Pak. J. Sci. Ind. Res. 2004 ***47****(2) 112 - 117*

Artificial Ground Freezing Method for Shaft Construction in Maddhapara Hardrock Mine, Bangladesh: Minimization of its Cost

Chowdhury S Jahan*, Chowdhury Quamruzzaman, Quamrul H Mazumder and Talukder AHFMA Haque

Department of Geology and Mining, University of Rajshahi, Rajshahi 6205, Bangladesh

(Received October 23, 2002; accepted November 17, 2003)

The Korea South-South Cooperation Corporation (NAMNAM) used Artificial Ground Freezing (AGF) during 160 m depth shafts (cage and skip) construction in the Maddhapara Hardrock Mining Project (MHMP). The freezing design calculation for AGF operation showed that freezing wall thickness was satisfactory for both kaolin and sand layer at existing vertical ground pressure. But after AGF operation freezing status revealed that the ice wall thickness in skip shaft attained as per design, but in cage shaft the achieved thickness was more than the expected due to deviation from original design for freezing hole by NAMNAM i.e., drilling of 31 freezing holes instead of 32 for cage shaft. The ice-wall bonding had affected the whole rock mass of the inner diameter of cage shaft that became hard like rock, but this effect was not so intensive for the skip shaft towards the inner portion and did not create any severe problem. As a result the cage shaft was excavated with explosive (drilling blasting) involving additional time (3 months) and cost (US$1,51,866), which NAMNAM could avoid by sinking an additional 160 m deep freezing hole during cage shaft construction with a cost of US$18,045 and thus saving a total of US$1,33,820 for the whole operation in MHMP.

***Key words*: Artificial Ground Freezing, Maddhapara Hardrock Mine, Cost effectiveness.

Introduction

Freezing is reliable, safe and cost - effective approach for the development of mine and civil engineering construction within the water bearing zone for the protection of water leakage from aquifer, especially to counter the tendency of seepage and collapse of the side wall (Harris 1995). Artificial Ground Freezing (AGF) method was used for the first time in 1862 for a mineshaft construction in Swansea in South Wales and is widely used till today for ground freezing without affecting the water table or the quality of ground-water.

In 1974 - 1976, the Geological Survey of Bangladesh (GSB), based on the results of geophysical prospecting, located dome-shaped body of Archean Basement of the Indian Platform of granodioritic composition in the Maddhapara area at the shallowest depth of 128 m from the surface. The Korea South-South Cooperation Corporation (NAMNAM) of the Democratic People's Republic of Korea came into contract with the Petrobangla (Bangladesh Oil, Gas and Mineral Corporation) in 1994 for the development of underground hardrock mine in Maddhapara. Then, Maddhapara Hardrock Mining Project (MHMP) came into existence with annual production target of 1.65 million ton of rock. It is the first experience of hardrock mining and the second major mining project in Bangladesh (Fig 1).

The Basement Complex has two units; fresh and weathered. The fresh rock forms the fissure artesian aquifer (NAMNAM 2000). The weathered portion is divided into weathered layer in the lower part, and impervious kaolin layer in the upper part. Tertiary Dupi Tila Formation, Tura Formation and Permian Gondwana Group lie above the Basement and form porous aquifer with 26°C temperature at the top and 31°C at the bottom, and hold non-pressure gravitational water that infiltrate into it. Impervious Madhupur Clay overlies the porous aquifer.

Keeping in mind hydrogeological and engineering properties of the formations, AGF method was used for sinking cage and skip shaft, which is the first experience of this kind in Bangladesh. The period of construction as per schedule for the skip and cage shafts was 3 months. The construction of skip shaft was completed as per schedule, but additional 3 months were needed for the cage shaft construction involving additional cost of manpower, pneumatic air, explosive per shift per hole and power, which was not considered in the project proposal. So, the study on the AGF for shaft construction in MHMP is carried out to authenticate the financial involvement in shaft construction after practical experience.

