

NOTES ON SINKING A RECTANGULAR SHAFT THROUGH WET CLAY AT WELGEDACHT EXPLORATION CO., LTD.

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A borehole put down many years ago at a distance of 2,500 ft. from the position of our No. 1 shaft passed through 250 ft. of Karroo beds above the Dwyka conglomerate. These consisted of a considerable thickness of surface clay, followed by coal seams and sandstone beds.

A trial borehole on the shaft site disclosed 98 ft. of soft wet clay followed by decomposed measures with brecciated fragments which it was thought might represent the Dwyka, but the position was uncertain.

The problem was to sink through this ground a five-compartment rectangular shaft 33 ft. by 9 ft. 6 in. outside timbers. It was clear that it would have to be lined with concrete for over 100 ft. and perhaps considerably further, and that suitable foundations would have to be provided for the headgears, rock bins, temporary hoists, etc., of a calculated deadweight of about 2,000 tons, and that the weight of the adjacent permanent hoists might be a factor.

Owing to the semi-incompressible nature of the wet clay, it was thought that a considerable portion of this load might well be transmitted to the shaft walls as lateral pressure, and it was also deemed essential to retain the moisture in the clay to prevent shrinkage and consequent settlement of the main surface foundations.

It was definite that there would be no "skin friction" for at least the first 100 ft. to take a portion of the weight of the concrete lining, which would therefore have to be entirely suspended, and as the position thereafter was uncertain, it was considered advisable to calculate the reinforcement for a lining not less than 150 ft. in depth. The anchorage for this would have to be a raft or mat capable of withstanding a certain dynamic load due to the passage and filling of ore trains in addition to the static load. The column represented by the lining would be in tension until "toed in" on a suitable footing, after which it would become a beam in compression which would also have to stand a considerable shearing stress.

Assuming that the lateral pressure transmitted by the wet clay on to the shaft lining would be 50 per cent. of that transmitted by a liquid, which in turn would be a function of the depth or "head," calculation showed that the concrete would need to be tapered downwards from the surface until a thickness of 6 ft. was reached 100 ft. below the collar.

Preliminary work showed the inadvisability of attempting to excavate the clay in this fashion, and the attempt to design reinforcement to provide for this extra thickness at the base of the lining was unsatisfactory. The problem was met therefore by placing steel girders laterally across the shaft in the position normally occupied by dividers, and by increasing the size of the girders as the depth progressed, at the same time shortening the interval between girders, the necessary increased resistance to shearing of the concrete walls at depth was obtained.

The design provided for 10 in. by 8 in. 55-lb. rolled steel joists being placed at 7 ft. 6 in. centres (vertically) immediately below the collar sett to a depth of 24 ft.,

then 10 in. × 8 in. 55-lb. R.S.J.	at 5 ft. 0 in. centres from	24 ft. to	34 ft.	
12 in. × 8 in. 65-lb.	„ 5 ft. 0 in.	„ „	35 „	39 „
12 in. × 8 in. 65-lb.	„ 3 ft. 9 in.	„ „	39 „	54 „
16 in. × 8 in. 75-lb.	„ 3 ft. 9 in.	„ „	54 „	79 „
16 in. × 8 in. 75-lb.	„ 2 ft. 6 in.	„ „	79 „	102 „

These girders, in compression, enabled the thickness of the concrete lining to be maintained at a uniform figure of 3 ft. The girders were embedded for 2 ft. 9 in. of their length at each end in the concrete. The question of riveting angles to the girders at such positions as to place their surfaces in contact with the concrete lining, and so give increased area to resist compression, was considered, but was discarded as the adhesion between good cement concrete and embedded steel is upwards of 100 lb. per square inch of steel surface, which, in other words, meant that the concrete lining would crack in all directions before this adhesive force was exceeded.

It was apparent that with this amount of steelwork in the shaft placed in the position of dividers, timber setts were unnecessary. The girders were drilled, therefore, to take the guide shoes, and 6 in. by 3 in. steel channels were fitted as distance pieces in the position usually occupied by wall plates; these distance pieces were bolted in position to ensure the exact alignment of the girders before the concrete was run in.

The main reinforcing bars in the concrete mat were of $1\frac{1}{2}$ in., $1\frac{1}{4}$ in. and 1 in. diameter, according to their position as shown in Fig. 19, and were tied with $\frac{5}{8}$ in. diameter cross bars fastened with baling wire.

In the shaft lining, $1\frac{1}{4}$ in. hanging bars were used, the horizontal reinforcement being of $1\frac{1}{8}$ in. diameter bars spaced at 15 in. centres at the top, and decreasing by stages to 6 in. centres at a depth of 60 ft. The usual subsidiary reinforcement was used. Our experience in sinking the shaft through this ground justified the precautions taken.

