Design features of a deep-level shaft

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SYNOPSIS

Design and technical features of a large, deep shaft are described, and details of the sinking equipment are given. Special features in shaft steelwork, materials handling, and station layouts are described and illustrated.

The details of the precast brattice wall are given, together with the reasons for the separation of all steelwork from the brattice wall.

A newly developed device for the location of the shaft conveyances while loading or unloading at underground stations is briefly described and illustrated.

The paper concludes with a summary showing the rates of progress and costs for the shaft-sinking operation.

SINOPSIS

Die ontwerp en tegniese aspekte van 'n groot, diep skag word beskryf en besonderhede van die graafuitrusting verstrek. Spesiale aspekte van skagstaalwerk, die hantering van materiaal en die uitleg van stasies word beskryf en geïllustreer.

Besonderhede word verstrek van die voorafgegiete skermmuur asook die redes vir die skeiding van alle staalwerk van die skermmuur.

'n Pas ontwikkelde toestel vir die plasing van skagvervoermiddels tydens die laai of aflaai by ondergrondse stasies word kortliks beskryf en geïllustreer.

Die verhandeling sluit af met 'n opsomming van die vorderingstempo's en koste van skaggraafwerk.

INTRODUCTION

Originally it was intended that mining of President Steyn's south-eastern section of the lease area would be carried out from a sub-shaft system as an extension to the existing No. 3 shaft system, which provides access to the ground above the 1830 m level. Re-assessment of the potential of the area following promising borehole results to the south showed the need for revision of the shaft requirements of both President Steyn and President Brand. New planning required the President Steyn No. 3 shaft to be handed over to President Brand so that the latter could exploit their southern area, and the replacement of President Steyn No. 3 shaft by a new No. 4 shaft system to a depth of 2300 m sited as shown in Fig. 1. The new shaft not only replaces No. 3 shaft but allows an increase in production.

The economics of several shaft systems ranging from main and sub-vertical shafts to twin vertical main and ventilation shafts were examined, and finally a large single-lift shaft, divided by a brattice wall for ventilation purposes, was selected as presenting the most economical solution in terms of capital and running costs.

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SHAFT REQUIREMENTS

The shaft was planned for hoisting from 2330 m below collar, which was considered the maximum depth possible for the winding plant already in the mine's possession and the winding ropes that could be accommodated. The main collecting level will be at 2234 m (73 level), the upper working level at 1 759 m (58 level), and five levels between these horizons together with the necessary service levels as shown in the diagrammatic section of Fig. 2.

The capacities required of the shaft are as follows:

Tons hoisted per month — 246 000
Ventilation—528 m^3/s at 7,72 kPa
Men, daily—approx. 7300 persons
Material, daily—approx. 340 cars.

While the tonnage to be hoisted and the ventilation capacities set the main parameters of the shaft, the transport of men and material received careful consideration because these aspects have caused problems in older shafts. To meet the capacities, four skip compartments and four men and material compartments are necessary. The configuration arrived at is shown in Fig. 3.

The main particulars of the shaft are as follows:

Total depth from collar—2365 m
Depth of wind—2315 m
Cross section—Two semi-circles of 5105 mm radius separated by a rectangle 762 mm by 10 210 mm
Upcast area—28,7 m^2,
Skips 2 at 17,3 t and 2 at 9,1 t—Cages 2 at 4 deck and 2 at 3 deck.

Winders and Conveyances

Four double-drum winders are provided to serve the eight compartments, two for mineral and two for men and material. The leading information on the winders is given in Table I.

Should an increase in the shaft capacity prove necessary at a later stage, a fifth winder similar to the existing 5450 kW Blair multi-rope winder can be installed to serve the two inner skip compartments, increasing the rock load from 9,1 to 17,3 t. The increased rock capacity would in turn require an additional facility for men and material, and accordingly provision has been made to convert the 3180 kW rock winder to serve two additional cage compartments in the upcast segment of the shaft. However, this would necessitate the establishment of a separate upcast shaft in a position remote from this shaft and the relocation of the refrigeration plant cooling towers at the new site.

Cages

The cages in the four men and material compartments are of aluminium construction and of sufficient

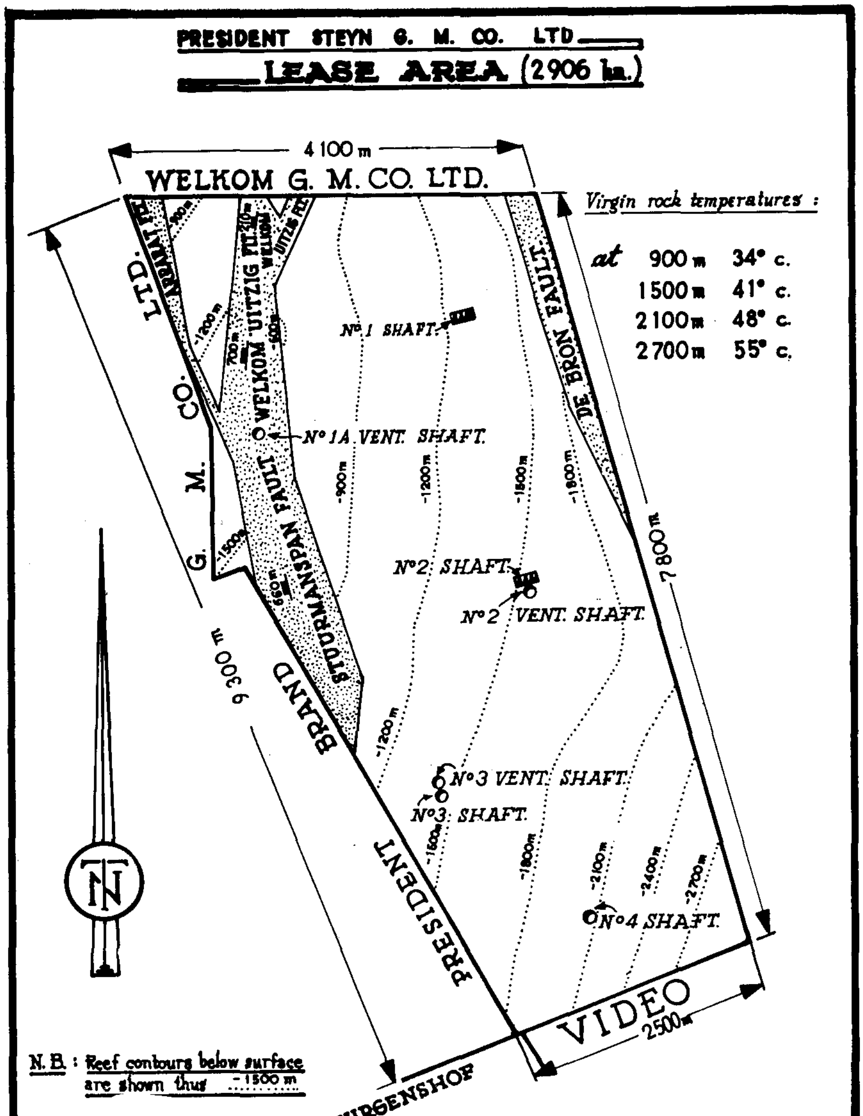


Fig. 1

length for material up to 9,15 m long to be loaded inside the cage; for this purpose, the front portion of each deck can be removed, thus providing a clear space for the full length of the cage. The surface equipment for handling the cages in and out of the compartments for maintenance is also capable of handling long material in and out of the cages up to a maximum of 6 t. Sling points have been provided to suspend large pieces of equipment beneath the cages in case of need.

Skips

The skips chosen for the shaft are of the 'SALA' type: firstly, because in this design the skip pan is firmly located within the bridle, whereas in other types the tipping action requires the pan to move relative to the bridle and inadvertent opening of the skip in the shaft has resulted in extensive damage to shaft steelwork; secondly, provision for the tipping of waste at a midshaft position is required, and this is easily accomplished by a retractable control crosshead, instead of the rather complicated and large retractable tipping path required by other types.

Shaft Stations

The shaft stations and associated equipment were designed to reduce the time required during the loading and unloading of men or material (Fig. 4).

On the stations, platforms are so arranged that all decks can be loaded or unloaded simultaneously with only one decking point.

A small elevator is provided in each compartment for lowering (or raising) cars to the station level from the platforms after unloading from the cages. By this means the time spent at the stations by the cages is minimized and shaft time saved; persons have access to the various platforms by way of stairs from the station level (Fig. 5).

To overcome the problem of rope stretch, which will be of the order of 2,1 m, a locating device has been developed to prevent any movement of the cage during loading and unloading (Fig. 6). The device is fully described elsewhere; basically, the principle allows the cage, whether empty or loaded, to be stopped at the station with comparatively small error by the winding driver who works to signal lights.

Once the cage is so positioned, the interlocking circuit is cleared and the clamping operation is initiated by the onsetter. The hydraulically driven chains cause the clamps to close towards one another until they engage lugs on the cage and then locate the cage accurately at station level; errors of up to 150 mm in the initial positioning of the cage can be accommodated. Immediately the clamping operation has been initiated, the safety circuit of the winder is de-energized and the winder rendered inoperative until the loading or unloading operation is complete and the clamps have returned to the 'at rest' position.

The conveyance mass is never removed from the rope, only the transferable mass being handled by the device. The rate of induced change in the length of the rope due to loading or unloading of men and materials is controlled by the device during unclamping to prevent sudden movements of the cage. This was an operational fault in previous devices. During the load-transfer operation, the cage remains in a secured position at station level without movement. The design provides failure to safety should loss of either electric or hydraulic power occur.

VENTILATION PLANT

Surface Fans

Centrifugal fans on surface will provide the volume of air required in two phases:

Initial duty (two fans)—432 m^3/s at 5 kPa

Final duty (three fans)—528 m^3/s at 7,5k Pa

Make—Airtec-Aerex

Power—2240 kW.

Refrigeration

Refrigeration equipment has been provided for in three stages:

Initial—15 500 kW,

Intermediate—24 500 kW

Final—31 500 kW, depending on sub-shaft requirements.

The refrigeration plant has been centralized on 58 level with upcast air from the shaft bypassed through three cooling towers via the lower and upper ventilation ports shown diagramatically in Fig. 3. The chilled water will be distributed to the working levels through two shaft columns and thence through break-pressure heat-exchangers of the shell and tube type in closed circuit. The secondary chilled-water circuit is closed separately between the break-pressure heat-exchangers and the water/air heat-exchangers in the working areas.

SURFACE PREPARATION

Pregrouting

Two pregrouting holes were drilled from the surface to 1751 m and 1780 m respectively. They were located on the north-south line 14 m east of the shaft centre line and 28 m apart. A total of 2175 t of cement was injected, 1880 of which were used at 480 m, which is just below the base of the Karroo System.

