History of the development and deployment of the parallel sided mortar intrusion concrete watertight bulkhead in underground mines

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Synopsis

In this paper the origins of the mortar intruded concrete concept and its development and application in the construction of watertight bulkheads in South Africa are described.

The events leading to the commissioning and execution of the West Driefontein Experimental Plug and the Virginia/Merriespruit Boundary Plugs, and their roles in the proving of the technique, follow.

The development of the first Transvaal and Orange Free State Chamber of Mines Code of Practice for Mortar Intrusion Concrete for Underground Plugs and Bulkheads, Johannesburg, November 1962, is explained.

The saga of the October 1968 flood and subsequent salvage of the West Driefontein Gold Mine is recounted.

The paper concludes with mention of the validation programme carried out for the Placer Dome Western Areas Joint Venture and their South Deep water barrier programme.

Introduction

During the Second World War the Cementation Company in the United Kingdom developed a technique for the rapid construction of aircraft landing strips, which involved the laying down of a bed of coarse aggregate (plums), which was followed by the intrusion of mortar comprising fine aggregate (sand), binder (cement) and water. The mortar was called 'colgrout' and the product 'colcrete'. The technique was exported to South Africa and applied by its subsidiary, the Cementation Company (Africa), to underground concrete construction, for example foundations and support in the form of grouted packs.

The ingredients, sand, cement and water, were fed into a high shear mixer in which a rapidly rotating impeller imparted colloidal characteristics to the emulsion. This could then be pumped long distances of up to several kilometres, both vertically and horizontally, in small diameter ranges (pipes), without segregation or settlement, to a remote placement site.

Such a system has obvious advantages in a mine where blasted rock for coarse aggregate abounds, and where transport, vertically in shafts and longitudinally in decline shafts or horizontal haulages, is always at a premium or rarely available.

Another substantial advantage of the technique is that mortar is considerably less viscous than conventional concrete. This ability to flow into and fill nooks and crannies, combined with a high point and an indicator pipe, virtually ensures complete filling, rockwall to concrete contact, and bonding. This knowledge is a great comfort to plug constructors, especially in flattish tunnels, where filling the top of the structure to the hangingwall is problematic.

Plug material and design

Mortar intrusion concrete

When it came to water barrier construction and watertight door installations, the terms 'colgrout' and 'colcrete' were never referred to, but termed 'mortar intrusion concrete'. Bill Garrett, the high priest of cementation and who understood all its mysteries, explained why this ponderous phrase was used instead of the catchy term colcrete: 'That is what the Americans called it in their airstrip specifications and the Americans always get their terminology right.'

He also indicated that Colgrout and Colcrete were Cementation Company coined trade names and not generic terms.

It seems that 'mortar intrusion concrete' have arrived as a developed technology. However, in view of the uncertainty, the author proposes as a thesis for its genesis and evolution, the following:

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Figure 1—Mr. W.S. Garrett, Managing Director, The Cementation Company (Africa) Ltd (1936–1971)

Once upon a time in the olden days, when ‘necessity’ and not ‘luxury’ was still the mother of invention, the Cementation Company developed a method for the salvage of flooded shafts termed ‘the reverse flow technique’.

It has been applied successfully many times in this country. Recent instances are well recorded in the Papers and Discussions of the Association of Mine Managers of South Africa—they are the recoveries of the Vent Shaft at AngloGold’s Mponeng Mine and of the Main Shaft at the South Deep Gold Mine.

The technique is generally applied when a sinking shaft is lost by flooding due to the uncontrolled intersection of an aquifer.

It involves:

- Letting the shaft flood to the water table (equilibrium level)
- Tipping coarse waste rock down the shaft and filling the bottom to a predetermined elevation.
- Lowering clusters of cementation ranges down the shaft supported on ropes to the top of the waste fill.
- Pouring large volumes of water into the shaft while simultaneously introducing thick cement grout down the shaft via the ranges. The higher head in the shaft induces water to flow from the shaft into the aquifer, carrying grout with it. As velocities reduce, the cement settles out on the fissure walls and sets under pressure. The deposit gradually builds up, finally choking off the aperture and affecting a seal.
- The water level then begins rising in the shaft, indicating that this has been achieved. This phase can be lengthy—the South Deep Main Shaft intrusion lasted for forty days and forty nights and accepted seven million kilograms of cement.
- The shaft is then dewatered, the aquifer further treated with grout injections through probe holes and then the shaft bottom plug is mined out.
- In all instances the plugs have proved to be good examples of mortar intruded concrete.

