The Flooding at the West Driefontein Mine

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Discussion:

L. T. Campbell Pitt: When Mr Garrett and I discussed the design and construction of plugs and bulk head doors to resist great water pressures in mines about ten years ago, we visualized an emeregeny when there would be no time for site preparation. We could not however, anticipate a problem of such magnitude and urgency as the one described in the paper under discussion.

The paper very clearly describes the flooding and the measures taken to save the mine. The complete flooding would have been a national disaster. The account of the combat between man and water reads like the account of a military operation. It was an endeavour which achieved success because there was a master plan, tenacity and, in fact, heroism. The paper is of necessity a long one. In my contribution I will mention some historical facts and factors that I believe have relevance to the flooding and the saving of the mine.

It is of great satisfaction to me to have been one of the two initiators of a new approach to underground plug design and construction. The investigation was taken over by a Chamber of Mines Committee which combined our early work with further research and the resulting data had a significant bearing on the West Drie emergency plug designs. The final plug length was correctly based on the requirements to obviate leakage. A plug to have structural strength only would have been very much shorter but so ineffective as to have become a waste of labour, material, and in consequence, wasted the limited time available to prevent flooding of the whole mine.

The figure of 75 lb per sq in. sheer stress provided a very ample margin, in my opinion, but under the very difficult site conditions and the limitations of plug material suitable for the very unusual construction, justified such a figure. There must have been considerable temptation to reduce the safety margin due to the urgency to complete and commission the plugs, but it is much to the credit of the directors of this operation that nothing less than a safe design was permitted.

In about 1945 Blyvooruitzicht Gold Mining Company, which was then mining in to the West Driefontein area to assist in early development, decided to protect themselves from a possible inrush of water from the latter mine. A bulk head door was accordingly designed and installed on 2 level between 1945 and 1948 at 4,218 ft below surface. Since West Driefontein paid for it, Gold Fields consulting mechanical engineers collaborated with their colleagues of Rand Mines who completed their design after a few modifications were agreed. This door was never used to prevent an inrush into Blyvooruitzicht but the exercise was very useful to Gold Fields when the high pressure doors initially installed on 10 and 12 levels between Nos. 2 and 3 shafts to enable isolation of one section of the mine from another were designed. At that time the capacity of West Driefontein to cope with an inrush of water was comparatively small because the storage in stoped areas and the installed pump capacity were much less than in later years.

These doors together with others of the same design were later moved to the lower levels served by sub vertical shafts. In addition, doors to prevent flood water entering the pump chambers on 18 level were installed at each end of that level, and designed for a head of 360 feet so that water would have to reach 16 level before the pumps were flooded.

All these doors were called upon to hold water and it is reported that only a small plug in one of the doors and a 4 in. dia flanged pipe joint failed. The lesson is that in these cases the smallest details warrant as much attention as the major ones.

That these were the only equipment failures when so much depended on equipment, is very much to the credit of design engineers, both of the Gold Fields head office and companies who supplied both mechanical and electrical equipment.

Until I had read the paper I wondered why the policy of isolation by bulk head doors was not continued as the development moved eastward towards the Bank Compartment and particularly when it pierced the Bank dyke. The reasons have been given in the paper. It was unreasonable to expect provisions to be made to counter the remote contingency that the large installed pumping capacity and mine capacity to store water would be exceeded during a peak inrush.

When pumps were being considered for West Driefontein, it was decided that the Gold Fields standard underground main pumps at that time of 1 million gallons per 24 hours would be too small. Three alternatives were considered.

1. Very large units that would require underground sub assembly and dismantling of both pump and motor.
2. The largest pump and motor that could be conveyed as a complete pump or motor from surface to the pump chamber.
3. Pumps of higher speed to reduce dimensions and weight.

It was decided to adopt alternate 2 because of avoidance of transporting pumps in parts and assembling underground. Alternative 3 was not favoured because high speeds would have introduced problems of more exact rotor balancing.

I believe the decision was correct and in the crisis enabled comparative easy transport of pumps and motors to surface for overhaul and, if required, transfer to other pump stations.

The standard pump thus became a 10 stage 1,500 rpm pump with a capacity of approximately 2 million gallons per 24 hours against a static head that varied between 2,600 and 2,800 ft. The capacity also varied with the friction head depending on delivery column capacity employed and, of course, the pump condition. The motors are 2,100 HP.

