SHAFT EXCAVATION METHOD IN SOFT SOIL

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Shaft E2, Gautrain Rapid Rail Project

SYNOPSIS

This paper describes the method used for excavating the upper 33m of emergency access shaft E2 for the underground single track tunnel running between Park and Rosebank station of the Gautrain Rapid Rail System. The soil was decomposed shale and diabase from the Witwatersrand Supergroup. The location was in the car park of The Wilds (a public park) in Johannesburg.

The method proved very simple and required less complex plant and equipment than normal when excavating the shallow soil sections in shafts. It involves driving steel sheets ahead of the shaft sump into the soils and then excavating inside the "tub" created by the sheets whilst supporting the sheets above with regularly spaced circular Steel Rings.

It is the intent of this paper to discuss the method and design approach to the method. This will be done at the hand of experiences at E2 shaft..

THE METHOD.

The method has its origins in North Africa and more specific Morocco. French national employees on the project introduced the method known appropriately to them as the "Moroccan Method".

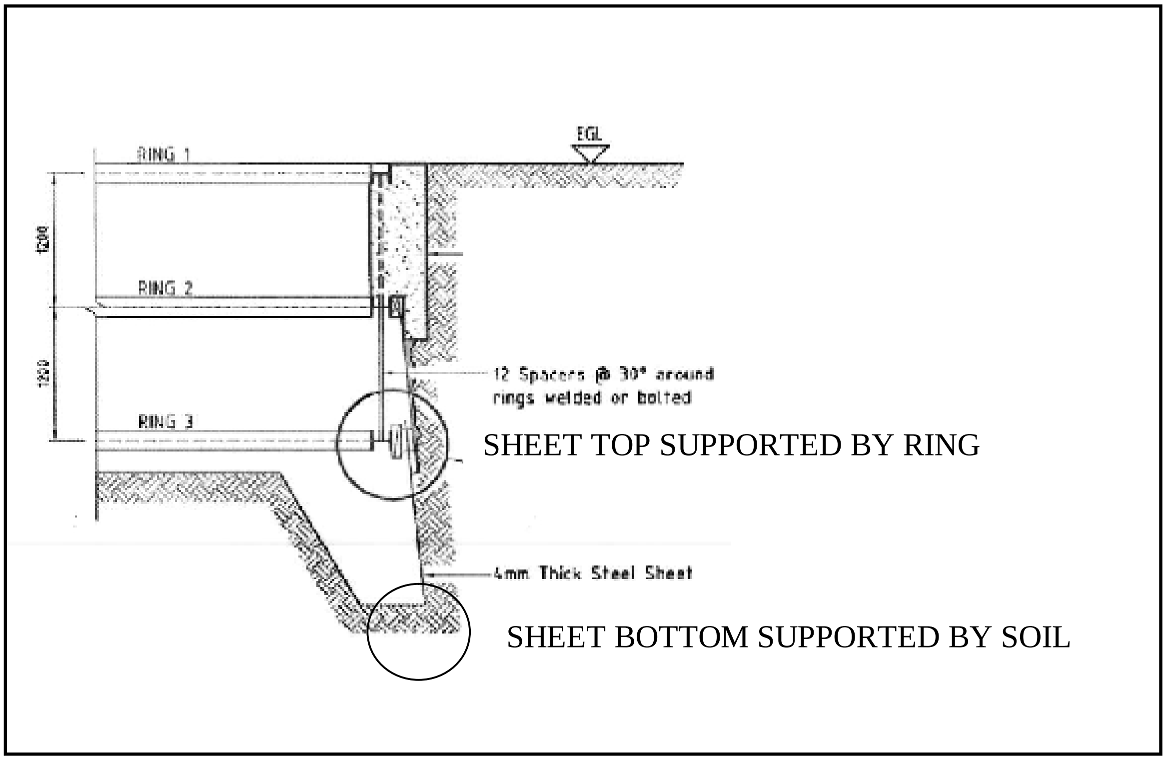
It is appropriate to apply the method in soils that are soft enough to drive a steel sheet of maximum thickness 10mm and 500mm width into the soil for a depth of no more than 1.5m.Those are soils of up to 15MPa strength or Weathering Grade 3 typically soil that can be excavated by a hydraulic excavator without blasting or moiling.

The sheet can be driven by hammer in hand or as done on the case of E2 shaft by means of a hydraulic hammer attached to a mini excavator. The following paragraphs describe the method in principle and sequence.

Principle.

The principle on which the method is based is that material can be excavated whilst the sheets on the perimeter retain the soil wanting to collapse due to ground pressure. This can be seen in the following illustration. This is analogue to techniques such as sheet piles used mostly in civil construction. The difference is that the described method of rings and sheets (R&S) can handle larger horizontal pressures, requires less excavation than sheet piles, does not require a subcontract as it can be done by a shaft sinking crew.

Figure 1 Principle Illustration.