From 58 level, one hole 623 m

TABLE I
WINDERS AND CONVEYANCES

WINDER	kW	DRUM SIZE	ROPE PARTICULARS	CAPACITY
W.L. men/material	5000	Dia. 4,876m	51 mm dia. 6≥ 33 triangular construction	Decks 4
Max. rope speed 1067 m/min	Twin-motor drive	Width 1,828 m	Tensile grade 2100 MPa	Men 128 per cage, 1280 per hour
Manufactured by Vickers-Armstrong/ Metro Vickers			Breaking force 2177 kN	Material load 8,96 t
			Mass 11,285 kg/m	No. of cars 24 per hour
			Max. length of wind 2316 m (multi-level)	Long material slung in cage
A.C. men/material	3900	Dia. 4,875m	As above	Decks 3
Max. rope speed 914 m/min	Twin-motor drive	Width 1,828 m		Men 96 per cage, 960 per hour
Manufactured by Vickers-Armstrong/ Metro Vickers				Material load 6,72 t
				No. of cars ±24 per hour
				Long material slung in cage
Blair multi-rope rock	5450	Dia. 4,267m	42 mm dia. 6≥ 30 triangular construction	Payload 17,3 t. Bottom-discharge skips
Max. rope speed 914 m/min		Width 1,6 m	Tensile grade 2100 MPa	Skip mass 9,98 t
Manufactured by Vecor/G.E.C.			Braking force 1482 kN	160 000 t per month based on 20 hours per day
			Mass 7,645 kg/m	and
			Two ropes per conveyance	10% allowance for unscheduled delays
			Length of wind 2347 m	
Vecor W.L. rock	3180	Dia. 4,876m	46 mm dia. 6≥ 31 triangular construction	Payload 9,1 t. Bottom-discharge skips
Max. rope speed 914 m/min		Width 1,524 m	Tensile grade 2050 MPa	Skip mass 5,443 t
Manufactured by Vecor/G.E.C.			Breaking force 1753 kN	86 000 t per month
A.E.I.			Mass 9,215 kg/m	
			Length of wind 2347 m	

of the shaft collar and the manner of excavation.

The Shaft Collar

The collar of an earlier shaft in the vicinity was excavated by making use of a concrete caisson, but on this occasion it was considered more economical to protect the excavation by a ring of interlocking piles to a depth of 12,83 m (Fig. 7).

Some deflection in the drilling of the pile holes made the stability of the annular ring suspect, and, as a precaution, two mild-steel channel rings were installed as the excavation proceeded, the first at 2 m and the second at 8,3 m from the surface. The operation proved entirely successful despite several of the 'off-vertical' piles having to be partially chipped away to permit the full thickness of the concrete lining to be maintained.

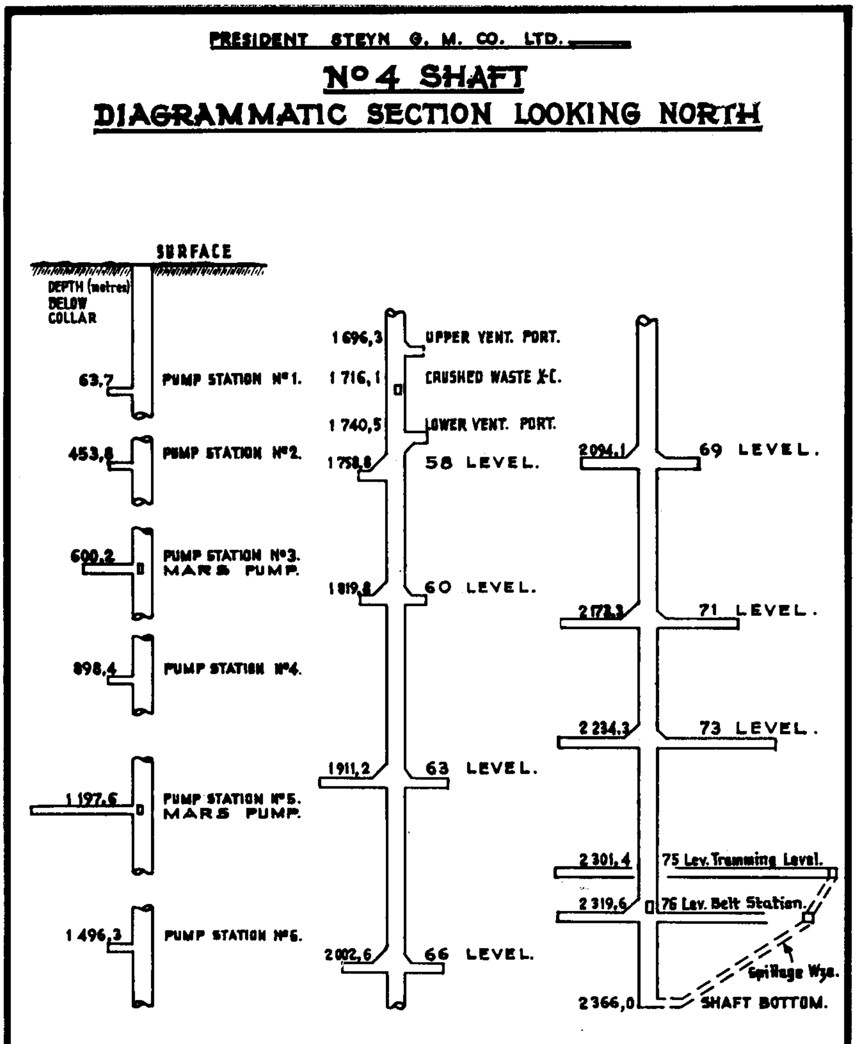
Figs. 7 and 8 show the arrangement of the interlocking piles and the layout of the collar respectively. It will be noted that an auxiliary air duct has been provided to reduce the restrictive effect on the downcast airway when conveyances are stopped at the bank, and this duct also carries the service columns and cables to the shaft.

Headgear

Because of the adverse ground conditions, an 'A' frame headgear was chosen to remove high foundation loadings from the perimeter of the shaft (Fig. 9). The headgear is carried on piled foundations consisting of five piles, 0,915 m in diameter and 19,5 m long, to each main leg. Each pile was sleeved over the upper 9 m and surrounded by clinker fill to prevent tensile loads being imposed by the action of the expansive clays (Fig. 10).

To relieve the foundation piles of both the headgear and the winders of horizontal loads, concrete struts were constructed between them as shown in Fig. 9.

The height of the sheave platform was dictated by the possibility of two additional conveyances being required in the upcast compartment at some future date. This made it possible to position the permanent men-access platforms at a level that allows an unimpeded access for the handling of material and cars at bank level (Fig. 11).



N. B. *The 58 & 60 levels were developed to the shaft-position before the shaft reached these stations*

Fig. 2

deep was drilled to cover the shaft to final depth; no water was encountered in the lower portion of the shaft.

Diamond-drill cover was not used during sinking, though four 2,75 m pilot holes were carried with each round. The shaft is dry except for a small amount of surface water, which is collected and piped to drainage.

Surface Ground Conditions

Ground conditions were known to be poor, and test holes were sunk to establish the parameters for designing the foundations for the headgear, winders, and shaft collar. The tests revealed active clays and soft shales to an average depth of 8 m, these being underlain by partly broken and weathered shales extending to 20 m. Below this, fairly solid, hard shale alternates with fine-grained sandstone. These conditions called for the use of piled foundations generally and, because of considerable surface water, required careful thought in the design

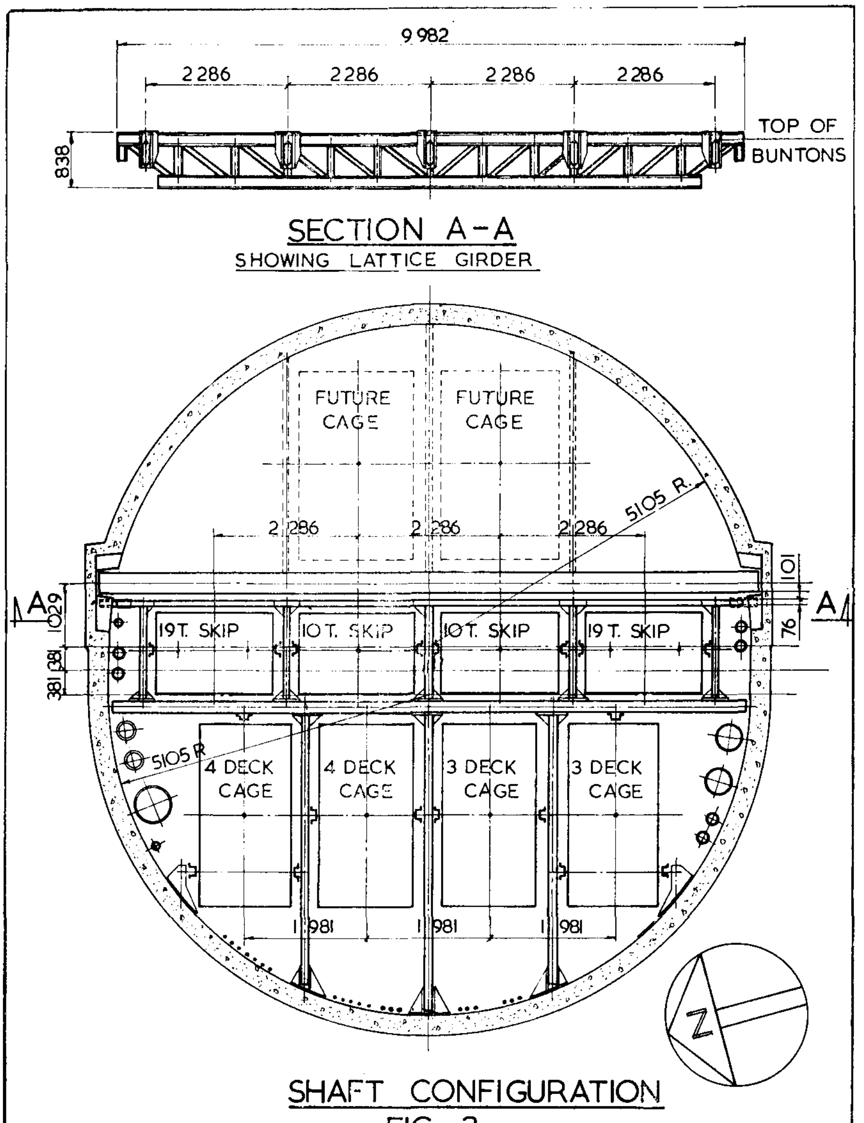
SHAFT SINKING

Equipment

The two permanent men and material winders were installed prior to the start of sinking to serve four kibbles disposed as shown in Fig. 12. It will be noted that one kibble was located over the centre line of the future brattice wall to aid in the installation of the precast brattice panels.

The kibbles were 1828 m in diameter by 2,64 m high, with a capacity of 10 t, and were fitted with jack-catch rings to suit the four jack catches installed in each compartment, this arrangement being preferred to conventional crash doors.

