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Ventilation shaft construction by conventional freezing method in Maddhapara Granite Mine, Bangladesh

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Abstract : *The The Korea South–South Cooperation (NAMNAM) started to explore the Maddhapara Hardrock mine in 1994 within an area of 1.25 Km^2 and handed over it to Petrobangla. Petrobangla is planning now to extend the area of mine to fulfill the yearly production target 1.65 million tons. There are two shafts (skip & cage) at Maddhapara Hardrock mine and NAMNAM didn't propose any ventilation shaft for ventilation. But if the mine will go for targeted production then more air will be required for miners for a good working environment. This additional air can be ventilated though a ventilation shaft. The present study proposes a ventilation shaft that can be constructed by conventional freezing method.*
Keywords - *Ventilation shaft, Freezing method, Ice wall, Vertical Ground Pressure, Freezing hole.*

I. INTRODUCTION

The introduction of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

Maddhapara Granite Mining Company Limited (MGMCL) is the first experience of underground hard rock mining and the second major mining project in Bangladesh. Geographically the Maddhapara area is lies between Latitude $25^0 23^/ 22^{//}$ N and $25^0 34^/ 43^{//}$ N and longitudes $89^0 03^/ 34^{//}$ E and $89^0 05^/ 04^{//}$ E in the Parbatipur Thana, Dinajpur district (Fig.-1).

Due to expansion of mine area, volume of required fresh air will be increased. So, additional ventilation shaft is necessary to provide the required fresh air to the miners. The interested mineral resources 'hard rock' is located beneath the loose sand and water-bearing zone, known as Dupi Tila. Therefore, the proposed shaft can be developed by conventional freezing method. The original technology was developed by F.H. Poetsch in 1883 and has been used in mining industries for over 100 years. Freezing can save the shaft from influx of water, providing ice-wall between the water outside and the shaft itself is strong enough to resist the hydrostatic pressure. Artificial ground freezing is an effective method of stabilizing wet, unconsolidated ground and controlling groundwater inflows.

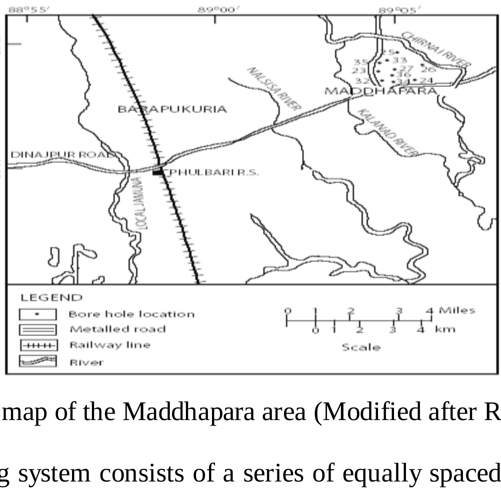

Fig. 1: Location map of the Maddhapara area (Modified after Rahman, 1987)

A typical ground freezing system consists of a series of equally spaced boreholes that are drilled on a concentric circle enclosing the site of the shaft. The freeze pipes installed around the perimeter of the proposed excavation and extend into the subsurface strata. The probe contains an external pipe and an open-ended inner tube of slightly shorter length (Fig. 2).

The freezing tubes are connected with two circulation mains, in such a manner that cold brine may be pumped down the inner tube and

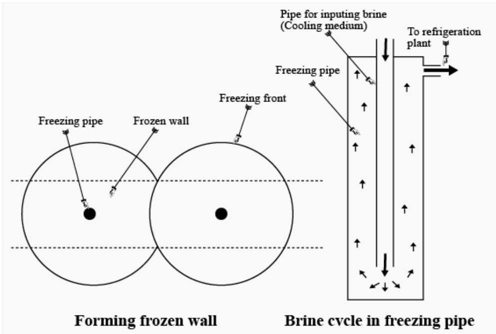

Fig. 2: The principle of ground freezing method

allowed to return along the annular space between the two tubes and thence through the collection main back to the refrigeration plant. A water-based calcium chloride solution (brine) is chilled by a series of electrically-powered refrigeration plants. A cylindrical column of soil and ground freeze around each pipe as the brine circulates through the closed-loop pipe system. The size of the frozen soil columns increase with time and form an extremely strong, virtually watertight and impermeable barrier (Fig. 3).