Experimental

Shaft sinking by AGF method in MHMP. Two types of vertical shafts were constructed; cage shaft for transporting class locomotive and mine car for man and material lifting, and skip shaft for lifting 1.65 million tons of rock a year. Polish double-step compression of refrigerant plant was used for

*Author for correspondence

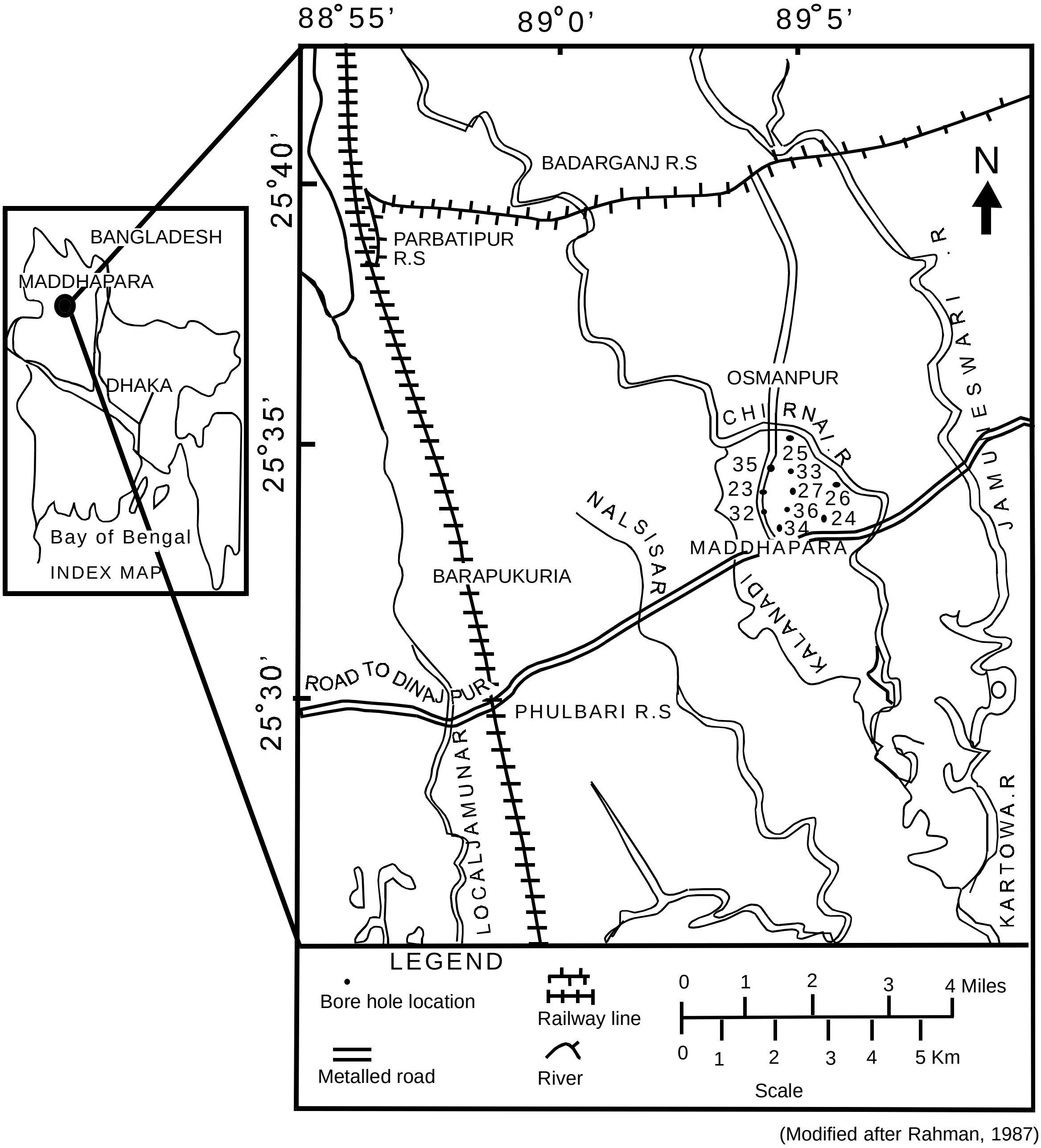

Fig 1. Location map of the study area.

AGF method in MHMP. At first, boreholes were drilled with 0.8-2.0 m interval along the perimeter of shafts and then freezing pipes were put into the holes. Water solution mixed with $CaCl_2$ was supplied into the freezing pipes by pump. As a result of continuous circulation of the chilled salt water into the freezing pipes, water within the rock mass was frozen. The ice column was formed gradually around each borehole and after a certain period a united ice wall was formed and the sinking of shaft began. The longitudinal section of freezing boreholes is shown in Fig 2.

