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Location of Pit in Underground Coal Mining – A Geometrical Approach

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Abstract: *Mine Opening or what is commonly known as Pit plays an important role in Underground Coal Mining. It serves as the entry / exit point in transporting men, machinery, power etc. inside the mine; maintains ventilation; serves as the point of transportation of coal from the mine to the surface, and many more. In short, it plays the role of a gateway to the underground coal mine. The decision regarding size, site, number and type of mine openings to be created is one of the major decisions for a new mine. In case of expansion of an existing mine, the existing openings influence the decision regarding new additional openings to a large extent. A number of factors like Size and shape of the property, Availability of land, Presence of surface features, Geo-mining conditions, Number of seams to be worked on etc. influence the choice of mine opening or Pit. In this paper, we have worked on the' Size and shape factors of the property' and have done a geometrical analysis on the total effort required to mine the entire area considering Pits at different positions for various shapes of the mine boundary.*

Keywords: *Pit Location, Mine Boundary, Geometrical Analysis, Underground Coal Mining*

1. Introduction and Related Works

In an underground mine, coal is extracted in a confined space with controlled strata movement and there are principally two methods of coal extraction, namely: 1) Bord/Room and Pillar and 2) Longwall. A coal deposit is divided into pillars by a network of tunnels in coal forming two sets of mine roadways, normally, right angle to each other, forming pillars in between. Generally, rooms are 20-30 feet wide and the pillars up to 100 feet wide. As mining advances, a grid-like pattern of rooms and pillars is formed. When mining advances to the end of a panel or the property line, retreat mining begins. In retreat mining, the workers mine as much coal as possible from the remaining pillars until the roof falls in. When retreat mining is completed, the mined area is abandoned. Since pillars contain far more coal than what is extracted through gallery drivage, it is obvious that, to make the entire process of coal extraction efficient, the method of pillar extraction has to be efficient and the development done for formation of pillars has to suit the method of pillar extraction [9][11][3].

The decision regarding size, site, number and type of mine openings to be created is one of the major decisions for a new mine. In case of expansion of an existing mine, the existing openings influence the decision for new additional openings to a large extent.

The mine openings for an underground mine are of four types:

- Shafts,
- Inclines or drifts,
- Adits, and
- Large diameter boreholes [9].

A minimum of two openings are essential for any underground mine. The openings serve the following purposes:

- Intake of fresh air to the mine and exhaust of full air.
- Transportation of machines and material to and from the mine.
- Transportation of main or providing passage permitting travel of men to and from various work places.
- Bringing coal out for despatch to consumers.
- Taking power line inside the mine.
- Lying pipes for pumping water outside the mine and for taking water inside the mine for drinking and special purpose.
- Enabling a network for communication (telephone, signalling etc) and monitoring system (fire alarm, gas indicator, indicators showing working of men coal producing equipments etc.) to be installed at the required places in the mine.
- Shape of the property also influences number of mine openings. It is more convenient to have rectangular properties with more length along strike and less along deep-rise. More the angle of deep more should be the length along strike. Thus, long, thin properties may, advantageously, have more openings along strike compared to near square property of approximately the same area.

Thus, the number, size and type of mine openings depend on:

1. <u>Size and shape of the property:</u> Properties that have more strike length are better opened by boundary shafts for inclines for better men and material transport and ventilation. Properties that relatively, have more length in deep-rise direction can have central shafts and even incline that touch pole near the centre of the property [9].

2. <u>Number of seams to be worked:</u> A shaft winding is more convenient if production is to be raised form a single point/level. The winding system can be balanced. If it is intended to have simultaneous production from seams far apart, a central incline with belt system can receive coal from multi-points more conveniently [17].

3. <u>Provision for possible expansion and extension of the mine:</u> If it is felt that the proposed mine may be expanded in future by annexing and adjoining property, the fact can influence the site of mine openings which may be less central in the beginning but will become more central when the mine is expanded [21].

4. <u>Availability of land:</u> Sometimes a mine opening, along with infrastructure, is sited at a particular place because land is readily available there. Certain lands like forest land and land with high agricultural produce should be avoided, if possible [19].

5. Need and economies of early coal production: Early return on investment is always preferred. In shallow properties, therefore, openings near the coal in crop area can be sited for early production which later on can be replaced by more central openings, if found viable [6][8].

