CHAPTER 4 RESULTS AND EVALUATION OF SHAFT TESTS

4.1 RESULTS OF SHAFT TESTS

4.1.1 Tests on No. 14 shaft

4.1.1.1 Shaft details and installation of equipment

The tests for No. 14 shaft of Impala Platinum were conducted from 15 to 22 July 2010. The required instrumentation was installed in the following positions in the shaft:

1. Surface (environmental logger was installed in the winder house immediately adjacent to the shaft)
2. 20 level – Environmental logger (895 m BC)
3. 21 level – Environmental logger (950 m BC)
4. 22 level – Environmental logger (1 005 m BC)
5. 23 level – Environmental logger (1 060 m BC)
6. Rock winder (6.3 m diam.) – Rotary encoder – PLC1 (log channels 3 and 4) (double drum winder) (measured conveyance speed – 15.2 m/s)
7. Man winder (6.9 m diam.) – Rotary encoder – PLC2 (log channels 1 and 2) (double drum winder) (measured conveyance speed – 14.1 m/s)
8. Service winder (4.3 m diam.) – Rotary encoder – PLC2 (log channels 3 and 4) (single drum winder) (measured conveyance speed – 13.2 m/s)
9. Free Air Velocity of ventilation air in shaft – measured as 9.4 m/s

It is not necessary to have the data collected over such an extended period but, as discussed above, shaft access was only available during the weekly shaft inspections.

This is a 7.4 m diameter shaft which has been equipped with the airflow buntons. The conditions of the shaft were found to be generally good with little or no interference in the shaft as a result of additional fittings and extraneous installations. This shaft was also concrete-lined.

The ventilation air is introduced into the shaft via a sub-bank air duct. It was not possible to place the environmental data loggers directly in the shaft. These were therefore placed immediately adjacent to the shaft on the levels indicated above.

The dimensions of the various cages, skips and fittings in the shaft can be found on a detailed shaft cross-section in Appendix D.

It should be noted at this point that it was not possible to place a rotary encoder on each drum of the double drum winders. This was because no external shaft was available on the motor side of the winder. However, the standard policy at Impala limits clutching of a winder (i.e. the moving of one drum and its associated conveyance) to the shift-change period only. These times are easily discernible from the data and have not been used in this analysis. A schematic of the shaft cross-section is provided in Figure 4-1.

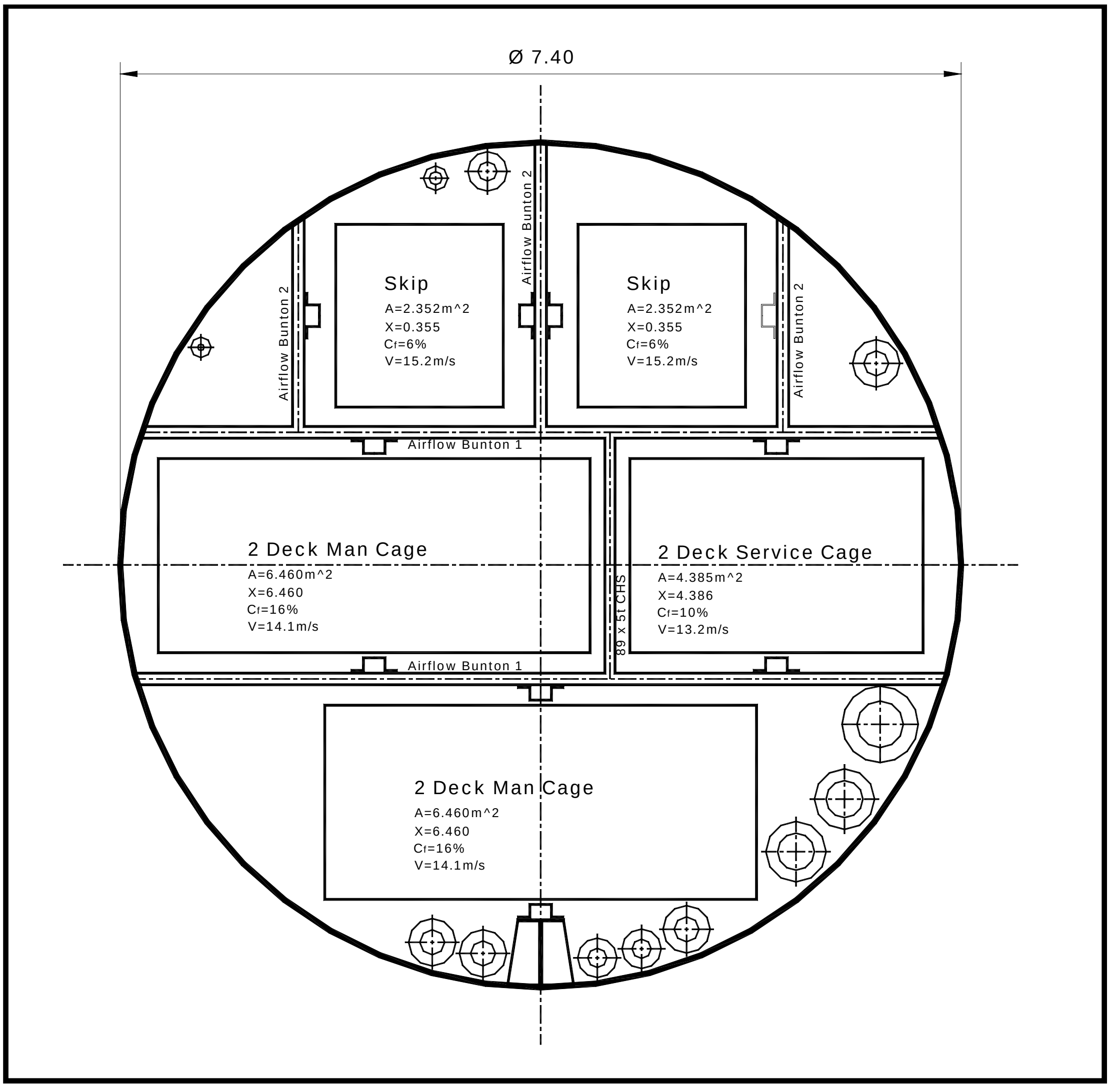

Figure 4-1: Cross-section of No. 14 shaft

4.1.1.2 Environmental loggers

All the environmental loggers were time-stamped from a common computer before they were installed. These data were then sorted to display the results from each of the days on which testing took place.

The test results from the first day were discarded as a result of inconsistencies in the readings from the surface data logger. This logger had been moved by the mine personnel. It was repositioned appropriately and the remainder of the results were found to be consistent and could be used for the rest of the test.

It should be noted that there were times in the shaft when the pressure readings varied significantly. These times are consistent with the times that the ventilation fans were not operating at full flow. These periods were also avoided in the evaluations given below.

4.1.1.3 Rotary encoders

The PLCs associated with these encoders were time-corrected to the same computer used for the environmental loggers. The results of these encoders were corrected to show the conveyances in appropriate positions in the shaft. This was done primarily by using the drum diameter and matching the conveyance position on each of the levels to the movement of the drum.

