A review of the requirements for the testing of

# THE STRENGTH OF VENTILATION STRUCTURES TO BE USED IN QLD MINES

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**Abstract**

The regulations in Queensland require that ventilation structures conform to strength requirements in terms of the overpressures that they can withstand. Prior to the enactment of the regulation on 16 March 2001 the testing of Ventilation control devices were described in an approved standard. As this standard did not however fully cover the testing of all the ventilation devices due to the availability of suitable methods a need arose to review suitable methods that could be used to determine the strength characteristics of ventilation structures.

To test these structures at the presently available facilities in the world is costly and difficult for manufacturers developing new designs. This has created the need for alternative processes that include both destructive and non-destructive methods. There has been a move throughout the world to different types of testing processes for seals.

This paper reviews the newer method used throughout the world and uses them as a basis for reviewing the test requirements of structures to be used in Queensland.

Based on the purpose of the ventilation devices a set of leakage criteria to be used in an adapted standard has been derived for stopping and other ventilation devices.

To ensure conformity with such a proposed standard the overpressure against which the structures are tested against is also reviewed and processes proposed that would make the testing of ventilation control devices significantly cheaper while still in line with the best practice used in international organisations.

## 1.0 Introduction

The underground explosion at Moura No2 mine on 7 August 1994, presented challenges to mining engineers that had not been formally addressed previously throughout the world. Soon after the first explosion the mine tube bundle gas monitoring system proved to be partly operative .

The gas analysis showed that in addition to the predictable high levels of carbon monoxide throughout the mine, there was a large area where the atmosphere contained high level of methane and reduced oxygen levels .

The atmosphere was potentially explosive and prevented rescue teams from entering the mine .The low levels of oxygen also prevented the possible escape of other persons from a large portion of the mine.

The gas monitoring data strongly indicated that the explosion had breached multiple seals. Two days after the first explosion, a second and more violent explosion occurred.

The failure of the seals significantly increased the risk to the chances of survival for the mineworker's underground at that time. The efforts of Task Group 5 concentrated on establishing practical design criteria to assist mining engineers minimise these risks

The purpose of any ventilation structure, including a seal, is to separate the mine into different areas with regard to airflow and the general atmosphere in that area. In the case of structures like stoppings, curtains, aircrossings and regulators the main purpose is to separate intake air from return air in the process of ventilating the mine. Seals on the other hand separate worked out areas

**Table 1. Strength criteria for ventilation structure to be used in Queensland mines**

| Design Criteria | Location |
|---|---|
| Type A<br>(2 psi) 14 kPa | Limited Life Production Panels |
| Type B<br>(5 psi) 35 kPa | Main Roadways |
| Type C<br>(20 psi) 140 kPa | Sealed Areas |
| Type D<br>(50 psi) 345 kPa | Sealed Areas in the event of explosive conditions. |
| Type E Pressure Relief<br>(10 psi) 70 kPa | Surface Infrastructure |

of the mine from the accessible part and on the whole are structures that play a longer-term role.

These structures, apart from separating the parts of the mine, also have to ensure that if any occurrence happens in one part of the mine the sealed atmosphere it is contained there and is unable to enter other parts.

Even though seals have a different primary role and have to contend with significantly more serious occurrences than normal ventilation structures they can still be considered to be a ventilation control device.

The Queensland Mining Regulations require that all ventilation structures in a mine have to conform to certain strength requirements.

These strength requirements are expressed in terms of the overpressure that the structure has to withstand. Previous to the introduction of the Coal Mining Regulation on 16 March 2001 there had not been any recognised testing criteria method to which ventilation devices (excluding seals) could be conducted, The previous approved standard did not cover the testing of ventilation control devices (VCDs) for leakage of ventilation sufficiently.

Queensland is unique in that it has regulated the strength of ventilation structures in addition to seals. These strength requirements that are set according to the different areas in a mine, are presented in the following table.

These criteria were developed as a result of the Warden's Inquiry into the circumstances surrounding the explosion that occurred at Moura No.2 mine in August 1994.



All of the recommendations made were acted upon by various Task Groups. The above criteria was developed by Task Group 5 and its main purpose was to establish a standard for ventilation control devices to ensure a high level of survival of mine workers following a fire or an explosion.

