Shaft Steelwork Modifications for the Mining of the No 2A Sub-Shaft Pillar

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SYNOPSIS

Late shaft pillar extraction is always associated with damage to the shaft. If the shaft is to be kept fully operational during and long after the extraction of the reef, means to prevent damage to the shaft steelwork, services and winding equipment must be in place before the pillar mining operation starts.

This paper describes the shaft steelwork modifications and the shaft layout to suit future hoisting operations at Avgold's Hartebeestfontein Gold mines' No 2A shaft after mining of the pillar.

INTRODUCTION

No 2A shaft is a circular sub vertical shaft to No 2 shaft. Before the shaft pillar preparation work started, the shaft was served by two men & material winders - "A" and "B" - and one rock winder - "C" -. These winders are situated on transfer level. The shaft is divided into six compartments.

The following objectives were set during the planning phase:

- Maintain its dewatering pumping capabilities. This shaft is used to pump between 10 Ml and 12 Ml of water daily to transfer level. Water sources are from mining activities at No's 2A, 4 and 5 shafts, as well as from Stilfontein Gold mines' Scott shaft.
- To maintain the men, material and rock hoisting capabilities of the shaft.

- Modifications to the steelwork in the shaft to be such that it will accommodate the expected vertical and horizontal ground movement with minimal additional maintenance.

- To mine the No 4 shaft pillar via this shaft.

MODELLING AND STRAINS

Modellings were done to predict the horizontal and vertical displacements of the shaft barrel. The X and Y directions give the horizontal (lateral) displacement from the original centre line of the shaft barrel (Table 1 and Figures 1, 2) while the Z direction gives the vertical up and down displacement (Figures 3, 4) from fixed points on the shaft barrel centre line.

These displacements will induce either tensile or compressive strain into the steelwork. The magnitude of the strain will vary according to the relative position of the steelwork with respect to the reef intersection.

This strain is measured in millimetres per metre shortening or lengthening of the shaft barrel or steel. Also, called milli-strain.

For strains of 0,4 milli-strain and lower, no special modification to existing steelwork is necessary. For strains higher than 0,4 milli-strain, damage to steelwork and shaft barrel lining can be expected.

As can be seen (Figure 5), steelwork installed in the Z direction at the reef intersection area will experience a compressive strain, which will tend to buckle the guides. Above and below the reef intersection, steelwork installed in the Z direction will experience a tensile strain, which will tend to shear the bolts at the guide to guide and guide to bunton connections.

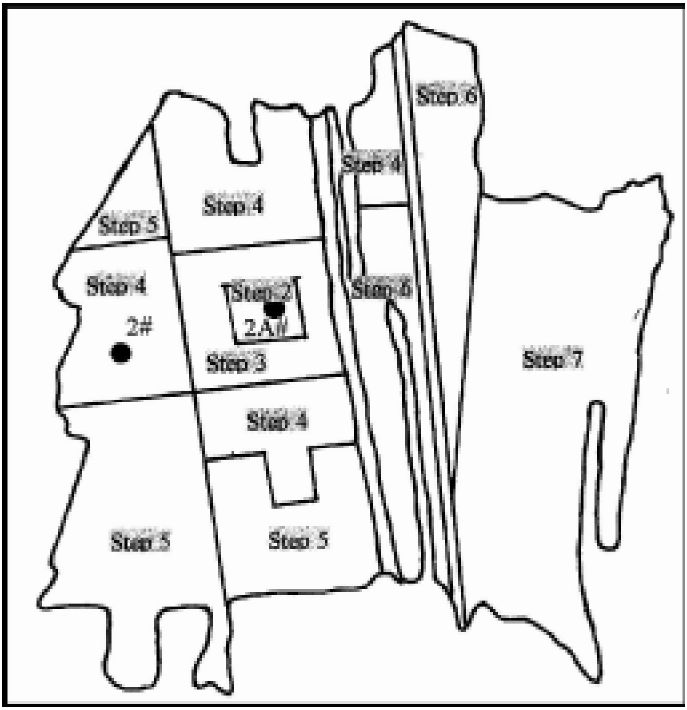


Figure 1

Preferred mining sequence - steps 0 ... 7

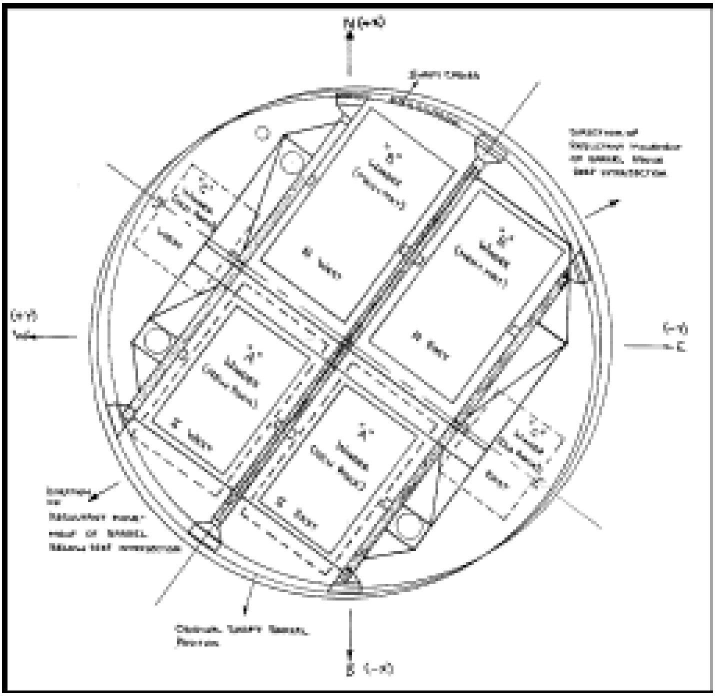


Figure 2

Predicted Shaft Barrel Movement (X + Y Directions)

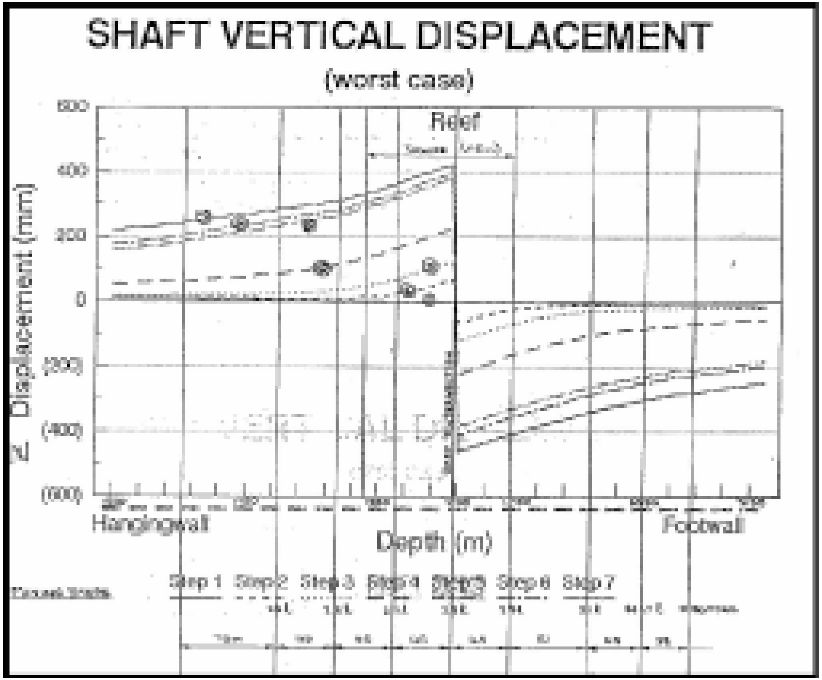


Figure 3

Shaft Vertical Displacement (worst case)

