

Safety in Mines Research Advisory Committee

**Performance requirements for
locomotive braking systems**

**P Vermaak
T P T Page
A G du Plessis
W J Kempson
C F P Smythe**

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Executive Summary

Accidents involving rail bound equipment account for the greatest number of underground accidents away from the face. Although brake related accidents were in the minority, it is obvious that any equipment weighing over 60 tonnes must be capable of being stopped within a safe distance if serious incidents are to be avoided.

The main focus of the project was to determine the degree to which current practice in underground mines ensures the safe use of rail bound haulage equipment. The project investigated the specifications, design and braking performance of underground locomotives, excluding those used on high speed main haulages. In addition a survey was carried out on the most widely used types of locomotives and the braking systems. The survey gave an insight into the knowledge of the mine personnel of the rail bound systems on their mines. For a comparison with local practice, international standards, systems and legislation were acquired.

The project indicated that the matter of mine locomotive braking requires attention. Some of the issues that were identified were:

- An almost complete lack of local specifications;
- A lack of knowledge on the part of mine personnel of the rail bound equipment on their mines or in their care;
- The nominal mass of the locomotives in use being substantially different to the actual mass. This issue affects the ability of the locomotive to stop the train;
- Braking systems which can be rendered ineffective by the failure of a component in the transmission system,
- A complete absence of regular brake performance testing;
- Failure to regulate the hauled mass of trains or the ratio of un-braked hauled mass to mass of the locomotive which will affect the braking performance of the train;
- The absence of legislation, Codes of Practice or Procedures to address the un-braked hauled mass;
- Unacceptable delays in applying certain types of emergency brakes;
- The lack of training in, and the inability of locomotive drivers to, control skids;
- The difficulty in testing emergency brake systems due to the inherent braking action of the service brakes and/or locomotive controllers;
- Potential problems limitations to braking effort associated with the prime movers and/or hydraulic systems on hydrostatically driven locomotives;
- Failure to apply written instructions or equip the track with speed restriction signs where the visibility is below the stopping distance of the train.
- Failure to comply with the Minerals Act requirements for the employer to provide assurance on locomotive brake performance. Refer to Section 9.1.

Positive aspects identified during the project are:

- The attention being paid to legislation concerning rail bound equipment by MRAC;
- The compilation of SABS Codes of Practice for underground track and locomotive controllers; and
- The performance of the test equipment designed by LGI for the project.

The project left little doubt that more attention needs to be paid to locomotive braking. This includes:

- Compiling specifications for underground locomotives;
- Attention to design details and quality control by manufacturers;
- Technical and awareness training of train operation and maintenance teams, as well as production personnel involved with train operations, where applicable; and
- The compilation of mine Codes of Practice and Procedures.

Of all the equipment used to mine and transport ore, track bound haulage systems are most commonly overlooked provided that the production is not affected. In order to reduce incidents involving this equipment or to prevent potentially disastrous accidents, it is essential for more attention to be paid to the equipment.

The Project Team hope that this project will achieve that end.

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1 Background and objectives of the work

This project was motivated by a perceived need to address any potential hazard arising from the failure of braking systems in underground rail transport systems. Addressing this hazard is difficult because of the multi-dimensional nature of the problem. Braking system failures can arise from a variety of causes, including inadequate design, manufacture, installation, operation and maintenance. In addition, there is no uniformity and consistency regarding performance requirements of braking systems resulting in uniform standards being difficult to impose across the mining industry.

The objective of the work presented in this document was to address the issue of braking system performance requirements in a holistic, comprehensive and systematic manner, taking account of the practical limitations of measuring equipment (particularly devices for measuring retardation), and the conditions prevailing underground with regard to the environment, typical track conditions, and the availability of skilled personnel.

2 Methodology

The methodology employed for the project is discussed in detail in Section 3.6.

Briefly, the programme followed included:

- A review of local legislation and standards;
- A review of accident statistics;
- A literature survey of relevant material;
- A review of appropriate overseas standards;
- An investigation into the population and application of locomotives on local mines;
- An investigation into the specifications used by local locomotive manufacturers;
- Locomotive brake performance measurements on mines;
- Consideration of the engineering and performance specifications necessary to ensure adequate braking.

3 Project primary outputs

In order to draw up engineering and performance specifications for locomotive braking systems the following variables and guidelines were considered:

- Establishing a safe stopping distance.
- Establishing the inter-relationship of brake performance with the maximum permissible speed.
- Determining the ratio of hauled mass to locomotive mass.
- Establishing the track gradient to be used as the norm.
- Typical track conditions.
- Condition of brakes.
- Coefficient of adhesion between the brake shoes and the elements to which the brake shoes are applied i.e. wheels, discs or brake race.
- Coefficient of adhesion between the wheels and the rails.
- The typical rolling resistance of the train.
- Achievable brake ratios, defined as the ratio of the braking force of the locomotive to its mass in the case of:
 - Coupled axles – where both axles are mechanically coupled.
 - Uncoupled axles – where each axle is connected to its own drive without any mechanical coupling between axles.
- The draft MRAC Guideline for the Compilation of a Mandatory Code of Practice for the Operation of Underground Railbound Transport Equipment.
- Visibility.
- The train speed when entering a blind corner.
- The locomotive driver's reaction time.

- The requirements of the South African Bureau of Standards Code of Practice for Fail Safe Underground Mine Locomotive Control Systems —SABS 1809.
- The requirements of the South African Bureau of Standards Code of Practice for the Design, Construction, Maintenance and Safe Use of Permanent Underground Trackwork in Mines - SABS 0339.
- Number of brake systems that can operate individually or in combination with one another.
- Current legislation.
- Recommendations contained in SIMGAP 520 report on The Investigation of Safety of Rail Vehicles and Systems Operating in South African Gold Mines.

Based on the work carried out, which is detailed in the body of the report, the primary outputs that were determined are listed below.

3.1 Brake systems

From the dynamic tests, the study of international and local standards and experience gained in mining operations, the project team strongly recommend that any locomotive used underground to haul unbraked loads must be equipped with all of the following brakes:

- A service brake used for operational control of the locomotive;
- An emergency brake, independent of the service brake, for use during emergencies or in the event of failure of the service brake;
- A park brake designed to hold the locomotive and any connected load on the maximum decline on which the locomotive may be used.

Note - The project covers locomotives that are normally used in gold and platinum mines for the hauling of un-braked rolling stock and does not include major dedicated railway systems used by some mines. Where a locomotive braking system cannot meet the performance requirements referred to later in the document, the braking systems may have to be applied to all or part of the hauled rolling stock in addition to the locomotive braking.

Consideration of the emergency brake as the prime brake to be available should the service brake fail, led to an approach that differs from the standard used by the United Kingdom, where the park brake is the prime brake and the emergency brake is de-rated.

3.1.1 Service brake

- The service brake must be equipped with a “dead-man’s” function. A “dead man’s” function in this regard refers to the application of the service brake if the driver should release his grip on the locomotive controller.
- The service brake may be either:
 - A hydrostatic brake on hydrostatic drives
 - A neutral dynamic brake on battery or electrical drives.
- The braking effort of the service brake may be less than that of the emergency brake provided that a fully loaded train’s retardation can be controlled with ease and safety.

3.1.2 Emergency brake

This brake must be available for use at all times should the service brake fail. This implies that any components or parts of the service brake system that would render the service brake ineffective may not be used in the emergency brake layout.

The emergency brake must be capable of slowing down and stopping the locomotive and its maximum hauled mass within 60 metres from when the driver has cause to apply the emergency brake when travelling down the maximum decline on which the locomotive operates.

The emergency brake must comply with the following minimum specifications:

- Stop a fully loaded train travelling at maximum speed on the maximum gradient within 60 m on a straight line.

- Attain and maintain a minimum average rate of retardation of 0,18 m/s² without the support of any other braking system during the stopping operation. (The determination of the minimum rate of retardation is discussed in Annexure C.)
- The brake must work directly on each of the four wheels when mechanically applied, and indirectly on both axles when electrically applied.
- The time between the commencement of an emergency brake application to a noticeable reduction in speed must not exceed two seconds.
- The maximum stopping distance shall be 60 metres measured under test conditions.
- Skidding of the wheels shall be prevented as far as possible.

3.1.3 Park brake

The park brake must hold the train mass stationery, without support from any other braking system, at the maximum gradient and maximum load encountered with the particular locomotive application. The park brake may not depend upon an accumulated energy source.