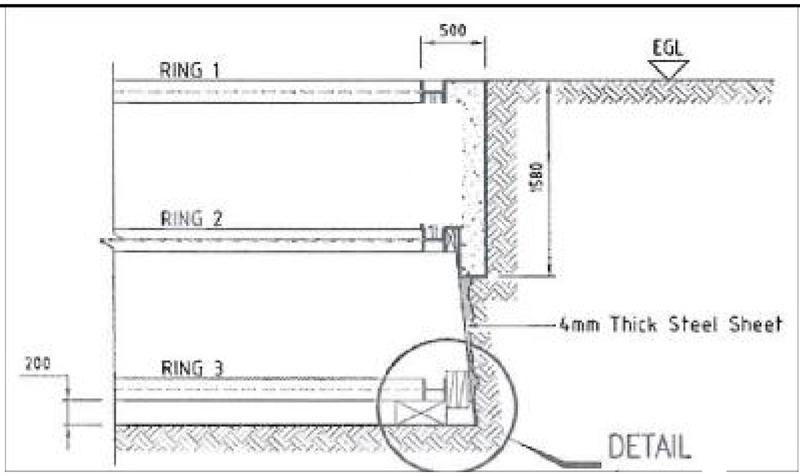
The illustration above clearly indicates how excavation is possible in soft soils when applying the R&S method.

R&S Excavation Cycle

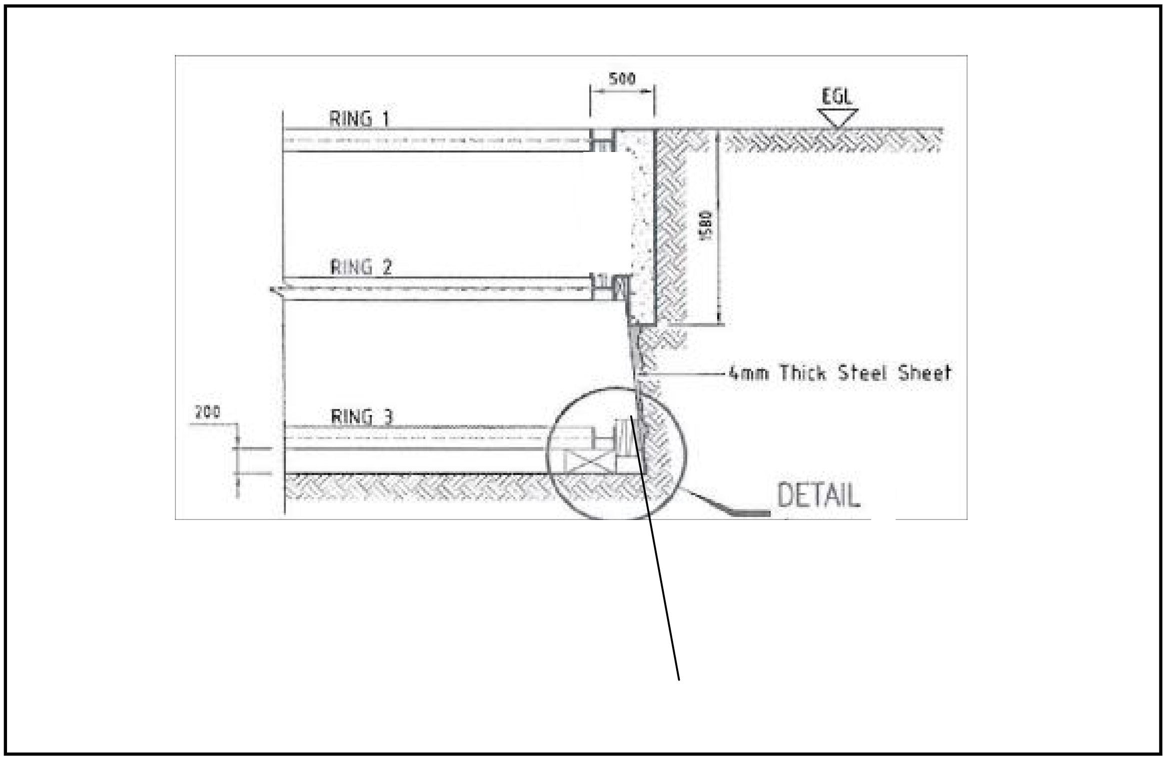
In order to form a holistic idea the sequence of activities that have to be completed in order to excavate the shaft will now be described.