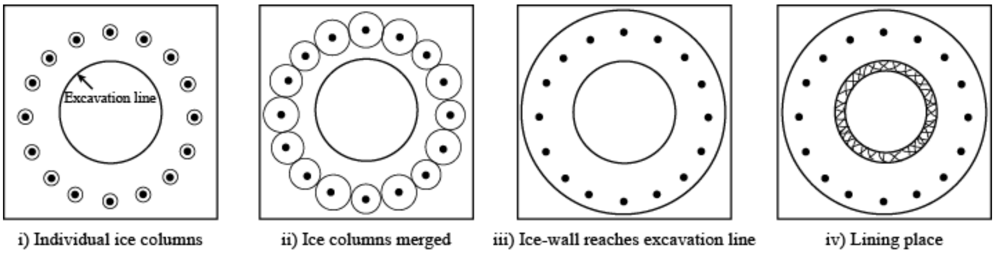

Fig. 3: Stages in growth of the ice-wall (Modified after Harris, 1995)

II. METHODOLOGY

Extensive field work has been carried out to collect required sample, various data related to freezing such as previous temperature monitoring data, excavation data, and deviation data for freezing borehole etc. Collecting all the required data from relevant institutions, the present study has calculated all the following parameters related to artificial ground freezing. In this respect mathematical calculation for thickness and height of frozen cylindrical wall; number and volume of frozen cylinder; total amount of calorie to be absorbed and heat loss during freezing; net and total productivity of freezing equipment; operation period of freezing horizon; amount of brine consumption; and diameter of brine main and inner diameter pipe have been calculated during the present research work.

III. GEOLOGY

Geology is the most reliable tool to know sub-surface information of an area. So detail study on geology is necessary before shaft sinking. Geo-engineering properties of different layers can be achieved from geological data. In account of shaft construction by artificial freezing method, it is very important to know the hydro-stratigraphic succession. The hydro-stratigraphic succession of Madhapara area is shown in Table-1.

Table 1: Hydro-stratigraphic succession of the Maddhapara area.

Age	Lithologic Unit	Lithology	Hydro-structural Unit	Average Thickness (m)
Recent-Pleistocene	Alluvium-Madhupur Clay	Sandy and silty clay	Aquiclude	0.52 6.18
Pliocene to Eocene	Dupi Tila	Sandstone and pebbly sandstone, pebble bed and siltstone, fine to coarse grained and few dark minerals and quartz present	Porous aquifer	113.27
	Tura Sandstone	Medium to coarse grained sandstone with subordinate calystone and shale		20.14

<table>
<tr><td>Permian</td><td colspan="2">Gondwana Group</td><td>Mostly feldspathic sandstone with conglomerate beds, fine to medium grained dark minerals. It is hard and massive</td><td></td><td>170.1</td></tr>
<tr><td rowspan="3">Archean</td><td rowspan="3">Basement rock</td><td>Completely and highly weathered zone</td><td rowspan="3">On top kaolinized weathered rock. Fresh rock: granodiorite to quartz diorite and gneiss, pegmatite, quartz veins</td><td>Weathered zone of Basement</td><td>14.05</td></tr>
<tr><td>Slightly weathered zone</td><td>Fissure artesian aquifer</td><td>23.74</td></tr>
<tr><td>Fresh rock</td><td>Aquiclude</td><td>unknown</td></tr>
</table>

IV. HYDROGEOLOGY

The hydrostratigraphic succession of the Maddhapara area is given in the table 1 and hydrogeologic cross section is presented in fig. 4.

Two types of aquifer, namely the porous aquifer and the fissure artesian aquifer, characterize the Maddhapara Hardrock Mining Project area. The Tertiary Dupi Tila, Tura Sandstone Formations and Gondwana rocks of Permian age constitute the porous aquifer of 30m. thickness although mudstone layer interbeded them, which is not impervious from hydrogeological point of view.