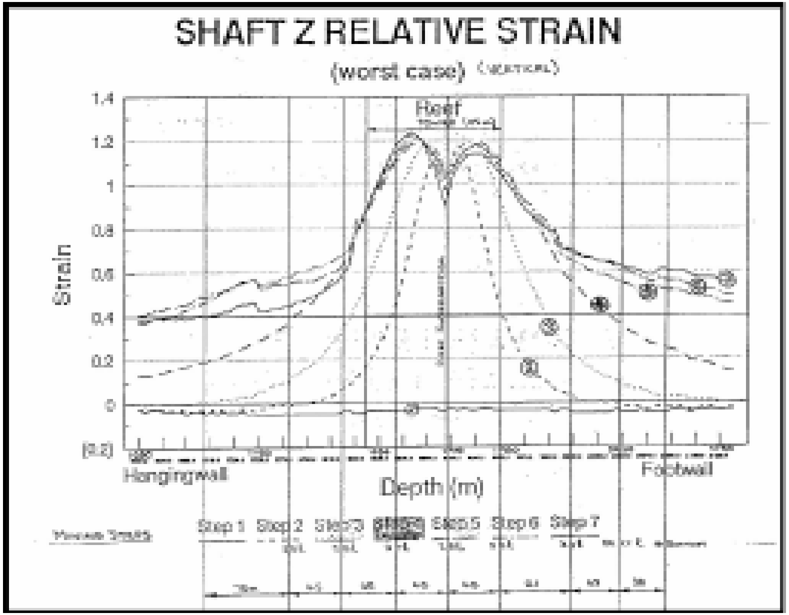


Figure 4

Shaft Relative Strain (worst case - vertical)

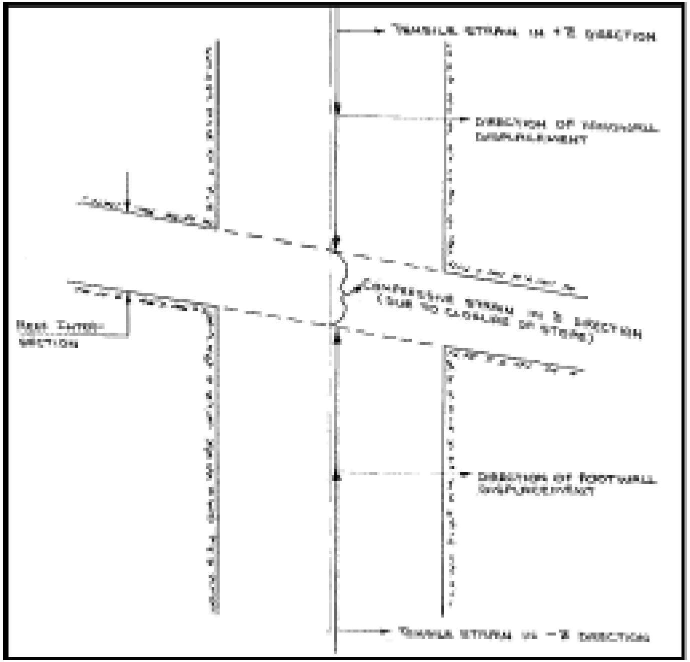


Figure 5
Vertical Strains

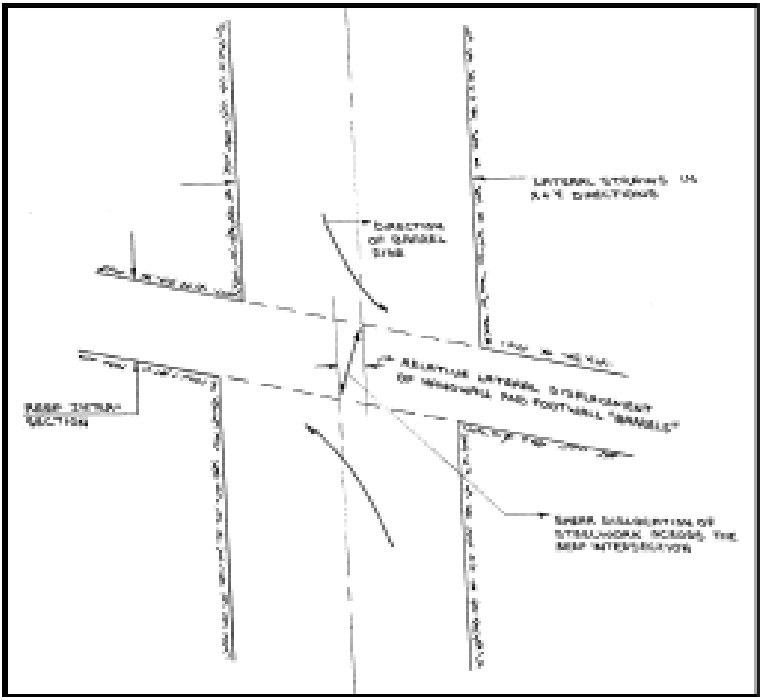
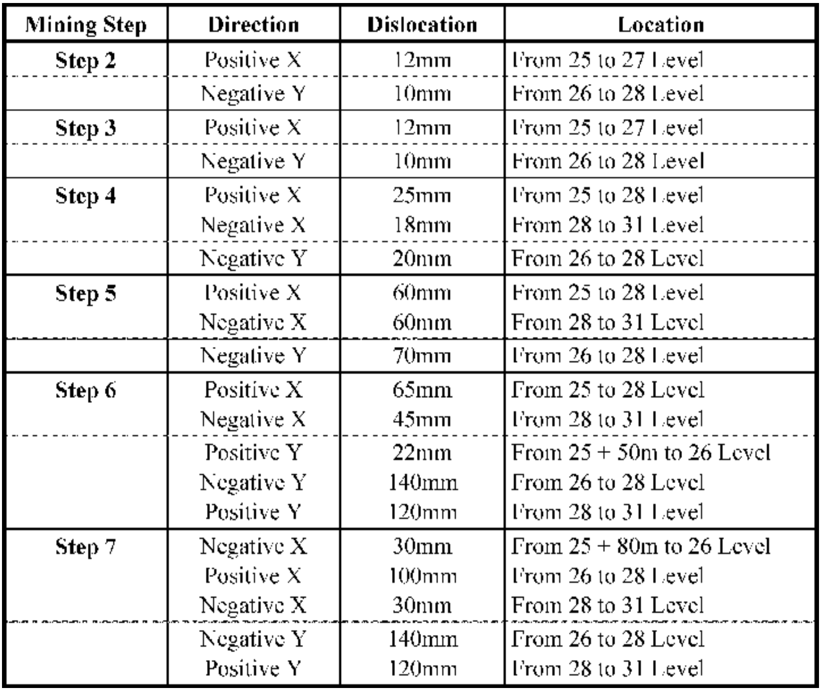