Figure 2 Graphical Representation Of The Excavation Cycle

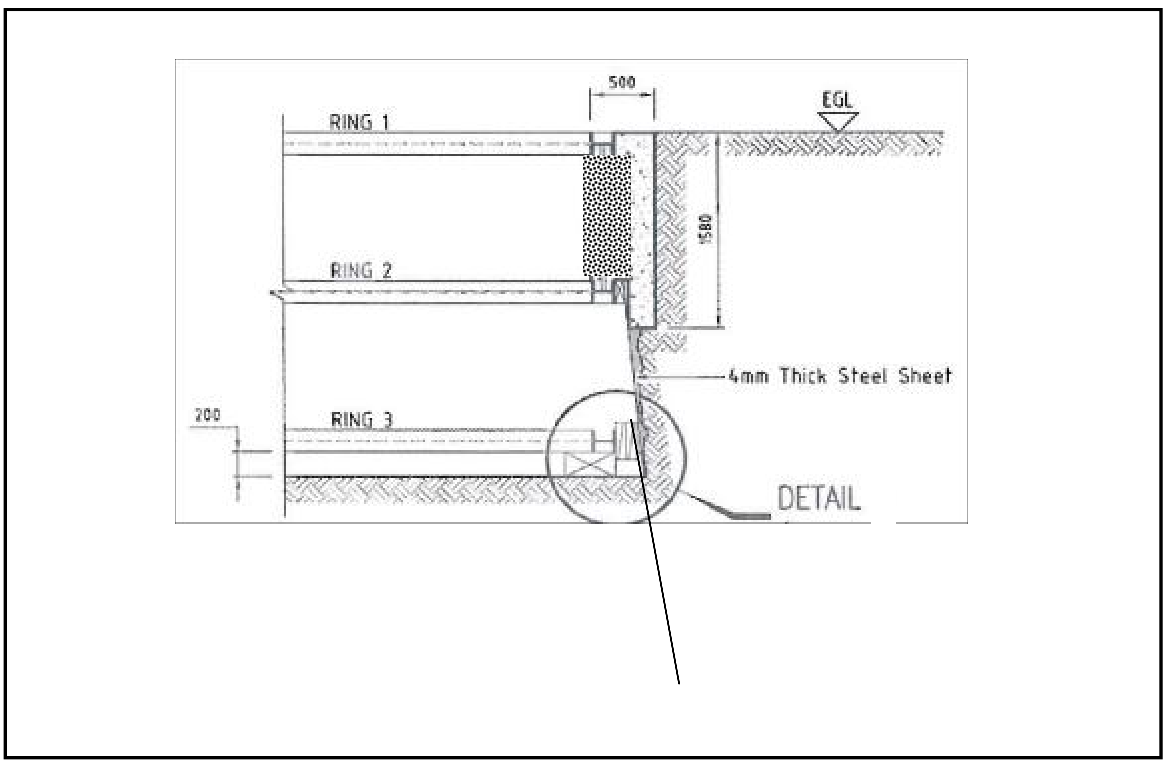
STEP 1 Install the Steel Ring – Ring 3 in the Illustration below.



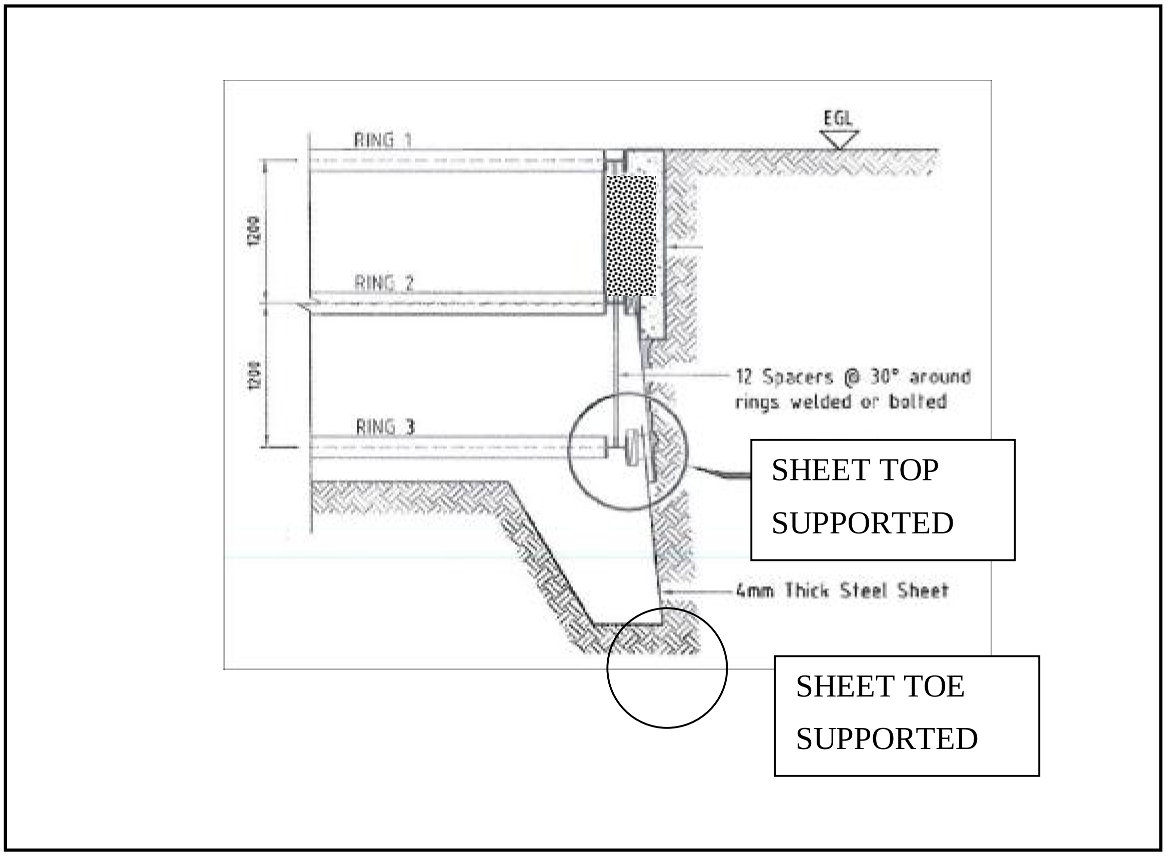
STEP 2 Install the Steel Sheets behind the Steel Ring – Ring 3 below



