CONCRETE-LINED INCLINE SHAFTS.

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Down to a depth of 6,850 ft., the horizon of 41 Main Haulage, Crown Mines has sunk, and is sinking, fully timbered incline shafts.

Below this level it was decided that the incline shafts should be concrete-lined.

The following advantages are expected.

(*a*) Less danger of fire.

(*b*) Increased ventilation, due to less friction in shaft.

(*c*) Drier air, owing to fact that less watering down will be necessary.

(*d*) Decreased cost of upkeep.

Two shafts P.1 and P.3 are completed, P.5 is in an advanced state of development, and P.2 has been commenced.

Overmining has not yet commenced, and therefore no data are available regarding the pressure-resisting capabilities of these shafts. P.1 is 100–180 ft. below the Main Reef Leader and P.5 commences 80 ft. below the Main Reef Leader.

P.1 Shaft.

Average dip 40°.

Distance between levels—150 ft. vertical.

Total length when finished—1,617 ft. below collar.

Compartments—two hoisting, one ladderway and pipes.

Finished width of shaft—16 ft. 2 in.

Gauge of track—3 ft. 10 in.

Skip capacity—3 tons sinking—5 tons on completion.

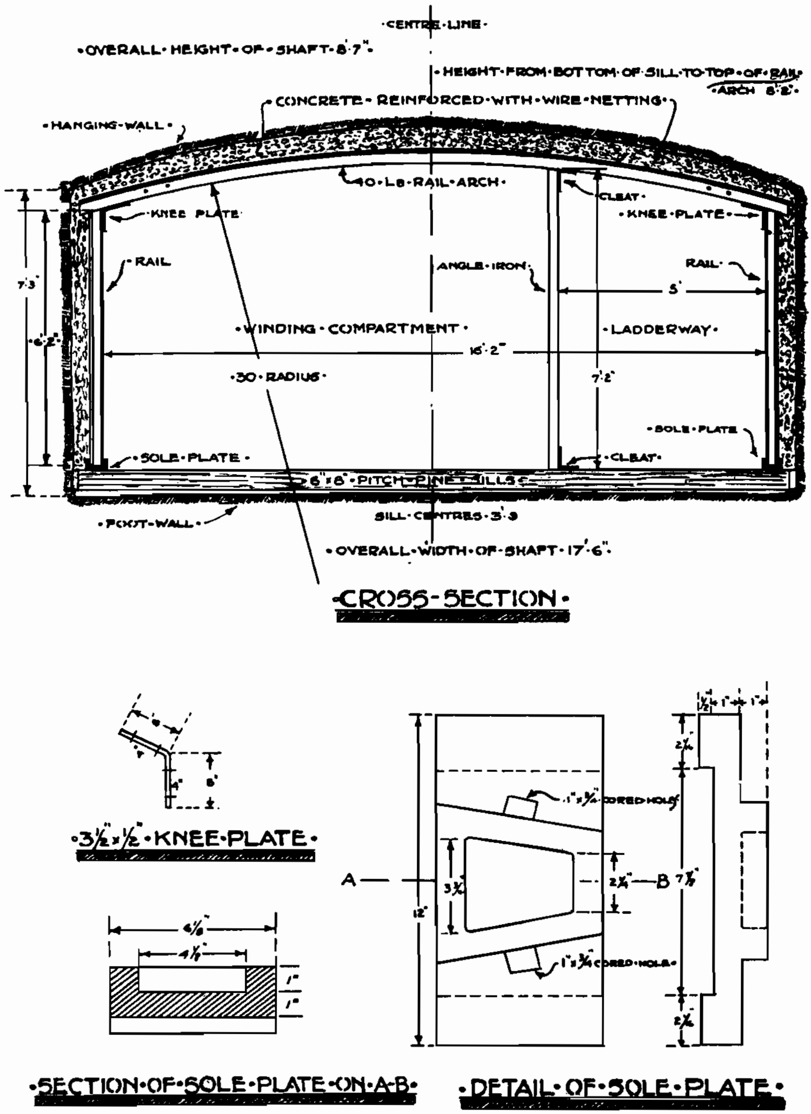
Weight of rails—60 lb.

Hoisting speed—2,000 ft. per minute.

Steel arches—40 lb. rail, 3 ft. 9 in. apart.

Hoist—Metro-Vickers three-phase induction motor 900 h.p.

The procedure of sinking is similar to that in an ordinary incline shaft. Sills are placed in position, graded, wedged and fitted with sole plates, and the arch erected during sinking operations. The arches are held in position by hanging bolts, and are kept within about 20 ft. of the shaft bottom.



Sketch of P. 1. Concrete Shaft.

FIG. 30.

When the bottom of the shaft is approximately 50 ft. from the last concreted arch, sinking is stopped, and the sills and arches are carried to within about 8 ft. of the face. The shuttering of the arches is then commenced. If the ground is bad the sinking is stopped and the concrete work brought up to the face. In very good ground 80 ft. has been sunk before concreting, but I consider this distance excessive.

Concreting.

The last rail arch sett having been erected, a 9 in. by 3 in. cross-deal is held securely in position across the shaft by means of two 6 in. diameter poles, wedged vertically at the shaft sides. The opening between the arch rail sett and the walls and floor of the shaft is then boxed in with $\frac{7}{8}$ in. planks and the whole spragged to the face to prevent bulging under pressure of the wet concrete. The boxing or shuttering is then carried over the setts up the shaft until the section to be concreted is entirely covered in.

The method of holding the boxing or shuttering beneath the setts is as follows :—

A $\frac{1}{4}$ in. iron plate strap with holes for $\frac{1}{2}$ in. bolts at either end is straddled across the rail. The two $\frac{1}{2}$ in. bolts are passed through the ends of the boxing, to form a butt joint under the flange of the rail. The bolts are fitted with nuts above the iron strap. Particular care is taken that the bolts are of such length that the ends do not protrude above the nuts, otherwise they, the bolts, cannot be removed after concreting.

When the boxing or shuttering has been completed a layer of 2 in. mesh is laid on the setts for reinforcement and concrete is then run in and allowed to set for two days. The boxing or shuttering is then removed. The mixing of the concrete is done on P.1 bank on the 41st Level in a mixing box 50 ft. by 4 ft. A side-tipping car of $1\frac{1}{2}$ ton capacity is used for the measuring of the material. The dry mixture is turned over twice before being wetted. To dry mix a cubic yard of material takes three boys one hour.

The original mixture used was 1 : 3 : 6 using 1 in. stone, but it was found that after the mixture passed the 44 Level there was a tendency for the stone to override the sand and cement to the detriment of the mixture. It was then decided to reduce the size of the stone used from 1 in. to $\frac{1}{2}$ in. and increase slightly the sand and cement, making the mixture 1 : 3 : 5. It was found that by keeping the mixture at the viscosity of mud the $\frac{1}{2}$ in. stone was retained satisfactorily.

The first type of launder used to convey the wet concrete to the site of concreting was a ventilation piping cut in half. This type of launder proved unsatisfactory, for loss of stone occurred owing to the top being open. An enclosed wooden launder 6 in. square and lined with galvanized iron made of old and cut pipes is now used and is proving satisfactory. The wet concrete is run down in three minutes, the velocity averaging 500 ft. per minute.

The launder conveying the concrete is led into the top centre of the setts, and the concrete fills completely the space left for it between the shuttering and the walls.

A different procedure is adopted, however, when a station is reached. The shaft is stopped after sinking a distance equivalent to four to six setts below the station, and the station is cut in for a distance of 33 ft. This 33 ft. is then fitted with setts and concreted, concreting being done mostly by hand.