The PLCs measured the position of the conveyance every second, whereas the environmental loggers measured every 10 seconds. The winder data were therefore also corrected to start and stop at equivalent times to the environment loggers.

The PLCs attached to these encoders were placed in the drivers’ cabins where appropriate. These were not tampered with for the duration of the experiment.

4.1.1.4 Summary of data from tests on No. 14 shaft

The friction losses in the shaft were measured and calculated in accordance with the theory discussed in previous chapter of this thesis. The analysis was completed using the data between surface and 20 level as these data showed the least amount of scatter. A summary of these results is given in Table 4-1 to Table 4-4.

Table 4-1: No. 14 shaft test results – Data

Item	Value	Symbol	Units	Description
1	0.076	f_{BTotal}	-	Total bunton Chezy-Darcy friction factor(
2	0.022	f_{Shaft}	-	Shaft asperities Chezy-Darcy friction factor
3	0.098	$f_{Total\ Shaft}$	-	Total shaft Chezy-Darcy friction factor
4	1.099	$X_{Skip\ 1\ Corr}$	-	Skip shock loss correction factor
5	0.434	$X_{Cage\ 1\ Corr}$		Man cage shock loss correction factor
6	0.466	$X_{Service\ Cage\ Corr}$		Service cage shock loss correction factor

Table 4-2: No. 14 shaft test results – Service cage

	$P_{loss\ (measured)}$ (surface to 20 level)	$P_{loss\ (calculated)}$ (surface to 20 level)	Units	Description
1	891.1	645.0	Pa	Below 20 level in shaft
2	1.77	1.28	Pa/m	Below 20 level in shaft
3	899.5	644.7	Pa	Above 20 level in shaft
4	1.78	1.28	Pa/m	Above 20 level in shaft
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

Table 4-3: No. 14 shaft test results – Rock skip

	$P_{loss\ (measured)}$ (surface to 20 level)	$P_{loss\ (calculated)}$ (surface to 20 level)	Units	Description
1	897.5	630.1	Pa	No conveyance moving
2	1.78	1.25	Pa/m	No conveyance moving
3	893.5	630.1	Pa	Rock skip moving
4	1.77	1.25	Pa/m	Rock skip moving
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

Table 4-4: No. 14 shaft test results – Man cage

	$P_{loss\ (measured)}$ (surface to 20 level)	$P_{loss\ (calculated)}$ (surface to 20 level)	Units	Description
1	930.0	636.8	Pa	No conveyance moving
2	1.85	1.26	Pa/m	No conveyance moving
3	947.9	635.4	Pa	Man cage moving
4	1.88	1.26	Pa/m	Man cage moving
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

4.1.2 Tests on No. 11 shaft

4.1.2.1 Shaft details and installation of equipment

The tests for No. 11 shaft of Impala Platinum were conducted from 13 January 2011 to 21 July 2011. The required instrumentation was installed in the following positions in the shaft:

1 Surface (environmental logger was installed in the winder house immediately adjacent to the shaft)

2 14 level – Environmental logger (619m BC)

3 15 level – Environmental logger (674m BC)

4 18 level – Environmental logger (839m BC)

5 19 level – Environmental logger (894m BC)

6 20 level – Environmental logger (949m BC)

7 Rock winder (5.5 m diam.) – Rotary encoder – PLC1 (log channels 1 and 2) (double drum winder) (measured conveyance speed – 14.3 m/s)

8 Man winder (4.5 m diam.) – Rotary encoder – PLC2 (log channels 1 and 2) (Blair winder) (measured conveyance speed – 15.9 m/s)

9 Service winder – This shaft has no service winder

10 Free Air Velocity of ventilation air in shaft – measured as 10.0 m/s

It is not necessary to have the data collected over such an extended period but, as discussed above, shaft access was only available during the weekly shaft inspections.

This is a 6.2 m diameter shaft which has been equipped with the airflow buntons. The condition of the shaft was found to be generally good with little or no interference in the shaft as a result of additional fittings. This shaft was also concrete-lined.

The ventilation air is introduced into the shaft via a sub-bank air duct. It was not possible to place the environmental data loggers directly in the shaft. These were therefore placed immediately adjacent to the shaft on the levels indicated above. The dimensions of the various cages, skips and fittings in the shaft can be found on a detailed shaft cross-section in Appendix E.

It should be noted at this point that it was not possible to place a rotary encoder on each drum of the double drum winders. This was because no external shaft was available on the motor side of the winder. However, the standard policy on Impala limits clutching of a winder (i.e. the moving of one drum and its associated conveyance) to the shift-change period only. These times are easily discernible from the data and have not been used in this analysis. A schematic of the shaft cross-section is provided in Figure 4-2.