Drilling of freezing boreholes for cage and skip shaft. Shaft construction design in MHMP was divided into; the freezing section for aquifer zone and non-freezing section for fresh rock at the bottom of mine. The total depth of freezing borehole in the freezing section of aquifer zone was 154 m (Juche 1998). The initial sinking diameter and finished diameter of shafts were 6.8 and 5.0 m, respectively. The number and dia-meter of freezing hole were 32.0 and 11.5 m, respectively.

According to the project proposal of NAMNAM for ground freezing operation before the construction of shaft, a total of

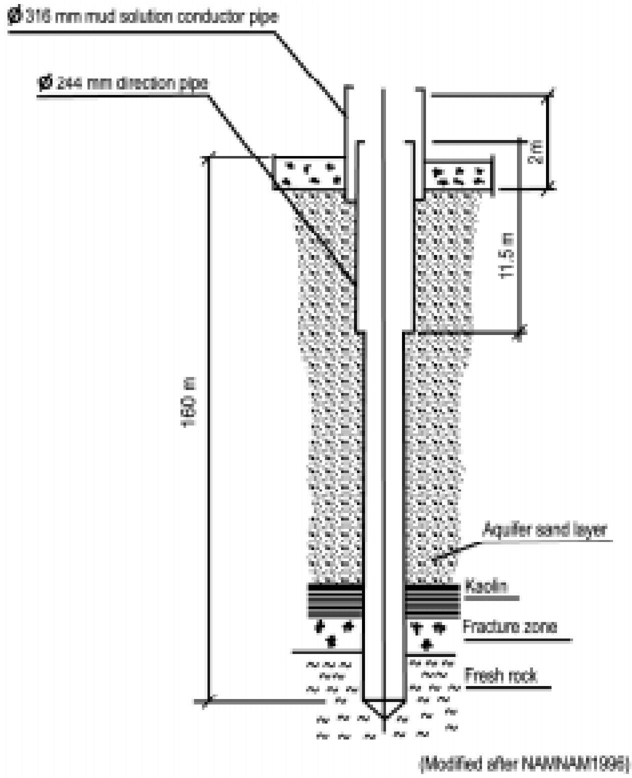

Fig 2. Longitudinal section of freezing borehole in MHMP.

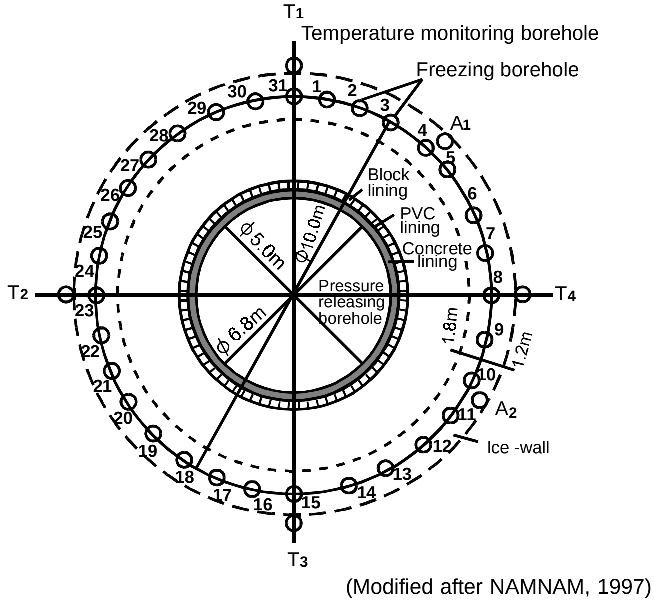

Fig 3. Arrangement of freezing borehole for cage shaft sinking.

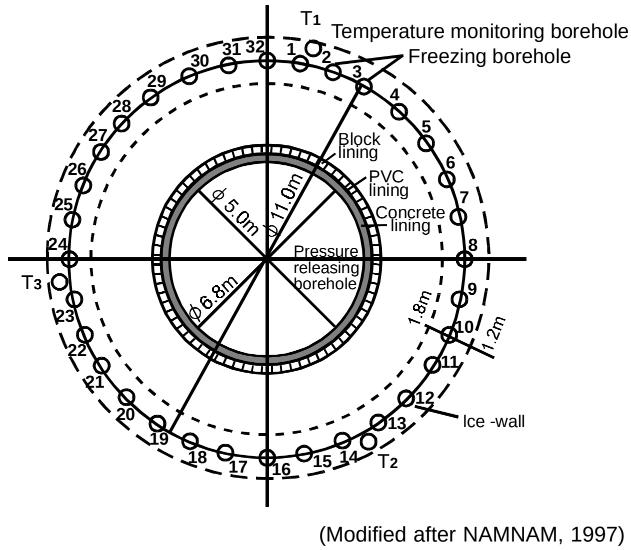

Fig 4. Arrangement of freezing borehole for skip shaft sinking.