Owing to the difficulty of maintaining the tension of the dead turns of rope on the winder drums, short ropes were used at the start and these were to be changed for the full-length ropes at a depth of 915 m. Unfortunately, the short ropes exhibited loss of their non-spin properties and had to be changed before reaching 915 m. The full-length ropes were installed at this depth and lasted until 1830 m was reached, when a substantial reduction in



SHAFT CONFIGURATION
FIG. 3

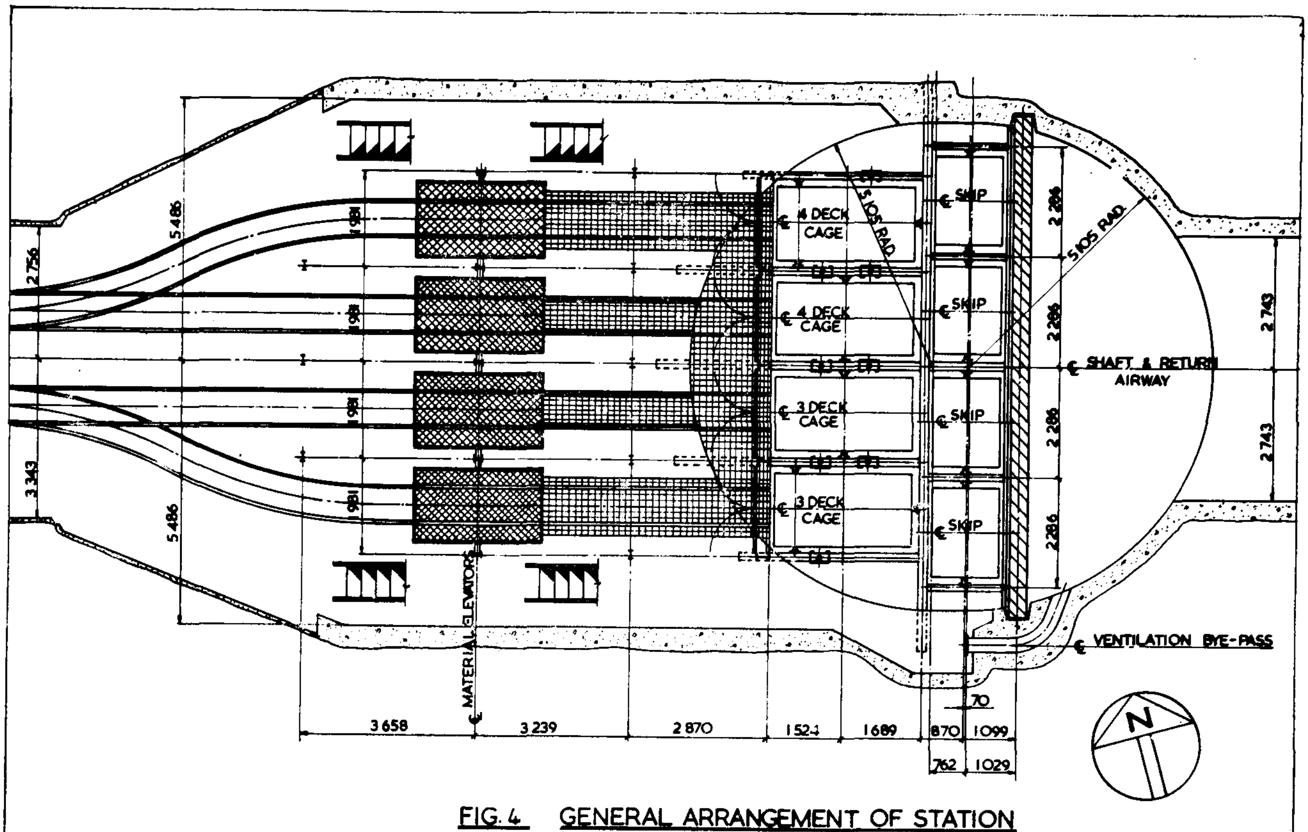


FIG. 4 GENERAL ARRANGEMENT OF STATION

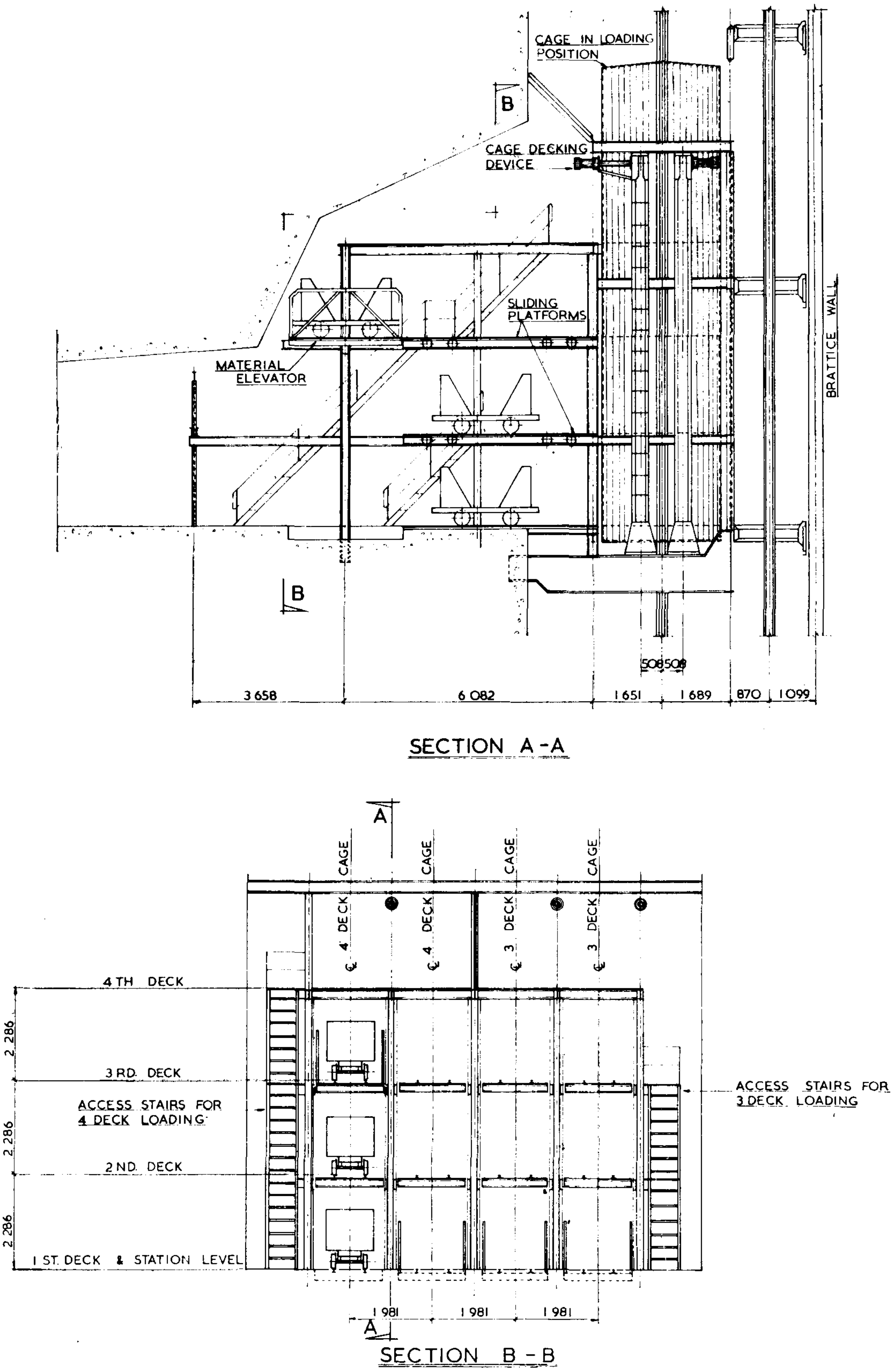


FIG. 5 STATION-LOADING ARRANGEMENT

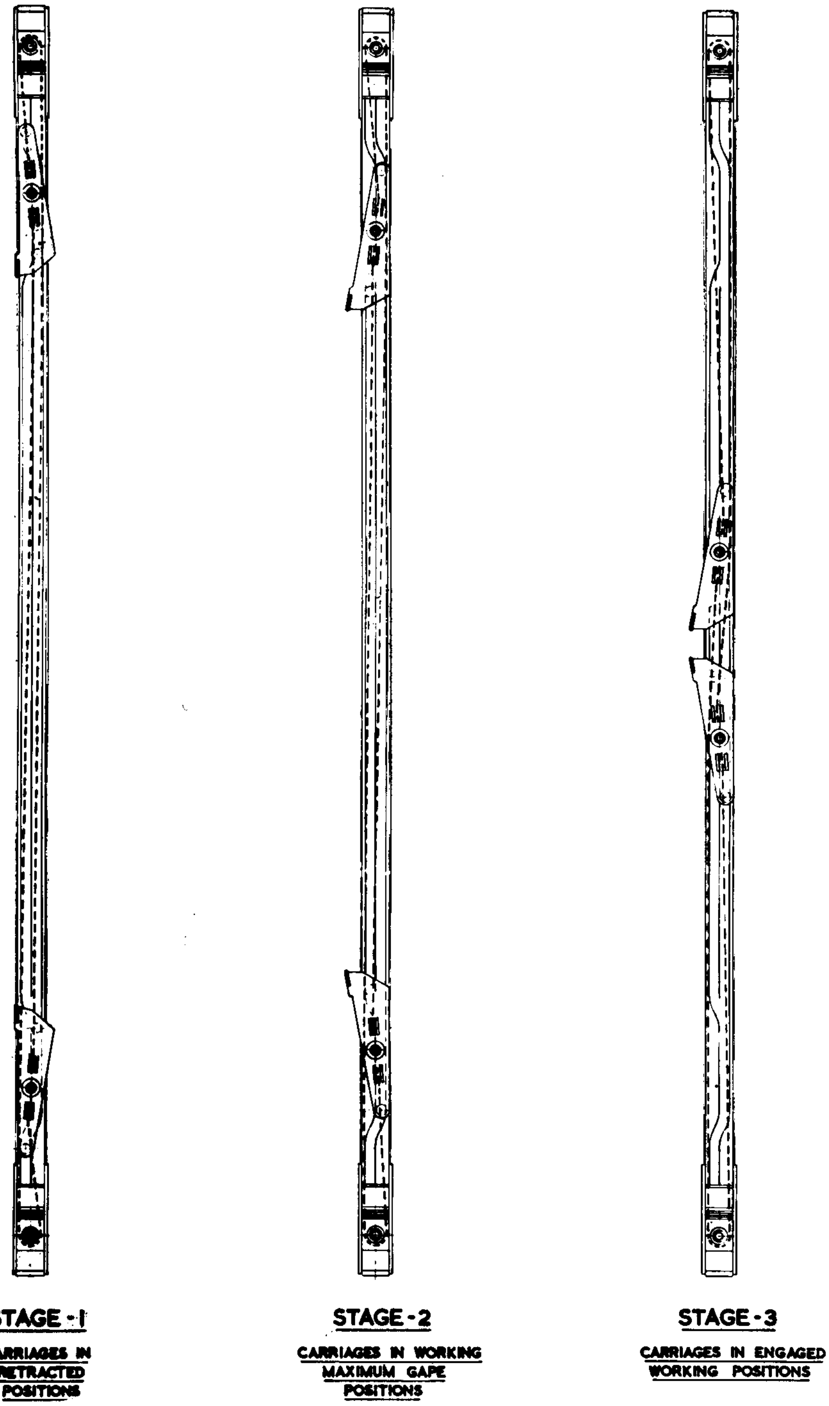


Fig. 6a—General arrangement of cage-decking device

breaking force resulted from heavy internal corrosion; at this point galvanized ropes were fitted, which lasted until sinking was complete and the brattice wall and the shaft steelwork had been installed.

The high rate of corrosion is attributed to the slow rise of explosive gases in a shaft of this size and depth.

The stage winder consisted of two Blair friction hoists coupled mechanically and electrically to provide four ropes, each reeved with three falls, thus giving twelve falls of rope to support the stage. The anchor ends of the four ropes were located on the stage by means of two compensating sheaves to ensure even distribution of the loads. The arrangement is illustrated in Fig. 13.

It became necessary to renew the stage ropes at approximately 1830 m owing to corrosion, which had resulted in a lowering of breaking strength. The specification of the stage ropes was as follows:

Diameter—37 mm
Type—Non-spin construction 9 over 6 strands
Tensile grade—2000 MPa galvanized
Breaking force—1752 kN,
Mass—9,570 kg/m,
Length—8300 m.

The forces on the stage ropes were monitored throughout the sinking period by load cells installed under the supports of two of the headgear sheaves.

The sinking stage was of a conventional design and is illustrated in Figs. 14 and 15. It had a total mass of 123 t while supporting a normal cactus grab of 0,86 m^3 capacity. Signalling needs from the stage to the bank and winders were supplied by three electric cables of seven cores each, backed up by four carrier wave transmitters operating on the winding ropes, these latter being used in preference to pull bells, which for this depth would have been approximately 20 mm in diameter.