6. Site of infrastructure and railway siding: All lands may not be suitable for creating infrastructure facilities and for bringing a railway siding. For such facilities, flat and non-coal bearings land may be ideal, if available, near the property under consideration. The mine opening that will bring the coal out may be sited near such land [20][21].

7. Presence of surface features like townships: It is better to avoid a mine opening near township [23].

8. Site of existing mine openings and infrastructure: For expansion of an existing mine, it should always be an attempt to utilise the existing facilities to the maximum. Even an opening of an adjoining new mine can be influenced by such facilities.

9. Geo-mining conditions: Highly disturbed zones should be avoided for mine openings. If there is any particular zone in the property where seam(s) have become non-mineable (say, due to reduce thickness or due to development of a dirt band in the middle or splitting of coal seam etc), the fact should be considered while deciding the site of the mine opening. For deep deposits, central shafts are perfect. For medium deep deposits (depth 150-300m), a central intake shaft for men and material transport, a rise-side upcast shaft and an incline for coal transport (with surface opening such that the incline touches the main seam near the central shaft) are perfect. For shallow properties, pair of inclines and one or a pair of shafts at shallowest possible cover is preferred [9][11][3].

10. Topography: Topography also influence site of mine openings (and sometimes type of opening). If a deep property has a hill in the centre, centre shafts are avoided and openings are planned at more convenient shallow site. Mine opening are, similarly, avoided in high flood areas [5][1][2].

A mine opening should, as far as possible, be *central* to a property for the functions it has to discharge. But due to many geo-logical, geographical or socio-political factor it's not allowed to be at the Centre always [15][7]. It can be seen from the above that, there are several factors which influence siting of a mine opening and a decision, based on them, has to be carefully taken as a mistake committed cannot easily be rectified [13]. Thus, a suitable Pit Location with a suitable method of spanning the whole mine would make a mine more viable and would make it more profitable [20][21][16].

So, our objective would be to find an efficient location of pit that would minimise the Total Effort required to extract the total amount coal from the entire underground area of a given shape.

2. METHODOLOGY

In this paper, we have considered the Mine Boundary to be either (i) Rectangular or (ii) Circular in shape, and then applied a geometrical approach to calculate the *Total Effort* required to mine the entire area for pits located at various points within that boundary with different mining movements for each of those Pit Locations.

In our first set of calculations, we have considered the mine boundary to be of Circular shape, and have placed the pit at the (a) Centre and then calculated the Total Effort required to mine the whole Circular area with (i) Radial Movement and (ii) Arcwise movement. Similarly, the Total Effort is again calculated by locating the Pit on the (b) Periphery with (i) Radial and (ii) Arcwise movement of mining. Then those four Total Efforts are compared and the best location and movement combination is inferred for the Circular Mine Boundary.

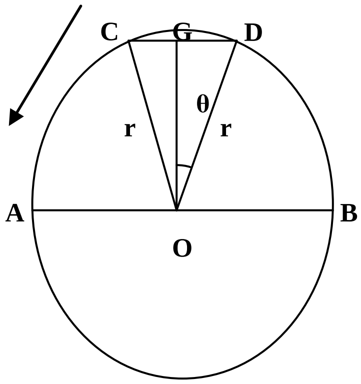
In our next set of calculations, we have considered a Rectangular Mine Boundary and have placed the Pits at (i) the Centroid and on (ii) the Periphery. Then for each Location of Pit the Total Effort is calculated by taking the mining movement (a) Vertical and (b) Horizontal and then those

Efforts are compared to select the best Pit location and movement combination for the Rectangular Mine Boundary.

Here, in these calculations, only the 'Size and Shape of the Property' have been considered as the 'variable' and all the rest of the factors have been assumed to be constant (e.g. we have assumed that the seam is not multi-layered, and the geological and geo-technical factors etc. are constant).

3. GEOMETRICAL ANALYSIS FOR AN EFFICIENT LOCATION OF PIT

3.1. Circular Boundary, Pit at the Centre with Radial Movement



Let, r be the radius i.e. OA = OB = r and $\angle GOD = \theta$

Let, the cutting width, CD = 2Δx i.e. GD = GC = Δx

∴ Total number of cuts required = 2πr/Δx

Here, the radial cutting and loading is going on and so cutting motion is along $\xrightarrow[OG]{}$ and loading motion is along $\xleftarrow[GO]{}$. Coverage of the entire boundary is done in anti-clockwise motion.