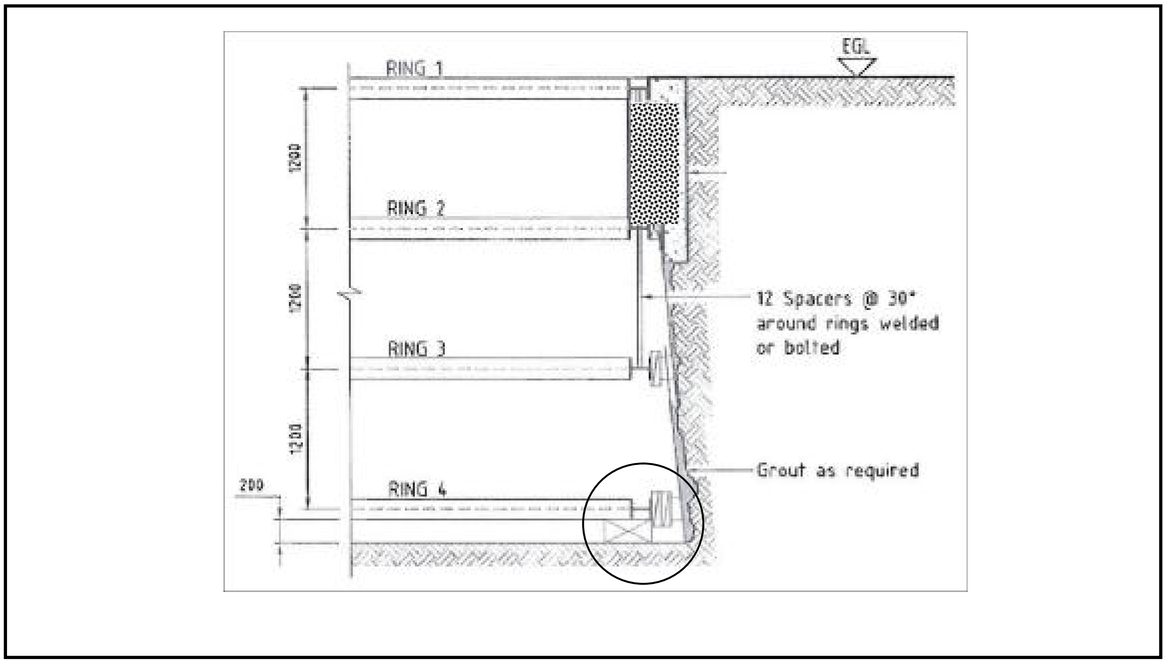
STEP 3 Apply shotcrete between the previous two rings Ring 1 and 2 below



STEP 4 Excavate the shaft sump.



STEP 1 Install the Steel Ring – Ring 4 in the illustration below.



The cycle is suitably carried out by a shaft sinking crew as each shift can be allocated a part of the cycle to complete in their shift and thus a rithm can be obtained.

During the construction of E2 shaft the advance rate of the sump started at around 0.5m/day and increased to one ring per day (1m/day).

Material Components And Their Design.

The material components of this method are the most expensive cost item. This is easily understandable as the shaft is "lined" with steel sheet for the whole height traversed.

The following discussion on the material configuration and design should act as a guideline on aspects to be taken into consideration when engineering this method into a solution for similar circumstances.

Ground Treatment.

The considerations of ground treatment that should be taken into account when engineering the method of R&S are the following:

- How much water should be expected in the shaft after the ground treatment is done? Remember that working in soil conditions with minimal water inflow will cause major difficulty.
- What soil strength was specified to be achieved by treatment. This is a required input for Steel Sheet and Ring design.

It should be kept in mind that low cohesion soils are encountered close to surface and so is groundwater. The water will also like to move along the pressure differential caused by the shaft excavation. So no matter how tight the Steel Sheets are going to be set, the groundwater is likely to perculate through the sump of the shaft and make construction difficult.