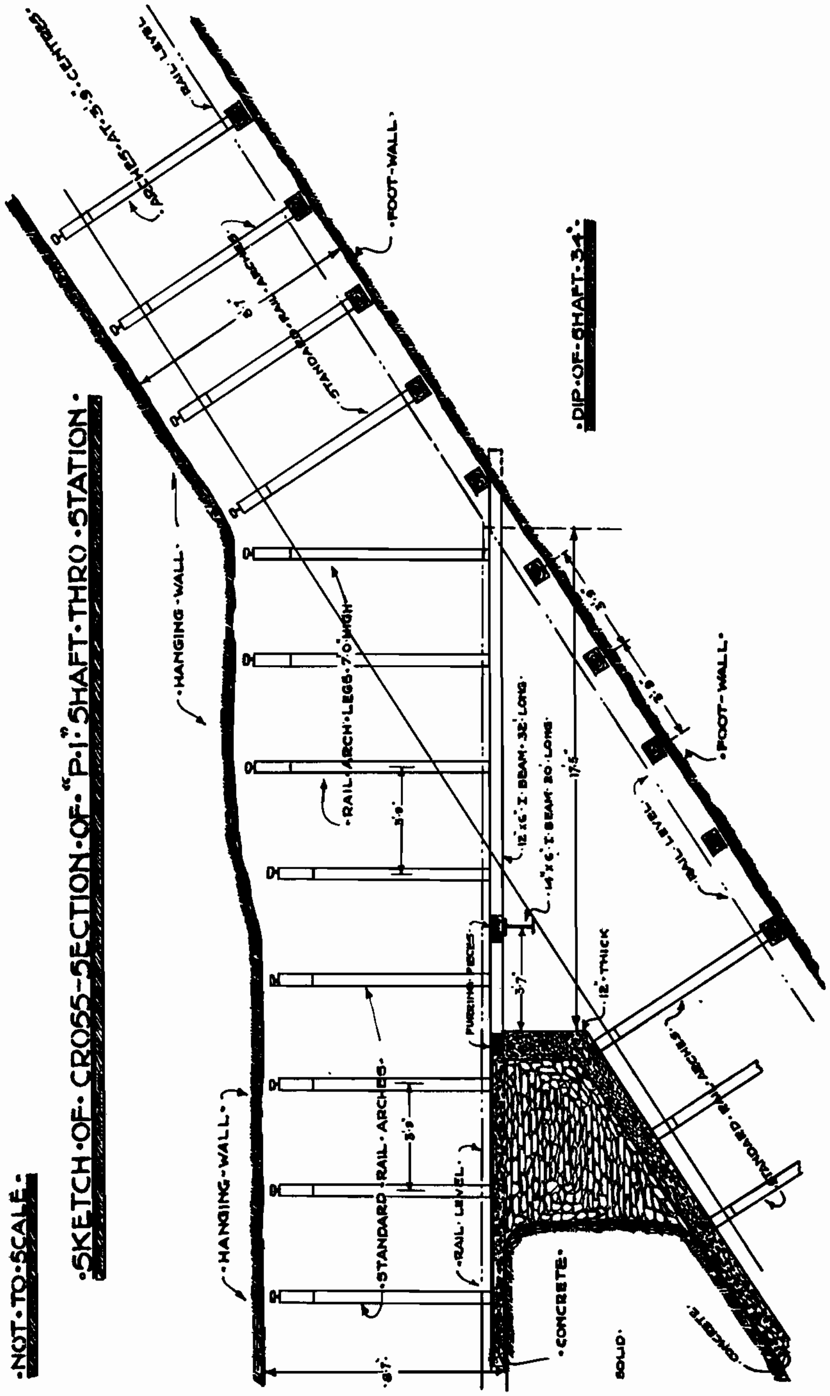

NOT TO SCALE
SKETCH OF CROSS-SECTION OF "P.1" SHAFT THRO STATION
HANGING WALL
FOOT WALL
DIP OF SHAFT 34°
RAIL LEVEL
STANDARD RAIL ARCHES
RAIL ARCH LEGS 7' 0" HIGH
ARCHES AT 3' 6" CENTRES
CONCRETE
SOLID

FIG. 31.

On completion of this stage of concreting the brow of the station is removed and the concreting brought to the shaft bottom. Sinking operations then recommence.

After two days of filling the bottom concrete is considered to be set, and sinking operations are recommenced. The filling of the upper portion is carried on until the section is completed.

P.5.—This shaft, commenced in August, 1934, is of a similar design to P.1. The arches, except in bad ground, are not kept so near to the face. Generally a penthouse is built about 30 ft. from the face, and 50 ft. below the last concrete filling. Sills which have been put in during sinking are levelled and the arches erected. The bottom shuttering is held by 9 in. by 3 in. cross pieces which are retained by four 6 in. laggings.

Sinking operations are not stopped unless it is necessary to carry the arches within 10 ft. of the face.

Concreting.

The shuttering or boxing is held to the underside of the rail setts by means of a loose or floating rail arch, suspended by means of the usual plate and bolts, in this case an under-plate being required to hold the rail. The shuttering rests on the top surface of the loose arch and is wedged into smooth alignment, the resulting surface of the concrete being somewhat smoother than in P.1 shaft.

Reinforcement for concrete is by means of 2 in. square mesh as in P.1 shaft.

The shuttering is made of 1 in. planks and is carried down to the foot-plate of the rail and setts, and it is so managed that it forms a 4 in. step towards the centre of the shaft before being carried down to the foot-wall.

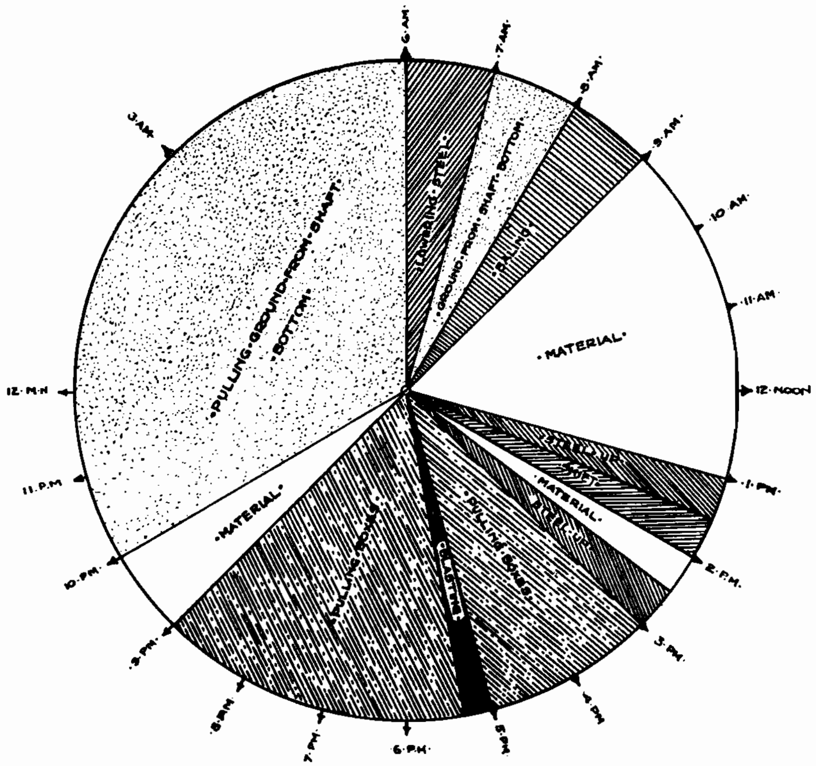
The sills are then sawn off level with the inside line of shuttering nearest to the wall and, when the concrete has set, the sill is retained in position by a 4 in. ledge of concrete. The rail arch sett rests on the blocks of wood cut off from the sills. By this arrangement it is possible to replace sills without disturbing the setts.

The mixture of concrete is 1 : 2 : 4 by measurement in a truck but as development waste is used in the aggregate, the stone being up to 3 in. in size and containing many fines, the mixture is probably some other ratio, but nevertheless makes a strong concrete.

The concrete is made in small batches and the dry mixture turned over twice and shovelled into the launder at the same time as the water is applied.

As the concrete is mixed on the level nearest to the work in hand the launder is never more than one and a quarter levels in length, and consequently the stones in the mixture do not override the sand and cement.

Large gaps are filled with large boulders before the introduction of concrete.



Time Graph of Winding Operations on P. 1. Shaft.

Fig. 32.

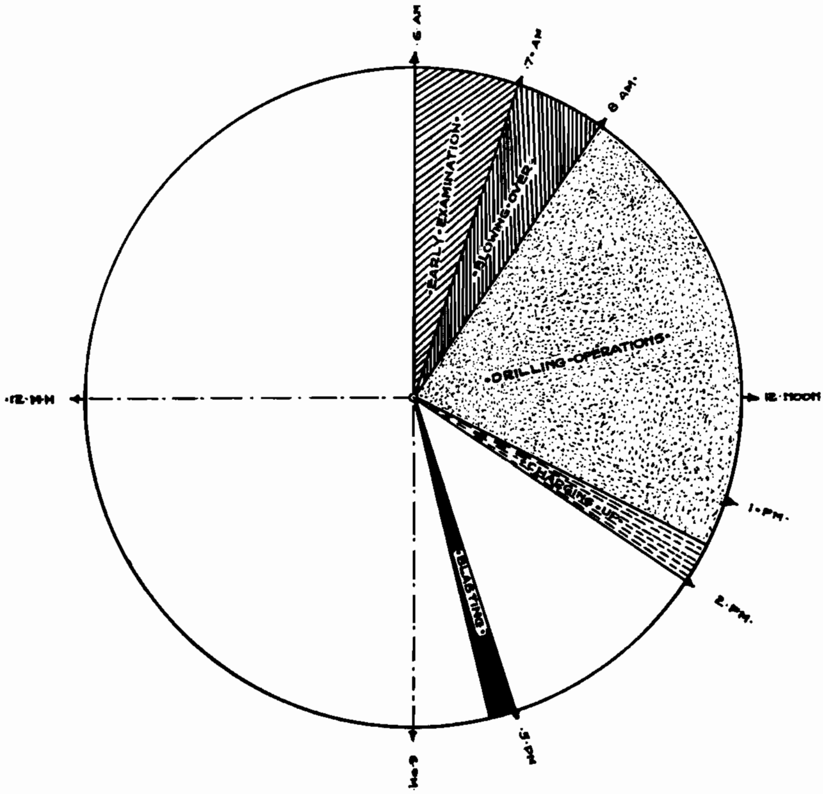
The launder used for conveying concrete is 9 in. square and is jointed by butt joints held by straps, no nails being used in order to prevent leakage. The launder is not lined and is turned when removed to the next level; it may be deviated from one side to the other by means of an extension piece.

The shuttering is done over a length varying from five to fourteen setts and completed before concrete is run in. In order to facilitate filling of the last sett and to make a good join, all end pieces have a special gap of 2 ft. left in the centre extending up to the roof, through which concrete is finally fed.

All the cracks in the shuttering are tamped with paper in order to prevent leakage.

No stoppage takes place when a station is reached. The shaft is sunk for a further distance equivalent to eight to ten setts and the station is developed for a distance of 15 ft. while sinking operations are continued in the shaft.

The fastest work accomplished to date was the erection, concreting and the finishing of fourteen setts in three shifts.