Figure 6

Lateral Strains

Table 1

Predicted maximum Horizontal X + Y movement



Mining Step	Direction	Dislocation	Location
Step 2	Positive X	12mm	From 25 to 27 Level
	Negative Y	10mm	From 26 to 28 Level
Step 3	Positive X	12mm	From 25 to 27 Level
	Negative Y	10mm	From 26 to 28 Level
Step 4	Positive X	25mm	From 25 to 28 Level
	Negative X	18mm	From 28 to 31 Level
	Negative Y	20mm	From 26 to 28 Level
Step 5	Positive X	60mm	From 25 to 28 Level
	Negative X	60mm	From 28 to 31 Level
	Negative Y	70mm	From 26 to 28 Level
Step 6	Positive X	65mm	From 25 to 28 Level
	Negative X	45mm	From 28 to 31 Level
	Positive Y	22mm	From 25 + 50m to 26 Level
	Negative Y	140mm	From 26 to 28 Level
	Positive Y	120mm	From 28 to 31 Level
Step 7	Negative X	30mm	From 25 + 80m to 26 Level
	Positive X	100mm	From 26 to 28 Level
	Negative X	30mm	From 28 to 31 Level
	Negative Y	140mm	From 26 to 28 Level
	Positive Y	120mm	From 28 to 31 Level

From Figure 6, the shaft barrel above the reef intersection will tend to ride in one direction while the shaft barrel below the reef intersection will tend to ride in a different direction. From the modellings, the centre lines of the "upper and lower" barrels would be 300mm apart at the reef intersection. The resultant of these lateral movements will cause a sharp transition point at the reef intersection. At this point the guides will tend to bend, buntons will be deformed and misalignment between consecutive buntons will result.

SHAFT LAYOUT ALTERATIONS

The original layout of this six-compartment shaft, served by three winders, is shown in Figure 7.

The skips were operating in the outer west and east compartments. In each of these compartments the outer guide is fixed directly to the shaft wall by means of wall brackets. Any inward ground movement will cause these guide-to-guide openings to reduce.

From the predicted ground movement it was clear that these outer compartments would need to be abandoned.

The decision was made to convert the "A" winder to a rock winder (Figure 8. Therefore, it was necessary to rearrange the whole loading, spillage handling and tipping arrangements.

SUPPORT OF THE SHAFT WALL

Although the support of the shaft wall is not an engineering function, this support work would not have succeeded without a fair amount of engineering input.

"Mobile platform"

Three special big inspection cages were attached below the three conveyances of the "A", "B" and "C" winders. The floor areas of these inspection cages were designed to cover the whole area of the compartments. Gates on each inspection cage allowed for travelling from one inspection cage to the other.

When all inspection cages were parked adjacent to each other, a working "platform" covering half the shaft was established. This enabled the drilling of holes and installation of rock studs, cone bolts, rope anchors and wire or welded mesh.

The Seco type S36 drilling machine, used to drill the 6m long holes, was attached to a vertically mounted pipe inside one of the inspection cages. There was no need to dismantle this machine when the inspection cage was lowered or raised to a new position.

All water and compressed air manifolds were installed permanently against the roof of the "B" winder inspection cage from where these services were piped via PVC hoses to the drilling machines on all the inspection cages.

To ensure that no accidental moving of the inspection cages could take place, each inspection cage was fitted with an IST 2000 voice and tone radio communication system. This enabled the winder brakes to be locked and unlocked the same way as a hardwired lockbell system. All signals exchanged between the driver and the persons on the inspection cages were recorded on the Deebar event recorder.

Battery operated fluorescent lights were installed on each inspection cage, which provided adequate illumination of the working area.

Water and compressed air supply

Between stations, water and compressed air were tapped off existing columns from the nearest upper station by means of PVC hosepipes.

For the area above the first station, water for drilling was tapped off from the clear water-dewatering column at three selected points through pressure reducing valves. At the same positions in the shaft, compressed air was tapped off the compressed air column.

Material and shift handling

The inspection cages of the "B" and "C" winders were, for all practical purposes, permanently positioned at the working area.

The "A" winder was used to transport pump shifts, contractor workers and for emergency purposes.

Additional cage doors were installed on the shaft side of the bottom decks of the "A" winder to enable contractor shift changes and material to be handled to and from the inspection cage of the "B" winder in the shaft.

MINING OF THE REEF SLOT

Because the position of the reef intersection with the shaft was just above 28 level station, it was decided to deck off the shaft