The sealing structures had to contain the explosion to the area in which it occurred and not increase the contamination of the mine airways with the previously sealed atmospheres.

The ventilation structures had to be partly functional after the incident. If the ventilation structures could survive the overpressures resulting from explosions, then the airflow in the mine would not be severely disrupted and workers surviving the incident would be able to reach fresh air much more quickly than what would be the case if the structures were completely destroyed, as would be the case when they had no explosion resistance.

To comply with the requirements of the law, as well as ensure that the structures in a mine are fit for purpose, there is a need to determine the strength of ventilation structures.

This paper compares the methods that are being developed and used and indicates the suitability of these methods for future use.

**2.0 Testing of structures for use underground.**

In the development of ventilation structures for use in the underground environment there is a process that needs to be followed.

This process conforms to most other needs driven developmental processes in the engineering field. The setting of strength requirements of a ventilation structure is usually done by or under the auspices of the legislators or the organisations that set standards. These requirements are based on a prediction of what would be the performance criteria for the device to reach a desired outcome. In the specific case of ventilation structures, the criteria are in terms of the forces that a structure would have to withstand so that it could still fulfil its function, or part of its function, after being subjected to these forces. In the USA, it has been stated by Mitchell (1997) that because no one can foretell what forces might be exerted on bulkheads due to explosions in isolated areas, studies should be directed at preventing flames from propagating into sealed areas and minimising gas flows into the path of the flame.

The next step in the development of a seal to be used in the mine is to design the seal according to good structural engineering practice to satisfy the requirements. This is usually done by the organization that is going to construct the seal or develop such a structure as a commercial venture. The seal design is then tested by constructing it in a suitable gallery and subjecting it to the overpressure as specified in the requirements .In the USA seal designs have been developed and approved using test galleries. The seal designs in Australia have mostly been developed as commercial ventures and until fairly recently been tested at the Lake Lynne Experimental Mine (LLEM). During the last few years' tests to determine the strength of seal designs and other ventilation control devices have also been conducted in Australia and in South Africa.

The fourth aspect of the process is when the erected seals themselves are being tested in situ. In work done by Oberholzer (1997) in determining the strength characteristics of refuge bay bulkheads it became very clear that while the design aspect was important, the way that this design was implemented in the underground environment was of greater value in determining the performance of the structure. This rationale was further supported by observation of the deleterious effects that the mine environment could have on these structures. This led to the conclusion that to determine what the characteristics of the structure were, and especially over the longer term, a method would have to be devised to test the structures in situ. The feasibility of non-destructive testing was investigated to satisfy this need.

**3.0 Destructive test methods.**

The methods used to test seals have basically been derived from the technology as developed in the USA at the Lake Lynne Experimental Mine. These methods have not only been used to test structures for the use in the USA, but have also been used to test structures intended for use in Australia.

There is a plethora of literature that describes the testing methods, the results and the seal designs emanating from this facility. Traditionally testing has been conducted by using large-scale explosions resulting in overpressures in the 20-psi range in the mine passages to test ventilation structures.

The testing of seals up to now has been done by using an actual seal and subjecting it to the closest simulation of a underground explosion that is possible. There is no practical way whereby the actual conditions of an underground explosion in a mine can ever be created, therefore use had been made of explosion galleries using methane explosion to create the overpressure.

By varying the mixtures and amounts of gases used in the explosion, different overpressure can be obtained.

The strength criteria for a ventilation control devices is usually given in terms of this overpressure. After the structure has been subjected to this overpressure there are basically three outcomes.

- The structure is completely undamaged and in the same conditions as it was prior to being subjected to the overpressure. No evidence of change can be noted in this case
- The structure is evidently destroyed. It has been demolished, broken and moved to the extent that it does not exist as a structure
- It shows evidence of change, possible cracking but not to the extent that it has evidently been destroyed.

It is in the latter case where the leakage criteria are used to determine if the structure has withstood the overpressure event or not. Through usage this leakage criteria has become the ultimate determinant of success or failure of the structure.

As the purpose of a seal is to stop flames from propagating into sealed areas and minimising gas flows into the path of the flame the allowable leakage is very low.