Surface Collar

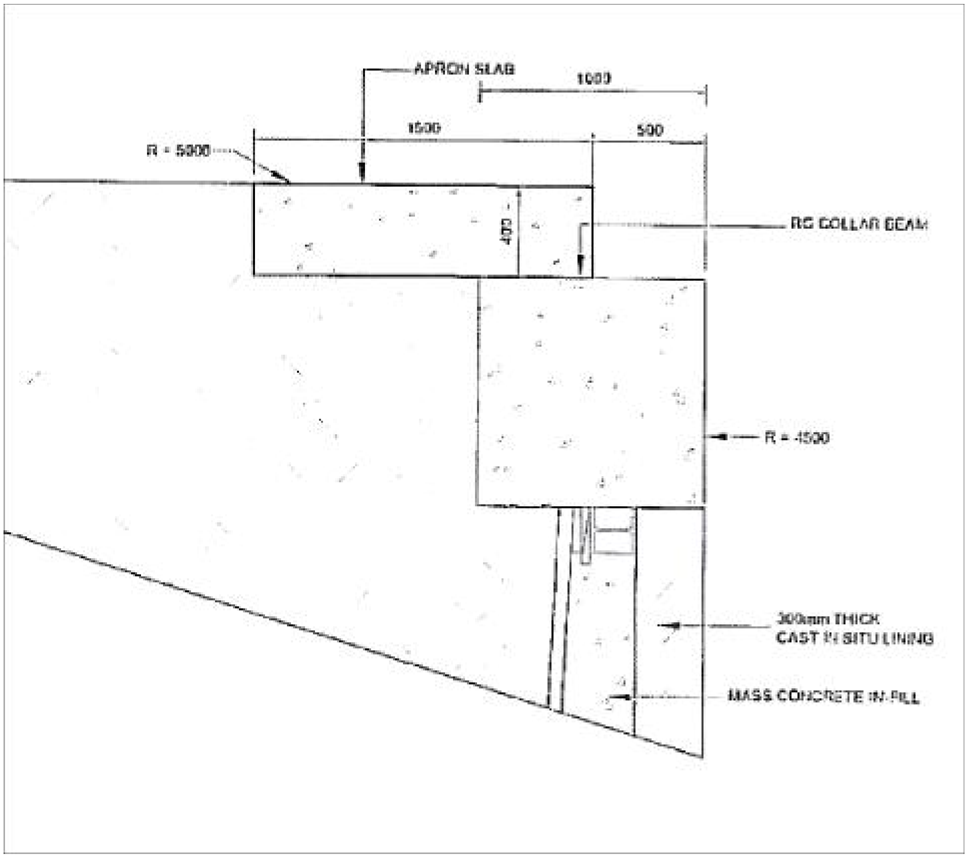
The collar structure serves a dual purpose in this case.

Firstly it needs to be of such design in area and point load capacity that it will protect the excavation from surface installations. These installations are for instance the crane used for hoisting, a muck pile, close-by buildings etc.

Secondly the Steel Rings installed for lateral support in the shaft have to be suspended from the collar. If it is considered that the Steel Sheets and Shotcrete adhere to the Steel Rings the Collar needs to support that load minus the friction force between the soil and the Steel Sheets.

The Collar will typically be a concrete reinforced slab with a circular hole (the shaft) in it. The geometry and structure will depend on the site specific conditions. The following illustration shows the Surface Collar for E2 shaft.

Figure 3 E2 Shaft Collar Layout.

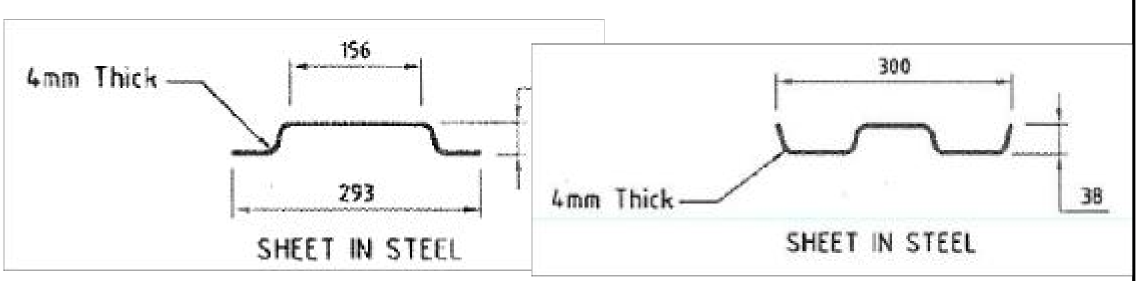


Steel Sheets

The Steel Sheets serve to retain the soft soil by resisting the force over its height and transferring it into the Steel Rings. Corrugated steel sheets should be used as thy will e more cost effective than flat sheets to attain the same structural strength. The sheets should be designed keeping in mind the spans between the Steel Rings.

The following figure indicates the type of sheets commonly used in similar applications.