I cannot leave pumps and pumping without paying a tribute to the resident engineer, Mr C. R. Anderson, and his staff. Firstly, it is a human failing, when machines are not required, to allow their condition to deteriorate to a point when they will not respond when required. It will have been noted that the installed capacity was 63 million gals/day. The maximum employed before the flooding was 32 million gals/day which had dropped to 17 million gals/day. I understand that every installed unit responded immediately and efficiently when switched on. This is an example of outstanding maintenance discipline. Secondly, one cannot leave unpraised the immense task of transferring an increasing electric power supply to pumps as and when they were required in an unbelievably short time. The installation of additional pumps with all their pipework and electrical switchgear in a similarly short time was also a great achievement. To do this it was also necessary to have full and vigorous assistance from head office. This was given in very full measure by Mr L. R. Robinson and his staff. Escom engineers and equipment suppliers also made a noteworthy contribution.

There are many aspects I would like to mention but I will make this my last.

The decision by Gold Fields to convey all surplus water raised to surface out of the dolomitic compartment in a concrete lined canal was not an unopposed one. Prevention of re-entry of water spilled on surface to find its own way from the mine assisted, perhaps, by unlined canals was considered by Gold Fields to be unwise. A cementation cover over stopes had been tried without success. Water pumped to unlined areas on surface had been proved to reappear in the pump sumps in less than a week. Had the pumps during those critical days had to cope with recirculation water in addition to the inflow, there might well have been such a shortening of time for plug construction that the mine would have been lost. In spite, then, of the serious surface subsidences, sinkholes and other disadvantages of dewatering, I firmly believe that very important policy decision to have been correct. That policy was supported by a report by an Interdepartmental Government Committee. As will have been noted from recent press reports the Government supports the recommendation that the Bank Compartment be dewatered.

I thank you, Mr Chairman, for giving me the opportunity of commenting on an epic in mining history in which the head office and mine staffs of Gold Fields and the Cementation Company so very successfully without loss of life or limb dammed the river that ran

"Through caverns measureless to man
Down to a sunless sea".

R. Buley: The control plan which was prepared to deal with the inflow of water had two main objects:

1. To supply water to the pumps so that the maximum amount of water could be pumped out of the mine in order to obtain the longest possible time for the installation of the plugs.
2. To control this water so that surplus water would not drown the pump chambers on 12½ level 3 shaft and 18½ level 2 shaft.

The pumping capacities to surface shortly after the inflow were as follows (as given in Fig. 14 of the paper).

Relay to surface 5 shaft 22,000,000 g.p.d.

Relay to surface 2 shaft 34,000,000 g.p.d.

Relay to surface 3 shaft 16,000,000 g.p.d.

In addition, water had to be transferred to Western Deep Levels.

The water to 3 shaft pumps at 12½ level originally came along 10 level from 4 shaft at an approximate rate of 40,000,000 gallons per day. This quantity of course overran the water raise next to the shaft and cascaded down the shaft. The outlet to 14 level and the pumps at 18½ level 2 shaft were two 14 in. pipes through a ventilation plug at the bottom of the shaft. These pipes could not take the quantity of water with the result that the water rose in the shaft to close to 12½ level pump chamber, but before the pump chamber was lost a deviation wall at 12-29 was built which diverted sufficient water away from the shaft so that the water level balanced about 120 feet down from the pump chamber. This state of affairs continued throughout the emergency, but the dreadful thought of an odd piece of timber or cement bags jamming the 14 in. pipes was with us to the end.

The excess water, approximately 24,000,000 gallons, flowed along 14 level to 2 shaft, where originally we had steel doors 3 ft high protecting the shaft. This water would have been too much for these doors, and would have gone down the shaft and flooded 18½ level pump chamber but a steel sheet got caught in a ventilation door frame and diverted a lot of water down 14-19A raise until such time as we could build walls in place of the steel doors. These walls were always a source of trouble because access had to be maintained across them and the water was within inches of the hangingwall at times when the emergency dam was over full.