Time Graph of Sinking Shift on P. 1. Shaft.

Fig. 33.

It has been noticed that the concrete does not fill well on the bottom side of the rail legs. This causes a line of weakness. To remedy this, we propose to dispense with the upright leg on P.5 shaft and have a continuous concrete wall. In order to support the arch during filling, the legs will be set back sufficient to allow the shuttering to be inside the leg (the leg being used in the same way as the present floating rail). The leg would be removed after the concrete has set, and used again. This system has not yet been tried.

The ladderway is bratticed off by 1 in. netting supported on 3 in. angle-iron. The hand-rail is $1\frac{1}{2}$ in. piping and is utilized for the drinking water service.

P.5 shaft is equipped as far as the last completed station. The concrete lining is whitewashed, which helps lighting considerably.

COMPARATIVE STATISTICS.

EXCLUDING ALL WORK ABOVE COLLAR AND WINDING CHARGES.

	Fully Timbered.							Concrete-Lined.		
	H6	H7	K2	K4	K6	M3	M4	P1	P3	P5
Level sunk from	24	24	29	29	29	35	35	41	41	41
Date sinking commenced ...	Jan. '29	June '31	Sept. '26	July '29	June '32	June '29	Dec. '31	Nov. '32	March '32	Aug. '34
Date sinking finished ...	Jan. '31	Feb. '33	Feb. '28	March '31	March '34	Jan. '31	Aug. '33	June '35	Sept. '34	—
Footage sunk below Collar ...	1,621	1,294	1,453	1,600	1,710	1,550	1,635	1,617	1,035	783
Footage—Stations ...	315	156	340	270	246	231	285	290	209	118
	Cost per Foot.									
	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.
Cutting shaft and stations, etc., below collar, including cleaning	6 9 8	6 5 8	7 17 10	7 5 10	5 13 4	8 1 3	7 2 1	6 9 10	7 14 8	6 5 7
Equipment, support, etc. ...	10 5 1	9 13 3	9 15 9	9 8 8	8 16 0	9 8 11	9 10 7	16 17 6	11 19 10	13 3 7
Total Cost ...	16 14 9	15 18 11	17 13 7	16 14 6	14 9 4	17 10 2	16 12 8	23 7 4	19 14 6	19 9 2

Fig. 34.

Introductory Remarks by the Author: The question of sinking concrete-lined incline shafts in the deeper workings of Crown Mines was considered by Mr. Walton for some time before he actually introduced them in the beginning of 1932.

Mr. Ardler was in charge of sinking one of the earlier shafts, and he originally intended presenting this paper, but owing to stress of work was unable to do so. I thank him for the use of his notes, especially in connexion with P.1 incline.

The paper gives a brief outline of the work in connexion with concrete-lined incline shafts, but a better idea would be obtained by paying a visit to one in course of construction.

These shafts are developed only for supplying men and material to intermediate levels between haulages which are placed at approximately 1,000 ft. apart on the dip. When these areas are worked out the sills and equipment will be removed, and the shafts used as return airways.

Any permanent rock-hoisting shafts which may be sunk from the bottom haulage levels will be equipped with concrete sills as well as being concrete lined.

MONTHLY RATE OF SINKING.

	Shaft only.	Shaft and Stations.
H.6	67 feet.	80 feet.
H.7	61 „	68 „
K.2	81 „	100 „
K.4	73 „	85 „
K.6	78 „	89 „
M.3	77 „	89 „
M.4	78 „	91 „
P.1	50 „	60 „
P.3	34 „	41 „
P.5	65 „	75 „

P.1 and P.3 were the first concrete-lined shafts sunk on Crown Mines and the initial rate of sinking was low. Neither was equipped for handling reef and waste separately, and, as reef development was carried on concurrently with sinking, many delays arose. P.1 shaft also slowed down owing to the necessity of handling rock and material during the preparatory stages for deepening 14b sub-vertical.

P.5 incline being commenced later has the advantage of the experience gained in the two previous shafts. The headgear bin is constructed to handle both reef and waste.

During August 105 ft. was sunk in this shaft and 90 ft. concreted.

Costs.—It will be noted that P.1 costs are considerably higher per foot than P.3 and P.5. This is accounted for as follows :—

(*a*) White wages £1 per foot more. Three learners were always in training. Also additional ore chutes absorbed more labour.

(*b*) P.1 used crushed stone for concrete. This cost £1,391. No arrangements were made to handle waste for this purpose—probably owing to the reef development.

(*c*) Cement at P.1 cost £1 per foot more. The shaft excavation was slightly larger, and several bad patches were met with where the rock came away a considerable distance above the arches. In addition, loading boxes were constructed on four levels. So far only one has been constructed at P.5, and one at P.3.

(*d*) Extra steel for loading boxes and necessary workshop time cost approximately an additional 10s. per foot sunk.

J. S. Ford : Mr. Unwin has compiled the method and details of the construction of the Crown Mines concrete incline shafts so thoroughly and carefully that in this paper, which is a supplementary one rather than a discussion on his, only a few of the main constructional points will be mentioned of the North Incline Shaft, New State Areas.

The shaft is 1,320 ft. long, 18 ft. 9 in. wide and 7 ft. 0¾ in. at right angles to the dip from the rail to the highest point of the arch. It dips at 25° and extends from the tip above 22 Level to a short distance below 28 loading box. It serves 23 and 28 Levels, 22 being the transfer level between the incline and vertical shafts.

The shaft takes two skips of 6 tons capacity running on 60 lb. rails bolted to longitudinal concrete sills. The gauge is 6 ft. and hoisting speed 2,000 ft. per minute. The shaft is also equipped with a pipe and ladderway compartment.

The walls consist of 4½ in. brick backed by reinforced concrete to a total minimum thickness of 12 in. The roof is constructed of 8 in. by 4 in. " I " beams placed at intervals of 6 ft. centres and arched to an off-set of 12 in. in the centre, the ends being fitted into a steel shoe which acts as a bed on the wall. Shuttering boards are drawn up firmly against the inner periphery of the " I " beams by means of wire suspended from them. The " I " beams are embedded in a 1–2–4 mixture of concrete strongly reinforced with wire ropes over one portion and rails over the other. The concrete is built up to the hanging.

The chief claim to interest of this shaft lies in the geological features of the rock through which it was sunk. As will be seen from the section, Fig. 35, the ground traversed by the shaft has been subjected to marked disturbances. Besides the faults and dykes shown, the rock is criss-crossed in every direction by quartz veins of varying size. This had the effect of so destroying the cohesion of the rock that it was not self-supporting over the width of the shaft, and it was this weakness that influenced the decision in favour of the adoption of concrete support, which was started about December, 1925.

The rock became weaker and more difficult to support as the shaft was advanced and approached nearer to the steeper dipping dyke in its hanging.

It was assumed at one period of the sinking that temporary support could be used safely until the shaft was completed, after which the permanent concrete support would be done. This method

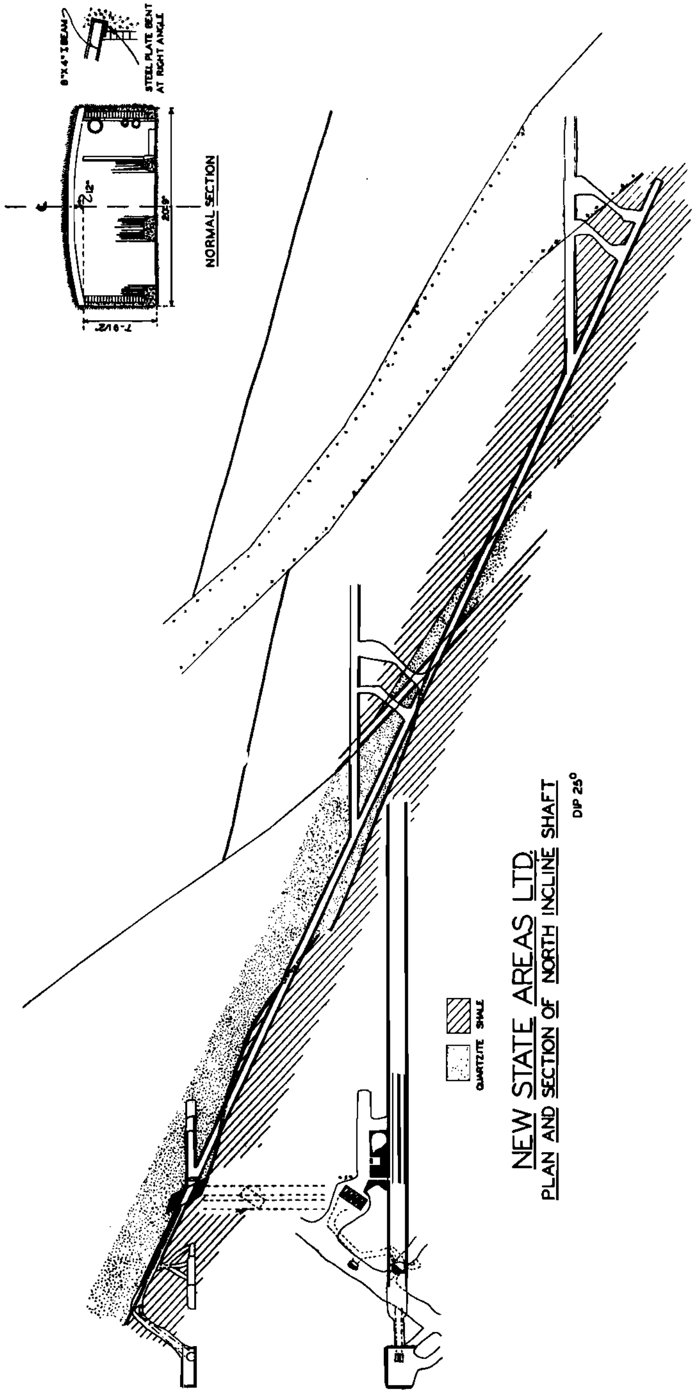

NEW STATE AREAS LTD.
PLAN AND SECTION OF NORTH INCLINE SHAFT
DIP 25°
QUARTZITE
SHALE
NORMAL SECTION
STEEL PLATE BENT AT RIGHT ANGLE

FIG. 35.

of temporary support seemed successful and it enabled the rate of sinking to be appreciably increased, but after some months the hanging throughout most of the length of the temporarily supported part of the shaft collapsed to a thickness of from 4 or 5 up to 10 ft. After that the shaft was advanced to its ultimate depth by carrying it to its full width for only about 4 ft. of its height and to the full height for only about 8 ft. of its width, as shown in Fig. 36. The shaded portion shown in the drawing was popped down to allow for the putting into place of the permanent concrete support, which was kept up to within a reasonable distance from the face.