The thickness of porous aquifer is 134m. The fissure artesian aquifer in the Archean Basement rock consist of numerous structure fissures, joints and groundwater penetrate into the fissure to form fissure artesian aquifer.

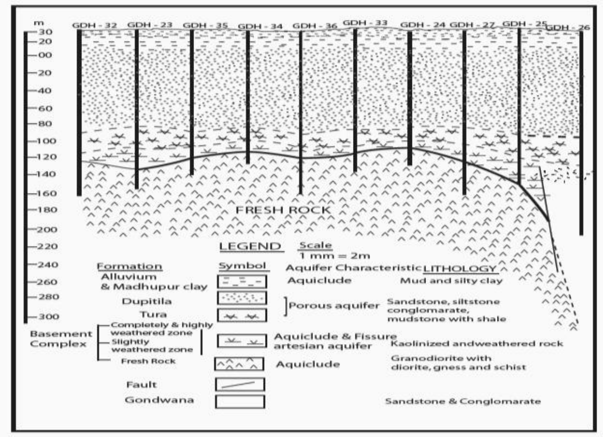

Fig. 4: Hydrogeologic cross section of Maddhapara area (Modified after Rahman, 1987**)**

The Permeability in porous aquifer is 34 m/day and in fissure artesian aquifer varies from 0.032 to 0.196 m/day in average (NAMNAM, 2000). The huge water inflow from the porous aquifer may stop shaft sinking operation.

V. DISCUSSION AND CALCULATION

Today, freezing method becomes one of the most important special methods in the construction of underground buildings including shafts in a complex and unstable aquifer formations in mining industry due to its high reliability and good security. In recent years, freezing method has become popularized in construction projects such as Metro and city communication too. In engineering geology many geotechnical processes (Groundwater lowering, Injection method, Compressed air, Artificial ground freezing etc.) are used to modified soil properties and incoherent rocks to make them suitable to run engineering operations without any risk of collapse or flooding.

Particle size of different lithological formations and their permeability are very important for proper applicability of geotechnical process (Littlejone, 1993). Considering lithology, hydrogeological & engineering geological properties and cost of operation, Artificial Ground Freezing (AGF) method is considered as most suitable technique for ventilation shaft construction in Maddhapara Hardrock Mining Project.

Freezing design calculation: The Maddhapara hard rock mine has two shafts namely Skip Shaft-for rock lifting and Cage Shaft-for man and material lifting. The lithological data of Maddhapara area reveals that the total thickness of clay, aquiferous sand, & kaolin layer and pebbly weathered Basement is 148.3m. As both the shafts were constructed unstable soil and aquifer layer, conventional freezing method was used to protect water flow and to improve the soil strength.

The most important parameters those have to be considered before shaft sinking by freezing method is to calculate thickness of ice wall, Tongki formula, vertical ground pressure, diameter of arrangement circle, number of freezing hole, allowable face height, volume of frozen cylinder, total calorie to be adsorbed, net productivity of freezing equipment, heat loss, total productivity of freezing equipment, number of freezing compressors, operation period by calorie absorbed, operation period for ensuring freezing column, calorie needed to keep frozen state, brine consumption for freezing cellar, diameter of main brine delivery pipe, diameter of inner brine delivery pipe, and stream velocity of brine in freezing pipe.

Thickness of ice wall: Calculation of the thickness of ice wall is one of the main parameters in artificial ground freezing method. By considering cylindrical shape of ice wall, the thickness of ice wall E, can be calculated using Rame formula (NAMNAM, 1996) –

$$E = R\left(\sqrt{\frac{(\sigma)}{(\sigma)-2P}}-1\right) = 1.993m \qquad \text{- (1)}$$

Where

R-Initial sinking radius of shaft = 2.4m

(σ)-Allowable compressive strength of frozen rock $= \dfrac{\sigma}{k} = 4.33$

σ -Compressive stress of freezing horizon = 6.5

K-Safety coefficient = 1.5

P-Maximum ground pressure in freezing zone = 1.52 MPa

The thickness of frozen rock cylindrical ice wall (E) is calculated by Rame formula and it is checked by Tongki formula, the equation is-

$$\frac{E'}{R} = 0.29\frac{P}{(\sigma)} + 2.3\left(\frac{P}{(\sigma)}\right)^2 = 0.923m \qquad \text{- (2)}$$

If $E > E'$, then freezing method is satisfied with the original required condition and vice versa.