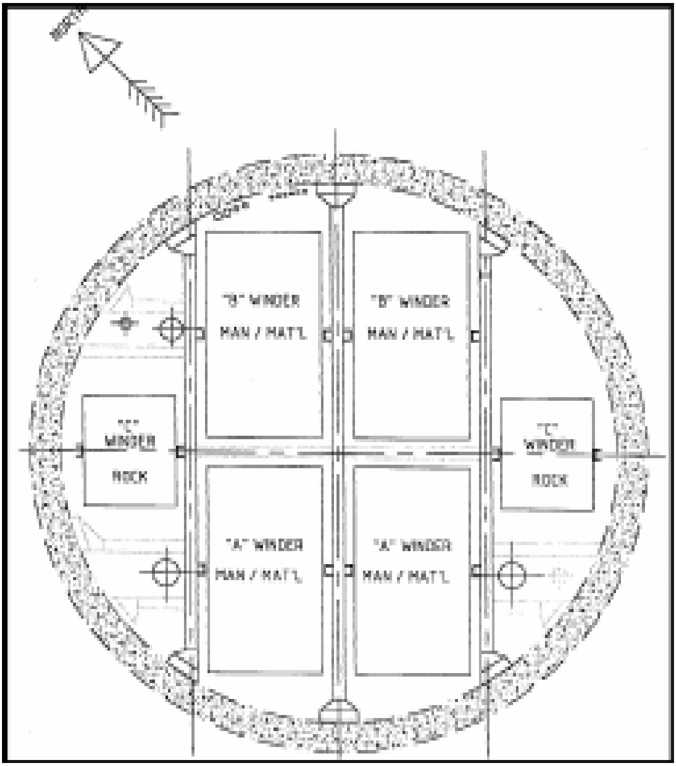


Figure 7

No 2A Shaft - Old Permanent Shaft Section

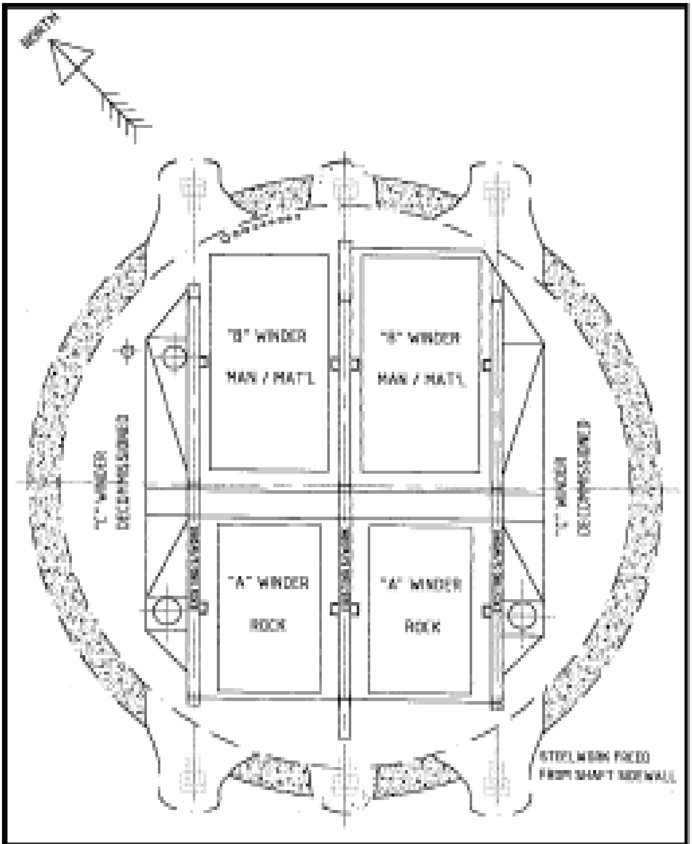


Figure 8

No 2A Shaft - New Permanent Shaft Section

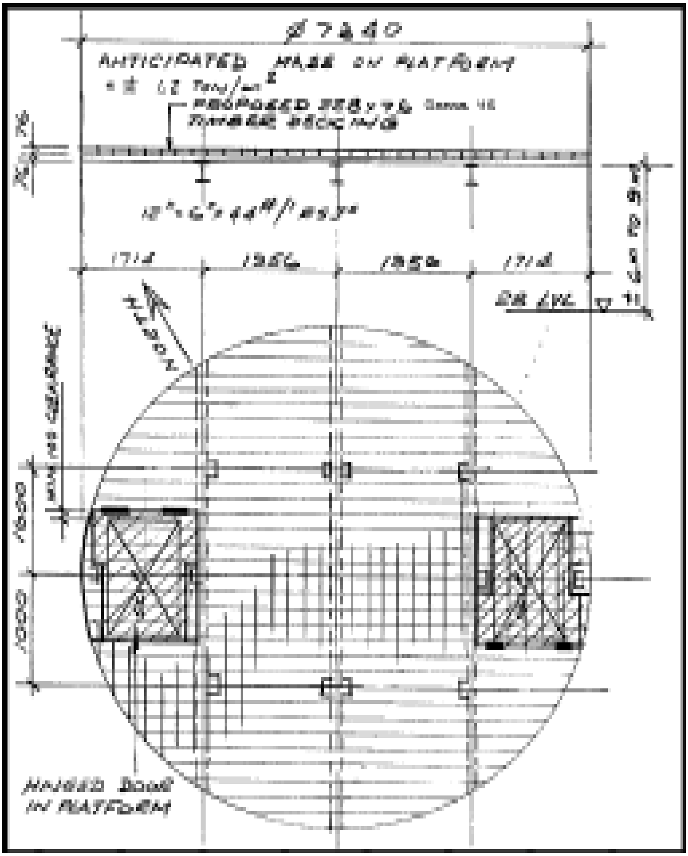


Figure 9

Project: 2A Shaft Pillar Mining

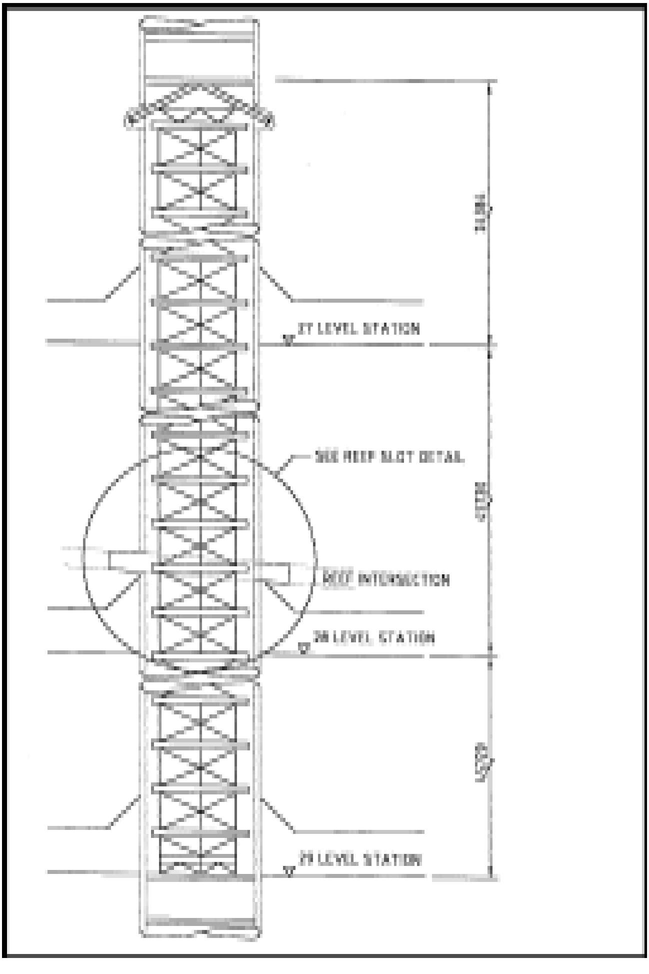


Figure 10

No 2A Shaft - Longitudinal Section thru Tower Steelwork with a temporary platform (Figure 9) onto which removal of the concrete lining and blasting of the reef slot rock could be done.

The platform consisted of two layers of 228mm x 76mm grade V5 timber planks with chequer plates on top. The platform rested firmly on the existing station floor bunton set.

Rock was scraped off this platform by means of a scraper, up a fabricated ramp and into a hopper.

All shaft steelwork, columns and cables were protected from these controlled blasting operations.