3.1.4 General requirements of braking systems and components

- Where the braking effort is not directly applied to the wheels, the Factor of Safety of the component material specifications and wear limits, shall be determined by the supplier for all the components that form the link between the place of application of braking effort and the wheels. During maintenance of the brake system, or in the event of brake component replacement, the above criteria shall be maintained.
- The three braking systems referred to above may use common components, but any one failure in the common components shall not reduce the capability of the emergency brake to stop the locomotive or train safely.
- Where the operation of the service braking system depends upon accumulated hydraulic or pneumatic power, the system must include a reservoir capable of sustaining at least five consecutive full brake applications after the source of supply to the reservoir has ceased.
- The design of braking systems must be such that the temperatures of any of the components due to heat generated in the most severe braking conditions, must not be capable of igniting combustible materials that are likely to be present.
- The brake suspension components, linkages, levers and connecting rods must be designed and placed in such positions that the possibility of damage to such components due to derailling and re-railing is reduced, as far as possible.
- Where wear tolerances are critical for the operation of any brake system, components must be designed in such a manner that wear is eliminated as far as possible. The means used to achieve this requirement include, but are not limited to, pre-lubricated bushes or bearings or bearings or bushes equipped with lubrication facilities.
- Should operating conditions prevent any of the braking requirements listed in Sections 3.1.1 to 3.1.3 above being met by the locomotive braking, then the respective braking system shall be extended to the entire train or part of the train.
- Where brake links, pivots and connections are secured by means of split pins or circlips, the brake links, pivots or connections must be designed in such a manner that no thrust will be applied to the split pins or circlips due to wear or misalignment.

3.1.5 Quality control for braking systems

Suppliers of new equipment, companies that overhaul brake components and companies that supply replacement components must make the following information available to the users:

- Specifications of materials used.
- “Go/no-go” wear tolerances.
- Non destructive test results of critical components, which, should they fail, may impact on brake performance.
- Discard age of components.

Users of locomotives underground must ensure that the following arrangements and standards are in place and maintained:

- Only reputable companies are used for the supply of brake components and for the

- overhauling of locomotive brake systems.
- Only trained and appointed persons are allowed to repair and maintain braking systems.
- Inspections and maintenance intervals are done on a regular basis.
- Comprehensive reports on the maintenance done and the components checked and/or replaced by authorised persons are completed, carefully scrutinised and kept on record for each locomotive.
- Over inspections are conducted on a regular basis and such over inspections and findings are reported in the records referred to above.

3.1.6 Additional considerations

Regardless of safe stopping distances that may be attained from the above, the following additional measures need to be applied:

- Speed restrictions must be enforced for the driver to be able to stop the locomotive within the line of sight for any particular section of the track including corners.
- The track condition must be examined and classified and the maximum speed trains may travel on a straight line must be determined in terms of SABS 0339. (Annexures F and G.)
- Cognisance must be taken of other factors that may influence brake performance on any section of the track or in conditions applicable to any section of the track, and speed restrictions or other appropriate action must be taken to eliminate dangers arising therefrom. These factors are listed in Section 3.5 - Other Factors Influencing Brake Performance.

3.2 Brake shoe material

A survey of the materials used for brake shoes indicated that many different types are in use. This can partially be explained by the fact that retarding effort is obtained by:

- Brake shoes used in conjunction with brake drums;
- Brake shoes or brake pads being applied directly to the wheels;
- The use of disc brakes and brake pads.

The following brake lining materials are currently being used on mines:

- Cast iron and cast steel.
- Rubber composite.
- Rubber and steel compound.
- "Harmonised composite".
- Ferodo including brass impregnated Ferodo and steel backed Ferodo.
- Steel backed rubber lining.
- Polyurethane.
- Nylon.
- Plate packs.
- "Elastomer reinforced malleable iron".
- "Master medium blocks".

Based on the survey results it could not be determined without doubt that asbestos-free brake lining material has been completely eliminated. In addition, where polyurethane brake lining material is being used, it could not be confirmed that it will not emit potentially harmful gas when heated by the braking action.

Due to the variety of braking systems, it is not feasible to specify particular brake lining materials. However, the materials in use must comply with the following:

- Ensure that the braking systems comply with the requirements specified in this report. This implies that the materials must provide sufficient braking effort to ensure that the train may be stopped at a rate of retardation and within the distances specified in Section 3.1.2.
- Be asbestos free.
- Maintain adequate coefficient of friction when heated by the braking action.

- Are non-combustible.
- Do not emit potentially harmful gas or dust.
- Have adequate service life to ensure that the linings do not deteriorate to a dangerous degree from one service to the next.
- Do not cause a greater rate of wear to the brake drums, brake discs or wheels than the rate of wear of the brake materials themselves.

3.3 Deceleration

In order to arrive at an acceptable deceleration it is necessary to determine an acceptable stopping distance for a train under worst case conditions.

An acceptable stopping distance depends on:

- The available lighting on the locomotive or the front vehicle in the case of propelling.
- The visibility of potential hazards. In this regard the ability of the driver to see or determine the position of rail switches, or other material on the track such as spillage, requires consideration.
- The range of vision at bends or curves on the track.
- The means of communication between the guard and the driver when propelling.

The project team recommend a stopping distance of 60 metres on a straight section of a clean, un-sanded track at the maximum downgrade to which the locomotive will be exposed in operation, and provided that:

- The locomotive lighting ensures a clear visibility of at least 60 metres on the straight.
- The driver's visibility is not affected by the presence of dust or mist.
- The locomotive is hauling and not propelling the train.

Based on a stopping distance of 60 metres as stated above, a deceleration of 0,18 metres per second squared is recommended. The details of the considerations for this rate of retardation are contained in Annexure C.

Should any sections of the track not comply with the above conditions, then speed restrictions must be applied to ensure that the train may be safely stopped. It should also be noted that sections of the track which are wet or muddy may require speed restrictions to ensure that the train may be stopped safely.

It is further recommended that an official be appointed whose duty it would be to regularly survey the track and determine where speed restrictions should apply, including maximum speeds in propelled modes if applicable. Such information should be entered into a logbook kept for the purpose, and a procedure to bring the restrictions to the attention of all drivers who may use the track should be instituted.

3.4 Ratio of un-braked mass to locomotive mass

The stopping or braking effort available for a train in which the locomotive is the only vehicle equipped with brakes is dependent only on:

- The locomotive mass.
- The limiting coefficient of friction between the locomotive wheels and the rail.

Since the deceleration is equal to the braking effort divided by the train mass, it follows that the mass of the un-braked section of the train has a direct bearing on the rate of retardation and the stopping distance. Consequently, it is essential to consider the relationship between braking effort and train mass. This is most easily expressed as a ratio between the mass of the un-braked section of the train and the locomotive mass.

The SIMGAP 520 report on The Investigation of Safety of Rail Vehicles and Systems Operating in South African Gold Mines referred to a formula used in the United Kingdom to determine the acceptable ratio of un-braked mass to locomotive mass.

In addition, the braking tests carried out on mines gave an indication of acceptable ratios. The actual ratios on trains used for the tests varied between 4,9 and 11,3. Although some of the brake tests were adequate in the case of trains with high ratios, it must be borne in mind that some of the locomotives involved had been prepared for the test and were in excellent condition. In addition the track was in ideal condition.

Based on the UK formula and taking cognisance of the affects of wear and less than ideal operating conditions, a ratio of 6:1 is recommended. This gives adequate deceleration under conditions that are likely to be encountered in practice.

3.5 Other factors influencing brake performance

From a limited number of tests carried out by the Research and Laboratory Services Division (RLSD) in the UK, the following conclusions were drawn:

- Coefficients of adhesion are variable, even for locomotives with the same method of coupling.
- Coefficients of adhesion on dry rails are normally higher than on wet rails.
- Coefficients of adhesion developed by uncoupled bogie-mounted locomotives are higher than those developed by similar coupled and equal or better than coupled fixed frame locomotives.

The brake performance tests on the mines were carried out on a straight section of track that was clean and in a good condition. The results obtained were therefore better than would have been the case if conditions were less than ideal. (Refer Annexures L, M and N.)

Issues that affect braking performance, or the distance within which a train can be stopped, include:

- The speed of the train.
- The driver's reaction time.
- Wet or muddy track.
- Mechanical condition of the track.
- Super-elevation or the lack of super-elevation on curves.
- Dirt on the wheels of a locomotive.
- Differences between the nominal and actual mass of a locomotive.
- Dirt or water on the brake materials or brake shoes/discs.
- Maintainability of brake systems.
- Wear on, or damage to, brake linkages.
- Settings on hydrostatic drives. Refer to Section 9.6.
- Control system settings on battery locomotives.
- Prime mover characteristics. Refer to Section 9.6.
- Effectiveness of the locomotive or vehicle light.
- Obstructions to the driver's line of sight, such as curves or bends.
- Control system layout.
- Loose items or retrofitted equipment in the driver's cab.
- Visibility from driver's position.
- Environmental conditions, including dust or mist in the air, or excessive noise.
- Communication between guard and driver.
- Over loosening of the handwheel on a handwheel operated brake.
- The failure of chains on chain driven systems where the brake is not applied directly to the wheels.
- The rate of brake application.
- The position of the centre of gravity.