Shaft Lining and Station Support

The shaft lining is conventional unreinforced monolithic concrete averaging 305 mm in thickness and was installed by the normal long-established methods. The concrete was poured in 6,12 m lifts, a test cube being taken from each lift to ensure acceptable quality.

Two chases were cast into the lining to receive the brattice wall, and steel channels were cast into the lining at 6,12 m centres for securing the shaft steelwork and the services. The purpose of the cast-in channels is described more fully in the section on shaft steelwork (Fig. 16).

The conventional steel and reinforced-concrete support used on the stations above 69 level was changed to a more 'active' type of support for the lower stations following an investigation by the rock mechanics engineer who predicted displacement of the rock at a later date.

On the lower stations, steel girders and stanchions were installed for

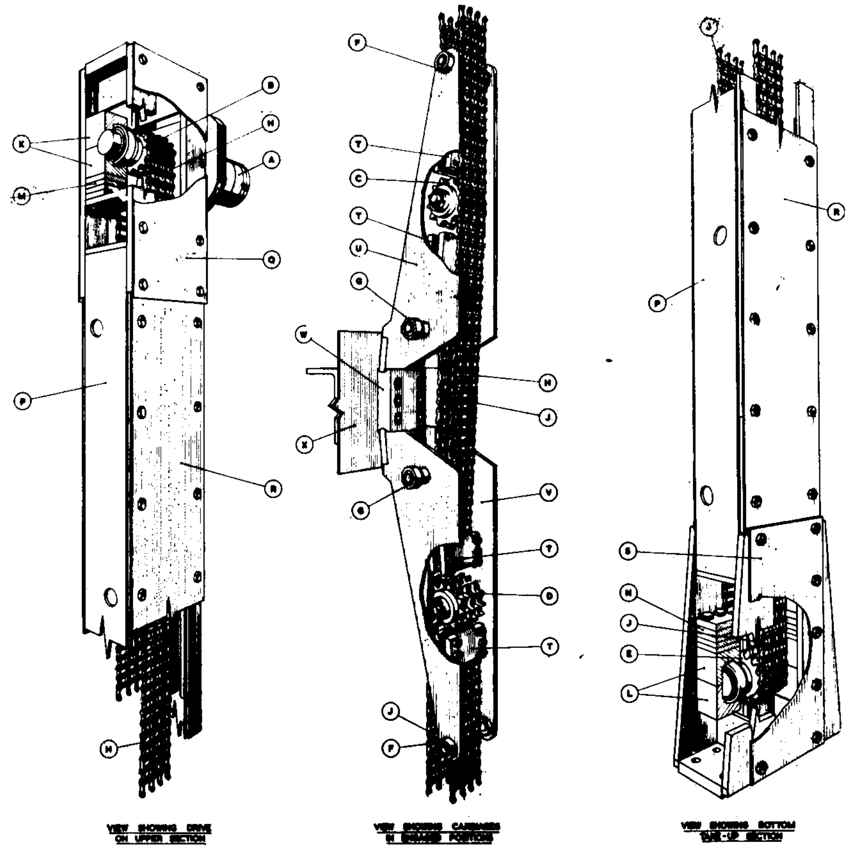


Fig. 6b—Pictorial view of cage-decking device

(a) Hydraulic motor drive
(b) Upper drive sprocket
(c) Upper idler sprocket
(d) Lower idler sprocket
(e) Take-up sprocket
(f) Inner guide rollers
(g) Outer guide rollers
(h) Upper drive chain
(j) Lower drive chain
(k) Upper split bearing housings
(l) Lower split bearing housings
(m) Upper bearing housing packs
(n) Lower bearing housing packs
(p) Main structure
(q) Upper cover plate
(r) Intermediate cover plates
(s) Lower cover plate
(t) Chain anchors
(u) Upper carriage
(v) Lower carriage
(w) Cage decking lug
(x) Conveyance

the first 2,5 m from the perimeter of the shaft to tie in the shaft steelwork; thereafter was a pattern of tensioned cables arranged in a radiating pattern, 12,2 m in length and four rows deep, followed by three rows of cables 6,1 m long spaced on a 1,8 m grid and tensioned to 36,3 t. The cables are made up of eight high-tensile rods with a combined ultimate tensile strength of 109 t. All cables were pressure grouted after tensioning.

Sidewall bolts are 6,1 m in length spaced on a 1,8 m grid but not tensioned; shorter 2,4 m bolts were placed between the long bolts in both side walls and hanging walls and used to secure wire mesh and ropes, which were finally shotcreted in position.

BRATTICE WALL

The kibble and stage winders were used for the installation of the wall, the sinking stage being modified on site (76 level) to a configuration providing working platforms on either side of the wall and a vertical slot for handling the precast panels.

In the earlier stages of design it was intended that the bunton steelwork should be attached to the brattice wall despite the fact that vertical and restraining loads in a horizontal direction would result. Analysis of the problem soon indicated that the vertical loads could be accommodated but horizontal restraints could not be easily overcome.

Economical design of the prestressed-concrete panels precluded a deflection of less than 20 mm at the centre. To prevent this deflection from inducing tensile horizontal loads into the bunton steelwork, the possibility of pre-loading the wall during the installation of steel was examined. Consideration of all the factors showed that, owing to the creep of the prestressed concrete under the further stress imposed by pre-loading, any benefits would disappear within six to eight months.

A number of alternatives were considered, but, as none offered economical and satisfactory results, it was decided that all shaft steelwork should be divorced from that

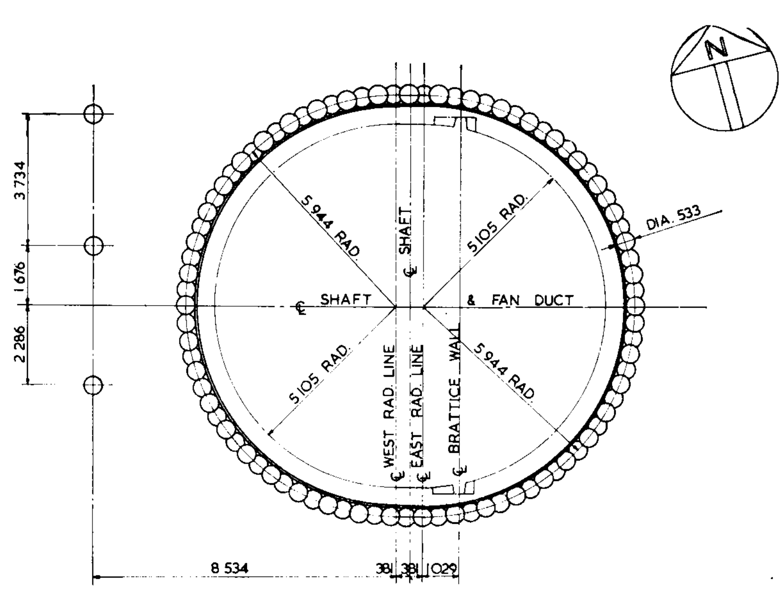


FIG. 7 COLLAR EXCAVATION

portion of brattice wall subjected to deflection. A narrow lattice girder of adequate depth to support vertical loads was therefore installed parallel to the wall to carry the skip compartment buntons (Fig. 16).

The precast panels were fabricated by contractors on site, the panel moulds being laid flat. Initially panels tendered to 'bow' after removal from the moulds, but this was overcome by attention to such aspects as the following:

(1) the even tensioning of the prestressed cables,

(2) prevention of uneven evaporation of moisture from the surface during the initial set by spraying of the exposed wet surface with a sealing preparation,

(3) good site discipline with regard to aggregates, moisture ratios, thorough mixing of the concrete, and attention to the results of concrete test cubes, and

(4) checking of the panels for straightness in the early morning before sun heat introduced uneven expansion.
Two steel tubes 43 mm in diameter were cast in the slab for handling and slinging down the shaft.

On removal from the mould, each set comprising a 6,12 m lift was checked in a vertical jig to ensure that the height tolerance was within 6 mm, and each panel was checked for bowing of not more than 12 mm over the total length.

It was found that most of the panels that exceeded the permissible bow could be corrected by being stored convex side up for 3 to 4 weeks. The completed panels were stored on edge on a smooth, flat surface to prevent distortion. As a further precaution, the long axis was oriented north to south to counter the effects of sun heat.

A special bridle was used for the installation to ensure that the weight of the panel was supported on its lower end by means of the jacking screw, and not on the slinging pins, while the panels were being lowered in the shaft (Fig. 17).

The horizontal joints between the panels were sealed with an epoxy mastic, and the ends were grouted into the chase. The slinging holes were closed with tapered rubber plugs.

The dimensions of the precast panels were as follows:
Length—10 515,4 mm
Height—1219,2 mm
Thickness—330,2 mm
Weight—7,2 t.

SHAFT STEELWORK

The method of attaching buntons to the shaft sidewall is a departure from the more commonly used grouted pockets.

A steel perimeter strip, illustrated in Fig. 16, was cast in the shaft lining at each set position, i.e. at 6,12 m centres. Slots were located in the strip to take tee-headed bolts for all bunton connections, pipes, cables, etc.

Strips were fabricated in five segments, each set up in a jig to ensure uniformity. A complete strip was attached to the shaft tubbing after setting the curb ring, thus locating all bunton and service positions in one operation.

The decision to use a tee-headed bolt system arose from the rather poor results obtained in the past from nut boxes cast in the shaft lining. Apart from the difficulty in locating such boxes accurately, problems frequently arose in replacing broken or corroded bolts.

The buntons were designed to limit their vertical deflection, which would affect the guides. Although this approach resulted in somewhat heavier steel than has been used in some designs, it was considered necessary in view of the number of compartments in the shaft.

Where possible, adjustment for vertical centres and lateral positions has been provided for by the use of packing shims, rather than of friction grip in slotted holes. However, because of possible sidewall movement in the future, allowance has been made for slotted bolt holes and clearance at the bunton ends so

TABLE II
Timing of activities

Activity	Period in days
1. Pregrouting from surface	281
2. Pregrouting from 58 level (ex No. 3 shaft)	112
3. Site preparation, collar excavation, and concreting	20
4. Sink to −18,3 m headgear foundations	40
5. Headgear erection	167
6. Man winders installed	226
7. Sink from −18,3 m to −64,0 m with 2-stage decks	29
8. Assemble stage	12
9. Sink to shaft bottom (−2365 m), including the following:	881
No. 1 pump station	6
No. 2 pump station	7
No. 3 pump station, including 59 m development	11
No. 4 pump station	8
No. 5 permanent intermediate pump station and sumps	31
No. 6 pump station	6
58 station	32
60 station	31
63 station, including 68 m development	34
66 station, including 97 m development	42
69 station, including 153 m development	40
71 station, including 229 m development	44
73 station, including 321 m development	54
76 station, including 73 m development	31
(During the cutting of 73 and 76 stations, a waste pass 1,828 m in diameter was raise-bored from 73 to 71 and 76 to 73 levels. Under normal conditions, a sinking rate of 4,57 m per day was consistently achieved.)	
10. Spillage winze — Belt station	57
11. Spillage plug	5
12. Modify stage and strip sinking equipment from bottom to 73 level	14
13. Installation of brattice wall and plugs at ventilation ports Concurrently sinking equipment stripped and main pipe columns installed, maximum length equipped in 24 hours 36,6 m	62
14. Cast seal-off plug on surface	3
15. Strip collar steelwork and lower portion of inner headgear, remove stage	7
16. Headgear change over to steel equipping conditions, assemble equipping stage	42 42
17. Installation of shaft steelwork up to king posts, including measuring bins, chutes, and shaft bottom steelwork	120