Vertical ground pressure: Vertical ground pressure (P_v) is related with thickness of ice wall and maximum ground pressure (P). If the vertical ground pressure is lower than the maximum horizontal ground pressure of a particular zone then the horizon/layer will sustain against vertical pressure. Vertical ground pressure can be calculated by following equation:-

$$P_V = \frac{H \times r}{1000 \times 1000} = 0.295MPa \qquad \text{- (3)}$$

Where

H-Depth of freezing layer = 1.41.2m

r-Average volumetric weight of frozen rock = 2090 Kg/m^3.

Diameter of arrangement periphery of freezing hole: The diameter of arrangement circle of freezing hole (D_f) is calculated depending on the thickness of freezing wall (E). The equation to calculate diameter of circle arrangement of freezing hole is as follows-

$$D_f = D_s + 2(0.6E + m) = 8.18m \qquad \text{- (4)}$$

Where

D_s-Initial sinking diameter = 4.8m.

0.6 -Coefficient as considered that the freezing circle causes a reaction towards the direction of shaft center (0.6E towards the direction of shaft center, 0.4E towards the direction of outside).

m-Coefficient of correction considering declination of hole to be frozen from the vertical state and it is expressed as m=H%

H-Depth of frozen layer =141.2m.

Number of freezing hole: The number of freezing holes is calculated depending on distance between freezing holes as follows-

$$N = \frac{\pi \times D_f}{L} = 21.4 \qquad - (5)$$

Where

L-Distance between freezing hole = 1.2m

All the parameters required to design a vertical ventilation shaft following artificial ground freezing method including calculation are shown in the following **Table:**

Thickness of ice wall $E = R\left(\sqrt{\frac{(\sigma)}{(\sigma)-2P}}-1\right)$	R-Initial sinking radius= 2.4m (σ)-Allowable compressive stress of freezing horizon P-Maximum ground pressure in freezing zone, 1.52 for Kaolin and 1.32 for sand layer
$(\sigma) = \frac{\sigma}{K}$	σ-Compressive stress of freezing horizon, 6.5 for Kaolin layer and 6.8 for sand layer K-Safety coefficient= 1.5
Tongki formula $\frac{E'}{R} = 0.29\frac{P}{(\sigma)} + 2.3\left(\frac{P}{(\sigma)}\right)^2$	R-Initial sinking radius= 2.4m (σ)-Allowable compressive stress of freezing horizon P-Maximum ground pressure in freezing zone, 1.52 for Kaolin and 1.32 for sand layer
Vertical ground pressure $P_V = \frac{H \times r}{1000 \times 1000} Mpa$	H-Sum of aquifer thickness, 141.2m up to Kaolin and 123.4m up to sand layer r-Average volumetric weight of frozen rock, 2090 Kg/m^3 for Kaolin and 2034 Kg/m^3 for sand layer
Diameter of arrangement circle $D_f = D_s + 2(0.6E + m)$	D_s-Initial sinking diameter= 4.8m m-Coefficient of correction considering declination of holes to be frozen from the vertical state and drilling deviation degree (0.35%)= H% H-Sum of aquifer thickness, 141.2m up to Kaolin and 123.4m up to sand layer
Number of freezing hole $N = \frac{\pi \times D_f}{L}$	L-Distance between freezing hole= 1.2m
Allowable face height $H = E \times \frac{(\sigma)}{r \times H}$	(σ)-Allowable compressive stress of freezing horizon r-Average volumetric weight of frozen rock, 2090 Kg/m^3 for Kaolin and 2034 Kg/m^3 for sand layer H-Sum of aquifer thickness, 141.2m up to Kaolin and 123.4m up to sand layer
Volume of frozen cylinder $V = F \times H$	F-Sheared width of frozen rock cylinder H-Freezing depth= 141.2m
$F = \frac{\pi}{4}\left(D_0^2 - D_i^2\right)$	D_0-Outside diameter of frozen rock cylinder D_i-Inside diameter of frozen rock cylinder
$D_0 = D_f + 2(0.4E)$ $D_i = D_f - 2(0.6E + m)$	m-Coefficient of correction considering declination of holes to be frozen from the vertical state and drilling deviation degree (0.35%)= H%
Total calorie to be adsorbed $Q_t = 1000 \times V\{n_s \times \delta \times 0.2(t_s - t_f) + n_w(t_s + 80 - 0.45$	V-Volume of frozen cylinder= 16801.4m^3 n_s-Quantity of solid part in aquifer= 0.75 δ-Specific heat = 2.65 t_s-Temperature of initial rock= 29ºC t_f-Average temperature of frozen rock= -10ºC 80-Heat as needed in converting water to ice at temperature 0ºC (Kcal/kg) n_w-Quantity of liquid part in the aquifer= 0.25
Net productivity of freezing equipment $Q_n = F_f \times C$	F_f-Sum of outside surface area of freezing pipe C-Calorie to be absorbed through F_f outside surface area of freezing pipe from the surrounding horizon at brine temperature -30ºC= 250 Kcal/m^2/h
$F_f = \pi \times d \times H \times N$	d-Outside diameter of freezing pipe= 0.146m H-Freezing depth= 141.2m N-number of freezing hole=22