Here, one conveyor belt will be placed in the direction $\xrightarrow[OG]{}$ that will move with each cut.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

Area of the ΔGOD = ½.GD.GO = ½.Δx.r

Area of the ΔCOD = 2. ΔGOD = rΔx

∴ Total cutting effort required is T_C = rΔx.(2πr/2Δx).t

$$\therefore\ T_C = \pi r^2 t \tag{1}$$

Loading effort required for ΔAOB = (r/v).(rΔx) [∵ Effort involved is proportional to the amount being carried]

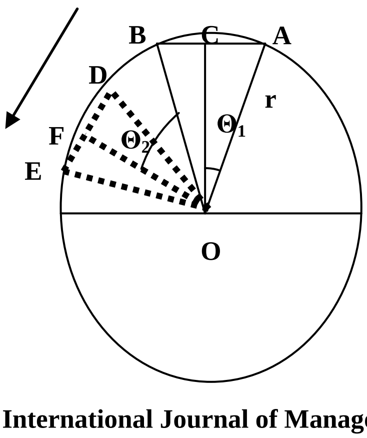
∴ Total loading effort required is T_L = (r/v).(rΔx).(2πr/2Δx)

$$\therefore\ T_L = \pi r^3/v \tag{2}$$

∴ Total effort required to mine the entire area is $T = T_C + T_L = \pi r^2 t + \pi r^3/v$

$$\boxed{\therefore\ \mathbf{T = \pi r^2[t + r/v]}}$$

3.2. Circular Boundary, Pit on the Periphery with Radial Movement



Let, r be the radius i.e. OA = OB = r and $\angle BOA = \theta$

Let, ΔDOE be the pth slice.

$\therefore\ \angle BOE = p\theta$

Let, the cutting width AB or DE be 2Δx.

Here, the cutting movement is radial i.e. in the movement $\xrightarrow[CO]{}$ or $\xrightarrow[FO]{}$. And the loading movement will be

$\xrightarrow[OF]{}$ + $\xrightarrow[FB]{}$ for the slice ΔDOE. Coverage of the entire mine will be periphery wise and anticlockwise.

Here, two conveyor belts, one in $\xrightarrow[AB]{}$, $\xrightarrow[DE]{}$ direction and the other $\xrightarrow[CO]{}$, $\xrightarrow[FO]{}$ direction will be placed.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

∴ Cutting effort for the ΔDOE required is ½.2Δx.r.t

∴ Total cutting effort required is, $T_C = r\Delta x.t.(2\pi r/2\Delta x)$

$$\therefore\ T_C = \pi r^2 t \qquad (3)$$

Loading effort here has two components, one radial and the other one arc wise.

Total radial loading effort will be,

$T_{LR} = (r/v).\ (2\pi r/2\Delta x).½.2\Delta x.r$ [∵ The effort involved is proportional to the amount of coal being carried]

$$\therefore\ T_{LR} = \pi r^3/v \qquad (4)$$

Total arc wise loading effort will be,

$T_{LA} = 2\Delta x + 4\Delta x + 6\Delta x + \text{--------}\ (\pi r)/\Delta x$ times

$= 2\Delta x.[1 + 2 + 3 + \text{-------}\ (\pi r)/\Delta x$ times$]$

$= 2\pi r + \pi r\{\pi r/\Delta x – 1\}$

$$\therefore\ T_{LA} = 2\pi r + \pi r\{\pi r/\Delta x - 1\} \qquad (5)$$

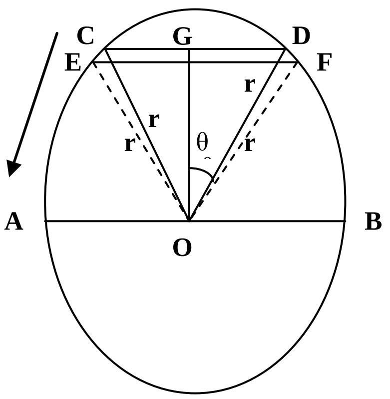
∴ Total loading effort, $TL = T_{LR} + T_{LA} = \{\pi r^3/v + 2\pi r + \pi r\ (\pi r/\Delta x - 1)\}.r\Delta x$

∴ Total effort required to mine the entire area, $T = T_C + T_L$

$\therefore T = \pi r^2 t + \{\pi r^3/v + 2\pi r + \pi r\ (\pi r/\Delta x - 1)\}.r\Delta x$

$$\boxed{\therefore \mathbf{T = \pi r[rt + \{r^3/v + 2r + r(\pi r/\Delta x - 1)\}.\Delta x]}}$$

3.3. Circular Boundary, Pit at the Centre with Arc Movement



Let, r be the radius i.e. OA = OB = r and $\angle GOD = \theta$
Let, the cutting width, width of CD = 2Δx.