- The height of the draw bar.
- The resilience between the couplers of the train.
- The suspension characteristics of the locomotive.

3.6 Methods, systems and equipment for regular performance testing of braking systems underground

3.6.1 Dynamic brake testing pre-planning and procedure

In order to conduct dynamic tests in a safe manner a risk assessment should be conducted, and a testing procedure compiled. Because of the nature of the tests such procedures must be machine and site specific.

It must be emphasised that a dynamic brake test of each of the brake systems may introduce dangers which are potentially more serious than the consequence of not testing locomotive brakes. In order for the tests to be safely conducted it is essential that proper procedures be drawn up and risk assessed.

Brake testing procedures are site and machine specific. In order to conduct brake tests in a safe manner a procedure must be drawn up to take cognisance of at least the following:

- The appointment of one person who will take overall charge and give all necessary instructions.
- The test track must be inspected by the person in charge to satisfy himself that it will be safe to conduct dynamic tests.
- All switches on the test track must be locked and remain locked in a safe position for the duration of the test.
- The portion of the track to be used for the test must be clean and free of oil, sand, dirt or spillage.
- In order to ensure that brake performances are not affected by other retarding forces, it may be necessary to disconnect drives. An example of such a case is the retarding effect of the hydrostatic drive when the performance of the mechanical brake is to be tested. In order to carry out such a test the removal of drive chains between the hydrostatic drive and the drive wheels of a locomotive is necessary.
- The length of the test track and the distance to shaft safety devices or other stopping devices must be such that a collision with such devices is avoided.
- A survey of the gradient of track or portion of the track where performance tests are going to be conducted should be carried out.
- Both ends of the track and any other entrances into the test track should be guarded or barricaded to prevent persons entering the area where the brake tests are being carried out.
- Personal protective equipment should be provided for persons conducting tests.
- Static brake tests should be carried out before dynamic tests are conducted.
- In any situation where one of the brake systems is rendered inactive, as indicated in the tests for hydrostatic drives, an additional means of emergency braking should be available under all conditions, should the brake undergoing a test fail. This additional means may be an additional locomotive forming a part of the train.
- The mass of the locomotive and rolling stock must be recorded for each test.
- Batteries must be fully charged where battery locomotives are going to be tested.
- Licensed locomotive drivers must be driving the locomotives under test and the standby locomotive, if applicable, should be manned by a licensed driver.
- The track past the point at which the locomotive should come to a stop may be sanded should the responsible person deem it necessary to provide over-run protection. The sanded portion of the track may not, however, form part of the track used for the dynamic tests.
- In certain cases the locomotive control system may interfere with the testing of the individual brake systems during a dynamic test. It is essential that steps are taken to ensure that the action of the controller does not hide a brake defect. This matter is discussed in Section

3.6.5.1 below.

- The procedure should be authorised by the responsible engineer.

3.6.2 Schedule for brake tests

The SIMGAP 520 report recommended that the following brake tests be carried out:

- Static functional tests should be carried out every seven days;
- Dynamic test should be carried out every seven days, on a designated test track, under the most onerous conditions; and
- Examination and test of the braking system should be carried out after an adjustment, repair or replacement of parts.

In addition it is recommended that locomotive drivers be trained to conduct some basic brake tests on locomotives at the commencement of each shift.

A procedure for conducting drivers' tests needs to be drawn up to satisfy the requirements of each type of locomotive braking system. The drivers and any other personnel conducting the tests should be trained on the procedures to be used.

3.6.3 Static brake tests

There are many factors that influence the testing of braking systems in a static mode and it is thus difficult to specify a test that will satisfy all brake/drive types as an output of this project. However, to ensure consistency and reasonably reliable brake performance monitoring, the following recommendations must be instituted as a minimum requirement:

- Each locomotive must be equipped with a reliable drive motor ammeter or pressure gauge.
- The static brake tests must be conducted with the locomotive parked on a reasonably horizontal rail.
- The locomotive must not be connected to any load.
- The holding torque of the park brake as observed on any of the instruments referred to above must not be less than twice the reading that is required to start moving a fully loaded train up the maximum operating gradient.
- The holding torque of the emergency brake, in the case of mechanically applied brakes, as observed from any of the instruments referred to above, must not be less than the limit specified by the supplier or the brake slipping reading recorded immediately after a successful dynamic test was conducted.

The recommendation is that at the start of each shift the locomotive driver must, before putting a locomotive in use, conduct static brake tests, as specified above, to satisfy himself that reasonable steps have been taken to ensure that the brakes are safe for use.

3.6.4 Dynamic brake tests

Ideally, metered dynamic tests on locomotives should be conducted at six-monthly intervals. However, such tests cannot be carried out on all mines, particularly those where only one locomotive serves a level.

It is thus recommended that each mine conduct a risk assessment that will satisfy their requirements with respect to the frequency of dynamic tests. As a minimum requirement, it is recommended that full metered dynamic brake tests be conducted on all locomotives:

- Before a locomotive is put in use for the first time.
- After a major service, before the locomotive is put in use.
- Before a locomotive is put in use after major changes of the brake system or systems.
- After a major accident or incident where the accident or incident was caused by or could have been caused by the failure of any component of the locomotive brake system.

3.6.5 Special considerations for dynamic brake testing – controller action

In order to produce test results on braking systems in such a way that specific brake tests are not effected by other means of braking, the following measures may have to be taken.

3.6.5.1 Battery/electric locomotives (Refer Annexure H)

Battery and electrical locomotives may be equipped with a dynamically operated “Neutral Brake”. This brake may become active immediately or after a certain time delay when the controller is placed in the neutral position or moved into the neutral position by the “dead-man’s device”.

Because this brake will interfere with the action of the mechanical brake, if it is to be tested, it will need to be inhibited for the test duration. In order to ensure adequate backup, should the braking system under test fail to bring the train to rest safely, an alternative means of braking must be available. This could be accomplished by ensuring that dynamic braking or reverse power braking of sufficient capacity on the same locomotive is kept available. The Annexure referred to above highlights the modes of alternative braking systems to fall back to in case of an emergency.

3.6.5.2 Hydrostatic driven locomotives (Refer Annexure I)

Hydrostatic braking is naturally introduced when the locomotive control lever is moved to the neutral position either by the driver or by the “dead-man’s device” and will interfere with the test results when other brake systems are tested. It is also not recommended to stop the hydraulic drive pump source while such a test is conducted because this could also cause interference by the hydrostatic system generating limited braking effort.

To ensure that the brake test is not affected by any hydrostatic interference, the locomotive hydrostatic drive must be disconnected by removing the drive chains. Because the locomotive will, in such a case, not be able to move the train, another locomotive will be required to haul the train to the test speed, stay connected to the train and be available to assist to stop the train should the brakes of the locomotive under test fail. The other locomotive should preferably be a battery locomotive with the “Neutral Brake” facility, if applicable, inhibited.

3.7 Recommendations for mine maintenance procedures

A. The following are recommendations for mine maintenance procedures:

- It is most important to enforce proper maintenance procedures to ensure that braking systems work efficiently when required.
- Every component of the braking system needs to be examined carefully at regular intervals.
- It is recommended that the checking and reporting of the condition of such components be done on a schematic sketch of the brake system. An example of such a schematic representation is referred to in Annexure J.
- Facilities to make it easy for maintenance personnel to gain access to the entire brake system should be provided at each workshop where maintenance is carried out. This will also have the added advantage that locomotives out-of-use time is reduced. The facility will also enhance safety.
- Locomotives “call up” schedules for maintenance must be respected by users and must always be complied with.
- After a maintenance service, regardless of whether a pre-use inspection was conducted before the machine was serviced, a pre-use inspection checklist must be completed by the driver, in the presence of the responsible maintenance personnel, before the locomotive is put into use.
- If any components of the brake system have been replaced, or changes made to any settings that could affect the locomotive braking, a “bench mark” test should be carried out on the locomotive.
- Following every service a static test shall be carried out before the locomotive is put into

service.

