PUMPING THROUGH ROCK

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ABSTRACT

Following the flooding of the lower levels of the mine with saturated tailings from No. 3 Dump at Mufulira in 1970, which seriously interrupted the hangingwall aquifer drainage programme, an accelerated dewatering programme was initiated in 1975. The need to pump at maximum available installed capacity could not be achieved, however, owing to problems during pump maintenance and breakdown periods. The result was that the aquifers recharged, which threatened the security of stoping operations. Thus the commissioning of the 810 metre level temporary pump station to provide additional pumping capacity became critical. Due to the shortage of steel pipes for a rising main, it was therefore decided to drill and use a 0.9 metre diameter raise bored hole as a rising main between the 810 and 430 metre levels. The pump station and rock rising main were completed and commissioned within a year, pumping domestic water at a rate of 0.3m^3/sec. The use of unlined raise bored holes as rising mains at Mufulira Division has been a success in terms of efficiency, low cost and flexibility.

INTRODUCTION

Mufulira, situated on the Zambian Copperbelt at an altitude of 1260 metres above mean sea level with an average annual rainfall of 1220 millimetres, is the location of Mufulira Division of Roan Consolidated Mines Limited, one of the largest underground copper mines in the world. Almost 500 000 tonnes/month of copper sulphide ore is produced from three superimposed tabular orebodies.

The orebodies at Mufulira form part of the southern limb of a NW-SE trending syncline and occur as disseminated sulphides in three superimposed arenaceous members of a late pre-Cambrian sedimentary succession. This succession forms the basal part of the Katangan system, known as the "Lower Roan" which lies unconformably on an Archean Basement Complex.

The orebodies, separated by weakly mineralised dolomites, argillites and arenites, are immediately overlain by the Argillaceous Quartzizite, in which several dolomite units occur. Above the Argillaceous Quartzite lies the Glassy Quartzite horizon which is the uppermost member of the Lower Roan Group and marks a major stratigraphic change from the predominantly arenaceous rocks of the Lower Roan Group to the predominantly dolomitic rocks of the Upper Roan Group.

The dolomites of the hangingwall succession are the major water-bearing horizons in the mine area. In the unweathered condition, they are generally white to pinkish in colour, massive, recrystallised dolomite, containing up to 30% anhydrite. Weathering is usually expressed by leaching of anhydrite and some dolomite, leaving a cavernous, water-bearing horizon. Intense weathering can locally reduce the horizon to a manganese or siliceous mud containing fragments of chert and dolomite. In the eastern part of the mine, weathering and thus water-bearing potential, in some of the dolomites is known to persist to depths in excess of 1000 metres.

The lowermost or 'C' orebody is also the largest and persists over a strike length of 5 500 metres, with an average true thickness of 14 metres. Mineralisation occurs predominantly as disseminated chalcopyrite and bornite with an average grade of 3.0% copper. The middle or 'B' orebody overlies the eastern portion of the 'C' orebody for 2 700m with an average true thickness of 11 metres. The 'B' orebody averages 3.6% copper with bornite as the most important ore-mineral. The uppermost or 'A' orebody is the smallest and overlies the 'B' orebody for a strike length of 1800 metres. It has an average true thickness of 9 metres and grade averages 4.1% copper with chalcocite as the predominant ore-mineral. The 'B' and 'C' orebodies persist down dip to below the 1550 metre level, which is the current base of ore reserves, but the 'A' orebody 'bottoms' at about 800m depth.

The Basement Complex comprises a recrystallised sedimentary succession, known locally as the "Lufubu Schist" intruded by granites and granodiorites in the eastern and western extremities of the mine. The Lufubu rocks range from medium-grained micaceous and chloritic quartzites, containing up to 70% quartz, to fine-grained sericitic schists or phyllites in which the quartz content can be as low as 10%. The quartz-rich rocks have a granular texture, but the finer grained sericitic varieties commonly exhibit a schistose texture. Structurally the basement rocks are in general very strong, with compressive strengths in the range of 150-250MN/m^2 but locally prominent joint sets necessitate the use of support for large openings.