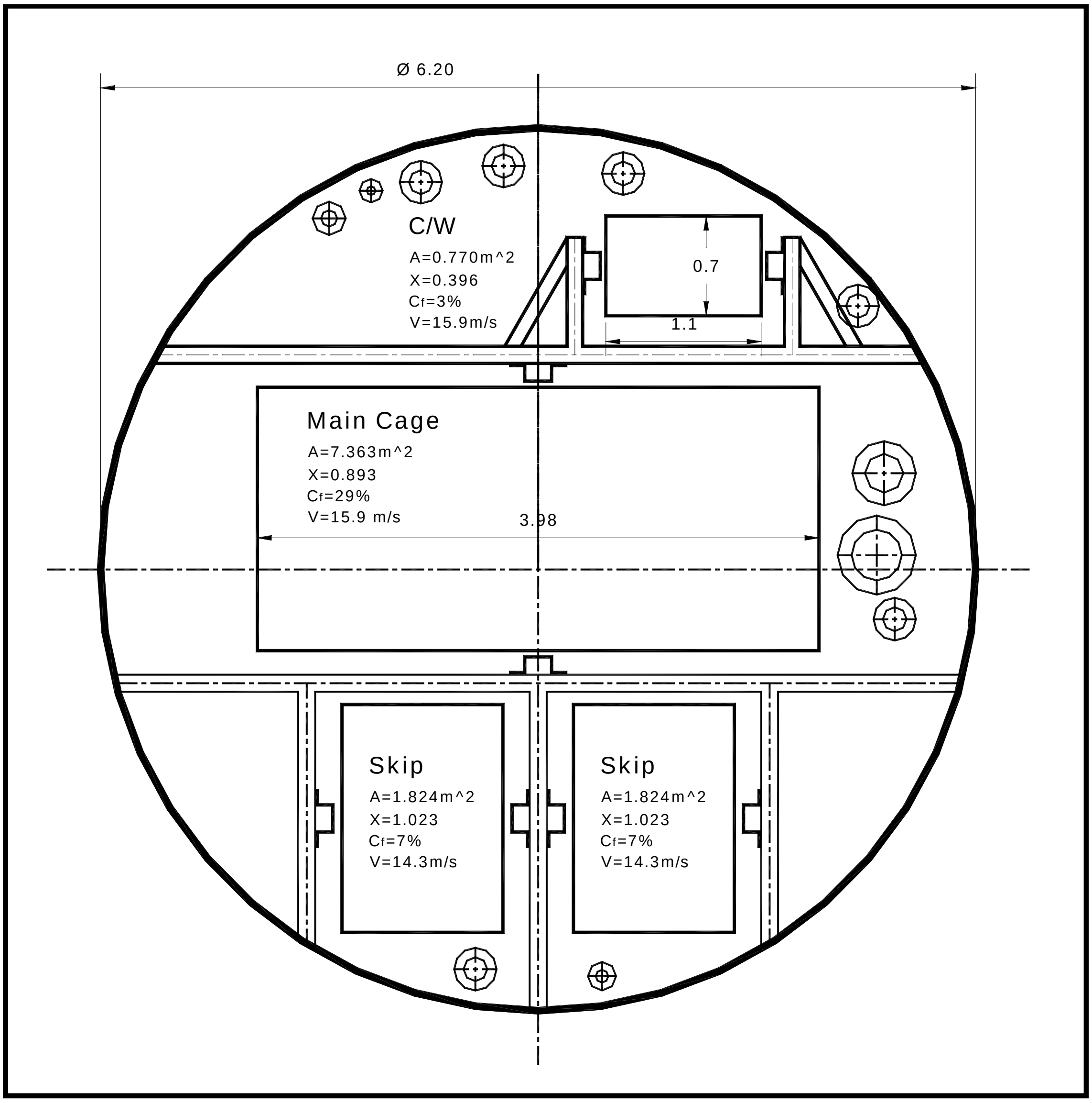

Figure 4-2: Cross-section of No. 11 shaft

4.1.2.2 Environmental loggers

All the environmental loggers were time-stamped from a common computer before they were installed. These data were then sorted to display the results from each of the days on which testing took place.

It should be noted that there were times in the shaft when the pressure readings varied significantly. These times are consistent with the times that the ventilation fans were not operating at full flow. These periods were also avoided in the evaluations given below.

4.1.2.3 Rotary encoder

The PLCs associated with these encoders were time-corrected to the same computer used for the environmental loggers. The results of these encoders were corrected to show the conveyances in appropriate positions in the shaft. This was done primarily by using the drum diameter and matching the conveyance position on each of the levels to the movement of the drum.

The initial two days of test results associated with the man winder encoder were discarded. This was a result of the attachment to the winder coming adrift. The attachment was reconnected and the rest of the tests showed good results which were used.

The PLCs measured the position of the conveyance every second, whereas the environmental loggers measured every 10 seconds. The winder data were therefore also corrected to start and stop at equivalent times to the environment loggers.

The PLCs attached to these encoders were placed in the drivers' cabins where appropriate. These were not tampered with for the duration of the experiment.

4.1.2.4 Summary of data from tests on No. 11 shaft

The friction losses in the shaft were measured and calculated in accordance with the theory discussed in the previous chapter of this thesis. The analysis was completed using the data between surface and 14 level as these data showed the least amount of scatter. A summary of these results is given in Table 4-5 and Table 4-6.

Table 4-5: No. 11 shaft test results – Data

Item	Value	Symbol	Units	Description
1	0.079	f_{BTotal}	-	Total bunton Chezy-Darcy friction factor
2	0.023	f_{Shaft}	-	Shaft asperities Chezy-Darcy friction factor
3	0.105	$f_{Total\ Shaft}$	-	Total shaft Chezy-Darcy friction factor
4	1.023	$X_{Skip\ 1\ Corr}$	-	Skip shock loss correction factor
5	0.881	$X_{Cage\ 1\ Corr}$	-	Man cage shock loss correction factor

Table 4-6: No. 11 shaft test results

	$P_{loss\ (measured)}$ (surface to 14 level)	$P_{loss\ (calculated)}$ (surface to 14 level)	Units	Description
1	721.3	585.7	Pa	No conveyances moving
2	1.16	0.95	Pa/m	No conveyances moving
3	756.3	584.3	Pa	Rock winder in operation
4	1.22	0.94	Pa/m	Rock winder in operation
5	796.3	587.7	Pa	Man winder in operation
6	1.29	0.95	Pa/m	Man winder in operation
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

4.1.3 Tests on No. 1 shaft

4.1.3.1 Shaft details and installation of equipment

The tests for No. 1 shaft of Impala Platinum were conducted from 12 to 16 March 2011. The required instrumentation was installed in the following positions in the shaft:

1 Surface (environmental logger was installed in the winder house immediately adjacent to the shaft)

2 7 level – Environmental logger (503m BC)

3 8 level – Environmental logger (549m BC)

4 9 level – Environmental logger (595m BC)

5 10 level – Environmental logger (641m BC)

6 Rock winder (4.9 m diam.) – Rotary encoder – PLC2 (log channels 1 and 2) (double drum winder) (measured conveyance speed – 14.5 m/s)

7 Man winder (4.35 m diam.) – Rotary encoder – PLC2 (log channels 3 and 4) (double drum winder) (measured conveyance speed – 12.2 m/s)

8 Service winder (3.5 m diam.) – Rotary encoder – PLC2 (log channels 3 and 4) (single drum winder) (measured conveyance speed – 10.0 m/s)

9 Free Air Velocity of ventilation air in shaft – measured as 7.7 m/s

It is not necessary to have the data collected over such an extended period but, as discussed above, shaft access was only available during the weekly shaft inspections.

This is a 7.7 m diameter shaft which has been equipped with the angled buntons. The condition of the shaft was found to be generally good with little or no interference in the shaft as a result of additional fittings. This shaft was also concrete-lined.

The ventilation air is introduced into the shaft via a sub-bank air duct. It was not possible to place the environmental data loggers directly in the shaft. These were therefore placed immediately adjacent to the shaft on the levels indicated above.

The dimensions of the various cages, skips and fittings in the shaft can be found on a detailed shaft cross-section in Appendix F.

It should be noted that it was not possible to place a rotary encoder on each drum of the double drum winders. This was because no external shaft was available on the motor side of the winder. However, the standard policy on Impala limits clutching of a winder (i.e. the moving of one drum and its associated conveyance) to the shift-change period only. These times are easily discernible from the data and have not been used in this analysis. A schematic of the shaft cross-section is provided in Figure 4-3.