3.8 Recommendations on test equipment for brake performance testing

B. The following recommendations are made:

- No test equipment may be used unless approved by SABS.
- Vibration or shock resulting from the tests or track conditions may not effect the accuracy of any of the equipment used.
- Test equipment should consist of at least the following:
 - A hand or foot operated switch or potential free contact on respective control devices to identify the driver's response.
 - A distance transducer to measure the actual distance under test.
 - A speed transducer to measure the actual speed.
 - A sensor to record wheel slip placed on each axle to which brakes will be applied. Only one sensor will be necessary when axles are coupled during the test.
 - A multi-channel high speed data acquisition unit.
- The energy storage device, when applicable, shall be tested weekly at intervals not exceeding ten days. The test is to be conducted by disabling the source of energy supply to the energy storage device. The brake shall then be fully applied and released repeatedly, while recording the stored energy pressure after each brake application and recording the number of brake operations achieved before the stored pressure drops below the safe operating level. The number of full brake applications must not be less than five.

4 Measurements of braking performance

4.1 Results of brake tests

The full description of the brake tests is contained in Annexure C.

The results of the brake tests are summarised in Table 4.1 below.

Table 4.1
Summary of Results of Brake Tests

Type of Brake	Time delay to partial application (seconds)	Time delay to full application (seconds)	Average rate of retardation (metres/second squared)
Hand wheel applied	0,67 to 3,70	1,83 to 4,53	0,17 to 0,24
Hydraulic to all wheels	N/A	N/A	> 0,2 in all cases

Some of the important factors identified during the tests were:

- The rate of retardation of $0,2 \text{ m/s}^2$ and better was obtained with locomotives fitted with hydraulic brakes on all 4 wheels even when the wheels were skidding.
- The skidding of wheels where uncoupled axles applied was difficult if not impossible to observe.
- The drivers did not apply any corrective action when skidding was detected.
- The maximum speed obtained during the tests was lower than expected. The average speed was 9 km/h with a maximum of 12 km/h.

4.2 Drivers' reactions to brake tests

While conducting dynamic tests it was noticed that most of the certificated drivers were not comfortable in executing such tests. This could be attributed by the fact that they were

surrounded by strangers or they may not have had much trust in the braking systems.

It should be pointed out that the tests were preceded by carefully explaining to the driver what was expected from him for each brake test. The conducting of such tests on a regular basis could improve drivers' driving experience, trust and self esteem.

4.3 Nominal locomotive mass

The locomotives that were used for the brake tests were weighed before the tests were carried out. This was done to accurately determine the ratio of un-braked mass to locomotive mass.

It was immediately apparent that the nominal locomotive mass was in most cases different from the actual locomotive mass. Of the 6 locomotives that were weighed, the two locomotives closest to the nominal mass were 94 percent and 106 percent of the nominal mass. The actual mass varied from 70 percent to 130 percent of the nominal mass.

It is obvious that the mass ratio referred to above could be substantially reduced if the locomotive mass is below the nominal mass.

4.4 Recommendation on locomotive mass

The following recommendation is made to obviate the factors mentioned above:

- All locomotives should be weighed.
- In the case of a new locomotive, the supplier should be required to provide the mine with a certificate indicating the true locomotive mass.
- Before a locomotive is sent underground after repair or overhaul the locomotive should be weighed on a surface weigh bridge.
- A plate, fitted to the locomotive in such a way that it is unlikely to be lost or damaged, should indicate the actual locomotive mass.

5 Hazard identification

Section 11 of the Mine Health and Safety Act (MHSA) covers risk assessments comprehensively. Proper compliance with this section will result in the elimination or the reduction of risk. It is found in practice, where risk assessments are properly conducted, involving knowledgeable representatives and manufacturers or suppliers, that most machinery and operational hazards are identified and corrective measures taken.

The hazard identification in this section of the MHSA is further refined in periodic reviews of identified hazards and conducting investigations of accidents, serious illness and health threatening occurrences and the following up that is required.

The Project Team's comments on the risks identified during the project execution are the following:

- Without the aid of a speed indicator mounted in the locomotive cabin, the enforcing of speed restrictions is impossible. Some mines refer to slow speed as 'walking speed'. The provision of speed indicators will play an important part in reducing risk where hauling is carried out using speed signs to indicate suggested or maximum speeds for ensuring that a train is stopped timeously when required.
- The leading ends of trains are not always well illuminated. This condition is made worse when trains are being propelled (pushed) where, in many cases, the only illumination relied upon is that of the caplamp of the guardsman.
- Some mines require trains to be hauled at a "slower speed" when being pushed by a locomotive.
- One mine is busy developing a driver's car that will be permanently mounted at the rear end of the train from where the locomotive driver will be able to remotely operate the train in a propelling mode. This system will ensure that the driver is always placed at the leading end of the train facing the direction of travel. This system will eliminate delay between the

guard's signal and reaction from the driver.

- In addition to the above, a further risk that will be eliminated is loss of contact with the guardsman. This is considered a positive step towards the reduction of hazards associated with the pushing of trains.
- The narrowing of rail gauges around corners is a condition that is found on some tracks where strict control over the installation of rails is not maintained. The narrowing of the gauge leads to the practice of entering the bend at speed to ensure that the train is not stopped. The speed used in such an event could exceed the safe speed for the curve.
- Another form of hazard identification is the careful scrutiny of maintenance reports, pre-use inspection checklists and track reports.
- The introduction of regular metered dynamic tests on trains will play an important part in highlighting possible hazards caused by ineffective brake systems.
- Drivers' performance should be monitored regularly by their supervisors.
- Over inspections by supervisors of maintenance personnel's performance and compliance to standards remain a valuable means of identifying potential hazards.
- Illumination requirements for trains in terms of the Minerals Act and Regulations, are poorly specified. Notwithstanding the above, train lights in the direction of travel, as observed during brake testing and other visits, are generally of a low standard.

Other hazards identified during the course of the project have been covered in this report under their associated headings. In particular, refer to Section 7 below for engineers' perceptions of risks.

6 Legislative matters being considered by MRAC

The MRAC Working Committee preparing the guideline for the compilation of a Mandatory Code of Practice for the Operation of Underground Railbound Transport Equipment is currently busy with the amendment of existing, and the preparation of new, brake related regulations for the Department of Minerals and Energy.

This involves:

- The critical examination of Chapter 18.
- Defining the requirements for locomotive brakes, including park, service and emergency.
- Locomotive driver's static brake tests.
- Dynamic brake tests.
- Locomotive lights.
- Ratio of unbraked hauled mass to locomotive mass.
- Minimum rate of deceleration.

7 Mine engineers' comments on locomotive braking systems

The following is a summary of the responses by engineers on locomotive braking problems contained in the questionnaires sent to the mines.

- Excessive wear was experienced on brake linkages that makes them difficult to maintain.
- Wear tolerances on certain components are critical for the safe application of brakes.
- De-railing is a major cause of damage to braking components.
- Braking systems are damaged when locomotives are incorrectly towed.
- Braking linkages require a high level of maintenance.
- Some functions can be bypassed permanently.
- Brake components are sometimes bulky which makes maintenance difficult.
- Mud accumulation between shoes and wheels affects brake performance.
- Skidding occurs when brakes are applied.
- Skidding correction is difficult to apply.
- Long reaction times are encountered on brake systems applied by hand wheel.
- Over winding of hand wheel towards the off position results in an increase of the driver's

- reaction time.
- Brake shoes are being pushed out of position because of the taper of the wheels.
- Brake shoes are difficult to fit where collars are provided to prevent shoes been pushed out.
- Excessive power is required by the driver to apply some brakes.
- Dynamic braking is lost when the battery power supply fails.
- Loose equipment in the driver's cabin like jacks, chains etc. makes it difficult for the driver to apply the brakes swiftly during emergencies.
- High ratios of hauled mass to locomotive mass are often experienced underground.
- Freewheeling practices are experienced on downgrades.
- Corrosion of linkages and pins affects brake application.
- The failure of chains on chain driven systems where the brake is not applied to the wheels causes locomotives to run out of control.
- Substandard maintenance methods render brakes inoperable.

8 Comments on the information obtained from the mines

As can be observed from the information obtained from the mines:

- There appear to be many brake problems and hazards as a result of:
 - Design shortcomings.
 - Substandard maintenance practices.
 - Misuse by operational personnel.
 - Environmental conditions.
- In most cases locomotives and their attached loads were not weighed.
- From some replies received it was evident that some engineers were not familiar with brake systems used.
- There were many more types of brake lining materials in use than the Project Team expected. It is also doubtful whether asbestos-free brake lining material is no longer in use. It was further not confirmed that where polyurethane brake lining material is being used it will not emit dangerous gasses when subjected to excessive heat.
- In most cases no formal dynamic brake tests were conducted.

9 Results of the literature survey

9.1 Current legal requirements

The South African Minerals Act and Regulations require self-propelled machines to be equipped with a device or a combination of devices to prevent unauthorised operation. It further requires locomotives to be fitted with a braking system or systems capable of safely stopping and holding the locomotive or train under operating conditions.