Access to the 14 level drive had to be maintained to regulate water down to the pumps on 18½ level. This was done by means of a plug, just like a bath plug, but over three feet in diameter, that could be raised or lowered into a tapered hole by means of a block and tackle; half an inch up or down from normal could regulate enough water to keep the pumps on 18½ level at full capacity. The excess water from this plug ran into the emergency dam with a capacity of 11,000,000 gallons, but this had to be kept at a high level to enable sufficient water to be sent through pipes to the pumps on 18 level 5 shaft. Further, sufficient water had to be-bypassed to the V.C.R. workings. Although, at first these had to be kept empty to enable Western Deep Levels to hole into them, they later had to be filled to transfer water to the Western Deep Levels pumps.

It was lucky that, initially, the water split between 10 and 12 level from 4 shaft was approximately in the proportion for maximum pumping. Later on, to enable 4 shaft to be used down to 10 level to build the plugs, we managed to use the shaft orepasses and ventilation columns to keep the water out of the shaft, as previously travel in the shaft had been impossible because of the falling water. This gave us some measure of control at 10 level 4 shaft by the raising or lowering of a sandbag barricade, but great care had to be taken in varying the amount of water here as it took nearly two hours to reach the V.C.R. and too much would have lost the pumps at 3 shaft or 2 shaft, too little, of course, meant less setting time for the plugs.

Finally, all water was shut off on 10 level and transferred to 12 level; here then the water was regulated by a wall on 3 sub shaft bank. Enough water for 3 shaft pumps was sent along 12-27 cross-cut to the settlers on 12 level and hence to 12½ level pumps, the overflow going along 14 level 2 shaft. Additional water was sent along 12 diagonal cross-cut, some to a low lift pump to 12 level sumps and the excess to the emergency dam. This set up continued until the valves were shut at 12 level plug.

From Sunday, 27th October until 18th November, the number of pumps installed which could pump water to surface was 32 and then 36 were available during the last two weeks. The number of pump-hours available was 17,420, the actual number of pump-hours worked was 16,863, giving a utilization factor of 96·7 per cent. Lost time included trip outs, repairs, lack of water and cleaning inlet screens. It is difficult to estimate exactly how much water was pumped during this time but at a conservatively estimated efficiency it amounted to 1,500 million gallons but any 2 million gallons going the wrong way could have lost the mine.

F. J. Bayley: Both Messrs Cousens and Garrett are to be congratulated on the excellence of their interesting paper. This paper will no doubt be used as a work of reference for many years to come. The management of West Driefontein are also to be congratulated on the manner in which they successfully accomplished an extremely difficult and hazardous operation.

At the time of the West Driefontein crisis, the pumping capacity at Western Deep Levels was approximately 15 million gallons per day; the quantity pumped per day was approximately 2 million gallons. The decision was taken to drill ten $4\frac{9}{16}$ in. dia boreholes through to West Driefontein. It was calculated that a quantity of approximately 10 million gallons per day could be drawn from these holes against a head of 120 ft of water.

The common boundary pillar linking the two properties is approximately 300 ft wide on the Ventersdorp Contact Reef horizon. A prospect raise 61/59 had previously been developed to within 50 ft of the West Driefontein boundary and it was decided that this would provide an excellent point of attack for drilling operations. Existing arrangements on West Driefontein made it possible to divert water into this area which could subsequently be handled by Western Deep Levels pumps.

Total development amounted to 174 ft of which 100 ft comprised of lateral development cut at 14 ft wide to facilitate the drawing of drill rods. This development end was designed to provide for the drilling of ten $4\frac{9}{16}$ in. dia boreholes approximately 110 ft long, which would be holed to an adjacent footwall crosscut in the West Driefontein property. Preparation for development started on 28th October, 1968. 200 ft of track, 1,500 ft of 6 in. and 4 in. pipe columns and 1,800 ft of electric cable had to be laid in what was basically an abandoned section of the mine.

The first round was blasted at 8.15 a.m. on 29th October, 1968, and development was completed on 5th November, 1968. Whilst this development was in progress, two 2 in. dia pilot holes were drilled to effect a West Driefontein holing for the purpose of correlating surveys. In addition, 30 consolidating holes were drilled in the drilling gallery and high-pressure grouted to 3,000 p.s.i. The boreholes were provided with a 20 ft length of 6 in. dia flanged casing pipe and an internal 4 in. dia casing pipe of 100 ft in length. The casings were high pressure grouted into the holes, the grout being subsequently drilled through until solid rock was encountered and at this stage the 6 in. dia high pressure gate valves were attached to the outer casing pipe. These valves weighed 2,000 lb and were provided with an automatic self-sealing (compound feeding) system. The final 10 ft of each hole was drilled through the valves and on holing the rods were withdrawn and the valves closed.