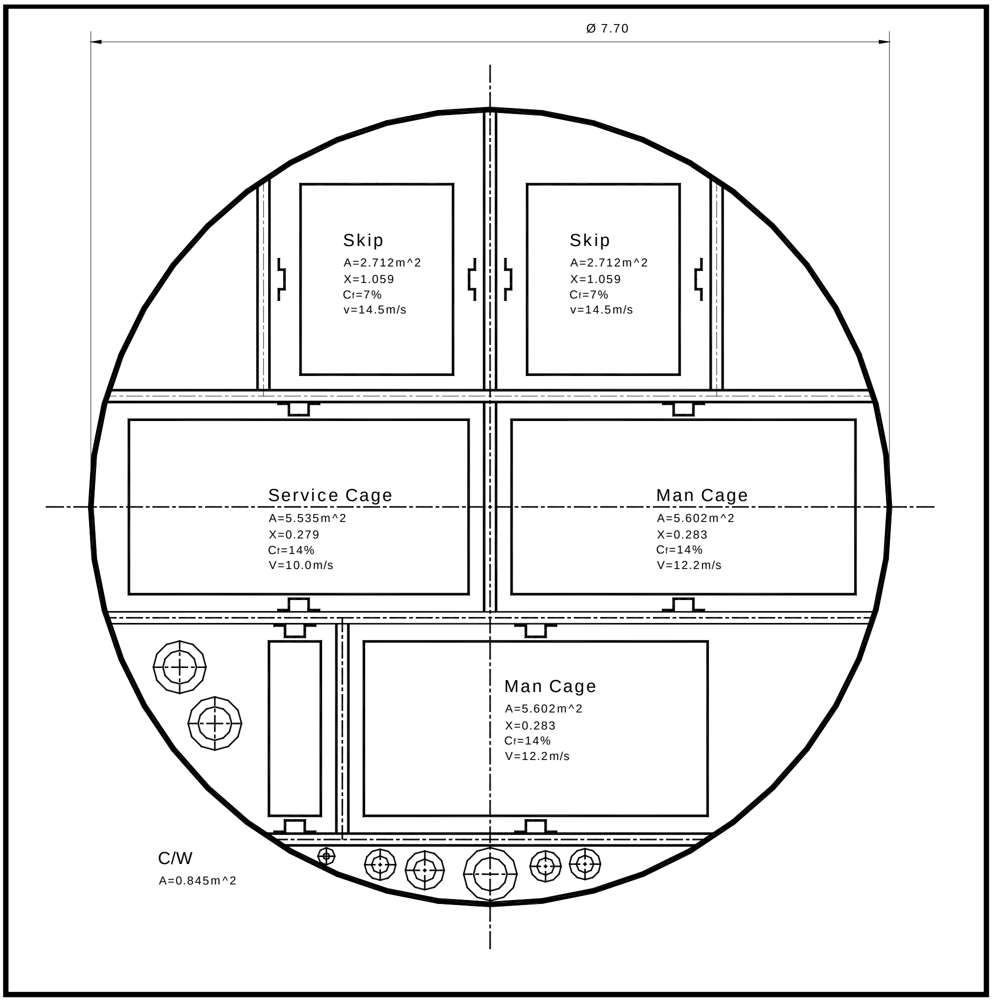

Figure 4-3: Cross-section of No. 1 shaft

4.1.3.2 Environmental loggers

All the environmental loggers were time-stamped from a common computer before they were installed. These data was then sorted to display the results from each of the days on which testing took place.

It should be noted that there were times in the shaft when the pressure readings varied significantly. These times are consistent with the times that the ventilation fans were not operating at full flow. These periods were also avoided in the evaluations given below.

4.1.3.3 Rotary encoder

The PLCs associated with these encoders were time-corrected to the same computer used for the environmental loggers. The results of these encoders were corrected to show the conveyances in appropriate positions in the shaft. This was done primarily by using the drum diameter and matching the conveyance position on each of the levels to the movement of the drum.

When the instrumentation was put in place, the service winder had been tripped. The winder only showed movement on 13 March 2011. All the data collation therefore started at this point. In addition, there was a power interruption to the PLC attached to the man and rock winder on 14 March 2011 at approximately 11:00. This left a small but sufficient window in which to evaluate the necessary data from 00:00 on 13 March to 11:00 on 14 March 2011.

The PLCs measured that position of the conveyance every second, whereas the environmental loggers measured every 10 seconds. The winder data were therefore also corrected to start and stop at equivalent times to the environment loggers.

The PLCs attached to these encoders were placed in the drivers' cabins where appropriate. These were not tampered with for the duration of the experiment.

4.1.3.4 Summary of data from tests on No. 1 shaft

The friction losses in the shaft were measured and calculated in accordance with the theory discussed in the previous chapter of this thesis. The analysis was completed using the data between surface and 14 level as these data showed the least amount of scatter. A summary of these results is given in Table 4-7 and Table 4-8.

Table 4-7: No. 1 shaft test results – Data

Item	Value	Symbol	Units	Description
1	0.102	f_{BTotal}	-	Total bunton Chezy-Darcy friction factor
2	0.021	f_{Shaft}	-	Shaft asperities Chezy-Darcy friction factor
3	0.123	$f_{Total\ Shaft}$	-	Total shaft Chezy-Darcy friction factor
4	1.059	$X_{Skip\ 1\ Corr}$	-	Skip shock loss correction factor
5	0.281	$X_{Cage\ 1\ Corr}$	-	Man cage shock loss correction factor
6	0.278	$X_{Service\ Cage\ Corr}$	-	Service cage shock loss correction factor

Table 4-8: No. 1 shaft test results

	$P_{loss\ (measured)}$ (surface to 14 level)	$P_{loss\ (calculated)}$ (surface to 14 level)	Units	Description
1	248.2	275.1	Pa	No conveyances moving
2	0.49	0.55	Pa/m	No conveyances moving
3	216.8	279.2	Pa	Service winder in operation
4	0.43	0.55	Pa/m	Service winder in operation
5	231.4	274.1	Pa	Rock winder in operation
6	0.46	0.54	Pa/m	Rock winder in operation
7	242.0	274.7	Pa	Man winder in operation
8	0.48	0.54	Pa/m	Man winder in operation

Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.

4.1.4 Tests on No. 11C shaft

4.1.4.1 Shaft details and installation of equipment

The tests for No. 11C shaft of Impala Platinum were conducted from 9 April 2011 to the 12 April 2011. The requisite instrumentation was installed in the following positions in the shaft:

1. Surface (environmental logger was installed in the winder house immediately adjacent to the shaft).
2. 24 level – Environmental logger (1 160 m BC)
3. 25 level – Environmental logger (1 215 m BC)
4. 26 level – Environmental logger (1 257 m BC)
5. 27 level – Environmental logger (1 308 m BC)
6. 28 level – Environmental logger (1 382 m BC)
7. Man winder (4.9 m diam.) – Rotary encoder – PLC1 (log channels 1 and 2) (double drum winder) (measured conveyance speed – 12.2 m/s)
8. Free Air Velocity of ventilation air in shaft – measured at 9.0 m/s

It is not necessary to have the data collected over such an extended period but, as discussed above, shaft access was only available during the weekly shaft inspections.

This is a 5.6 m diameter shaft which has been equipped with the airflow buntons. The condition of the shaft was found to be generally good with little or no interference in the shaft as a result of additional fittings. It should be noted that below 24 level the ventilation is split. This is reflected by the inconsistency of the readings below this level. Therefore the readings used in this evaluation will be those above this level. This shaft was also concrete-lined.

The ventilation air is introduced into the shaft via a sub-bank air duct. It was not possible to place the environmental data loggers directly in the shaft. They were therefore placed immediately adjacent to the shaft on the levels indicated above.

The dimensions of the various cages, skips and fittings in the shaft can be found on a detailed shaft cross-section in Appendix G.

It should be noted that it was not possible to place a rotary encoder on each drum of the double drum winders. This was because no external shaft was available on the motor side of the winder. This shaft, however, uses only a cage and counterweight and therefore the clutching concerns were not a problem. This shaft does not have a loading station as yet as it is still in the development phase. All the rock is hoisted from the shaft in rail hoppers. A schematic of the shaft cross-section is provided in Figure 4-4.