SHAFT STEEL MODIFICATIONS

To accommodate the predicted vertical and lateral shaft barrel strains, some form/s of modification to the steelwork are necessary.

Pipe columns and cables must also be made to accommodate the expected vertical and lateral displacements of the shaft barrel.

To realise the set objectives for the shaft, a maintenance intensive steelwork modification method such as slotting cleats and chair plates for guides and buntons will not be practical. The construction of a steel tower to span the portion of the shaft where high strains and displacements will occur is the better solution.

There was a choice between two types of hanger towers: a braced tower and a non-braced tower. The braced type tower is much more rigid in design and no winding speed limitation through the tower is necessary, regardless of the length of the tower. The non-braced type towers on the other hand are very flexible in design and winding speed through the tower must be slow. The braced type tower is more expensive than the non-braced type due to the steel volume.

In our case, if a vertical strain of 0.4 milli-strain and higher was to be accommodated, then a tower length of 220 metres was to be constructed. If a vertical strain of 1.0 milli-strain and higher was to be accommodated, a tower with a length of 115 metres needed

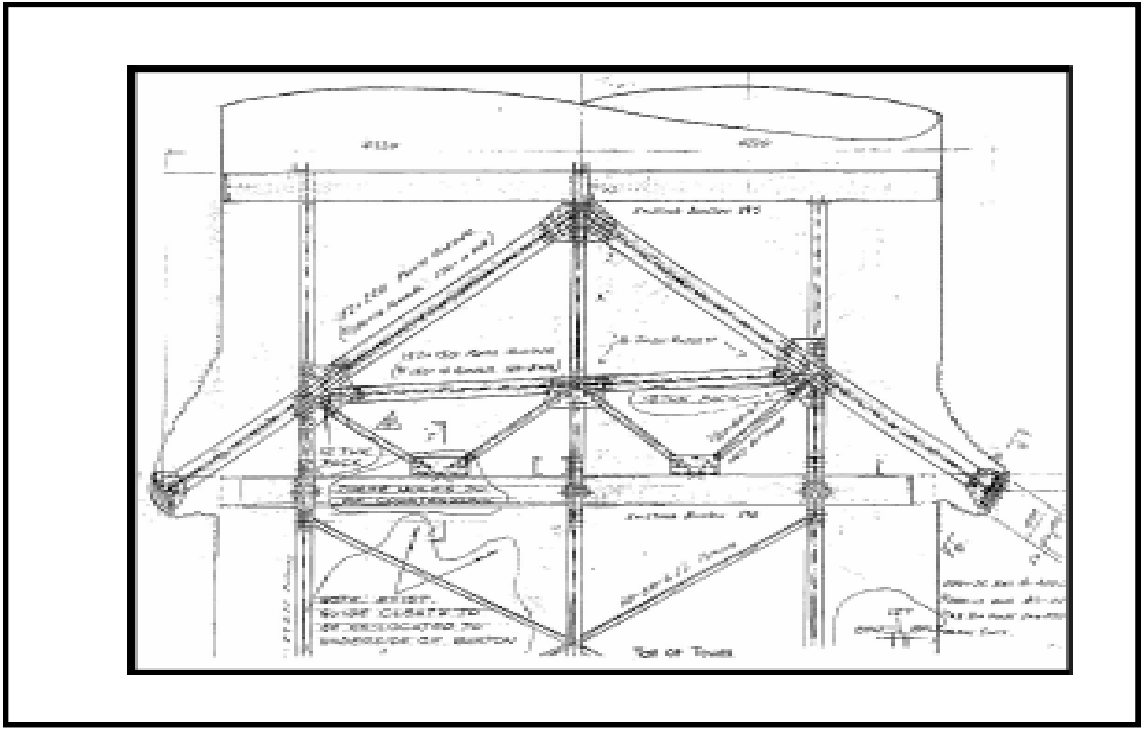


Figure 11
Top of Tower

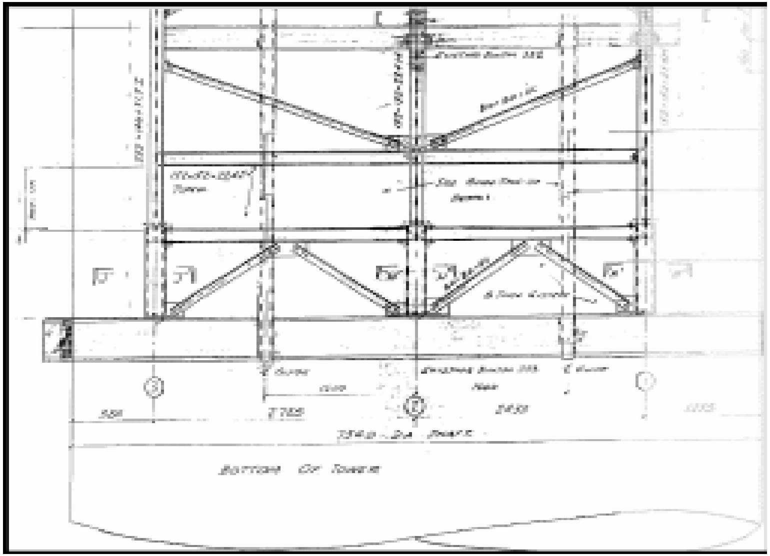


Figure 12
Bottom of Tower

to be constructed. In the latter case, to accommodate areas with vertical strains between 0.4 and 1.0 milli-strain, the guide to guide and guide to bunton connections must be slotted. The one end of each bunton should also be modified to include a slotted connection between the bunton end and the support chair plate.

Because the lateral dislocation will be at its peak at the reef intersection, the tower will act as a transition path across this dislocation.

Due to time and cost constraints the shorter tower was chosen. (Figure 10)

Main features of the tower.

- The top of the tower (Figure 11) consists of two bunton sets, which are braced to each other with six diagonal girders, which rest firmly into moiled out positions in the shaft wall rock. The whole tower is suspended from this "top of tower" bearer, which is situated halfway between 26 level and 27 level.

- The bottom of the tower (Figure 12) is situated on 29 level station. To cater for the shortening of the shaft, the "legs of the tower" will sag into fixed "pots" on 29 level station. Allowance of 640mm has been made for sagging of the tower.

- A guide take up facility (Figure 13) was installed on 29 level station. The length of the take up spacer was 640mm to allow for the sagging of the tower.

- To accommodate the vertical shortening of the shaft, vertical mounted bellows type compensators (Figure 14) were installed for the clear water, mud and compressed air columns just above 29 level station. All the compensators were manufactured to allow for vertical shortening of 750mm. The pressure rating for the compensators of the clear water and mud columns are 40 bar and 10 bar for the compressed air column.

- Lateral restraints (Figures 15, 16) were installed below 27 and 28 level stations in order to keep the compartments of the tower aligned with the station landing rails. These restraints were designed to accommodate vertical movement of the tower as well as concentric shaft barrel movement.