A further requirement for locomotive braking systems is the assurance by the respective employer that the braking systems in use are designed, operated, maintained and tested in accordance with an appropriate safety standard. Compliance with this requirement of the regulations was found to be minimal. It is assumed that the poor compliance can be ascribed to the recent introduction of the legislation referred to above.

9.2 Accident review

Detailed comments on the accident review carried out are contained in Annexure B. Some of the more important findings are summarised below:

- Brake design specifications were questioned in a limited number of cases.
- Earlier accident reports indicate a lack of appreciation of a means of managing an investigation on a broad basis, although more recent reports indicate a more realistic approach.

- More emphasis should be placed in investigations on issues such as:
 - The loads hauled by the locomotive or locomotives at the time of the accident.
 - A request for a report of possible recent brake tests.
 - Written proof of maximum permissible speeds at the place of the accident.
 - The maximum speed the respective locomotive may attain.
 - The physical condition of the brake systems.
 - A professional judgement of the maintenance standards.
- The following acts and conditions were noted in some cases as, major causes of accidents:
 - Collisions around blind corners.
 - Hydrostatic failures.
 - Engine cut out at speed on down hill.
 - Burst hydraulic pipe at speed on down hill.
 - Skidding when brakes are applied during emergency situations.
 - Loss of braking when drive chains fail and brakes are not directly applied to the wheels.
 - Lack of standards or compliance with standards with respect to maintaining a safe following distance when two locomotives are following each other in the same direction.
 - Non compliance of check list procedures.

9.3 Contents of the SIMGAP 520 report

9.3.1 With reference to legislation

A. The following findings of SIMGAP 520 with respect to legislation, are relevant:

- Currently, South African Regulations enable drivers as young as 18 years old to drive trains. It is recommended that consideration be given to increasing the minimum age of drivers to, say, 21 years old to ensure that guards have some experience of haulage prior to upgrading to driver.
- Only the UK requires a “dead man’s” device, or driver-in-position switch, to ensure that the locomotive can only be operated with the driver in position. This is considered to be a very important safety feature and it is understood that the Department of Minerals and Energy proposes a similar requirement.

9.3.2 With reference to locomotive braking

The following brake related extracts refer:

- By implication or by specific reference, all countries (covered by the project) require at least a service brake and an emergency brake.
- The UK and Australia require at least one brake to be applied by direct mechanical action from the driver, or by spring application, and the UK, Australia and USA (coal mines) require at least one brake system to be automatic or fail safe.
- The South African Department of Minerals and Energy proposed a rule which will require a train to stop within an acceptable distance. This appears to be a similar requirement to the old UK Codes and Rules requirement to stop within 60 m, the nominal range of a headlight. However, in the light of experience, the UK now bases brake performance requirements on a minimum deceleration of 0,2 m/s², the maximum train load for a particular gradient being calculated using the Research and Laboratory Services Division (RLSD) formula which incorporates this minimum figure.
- Australia also use a minimum retardation standard but the chosen figure of 0,1 m/s² was deemed by the UK Inspectorate to be too low for the driver to discern if the train was slowing or not.
- The UK and Australia have regulations for dynamic testing of brakes, both specifying that this should be carried out at least every seven days.
- The brake performance requirements for the UK and Australia have to take account of the steeper gradients on which steel tyred locomotives are permitted to operate in these countries; 1 in 15 and 1 in 12 for the UK and Australia respectively compared to 1 in 200 in South African gold and platinum mines. Nevertheless, using the UK RLSD formula for braking of a ten tonne steel tyred locomotive on a 1 in 200 gradient, assuming a coefficient

of adhesion of 0,16, gives a maximum allowable load of 56,5 tonne compared to the South African 6:1 'rule of thumb' figure of 60 tonne.

9.3.3 With reference to national standards and specifications for the design of locomotives and rolling stock

- A. The following findings of SIMGAP 520, are relevant
- National standards for underground locomotives and rolling stock do not exist.
 - Currently a number of standards are being drafted, in particular a standard for locomotive controllers and a standard for underground rail systems.
 - South African manufacturers do not work to any recognised written standards but tend to supply the equipment in accordance with the mine's requirements.
 - In many cases the mine specifications do not appear to be well documented but are based on the equipment previously supplied, with certain amendments or additions as specified by each mine.
 - It is understood that in South Africa and USA mines there is a rule of thumb of 6:1 for the ratio between maximum trailing load and locomotive weight.

9.3.4 With reference to training issues

- B. The following findings of SIMGAP 520, are relevant.
- A major strategy in reducing accidents is training. This includes hazard awareness training in addition to operator training.
 - At the mines visited, the training of drivers and guards was carried out at the mine operators' own training school.
 - Once selected for training, guards and drivers undergo the same course and are passed out and authorised to undertake either duty. This is in sharp contrast to UK coal mining practice where a driver can only be entered for driver training having already undergone a comprehensive shunter (guard) course, and then worked as a shunter for some time.
 - One locomotive driver training school was visited and the facilities were found generally to be very good, with typical track layout being set up in simulated mine track systems.
 - The locomotives on which the training took place appear to be of the same type as those seen underground although in considerably better condition. For instance, the drive controls returned to neutral when released. However, although the locomotives were of the same type, the loading box and the tipping arrangement were not. It is understood that arrangements were in hand for the supplier of the underground loading boxes to provide the correct type at some later date but in the meantime, a large number of men would have been trained on inappropriate equipment.
 - Similarly, the track switches were fitted with operating mechanisms which would not be found underground.
 - Some of the training courses are classroom based, to learn the operating rules, relevant regulations and details of the locomotive and its maintenance. Practical training then follows which includes both shunting and driving duties. It was estimated by the instructor that a driver would typically have about 20 hours actual driving experience during the training course. The courses are of a set length and drivers undergo a test at the end, supervised by the chief instructor.
 - In the UK, the shunter and driver courses are each a minimum of 20 days each. Trainees undertake a standard based assessment which gives some flexibility in the length of training to enable weak areas to be addressed adequately. The trainee's rate of progress through the course therefore depends upon personal attainment and the ability to demonstrate the acquisition and application of the skills to required standards.
 - The 20 days basic course allows the driver to drive one type of locomotive. Further training is required before the driver is certificated to drive another locomotive type.
 - Training is next undertaken underground under the supervision of a qualified instructor which ensures that conditions reflect real situations and equipment. Although the training is underground, the location in which training takes place has to be approved. Drivers would be expected to spend at least 60 per cent of the course time actually driving a locomotive.

- Training courses include a component covering accident prevention. This involves the use of relevant case studies. The awareness of the hazards involved in locomotive haulage systems is very important since it gives some purpose to all the rules and regulations. When British Coal operated the majority of the coal mines, it issued a booklet on locomotive driving which contained a useful section which illustrated typical types of accidents. Topics covered, of which many are common to the South African industry, were as follows:
 - Skidding.
 - Driving from outside the locomotive cab.
 - Insufficient haulage clearances.
 - Derailments (poor track, excessive speed).
 - Insecure parking.
 - Driving in forbidden areas.
 - Driving at excessive speed.
 - Unauthorised riding on the locomotive.
 - Poorly maintained locomotive.
 - Poor signals.
 - Not ensuring that the track ahead was clear.
 - Passengers jumping from moving trains.
 - Men slipping in locomotive haulages.
 - Catching feet in switches and crossings.
 - Using rods and chains to haul/propel vehicles.

9.3.5 Relevant recommendations contained in the SIMGAP 520 report

The following recommendations were made in the report:

- Locomotives should be approved by an inspection authority approved by the Chief Inspector.
- Locomotives should be fitted with a means, such as a keyswitch, to prevent operation by unauthorised persons.
- Locomotives should be provided with service, emergency and parking brakes.
- The emergency and parking brakes should be applied directly to the wheels or a shaft permanently connected to the wheels.
- Locomotives should be provided with means to apply the brakes automatically if the driver leaves the cab.
- The following brake tests should be carried out:
 - Static functional tests should be carried out every seven days;
 - Dynamic test should be carried out every seven days, on a designated test track, under the most onerous conditions; and
 - Examination and test of the braking system should be carried out after an adjustment, repair or replacement of parts.

9.4 The South African Bureau of Standards Code of Practice for the design, construction, maintenance and safe use of permanent underground trackwork in mines – SABS 0339

The Code of Practice highlights the importance of speed with respect to track conditions and should be used as a minimum requirement when maximum speeds are to be set for hauling ways.

Maximum haulage speeds, on straights, as proposed in the Classification Criteria (Annexure F) with reference to the Maximum Permissible Deviation (Annexure G) are recommended in the Code of Practice.