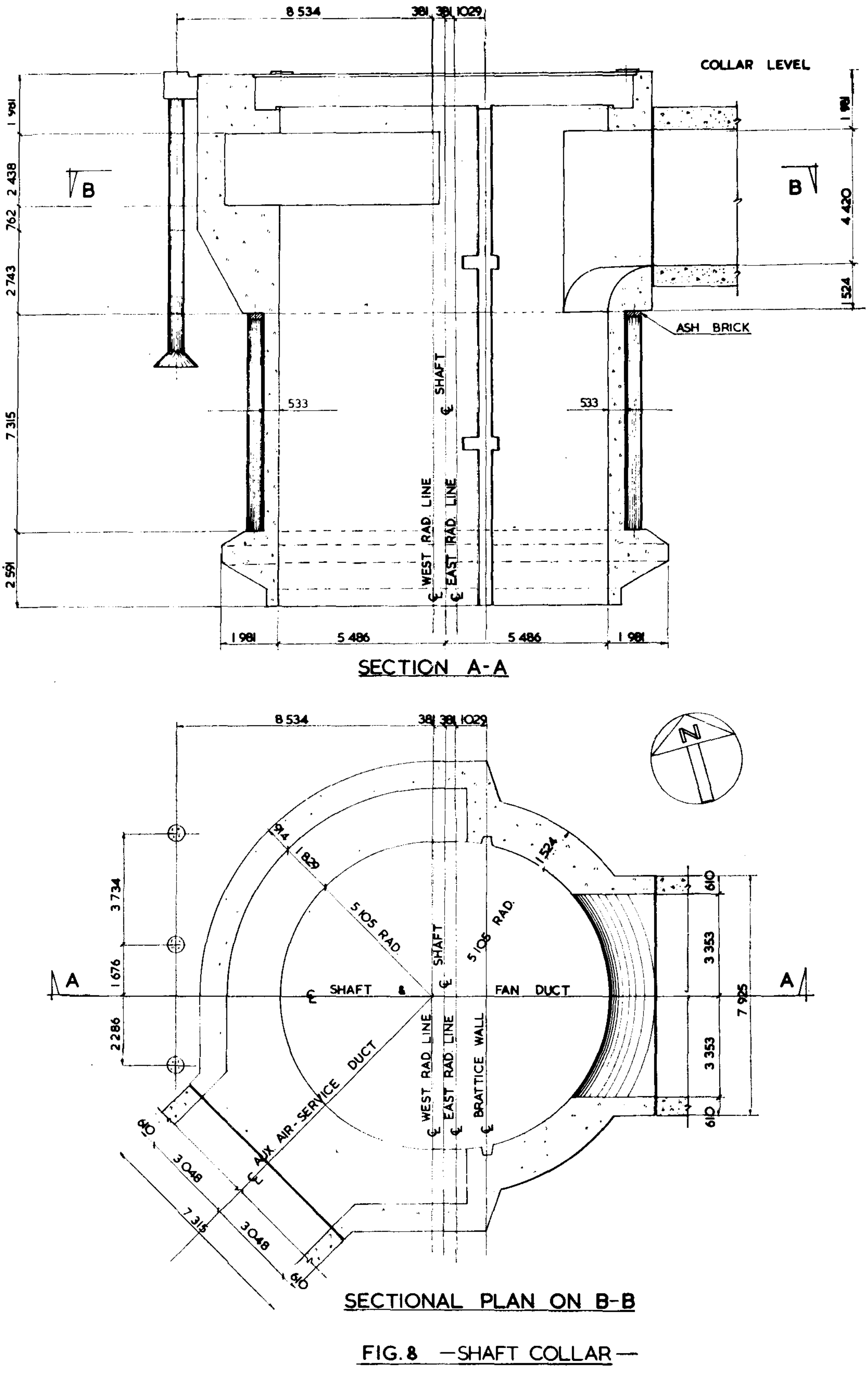


FIG. 8 —SHAFT COLLAR—

that small movements will not result in the immediate buckling of the shaft steel (Fig. 18).

The four permanent winders were used throughout the installation period.

PIPE COLUMNS

The support and jointing used for pipe columns are shown in Fig. 19. Each length is supported at bunton positions, and flanged joints are used only in station areas.

The principle of distributing the weight of columns throughout the length of the shaft was adopted to avoid concentrated loads on bearer sets, which pose problems in supporting large loads at specific points.

The liquid weight in the pump and sludge columns is supported on cantilever reaction supports at two points in the shaft on the intermediate level (1197 m) and on 73 level (2234 m).

The same arrangement will be used for the chilled-water columns below 58 level.

Prototype pump-column joints, specifically designed to simplify removal and replacement of individual pipes, were tested to 20,64 MPa.

Expansion and contraction allowances, as well as the accommodation for length tolerances, are provided for in each length of pipe. The possibility of creep of the pipes due to joint friction is prevented by the locating ring clamps on each length. These latter considerations are most important in the case of the chilled-water columns (Fig. 20).

PUMPING

Temporary pump stations were cut at 305 m intervals during sinking and twin pump sets held in readiness should water be encountered. In addition, two submersible pumps were available for emergencies.

As the 58 and 60 levels from No. 3 shaft had been cut to the No. 4 shaft position before the shaft reached that depth, it was necessary to install concrete stoppings and watertight doors on 60 level, which would serve to prevent any large amount of water encountered in the shaft from flooding 60 level and flowing to No. 3 shaft. The water would then be raised to 58 level in an emergency and led to the No. 3 shaft pump station on 59 level, where additional pumps were installed in case of need.

The permanent pumps are to be established at 1197 m and at 2234 m from surface. Provision has been made for two 250 mm diameter pump columns in the shaft, although only one will be installed initially; should the water encountered in mining the area be higher than anticipated, the second column and additional pumps will be installed. The activities involved in the shaft-sinking operation, their timing, and costs are summarized in Tables II and III.

TABLE III
Labour and costs of activities

Activity		Average labour per shift		
		White	Black	Total
Sinking		13	88	101
Brattice installation		10	80	90
Steel equipping		7	75	82
No. of holes per round	232			
Length of drill steel	1,5 m, 25 mm hex.			
No. of machines	32			
Tonnes broken per metre	307			

Shaft-sinking, lining, and station-cutting costs	R
1. Site establishment and clearing by sinking contractor	59 448
2. Pre-sinking and lining 160 ft and preparation for full sinking	66 126
3. Provision and hire of plant and equipment other than hoists, stage, kibbles, etc.	263 657
4. Sinking and lining 2365,9 m (7760 ft) R958,96 per metre or R292,37 per foot	2 268 814
5. Additional operating and maintenance personnel to original contract	81 487
6. Standing time	68 148
7. Labour and material escalation	15 560
8. Station cutting, lining, and support for two ventilation bypass ports 1 mid-shaft waste tip 8 stations including cost of shuttering	1 001 403
9. Pump stations and sumps, including the temporary pump stations and the intermediate permanent station together with the stations for solids pumping in the future	226 474
10. Cover drilling	54 148
11. Development on all levels, including initial loading station, conveyor crosscuts, spillage winze, and miscellaneous small works	322 826
12. The supply of 1868 brattice wall panels, including the provision of prestressing equipment and casting yard	436 803
13. The installation of 2176 m of brattice wall, installation of permanent pipe columns, and removal of sinking equipment working up from the bottom of the shaft (including modification of the sinking stage)	278 104
14. The installation of all steelwork within the shaft perimeter, guides, station steelwork up to first line of rangers (note that all eight compartments were equipped simultaneously working from the surface downwards)	254 887
15. Supply and delivery of shaft steelwork, including painting	936 735
16. Supply and delivery of permanent-station steelwork, including station platforms, stairways, material elevators, and screening	232 480
17. Pregrouting holes, drilling, and injection	173 105
18. Supply and delivery of 6-deck sinking stage and appurtenances	89 750

SUMMARY OF ACTIVITIES

General comments

1. Rock winders and fans were installed while sinking and the installation of the brattice wall were in progress.
2. Some raise-boring of the rock passes was attempted during the cutting of the upper stations but was discontinued because of interference in sinking occasioned by the disposal of chips and other delays.
3. The entire project (including the manufacture of certain items) was controlled by critical-path networks and schedules. The schedules were updated and monitored monthly, or at shorter intervals when critical areas demanding very close control were encountered.
4. All the work listed in Table II above was carried out by contracting firms.