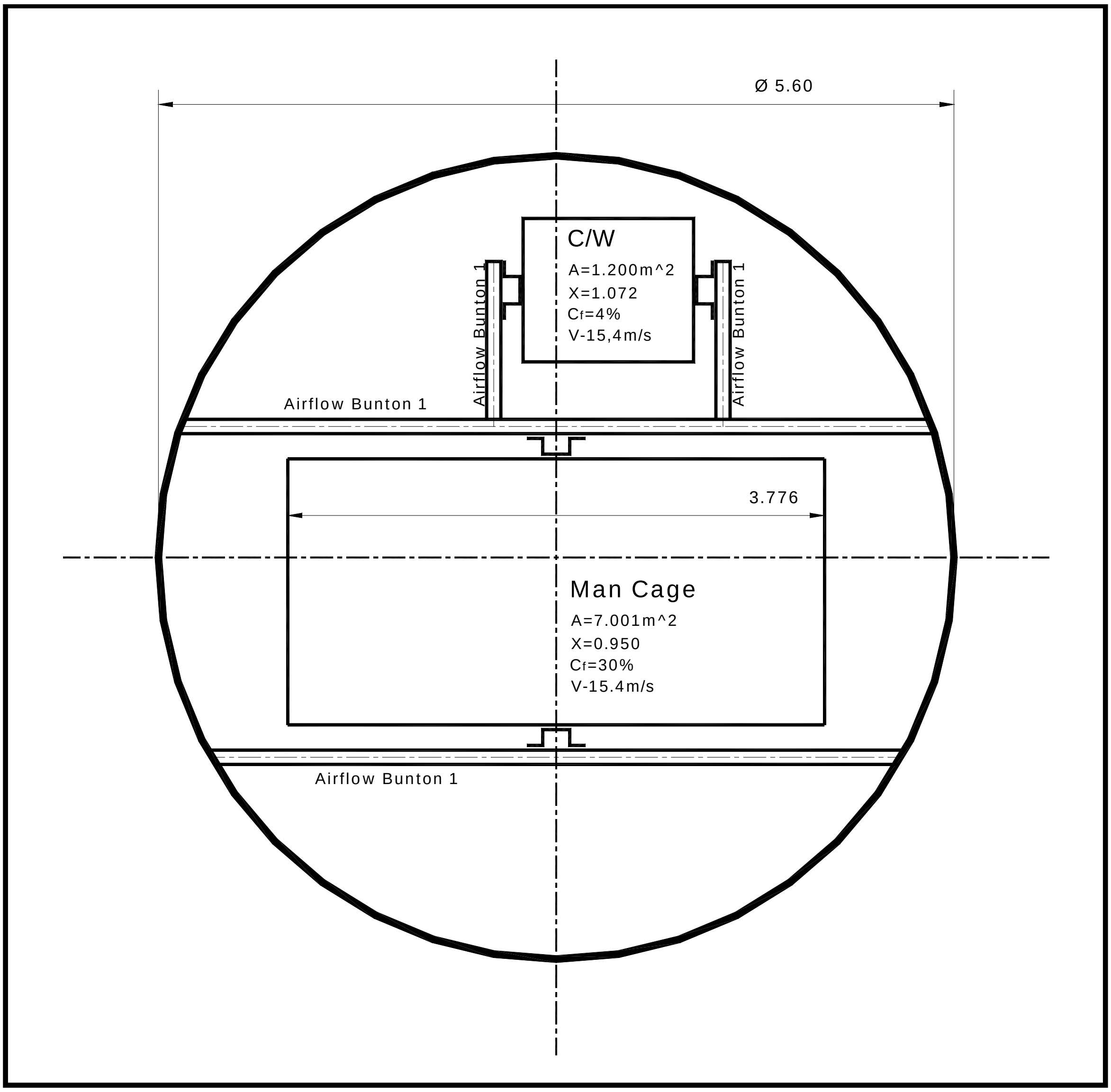

Figure 4-4: Cross-section of No. 11C shaft

4.1.4.2 Environmental loggers

All the environmental loggers were time-stamped from a common computer before they were installed. These data were then sorted to display the results from each of the days on which testing was done.

It should be noted that there were times in the shaft when the pressure readings varied significantly. These times are consistent with the times that the ventilation fans were not operating at full flow. These periods were also avoided in the evaluations given below.

4.1.4.3 Rotary encoder

The PLCs associated with these encoders were time-corrected to the same computer used for the environmental loggers. The results from these encoders were corrected to show the conveyances in appropriate positions in the shaft. This was done primarily by using the drum diameter and matching the conveyance position on each of the levels to the movement of the drum.

The PLCs measured that position of the conveyance every second, whereas the environmental loggers measured every 10 seconds. The winder data were therefore also corrected to start and stop at equivalent times to the environment loggers.

The PLCs attached to these encoders were placed in the drivers' cabins where appropriate. These were not tampered with for the duration of the experiment.

4.1.4.4 Summary of data from tests on No. 11c shaft

The friction losses in the shaft were measured and calculated in accordance with the theory discussed in the previous chapter of this thesis. The analysis was completed using the data between surface and 14 level as these data showed the least amount of scatter. A summary of these results is given in Table 4-9 and Table 4-10.

Table 4-9: No. 11C shaft test results – Data

Item	Value	Symbol	Units	Description
1	0.047	f_{BTotal}	-	Total bunton Chezy-Darcy friction factor
2	0.023	f_{Shaft}	-	Shaft asperities Chezy-Darcy friction factor
3	0.070	$f_{Total\ Shaft}$	-	Total shaft Chezy-Darcy friction factor
5	0.941	$X_{Cage\ 1\ Corr}$	-	Cage shock loss correction factor

Table 4-10: No. 11C shaft test results

	$P_{loss\ (measured)}$ (surface to 14 level)	$P_{loss\ (calculated)}$ (surface to 14 level)	Units	Description
1	752.4	678.4	Pa	No conveyances moving
2	0.65	0.58	Pa/m	No conveyances moving
3	856.1	682.9	Pa	Man winder in operation
4	0.74	0.59	Pa/m	Man winder in operation
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

4.1.5 Tests on No. 12N shaft

4.1.5.1 Shaft details and installation of equipment

The tests for No. 12N shaft of Impala Platinum were conducted from 17 to 21 June 2011. The required instrumentation was installed in the following positions in the shaft:

1 Surface (environmental logger was installed in the winder house immediately adjacent to the shaft)

2 Loading station – Environmental logger (880 m BC) (In this test two data loggers were placed on this level. This redundancy proved fortunate as one of these failed during the test period.)

3 Rock winder (4.9 m diam.) – Rotary encoder – PLC2 (log channels 3 and 4) (double drum winder) (measured conveyance speed – 16.2 m/s)

4 Free Air Velocity of ventilation air in shaft – measured at 11.0 m/s

It is not necessary to have the data collected over such an extended period but, as discussed above, shaft access was only available during the weekly shaft inspections.