9.5 The draft MRAC guideline for the compilation of a mandatory code of practice for the operation of underground rail bound transport equipment

The MRAC (Mine Regulations Advisory Committee) Guideline refers to the following items associated with braking systems:

- Definitions of:
 - Brake:
 - ◆ Emergency brake
 - ◆ Park brake
 - ◆ Service brake
 - Deceleration rate
 - Dynamic brake test
 - Gradient
 - Safe stopping distance
 - Static brake test
 - Train
 - Unbraked mass
 - Visibility/Field of vision
- Specifications and design:
 - Basic design of the park, emergency and service brakes
 - Design calculations with respect to power, speed, brakes, deceleration, skidding, surface friction and gradient
- Section 21 of the Mine Health and Safety Act
- Data displayed on locomotive:
 - Manufacturer's name
 - Mass
 - Maximum designed speed
 - Maximum permissible hauled load mass
 - Maximum braking effort
- Provision for a mechanical brake system for remotely controlled locomotives
- Tracks/Rails compliance with SABS 0339
- Maintenance:
 - Braking systems
 - Dynamic and static brake tests
- Operational requirements:
 - Classification of rails with respect to maximum permissible hauling speeds in terms of SABS 0339
 - Emergency procedures
 - Parking
 - Lockout systems
 - Pre-start check list including static brake test
- Health and Safety devices:
 - Dead-man's-device
 - Testing of devices
- Personnel:
 - Selection criteria
 - Training criteria complying with Section 10(3) of the Mine Health and Safety Act
- Record keeping of selection, training, re-training, certification, authorisation and appointment of railbound operational and maintenance personnel
- Code of Practice implementation plan
- Compliance with the Code of Practice
- New and amended Regulations

9.6 Suppliers' specifications for new locomotives

In an attempt to cover the project, as fully as possible, visits to reputable suppliers of battery and diesel locomotives as well as battery locomotive controllers and hydrostatic drives were arranged. It was felt that possible useful information could be gathered on suppliers views in providing safer locomotive brake systems in the future. The results of these visits are discussed in this section.

9.6.1 Battery locomotives

Most battery locomotives that are being used underground are equipped with dynamic brakes. The dynamic brake makes use of battery power to operate contactors that dissipate motor motion energy generation by means of an energy discharge resistor, thereby providing a braking force while the locomotive is in motion.

Some battery locomotive controllers allow reverse power braking where contactors or switches are configured to reverse the battery polarity and so provide a torque that opposes the motion of the locomotive.

In both the above cases the braking action is dependant upon the battery supply being healthy enough to energise the contactors and/or provide sufficient reverse torque. Should the battery supply fail when electrical braking is applied, all braking is lost.

Approximately 1,5 per cent of the battery locomotive population underground is equipped with the latest generation of electrical braking facility that is not battery supply dependent. Such controllers make use of the residual motion energy to provide various selectable means of electrical braking. A unique character of these brake systems is the fact that wheel slip cannot occur. When the wheels enter a locking (slipping) mode virtual zero braking energy is generated and the loco wheels are allowed to rotate. During the braking tests the worst case that was noted was a violent juddering effect on the locomotive wheels when maximum electrical braking effort was applied while the train was in motion.

9.6.2 Diesel locomotives

Most diesel powered locomotives are equipped with hydrostatic drives which operate by providing a variable supply of hydraulic fluid to drive a hydraulic motor.

The dynamic braking capabilities inherent with the closed circuit hydrostatic transmission may provide normal braking requirements.

The following constraints which are inherent in hydrostatically driven locomotives must be made known to all respective responsible engineers, locomotive drivers and maintenance personnel:

- The dynamic braking capacity is dependant upon the transmission size and relief valve settings, as well as the retardation characteristics of the prime mover. When negotiating downgrades at top speed, there is a greater probability that the prime mover braking will be inadequate to restrain the train speed and a runaway condition could result. Negotiating such a downgrade can be safely accomplished at lower speeds. In any event, the inherent braking capabilities of the transmission should not be construed as a braking sub-situation for secondary brakes. (Note – When hydrostatic transmissions are in a braking mode the hydraulic motor acts as a pump and the pump is driven as a motor. The pump will attempt to drive the prime mover at a greater speed than normal. If the pump torque exceeds the counter torque preventing the prime mover from accelerating, braking effort will be lost.)
- The loss of hydrostatic drive line power in any mode of operation may cause a loss of hydrostatic braking capacity. A braking system that is adequate to stop and/or hold the train, totally independent of the hydrostatic transmission, must therefore be provided should this condition develop.
- The loss of hydrostatic braking may be caused by:
 - A burst hydraulic pipe or hose.
 - Cutting out of the prime mover.

- Failure of the hydraulic motor, pump or a relief valve.
- Because of natural leakage within the transmission system a train parked on a downhill by means of the hydrostatic brake only, may start moving and run away because of gravitational force when the system pressure has reached a low enough level.
- Inadequate design measures to prevent froth formation in the hydraulic fluid in the fluid reservoir entering the hydraulic loop, can cause speed control and braking to be “spongy”.
- Controlling the rate of acceleration and retardation is normally accomplished by means of an orifice plate or a combination of orifice plates in the control circuit that regulates the pump throughput. A wrongly supplied orifice could be detrimental to the safe operation of a locomotive.
- Different hydraulic pumps and motors look alike. Persons changing these components must always ensure that the model numbers of the series of replacement units do not differ from the originally supplied equipment. (Note - the drives may be modified to suit the specific criteria of the mine to which the equipment is supplied. It will therefore be difficult to obtain comprehensive generic specifications even with the manufacturers approval and assistance. Pirate suppliers are not always aware of the design parameters used by original equipment manufacturers and components with different characteristics may have been used when pumps or motors are overhauled. This may result in overheating or destruction of the transmission system.)

Note – All the above information must be included in training procedures.

9.7 Standards and specifications by mines (Refer Annexure K)

- A.** The following is a summary of relevant observations made during a study of mine standards and specifications:
- The specifications obtained from one mine were based on stopping a loaded train within the length of the train span, the train span length being dependent upon the track gradient.
 - From the graph referred to in Annexure K the following variables for a grade of 1:200 apply:

➤ Stopping distance (200ft)	61,5 m
➤ Train speed (8 miles/hour)	13 km/h
➤ Rolling resistance (20lbs/ton)	0,01
➤ Coefficient of friction	0,17
➤ Reaction time	3 Seconds
➤ Ratio of hauled load mass to locomotive mass	12,8:1
 - No reference to such specifications was made when locomotives were purchased. From discussions with engineers on mines it appears that when locomotives are purchased the braking requirements are left “in the good hands of the suppliers”.
 - No evidence of compliance with the Government Mining Engineer ruling in 1984 was observed. In one case this ruling formed part of a standard procedure for brake testing on a mine. However, no documentation indicating compliance could be obtained. The calculated retardation rates based on the ruling are high and it is doubtful whether such retardation rates could be achieved consistently in practice.
 - Some mines have prepared brake testing standards and have performed some dynamic metered tests. Such tests do not appear to be conducted on a regular basis, but are repeated only if a locomotive has been involved in an accident. No minimum “no-go” limits were referred to in the standards. There is also doubt about the accuracy of the test instrumentation used for the brake tests.
 - No local standards with respect to the mechanical brake criteria followed by mines, when locomotives were ordered, could be obtained.

9.8 International standards

- A.** The following comments on international standards are relevant:
- The draft European Committee for Standardisation Standard for “Machines for Underground Mines – Mobile machines Working Underground – Safety Part 2 – Rail Locomotives” was

- studied. Relevant sections of the Standard have been used for the project execution.
- The British Coal Corporation has done a major amount of work on braking systems on underground locomotives and their regulatory measures played an important part in this project.
 - Other countries' standards that were obtained place the responsibility on the employer to ensure that safe means of braking is provided.

10 Conclusion

The major changes with regard to the operation of rail systems underground in South African mines, that would arise as a result of the implementation of the recommendations contained in this report are:

- Static tests would be conducted on all locomotives at the start of each shift.
- Dynamic brake tests would be conducted from time to time, as described in Section 3.6.4.

With regard to the engineering of locomotive braking systems, the work reported here indicates the benefit of specifying three distinct braking systems on locomotives in the future, as well as the benefits of various other engineering specification requirements, as described in the body of the report.

The implementation of the above recommendations will, in our view, ameliorate the hazards that might arise from locomotive braking systems, as far as is reasonably practicable.