Testing of ventilation structures was conducted locally under the auspices of an ACARP funded project (Pearson et al, 2000). Although the Testsafe facility at Londonderry, which is basically a surface structure, was found suitable to test ventilation structures requiring lower overpressures it was not deemed suitable to test seals requiring an overpressure of 140 kPa and above.

This means that structures in this range still have to be tested at LLEM. The lower range tests conducted in the Testsafe facility correlate well with those done at LLEM and is considered adequate for proving compliance with the requirements of the Queensland mining regulations.

**4.0 Non-conventional destructive test work**

During the past two to three years various parties conducted destructive tests to develop methods that would not require the use of a gallery or even explosion to obtain the overpressures.

The following are examples where these innovative methods have been used with success. The success of these testing methods put the use of galleries as prescribed in the old approved standard in a completely new light.

**Case 1**

Two chambers for testing containment walls and seal strengths were constructed at the NIOSH Lake Lynn Experimental Mine (Cashdollar, 2000).

The intention was to develop more easily executable tests for seal testing as well as to establish the technology to satisfy the need to evaluate these structures at the mine site in the future. The first chamber is approx. 2m high and the second approx. 4m high. In these chambers, seals can be tested through using water (hydrostatic pressure) and methane explosions .

These chambers were commissioned during the latter part of 1999 with most of the work focussing on either compressed air tests or methane explosion testing.

Even though the time period in these test seem to be slightly longer than in the case of the conventional test the new result correlate well with the older ones.

**Case 2**

In South Africa a collaborative effort between manufacturers, mines and the CSIR Miningtek was implemented to develop other evaluation methods. The overpressures were to be achieved using either compressed air or the hydraulic pressure resulting from a static water head.

To make the test more representative the evaluation methods were devised to be used within a mine where the structure was constructed under mining conditions.

In these tests the following methods were used to achieve the required overpressure pulse.

- Uncontained compressed air
- Contained compressed air
- Uncontained but sealed hydraulic pressure
- Contained methane explosion.

In all the cases the seal was constructed in such a way that an enclosed void was created behind the structure.

Tests with compressed air did not succeed in reaching 140kPa pressure as the nature of the coal strata caused leakage to occur at such a rate that no pressure higher than 40kPa could be obtained.

The compressed air system could not transfer the air at a fast enough rate to compensate for the outflow of air. Further to this, it was found that when cracks started to form in the structure, the air leakage increases to the extent that very little force can be applied to the wall.

In an effort to circumvent the problems experienced with previous tests it was proposed to create an airtight pressure bag of the correct size and strength to assist in preventing air leakage when cracks were formed.

In this test with the containment bag the maximum pressure increased to 80kPa before failure of the containment bag occurred.

The most successful tests with compressed air were conducted at the Douglas Colliery in South Africa where a wall that was very well sealed off and constructed in very competent strata was able to withstand 125kPa prior to the formation of cracks, which stopped a further increase of the overpressure.

Successful tests using water were conducted at the Koornfontein mines, South Africa, where a seal was constructed in such a fashion that the void behind the seal was sufficiently watertight that the outflow of water could be kept to a minimum.

By filling the void through a borehole to surface, the required pressure could be obtained and the pressure at which the seal started breaking could thus be determined quite easily.

In both of these methods the slow application of static pressure could be applied with success to determine the strength of the seals.

A further innovative testing method was conducted when a special gallery was built underneath an old bridge across a dry riverbed.

Access to the chamber was gained by means of a manhole and steel door. The bridge consisted of I-beams, steel reinforcing and concrete of unknown design or strength.

To reinforce the resistance of the structure to withstand the pressure in the chamber an amount of fill material was placed on top of the bridge.

The quantity was calculated as if the bridge had no inherent strength. The gallery was equipped with static pressure sensors to measure the increase in pressure.

A methane explosion was used to obtain the required overpressures. All the tests were done with a volume of 31.5 $m^3$ air-methane mixture of between 9 and 9.5% per volume.

The mixture was ignited by using three fuse caps in parallel. The ignition simultaneously triggered a PC based data acquisition system. Data for the pressure rise over time was stored in a data file, which was then imported into a commercial spreadsheet package that could be used to generate a graph of pressure rise against time.

Due to the configuration of the test chamber it was impossible to do the leakage test as required by the MSHA test protocol.



