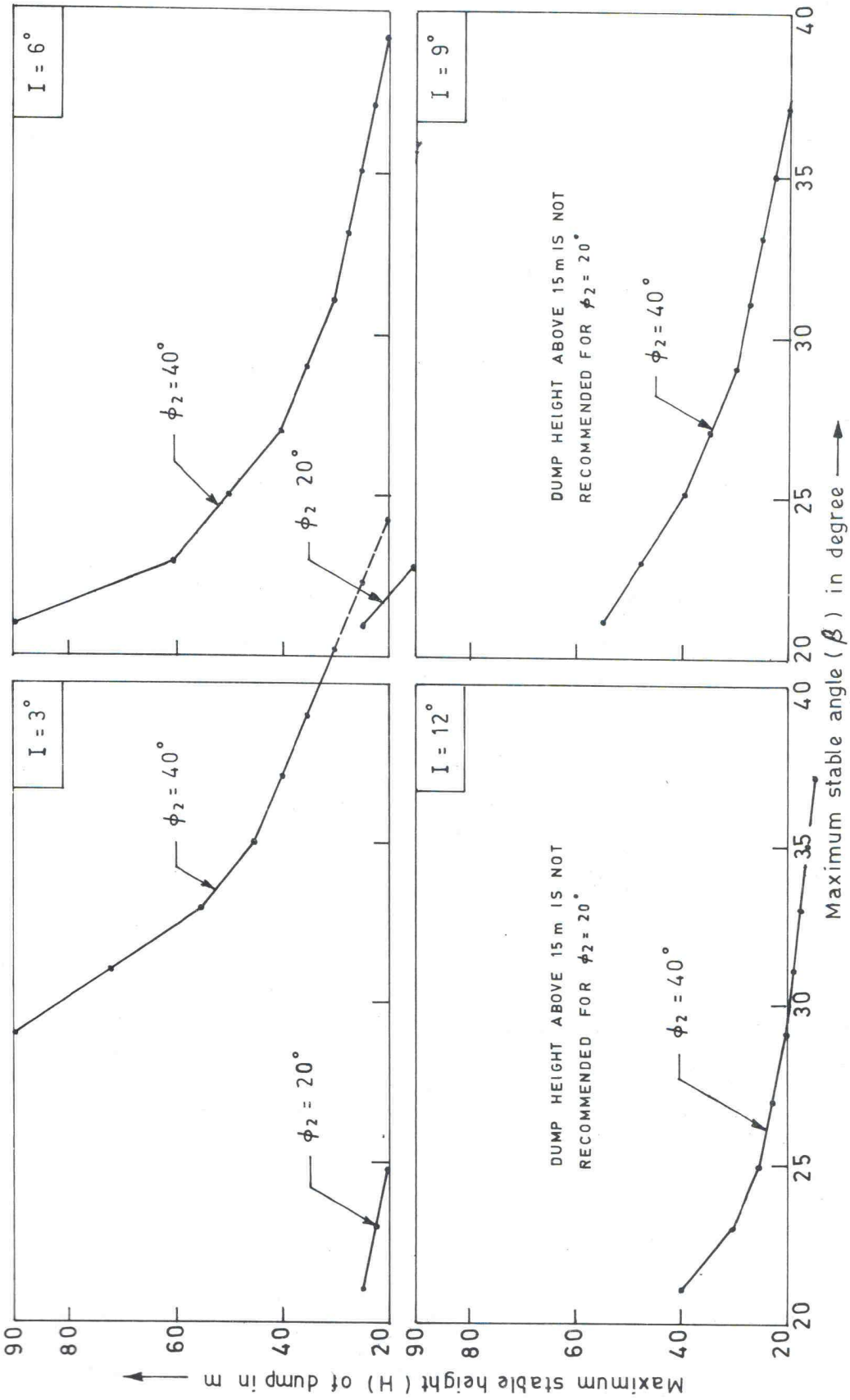


Fig.7 Influence of face angle of internal dump on its stable height in low risk zone (F.S = 1.15 to 1.20) for different values of angle of internal friction (ϕ_2) of dump material and angle of inclination of floor of internal dump with horizontal (I). (C_2 = 25 KN/m², C_3 = 30 KN/m², ϕ_3 = 20°, DW_3 = 0m, DW_4 = 0m, γ_2 = 21KN/m³, Ag = 0, Cap = 50 T)

- Seismic acceleration of mine area (A_g) = 0 m/sec^2
- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonne

Dump is considered to be in such a situation in which failure will lead to loss of life and severe damage to property (high risk zone). Factor of safety in this case is taken as 1.30 to 1.35. The analysis has been carried out without considering the coal rib/barrier. Influence of Dw_3 is explained in following manner (Fig. 8).