Here, arcwise cutting and loading is going on and so cutting motion is along $\xrightarrow[CD]{}$ / $\xrightarrow[DC]{}$ i.e. a horizontal movement and loading motion is along $\xrightarrow[CO]{}$ / $\xrightarrow[DO]{}$ i.e. a radial movement. One loading would be done from the Point C and then next loading would be done from the

Point E. Coverage of the entire mine would be done in the direction of $\xrightarrow[OG]{}$.

Here, two conveyor belts will be placed in the direction $\xrightarrow[CD]{}$ / $\xrightarrow[DC]{}$ and $\xrightarrow[CO]{}$ / $\xrightarrow[DO]{}$ where $\xrightarrow[CD]{}$ / $\xrightarrow[DC]{}$ will be shifted with each shift in cut.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

Now, CD = 2CG = 2GD = 2rsinθ

$\therefore$ Area of the entire slice ΔCOD = 2rsinθ.2Δx

$\therefore$ Cutting effort required for the slice AOB = 2rsinθ.2Δx.t

$\therefore$ Total cutting effort required,

$$T_C = 2.\int_0^{\pi/2} \mathrm{TC}\, d\theta = 2.\int_0^{\pi/2} 4\Delta x.r\sin\theta.t\, d\theta = 8r\Delta xt\int_0^{\pi/2} \sin\theta.d\theta = 8r\Delta xt\left[-\cos\theta\right]_0^{\pi/2}$$

$$\therefore\ T_C = 8r\Delta xt \tag{6}$$

Loading effort required for the slice AOB = (r/v).4rΔx.sinθ [$\because$ material has to come to the Point O from the Point B or A]

$\therefore$ Total loading effort required,

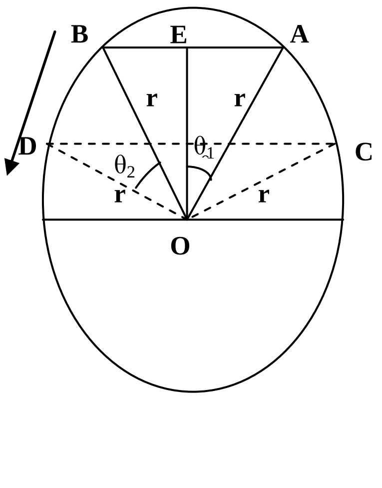
$$T_L = 2.\int_0^{\pi/2} \mathrm{TL}d\theta = 2.\int_0^{\pi/2} (r/v).4r\Delta x.\sin\theta d\theta$$

$$\therefore T_L = 8r\Delta x.\ (r/v) \tag{7}$$

$\therefore$ Total effort required to mine the entire area, $T = T_C + T_L$
$= 8r\Delta xt + 8r\Delta x.(r/v)$

$$\boxed{\therefore \mathbf{T = 8r\Delta x[(r/v) + t]}}$$

3.4. Circular boundary, pit on the periphery with arc movement



Let, r be the radius i.e. OA = OB = r and $\angle AOE = \theta_1$ and $\angle BOD = \theta_2$. Let, the cutting width of AB or CD be 2Δx.

Here, arcwise cutting and loading is going on and so cutting movement is along $\xrightarrow[BA]{}$ or $\xrightarrow[DC]{}$ and loading movement is along $\xrightarrow[AB]{}$ or $\xrightarrow[CD]{}$ plus the arc distance $\xrightarrow[DB]{}$. Coverage of the entire mine would be done in the direction of $\xrightarrow[EO]{}$.