This is not seen to be insurmountable problem as the use of a compressor and the extrapolation of the curve could allow for adequate leakage testing to be done.

The maximum overpressure reached in the first test was 141.8kPa with a maximum deflection of 20mm. In the second test, the failure of the manhole and the roof structure resulted from a maximum over pressure of 144.3kPa.

Although the test gallery was destroyed during the last test it nevertheless proved that the seal that was being tested withstood the overpressure obtained from the methane explosion.

What these tests further proved is that a cost effective gallery can be constructed and that, by using a contained methane explosion, the overpressures necessary to test seals can be obtained.

It is anticipated that due to the confined nature of such a test chamber significantly higher pressures could be achieved if it was required.

**Case 3**

Tests using commercial explosives to create the overpressure have been conducted by a Queensland firm in a metal mine in Western Australia. In these tests the expending gases of a charge of explosives was used to create the overpressure on the structure .

As these tests were very well instrumented, the pressure pulse was well determined. It was found to be less than 0.3 of a second, which is considerably shorter than the pressure pulse lengths as obtained with methane mixtures that are in the order of a second or longer. It has been determined that by using a slower commercial explosive pulse lengths of significantly longer duration can be obtained.

What these test has proved is that the destructive testing of structures need not be confined to be done in galleries but can be done in any place where the appropriate overpressure can be generated and where the leakage through the structure can be measured.

## 5 Non-destructive testing

The requirement for non-destructive testing arose from the need for a less costly method to test prototype designs and the need of the mines to ensure that the structures that have been installed in their mines conform with, and continue to conform to the set requirements.

Simtars has completed an investigation into the feasibility of developing non-destructive testing methods that can be used to test ventilation control devices.

This work forms part of an ACARP sponsored project. (No C10014- Develop testing methods that will allow for the in-situ testing of ventilation structures in coalmines. Phase one – Identify suitable testing methods.)

To be able to assess the ventilation structures in a mine without affecting its strength the use of non-destructive methods is required.

The condition of a ventilation device is presently determined by how effectively it separates two parts of a mine and therefore leakage criteria is quite rightly used as the deciding factor.

Using leakage as the criterion is suitable to define the performance of a structure after it has been subjected to an overpressure but is, however not adequate to describe the state of a structure and its immediate surroundings.

It is thus necessary that other accepted criteria will have to be established to describe the condition of the structure.

These acceptance criteria will then have to be formulated in terms of physical characteristics or in terms of how they are allowed to change after the structure has been subjected to the overpressure.

These descriptive characteristics will not be restricted to the structure only but will include the system linking the structure to its environment as well as the conditions of the environment.

One of the most critical aspects would be to relate the physical characteristics with the leakage criteria. The state of the structure that would result in an acceptable or unacceptable leakage criteria would have to be determined in terms of the descriptive characteristics.

This is presently seen to be the biggest hurdle to the achievement of a satisfactory outcome of the process. The matter is exacerbated due to fact that this relationship will have to be done for all the different types of ventilation structures types being used by the mining industry.

It is also foreseen that although a significant portion of determining the relationships can be done at the hands of structural engineering practice it would still have to be confirmed through actual testing. Only then will it be possible to determine if a structure is acceptable or not in terms of the physical characteristics.

The use and suitability of these methods will have to be tested and the level of confidence that can be attributed to the results determined.

Only when both the relationships between leakage and the physical characteristics and between the physical characteristics and non-destructive measurement parameters are determined will the process be suitable for the adjudication of the condition of a seal with regard to its strength.

The challenges with regard to the testing of prototype structures now becomes significant. This is because the criteria that will be used to determine if a structure has passed the compliance test will be based on the design that is used, the materials involved and the method of construction.

Primarily these criteria will set out to determine if the design is adequate and then if the structure under investigation complies with the design.

There is no present method apart from controlling the design process or simulating the design of the structure that would enable non-destructive methods to predict how a structure will perform.

This leads to the finding that non destructive testing processes will, over the shorter term, only be suitable to test the conditions of a structure the design of which has been proven in a destructive test process.

**6 Determination of the criteria for ventilation devices**

In order to develop criteria for ventilation control devices two aspect had to be considered. The obtaining of the required overpressure and proving that the structure remained within the allowable leakage criteria would indicate that the structure has survived or withstood the overpressure.