ANNEXURE A : INFORMATION FROM MINES

- The response obtained from mines on questionnaires submitted to them was disappointing. Measured against the Department of Minerals returns for 1998, an estimated 40 per cent feedback was received.
- The information received was reviewed and the results are reported below:
 - Skid correction training was confirmed by one mine only without reference to the method of such training.
 - Gradients used on mines varied, the maximum was 1:100 with an average of 1:200.
 - Factors of safety of the components used to transmit braking energy from the place of application to the wheels, where braking was not applied directly to the wheels, was not available. It can be assumed that engineers do not know what these factors of safety are.
 - Locomotive population:
 - ◆ Battery Locomotives

4,5 to 6 tons	39%
8 to 11 tons	33%
 - ◆ Diesel Locomotives

4,5 to 6 tons	20%
8 to 11 tons	7%
 - ◆ Trolley-line Locomotives

8 to 15 tons	1%
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 - ◆ Hand wheel mechanical brakes 80%
- The following information was obtained on the types of locomotive brakes used on underground locomotives:
 - Hand wheel with brake blocks on four wheels – most widely used.
 - Hand wheel with brake blocks on two wheels.
 - Disc brake on drive gearbox output shaft.
 - Clutch band on drive gearbox output shaft.
 - Fail safe spring applied hydraulic release brakes on four wheels.
 - Fail safe spring applied hydraulic release brakes on two wheels.
 - Fail safe spring applied air release brakes on two wheels.
 - Fail safe spring applied hydraulic release brake on hydrostatic drive.
 - Combinations of the above with normal hydrostatic, reverse power hydrostatic, dynamic or battery reverse power braking.
 - Hydrostatic braking only.
- The questionnaires yielded the following information on brake lining materials:
 - Cast iron.
 - Cast steel.
 - Rubber composite.
 - Rubber and steel compound.
 - “Harmonised composite”.
 - Ferodo.
 - Brass impregnated Ferodo.
 - Steel backed rubber lining.
 - Polyurethane.
 - Nylon.
 - Steel and Ferodo.
 - Plate packs.
 - “Elastomer reinforced malleable iron”.
 - “Master medium blocks”.
- Estimated reaction times reported varied from zero to fifteen seconds. However, most engineers estimated a reaction time of two seconds.
- The survey indicated that locomotives are not weighed at most of the mines.
- The following concerns were raised by engineers with respect to brake systems on

underground locomotives:

- Excessive wear was experienced on brake linkages which makes them difficult to maintain.
- Wear tolerances on certain components are critical for the safe application of brakes.
- De-railing is a major cause of damage to braking components.
- Braking systems are damaged when locomotives are incorrectly towed.
- Braking linkages require a high level of maintenance
- Some functions can be bypassed permanently.
- Brake components are sometimes bulky which makes maintenance difficult.
- Mud accumulation between shoes and wheels affects brake performance.
- Skidding occurs when brakes are applied.
- Skidding correction is difficult to apply.
- Long reaction times are encountered on brake systems applied by hand wheel.
- Over winding of hand wheel towards the off position results in an increase of the driver's reaction time.
- Brake shoes are being pushed out of position because of the taper of the wheels.
- Brake shoes are difficult to fit where collars are provided to prevent shoes been pushed out.
- Excessive power is required by the driver to apply some brakes.
- Dynamic braking is lost when the battery power supply fails.
- Loose equipment in the driver's cabin like jacks, chains etc. makes it difficult for the driver to apply the brakes swiftly during emergencies.
- High ratios of hauled mass to locomotive mass are often experienced underground.
- Freewheeling practices are experienced on downgrades.
- Corrosion of linkages and pins affects brake application.
- The failure of chains on chain driven systems where the brake is not applied to the wheels causes locomotives to run out of control.
- Substandard maintenance methods render brakes inoperable.

ANNEXURE B : ACCIDENT REVIEW

From the brake related accident reports (1995 to 1999) investigated the following was observed:

- No non-compliance with designed brake specifications was reported. The design specifications were questioned in a limited number of cases.
- Where an accident resulted in an injury or a fatality when two locomotives were involved, the investigations tended to be concentrated around the machine on which, or by which, a person was injured. Cases were noted where the other locomotive may have been the primary cause of such an accident.
- Earlier accident reports indicate a lack of appreciation of a means of managing an investigation on a broad basis. The "who is to be blamed" element played the most important roll. As a result questions which should have been asked were not raised at the time and valuable information with respect to real causes has been lost. Recent reports indicate a more realistic approach, but some more emphasis should be applied to the following:
 - The loads hauled by the locomotive or locomotives at the time of the accident.
 - A request for a report of possible recent brake tests conducted.
 - Written proof of maximum permissible speeds at the place of the accident.
 - The maximum speed the respective locomotive may attain.
 - The physical condition of the brake systems.
 - A professional judgement of the maintenance standards.
- The following acts and conditions were noted in some cases as, major causes of accidents:
 - Operating a locomotive from outside or partially outside the driver's cabin.
 - Diesel locomotives moving inadvertently during start-up.
 - Battery locomotives moving inadvertently when a lock-out key is inserted.
 - Passengers injured in driver's cabins when collisions occur.
 - Lack of maintenance.
 - Locomotive being put in motion inadvertently while getting in or out of the driver's cabin.
 - Collisions around blind corners.
 - Moving of parked locomotive when bumped by trackless or other machines.
 - Hydrostatic failures:
 - Engine cut out at speed on down hill.
 - Burst hydraulic pipe at speed on down hill.
- Skidding when brakes are applied during emergency situations
- Loss of braking when drive chains fail and brakes are not directly applied to the wheels. In once case, where the emergency/park brake was applied to the drive motor with the drive motor connected to the two locomotive axles by means of a drive chain to each axle, one chain failed. The chain was removed and hauling operations were resumed. The second drive chain snapped on a down hill causing the train to run out of control resulting in a fatal injury.
- Lack of standards or compliance with standards with respect to maintaining a safe following distance when two locomotives are following each other in the same direction.
- Non compliance of check list procedures.
- Drivers dismounting locomotives that are in motion to open a ventilation door or to do some rail switching getting trapped while attempting to do such operations.

ANNEXURE C : MEASUREMENTS OF BRAKING PERFORMANCE

1 Methodology

- The dynamic brake performance tests were carried out using the test equipment designed and supplied by LGI. Details of the test equipment are contained in Annexures L, M and N.
- The information received from the mines was used to select the following types of locomotives to be used for the brake performance tests:
 - 5 ton battery
 - 10 ton battery
 - 5 ton diesel
 - 10 ton diesel
 - Handwheel operated mechanical brakes
- The locomotives that were subjected to dynamic tests were those that were available at the time, and were mostly locomotives that are in daily use and maintained as per the respective mine's requirements. In one case a overhauled locomotive was made available for testing. The tests, however, covered the intended types as mentioned before, namely:
 - 10 Ton battery locomotive with handwheel mechanically brakes applied to four wheels – 2 off.
 - 10 Ton hydrostatic locomotive with hydraulic disc brakes applied to four wheels – 1 off. The mechanical brake test on this locomotive was not successful.
 - 5 Ton battery locomotive with handwheel mechanically applied brakes to four wheels – 2 off.
 - 5 Ton hydrostatic locomotive with hydraulic disc brakes applied to four wheels – 1 off.
 - Coupled and uncoupled axle configurations.
- To ensure that braking performance tests are conducted in a safe manner and cover the reasonably accepted practices applied underground the following methods were followed:
 - The test tracks were surveyed.
 - All test locos were weighed.
 - All test hoppers were weighed in a loaded state. (Because it was not possible to do the weighing and performance tests on the same day, note was taken of how the hoppers were loaded, in other words whether the hoppers were heap loaded, overloaded or underloaded. The loads on the day of the test were expressed as a percentage of a fully loaded hopper)
 - The guard cars were weighed, where applicable.
 - The hopper bogies were weighed where hopper tubs mass was shared by one bogie placed between tubs.
 - Actual test load mass of the hoppers used for the tests was calculated from observations on percentage loading compared with weighed results.
 - Where the test tracks length or placing could be dangerous, should a train not be able to stop in time, the tests were conducted as follows:
 - ◆ Half load, half speed
 - ◆ Half load, full speed
 - ◆ Full load, half speed
 - ◆ Full load, full speed
 - ◆ Approximately 120 per cent load, half speed
 - ◆ Approximately 120 percent, load full speed
 - Where the test tracks length and placing allowed full speed tests no half speed tests were conducted.

2 Conditions at test sites

The tests were all conducted on rail tracks that were considered to be of good quality without any elements present that would negatively affect the braking performance. It appears that engineers are deliberately reducing maximum hauling speeds by not allowing battery traction motors to operate in parallel and by the selection of hydrostatic transmissions to operate at lower speeds.