(a) For angle of internal friction of interface material (ϕ_2) = 40° and for slope angle of dump (β) = 25°, variation of Dump Height for different values of height of water table (Dw_3) is tabulated below.

Dw_3 (Height of water table within dump)	H/4	H/2	3H/4	H
Dump Height(m)	45	40	25	20

(H is the full height of water table within internal dump, i.e. water table is almost at the surface level of dump).

Water table within internal dump is one of the major geo-engineering parameters in the slope stability of internal dump. Hydro-geological study of internal dump mass is an important aspect of stability analysis.

5. A CASE STUDY

Above approach has been applied to Jayant opencast coal mines of Northern Coalfields Limited, India for the stability of waste dump considering the effect of coal rib/barrier. Coal rib dimensions are shown in Fig. 2. Following values of various input parameters were considered (CMPDI, 1999).

- Angle of internal friction of dump material (ϕ_2) = 40°
- Angle of internal friction of interface material (ϕ_3) = 25°
- Cohesion of dump material (c_2) = 36 kN/m^2
- Cohesion of interface material (c_3) = 48 kN/m^2
- Angle of internal friction at the contact layer between coal rib and mine floor = 42°
- Cohesion at the contact layer between coal rib and mine floor = 110 kN/m^2
  [Due to blasting of adjacent coal before excavation , the contact layer is fractured and hence, there is sharp reduction of shear strength at the contact layer between coal rib and mine floor].
- Height of water table within internal dump (Dw_3) = 0 m
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Inclination of mine floor (I) = 2°
- Seismic acceleration of mine area (A_g) = 0.02 m/sec^2
  [Mine is situated in zone-II of Indian seismic zone]