- To keep the existing cages in service, the compartment where the HT feeders and other cables are present was left open on the station side, i.e. without any bracing members. This was done because of the lack of clearance between the front of the cage and the shaft cables.

  In order to keep this compartment from opening or closing, it was necessary to install stabilising apron steelwork (Figure 16) around the perimeter of each bunton set.

- The HT feeders and other cables were left at their respective positions against the shaft wall.

Construction of the steel tower

Each of the 38 steel sets to be fitted were assembled, marked and bundled together. This was done on a jig on surface, which simulated their position in the shaft. By doing this many small problems were eliminated.

Construction of the steel tower steelwork commenced with the blasting of the six slots in the shaft wall for the legs of the six diagonal support girders. During this period the shaft was also completely decked off one bunton set below these slot positions. All steelwork associated with the top of the tower at bunton sets 295 and 296 were installed while the shaft was still decked off with the platform.

From bunton set 296 downwards to bunton set 332, the steelwork between bunton sets was just a repetition of the same layouts. (Figure 17)

Between bunton sets 332 and 333 the tower steel and guide take up arrangements were installed.

At 27, 28 and 29 level stations it was also necessary to remove and reinstall the king posts, screens and shaft gates approximately 1 metre away from the shaft.

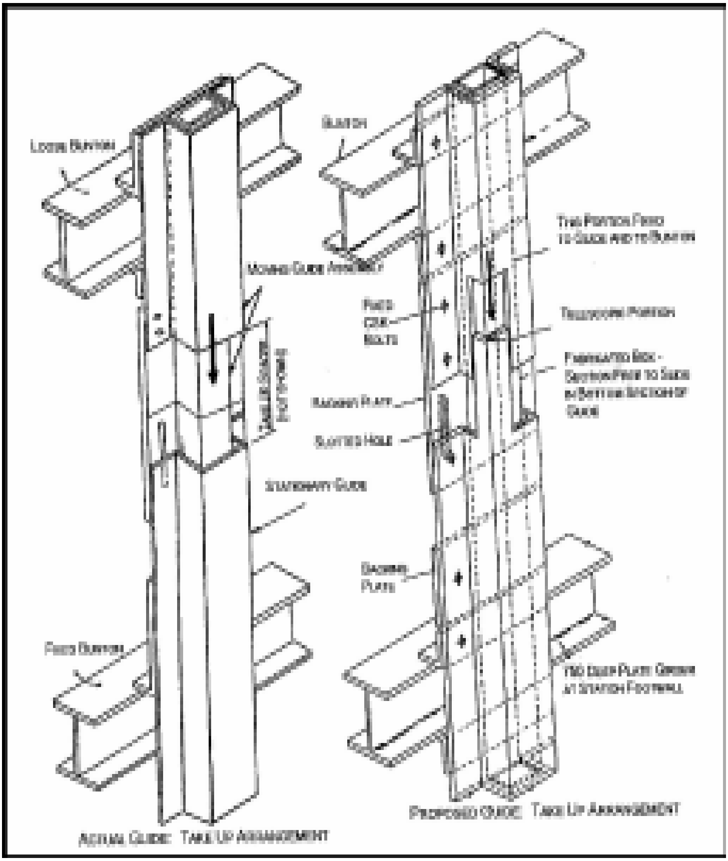

Loose Bunton
Bunton
Moving Guide Assembly
This Portion Fixed
to Guide and to Bunton
Fixed
CSK
Bolts
Telescopic Portion
Fabricated Box-
Section Fixed to Guide
in Bottom Section of
Guide
Backing Plate
Slotted Hole
Stationary Guide
Backing
Plate
Fixed Bunton
750 Deep Plate Girder
at Station Footwall
Proposed Guide: Take Up Arrangement
Actual Guide: Take Up Arrangement

Figure 13

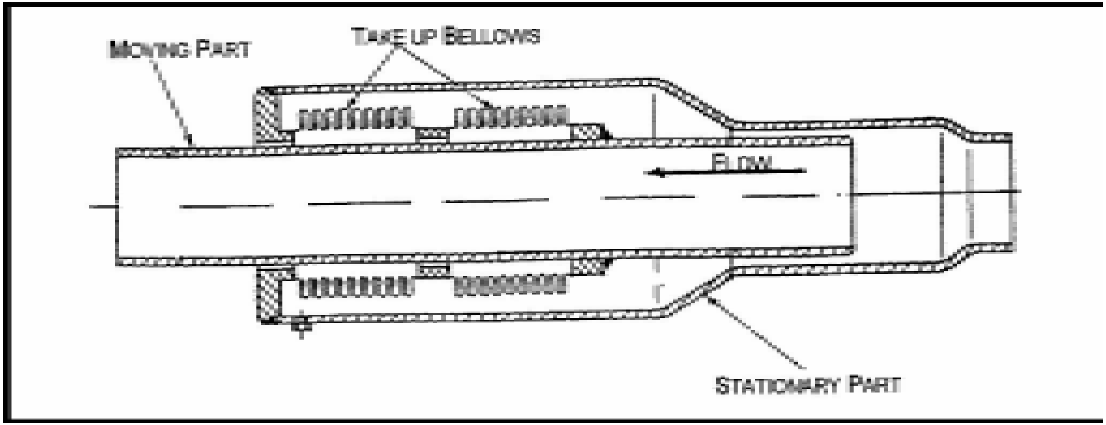


Figure 14

Bellows Type Pipe Compensator

The bunton end stubs were cut and removed from the bottom of the tower upwards in a predetermined pattern to prevent any sudden loading on parts of the upper tower.

Both big inspection cages of the "A" and "B" winders were attached below the new skip bridles of the "A" winder. Both inspection cages were clutched to the working area and as the installation of the new steel progressed, they could only go downwards. This was because these two compartments became smaller with the installation of the additional steelwork.

A smaller inspection cage was attached below the cage of the "B" winder. When parked next to the inspection cages of the "A" winder, a working platform was established. This winder was used to transport pump shift, contract workers and material to and from the working area.

After completion of the steelwork installation process, both big inspection cages below the "A" winder bridles were removed on 31 level.

Due to the predicted ground movement and nature of the tower steelwork design, the use of the "C" winder below 26 level became obsolete and could not be utilised to assist with the installation of the steelwork. (Figure 2)

ACTUAL GROUND MOVEMENT AND TOWER BEHAVIOUR TO DATE

The first distinct concrete lining failure due to horizontal and vertical ground movement was noticed 3 months after mining of the window and inner pillar had started.

The cracks in the concrete lining above and below the reef intersection are generally in a horizontal plane around the shaft. The western half of the shaft barrel is suffering most of the damage and deformation.