HANGINGWALL DRAINAGE AND PUMPING

Of the ore tonnage produced some 70% is currently extracted by caving methods of mining and as hangingwall dewatering is an essential feature of the mining schedule, it has to be completed in an area before caving of the hangingwall can be allowed to take place.

Drainage of the hangingwall is best effected at Mufulira by developing 2.2m x 2.2m crosscuts into the aquifers thereby releasing the water. The drainage crosscuts are advanced under pilot hole cover to safeguard against unexpected holing into a source of water under high pressure. In addition, watertight doors, designed to withstand a head of 412 metres, are sited in competent hangingwall formations prior to intersection of the expected aquifers so that should the need arise, for example in the event of a major pump failure, the water flow from the crosscuts can be quickly and effectively sealed.

Over the decade up to 1970, pumping rates at Mufulira showed a gradual increase from 70 000 to 93 000m^3/day. However in September 1970, the hangingwall dewatering programme was severely disrupted when a major inrush of tailings from a surface dump into the mine led to the temporary loss of the 826 metre level pump station. Following rehabilitation, dewatering resumed, but much progress had been lost and by 1975 it was deemed necessary to introduce an accelerated dewatering programme to ensure that the security of stoping operations would not be threatened. By 1979, the pumping rate had been increased to 110 000m^3/day, the maximum capacity of the 826 metre level pump station.

About 60% of this quantity was uncontaminated "domestic water", piped from active drainage crosscuts, the remainder being contaminated "industrial" water from a variety of sources.

The "domestic water" was transferred to the 826 metre level pump station and pumped to surface via the 430 metre level relay pump station. The relatively high suspended solid content of the industrial water would be detrimental to the clear water pumps installed on the 826 metre level and thus the water was passed through a system of settling sumps prior to pumping. The sludge from these sumps is handled separately by specialised pumps.

However, the need to pump at this rate created problems during pump maintenance and breakdown periods. To compound the problem, a shortage of essential spares for the specialised sludging pumps reduced the efficiency of the settling system. The resultant increased suspended solid content of the"industrial water"inflicted greater wear on the clear water pumps, thereby further increasing the frequency of pump breakdown. By March 1979, all but one of the drainage crosscuts had been closed and considerable recharge of the hangingwall aquifers was taking place.

Thus the commissioning of the 810 metre level pump station to provide additional pumping capacity became critical.

THE 810 METRE LEVEL PUMP STATION

The criteria used for design and location of the new pump station on 810 metre level were minimum project time and cost since the pump station would be a temporary installation. Both the 810 metre level and 826 metre level pump stations would be initially supplemented by the 1040 metre level pump station and then superseded by the next scheduled main pump station on 1255 metre level.

Large diameter steel pipe was unavailable in the country at the time and it would have been prohibitively expensive to airfreight a sufficient quantity into Zambia. Besides this, the established underground routes for installation of pipe rising mains had already been utilised to capacity and establishing a new route and installation of the pipeline would have been an expensive and slow exercise. Thus the possibility of using unlined boreholes as an alternative for a rising main between the proposed new pumping facility on the 810 metre level and the 430 metre level relay pump station was considered.

Being generally homogenous and competent in nature, and outside the zone affected by cave, the Basement Complex affords the most suitable location for permanent installations at Mufulira. Sinking of a secondary shaft system was about to commence near the proposed pump station and rising main location and considerable geotechnical investigations had been carried out to assess the rock mass quality of the Basement Complex in the area. Stereographic interpretation of data from mapping joints exposed in the shaft area indicated that a small, smooth-walled, steeply-inclined opening, such as a raise bored hole, would be unlikely to experience stability problems, provided it did not encroach on the basement/footwall unconformity, where weathering along the joints significantly reduces the strength of the rock mass. It was therefore concluded that the basement rocks would provide a suitable location for the raise bored holes.