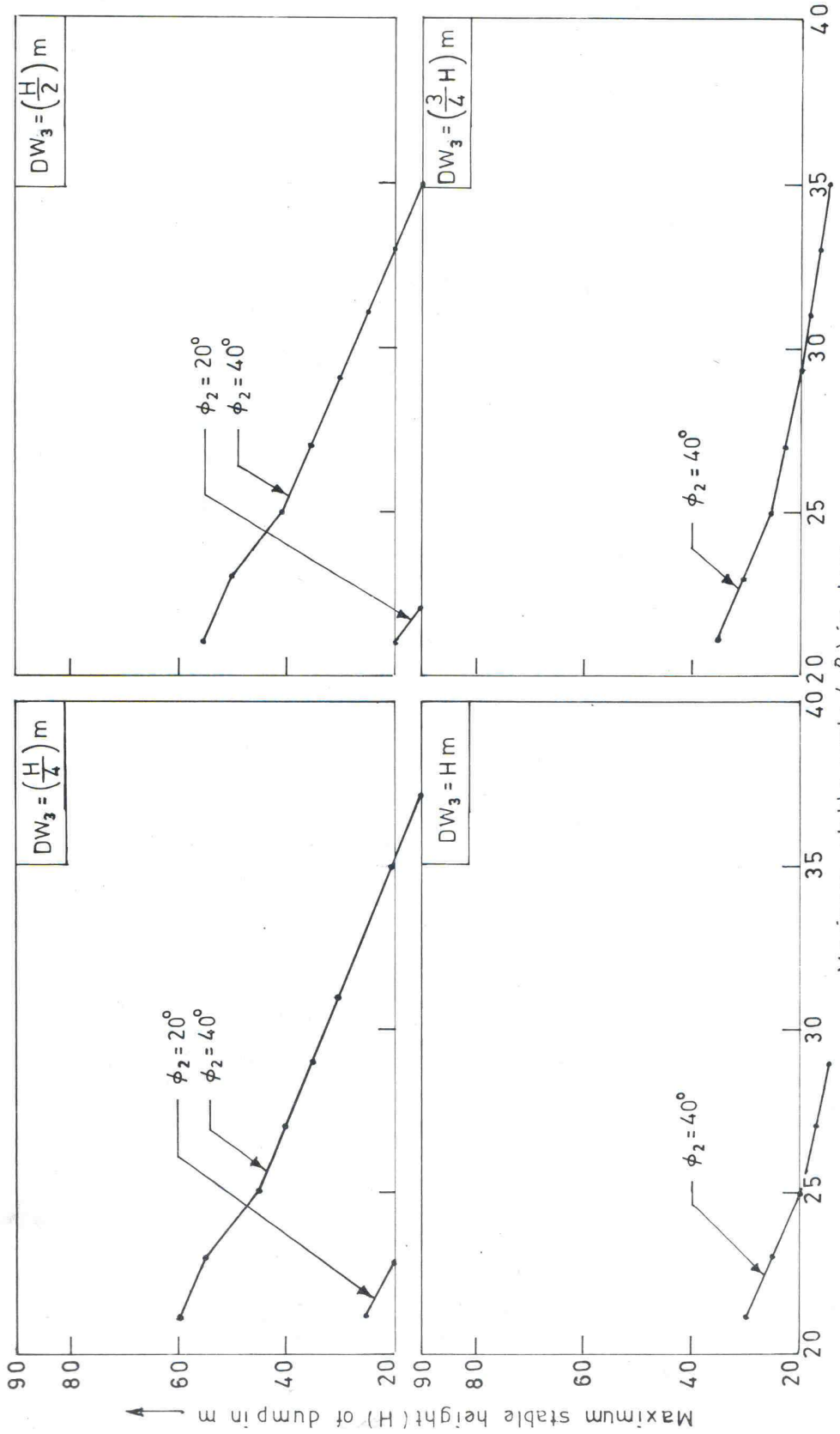


Fig. 8 Influence of face angle of internal dump on its stable height in high risk zone (F.S.=1.30 to 1.35) for different values of angle of internal friction (ϕ_2) of dump material and height of original water lable (DW_3) (C_2 = 25 KN/m², C_3 = 30 KN/m², ϕ_3 = 20°, DW_4 = 0, Ag = 0, γ_2 = 21 KN/m³, Cap = 50 T, I = 3°)

- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonnes

Recommended slope in this case is 36° for a height of 90m for factor of safety 1.15 to 1.20.

5.1 Safe Height and Slope of Dump with and without Coal Rib

The effect of coal rib on the stability of dump has been studied and the result in respect of height and slope of dump with and without coal rib has been compared. Coal rib dimensions are shown in Fig. 2. Following other controlling parameters are considered to be constant.

- Angle of internal friction of dump material (ϕ_2) = 33°
- Cohesion of dump material (c_2) = 35 kN/m^2
- Cohesion of interface material (c_3) = 40 kN/m^2
- Angle of internal friction of interface material (ϕ_3) = 21°
- Angle of internal friction at the contact layer between coal rib and mine floor = 35°
- Cohesion at the contact layer between coal rib and mine floor = 43 kN/m^2
- Height of water table within internal dump (Dw_3) = 18 m
- Height of water table at the toe of internal dump (Dw_4) = 0 m
- Inclination of mine floor (I) = 3°
- Seismic acceleration of mine area (A_g) = 0 m/sec^2
- Unit weight of dump material (γ_2) = 21 kN/m^3
- Capacity of dumper plying above dump (Cap) = 50 Tonnes

The results of analysis are presented in Table 1 considering a factor of safety between 1.15 and 1.20. The Table shows that due to presence of coal rib the allowable height increases for same slope angle.

Table 1 – Safe height and slope of dump with and without coal rib

Slope of Internal Dump (degrees)	Height with Rib (m)	Height without Rib (m)
35	80	72
32	90	81

The rib dimensions are site specific according to geo-mining characteristics of the mine. Jayant opencast coal mines of Northern Coalfield Limited, India has one of the most competent rock strata among all the other existing opencast coal mines of India and existing base width of rib in this mine varies from 7 to 10 m. In case of Sasti opencast coal mines of Western Coalfield Limited, India existing base width of coal rib varies from 18 to 20m as the mine is facing more frequent slope failures due to very soft rock strata with thick cover of black-cotton soil.

6. CONCLUSIONS

Following conclusions are drawn from the above study.

* Leaving coal rib at the toe of the internal dump is very useful from stability point of view.
* Other than geo-technical parameters of dump material and interface material between dump and foundation, inclination of mine floor plays an important role in stability of dump. There is a steady decrease in safe height of dump with the increase in inclination of floor. With the increase in inclination of mine floor, most probable failure surface will have a tendency to pass through interface material. For such type of failure surface, shear strength properties of interface material plays an important role in the stability of internal dump.
* Before back-filling of dump material over the de-coaled area of the mine, the slushy mixture of left out crushed rock and crushed coal should be scrapped as far as possible from the de-coaled area to make the mine floor more competent.
* Excavated soil should be dumped outside the running mine to prevent mixing of excavated soil with excavated waste rock which will lead to sharp deterioration of shear strength value of internal dump mass.
* Irrespective of factor of safety as indicated by the stability analysis, monitoring of crest and toe displacements provides a warning of potential instability (Cambell, 1986). Systematic observation of slope by modern stability monitoring instrument like non-contact survey technique is essential.

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