75 freezing and temperature measuring boreholes were planned to drill. But they drilled 74 freezing, center, supplementary and temperature measuring boreholes of which 63 were freezing boreholes (32 for skip shaft and 31 for cage shaft) from October 28, 1995 to October 21, 1996 (NAMNAM 1999). The arrangements of freezing borehole for cage and skip shafts are shown in Fig 3 and 4, respectively.

Calculated values for freezing design before AGF operation in the present study showed that the thickness of freezing wall was satisfactory for both kaolin and sand layers and their values were 2.83 and 1.88 m, respectively at existing vertical ground pressure, but during AGF operation, the thickness were achieved as 3 and 2 m, respectively.

Technology of mass freezing. Freezing work in MHM included two steps; (i) Active freezing work, it started to activate the freezing wall first. The difference of temperature of inlet and outlet brine at the initial time of active freezing work was 3 - 5˚C in normal. The difference of temperature of outlet and inlet brine for the first 10-15 days of freezing was about –3.5˚C and gradually it reached to 2 - 3˚C at the end of active freezing and it reached to below 1˚C in the passive freezing period. Temperatures were recorded from temperature measuring borehole at a depth of 10 m interval once in a day during active freezing period.

(ii) Passive freezing work; Passive freezing starts to maintain the required thickness of ice wall just after completion of active freezing and is continued up to total construction.

Observations in course of stratum freezing. After AGF operation and before the construction of shaft, the temperature of stratum freezing and ice wall thickness at 10 m interval from three temperature monitoring holes arranged at different distances (0.8, 1.0, 1.25 and 1.5 m) at inner and outer circle of the freezing ring. It was measured in MHMP by NAMNAM (NAMNAM 1996). These data are used in the present study. The temperature data are plotted graphically with respect to depth for the months of November 1996 to December 1997 and

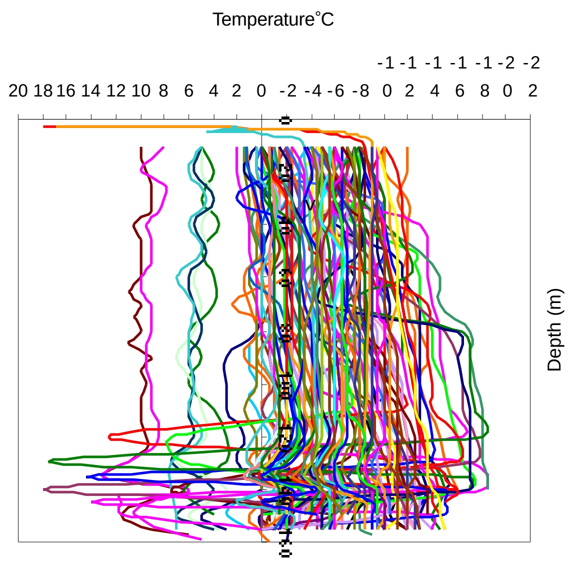

Fig 5. Freezing status of cage shaft.

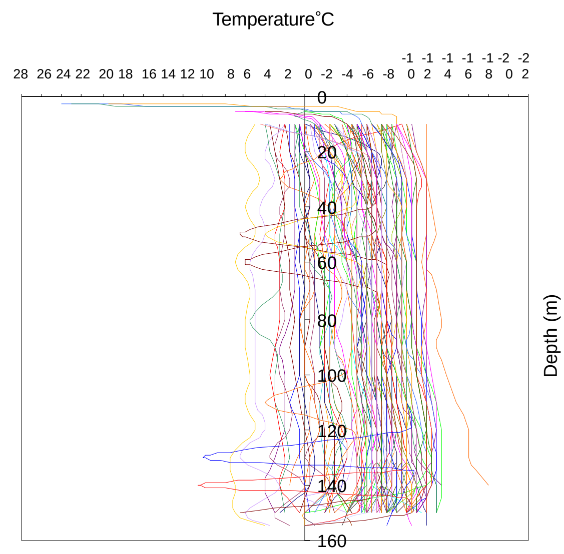

Fig 6. Freezing status of skip shaft.

the freezing status of the stratum freezing for the shafts are shown in Fig 5 and 6.