Hence the pump station was located in an already developed crosscut to the subvertical shafts which are currently being sunk; and designed to pump clear "domestic water" only, to avoid eleborate settling systems.

Utilization of three 0.15m^3/sec (9m^3/min) Harland pumps and motors previously purchased for a future pump station entailed further savings. With two of these pumps in operation the pump station would handle the additional pumping requirement and have a 50% standby capacity.

The raise bored rock rising main was completed and tested in six months and the pump station was commissioned six months later in July 1980 at a cost of K300 000. Clean "domestic water" is pumped from the 810 metre level to the 430 metre level at the rate of 0.3 cubic metres/second (26 000 cubic metres/day) compared with a mine total to surface of 1.27 cubic metres/second. The new pump station and rising main have provided spare pumping capacity such that regular shutdown and maintenance of pumps can be effected without restricting drainage and jeopardising stoping operations.

DESIGN OF THE ROCK RISING MAIN

The design criteria used for the unlined rock rising main was that the optimum diameter is such that the resultant friction head loss equals the friction head loss in an equivalent length of standard 0.457 metre diameter steel pipe. The pressure at the delivery end of the pumps must be sufficient to overcome the static lift and friction head losses in the rising main. The latter can be expressed in terms of velocity which in turn is inversely proportional to the cross sectional area of the conduit i.e.

$$H \propto \frac{1}{A} \propto \frac{1}{D^2}$$

Under the high velocity and pipe surface roughness conditions that apply, a turbulent flow regime exists. Under such conditions the friction head loss varies almost inversely as the diameter of the conduit.

$$H \propto \frac{1}{D}$$

Hence assuming that the optimum diameter of the rock rising main is such that the resultant friction head loss is the same as for standard 0.457m diameter pipe rising main.

$$H_r = H_p \quad \text{or} \quad \frac{f_r}{D_r} = \frac{f_p}{D_p} \qquad \text{Eqn. 1}$$

Where H is the friction head loss

D is the diameter of the conduit

A is the cross sectional area of the conduit

f_r is the friction factor for the rock rising main

f_p is the friction factor for the pipe rising main

H_r is the friction head loss for the rock rising main

H_p is the friction head loss for the pipe rising main

D_p is the diameter of the pipe rising main

D_r is the diameter of the rock rising main

The friction factors assumed for the pipe and rock rising mains were 0.006 and 0.01 respectively (3). In choosing the latter friction factor the surface of the rock rising main was approximated to a concrete surface. The required diameter of the rock rising main for an equivalent head loss in a 0.457m diameter steel pipe using Equation 1 is 0.76 metres. Within the size range of holes bored by the available raise boring machine (Robbins 71R) the economic diameter of the rock rising main is 0.9 metres. An added feature in choosing a larger diameter than that required was to ensure man access to concrete line any permeable zones. The 30% reduction in velocity, due to the enlarged flow section, would induce settlement of solids within the rising main but, as "domestic water" is to be pumped, this can be discounted.

The rock rising main was bored in two sections, from the 430 metre level to the 580 metre level and from the 580 metre level to the 810 metre level, at inclinations of 57° and 65° respectively. A lateral displacement of 150 metres exists between the holes on 580 metre level to avoid intersecting the basement unconformity, near which the basement schist is generally less competent. The overall length of the rising main including pipe sections is 1200 metres.

DESIGN AND CONSTRUCTION OF THE CONCRETE PLUGS

The theory generally accepted in South Africa, where considerable work on plug design has been done, is that the load exerted by water pressure on the plug is transferred to the surrounding rock in the form of punching shear around the periphery of the plug and over its full length. This was used as the rising main plug design criterion and in the case of a parallel - sided plug, W.S. GARRET et al (2) have given the following formula for estimating the required lengths of plugs:

$$L = \frac{F \times H \times d \times A}{S_c \times P} \qquad \text{Eqn. 2}$$

Where L = plug length

F = safety factor

H = head of water

d = density of water

A = area of plug

S_c = average shear stress

P = active perimeter

A plug 5 metres long was constructed at the bottom of the 0.9m diameter rock rising main on 810 metre level to accommodate the pump delivery pipe. Two plugs 4 metres in length were constructed on 580 metre level for the connecting pipeline between the two sections of the rock rising main and a 3 metre plug was constructed at the 430 metre level relay pump station. A factor of safety of four and an average shear stress of 826 KN/m^2 for "colcrete" was used in designing the plugs.