At various positions above and below the reef intersection, "bags" of loose chunks of concrete are accumulating behind the welded

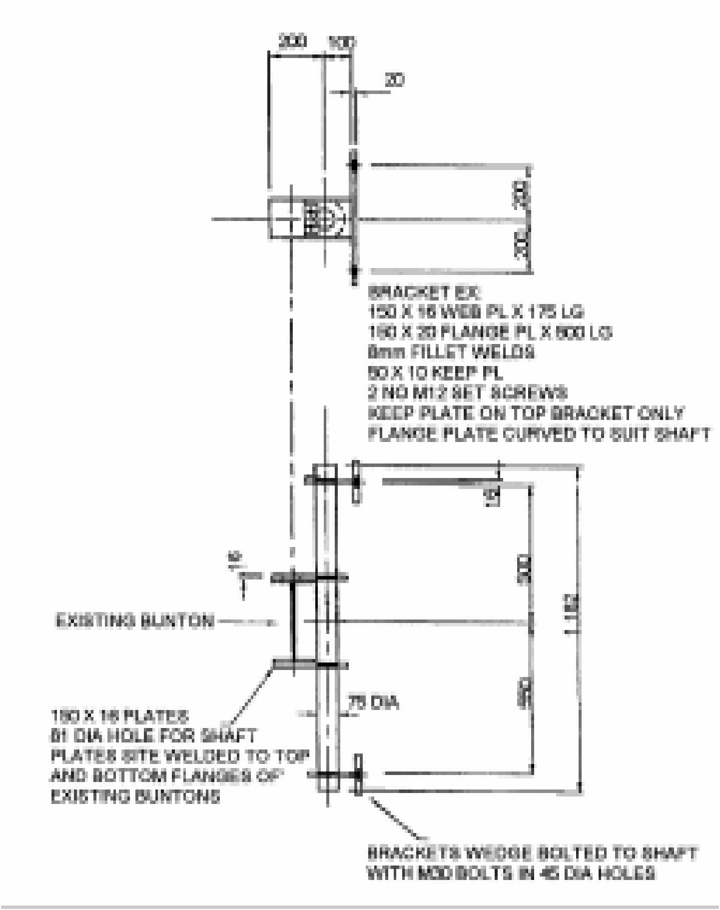


Figure 15

Lateral Restraint Detail

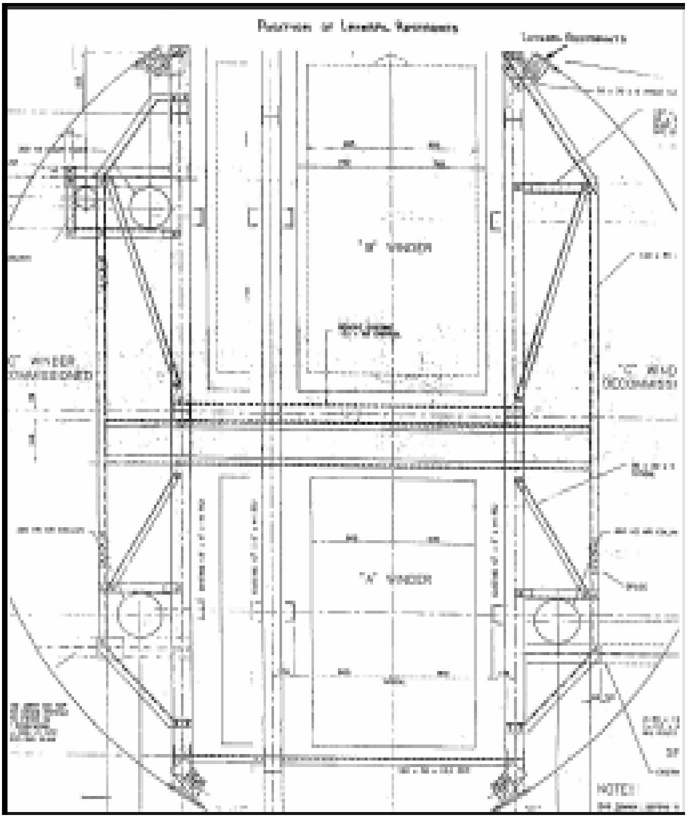


Figure 16

Position of Lateral Restraints

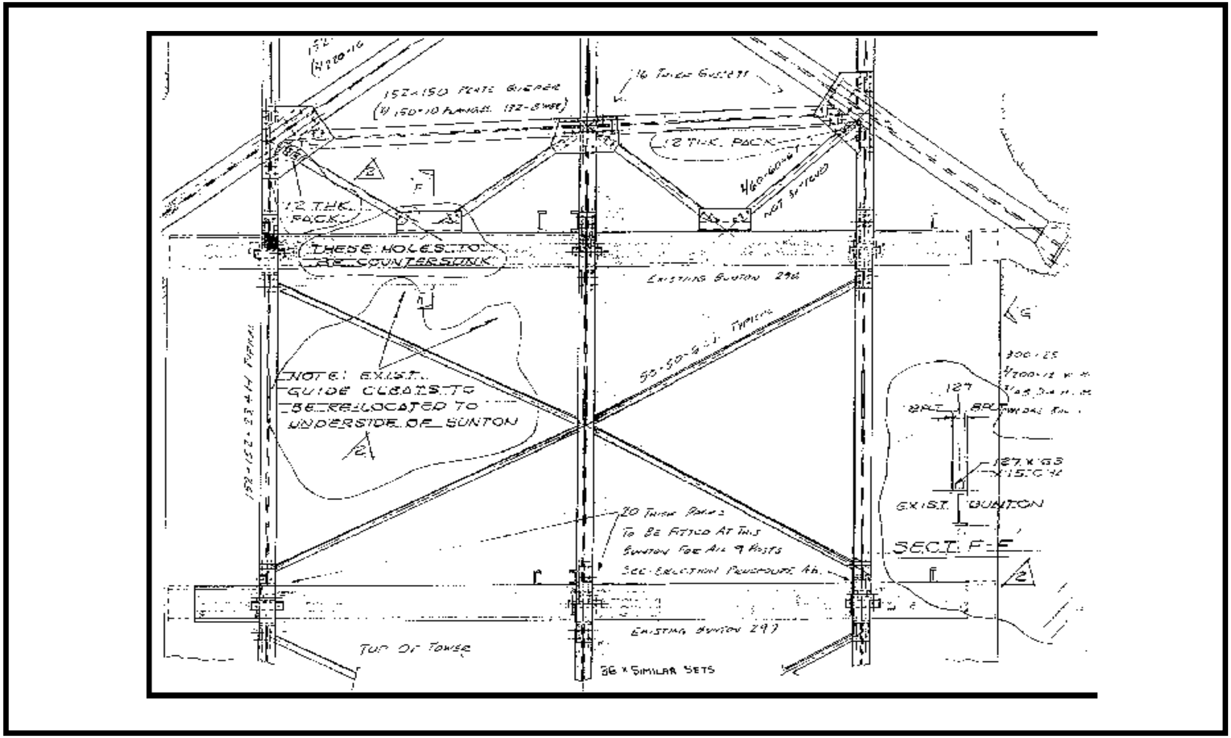

152
(4/220×16)
152×150 Plate Girder
(4/150×10 Flanges. 132-8 web)
16 Thick Gussets
12 THK. PACK
12 THK. PACK
4/60-60-6
Not Stitched
2
F
THESE HOLES TO BE COUNTERSUNK
Existing Bunton 296
G
50-50-6 Typical
NOTE: EXIST. GUIDE CLEATS TO BE RELOCATED TO UNDERSIDE OF BUNTON
2
152×152×23.4 H Typical
300×25
4/200×12
127
8PL
8PL
127 × 63
× 15 C 4
EXIST. BUNTON
SECT. F-F
2
20 Thick Packs
To Be Fitted At This
Bunton For All 9 Posts
See Erection Procedure
Existing Bunton 297
Top Of Tower
36 × Similar Sets

Figure 17

mesh lining support.