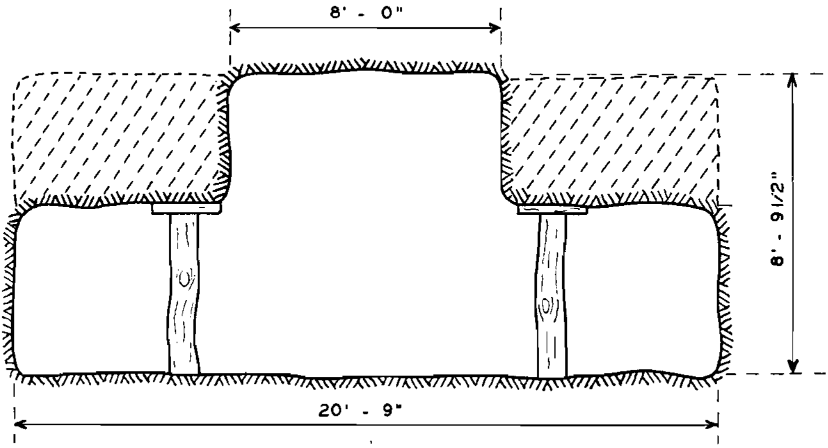


FIG. 36.

In spite of the fact that this shaft was sunk in bad ground, and that the concrete was built up to the hanging, the walls and roof show no signs of disturbance excepting at a point about 275 ft. below 23 station where flaking of the roof took place. Further flaking was stopped by removing certain large pillars in the stope about 300 ft. vertically over the portion of the shaft where it was taking place.

An interesting application of the use of concrete support for the reclamation of an old incline shaft was put into practice at the Witwatersrand Mine. Only a portion of it was dealt with in this way when it was decided to serve the area by another method.

This shaft is in a heavily caved area and a pillar of an average width of about 70 ft. was left over it. Owing to it being upcast and humid, timber in it rots rapidly. Several attempts to retimber it had failed through the timber being insufficiently strong to stand the weight. Fig. 37 represents a section of the completed work. It shows the concreted shaft, the excavated area over it, the packs and the backing of fine stuff on the roof to cushion any falls of hanging which might take place over it.

In the cases where the shaft had not caved to a sufficient height the walls were first erected and the hanging was then taken down to a height of about 3 ft. above the position of the roof. After that the roof was erected and the ground removed to a distance of about 12 ft.

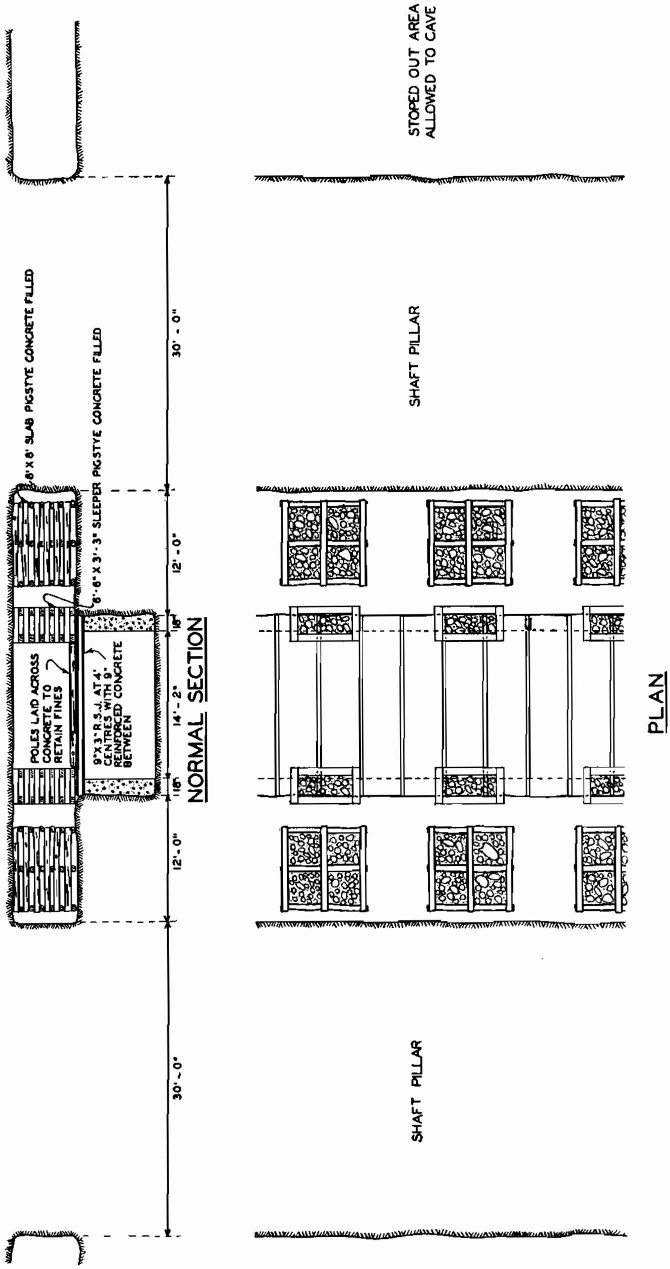

STOPED OUT AREA
ALLOWED TO CAVE
SHAFT PILLAR
SHAFT PILLAR
8' X 8' SLAB PIGSTYE CONCRETE FILLED
6'-6" X 3'-3" SLEEPER PIGSTYE CONCRETE FILLED
POLES LAID ACROSS CONCRETE TO RETAIN FINES
9" X 3" R.S.J. AT 4' CENTRES WITH 9" REINFORCED CONCRETE BETWEEN
30' - 0"
12' - 0"
1'6"
14' - 2"
1'6"
12' - 0"
30' - 0"
NORMAL SECTION
PLAN

Fig. 37.

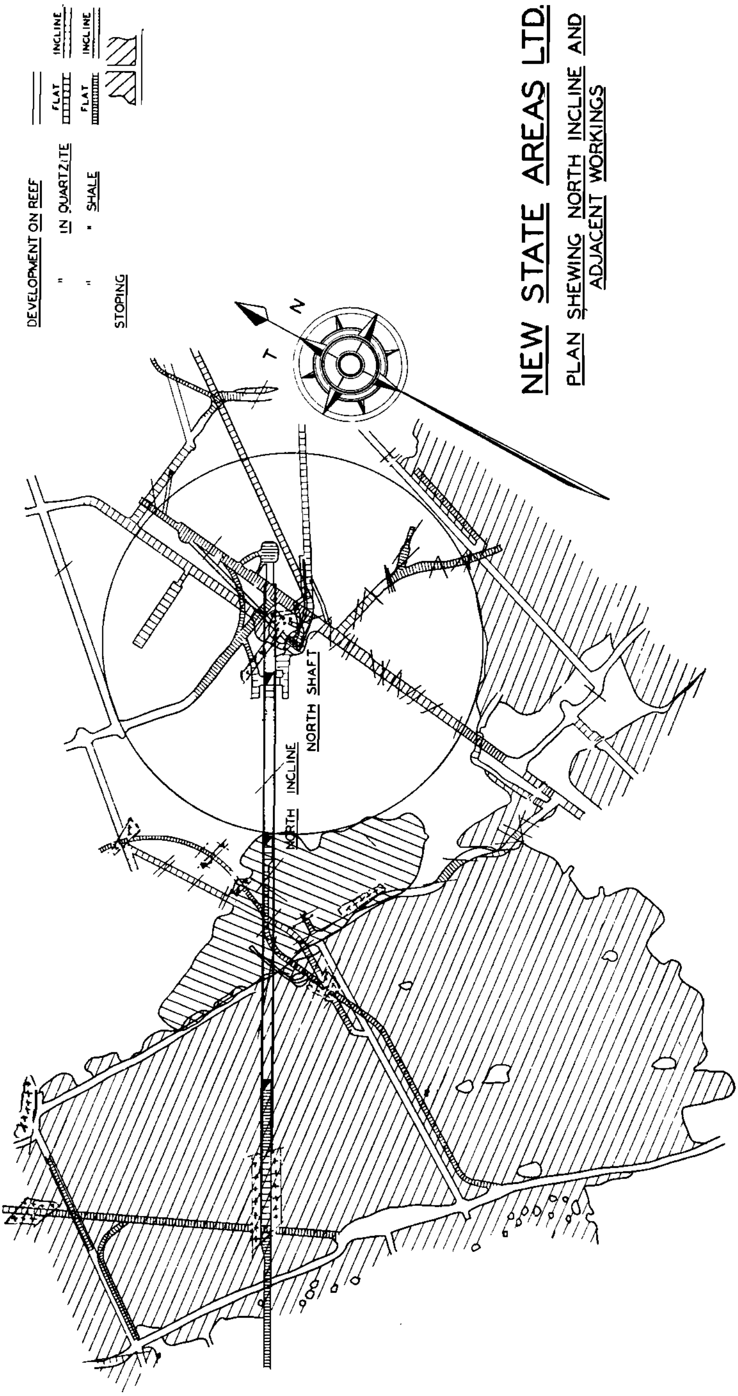

NEW STATE AREAS LTD.
PLAN SHEWING NORTH INCLINE AND ADJACENT WORKINGS
DEVELOPMENT ON REEF
" " IN QUARTZITE
" " SHALE
STOPING
FLAT
INCLINE
N
T
NORTH SHAFT
NORTH INCLINE