It had been decided that the water would be gravity fed to the clear water sumps at both shaft systems. To do this, 5,800 ft of 12 in. dia column was laid to link up to a 10,000 ft long 15 in. dia emergency pump column providing access to the No. 2 Shaft sumps and 4,000 ft of 10 in. dia piping was laid to provide access to the No. 3 Shaft sumps. The first water accepted from West Driefontein was on the 13th November, 1968, and amounted to 3½ million gallons per day. This quantity increased to a maximum of 11 million gallons per day through eight boreholes. The last water received from West Driefontein was on the 19th November, 1968.

Precautionary measures were taken to safeguard the mine from a possible inrush due to reactivation of fissures or failure of the pillar on the Blyvooruitzicht boundary on the Carbon Leader reef horizon. An additional danger was constituted by the Kimberley shales which were exposed in development on either side of the V.C.R. boundary pillar and were found to "weep" at very low pressures. On the V.C.R. horizon eleven concrete plugs were designed to provide a sump capacity of some 65 million gallons. The plugs varied in length from 80 ft on 58 level, expected pressure 2,200 p.s.i., to 110 ft on 75 level, expected pressure 2,970 p.s.i. The plugs were constructed within the pillar of a service incline shaft, after careful site preparation had been carried out. The interior of the plugs consisted of +2 in. washed aggregate which was hand packed. Three rows of five 2 in. dia grouting tubes were installed into the aggregate. The length of the tubes was varied to provide maximum uniformity of injection and staggered draw-off facilities. One in. dia steam pipes were positioned at all high spots in the plug. In addition to the pipes already outlined, 4 in. dia bleed pipes were installed in most plugs. These pipes had wall thicknesses varying from $\frac{3}{8}$ in. to $\frac{7}{16}$ in. The bleed pipes were screwed, welded and then pressure tested to 3,500 p.s.i. using a manual test pump. High pressure gate valves were attached to the bleed pipes by means of 1¼ in. dia bolts and tightened to a torque of 850 lb/ft. Seven days after grouting, the plugs were subjected to high pressure grout injection to consolidate both the plug and surrounding rock faces.

Precautions taken on the Carbon Leader reef horizon workings at the No. 2 Shaft amounted to a stabilization programme of the pillar bordering the Blyvooruitzicht workings. The width of this pillar amounted to 90 ft at a depth of 8,000 ft below surface. The length of mined-out area adjoining the pillar was 290 ft. In an effort to consolidate the pillar, rings of holes 10 ft apart on strike with 4 holes to a ring were drilled and grouted to 4,000 p.s.i. The average acceptance per hole only amounted to approximately 10 pockets of cement which indicated that relatively little fracturing had taken place.

Fortunately neither plugs nor pillar were put to the test due to the success of the No. 4 Shaft isolation programme at the West Driefontein mine.

G. L. H. Diering: Blyvooruitzicht and West Driefontein have a common North-South boundary 11,950 ft in length on plane of reef. From the sub outcrop of the Carbon Leader at 3,525 ft below surface the two mines are separated by a statutary boundary pillar 60 ft in width and 3,900 ft in length. This forms a long strip abutment as the Carbon Leader has been fully extracted on either side. At 4,218 feet below surface, equivalent to Blyvooruitzicht's second level, the pillar is holed by a reef drive that was developed into West Driefontein in 1945. A concrete plug was installled in this drive in 1958 and straddles the boundary.

In the event of total flooding of West Driefontein the fate of Blyvooruitzicht hung precariously on the unknown behaviour of the 60 ft boundary pillar and the dubious qualities of a plug that had been subjected to high stress by subsequent stoping in the immediate vicinity. Faced with this somewhat alarming situation efforts on the mine were immediately directed to provide all possible assistance to West Driefontein, together with certain self-defence measures. Much work was done in the ensuing three weeks. As events subsequently turned out none of it was proved necessary.