At some places large pieces of cracked concrete lining and loose rocks are pushing out towards the tower.

The shaft cables, which were left against the shaft wall, are being pushed out towards the travelling path of the northwest compartment cage of the "B" winder.

The area of most concern is just below 28 level station where the western half of the shaft barrel is showing signs of folding in on itself. The effect of this is that the barrel is starting to strangle the tower. (Figure 18)

Some of the washers of the rope anchors and rock studs, which form part of the barrel support, are also starting to push against the tower.

Some guide to bunton bolt connections just above the tower at bunton set 295 failed due to vertical strain.

The centre buntons at bunton sets 291 and 292 bent due to horizontally induced strain causing all the compartments of the "A" and "B" winders to close by either 50mm across the guides or open up by 50mm across the guides.

The western side and centre buntons just below the tower at bunton sets 334, 335 and 336 were also bent due to horizontal ground movement. All these buntons have been cut and spliced.

To date - end October 97 - the 640mm guide take up gap facility on 29 level has been reduced to 540mm indicating that the tower has closed 100mm relative to the tower top and bottom on 29 level station.

A seismic event of magnitude 3,3 occurred on 11 October 97 within the shaft pillar. The tower and shaft support stood up well to contain the effects of the damage to the concrete lining.

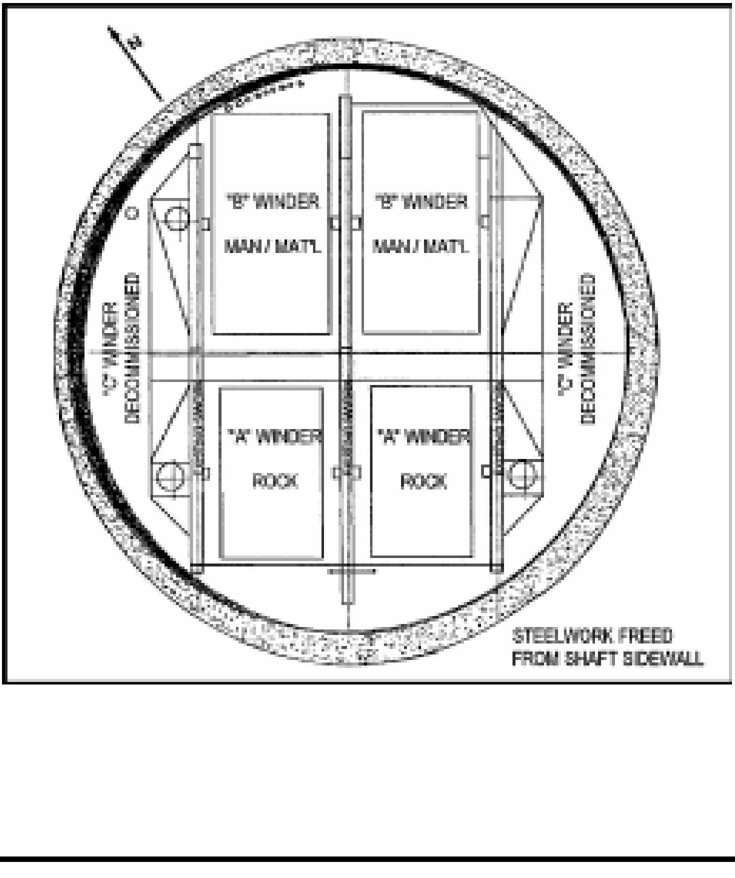


Figure 18

No 2A Shaft - New Permanent Shaft Section Shaft Barrel Deformation (Immediate Area below 28L)

LESSONS LEARNT

- The positions of buntons and shaft columns in the area of the shaft that must be spanned by a tower or similar construction must be surveyed, to exactly determine their relative positions to each other;
- Bigger tolerances to be allowed when designing new steel that must be fitted to old shaft steelwork;
- The exact position of the reef intersection within the shaft must be determined before any steelwork design can be made;
- The position of the diagonal girders forming the top of the tower must be carefully selected on the site. The ground condition and shaft concrete lining properties must be taken into account;
- The position of the bottom end of the tower must be carefully selected on site to avoid station areas and fouling of main pipe support girders;
- The position of the shaft column compensators must be selected on site to ensure that the downward movement of the tower does not foul the static part of the compensators. It is important that all pipe clamps are in position to hold the columns steady in their positions;
- The position of additional column bearers, if necessary, must be selected on site;
- If the reef intersection is not situated near a level, means to remove blasting debris efficiently from the temporary platform covering the shaft must be thoroughly planned;
- Future slinging requirements to working stations within the tower to be determined;
- The position of holes in the foot plates of new brackets which must be installed against the shaft wall must be such that the existing steelwork does not interfere with the drilling of such holes in the shaft wall;
- The bolts, nuts and washers schedule must be drawn up properly;
- The shaft wall support pattern and the position of the rope anchors, rock studs and cone bolts must be such as to prevent them from fouling the tower and the edges of the conveyances when they are pushed out into the shaft due to ground movement;
- The length of the tower must be carefully planned;

- All additional steelwork, bolts and nuts necessary to construct the tower must be galvanised;
- HT feeders and other cables should be removed from the shaft wall in the tower area and be attached to the tower steelwork;
- The use of lateral restraints must be carefully considered. The lateral restraints, which were installed just below 28 level, started to strangle the tower causing the northwest compartment to become smaller. It also caused some braces and dividers to bend slightly;
- The proposed guide take up arrangement was too flimsy in design and was changed to a more rigid spacer take up arrangement. The drawback with this take up spacer is that it must be cut frequently to allow for a gap of at least 10 - 20mm at all times. The use of a stiff but a crushable spacer to cater for sudden large vertical movement should be investigated.

CONCLUSION

Understanding of the Rock Mechanics modellings and the design criteria for the shaft steelwork modifications is vital.

The Engineer who is in charge of a project like this, should be relieved of his normal duties to enable him to devote all his energy and time to the project.