Figure 4 Steel Sheet Arrangement.

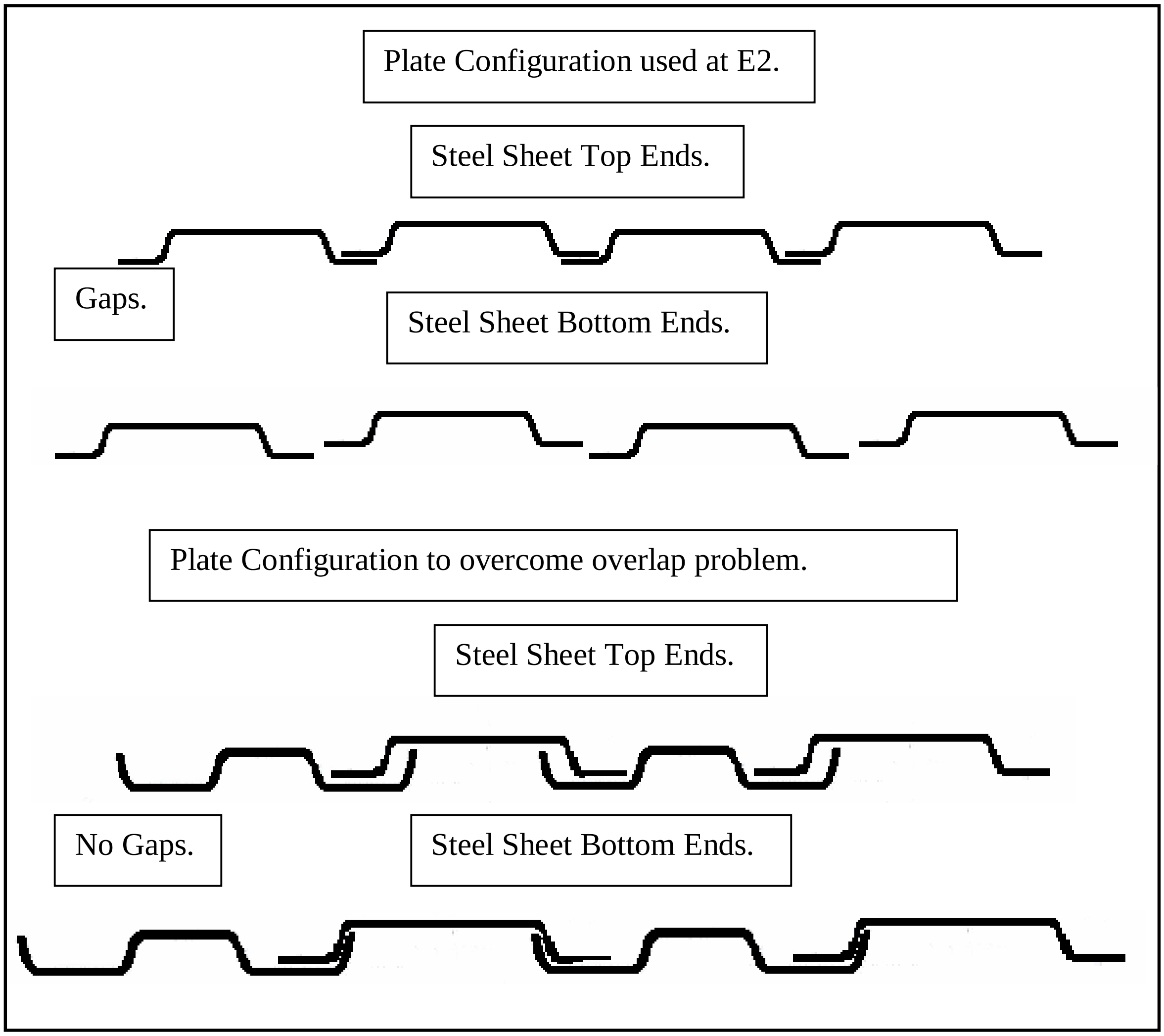


Above are typical sheet profiles that may be considered for use. The profile at the top was used in the case of E2 shaft.

The sheets have to be hammered into the soil with an overlap between sheets in order to ensure proper area coverage so that the soil can be properly contained behind the sheets when excavating.

A problem arises when sheets with parallel corrugations are used. The required overlap at the sheet toe cannot be maintained as sheets are hammered in at an angle to the vertical and thus the toe circumference of the sheets is larger that the top circumference. The result is a triangular gap between sheets on the toe side. This is a real problem in wet material and much less problematic in dry material. Should there be a loss of material into the shaft this will cause voids behind the sheets and surface settlement can occur. Applying the shotcrete to the inside of the sheets whilst water is flowing is very difficult and should be avoided by minimising leakage.

Figure 5 Possible Sheet Configurations.