Heat loss $S_1 = F_t \times C_s$ $S_2 = (0.2 \approx 0.25) \times Q_n$	F_t-Total surface area of frozen cylinder C_s-Calorie flowing from surrounding= 6 Kcal/m^2
$F_t = (D_0 + D_i) \times H$	H-Freezing depth= 141.2m
Total productivity of freezing equipment $Q_t = Q_n + S_1 + S_2$	
Number of freezing compressors $n = \frac{Q_t}{Q_i}$	Q_t-Total productivity of freezing equipment= 766483.5 Kcal/h Q_i-Cold heat productivity of installed freezing equipment, theoretical cold heat productivity=200000 Kcal/h and practical cold heat productivity=180000 Kcal/h
Operation period by calorie absorbed $T = \frac{Q_t}{(Q_n - S_1) \times 24}$	Qt-Total calorie to be absorbed= 720192011 Kcal/h Qn-Calorie to be extracted from the rock by freezing pipe= 564750 Kcal/h
Operation period for ensuring freezing column $T = \frac{r}{V_1}$	V1-Propagation speed of ice= 0.015 m/day for Kaolin and 0.02 m/day for sand layer r-radius of freezing column= 0.99m
Calorie needed to keep frozen state $Q_k = S_1 + S_2$	S1-Heat loss as takes place from the calorie S2-Heat loss due to wrong heat insulation of conduit network and freezing equipment
Brine Consumption for freezing cellar $V_b = \frac{Q_f}{(t_2 - t_1) \times \delta_b \times C_b}$	Qf-Total productivity of theoretical freezing equipment= 1000000 Kcal/h δb-Specific gravity at -43ºC of freezing temperature= 1270 Kg/m3 Cb-Specific heat of brine= 0.64 Kcal/Kg/1ºC t1-Temperature of cold brine ºC t2-Temperature of warm brine ºC; t1 ≈ t2= 2 ≈ 3ºC, in average about 2.5ºC
Diameter of main brine delivery pipe $d = \sqrt{\frac{4 \times V_b}{\pi \times V \times 3600}}$	V-Stream velocity of brine= 1.5 ≈ 2.0 m/s
Diameter of inner brine delivery pipe $d = \sqrt{\frac{4 \times V_b}{\pi \times V \times n \times 3600}}$	V- Stream velocity of brine in inner delivery pipe= 0.6 ≈ 1.5 m/s n-Number of freezing pipe= 22 The specification is as follows:-Inner diameter= Φ60mm; Outer diameter=Φ67mm; Thickness= 3.5mm
Stream velocity of brine in freezing pipe $V_r = \frac{4 \times V_b}{\pi (d_{fi}^2 - d_{bo}^2) \times n \times 3600}$	dfi-Inner diameter of freezing pipe= 0.13m dbo-Outer diameter of brine delivery inner pipe= 0.067m n-Number of freezing pipe=22