FIG. 38.

from the outsides of the walls. The 9 pointer 8 ft. packs shown were filled with waste and then 1 cement to 10 dump sand mixture, with water added to attain the consistency of thin cream, was allowed to flow in so as to get a pack of great strength and the required rigidity and also to preserve the timber. The smaller packs on the wall were not filled to the hanging and overlapped the wall by a foot so as to reduce the span of the unsupported roof.

This method of varying the rigidity of the supports from solid rock, in the form of the pillar, to a relatively easily compressible support on the wall was done in an endeavour to give the hanging a maximum support in view of the conditions of the case, but at the same time to allow it to assume its natural curve of sag without distortion.

The roof itself consisted of 3 in. by 9 in. girders spaced at 4 ft. intervals ; they were embedded in a 1–2–4 mixture of concrete heavily reinforced with specially made wire mats to fit into the spaces between the girders. The concrete was mixed by a concrete mixer on the surface and lowered in skips.

The walls were built against the rock as it was considered that the weight of the superincumbent rock was not such as to exert a sufficient force through the pillar and 12 ft. of quartzite footwall to disturb them. However, cracks did appear in the walls after one or two years, and the questions as to whether the distance between the wall and the pillar should have been greater, or whether there should have been a space between the wall and the rock, and if so how much, or whether there should have been both a space between the wall and the rock and a greater distance between the wall and the pillar, or whether the pillar should have been removed entirely, appear to be worth considering.

The shaft dips at 35° and was subject to severe bumps in spite of the fact that the greatest vertical depth of the concreted portion was only 1,000 ft.

B. T. Altson : In 1933, thanks to the kind invitation of Mr. A. J. Walton, then General Manager of the Crown Mines, Limited, Mr. Lange and I paid a visit to that mine to see shaft P.1, I think, which at that date had been sunk and concrete-lined for a distance of a level and a half. We were both most impressed by what we saw, and Mr. Lange at once decided to adopt the idea. We naturally modified the method of concreting, etc., to suit our different conditions, but in the main, the underlying idea remains the same.

What chiefly impressed us was, I think, the possibility of being able to course the ventilating current through 2,000–2,500 ft. of incline shaft with the minimum possible diminution in the separation of the wet and dry bulbs, which Mr. Unwin has pointed out under advantages (*b*) and (*c*).

At the moment we are sinking and concrete-lining three incline shafts on the City Deep, namely, Nos. 4b, 4c and 1d, and it is proposed to sink two more, namely 1e and 1f, of which 1e has just been commenced. Nos. 4b, 4c, 1e and 1f will be three-compartment shafts approximating in dimensions to P.1, but 16 ft. 6 in. in width, and served by 5-ton skips on a 4 ft. 4 in. gauge 80 lb. rail track. 1d is to be 18 ft. 5 in. in overall width, served by 8-ton skips on a 5 ft. 6 in. gauge 80 lb. rail track. It is proposed that these five shafts will serve the mine to the 8,500 foot horizon.

Each shaft will be equipped with its own ventilating unit, which it is estimated will be capable of delivering 90,000 cu. ft. of air per minute direct into the shaft at a water gauge of 4 ft. 0 in.±. Much consideration was given to the fan duct delivering the air to the shaft, and although it was originally decided to construct an elliptical concrete-lined evase, as the time required for this work would have been excessive, this scheme was abandoned, and the ducts are now constructed in concrete of rectangular section, but in the manner of an evase, the idea being to deliver the air into that shaft with a minimum loss of velocity pressure due to shock. The width of the duct in the side of No. 4c shaft, where it enters the shaft, is 26 ft. This duct is supported by steel girders, which will be stream-lined with steel plate and concrete in the direction of the flow of the air current. The sides and roof of this duct are of concrete reinforced with straight 45 lb. rails, the floor being smooth concrete with steps up one side to permit of inspection.

Recent figures obtained at 4b and 4c shafts may be of interest. The surface temperatures were Tw. 46°, Td. 48°, relative humidity 87 per cent. The air reaching the bottom of the sub-vertical 6,746 ft. from surface, showed a separation of 15°, Td. being 83°, relative humidity 45 per cent. This air is split ; a portion travels to 4b and a portion to 4c fans—both 70-in. Aerotos. At 4b shaft fan intake, 1,900 ft. west from the sub-vertical, the separation in the air had dropped to 9·5°, Td. being 79·5°, relative humidity 62·5 per cent. On the delivery side in 4b shaft the separation is 11·5°, Td. being 83·5°, relative humidity 57·5 per cent. At 33 horizon in 4b shaft, 250 ft. from the fan delivery at a vertical depth of 6,867 ft., the separation is 11·0°, Td. being 84°, relative humidity 59 per cent. At 35 horizon, in the same shaft, 750 ft. from the fan delivery at a vertical depth of 7,143 ft., the separation is 8°, Td. being 84°, relative humidity 69 per cent. Thus this air, a volume at present of only 60,000, as the fan is not running at full speed, loses 3·5° in separation, with a rise in wet bulb of 4° after travelling through 750 ft. of shaft.

I may say that an improvement on these figures is expected, as the shaft is not finally completed to this depth, there being an appreciable amount of unnecessary and avoidable water helping to reduce separation.

At 4c shaft fan intake, 1,900 ft. east from the sub-vertical, the comparative figures are :—Fan intake, separation 8°, Td. being 80°, relative humidity 68 per cent. ; fan delivery, separation 10°, Td. being 84°, relative humidity 62 per cent. ; 33 horizon, separation 6°, Td. being 83°, relative humidity 74 per cent. The holing on 35 horizon has not yet been made. I have no doubt this shaft will cool down in a way similar to 4b when further holings have been made.

With the concrete lining we are adopting a more or less similar idea to Mr. Unwin's, with certain modifications. We run the side walls in first and then run in the concrete piers—timber sills are not used. These side walls are dowelled on to the rock surface, and are built to the correct height to receive the arch. The arch is built of 45 lb. rails 3 ft. 9 in. centres bent to a 34 ft. $6\frac{3}{8}$ in. radius in 4b and 4c shafts, and 40 ft. $10\frac{1}{2}$ in. radius in 1d shaft. Between arch rails we use $\frac{3}{4}$ in. steel reinforcing rods, 9 in. centres, which, during construction, are kept in place by two spreader plates resting on the arch rail hanging bolts. Latterly, we have been using 5 in. by $2\frac{1}{2}$ in. by 9 lb. per foot "I" beams bent to the same radius instead of the rails.

The concrete is run to walls, piers and arches from mixing platforms in one compartment in the shaft; this allows us to use 1 in. to $1\frac{1}{2}$ in. stone, as we experienced the same difficulty as Mr. Unwin when running concrete from the station above with the larger stone. As the concreting progresses, so the mixing platforms are lowered.

Loading boxes in the shaft are cut in a similar manner to stations. The excavation required for the box and skipman's platform is taken in on the roof first to the limits required: the footwall is then removed and sinking continues until 30 ft. below the box, when the side walls are run. After the walls are completed, three 18 in. by 6 in. girders are built into the walls, and these carry the loading box and chutes without supporting legs.

We adopted the Crown Mines idea regarding the ladderways, but the bolts which eventually serve for bratticing supports—3 in. by 3 in. angle-iron—are welded to the arch rail or girder as the case may be.

Below each box an open concrete ring is built diagonally across the shaft, the water from which is led into a launder carried on the footwall in the ladderway compartment, which delivers to the lowest pump sump, the idea being to maintain the shaft as dry as possible over the maximum distance.

Using concrete sills there is every inducement for the 80 lb. rails to creep, over a period of years, and in order to avoid this serious drawback—which I consider is responsible for many skip derailments—a short steel girder is embedded in the concrete pier at intervals of 150 ft., and so placed that it is at the junction of two rails. Fish-plates are dispensed with at this point, the rails being bolted direct to this girder through the rail base.

The cost of sinking and equipment compares favourably with timbered shafts, when one takes into account the advantages which are likely to be gained from ventilation. 4b shaft over a distance of 1,255 ft. shows a cost to date of £21 18s. 0d. per foot. 4c shaft over a distance of 1,078 ft. shows a cost to date of £21 5s. 1d. per foot, whilst 1a shaft—a timbered shaft—over a distance of 1,326 ft. shows a cost to date of £20 10s. 4d.