It reveals that the thickness of ice wall in skip shaft was achieved as per design but in cage shaft the ice wall attained thickness more than the original design due to wrong freezing planning i.e., drilling of 32 freezing holes was done ins-tead of 31 during cage shaft construction by NAMNAM. The ice-wall thickness in clay layer (up to 7 m depth) did not form well-satisfactory required ice-wall thickness due to presence of capillary water or soil moisture but with increasing depth, on the other hand the ice-wall is formed more satisfactorily in porous sandy aquifer layer.

The ice wall bonding (overlapping) at 10, 50, 130, 140, 150 and 160 m depths of cage and skip shafts are constructed in the present study and their representatives are shown in Fig 7a - f. It is observed that the ice wall bonding has affected the whole rock mass of the inner diameter of cage shaft but for skip shaft, this effect is not so intensive towards the inner portion. The effect of ice wall bonding between depth intervals of 10 - 40 m in the cage shaft is not so intensive but that of between 40 - 50 m depth interval is intensive. This effect became severe below 100 m depth and continues up to 160 m, where ice-wall bonding ingress up to the center of the cage shaft. But the effect of ice wall bonding in case of skip shaft construction through porous aquifer, weathered hardrock and fissure artesian aquifer did not create any severe problem.

Results and Discussion

The periods of skip and cage shaft construction as per schedule were 3 months. But additional 3 months for the cage shaft construction were needed due to wrong freezing planning i.e., deviation from original design for freezing hole and as a result freezing was done so intensively that the total area of the freezing ring as well as the cage shaft excavated area become hard like rock and was excavated with the help of explosive (drilling blasting) involving the additional cost of followings; (a) man - power, (b) consumption of pneumatic air (compressor of 800 kwa / h capacity), (c) consumption of explosive per shift per hole, and (d) power consumption.

(a) *Manpower*. Total cost of additional manpower needed for cage shaft construction is given in Table 1.

(b) *Consumption of pneumatic air*. Jumbo drill machines pneumatic air compressor run in each shift for 6 h per day with two electric compressor of total capacity of 1600 kwa / h. Therefore, the total amount of electricity consumption per day was 9600 kwa / h (6 h × 1600 kwa / h). So, the total cost of electricity for drilling blasting operation during excavation stood US$ 960 (9600 kwa / h × US$ 0.1) considering per unit cost of electricity for industrial purpose in Bangladesh is US$ 0.1. The construction of shaft below 40 m from the surface that was for 120 m (160 - 40) m, compressed air was circulated in 3 shifts in a day with an efficiency of 1.8 m per blasting, involved the total time 22.22{120 ÷ (1.8 × 3)}. So, that the cost of consumption of pneumatic air was US$ 21, 331.2 (US$ 960 × 22.22).

(c) *Consumption of explosives per shift in a hole*. Each blasting had an efficiency of 1.8 m of excavation in the shaft, so excavation of 120 m of freezing part of the shaft needed 66.66 times (120 m / 1.8) of blasting. Each operation consumes 100 kg of explosive and 100pcs of detonators were consumed for