VI. RESULT AND DISCUSSION

Ventilation is a very important task in underground mining. To maintain a good working environment into underground hardrock mine, the present study suggest to construct the ventilation shaft before extend the development activities to increase its production rate. As the hardrock is overlying by water bearing zone, the study also suggests to construct the ventilation shaft by conventional freezing method. Considering 2.4m radius of the proposed shaft, the calculated thickness of frozen wall (1.993m) is more than the thickness of frozen rock according Tongki Formula. Therefore, the conventional freezing method is applicable for shaft sinking at Maddhapara Hardrock Mine. According to geology and hydrogeological condition of Maddhapara area there are two definite sections (Lower kaolin & Upper sandy section) in which freezing operation need to be accomplished.

The locations of freezing borehole, pressure release borehole and temperature monitoring borehole of the proposed shaft is shown in fig. 5.

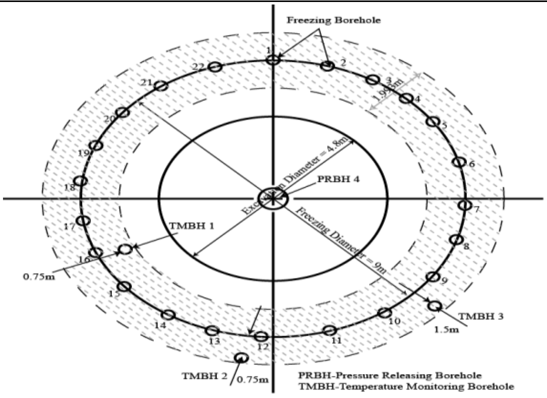

Fig. 5: Proposed locations of freezing, pressure releasing & temperature monitoring borehole

Arrangement circle diameter of freezing hole is 8.18m. Therefore, in design the diameter of arrangement circle of freezing hole will be 9m. Total numbers of freezing boreholes are 26, among them freezing boreholes – 22, temperature monitoring boreholes –3 and pressure releasing borehole –1.

VII. CONCLUSION

Bangladesh is a developing country, so high extraction ratio from mine is the main target to meet large-scale demand of hard rock throughout the country. In this context, Maddhapara Hard rock Mining Company is thinking to extend the mine boundary. For this reason, they have to modify mine ventilation system, otherwise mine production capacity will be hampered due to decrease of labor efficiency as well as problem of health hazard will occurred. If, they would like to modify ventilation system, an additional shaft construction is necessary. From economic point of view, we propose ventilation shaft construction by conventional freezing method. This paper justified the liability of shaft sinking by conventional freezing method. The calculation results of freezing method are adequate considering subsurface condition of Maddhapara area.

To develop the ventilation system a ventilation shaft need be constructed at Maddhapara. Considering geology, hydrogeological condition & engineering properties of the Maddhapara area and considering the advantages of freezing method which is environmentally noninvasive, twice as strong as concrete, creates an impervious layer, works in all types of soil and groundwater conditions, controls water flow, eliminates the need to discharge massive volumes of water on the surface, lower the operating costs than dewatering or grouting, can be completely removed after construction, if needed, the present study recommend to construct the proposed ventilation shaft by conventional freezing method.

The present study reveals that 2.4m initial sinking radius or excavation diameter support all the required parameters to apply conventional freezing method. Considering 2.4m radius of the shaft we need to drill only 26 boreholes around the periphery of the shaft and the freezing diameter will be 9m. The present study also recommend for additional 0.5m block lining, 0.005m pvc lining and 0.3m concrete lining with 4.8m excavation dia. of the proposed shaft.

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