The answer to the question as to how our concrete-lined shafts are going to stand up to mining remains to be seen. We have already started mining over 4b, and are mining out the solid on resuing. The faces are being carried very flat, at 30° to the reef strike, and are being mined initially to a distance of 50 ft. east and west of the shaft sides.

It is too early yet to pass an opinion as to how the shaft will react, but personally I do not entertain any serious misgivings.

The problem of skip derailments has already entered the arena, and in order to facilitate the work of replacing skips, with nothing to hold on to, we are putting $1\frac{1}{2}$ in. eye-bolts 18 in. into the shaft hanging at 50 ft. intervals before arching commences, so placed that they are over the centre line of hauling, and in the centre between arched rails. They have already proved themselves.

M. O. Tillard : The problem of a concrete-lined incline shaft at Modder East differs in several essentials from those described in the paper under discussion. Modder East No. 3 incline shaft was laid out to be the main underground hoisting shaft of the mine, so that it was essential to have sufficient hoisting capacity. Its collar is 1,890 ft. below the surface. It was designed to accommodate 10-ton skips, running on 80 lb. section rails with a track gauge of 6 ft. The tracks were designed to be laid on longitudinal concrete sills.

The shaft is being sunk at 12·5° dip, in slate about 100 ft. below the reef, and when completed will be 4,875 ft. in length, excluding 175 ft. of flat rope race. To accelerate the completion of the shaft it has been sunk from the 18th Level, raised and winzed from the 19th Level, raised and winzed from the 23rd Level and raised from the 27th Level. Until most of these connexions were holed no concrete work could be done.

After the mining of the shaft had commenced, it soon became apparent that the shaft would require some type of support, as the shale through which it was being cut was definitely dangerous when opened out to the span required. It was eventually decided to concrete the sides and roof of the shaft, and the various headings of the shaft being driven were cut down to more stable dimensions—10 ft. by 8 ft., etc.

On completion of the necessary holings and the fixing of the survey through the length of the shaft, from 18 Level to 23 Level ore chute, which it was decided to equip for hoisting pending the holing of the raise from 27 Level, sliping to the final size was commenced. The excavation necessary in the slate gave considerable trouble. The rock continually broke away in layers from slips across the bedding planes, a span much over 10 ft. proving unstable. The shaft is sunk at a small angle to the true dip, which increased the difficulty in controlling the hanging. A cross-section of the shaft is shown in Fig. 39, where it will be seen that the finished dimensions are 18 ft. wide, 8 ft. 6 in. from crown of arch to rail and side walls 6 ft. 7 in. high from the rail level; the sills are from 20 in. to 28 in. high above the footwall.

The concrete is 12 in. thick on sides and roof and all spaces between concrete and rock faces are filled with waste fines, the empty cement bags being rammed in over the roof concrete. 45-lb. rails, crown up, at 6 ft. centres give the shape of the arch, while the concrete is filled on to the shuttering, which is held in position flush with the base of the rail.

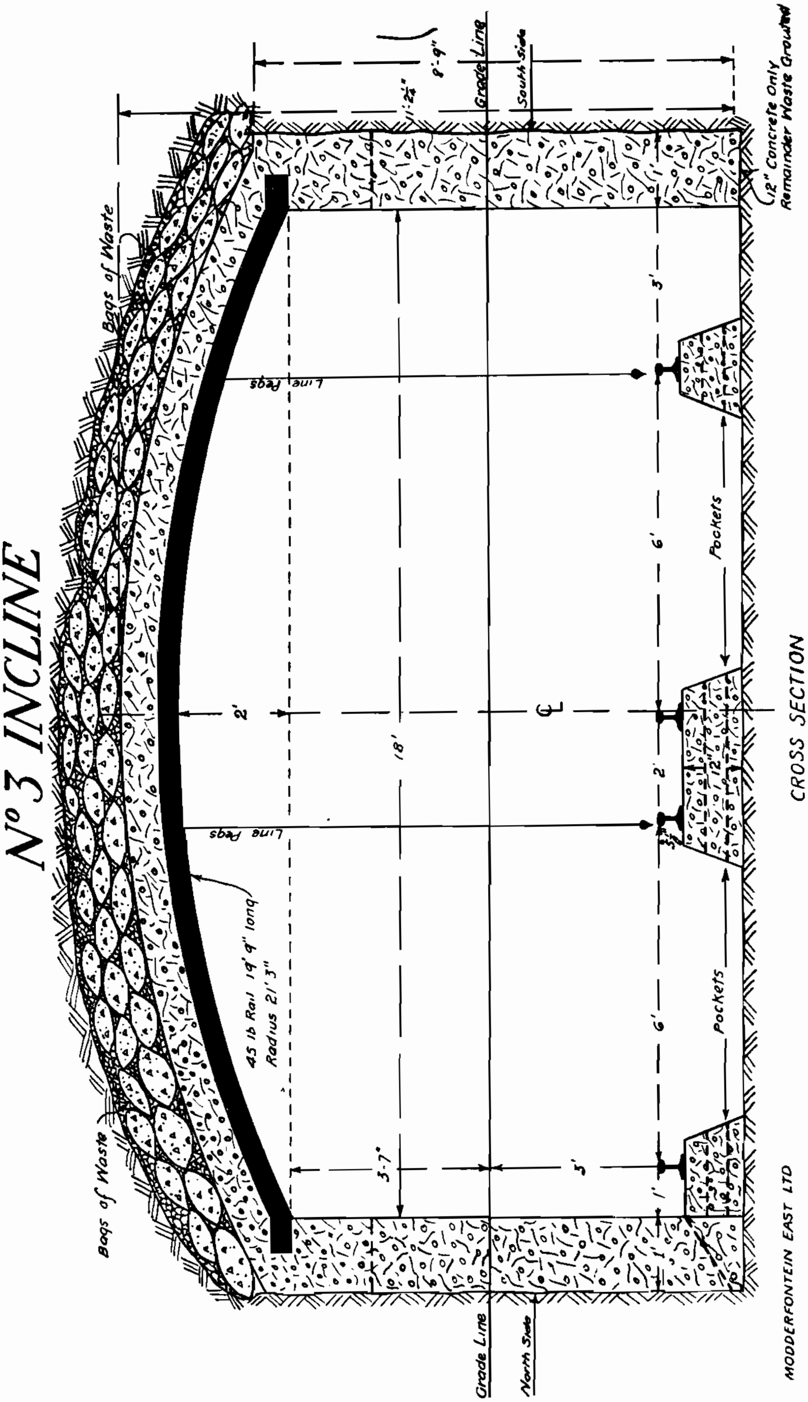

No 3 INCLINE
CROSS SECTION
MODDERFONTEIN EAST LTD
Bags of Waste
Bags of Waste
45 lb Rail 19' 9" long
Radius 21' 3"
Line Pegs
Line Pegs
Grade Line
Grade Line
South Side
North Side
12" Concrete Only
Remainder Waste Grouted
Pockets
Pockets
18'
2'
6'
6'
5'
5'
3'-7"
1'
2'
8'-9"

FIG. 39.

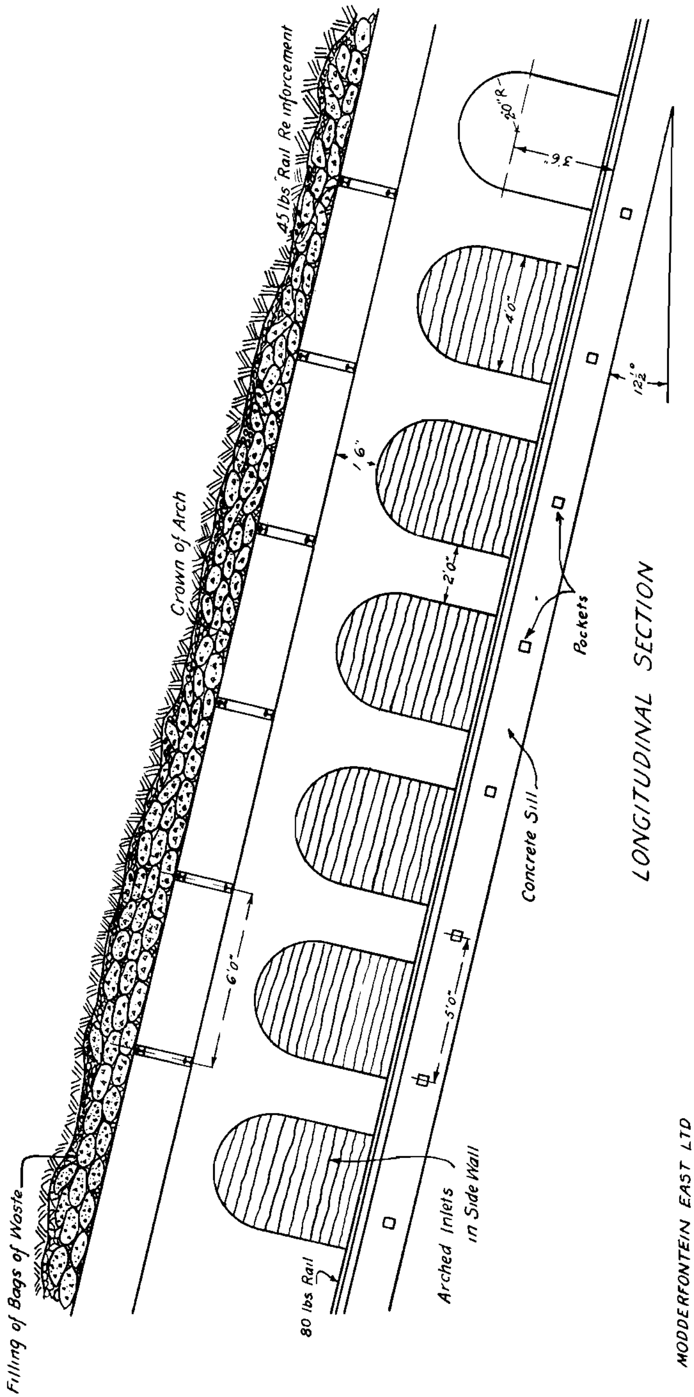
Concrete Work in Shaft.—As soon as the shaft was opened up to the necessary size, which was done at several convenient points, the concrete work was commenced. The mixture employed was—cement 1 part, washed sand 3 parts, washed $2\frac{1}{2}$ in. quartzite stone 6 parts. At 12·5° there was no hope of gravitating the concrete to the filling point, so other means had to be employed. Three main concrete mixing stations were established, one at 19 Level, main station, with two 3 h.p. $3\frac{1}{2}$ cu. ft. (finished product) electric drive mixers, one above 23 Level with one similar mixer and one on the ore chute loading platform, below the 23 Level, with another of the same type mixer. Each mixing station is served with a winch, which either hoists or lowers a tray containing the wet concrete delivered direct to it by the mixer. The tray holds approximately $\frac{3}{4}$ cu. yd. wet concrete and is mounted on a scotch cart in such a way that it is horizontal in the 12·5° shaft. By these arrangements it is possible to average about 7 to 10 cu. yds. in an 8-hour shift.