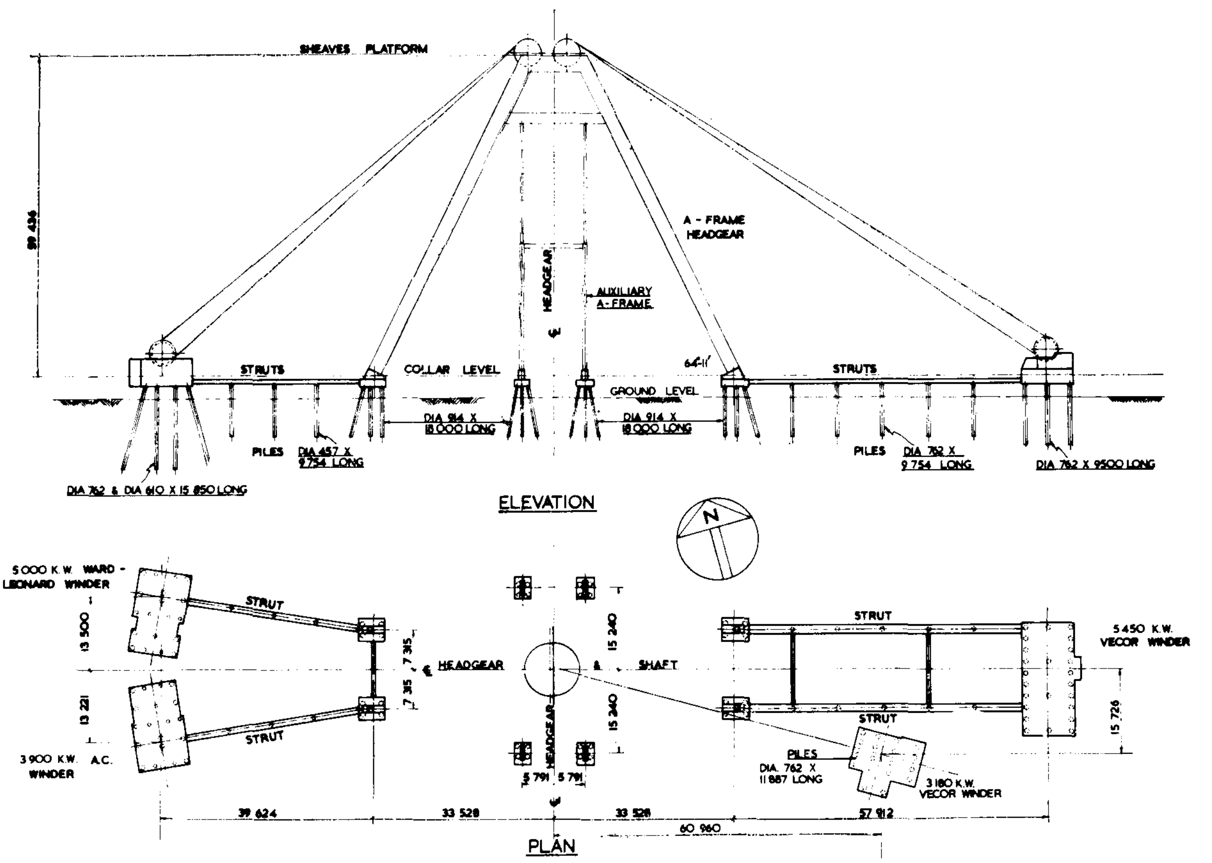


FIG. 9
A-FRAME HEADGEAR, PILES & STRUTS

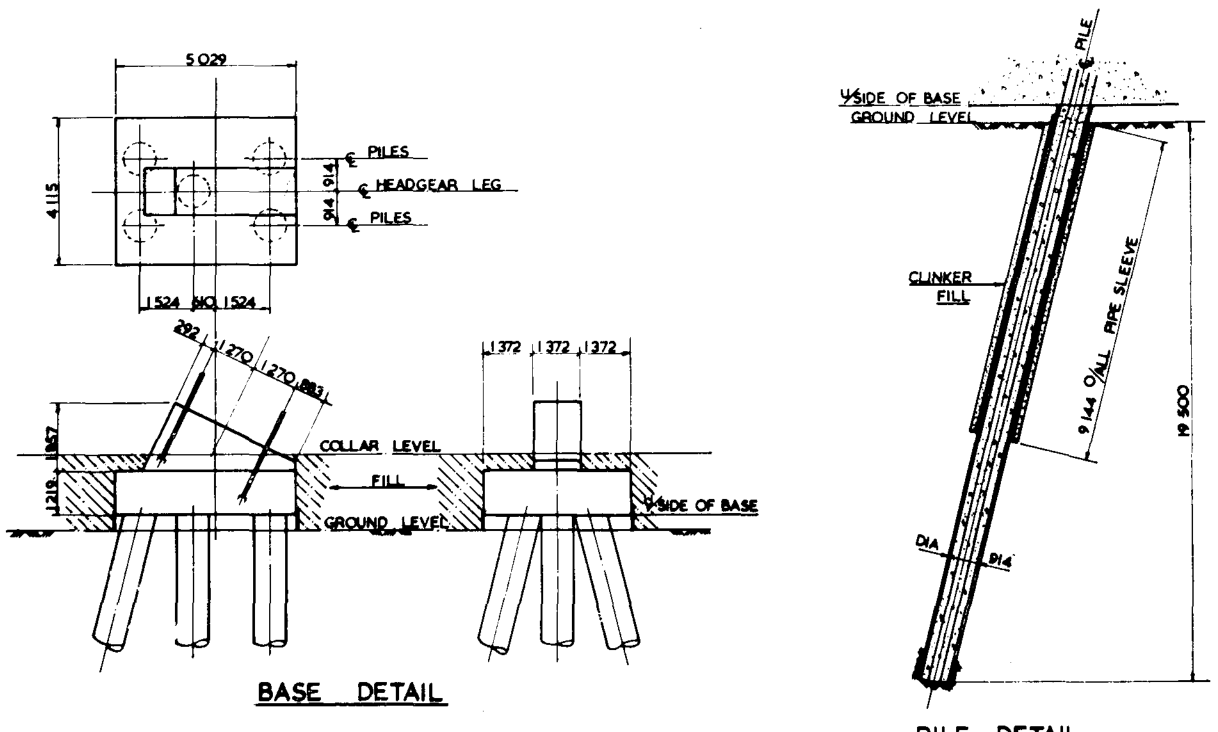
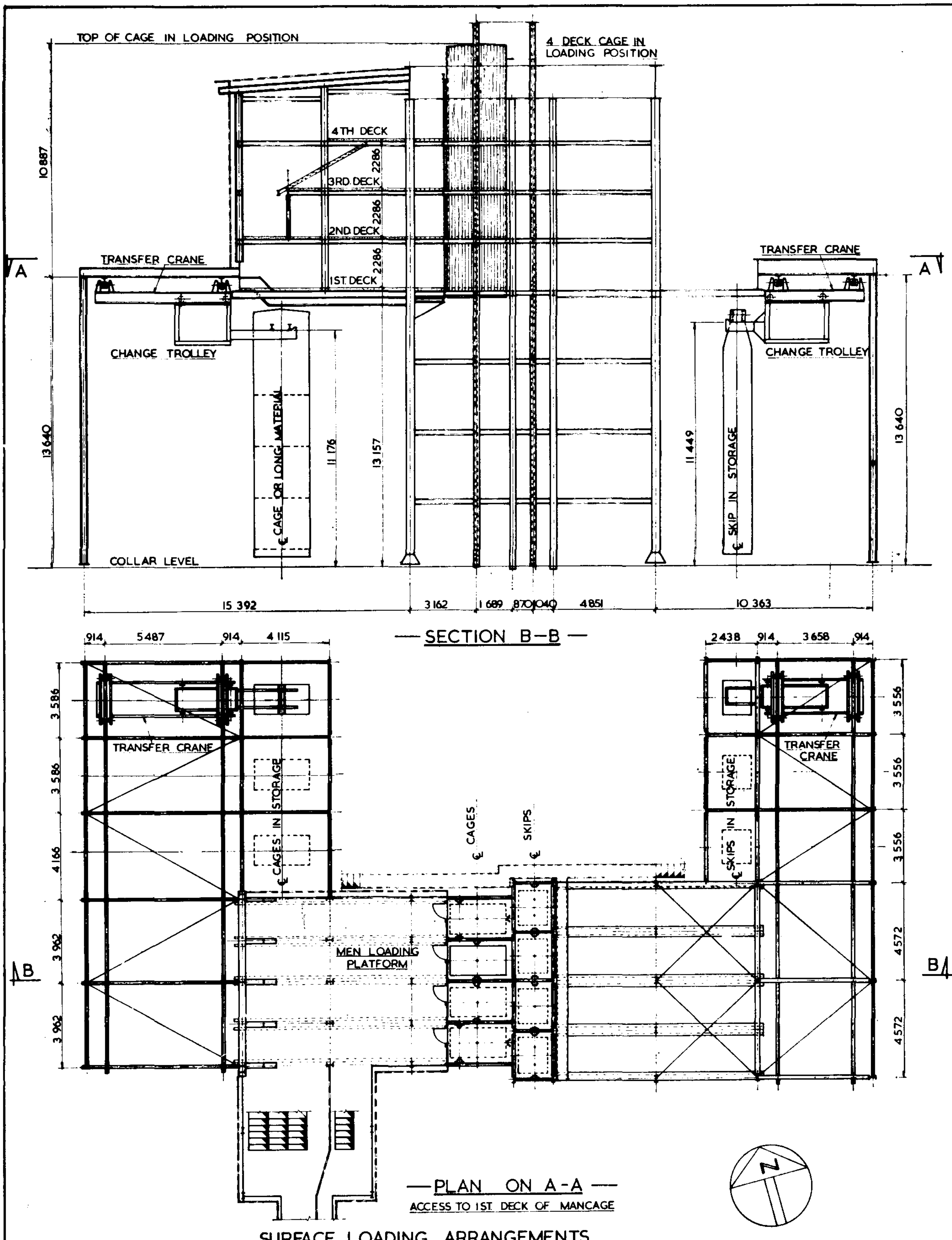