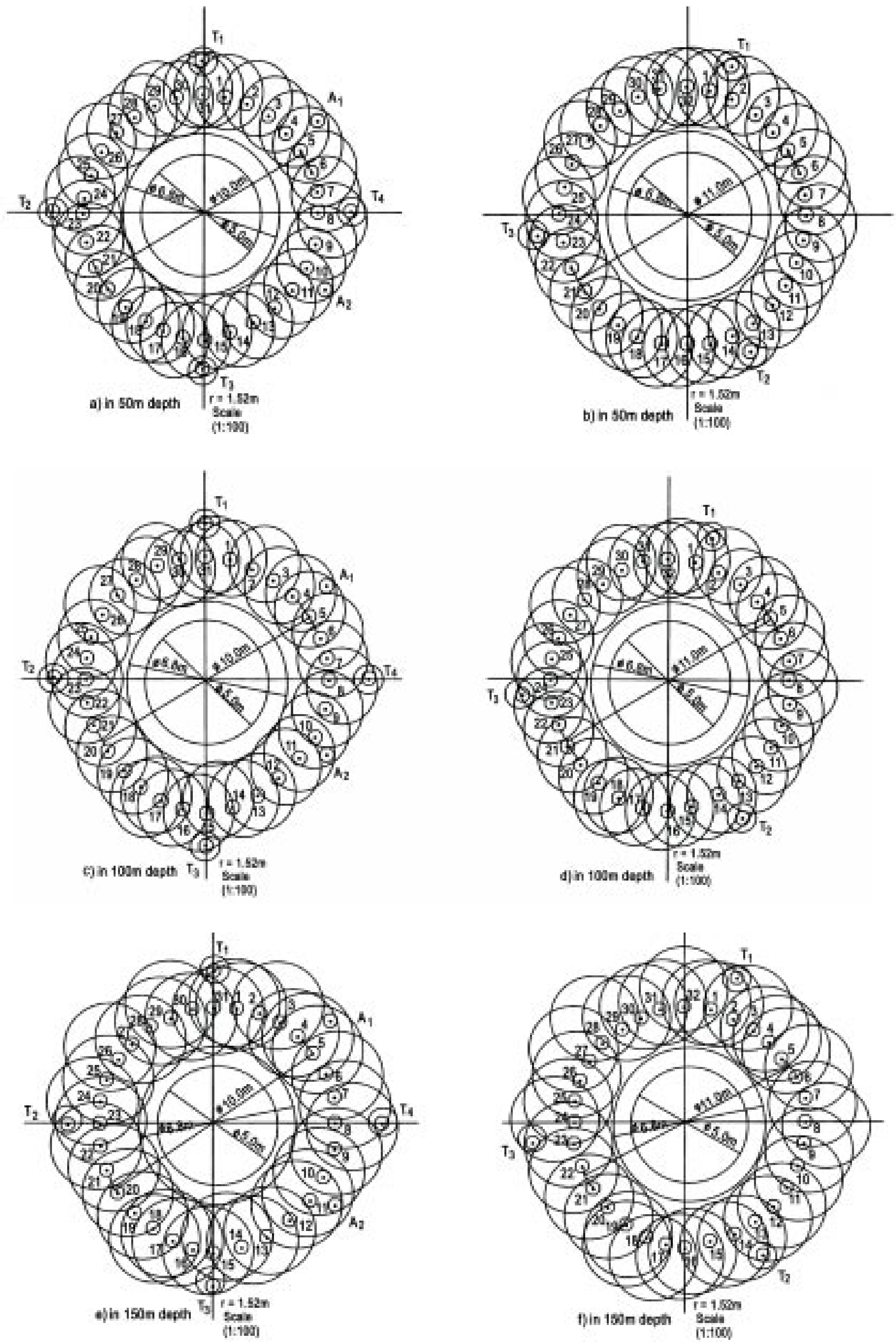

Fig 7. Representatives of ice wall bonding (overlapping) at different depths (a, c, e) for cage shaft and (b, d, f) for skip shaft.

Table 1
Total cost of additional manpower

Personnel expertise	Unit	Per unit salary (US$)	Total salary (US$)
Engineer	1	1,500	1,500
Explosive expert	1	1,500	1,500
Shot firer	2	900	1,800
Explosive loader	4	900	3,600
Mucking labour	10	700	7,000
Signal man	2	700	1,400
		Total for 1 month	= US$ 16,800
		Therefore additional cost for 3 months	= US$ 16,800×3
			= US$ 50,400

blasting operation, so that the blasting explosive involve the cost of US$ 50,000 (66.66 × 100kg = 6666.66 × US$ 7.5) and that of the detonator was US$ 1335 (66.66 × 100pcs = 6666 × US$ 0.2). The total cost of explosive and detonator for blasting operation during shaft construction was US$51,335(US$50,000 + US$ 1,335).

(d) *Electricity consumption for freezing plant*. Each freezing plant was consisted of one compressor with a capacity of 800 kwa / h and four freezing plant units were running uninterruptedly for 3 months. So, the involvement of excess cost was estimated as follow:

800 kwa / h × 4 units × 3 months or 90 days × US$ 0.1 = US$ 28,800.

Finally, the total cost for additional 3 months needed for cage shaft construction due to involvement of excess manpower, consumption of pneumatic air, explosive per shift per hole and electricity for freezing plant was US$ 1,51,866.2, which NAMNAM could avoid by sinking another single 160 m deep freezing boreholes in addition to 31 freezing borehole during the construction of cage shaft, with a cost of US$ 18,045 and thus saves excess time (3 months) and additional cost (US$ 1,33,820) for mining operation in the Maddhapara Hardrock Mining Project.

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C S Jahan, C Quamruzzaman, Q H Mazumder, T AHFMA Haque