A reinforced concrete mat measuring 90 ft. by 80 ft. in plan, 3 ft. in depth at the edges and 12 ft. at the shaft was first laid down with tongues running out to connect up with the headgear back leg foundations, and the girders of the collar sett placed in position. The surface soil and clay was then excavated to the shaft size for a depth of 12 ft. below this,

the reinforcing bars placed in position and the concrete poured into the formers in the usual way. 7 ft. to 10 ft. lifts were excavated and 12 in. by 2 in. oregon placed vertically was used to keep the clay back, but at a depth of 40 ft. these gave way. 30-lb. rails placed at 4 ft. intervals were then "spiled" ahead and horizontal boards fastened to these as a framework to stiffen the oregon plank lining.

At a depth of 50 ft. these rails were bent over at right angles by the pressure of the clay. This could doubtless have been relieved by leaving open pipes in the concrete as weepholes, but this procedure was forbidden as our object was to retain the water in the clay.

Recourse was had to making false setts of 30-lb. rails: these were cut to fit the outside dimensions of the excavation, were bent to form the corners, and fishplated together along both the long and the short sides. By installing these at 3 ft. 9 in. centres we were able to hold the clay back until the next set of girders and lift of concrete had been installed.

At a depth of about 70 ft. it was impossible to excavate more than 4 ft. ahead of the solid concrete, and then the clay was running as a semi-liquid through half-inch gaps between the oregon planking.

The position was complicated by large cavities being formed outside the shaft area due to the amount of clay that oozed between the planks before the pressure was relieved. These cavities were carefully filled with bagged sand, and subsequent to the building of the concrete lining, were consolidated by running liquid concrete through the grouting joints. The position was extremely uncomfortable, and we were considering sinking the centre compartments only and prospecting ahead for something more solid, when the clay stiffened to a consistency resembling fireclay, which, in spite of some awkward seams of soft graphite shale, enabled us to get down without recourse to shortening the centres of the steel setts to 2 ft. 8 in. as designed. This we were loath to do, as the vertical interval between the flanges would have been barely 2 ft.

At 98 ft. the shaft passed into decomposed Dwyka conglomerate followed by a narrow bed of chert, neither of which was suitable for a "toe," and then into green dyke.

The bottom steel sett was placed in the concrete at 105 ft. from the surface and the timber setts hung therefrom.

The problem now became the more normal one of sinking through the green dyke, the special feature being the necessity for hanging the concrete lining from the reinforcing rods projecting from the concrete above, so as to wall in the dyke as rapidly as possible. Owing to the great surface area of the mat, and the strength of the reinforcement, we felt that we could safely continue the suspension method for another 100 ft. as skin friction would assist us in the dyke.

When the green dyke was intersected, the concrete lining was decreased to a width of 2 ft. but was still hung from the reinforcement of the last lift above. In all, 246 ft. of vertical concrete was hung from the surface mat before we were able to "toe in" in dolomite.

The permanent hoist and headgear have been erected, and the temporary hoists are still in position on the surface mat. The following table shows the amount of discernible settling that has taken place over a period of seven months: two sets of observations taken in May and October, 1936, are compared with those taken in March:—

Location.	Difference between March and May.	Difference between March and October.
Collar Sett E	Nil	Nil
Collar Sett W	$\frac{3}{8}$ in. low	$\frac{3}{4}$ in. low
East Front Pier	Nil	Nil
West Front Pier	$\frac{1}{2}$ in. low	1 in. low
East Back Pier	Nil	Nil
West Back Pier	—	$\frac{3}{8}$ in. low
ENGINE HOUSE :		
S.W. Corner	—	$\frac{3}{4}$ in. low
S.E. Corner	—	$\frac{1}{2}$ in. low
N.W. Corner	—	$\frac{3}{8}$ in. low
N.E. Corner	—	$\frac{1}{2}$ in. low

STATISTICS.

First sod cut on July 3rd, 1935.

Dwyka conglomerate exposed at 98 ft. December 2nd, 1935.

Number of days worked : 147.

ESTIMATED WEIGHT CARRIED ON THE MAT :

Weight of concrete in Mat	2,483 tons.
„ reinforcement in Mat	157 „
Total	2,640 tons.
„ concrete in collar and shaft lining	3,427 tons.
„ reinforcement in collar and shaft lining	197 „
„ steel shaft setts	50 „
„ temporary hoists	55 „
„ temporary headgear	120 „
„ permanent headgear	400 „
Total	<u>4,249 tons.</u>

PRESSURE EXERTED OUTSIDE THE MAT AREA :

Weight of Hoists, etc. 575 tons.

Note.—Steel ore bin with contents not included.

COST OF ESTABLISHING MAT AND COLLAR SETT AND OF SINKING
AND LINING SHAFT TO A DEPTH OF 98 FEET.