Here, two conveyor belts will be placed in the direction

$\xrightarrow[CD]{}$ and $\xrightarrow[DB]{}$ where $\xrightarrow[CD]{}$ conveyor belt will be shifted with each shift in cut.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

So, cutting effort for one slice $\xrightarrow[BA]{}$ is $2.r\sin\theta_1.2\Delta x.t$

∴ Total cutting effort required, $T_C = 2.\int_0^{\pi/2} 2r\sin\theta 1.2\Delta x.t\, d\theta 1$

$$= 6r\Delta xt\left[-\cos\theta 1\right]_0^{\pi/2} = 6r\Delta xt$$

∴ $T_C = 6r\Delta xt$ (8)

Loading effort for one slice $\xrightarrow[CD]{}$ = time to travel $\xrightarrow[CD]{}$ + time to travel $\xrightarrow[DB]{}$

∴ Loading effort for one slice $\xrightarrow[CD]{}$ = $(2r\sin\theta_1/v) + r\,\theta_2$

∴ Total loading effort required,

$$T_L = 2.\int_0^{\pi/2} 2r\sin\theta 1/v\, d\theta 1 + 2.\int_0^{\pi/2} r\theta 2\, d\theta 2 = (2r/v)\left[-\cos\theta 1\right]_0^{\pi/2} + 2.r/2\left[\theta 2\wedge 2\right]_0^{\pi/2}$$

∴ $T_L = 2r/v + r\pi^2/4$ (9)

∴ Total effort required to mine the entire area,

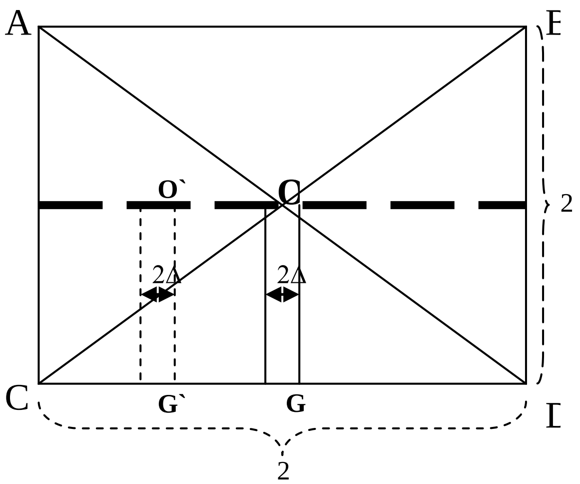
$T = T_C + T_L = 6r\Delta xt + 2r/v + r\pi^2/4 = 2r[3\Delta xt + 1/v + \pi^2/8]$

$$\boxed{\therefore \mathbf{T = 2r[3\Delta xt + 1/v + \pi^2/8]}}$$

3.5. Rectangular Boundary, Pit at the Centroid with Vertical Movement

Let, AB = 2a and BD = 2b

Let, the cutting width be 2Δx i.e. the width of OG.



Cutting movement will be vertical i.e. parallel to $\xrightarrow[AC]{}$ or $\xrightarrow[BD]{}$ direction. Here, one conveyor belt will be placed in the direction $\xrightarrow[OO`]{}$.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

Cutting effort required for one slice is 2Δx.b.t

$\therefore$ Total cutting effort required, $T_C = 2.2\Delta x.b.t.(2a/2\Delta x)$ [$\because$ the activity will be repeated $2a/2\Delta x$ number of times]

$\therefore T_C = 4abt$ (10)

Loading the r^{th} slice will be at a distance $r.2\Delta x$ from the pit O.

$\therefore$ Loading effort for r^{th} slice will be $2r\Delta x/v$.

$\therefore$ Total loading effort required is, $T_L = 2.\sum_{r=0}^{2a}(2\Delta x/v).r = (4\Delta x/v).(0 + 1 + 2 + \text{---------} + 2a)$

$\therefore T_L = (4\Delta x/v).a(1 + 2a)$ (11)

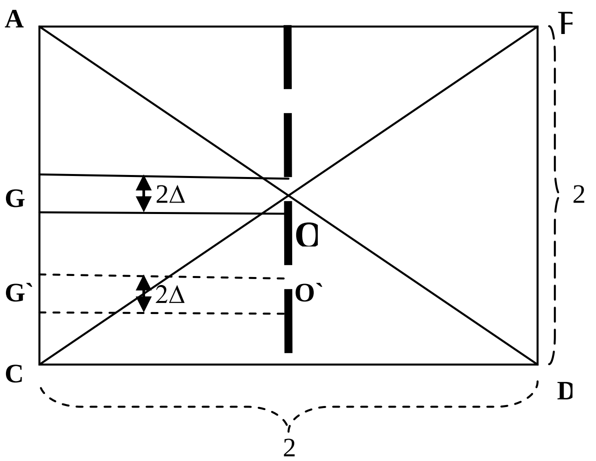
$\therefore$ Total effort required to mine the entire area, $T = T_C + T_L$