On 810 metre level a drive 25 metres in length was developed from the existing main haulage development to the rock rising main position, the last 5 metres of the drive being 1.6 metres x 2.4 metres to accommodate the plug. The plug was constructed by erecting shuttering on both sides of the plug section of the drive. In addition to the pump delivery pipe and that for draining the rising main, perforated pipes of 0.038 metre diameter for injection of a grout mix into the plug were inserted in the shuttering at 0.5 metre centres on both sides of the plug. The shuttering was packed with 50 mm to 150 mm clean rock into which a grout mixture of water:cement ratio of 1:2 was introduced at a pressure of 13.8MN/m^2. The plug was statically pressure tested after 28 days by filling the rising main with water. The plugs on 580 metre and 430 metre levels were built of concrete of stone : sand : cement ratio 4:2:1.

Pressure testing of the rising main

The rock rising main was filled to the 430 metre level and the water pressure monitored at the 580 metre and 810 metre levels. The largest static pressure attained was 3.1MN/m^2 and not 3.7MN/m^2 as expected, the loss being attributed to rock jointing in the risers. The column was then completely drained and a time against feed rate relationship employed during the refilling of the rising main. The results obtained were satisfactory but further static pressure tests still indicated 3.1MN/m^2 which was attributed to losses due to fissures in the rock being filled.

Head losses in the rising main have not been ascertained as the pumps were overdesigned (670 metre head) and as such these losses would have little or no effect on the performance of the system. The pumps have subsequently been destaged to operate at 57% load.

A potential major problem with rock rising mains is erosion of the boreholes hence reducing their economic life. As the basement rock at Mufulira is competent and chemically stable no appreciable erosion is anticipated in the rock rising main over the 10 year life of the pump station on 810 metre level. Scaling due to hydraulic pressure fluctuations is not thought to be a danger as the pump station is generally on continuous operation.

PUMP STATION INSTALLATION

Three Weir MSD ten stage pumps are installed, each driven by squirrel cage motors. Each motor is cooled through a water cooled heat exchanger through which ventilating air is circulated; the water, once used, being discharged into the pump station manifold. Two thermostats monitor the temperature of the airflow through each motor. One thermostat switch initiates an alarm signal at a temperature of 55°C and the other initiates motor shutdown at 60°C. Pump balance valve wear is monitored by an Airmec switch which comprises a proximity probe housed in an extension to the non-drive end bearing housing, together with control unit, junction box and extension cable. A direct visual check on balance disc wear is also provided. A pressure gauge is fitted to the discharge end of each pump. Both motor bearings are fitted with thermostats whose switches operate at 60°C and the lower stator frame is fitted with two strip heating elements for use in counteracting dampness during long periods of inactivity.

FURTHER APPLICATIONS

Following the commissioning of the pump station and the rock rising main, two 150 mm diameter compressed air service boreholes drilled by an Atlas Copco ROC 306 from 810 metre to 880 metre level located in the Basement Granite have been commissioned, the pressure loss in each being 0.4 bar. A rock rising main is planned for the next scheduled pump station on 1040 metre level for pumping between 1040 metre and 810 metre levels. The rock rising main has already been bored and the pump station is due for commissioning at the end of 1981. It is also planned to replace a conventional steel pipe desludging line from the 826 metre level pump station sumps, discharging on 430 metre level.

CONCLUSION

The use of raisebored holes as rising mains at Mufulira Division has been so successful in terms of efficiency, low cost and flexibility that future permanent pump station designs will endeavour to incorporate this system.