Latter day work has shown that different methods of obtaining the overpressure can be used however the leakage criteria for seals presently being used at the LLEM are deemed not to be practical for VCDs in Queensland.

It was therefore proposed that leakage criteria should be developed in keeping with the intent for establishing strength specifications the structures. The overpressure requirement will thus impact on the testing method and the leakage criteria will determine if the structure has passed or failed.

As the intent of specifying the strength of the ventilation devices was to ensure that they would be strong enough so that sufficient airflow to the sections can be restored or maintained after the occurrence of an incident.

If the airflow can be maintained or restored such that a worker exiting the mine can reach fresh or uncontaminated air as soon as possible, the structure would have fulfilled its purpose. This might typically be around 30 minutes with the use of oxygen self-rescuers.

A further motivation for a less stringent leakage levels is that in many cases the air leakage of newly built ventilation control devices (stoppings) would not comply with the NIOSH seal leakage criteria even before being subjected to an overpressure.

By calculating the maximum leakage that would allow air to reach the face in time, a new set of leakage criteria has been developed and is recommended for use when evaluating ventilation structures after being tested in a gallery.

**7 Overpressure requirements for testing**

The levels of overpressure defined in the regulation(schedule 4), requires the test methods at the internationally accepted test galleries.

The majority of the testing work on which the present criteria for Australia, as well as South Africa, are based upon was conducted in the Lake Lyne experimental mine (LLEM) and Bruceton facilities. The basis of developing seals and determining their ability to withstand certain overpressure has been based on an unconfined methane explosion in mine workings.

Although test has been conducted with gunpowder added to the fuel the majority of explosion test have been done with methane and methane and coaldust mixtures.

It would seem that it is very difficult to exceed the 20psi or 147kPa level purely with an uncontained methane explosion.

The factors that determine the peak loading on the bulkhead is the explosion intensity, the passage length between the bulkhead and the explosion source and the orientation of the bulkhead with respect to the passage in which the explosion occurs.

On first contemplation it might be expected that the damage caused by an explosion would depend simply on the peak pressure that was generated.



**Table 2 Comparison between the periods of vibration of structural elements, and duration of pressure pulses. (Harris, 1989)**

| **Structure** | **Period** ( milliseconds) |
|---|---|
| Concrete floors | 10-30 |
| Concrete walls | 10-15 |
| Brick walls | 20-40 |
| **Explosion type** | Duration ( milliseconds) |
| Confined gas explosion | 100-300 |
| Pressure wave from the detonation of an explosive charge | 1-10 |
| Pulse length –Londonderry | 2000 |
| Pulse length LLEM | 500 |
| Pulse length LLEM large chamber | 8000 |

(This in a way is what is implied through the use of 'overpressure'.)

However the response of structures to the pressure loading generated by the explosions is more complex.

An explosion produces a pressure loading that varies with time and the response of the structure to this load is in itself time dependant.

What this means in simple terms is that the response to an explosion will be determined by the peak pressure generated and upon the ratio of the time period of the imposed pressure load $t_d$ and the natural period of vibration of the structure Tn.

The ratio $t_n$ /Tn determines how the structure will 'feel ' the application of the overpressure.

Three basic types of response can be defined. (Harris ,1983)

1 $t_d$ > Tn
Where the duration of the overpressure is longer than the natural period of vibration.

In this case the loading on the structure will effectively be equivalent to the static loading.

2 $t_d$ @ Tn
The duration of the overpressure is about the same as the natural period of vibration. In this case the loading experienced would be effectively equivalent to a static loading of a magnitude greater than the peak overpressure generated in the explosion. The equivalent static pressure can be up to P/2 time the magnitude of the incident overpressure.

3 $t_d$ < Tn
The duration of the overpressure is shorter than the natural period of vibration. In this case the structure will not be able to absorb the energy of the pulse and the pressure will be partially absorbed and the loading experienced will be equivalent to a static loading of a magnitude lower than the static loading.

Expressed in a different way this means that under these conditions a structure could withstand a higher-level pressure pulse of very short duration that it would under static load conditions.

The length of the explosion pulse used to test the ventilation control device is thus of great importance.