This is a 8.5m diameter shaft which has been equipped with rope guides sufficient for two skips. This shaft also has a brattice wall installed, which results in an irregularly shaped shaft necessitating the use of the hydraulic diameter in the resolution of the theoretical calculation.

The condition of the shaft was found to be generally good with little or no interference in the shaft as a result of additional fittings. This shaft was also concrete-lined.

The ventilation air is introduced into the shaft via a sub-bank air duct. It was not possible to place the environmental data loggers directly in the shaft. These were therefore placed immediately adjacent to the shaft on the levels indicated above.

The dimensions of the various cages, skips and fittings in the shaft can be found on a detailed shaft cross-section in Appendix H.

It should be noted that it was not possible to place a rotary encoder on each drum of the double drum winders. This is because no external shaft was available on the motor side of the winder. This shaft, however, only sent skips to one level and therefore the clutching concern for determining the placement of the conveyances in the shaft is not valid. A schematic of the shaft cross-section is provided in Figure 4-5.

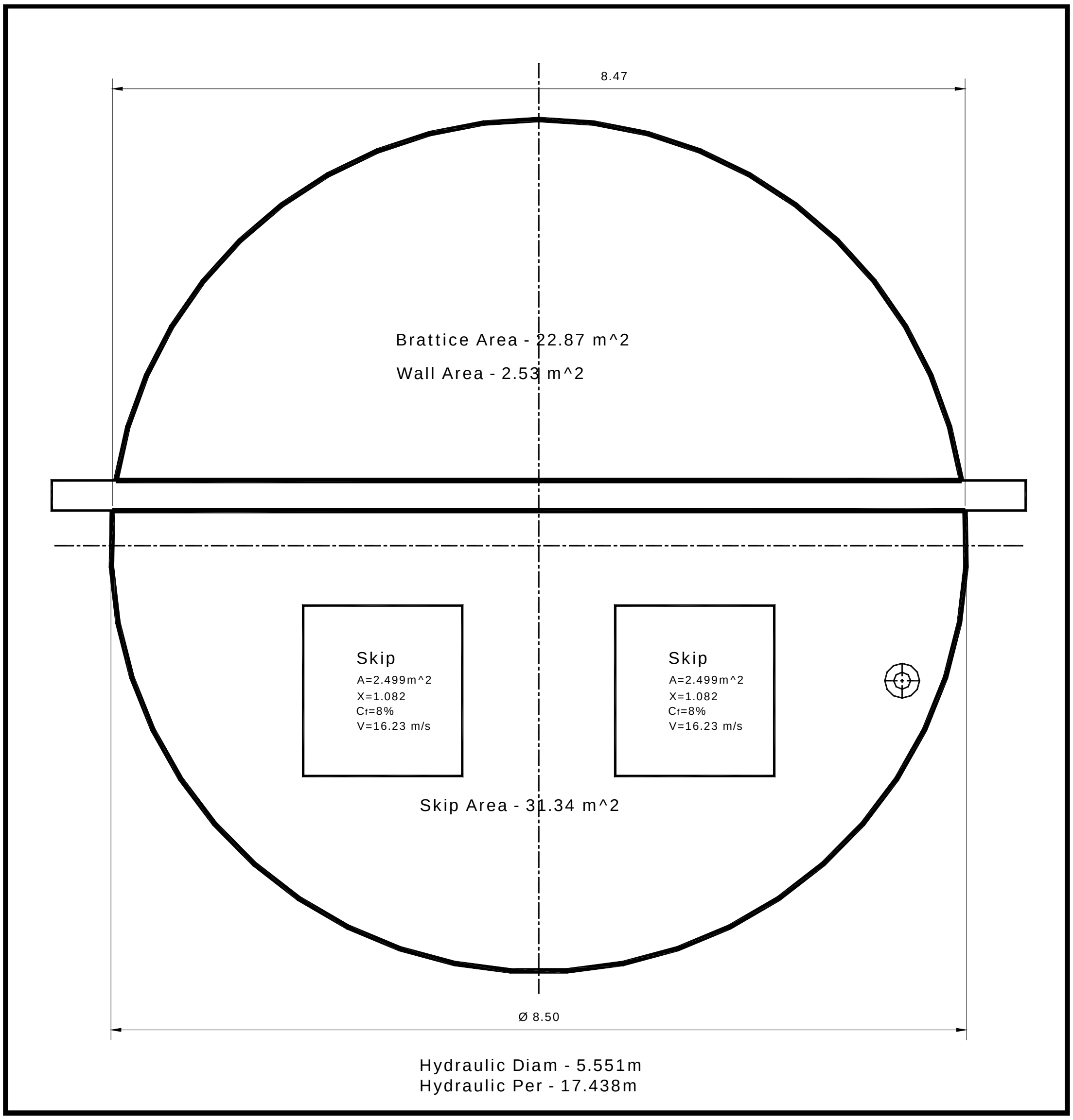

Figure 4-5: Cross-section of No. 12N shaft

4.1.5.2 Environmental loggers

All the environmental loggers were time-stamped from a common computer before they were installed. These data were then sorted to display the results from each of the days on which testing took place.

It should be noted that there were times in the shaft when the pressure readings varied significantly. These times are consistent with the times that the ventilation fans were not operating at full flow. These periods were also avoided in the evaluations given below.

4.1.5.3 Rotary encoder

The PLCs associated with these encoders were time-corrected to the same computer used for the environmental loggers. The results from these encoders were corrected to show the conveyances in appropriate positions in the shaft. This was done primarily by using the drum diameter and matching the conveyance position on each of the levels to the movement of the drum.

The PLCs measured the position of the conveyance every second, whereas the environmental loggers measured every 10 seconds. The winder data were therefore also corrected to start and stop at equivalent times to the environment loggers.

The PLCs attached to these encoders were placed in the drivers' cabins where appropriate. These were not tampered with for the duration of the experiment.

4.1.5.4 Summary of data from tests on No. 12N shaft

The friction losses in the shaft were measured and calculated in accordance with the theory discussed in the previous chapter of this thesis. The analysis was completed using the data between surface and 14 level as these data showed the least amount of scatter. A summary of these results is given in Table 4-11 and Table 4-12.

Table 4-11: No. 12N shaft test results – Data

Item	Value	Symbol	Units	Description
1	0.000	f_{BTotal}	-	Total bunton Chezy-Darcy friction factor
2	0.028	f_{Shaft}	-	Shaft asperities Chezy-Darcy friction factor
3	0.028	$f_{Total\ Shaft}$	-	Total shaft Chezy-Darcy friction factor
5	1.082	$X_{Cage\ 1\ Corr}$	-	Cage shock loss correction factor

Table 4-12: No. 12N shaft test results

	$P_{loss\ (measured)}$ (surface to 14 level)	$P_{loss\ (calculated)}$ (surface to 14 level)	Units	Description
1	917.6	311.2	Pa	No conveyances moving
2	1.04	0.35	Pa/m	No conveyances moving
3	866.0	297.8	Pa	No conveyances moving
4	0.98	0.34	Pa/m	No conveyances moving
Note: The measured pressure measurements were taken at a time when the conveyances were not moving. The calculated pressure loss has, therefore, been completed assuming no conveyances are moving in the shaft.				