$\therefore T = 4abt + (4\Delta x/v).a(1 + 2a) = 4a[bt + (\Delta x/v).(1+2a)]$

$$\boxed{\therefore \mathbf{T = 4abt + 4a(\Delta x/v).(1+2a)}}$$

3.6. Rectangular Boundary, Pit At The Centroid With Horizontal Movement

Let, AB = 2a and BD = 2b



Let, the cutting width be $2\Delta x$ i.e. the width of OG.

Cutting movement will be horizontal i.e. parallel to $\overrightarrow{AB}$ or $\overrightarrow{CD}$ direction.

Here, one conveyor belt will be placed in the direction $\overrightarrow{OO`}$.

Let the cutting effort ∞ t m^2/sec.

Let the loading effort ∞ v m/sec.

Cutting effort required for one slice is $2\Delta x.a.t$

$\therefore$ Total cutting effort required, $T_C = 2.2\Delta x.a.t.(2b/2\Delta x)$ [$\because$ the activity will be repeated $2b/2\Delta x$ number of times]

$\therefore T_C = 4abt$ (12)

Loading the r^{th} slice will be at a distance $r.2\Delta x$ from the pit O.

$\therefore$ Loading effort for r^{th} slice will be $2r\Delta x/v$.

$\therefore$ Total loading effort required is,

$$T_L = 2.\sum_{r=0}^{2b}(2\Delta x/v).r = (4\Delta x/v).(0 + 1 + 2 + \text{---------} + 2b)$$

$\therefore T_L = (4\Delta x/v).b\,(1 + 2b)$ (13)

$\therefore$ Total effort required to mine the entire area, $T = T_C + T_L$

$\therefore T = 4abt + (4\Delta x/v).b(1 + 2b) = 4b[at + (\Delta x/v).(1+2b)]$

$$\boxed{\therefore \mathbf{T = 4abt + 4b\,(\Delta x/v).(1+2b)}}$$

4. Discussion and Conclusion

The Total Efforts required for mining the differently shaped mine boundaries with Pits located at different positions with different mining movements are given as follows:

Shape of the Boundary	Pit Location	Mining Movement	Total Effort required (T)
Circular	Centre	Radial	$\pi r^2[t + r/v]$
Circular	**Centre**	**Arcwise**	$\mathbf{8r\Delta x[(r/v) + t]}$
Circular	Periphery	Radial	$\pi r[rt + \{r^3/v + 2r + r(\pi r/\Delta x - 1)\}.\Delta x]$
Circular	Periphery	Arcwise	$2r[3\Delta xt + 1/v + \pi^2/8]$
Rectangular	Centroid	Horizontal	$4abt + 4b(\Delta x/v).(1+2b)$
Rectangular	Centroid	Vertical	$4abt + 4a(\Delta x/v).(1+2a)$

From this table we can see that given the shape of the mine boundary *circular*, pit at the *centre* with *arcwise* movement takes the least effort to mine the entire area as the highest order of r in the expression is r^2. Similarly, we can see for rectangular shape of mine boundary pit at the *centre* with *vertical* mining movement takes the least effort to mine the entire area since $a < b$.

Now, comparing these two least efforts for the circular and rectangular shapes of mine boundary respectively, we can say that the Total Effort required for the circular shape would be lesser than that of the rectangular one.

So, finally we can conclude that a circular shape of mine boundary with pit at its centre with an arcwise mining movement will take least effort to mine the entire area.

5. Future Scope of Research

We have considered in our paper only two shapes of mine boundary, circular and rectangular. But, in reality the mine boundary can have many different shapes. The most general shape of a mine boundary can be assumed to be *polygonal*. So, this work can be further extended for a polygonal shape of a mine boundary, considering it as a summation of some finite scalene triangles. Moreover, we have considered only the 'Size and shape factors of the property'. The optimal location of pit can be obtained by incorporating all the other factors that could affect the mining operations into the calculation for a polygon shaped mine boundary.

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