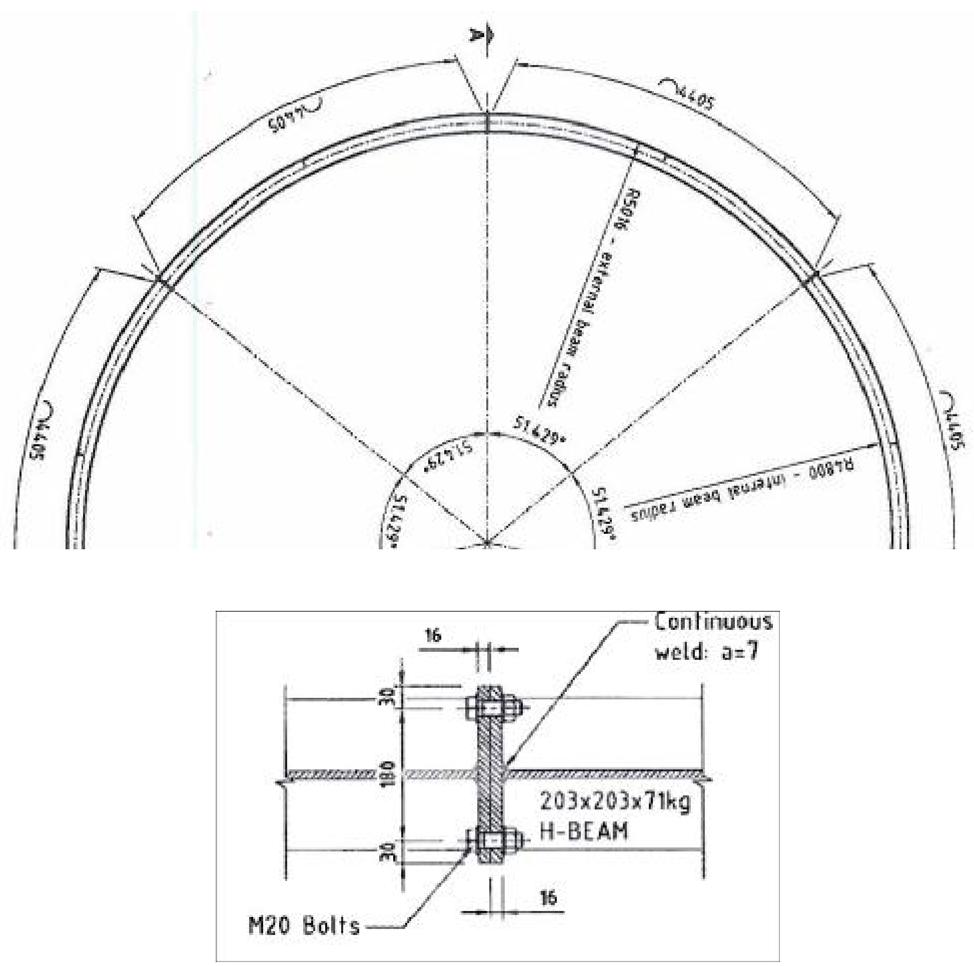
The illustrations above indicate the sheet configurations as well as how gaps forming can be eliminated. It is not the intent to make the sheets water-tight, it is to make the path arduous so that the water rather drains downwards and gets away from the area where shotcrete is going to be applied.

Steel Rings And Suspenders

The Steel Rings bear the lateral earth pressure that is pushing against the Steel Sheets. They are thus the element of the structure that carries all the load. An important design approach is that of uniform vs non-uniform loading. This has a significant influence on the beam strength required.

The Steel Ring should be split into sections that are easily handled. Initially the Steel Rings at E2 were manufactured in 7 Sections using 71Kg/m 201mmx201mm H-Beam. This configuration proved difficult to assemble on an uneven shaft bottom that was also muddy. The following illustration indicates the initial Steel Ring design.

Figure 6 **Initial Steel Ring Design at E2.**



It can be seen in the illustration above that making the splice between sections where bolts had to be inserted from the underside was difficult and hand injuries were a risk. Another problem was fitting the last section. This had to be slid in from the top as sliding it outwards from the shaft it could not fit the gap. Handling a 230kg steel section when it cannot be lifted by crane is quite dangerous.

An alternative was found in using T-H section steel to fabricate the Steel Rings. This is the same steel section as often used in mine excavations. The benefits is that the overlap joint is more easily assembled as they fit into each other and the clamps used are easier to put together than bolted splices of the previous design.

The vertical spacing of the Steel Rings is an important consideration from the operational side. It becomes difficult to maintain the required Steel Sheet angle to vertical when the spacing between Rings becomes less than 1m. Thus a balance should be struck between the safe design excavation height as allowed by the soil and Steel Sheet design on one hand and what can be physically constructed on the other.

Lastly the Steel Ring inner diameter will also define the final lining outside diameter. Te inner diameter if the rings should allow for some tolerance as it is not likely that all the rings will be vertically aligned.