In the following table the natural period of vibration are compared with the pressure pulses from different types of explosions.

From the above it is thus evident that when seals and ventilation control devices are tested by subjecting them to the most probable overpressure that they might have to cope with, a gas explosion, the pulse duration of the explosion will be longer than the natural period of the structure.

A static load can thus simulate the load of the pressure on the structure.

Where commercial explosives are used to simulate the overpressure pulse care will have to be taken to ensure that the pressure pulse is of sufficient duration to well exceed the natural period of vibration.

Any overpressure pulse that is used for the testing of the structures and that has a pulse length that exceeds that of the natural period of vibration of the structure being tested would be suitable to obtain the required loading .(In practice this pulse length is usually longer than 100 milliseconds in length and should be approximately the same as what would be obtained by using either a contained or uncontained air/ methane gas explosion.

**7 The leakage criteria**

The leakage that is measured through the structure after it has been subjected to an overpressure is taken as indicative of the competency of the structure.

As the leakage is determined by the ability of the structure to resist the flow of air through it the leakage criterion can be replaced by the resistance of the structure to determine its ability to seals of the flow of air.

The relationship between the pressure difference and the flow between two points are determined by the resistance (Atkinson's resistance) and is presented by the well-known square law.

$p = RQ^2$

Where p is the pressure difference in Pascal, Q is the volume of airflow in cubic meters per second and R is the resistance in $Ns^2/m^8$

Because of the highly non-linear relationship between the area available for flow and resistance, the resistance for structure can vary from one or two $Ns^2/m^8$ to literally thousands of $Ns^2/m^8$.

The relationship between the resistance and the size of the hole is given by;

$R\mu 1/d^5$

Where d is the hydraulic mean diameter of the opening.

In the calculation of ventilation flow it is this resistance that is of importance. Reality is that in the test situation it is impossible to directly measure the resistance of a damaged structure and the best way of determining it is to determine the leakage of air through the structure.

At Lake Lynne and in other instances where this has been tested, the pressure differential to create airflow over the structure is created by using a fan. A manometer measures the pressure differential. By installing a brattice or structure with a small hole of known dimensions in the airway the flow of air through this hole give the volume or quantity.

The hole is usually rather small as the flow of air through the seal is small and sufficient airspeed

**Table 3 Leakage rates for seals according to the USBM criteria**

| Pressure difference in kPa | Airflow in $m^3$ per cubic metre |
|---|---|
| <0.25 | <0.05 |
| <0.50 | <0.07 |
| <0.75 | <0.10 |
| >0.75 | <0.12 |

has to be obtained so that the flow can be measured by means of an anemometer.

It has become practice to present the acceptability levels in the form of leakage criteria in the form of a set pressure differentials and airflows.

It can safely be assumed that no changes will be brought about in the resistance of the structure in the testing process due to the presence of the brattice and therefore by using a curve representing the airflow relationship for a particular resistance, a whole range of testing criteria can be developed to suit the fan in the testing facility.

To develop the leakage criteria to be used for ventilation structures other than seals simulation exercises using resistances were done. Following consultation within the mining industry the following scenario was chosen:

- The VCD structures will form part of a panel of 3km in length.
- The size of the roadways would be 5 by 3 metres.
- The amount of air entering the section would be 50 cubic metres per second.
- Every VCD (stopping) in the panel will have the same leakage characteristics.
- No compensation for the attenuation of the explosion down the roadway would be made .
- The duration of the self-rescuer would only be 30 minutes and that a person can cover a distance of about 600 metres in that period. (For purposes of this calculation the placement of workers throughout the section is not taken into account)
- It is also assumed that when an explosive incident occurs it pollutes the whole panel.

In this exercise the critical value that had to be determined was the ratio of residual air in the last through road to the air entering the section.

This value should be such that it will allow the workers to be in clean air at 600 metres distance from the face and after 30 minutes.

In calculating the ratio it is further assumed that the contaminant gases will move in a plug through the headings and the ventilation flow will not dilute it and thus have a drag out effect.

Once the required residual flow has been calculated then the required resistance to obtain such airflow can be calculated. This in turn would give the maximum leakage that could be allowed in each stopping.

It should be noted that this value is not the value that would be accepted in the normal operating underground environment.