Watertight bulkhead—design development

From the mid 1950s a series of events took place that affected the direction in which the development of water barriers took in South Africa.

Free State Geduld—mid 1955

A crisis developed at No. 2 Shaft where an inrush of water coincided with the failure of two of the main pumps. Bill Garrett was called in to reconnoitre and report on the situation. He advised that the construction of a conventional concrete plug keyed into the walls of a prepared site was impractical because of time constraints.

He did, however, offer to build a plug of half the orthodox length with no site preparation except for the proper cleaning of the footwall, constructing it by filling the space between the shuttering with broken rock and consolidating it with cement grout pumped from surface. He further required a pipe through the plug connected to existing columns in the shaft so that water could flow to the 1 000 metre mid-shaft pumping station and thereby reduce the head which the plug would initially have to withstand. Anglo American accepted this offer, and the plug was built as indicated. The elapsed time between completion of grout pumping and the loading of the plug was a mere 72 hours.

The plug functioned exactly as intended with no sign of failure or stress other than some leakage that was quickly sealed off by pressure grouting. The plug size was 2.75m x 2.44 m x 8.23 m long and the pressure that it was subjected to was 5.7MPa. The plug length was later extended to 14 metres in order to resist the full hydrostatic head of 1 500 metres.

Merriespruit Flood – late 1956

A major inflow of water occurred on Merriespruit Mine in the Free State in 1956. This was initially diverted into the lower levels of the mine. As these were being inundated, a decision was taken to cast conventional mass concrete plugs in the No. 1 and 2 shafts.

These were constructed inside the shaft linings, were about 18 metres long and were traversed by several cast-in 250 mm diameter thick walled steel pipes. These pipes were capped with heavy duty valves for the planned subsequent dewatering and salvage of the workings.

The through pipes were 10 metres in length, bolted together at the planned mid-elevation of the plugs through heavy duty grooved flanges sealed with gutta-percha gaskets.

The pouring of the No. 1 Shaft plug was completed at 08:00 on Saturday, 27 October, and the water reached it by 15:00 the same day. By about 04:00 on 31 October, some four days later, the pressure had built up to almost 4.5 MPa when it failed suddenly and catastrophically with large loss of life. The No. 2 Shaft plug failed similarly some four days later, but at about three times the head, and the mine was lost.

Figure 2—Special sub-committee report on Investigation into causes of flooding at Merriespruit Mine—May 1965

The workings were subsequently dewatered through a neighbouring mine. In March 1964, as the water levels were being lowered, the Research Advisory Committee of the Transvaal and Orange Free State Chamber of Mines requested that the causes of the failures be investigated.

This was done and their findings were published in Research Report No. 17/65 in May 1965.

The combined loss of the mine and lives in those distant days was a cause of great consternation to the industry. This had happened in the Free State where Anglo American's Doctor Austen Bancroft had famously announced that 'he would drink every drop of water intersected in those gold fields'. What of the fabulously rich West Wits Line, which, besides being the greatest gold producer in the world, was overlain by the saturated Malmani Dolomites of the Transvaal Sequence that contain water by the cubic kilometre?

West Driefontein—test plug—Mid 1957

At this time two stakeholder individuals and companies took centre stage under the umbrella of the Chamber of Mines. They were Lyle Campbell-Pitt, consulting mechanical and electrical engineer of Gold Fields of South Africa and Bill Garrett, a civil engineer and managing director of The Cementation Company (Africa). A meeting between these two gentlemen to discuss water door installations at West Driefontein to secure pump chambers resulted in an agreement to cooperate on the building and testing of a similar one-third scale prototype.

The structure, a 0.66 m diameter door with cast iron tubular back up sections, was installed in a mortar intrusion concrete bulkhead support form in a 1.21 m x 1.21 m dead end tunnel. The surrounds were pressure grouted and the whole installation tested to higher and higher heads by pumping water into the chamber between the door and the tunnel face. Staged grout injections into the surrounding rock were undertaken to tighten the integrated system.

The arrangement performed admirably, but concerns were raised by the behaviour of the country rock under extremely high water pressures in excess of 47 MPa. Under these loadings the rock mass both absorbed and bypassed water. This raised concerns about siting, rock characteristics and the performance of a full-sized, high head installation.