FIG. 10 — HEADGEAR PILE FOUNDATION —



SURFACE LOADING ARRANGEMENTS
FIG. 11

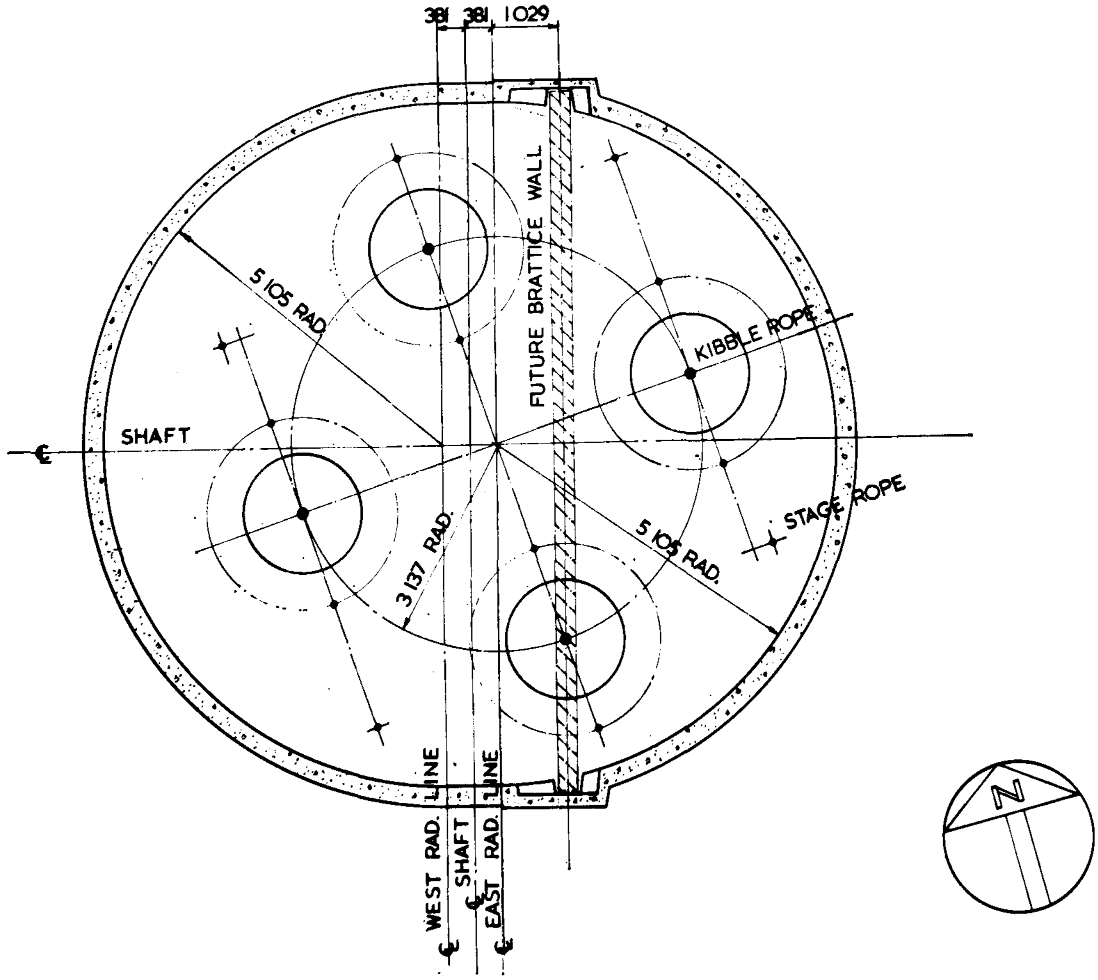


Fig. 12—Plan showing kibble positions

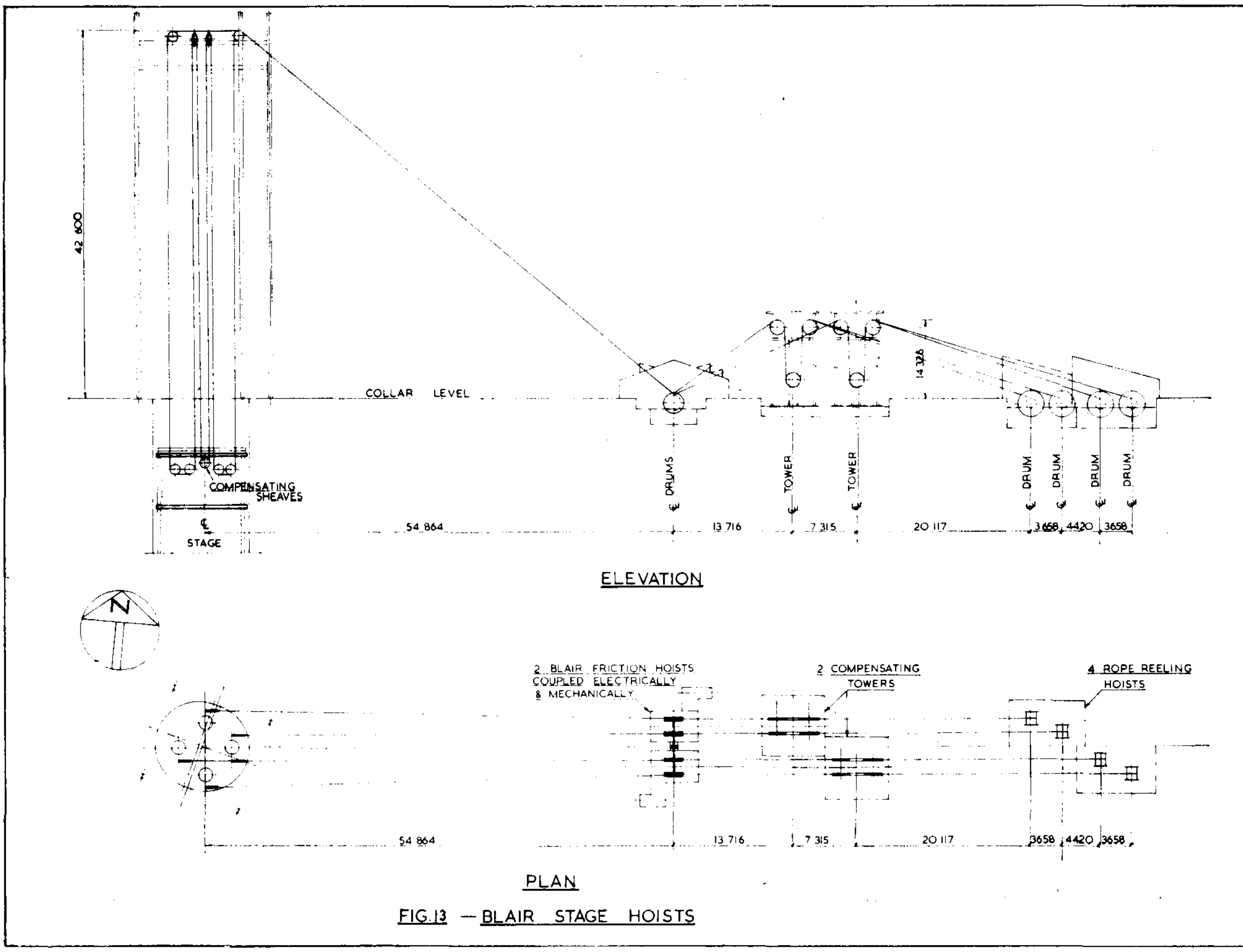


FIG 13 — BLAIR STAGE HOISTS

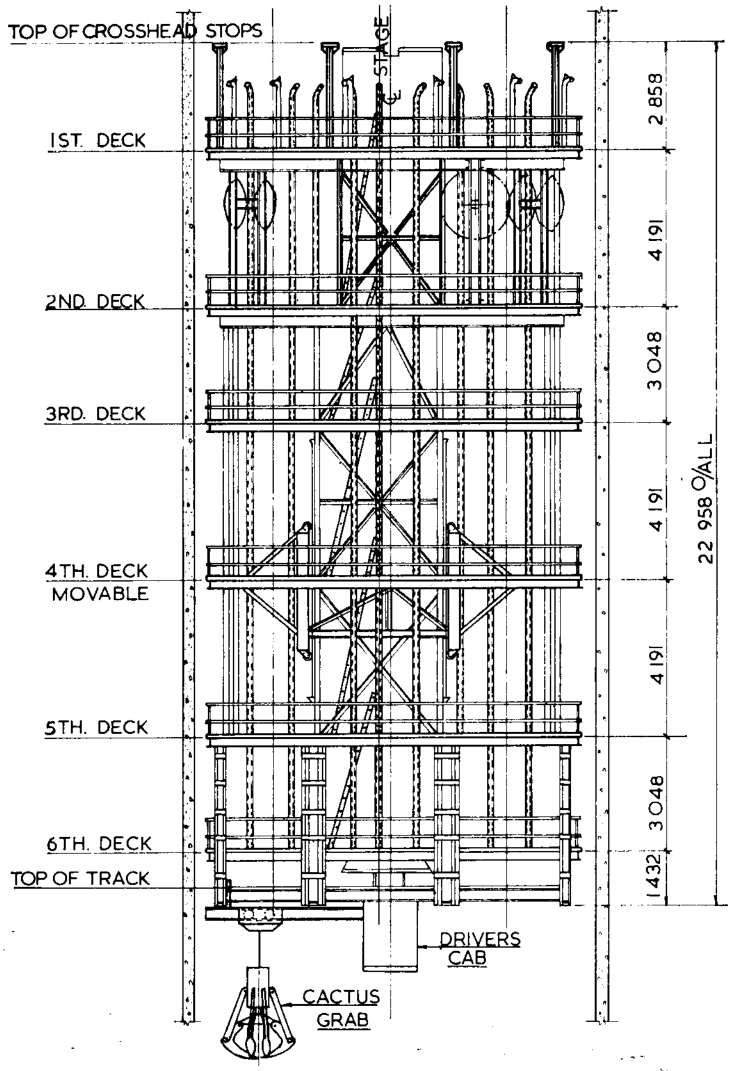


FIG. 14 ELEVATION ON STAGE

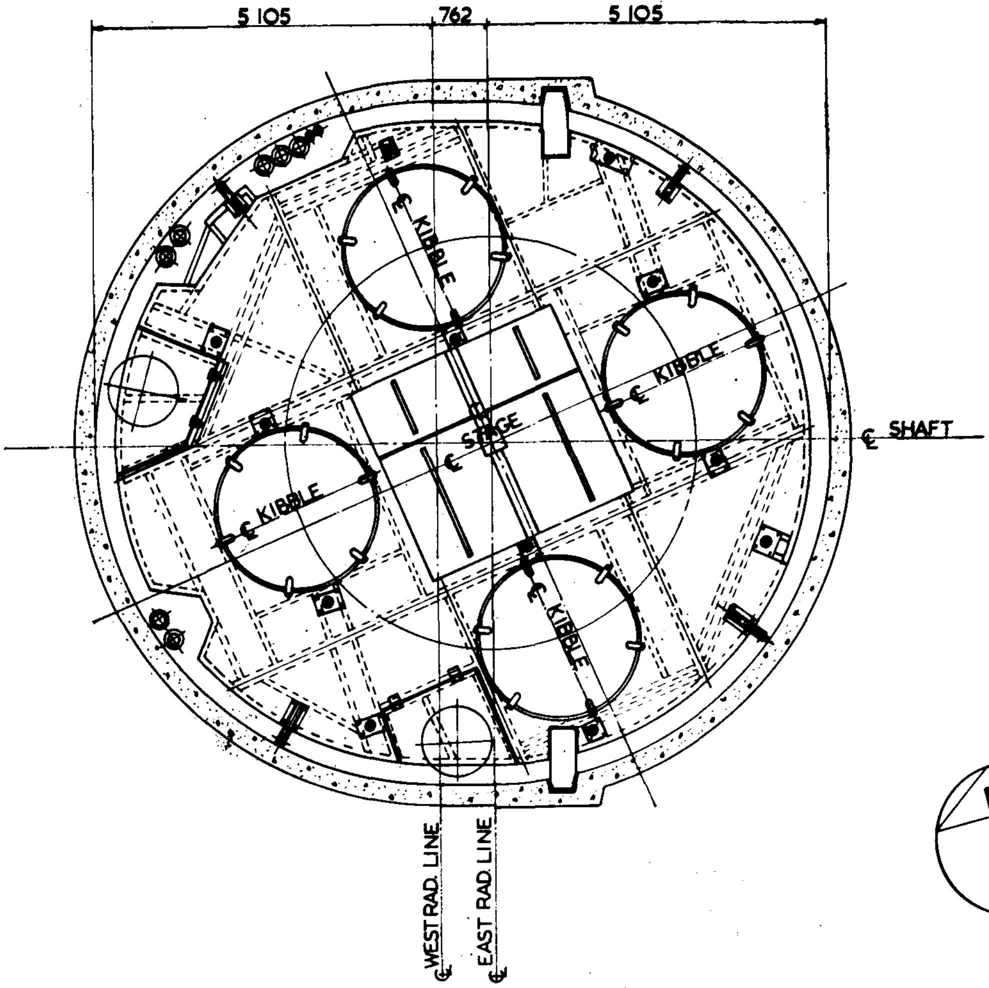


Fig. 15—Plan on 1st deck of stage