Suspenders or stringers should be included at required intervals on the Steel Rings in order to suspend the Rings from each other and ultimately the Surface Collar. These can vary in design and configuration to suit the specific situation. In the case of E2 shaft channel sections that bolt onto lugs that are welded onto the steel ring.

Shotcrete

Shotcrete is applied to the area between the Steel Rings in order to secure the structure of Sheets and Rings in terms of ridgidity. The shotcrete should not protrude into the excavation past the inner limit of the Steel Ring because it will influence the lining thickness.

During construction of E2 shaft it was found that the area between successive rings should be filled with shotcrete in one application I order to ensure a strong cylinder shaped volume of shotcrete between the rings. The shotcrete is dependent on staying in place by means of hoop stress and the top and bottom ring. There will be very little cohesion between the steel and the shotcrete.

Shaft Final Lining.

Depending on the purpose of the excavation a lining should be designed. E2 shaft was designed as a permanent concrete lined shaft. The lining was installed from the bottom up using commercially available shutters. The shutter was circular and dependent on hoop stress for ridgidity. The fact that the shutter could not be set to the required circularity to achieve hoop stress necessitated anchoring the shutter to the sidewalls to prevent derformation of character.

The final shaft lining does however not form part of the method *per se* and is not discussed in depth.

OPERATIONAL ASPECTS

The method was used without any outside resources being introduced such as contractors etc.

The following heading describe in more detail the plant and skills resourcing of the operation.

Plant And Skills.

There is not a noticeable difference in the requirement of the R&S method and drill and blast pre-sink as far as skills and plant on surface is concerned. The following table explains the plant and skill requirement for the shaft operation only. The engineering crew is not indicated.

Table 1 Plant And Skill Requirements Per Activity

Activity	Plant	Skill	Purpose
Supervision		1x Shift Supervisor	Supervision per shift.
		1x Sinker 1x Banksman	Bottom Supervision Collar Supervision
Surface Operation	Surface Crane – 100T Mobile	1x Crane driver 1x Bell ringer	Hoisting men and material.
Steel Ring installation	Hydraulic Excavator – CAT305CR	1x Excavator Operator	Pushing the rings into position.
		Labour - Physical 4x RDO	Assembly of the ring
Steel Sheet installation	Hydraulic Excavator – CAT305CR. Equipped with hydraulic hammer	1x Excavator Operator	Hammer the sheets into soil.
		4x RDO	Handling of the sheets.
Shotcrete Application	Wetmix pump (Rambo)	1x Nozzleman 4x RDO	Shotcrete operation
Sump Excavation	Hydraulic Excavator – CAT305CR	1x Excavator Operator	Lash Soil/Mud
	3x Kibbles	4x RDO	Handle Kibbles

Site Installation.

The Site Installation was characteristic of a pre-sink. One aspect of note was that a muck bin was installed to prevent having to wait for mucking trucks. Otherwise handling the wet soil caused some issues with mud on the public roads

Shaft Configuration.

A typical pre-sink configuration was adopted.

The shaft was surrounded by a 2m high railing to prevent anything from falling into the shaft. A small crows nest platform was installed over the shaft where the crane conductor could stand and direct the crane driver when material was lowered.

A stage was not installed because of the rings that had to be lowered into position. This meant that the crane had to be able to lower a load to anywhere on the sump.

Implementing a code of signals for te crane driver proved to be the safest as only one action could be indicated at a time. When a conductor indicates slewing and lowering at once the swinging load can be hazardous when approaching the bottom.

Services were only temporarily installed by means of flexible hose and cable. A submersible pump was used to deliver water to surface in one lift other than trying to bail water with the kibbles.

Controls Installation.

Because of the fact that one is working in a soil medium that can move when the structure becomes disturbed it is important to install enough control points for construction purposes.

Firstly monitoring points were installed on the shaft collar in order to monitor if settlement of the surface occurred. These points were measured on a frequency varying from weekly to twice daily depending on the risk anticipated or when a settlement occurred.

Secondly 6 to 8 plumb lines and tapes are required in the shaft to ensure the rings are properly elevated and aligned. The ring alignment is continually checked during ring and sheet installation because the hammering will affect the position and it needs to be rectified.

Lastly deformation arrays of 3 points (120degrees apart) per array are installed at approximately 5m intervals in the shaft to detect any movement of the shaft sidewall as construction is progressing. The frequency thereof should be the same as for the monitoring points on the collar.

Finally once construction is complete the section should be re-surveyed and it should be determined if the shaft centre position as set out is correct for the lining installation.

CONCLUSION

The R&S method has indicated itself to be quite an appropriate alternative for application when the need is to sink a shaft in soft soil with low cohesion and commonly used techniques such as box-cut excavation or sheet piling is not possible or available.

Because of the fact that the sinking crew can execute the work and no additional resources are required and considering the design and mobilisation time as well as sub-contract costs the R&S method will prove not to be more expensive than what is accepted as the norm.

With all said it can be imagined that this method is surely applicable in the mining industry in South Africa.