The value would be used as the criteria to determine if a stopping has withstood the effects of the overpressure after it had been subjected to a destructive test.

An initial exercise was used to obtain an order of magnitude result of the residual flow at the end of the panel that would be able to satisfy the fresh air criteria. A 3000m long panel consisting of two parallel roadways spaced 30m apart. In this panel 29 cut-throughs were placed at 100m intervals. Each cut-through had a 100 percent regulator placed in it. By changing the resistance of the regulators, thereby simulating the damage that the stopping had undergone, the amount of air reaching the face could be simulated. The resistances of the stoppings thus became the independent variable with the residual flow at the front of the panel the dependent variable.

**Table 4 Leakage rates to be used in testing ventilation control devices (other than seals)**

| Pressure differential in Pascal | Flow of air in cubic metres per second. |
|---|---|
| 10 | 0.271 |
| 50 | 0.606 |
| 100 | 0.857 |
| 150 | 1.049 |
| 200 | 1.211 |
| 300 | 1.484 |
| 400 | 1.713 |
| 500 | 1.915 |
| 600 | 2.098 |
| 700 | 2.266 |
| 800 | 2.423 |
| 900 | 2.570 |
| 1000 | 2.709 |

As all the stoppings in the simulation had the same value the results obtained gave a relationship that could be used to approximate the most suitable maximum leakage, or resistance, value.

It was accepted that this would not be the final value used but would give a very good indication of the allowable leakage that would ensure the fresh air to reach sufficiently into the panel.

Based on this initial exercise it was indicated that a residual flow of about 5.0 cubic meters per second in the last through road would be sufficient but that with a safety margin 9.9 cubic meters per second would be appropriate.

Using the accumulated time for air to move at each stopping the calculations were redone. This facility is available on the simulation package when the fresh air is used as a contaminant.

These calculations confirmed that a residual airflow of around 10 cubic meters per second would be sufficient to ensure that a worker could reach fresh air.

Making one of the airways into a belt road with the commensurately higher resistance an additional simulation was done to prove the validity of the figures.

Once the resistance characteristics of the stopping were determined they could then be used as the maximum leakage in a test that would be allowed for a stopping.

The resistance can also be stated in terms of a hole in the stopping. This should not be seen as being indicative of the damage but should be used as an indication only.

Using the formula for regulators areas the area of the regulators that will coincide with the resistance criteria of the stoppings is 0.378 $m^2$.

This is significantly larger than the area of a regulator that can be used to obtain the USBM criteria. Such a regulator for tests at LLEM would be 0.0042 $m^2$ in area.

In practical terms the criteria determined by this exercise indicates that a section with a set of holes through the stopping in the order of 0.378 $m^2$ each will still result in air reaching the face.

Using these results the following table sets out the criteria in terms of pressure difference and airflow that would be required to test the ventilation control devices are set out below in tables 3 and 4.

If the airflow through the actual stopping (after it has been tested) at a certain pressure difference exceeds that given by this graph then the stopping has failed the test

Table three presents the leakage rates as used in the LLEM test and is to be used for all seals.

The following leakage levels for ventilation control devices other than seals have been set to ensure the highest probability of maintaining a sufficient flow of air after the occurrence of an event in a mine.

**8 Conclusions**

The new and innovative methods for destructively testing seals and other ventilation structures are potentially viable alternatives. It can be foreseen that the testing of such structures will be done in smaller purpose built galleries or in special areas of mines.

This may lead to a reduction in the cost of testing. In all cases it will be critical that the quality of the instrumentation and competence of the persons conducting the test is documented and able to be subjected to re-examination

The use of non-destructive testing has application and merit in determining the state of ventilation structures in mines as well as determining the quality of installation.

It is however not seen as a method that in terms of both cost efficiency and reliability can be used to test innovative prototype structures.

The relaxed leakage rates for use with ventilation structures will be recommended for incorporation into the proposed Recognised Standard for the testing of ventilation control devices

This standard will also consider the use of innovative and alternative testing processes with the proviso that an organisation with the necessary competence to conduct the test conducts or oversee these tests.

In reviewing the testing methods better and more cost-effective methods of ensuring a higher standard of ventilation control structures may be developed in the near future.

**9 Acknowledgements.**

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