	<i>Total.</i>
White wages	£1,808
Coloured wages	1,371
Compound expenses	934
Workshops	315
Water Service	39
Stores and Materials	13,332
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	£17,799
Supervision	318
Winding Charges	1,651
Pumping	271
Waste Dump	658
Other Mine Costs	211
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	3,109
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	£20,908
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Analysis of cost of stores and materials used as shown above :—

Cement	£4,172
Sand and Stone	2,025
Reinforcing Steel	3,397
Rolled Steel Joists	1,620
Timber	407
Concrete Mixers	422
Sundry Stores	1,289
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	£13,332
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Below this point the cost was charged to shaft-sinking and shaft equipment.

Introductory Remarks by the Author: It was suggested to me that some notes on the sinking of No. 1 Shaft, Welgedacht, through what is possibly the thickest deposit of wet clay so far encountered on these fields, might be of interest and would form a record for the convenience of members of this Association who may be called upon to repeat this operation in the future.

These notes are submitted in this spirit, and, although it is not claimed that any new method has been demonstrated, I hope that sufficient description of the reasons actuating our decisions has been given to enable others to approach this problem, if called upon to do so, with confidence and with a knowledge of the detail of the job and of the cost likely to be incurred.

Perhaps the best introduction I can give to my paper is to examine briefly, from a wider standpoint, the problem with which we were faced.

When I joined the Welgedacht Exploration Company towards the end of May last year, the decision had already been made to sink two five-compartment rectangular shafts. This was considered the most suitable general purpose shape, *i.e.*, to deal with heavy water during sinking, to provide adequate hoisting capacity for the contemplated tonnage, and to give reasonable ventilation facilities at the fairly

shallow depths indicated. In addition, it had the merit of conforming to the most widely used type on the Far East Rand, so there did not appear to me to be adequate reasons for discarding the plans already made, with the consequent loss of time, and reopening the discussion *de novo*.

As regards the sinking through wet clay, quite apart from the other considerations, a circular shaft concrete, or if necessary, steel-lined, seems attractive both from the standpoint of cost and of sinking speed, and was in point of fact discussed, but the idea was abandoned for the above reasons. In defence of our decision, however, I would point out that the Mining Group whose name is pre-eminently associated with circular shafts has itself followed the rectangular practice in the latest shafts sunk in the same area.

Regarding alternative methods of tackling the wet clay, those familiar with the cementation process as practised by the Francois Cementation Company assured me the method would not be practicable and that, in effect, one could not solidify wet clay by the injection of cement. This confirms my own experience, and I think it can be accepted that the method is only applicable where the formation is sufficiently solid to resist the high pressures built up during injection.

The only other method considered was the "freezing process." This method has, as far as I know, not been used in this country, so that the delay and cost in obtaining information in building up the necessary organization made this unattractive as compared with other methods more in keeping with local experience.

Turning now to the floating raft method as actually installed: it may be that some members would not agree to considering the clay as half as compressible or incompressible as a liquid, and that, therefore, in their opinion, an unnecessarily high factor of safety was used in the design.

In defence of our view, I would quote Peele (Mining Engineer's Hand Book) who states (page 120) that ordinary clay contains 50 per cent. voids. Those voids were, as far as we could judge in our case, filled with water.

He states further (page 295) that in sinking through unstable soils "the water must be excluded permanently by a lining strong enough to resist external pressure corresponding to the head of water or of semi-fluid material"; and that "the presence of water increases instability which is a more serious obstacle to sinking than water itself."

Dealing with the question of external pressure, he says, "The lining at any given depth must be strong enough to resist the corresponding hydrostatic pressure, since it is due to a depth of fluid composed of water and mud, of greater specific gravity than that of water alone." This seems to me sufficient justification for the factor used. In addition it must be remembered as regards the lining itself that it may have to stand severe localized shearing stresses due to uneven distribution of external pressure.

The bending of the rails which were placed vertically in the clay, as mentioned in the paper, affords a rough check on the pressure exerted. It has been calculated that such a rail would require a pressure of about 2,000 lb. to so bend it at a point 12 in. above the clay. Half the pressure due to a liquid with a head of 40 ft. would be 8 lb. per square inch, from which it will be seen that the pressure due to the head applied over an area of 250 sq. in. should bend the rail. This, I think, conforms roughly to the condition we met in practice.

Regarding the figures of cost which I have submitted, I would point out that at the time this work was done we had to obtain our cement largely from import sources owing to the shortage then obtaining. The actual price paid averaged 4s. 9·7d. per pocket. If this were purchased at to-day's market price, this would result in a saving of £1,651 as compared with the figure I have given.

May I point out, in conclusion, and apologise for an error in Fig. 20, which shows the lining as being "toed in" at a depth of 100 ft. from the surface. The drawing in question was prepared in town and I did not have an opportunity of checking it before printing. It is a reduced sized copy of the original sectional elevation, and after perusal of my paper you will realize that this "toe" was in fact not cut until a depth of 246 ft. had been reached.

20th November, 1936.