Virginia/Merriespruit boundary plugs—mid 1959

The opportunity to conduct a full-scale live test was not too long in coming; an 11 metre long mortar intrusion concrete parallel sided plug with travelling way comprising a mild steel sleeve, heavy cast iron back-up sections and a domed door facing Merriespruit was installed on the intermine boundary of Virginia in a 3.75 m x 3.35 m haulage. A solid

Figure 3—Dr. J. Austen Bancroft

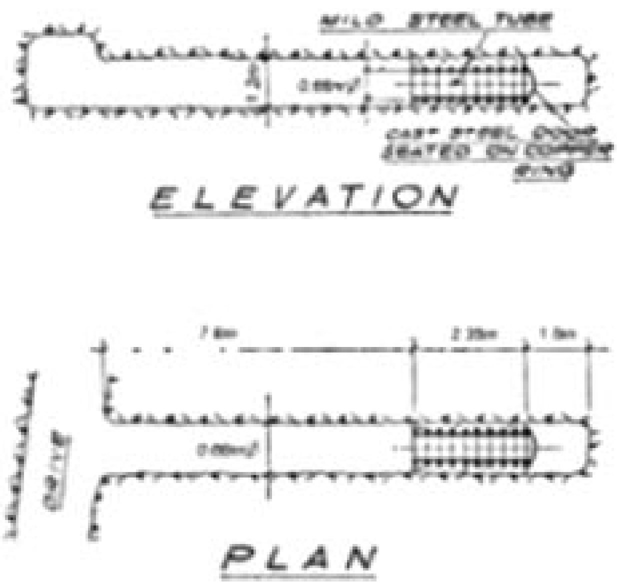

Figure 4—Experimental plug, West Driefontein

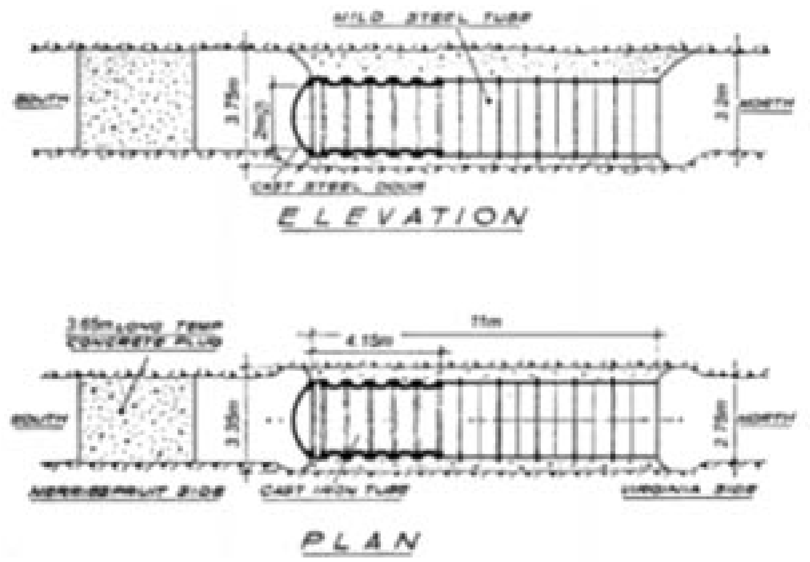

Figure 5—Boundary plug, Virginia/Merriespruit

similarly constructed 3.75 metre long temporary plug was positioned in the same haulage a few metres away on the Merriespruit side of the door. Both plugs and their surrounds were pressure grouted to about 20 MPa.

The space between the plug and door was filled with water. The object was to subject the permanent bulkhead to a test pressure of 12.5 MPa, which was a little higher than the static head it might ultimately have to resist. It was also hoped that structural failure would be induced in the short plug. To simulate emergency conditions, the temporary plug was subjected to pressure only 87 hours after completion.

This initial attempt at pressurizing the system failed because of excessive leakage. Further grouting then took place to a sealing pressure of 30 MPa. A chamber pressure of 10 MPa was then achieved. The limiting factor was again absorption of water by the ground, which was estimated at 17,000 litres per hour, matching the available pumping capacity. The temporary plug showed no signs whatsoever of structural failure.

Leakage through rock—tests at Blyvooruitzicht—1960

Leakage through the rock proved to be the limiting factor in both the West Driefontein and Virginia/Merriespruit tests. They indicated the possibility of incipient cracks opening at some threshold pressure probably related to the imposed load of the overlying rock mass or other inherent stresses and then closing elastically when the pressure was relaxed.

The sites selected for the tests were about 1 400 m below surface in strong quartzite with moderately defined bedding planes, remote from igneous intrusions and stoped-out areas.