(i) *Pumping relief for West Driefontein*

In order to effect holings with West Driefontein through which water could be tapped under control, multi-blast development commenced immediately on our 6 and 10 levels to reach suitable positions adjacent to the common boundary.

10 *Level:* A total of 255 ft of 9 ft by 8 ft development was completed in seven days to a point 78 ft east of the common boundary. The last 80 feet was sliped to 14 ft by 10 ft to form a chamber for subsequent long hole drilling. This chamber was positioned 125 ft vertically above, and parallel to, a high speed end developed by West Driefontein on their 20th level.

Nineteen percussion holes, 3 in. in dia by 125 ft long were drilled vertically downwards to intersect the drive developed by West Driefontein. This was calculated to be sufficient to tap off 15 million gallons per day prior to the flood waters reaching a critical level at which West Driefontein would loose their main pump installations. All holes were cased for 15 ft and fitted with 3 in high. pressure valves.

The main pump stations at Blyvooruitzicht are situated on 6 level and intermediate stations below this horizon had only limited capacity at that stage. To cater for the additional 15 million gallons per day a low lift pump station, capable of handling 7·2 million gallons per day, was excavated and equipped on 10 level. This elevated the water to 5 level where it could be distributed to the main pumps. Provision was made to handle the balance via a gravity column to two intermediate transfer stations situated on 16 level, where extra pumps were installed to meet the additional load.

Fortunately these efforts were not really necessary and only 39 million gallons was drawn off from West Driefontein.

6 *Level:* Given time, 6 level offered the best line of attack as any water from West Driefontein could be gravitated to the main pumping installations. To gain access to the boundary a total of 1,200 ft of 9 ft by 8 ft development was completed in 28 days. However, by that time the crisis was over.

(ii) *Probable behaviour of boundary pillar and plug:*

This problem was referred to the Chamber of Mines Research Laboratories. Tests indicated that the 60 ft pillar had probably been subjected to stresses ranging from about 120,000 p.s.i. to less than 50,000 p.s.i. at the sub-outcrop. As the uniaxial compressive strength of the rock was approximately 30,000 p.s.i., in all probability the pillar would have crushed extensively and reconsolidated. However, it was likely that the residual stress at any point would be more than adequate to withstand the hydrostatic pressure of about 2,300 p.s.i. to which the pillar would be subjected if West Driefontein was completely flooded. Sudden rupture of the pillar was unlikely, but seepage could be a major factor. As the plug installed on 2 level had obviously been subjected to the same stresses, strenuous efforts were made to gain access to it so that it could be reinforced by injection and backing up.

(iii) *Provision for emergency water storage area:*

As theoretical considerations indicated that there was a fair chance of the boundary pillar holding, but weeping copiously, an emergency cofferdam with a capacity of 300 million gallons was created by isolating the eastern one-third of the mine. This was achieved by installing a series of plugs in a north-south dyke which formed a natural line of defence.

The advantages visualized were:

(*a*) Depending on circumstances, normal mining could continue in the remaining two-thirds of the mine to the west of the barrier.

(*b*) The coffer-dam would absorb the initial shock of any sudden inrush of water and provide time for evacuating the remainder of the mine.

(*c*) Surge capacity of 300 million gallons would be provided for any eventuality.

Fifteen plugs, ranging from 62 ft to 11 ft in length were installed. The project was started on 29th October and completed in 15 days.

(iv) *Protection of main pumping installations:*

In the event of Blyvooruitzicht being faced with complete flooding, provision was made to isolate the main pumps situated at Nos. 2 and 4 shafts by installing further plugs. This work was well advanced when the West Driefontein plugs were finally completed and put to the test.

In conclusion, I would like to congratulate the authors on their paper. It is a fine record of a truly remarkable achievement that has no parallel in our mining history.

P. P. Venter: It is a real privilege for me to be present at this meeting and to have listened to Mr Cousens and Mr Garrett explain to us the flooding at West Driefontein Mine and the measures taken to save the mine.

As the authors have remarked both the event and the efforts and organization required to save the mine were unprecedented. I am sure that we will all agree that the undertaking will go down in the history of mining as an epic achievement. The planning and execution of the work were impeccable and it requires little imagination to appreciate the tremendous efforts that were made in the face of very real risk to life and almost insuperable difficulties.