References

1. Wightman D. Hangingwall dewatering at Mufulira Division of Roan Consolidated Mines Limited, Zambia.

2. Garret W. S. and Campbellpitt L. T. Design and construction of underground bulkheads and water barriers. Seventh Mining and Metallurgical Congress Proceedings, 1961.

3. Daugherty R. L. and Franzini J. B. Fluid Mechanics with Engineering Applications pp 215 - 219,McGraw - Hill Kogakusha Ltd 1965.

APPENDIX

PUMP/MOTOR TECHNICAL DATA

Pump/motor type	Weir Spiroglide. Multi-stage/ Weir CACW. Class B insulation. Squirrel Cage (BS2613/1957).
Pump/motor frame size	MSD 10 (ten stage) A39-28C2
Pump duty/head	$9m^3$/min/670m
Pump motor speed	1 485 rev/min
Pump efficiency (+2½%)	81%
Pump power absorbed	1 231KW
Motor supply rating	11KV/2ph/50Hz/1 492 KW
Motor efficiency full load/ 75% load/50% load	95.9%/95.7%/94.9%
Power factor full load 75% load/50% load	0.88/0.86/0.80
Full load current	93 A
Starting current/torque	FLC x 4.75/50% FLC
Heater supply/temp rise	110V . 1ph. 50Hz/80°C by resistance

ELEVATION ABOVE MEAN SEA LEVEL

430 metre level = 828.697 metres

580 metre level = 677.600 metres

810 metre level = 451.300 metres

DETAILS OF PIPEWORK FOR CEMENTATION ON
430m, 580m & 810m LEVELS

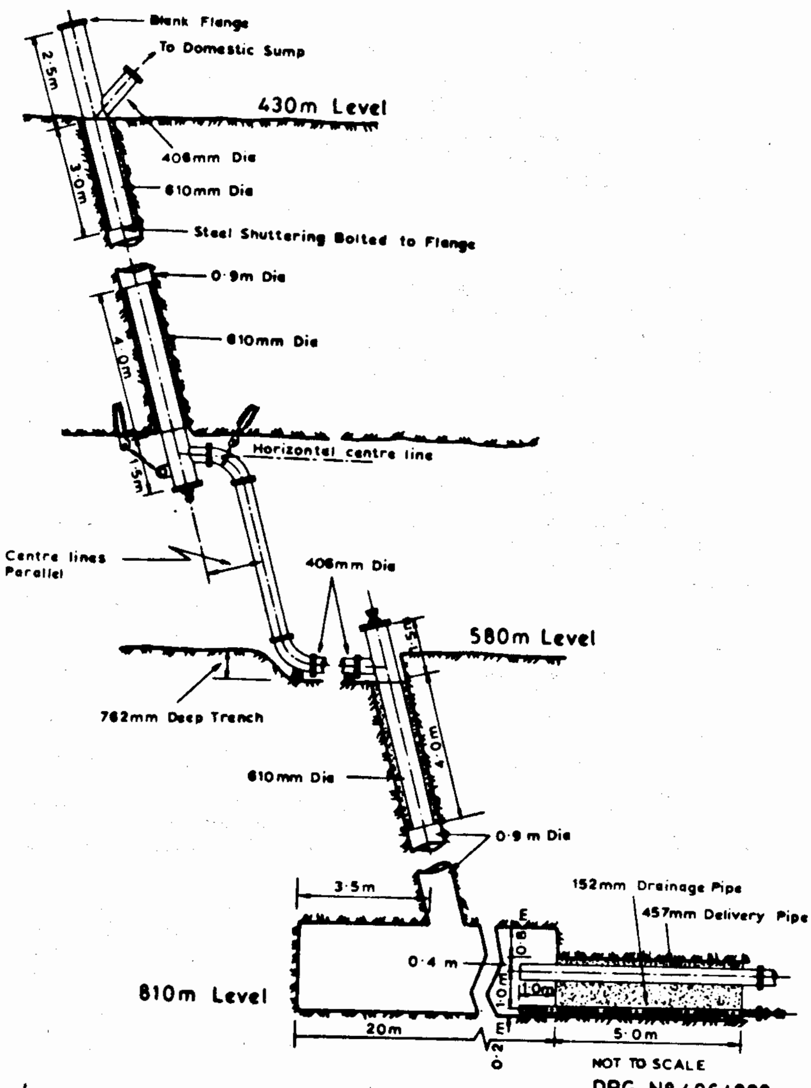

FIG. 1.