The first concrete to be put in is the north sill, as it is from this all the other dimensions are taken, the north wall is then incorporated with this and is built up to the required height: the south wall is next filled in. These walls are concrete filled from the tray direct by shovels. Owing to the difficulty experienced in obtaining the necessary sand and stone transported underground, the more economical use of concrete was forced upon us and a system of small arches was let into the side walls, which caused a saving of over 40 per cent. of the concrete in the walls, see Fig. 40. The side walls are reinforced with worn $\frac{3}{4}$ in. wire rope, stretched tight and woven into a mesh approximately 18 in. square.

The roof is built on 45 lb. second-hand rails bent to required section. The rails are laid on top of the walls at 6 ft. centres and are then concreted into position. The shuttering is applied flush to the base of the rail and kept in position by 3 in. by $\frac{1}{2}$ in. M.S. straps, which are made in two parts, bent to the same curvature as the rails. These straps are strutted to cross-beams temporarily fixed across the shaft and the planks are wedged tightly in position. This method enables the stripping to be done quickly. In order to pack the spaces between the concrete and rock faces, the concreting of the roof is limited to a single section, that is 6 ft. on the dip for each shift. Before commencing the concrete on the next section, the previous one is waste packed. The concrete is shovelled in from the tray, which is built up horizontally from its scotch cart to allow of this being fairly easily done. The concrete is well rammed into position, special attention being paid to the union with side walls and previous sections. The usual reinforcement of $\frac{3}{4}$ in. wire rope is employed.

The centre sill and the south one are put in as soon as possible after the roof and walls are completed. All measurements for these are made from the already completed north sill. This work has to be done very accurately as there is only $\frac{1}{2}$ in. clearance between the track gauge and the skip wheel gauge.

The boxes for all the sills are specially constructed with the necessary inserts for the holding down bolts and are set in positions accurately by means of special templates from the existing north sill. The concrete is well rammed in and pegged to a clean footwall.



Filling of Bags of Waste
Crown of Arch
45 lbs Rail Re inforcement
80 lbs Rail
Arched Inlets in Side Wall
Concrete Sill
Pockets
LONGITUDINAL SECTION
MODDERFONTEIN EAST LTD
6'0"
5'0"
2'0"
1'6"
4'0"
3'6"
20"R
12½°

FIG. 40.

The cost of concreting this shaft, *i.e.*, support and sills but excluding power charges only, works out just over £6 per foot run and an average rate of filling has been about 14 to 15 cu. yds. finished per day.

The advantages claimed for concrete work in this shaft are those mentioned by Mr. Unwin in the first paragraph of his paper, but it is doubtful whether it will ever be required to stand much pressure due to mining, as the depth is not great and an adequate pillar is being left over the shaft. It will be possible to deliver dry, downcast air to within a reasonable distance of our lower boundary. The maintenance and examination should be easy and cheap, an item of no little importance in these days of shortage of skilled timbermen.

H. Mitchell :—As far back as 1921 I designed and started a small incline at the Van Ryn Deep which was practically on a 100 per cent. concrete basis until the time I left. This arrangement was adopted for exactly the same reasons as are quoted by the author as the advantages he expects from concrete-lined inclines, and one is tempted to wonder why a depth of 6,850 ft. had to be reached at Crown Mines before these advantages were recognized.

Of late years at Government Areas we have had to do a great deal of haulage support of the same nature as is described by the author and we have come to the conclusion that good concrete will stand a great deal of static pressure, but it is definintely liable to fail under dynamic shocks.

My experience is that the sooner concrete supported excavations are released from possibilities of overhead and side pressure the better. If this is done before the general weight comes on to the country in which such excavations are situated, I see no reason why they should not be entirely satisfactory.

Coming now to detail. I am disposed to think that for the shaft P.1 shown in the sketches, the concrete being used is on the weak side. Apart from the 8 to 1 ratio which is itself weak, the ½ in. size of the large aggregate tends to further weakness and, from the author's description, it appears to be mixed very wet. The strength of concrete for any given proportions of dry material depends on the cement/water ratio and a mixture that will travel down a 40° 6 in. square launder at 500 ft. per minute gives the impression of being very liquid.

In our large work we only use an 8/1 ratio for side walls and then use 2 in. stone for the large aggregate. For arches we use a 6/1 ratio and, in all important work, we use a mechanical mixer and keep the mix as dry as possible consistent with reasonable workability.

I notice that in P.5 shaft there are certain variations from the practice in P.1. I prefer the P.5 arrangement of detaching the sills from the legs of the arch setts.

In P.5 I also notice that the concrete mixture is strengthened to a 6/1 ratio. Again, however, the water content is not mentioned and the method of adding the water does not seem to me to lend itself to good control. Perhaps Mr. Unwin will explain these variations in practice when he replies to the discussion and also tell us why there is such a large variation in the costs of equipment of the three concrete shafts shown in his table of costs.

To my mind, it is rather surprising that, having decided to use so much concrete in these shafts, timber is still used for sills. I should have expected concrete, which is giving satisfactory service in many places.

One other point that strikes me in Mr. Unwin's procedure is that there surely must be a great deal of dust created in the dry mixing of his concrete as described by him.

J. W. Jack: I have been particularly interested in Mr. Unwin's paper, because it has been considered good practice on the mines on which I have worked during the past 15 years to construct incline shafts in which the initial development has disclosed weakness, and to replace, when necessity arose, timbered stations with concrete and steel.

The shaft to which Mr. Mitchell refers in his contribution to the discussion was not completely lined, only about 50 ft. of shaft, including the station, at each of the three Levels 10, 11 and 12, and the ore boxes at 11 and 12 being so constructed.

This sub-incline is 780 ft. long and was sunk from 10 Level Haulage, on the strike of the reef, 16 ft. wide by 8 ft. high, with an average inclination of 32°. The vertical depth below surface at the collar is 2,909 ft.

The hoist chamber was cut in reef, the shaft, from the tip, passing successively through reef about 40 ft. above 10 Station, then a reverse fault with a downthrow of about 10 ft., bringing the reef down almost into the hanging wall of 10 Station, which was in particularly hard shale. Then the shaft intersects a dyke with 150 ft. of downthrow, passing into quartzite above 11 Station, reef at 11 Station, and finally, at 12 Station, reaches a depth of 190 ft. below the Main Reef Leader.

A drawing of the steel and concrete lining is attached (Fig. 41). Steel shaft runners were used for the arches, and it will be seen that no legs were used to complete the arch as a sett. This shaft was put into commission in March, 1924. As stoping progressed a shaft pillar of 200 ft. diameter was left on 10 Level, with the hoist chamber in the centre, and a block of ground 200 ft. wide was left over the whole of the shaft, excepting that portion 80 ft. long above 11 Station, where the shaft was in hanging wall.

In 1931, when the weight commenced, the removal of the pillar and/or stoping over was debated. It was decided to endeavour to re-distribute the weight by sandfilling all the stopes adjacent to the pillar, and to use concrete and steel girders to support the excavations in the hoist chamber area.

The haulage under the hoist chamber pillar and the chamber itself were lined with concrete and roofed with concrete and girders, which were in all cases 10 in. by 8 in. rolled steel joists of I section.