I remember the confident statements by Mr Louw which appeared in the press and recall wondering whether he was as confident as he said he was. But then I did not have his knowledge of the quality of the staff responsible for this work. It must have been a source of inspiration to all concerned to know that Mr Louw identified himself so completely with their efforts and had such confidence in them.

The excellent planning and execution revealed by the paper leaves me with little opportunity for critical comment. However, there are several thought provoking aspects.

The first that comes to mind is the question of whether we are right to assume that a major inflow of water is inevitable when we are mining in an area where the rocks contain water bearing fissures. The authors remark, and I concur with their view, that the sag and consequent fracturing of the hangingwall is a major factor. There are ways in which such sag can be limited, perhaps by the installation of relatively incompressible support such as sand filling followed by grouting of the hangingwall in selected areas. Or perhaps we could consider leaving a carefully designed system of pillars. Recent advances in Rock Mechanics should assist substantially in assessing the possibility of such action. It seems to me that we would do well to initiate some research into this problem.

The second thought that comes to mind is the vexing problem of estimating the pumping and storage capacity which we should instal in order to safeguard our mines against such major inrushes. We must admit that at present our estimates amount to almost pure guesswork and some vague idea that if our pumping capacity exceeds the actual pumping rate by a factor of three or four and we can store some hundreds or thousands of millions of gallons we should be safe. The events at Merriespruit and West Driefontein illustrate forcibly how fallacious such reasoning may be.

I refuse to believe that the problem is so intractable that with some diligent research we could not substantially improve our estimates. Established techniques in geohydrology coupled with the use of available computors and statistical methods should provide very useful results. Perhaps I can indicate very briefly a possible line of enquiry by discussing the factors governing the rate of inflow.

There are three permeability environments to be considered. The excavation itself in which I include the friction provided by the orifice; the fractured zone around the excavation and the aquifer itself—this is the undisturbed fissured formation itself.

In considering the possible magnitude of a major inrush we may start off by assuming that the orifice is so large that its resistance to water flow is negligible. This leaves us with the permeability of the fractured zone and the fissures in the formation. Here again we can assume that friction losses in the fractured zone are very small in relation to those in the formation; a not unreasonable assumption. This leaves us with the properties of the aquifer itself and here we have at our disposal useful geohydrological tools. In fact an analysis of the measured pressure build up after closing the plugs at West Driefontein and the excellent assessment of the rate of inflow should give good approximations of the coefficients of storage and transmissibility of the aquifer from which the water was derived.

Naturally such factors as the effects of turbulent flow and vertical variations in the coefficients defining the properties of the aquifer must be taken into account and also the effects of ground water barriers. Time does not permit me to deal with these aspects beyond pointing out that techniques exist or could in my view be developed to deal with such problems.

It seems to me that some research into this problem would not only be well worthwhile but also has a good chance of success.

We are indebted to Mr Cousens and Mr Garrett for presenting such a lucid paper. It provides us with three particularly valuable conclusions.

The first is that the design criteria for plugs are valid and we may with considerable confidence use them should the need arise again in the future.

The second is that when mining in water-bearing strata we must provide, as soon as possible, adequate water storage capacity to protect the pumps and to give us time to construct plugs.

The third is that the present design of bulkhead doors is inadequate and requires revision.

AUTHOR'S REPLY

Many of the contributions have given an extremely valuable addition to the knoweldge that the paper is intended to record for the future. Other than this, I do not think I can make any comment on the contributions made. I might take up an issue with Dr Venter on the design of bulk-head doors. I have no complaint against the design of the actual doors, but I do have complaint with the design of flange joints for pipes through plugs, and I consider that the Achilles Heel of a plug is likely to be any sort of a hole or service through it.

Notice

VI INTERNATIONAL MINING CONGRESS, JUNE 1970

This Congress will be held in Madrid from June 1-7, 1970. In addition to inaugurating the new Palace of Congresses and Conventions of the Ministry of Information and Tourism, there will be simultaneous exhibitions on mining machinery, and on the History of Mining in Spain and the Spanish-speaking countries. A number of technical excursions will visit the most important mines in Spain and Northern Africa between June 7-13.

The theme of the Congress is "Science at the service of the Mining Industry."

Copies of the first congress information leaflet are available at the offices of the South African Institute of Mining and Metallurgy.