4.2 SUMMARY OF AND CONCLUSIONS FROM THE SHAFT TEST RESULTS

4.2.1 Accuracy of the Results

The shaft tests discussed here were all conducted on shafts at Impala Platinum. In total five different shafts were tested for time periods varying from 4 to 8 days. The objective of the tests was to obtain sufficient measurements to allow the calculation of the pressure drops in an operating shaft. For this purpose environmental data loggers were placed immediately adjacent to a shaft at various points along the shaft length. In some instances it was not possible to place instrumentation on all the shaft levels. When this occurred discussions were held with the shaft ventilation officer to determine the ideal positions for this instrumentation. These positions were generally at the highest level in the shaft and at the stations where most of the ventilation air left the shaft. The data obtained from these instruments allowed the calculation of the pressure drop over the shaft using the barometric calculation.

In addition, rotary encoders were placed on each of the winders used for the conveyances in the shaft. This allowed the evaluation of the shaft pressure drops in conjunction with the movement of the conveyances within the shaft.

The placement of the various pieces of instrumentation for these tests does give rise to some experimental errors which must be considered when evaluating the test results. These are primarily the entrance losses for the ventilation air, as well as losses resulting from the indirect manner in which the pressures in the shaft were measured.

The pressure on surface was measured and used to evaluate the total pressure loss in the shaft. This did not take into consideration the pressure losses that would occur as a result of the transfer flow of air down the ventilation duct and into the shaft as well as on to the station. Generally, these losses are around 100 Pa, depending on the drift configuration.

In addition, there are other factors that cannot be effectively quantified as a result of the placement of the underground pressure sensors. These sensors were placed immediately adjacent to the shaft at various stations, as appropriate for the shaft under consideration. Therefore both *vena contracta* effects and the effects of the station steelwork should be considered.

Finally, the accuracies intrinsic to the instrumentation used as well as the calculation methodology must be considered. These were noted in section 3.5.4 above. These accuracies are repeated here for convenience:

1 Potential differences across the rage as a result of the instrumentation (+12% to -29%)

2 Potential differences inherent in the calculation of the pressure losses resulting from the shaft wall (+15% to -15%)

3 At this stage the potential inaccuracies for the calculation of the flow of the ventilation across and buntons and pipes is not known.

4.2.2 Summary of the Various Shaft Tests

4.2.2.1 Summary of results from the No. 14 shaft tests

There is a significant difference between the measured data and the calculated data (between 38 and 49%) for the data points considered. This difference is between 246 and 312 Pa. The reasons for these differences are discussed in Section 4.2.

There was very little change in the measured pressure as a result of the service cage moving by itself in the shaft. This is attributed directly to the small coefficient of fill that the service cage has on the shaft C_f = 13%. This is in spite of the fact that the theory showed that an increase in pressure loss of 58 Pa should be apparent when the cage was moving upwards in the shaft.

One of the more surprising findings is the increase in pressure loss of approximately 50 Pa as a result of the skip when it is moving consistently between surface and the shaft bottom. The available theory does offer a prediction of the shaft losses as a result of the movement of conveyances through the shaft, but states that, in the case of paired conveyances (i.e. conveyances of similar dimensions moving in opposite directions), the overall effect of the pressure from the conveyance moving will be cancelled out. This finding is therefore not consistent with the theory. However, if one evaluates this pressure rise as an obstruction in the shaft, the predicted increase for one skip blocking the airflow is 54 Pa, which is similar to the pressure increase noted above.

There is little difference between the pressure loss calculated for the shaft between the time when the man cage is moving and the pressure loss when it is not moving. This is consistent with the theory as the cages move in pairs.

This shaft is well laid out and the overall coefficients of fill of each of the individual conveyances is well within the recommended maximum of 30% (Figure 4-1).

4.2.2.2 Summary of results from the No. 11 shaft tests

There is a significant difference between the measured data and the calculated data (between 23 and 35% for the data points considered). This difference is between 135 and 208 Pa. The reasons for these differences are discussed in Section 4.2.

There is no evidence of pressure spikes when the skip and cages are moving and when they are not. This is consistent with the theory as the conveyances move in pairs.

A perusal of the measured data against time did, however, show some pressure spikes of approximately 150 Pa indirectly associated with the movement of the man cage. In some instances this spike lagged the movement of the cage by 2 to 3 minutes. This was especially noticeable when this cage was moving alone in the shaft. This pressure surge could be construed to result from the cage movement but was always short in duration when it did occur (total pressure swing of less than 30 seconds). Given the large C_f of the cage of 29%, this is to be expected and it is close to the value of 164 Pa predicted by the theory.

There was no general increase in the overall pressure loss measured in the shaft when the skip was in constant operation as was noted in the 14 shaft tests. This was in spite of the fact that the C_f of the skips in both shafts was identical (7%).

4.2.2.3 Summary of results from the No. 1 shaft tests

There is not a significant difference between the measured data and the calculated data (between 9 and 22% for the data points considered). This difference is between 26 and 62 Pa. The reasons for these differences are discussed in Section 4.2.

There is no evidence of pressure spikes when the skip and cages are moving and when they are not. This is consistent with the theory as the conveyances move in pairs.

In addition, there is no evidence of the anticipated pressure spikes when the service cage is moving and when it is not. The theory predicted a pressure rise of 24 Pa in this instance.

This small difference can be attributed to the small C_f that the cages and skips have in comparison with the shaft. These skips had C_f = 7% as in the other shafts, while the man cage and service cage had C_f = 14%. Both of these coefficients are significantly smaller than the recommended maximum of 30%.

4.2.2.4 Summary of results from No. 11C shaft

There is not a significant difference between the measured data and the calculated data (between 10 and 25% for the data points considered). This difference is between 74 and 173 Pa. The reasons for these differences are discussed in Section 4.2.

There is evidence of the anticipated pressure spikes from when the cage is moving and when it is not. This pressure spike of 100 Pa did, however, lag the movement of the cage by 1 to 2 minutes and was always short in duration (total pressure swing of less than 30 seconds). The cage has a C_f = 30%. The measured pressure rise of 100 Pa and the theory predicted a pressure rise of 167 Pa.

4.2.2.5 Summary of results from No. 12N shaft

There is a significant difference between the measured data and the calculated data (between 190 and 194% for the data points considered). This difference is between 568 and 606 Pa. The reasons for these differences are discussed in Section 4.2.

There is evidence of the anticipated pressure spike when the skips are moving. This pressure spike of 100 Pa did lag the movement of the skips by 1–1.5 minutes and was always short in duration (total pressure swing of less than 30 seconds). The skips move in pairs and this pressure spike is therefore not consistent with the theory.

However, if one evaluates this pressure rise as an obstruction in the shaft, the predicted increase for one skip blocking the airflow is 74 Pa, which is close to the pressure increase noted above.

4.2.3 Summary and Conclusions from the Shaft Test Results

4.2.3.1 Accuracy of the data

The results of the tests completed on all the shafts are listed in Table 4-13. As can be seen from this table, the results show varying agreement with the values calculated from the current theory. The specific circumstanced surrounding the measurements were discussed in section 4.2.1.