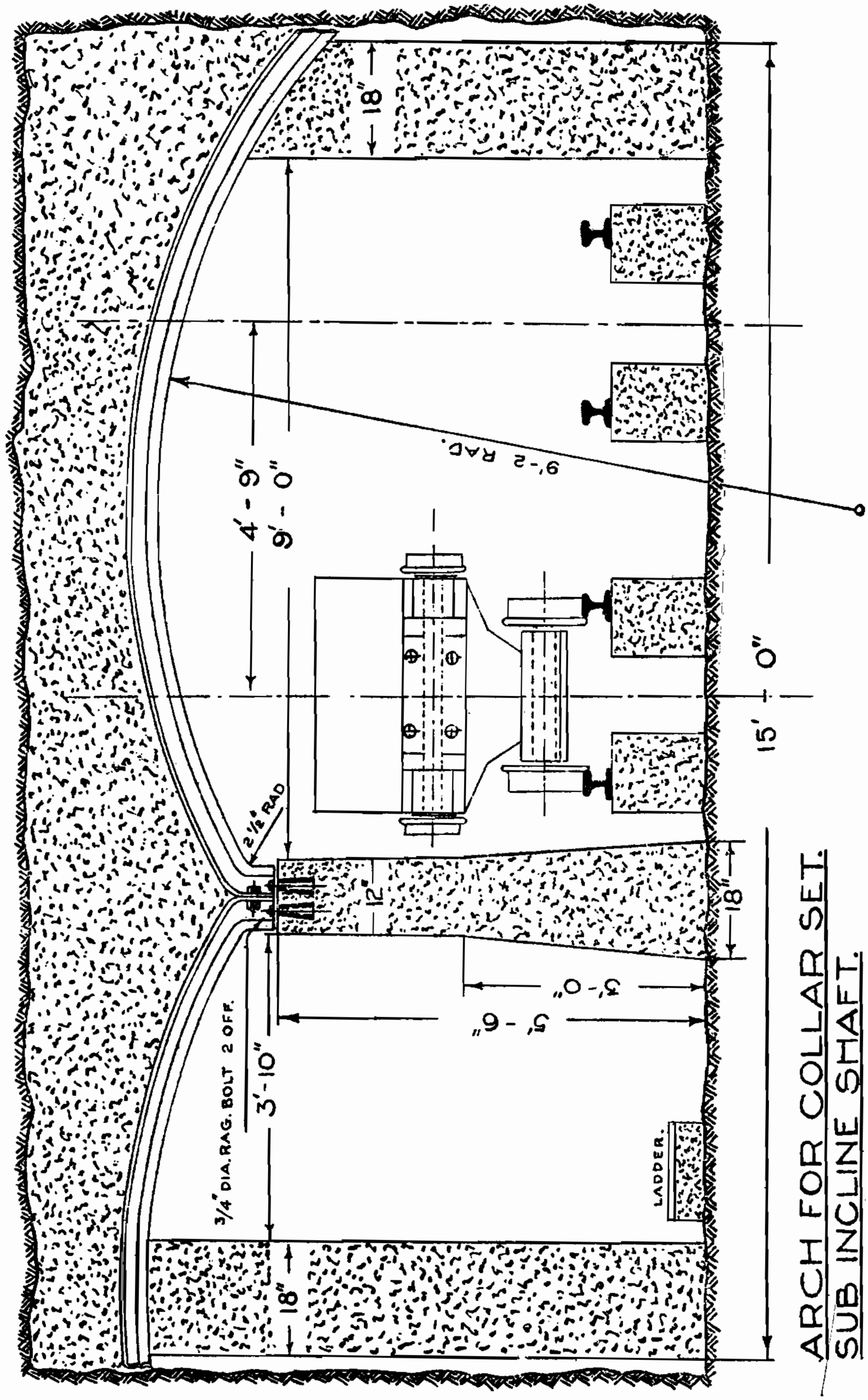

ARCH FOR COLLAR SET.
SUB INCLINE SHAFT.
9'-2 RAD.
4'-9"
9'-0"
15'-0"
18"
18"
18"
12"
3'-0"
5'-6"
3'-10"
3/4" DIA. RAG. BOLT 2 OFF.
2 1/2" RAD
LADDER.

Fig. 41.

In the haulage the girders were spaced at 5 ft. centres, a curved sheet of corrugated iron being used as a former for the roof concrete which was taken up to the hanging, no space being allowed, nor indeed was it available anywhere.

In the hoist chamber, soft wooden blocking was used to support the hanging wall from the girders, as many stanchions as the machinery would permit being put in to reduce the spans, particular attention being paid to the engine-drivers' platform and the motor.

The approach to the hoist chamber from the haulage was lined with concrete only, no girders being used, the roof being formed in a semi-ellipse of concrete with wire rope reinforcement.

10 Station showed very little disturbance at this time, the floor over the travelling way half-arch tending to lift, but the concrete sills began to move and were removed entirely from 10 Station to the tip, wooden sills being put in.

With the end of this support work in sight, it was decided to put in buttresses of concrete on which to erect the girders and so speed up the hanging wall support in the haulage, the intention being to join up these buttresses into a continuous wall later.

The mixture used was a 6/1 ratio in all cases, but it was noted that the tendency was to use too much water where the concrete had to be put into places not easily get-at-able, particularly in the non-steel approach to the hoist chamber where semi-elliptical formers were being used for the concrete roof.

Most of the support work planned had been completed, the girder support on 10 Station and the north wall from 10 Station to the tip still remaining to be done, when the inevitable pressure burst occurred in December, 1933. Chaos is the only word that fits the scene that met one's eyes !

Approaching the hoist chamber by the footwall haulage, several concrete buttresses had been thrown from the south side of the haulage to the other, and their girders had come to rest on the footwall. Some buttresses were ruptured but still retained the girders in position. All those girders where the concrete side wall was continuous were in position, although most were twisted out of shape.

The approach to the hoist chamber was almost closed with concrete debris, the largest parts about building-brick size with the reinforcement still pinned to the hanging wall.

The walls in the hoist chamber had all closed in but were still standing. Some 10 in. by 8 in. girders had been flattened out where they had been nipped between the hanging wall and some supporting point. Butt joints had been torn apart, and the 300 h.p. motor had been wrenched from its foundation and thrown up to the roof.

The hanging wall over 10 Station, which was unsupported, had collapsed, exposing the reef. The electric cables were found to be intact but the pump columns were broken.

That portion of the shaft to the tip, when examined, showed little or no damage.

Examination of the concrete under 10 Station showed that the medial wall had burst at the junction of the two arches, and that the side walls had been ruptured—being entirely traversed by fine cracks—but that reinforcement and the lack of cleavage planes had enabled the concrete to hang together, whereas had the shale at this point been unlined it would have collapsed as had the unlined portion above.

Returning to the haulage, it is sufficient to say that it was safe to travel in immediately after the burst, and that a few days sufficed to cut out fallen girders and relay the track to enable the caved portion at 10 Station to be attacked.

The approach to the hoist chamber was found to have completely collapsed, a fitting end to a poor concrete mix !

When the engine-room was cleared of small debris, the addition of a few props made the place safe and the engine, or what was left of it, was withdrawn.

The track in the drive to the south of the hoist chamber was thrown up to the hanging by the burst, and when, after cleaning out, the track was subsequently relaid on what was apparently the original elevation, it was found to be 4 ft. high, but that the hanging wall had only come down 0·7 ft. since the original development survey.

The outstanding features of the burst were that where concrete and steel had been used, quick and safe re-entry was possible, and that where the displacement of lining walls did not affect loco. and hopper clearances, it was possible to use the walls to hold up fresh hanging wall support.

The wall supporting the two arches under 10 Station was too weak, and indeed all the concrete at this point gradually frittered away under the shock of stoping over ; but had the arches been supported on steel legs, as the Crown Mines have done, it might have been possible to obtain some measure of support for the station hanging wall.

Concrete will not stand dynamic shock and it fails eventually under steady pressure, but whether reinforced or not, monolithic concrete gives a feeling of security, even under the most severe conditions, and it can be readily and safely removed when necessary if it has been incorporated with a steel structure, sufficiently strong to stand alone.

Mr. Unwin states that it is probable that the leg of the sett may be dispensed with in P.5 shaft, because of the difficulty of packing the lower side with concrete, but it would be preferable to retain the sett in its entirety rather than discard it for the sake of obtaining truly monolithic concrete.

It is realized that the Crown Mines do not anticipate retaining these concrete-lined shafts as hoisting points any longer than will suffice to rob the areas served of pay reef, and as P.1 and P.5 are situated well in the footwall, they should have no trouble with them ; yet should it be necessary to retain a concrete and steel-lined shaft for hoisting for a long period, the importance of the steel sett should be given full value and the advantages of the concrete lining willingly sacrificed if the pressure becomes such as to threaten the alignment of the steel.

The bulb-angle section used in the Van Ryn Deep Sub-Incline cannot be described as a suitable section, nor does the breaking load of the 40-lb. rail used in the Crown Mines shafts justify its use as anything else than a former for concrete, while the use of second-hand 60-lb. rails (whose load characteristics must be entirely unreliable) is to be deplored.

None of these sections are even self-supporting as 16 ft. beams supported at both ends, and indeed for a span of 16 ft. the least depth of steel section permissible is 9·7 in.

The Crown Mines arch would have been improved, at small cost, had a 40-lb. rail, with suitable shoes for head and foot been substituted for the angle-iron dividing the hoisting compartments from the travelling way.

Although the cost of steel girder setts constructed of 10 in. by 8 in. joists would be about three times that of 8 in. by 8 in. timber setts, it must not be forgotten that once the sett structure is decided upon it is not necessary to have 16 ft. spans, and that therefore a smaller section will serve ; but it is felt that the use of such setts would be justified, at depth, if it should be necessary to retain a shaft for an indefinite hoisting period ; and further that, if shafts are liable to pressure such as comes from ground left over them, or from movement on dykes, only such a section is worth consideration.

I wish to thank Mr. Unwin for his very interesting paper, and I would like to express the hope that it will serve to open up the subject of support in shafts where the weight is likely to be greater than that for which our standard timber setts are designed ; because, it is not without the bounds of possibility that, at the depth at which mining is now being done, an alteration in the shape of the shafts may have to be considered.

20*th September*, 1935.