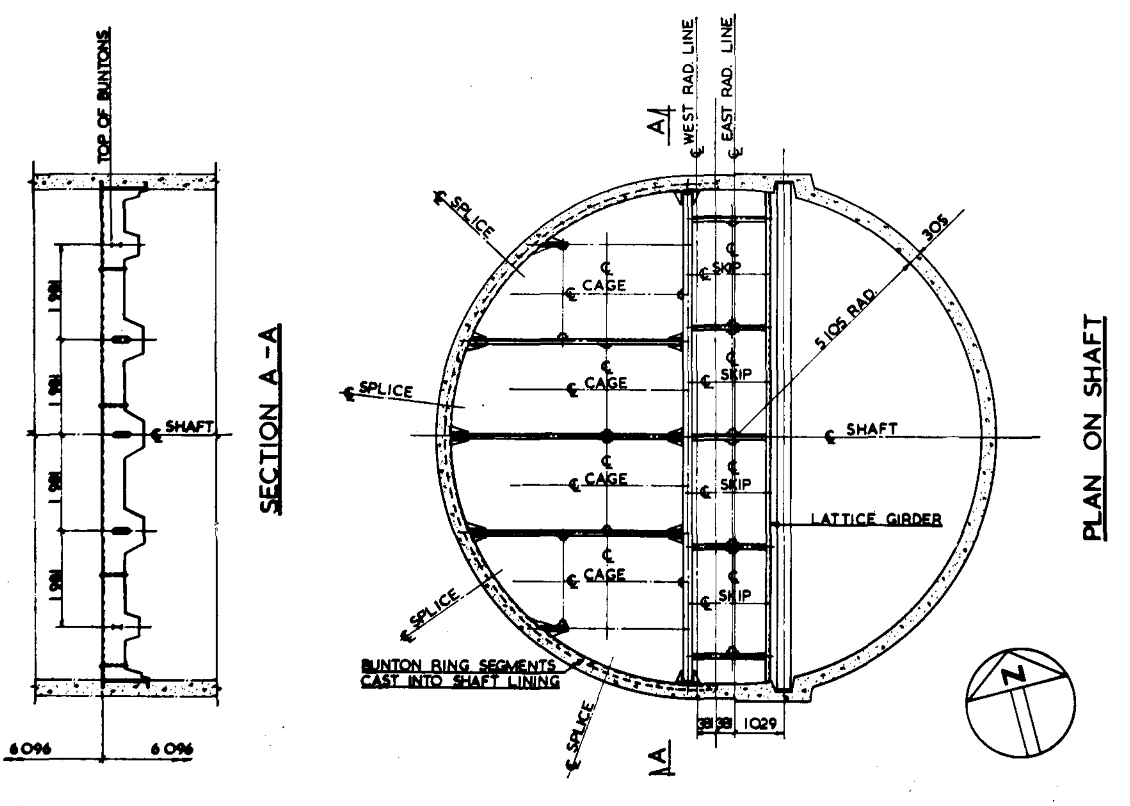


FIG. 16 —BUNTON RING—

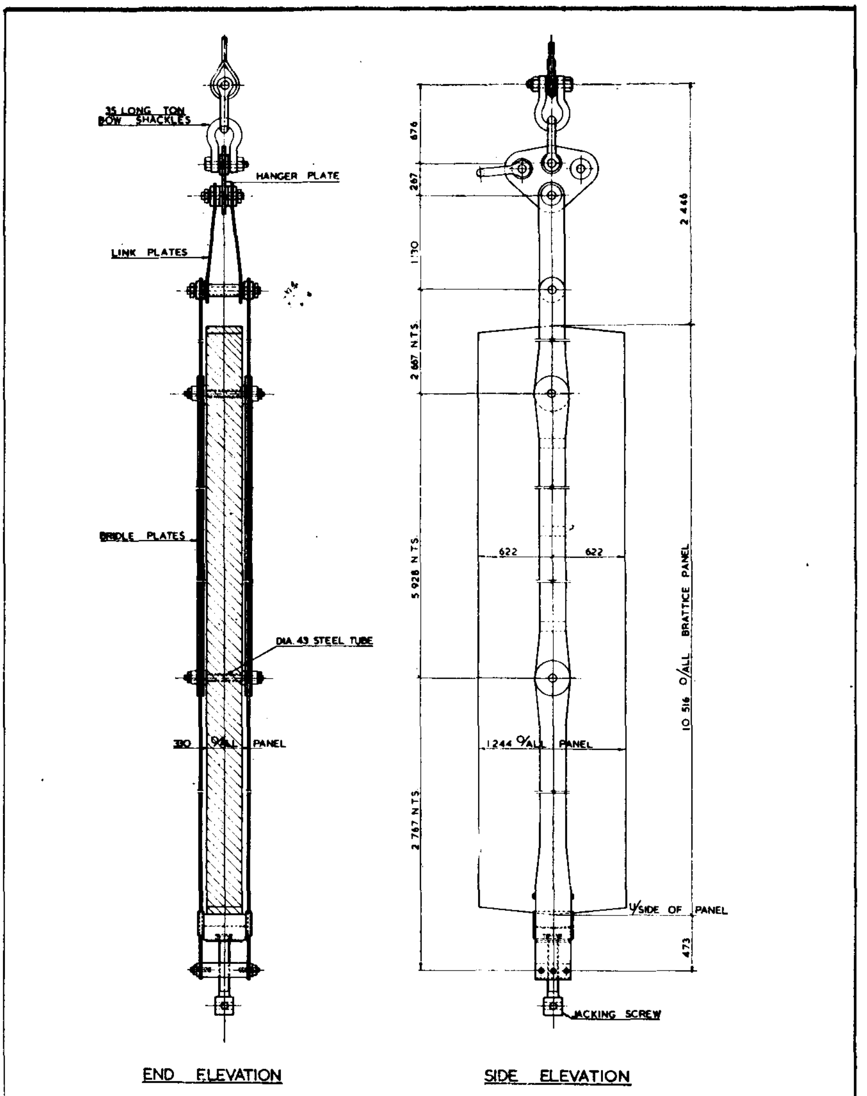


FIG 17 — BRATTICE PANEL SLINGING ARRANGEMENT —

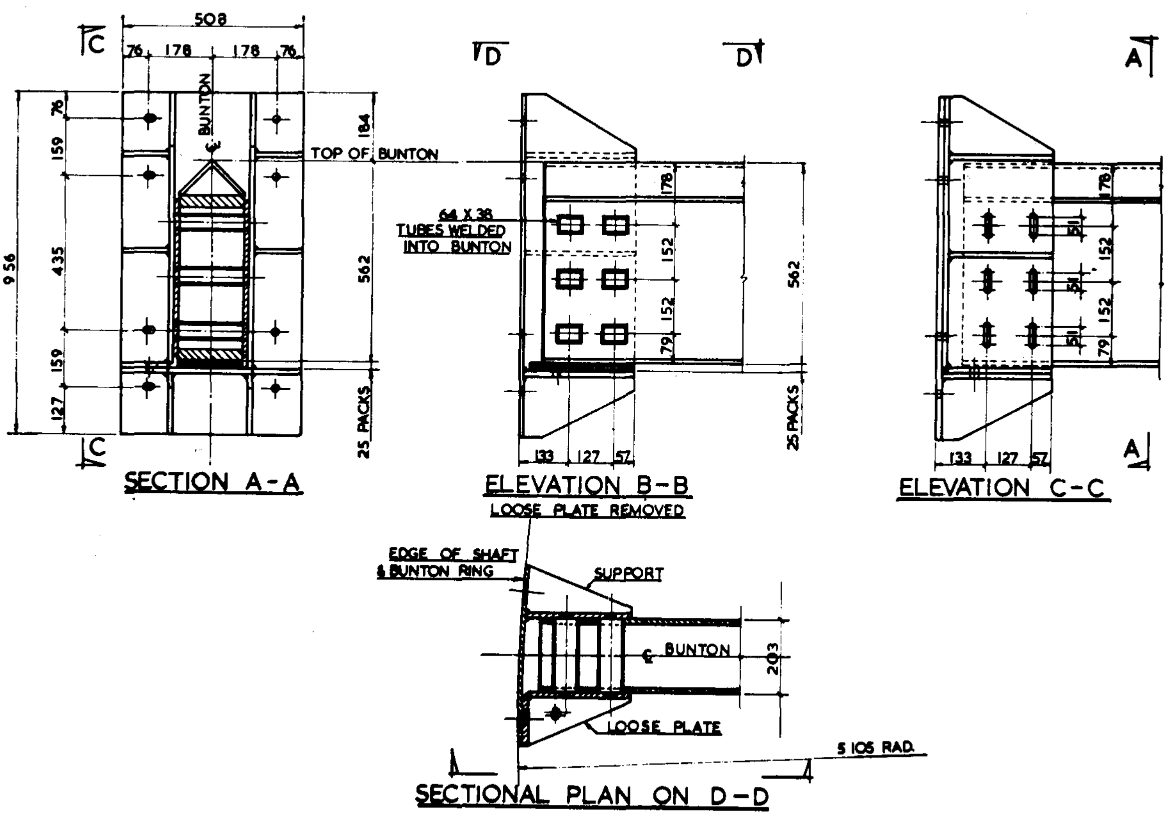


FIG 18 —BUNTON END-SUPPORT —

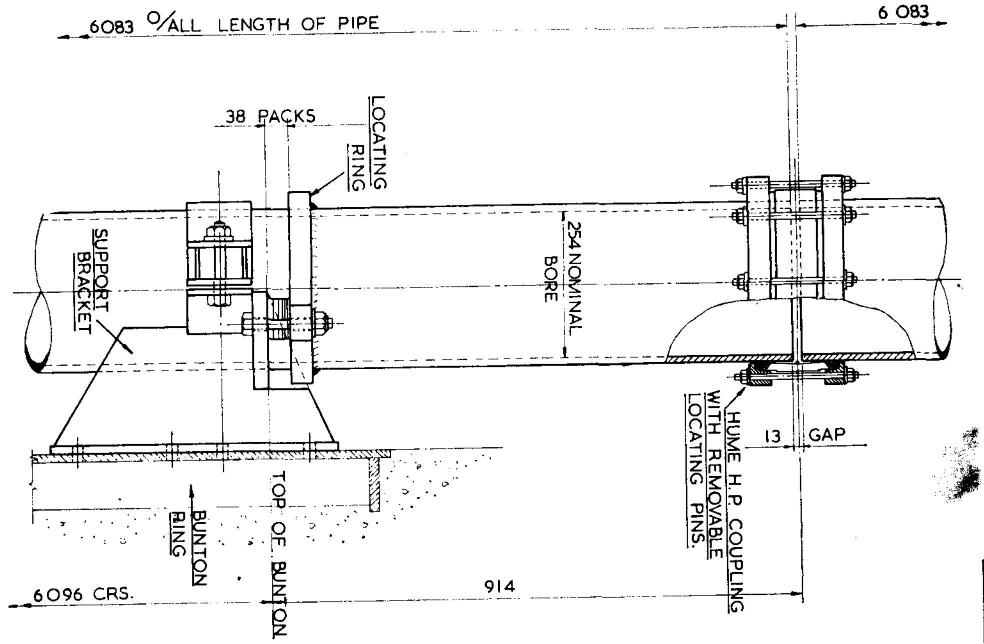


FIG.19 — PIPE SUPPORT & COUPLING —

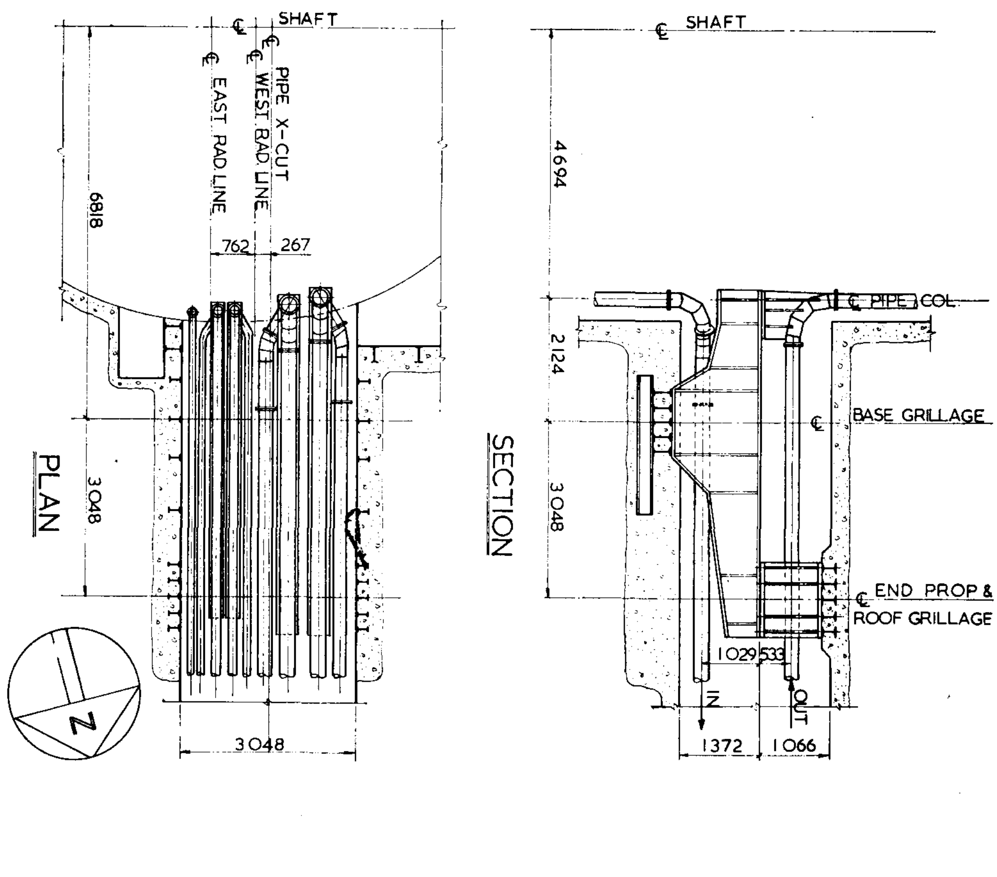


FIG.20 CANTILEVER SUPPORTS