The most significant difference is noted for the results of the tests for No. 12N shaft. These showed very little agreement with the theory. This difference is attributed primarily to the fact that it was necessary to place the pressure-measuring instrument in the steelwork associated with the shaft bottom. It is assumed that the additional losses resulting from this steelwork resulted in the significant pressure difference in these readings. Unfortunately, this also means that the results of this test are of little use in the context of this work.

Table 4-13: Summary of shaft test results

Item	P_{Loss} (measured)	P_{Loss} (calculated)	% Diff.	Difference		Chezy-Darcy friction factors		$f_{B\ Total}$ / $f_{Total\ Shaft}$
No. 14 shaft								
1	909.9	637.0	43%	272.9	Pa	$f_{B\ Total}$	0.076	78%
2	1.81	1.26	43%	0.54	Pa/m	$f_{Total\ Shaft}$	0.098	
No. 11 shaft								
3	757.9	585.9	29%	172.0	Pa	$f_{B\ Total}$	0.079	78%
4	1.22	0.95	29%	0.28	Pa/m	$f_{Total\ Shaft}$	0.102	
No. 1 shaft								
5	234.6	275.8	15%	-41.2	Pa	$f_{B\ Total}$	0.102	83%
6	0.47	0.55	15%	-0.08	Pa/m	$f_{Total\ Shaft}$	0.123	
No. 11C shaft								
7	804.3	680.6	18%	123.6	Pa	$f_{B\ Total}$	0.047	67%
8	0.69	0.59	18%	0.11	Pa/m	$f_{Total\ Shaft}$	0.070	
No. 12N shaft								
9	891.8	304.5	193%	587.3	Pa	$f_{B\ Total}$	0.000	0%
10	1.01	0.35	193%	0.67	Pa/m	$f_{Total\ Shaft}$	0.028	

The four remaining shafts show accuracies varying from an average of 42% in the case of No. 14

shaft to 15% in the case of No. 1 shaft. To try and understand the reasons for these differences, the shaft configurations need to be considered.

The two shafts that show the least agreement are No. 14 shaft and No. 11 shaft. These two shafts both use the airflow buntons, each of which contributed 78% of the calculated Chezy-Darcy friction factors for these shafts. These shafts are of similar configuration to No. 1 shaft, which showed agreement between the measured results and the calculated results of 15%. The shaft asperities in the calculation were all equal at 10 mm and the ventilation flow rates for the shafts did not vary significantly (7.7 m/s for No. 1 shaft, 10 m/s for No. 11 shaft and 9.4 m/s for No. 14 shaft). In addition the ventilation air was introduce to these shaft sub bank via well designed evase's. This leaves two variables that could account for the differences, namely the drag coefficient used for the evaluation of the buntons resistance to the ventilation flow and the number and placement of pipes in the shafts.

The values used for the drag coefficient for the evaluation were taken from the tables supplied by McPherson (1987). In this instance, the shape closest to the airflow bunton was that of a dumbbell. This drag coefficient was calculated from the data presented by Martinson (1957), whose paper was reviewed in Section 2.2.2. The same table was used to obtain the drag coefficient used for the triangular bunton used in No. 1 shaft. This coefficient was obtained from measured data.

This drag coefficient does highlight the potential pitfalls in calculations of this nature. The bunton Chezy-Darcy friction factors supply a large portion of the resistance within the shaft and thus the effect of assumptions in the quantification of these data can be significant.

The additional resistance that a shaft offers to ventilation air flowing through it as a result of the pipes in the shaft is difficult to quantify. The theory indicates that this should be accommodated by reducing the free area of the shaft by the area of the pipe and adjusting the rubbing surface of the shaft in the calculation accordingly. This approach results in a Chezy-Darcy friction factor for the pipes of less than 1% of the overall Chezy-Darcy friction factor. This is not sufficient to account for the differences noted above. However, the contribution of the piping to the overall Chezy-Darcy friction factor was more fully investigated during the CFD evaluation.

4.2.4 Conveyances Moving in the Shaft

The results of these data do not allow a meaningful conclusion to be drawn. The data from No. 14 shaft did not show significant differences in the measured pressure losses as a result of the cage movement. However, a small increase in the overall pressure was noted, consistent with the blockage that one of the skips would apply to the shaft if it remained stationary. This only occurred once the skip was being used to its full capacity and was moving up and down the shaft consistently.

This small increase was attributed to the length of time that the skip spent in the shaft. It was not noted in any of the other tests.

In the tests associated with No. 11 and No. 11C shaft, delayed pressure spikes were apparent when the cages moved up and down the shaft. These spikes were consistent with the predicted theory. In both of these instances, the cages occupied respectively 29% and 30% of the total shaft area available.

Interestingly, the measurement at No. 12N shaft exhibited similar results in spite of the skips in this shaft occupying no more than 8% of the total shaft area. However, the skips occupy the central portion of the shaft in which the ventilation air would be flowing the most freely, i.e. without the effects of the irregular shaft shape.

In all instances, the pressure spikes lagged the passing of the cage by 1–3 minutes. This pressure spike did, however, dissipate before the cages passed the same point again. This was also in spite of the fact that the pressure changes caused by cages moving up and down the shaft in pairs should cancel each other out. This was attributed to the damping effect of a shaft filled with air.

The results of this analysis show that the effects of a cage moving in the shaft can be largely ignored. This conclusion is, however, valid only for shafts of similar cross-section to those considered here.

4.2.5 Conclusions from the Results and Evaluation of Shaft Tests

The following specific conclusions can be drawn from the results of the tests and the comparison of these results with the current theory:

1. The differences between the results from the various tests and the theory for shafts of similar configuration demonstrate the importance of ensuring that the appropriate factors for the drag of the buntons are considered. The test results that showed the least agreement with the theory all used drag coefficients derived from tests on previous shafts. The shaft that showed the most agreement between the measurement and the theoretical evaluation used a drag coefficient taken from measurements on a scale model. The buntons are calculated to contribute approximately 78% of the total friction resistance in the shaft, and any discrepancy in the coefficient of drag can, therefore, make a significant contribution to the overall calculated friction resistance.

2. The contribution that pipes and fittings make to the overall friction resistance is calculated by considering the overall decrease in the shaft area that the inclusion of these pipes and fittings result in. This does not take into account the placement of these pipes and fittings with respect to the airflow, or the inclusion of flanges which would contribute further to the interruption of the airflow.

3 The movement of the conveyances within the shaft does not seem to have a large effect on the pressure drops over the shaft. This is attributed to the shaft being well laid out and the cages and skips all being below the recommended C_f of 30%. When it was apparent that the passing of the conveyances had created a pressure spike, this was small, of short duration and lagged the passing of the conveyance by between 1 and 3 minutes. This was attributed to the large compressibility of the air in a typical shaft and the damping effect this would have on any pressure spike in the shaft.

4 When evaluating these results, the potential inaccuracies of the instrumentation must be borne in mind as these could also account for the noted discrepancies.