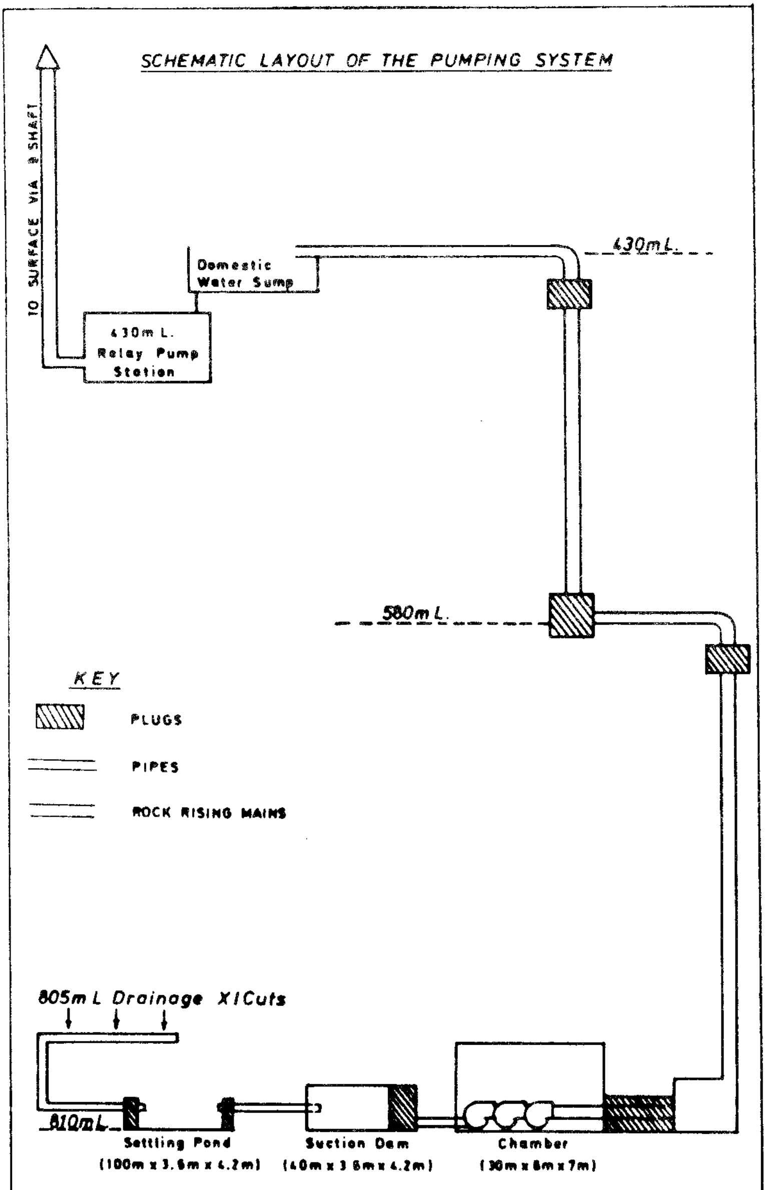
SCHEMATIC LAYOUT OF THE PUMPING SYSTEM
TO SURFACE VIA # SHAFT
Domestic Water Sump
430m L. Relay Pump Station
430m L.
580m L.
KEY
PLUGS
PIPES
ROCK RISING MAINS
805m L Drainage X/Cuts
810m L.
Settling Pond (100m x 3.6m x 4.2m)
Suction Dam (40m x 3.6m x 4.2m)
Chamber (30m x 8m x 7m)

FIG. 2.