Two pairs of holes were diamond drilled, each pair comprising 1 x 10 metre and 1 x 3 metre hole cased to within 1.5 metres of the end. One pair was sited in sound ground and the other traversed a faulted zone.

The test procedure in every case was to apply water pressure to a hole by means of a pump, measuring the volume of water absorbed by the rock over five minute periods. During each period the pressure was maintained and was stepped up in 1.75 MPa stages.

These tests established that rock behaves elastically and that there are critical pressures for the particular ground tested, below which it is useless to attempt to grout and above which serious leakage can be expected.

Results obtained from these experiments showed that:

- Heavily fissured and cracked ground will accept large quantities of water
- Sound ground will apparently open up to allow the passage of water above a limiting pressure, which will depend upon:
  - Type and strength of rock
  - Depth below surface
  - Stress conditions of the rock
  - Presence of faults, dykes and joints
  - Proximity of excavations or depth of test holes
- Water pumped into test holes may or may not appear as leakages and, irrespective of observable leaks, the limit of resistance of rock occurs at a clear, well-defined point. Up to this limit the leakages are small and the situation may be regarded as approximating a static condition. After leakage starts the situation corresponds with a dynamic condition in which the pressure applied and the volume of water flowing are interrelated
- Grouting will have the effect of converting heavily cracked rock into the equivalent of the same rock in an uncracked condition.

The Transvaal and Orange Free State Chamber of Mines Research Organization —Code of Practice

The foregoing, near misses, catastrophes and experimental work stimulated the Chamber of Mines to constitute a panel on research into underground plugs. This panel accumulated information until 1964 when it published a monumental document entitled: Report on: Research into Underground Plugs, By F.H. Lancaster, C.O.M. Reference: Project No. 203/64/-, Research Report No. 27/64, August 1964.

Appendix VIII is entitled: Code of Practice, For Mortar Intrusion Concrete, For Underground Plugs & Bulkheads, Johannesburg, November 1962. This document was revised and reissued as a version in metric units in February 1983.

West Driefontein—the flood—1968

Saturday the 26th October began as a bright sunny morning. At 09:40, under a clear blue sky, the banksman at No. 4 Shaft West Driefontein received a message from the onsetter to say that 'a great deal of water was coming down the shaft'. The man below sounded worried!

This was the big hit. The flood struck with the ferocity and sudden force that those with foresight had feared so much. A stope above 4 Level had breached an aquifer and the Bank Compartment was draining into the mine at the rate of 500 million litres per day. The mine had an installed pumping capacity of 350 million litres per day, which was the greatest in the world at the time. The race against time to save the world's richest and most prolific producer of gold had begun.

This was one of the rare historic occasions when impending disaster was prophesied and prevented by the preparations of the protagonists. They were able to counter the catastrophe with a fully developed tested technology that was simple to apply and which proved perfectly appropriate to the demands of the trial. This is delightfully recounted in A.P. Cartwright's book *West—Driefontein—Ordeal by Water*.

Figure 6—A partly submerged underground locomotive and passenger conveyance in a drive on 12 Level

Figure 7—Materials being manhandled by men who worked waist deep in fast-flowing water

Figure 8—A long view of the main plug on 12 Level, illustrating the cramped space in which the men had to work when they 'threw' the plug. The television camera can be seen in the top right-hand corner to keep its eye on the first five valves

The drama that was to unfold over the next few weeks and end when the valves on the 12 Level plugs were finally closed on 20 November, isolating No. 4 Shaft and silencing the torrent was, nevertheless, a close-run thing.

The Placer Dome/Western Areas Joint Venture—South Deep water barrier programme

The most recent challenge has been the construction of water plugs to provide security against a 1 500 m head at South Deep mine. The mine owner's concerns about water inflows were sharpened by the relatively recent failure of a low head plug at the Marcopper mine in the Philippines, which resulted in a slimes dam decanting into and severely polluting the surrounding coral seas. This ended in extensive reparations, rehabilitation and required the application of considerable resources. The large, ultra-deep, modern, South Deep mine is interconnected with the old Western Areas North Mine, operated at the time by Harmony Gold as their Randfontein Estates No. 4 Shaft. The mining areas are overlain by the water charged Malmani dolomites. This represents a risk factor that can and has been mitigated by a construction programme of water barriers.

Prudence dictated that the best technology be applied to this modern programme. Alternatives were investigated, expert advice gleaned globally, the empirical practices validated, tested and proved before application.

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