It was clear that without some formally arranged dynamic tests conducted at regular intervals, engineers have got no idea of the braking capabilities of their locomotives. Field tests indicate variations from hopelessly underbraked to overbraked systems. There is an urgent need for such tests to be legislated and conducted without delay.

3 Test results

3.1 Unbraked hauled mass to locomotive mass ratios

The calculated ratio of un-braked mass to locomotive mass based on the actual locomotive masses are indicated in Table 3.1

Table 3.1 : Summary of un-braked hauled mass to locomotive mass ratios

Mine	Nominal 10 Tone Loco Mass	Nominal 5 Ton Loco Mass	Average Load Ratio	100% Load Ratio
Mine No 1 Surface	9400 kg		6,36:1	6,66:1
		6480 kg	4,87:1	5,00:1
Mine No 2 Underground	7000 kg		11,33:1	12,86:1
		3800 kg	8,17:1	9,47:1
Mine No 3 Underground	8600 kg		6,51:1	7,43:1
		5200 kg	7,22:1	8,20:1

- It was evident that the practice with respect to the ratios of unbraked hauled mass to locomotive mass varied considerably, where the South African 'Rule of Thumb' is assumed to be 6:1;
- With the larger type of locomotives in the 8 to 11 ton range the ratio varied from 6,36:1 to 11,33:1 for a normally loaded train. With a fully loaded span of hoppers the ratio varied between 6,66:1 and 12,86:1. (Note: A normally loaded span is the actual weight of the weighed span which consisted of fully loaded, overloaded and underloaded hoppers. A fully loaded span is the calculated weight with all hoppers fully loaded).
- For the smaller type of locomotives in the 4,5 to 6 ton range, with a normally loaded span of hoppers the ratio varied between 4,87:1 to 8,17:1, while with a fully loaded span the ratios were from 5,00:1 to 9,47:1.
- Test results indicated a positive decrease in the rate of retardation when hauled masses were above 7 times the locomotive mass.

3.2 Deceleration rates

Where the mechanical brakes were fully functional, average rates of retardation between 0,17 to 0,24 m/s² were achieved for loading ratios of between 6 and 7:1.

Where the mechanical brake was only applied to one set of wheels the rate of retardation was 0,14 m/s² at a load ratio of 6:1.

The rates of deceleration for electrical dynamic braking varied between 0,17 to 0,202 m/s² at load ratios of 6 to 6,36:1.

The rates of retardation for hydrostatic driven locomotives varied from 0,038 m/s² for a load ratio of 11,33:1 and 0,345 m/s² for a load ratio of 8,17:1.

4 Causes of inadequate braking

- The braking effort being applied to one set of wheels while the other brake set was frozen into an off position.
- Wrongly adjusted hydrostatic transmission pressures resulting in over- and under-braked conditions.
- The enabling of a mechanical brake release after the source of energy accumulator had been depleted.
- Wrongly adjusted rate of emergency brake application and a lack of a facility to do skid correction where the mechanical brakes are hydraulically or mechanically applied.
- The unbraked hauled mass being, in some case, double the expected norm.

5 Conclusion

The results of the tests indicate that a minimum average rate of retardation of 0,18 m/s² may be used in locomotive mechanical brake design provided that:

- Brakes are maintained at exceptional standards.
- Hauled mass to locomotive mass ratios are maintained at 6:1.
- Locomotive driver's reaction times are kept below 2 seconds.
- Dynamic and hydrostatic brakes be tuned to operate at a retardation rate of 0,14 to 0,16 m/s².

ANNEXURE D : DETERMINATION OF THE RATIO OF UNBRAKED MASS TO LOCOMOTIVE MASS

For the calculation of the ratio of unbraked mass to locomotive mass the UK brake calculation, which is considered the most practical, will be used. The formula is given as:

$$L = W (K_L - K_R) / (0,108f - K_R + G) - W$$

Where:

L	=	maximum trailing load (tonne)
W	=	locomotive mass (tonne)
K _L	=	locomotive operational brake ratio – minimum 0,16 for coupled and 0,135 for uncoupled axles
K _R	=	trailing load rolling resistance (0,003 for roller bearings)
F	=	train deceleration (0,2 m/s ² minimum)
G	=	gradient (+0,005 for 1:200)

Under the above conditions, the ratio of hauled mass to locomotive mass will be 5,65:1.

At a retardation rate of 0,18 m/s² and other variables at the same levels the ratio of hauled mass to locomotive mass will be 6,32:1.

It would be reasonable to imply that the maximum safe stopping distance will ensure that a train is stopped within sixty metres on the straight at maximum speed. In order for a train to be stopped within the same distance at low speeds the retardation rate could be very much lower.

However, a retardation rate of 0,18 m/s², enables a train travelling at speeds likely to be used underground to be stopped within the required distance.

It will be noted that the application of the classical formulae below will result in a stopping distance of 55 m at a speed of 16 km and an average rate of retardation of 0,18 m/s².

$$V^2 = 2FS$$

Where

V	=	Full speed velocity in m/s
F	=	Rate of retardation in m/s ²
S	=	Stopping distance in m

In the event were a speed restriction of say 8 km/h is imposed, the stopping distance for a train at an average rate retardation of 0,18 m/s² will be 13,7 m.

Should conditions require and allow a maximum speed of 20 km then the following will apply:

Maximum stopping distance (S)	=	60 m
Rate of retardation (F)	=	0,18 m/s ²
Maximum speed (V)	=	20 x ¹ / _{3,6} m/s
V ²	=	2FS
(20 x ¹ / _{3,6}) ²	=	2 x a x 60
F	=	0,257 m/s ²

In this event the deceleration rate would require the use of rubber tyred wheels on locomotives, or alternatively, extending the braking system to the entire train or to part of the train.

ANNEXURE E : STOPPING DISTANCES FOR LOCO-DRAWN PERSONNEL TRANSPORTATION TRAINS

ANNEXURE F : CLASSIFICATION CRITERIA – SABS0339

The South African Bureau of Standards Code of Practice for the design, construction, maintenance and safe use of permanent underground track work in Mines – SABS0339.

CLASSIFICATION CRITERIA

Yes = recommended. N/r = no recommendation. N/a = not advised. No = not permitted.

ITEM	CLASS OF TRACK					ADDITIONAL INFORMATION
	1	2	3	4	5	
TONNAGE PER MONTH	>125	125-50	50-20	20-7,2	<7,2	X 1 000
PERSONNEL	Yes	Yes	Yes	N/r	N/r	
ROCK	YES	YES	YES	YES	YES	
EXPLOSIVES	YES	YES	YES	YES	N/r	
MATERIAL STANDARD VEHICLE	YES	YES	YES	YES	YES	
MATERIAL ABNORMAL LENGTH	YES	YES	YES	YES	N/r	
MATERIAL ABNORMAL MASS	YES	YES	YES	N/a	N/r	
MAX AXLE LOAD	15	10	7,5	5	5	Tons
MAX SPEED (ON STRAIGHT)	45	24	16	10	5	Kmph (Note 1)
PLANNED OPERATION LIFE	25	20	10	5	3	Years (Note 2)
RAILS	40/30	30	30/22	22	22/15	Kg/Metre
SLEEPERS	10+	10	7	5	5	(Axle load) tons cap.
SLEEPER TYPE= concrete, steel, wood	C/S/W	C/S/W	C/S/W	C/S/W	C/S/W	On graded ballast nominal 38,5 mm (+15mm-60mm).
SLEEPER TYPE= steel, wood	N/a	N/a	N/a	C * S/W	C * S/W	Run of mine waste. Ungraded Max 0-75mm
MIN. CURVE RADII (Restricted speed)	75	50	30	20	15	Metres radius. (Note 3)
MIN. CURVE RADII (Unrestricted speed)	250	150	90	60	30	Metres radius
JOINTS WELDED	YES	YES	YES	N/r	N/r	
JOINTS FISH PLATED	N/a	YES	YES	YES	YES	
PEDESTRIAN TRAFFIC	N/a	N/a	YES	YES	YES	Under restriction (Note 4)
SIGNALLING	YES	YES	N/r	N/r	N/r	(Traffic control)

Notes:

1. By special arrangement where speed exceeds 16 kph see Mines Health and Safety Act (Act 29 of 1996 as amended).
 2. Life expectancy based on ongoing maintenance with 20% of original permissible deviation (PD).
 3. See table of speeds, gauge widening, super elevation.
 4. Consult Mines Health and Safety Act regarding restrictions.
- * Subject to concrete sleeper manufacturers risk analysis.

ANNEXURE G : MAXIMUM PERMISSIBLE DEVIATION – SABS0339

The South African Bureau of Standards Code of Practice for the design, construction, maintenance and safe use of permanent underground track work in Mines – SABS0339.

MAXIMUM PERMISSIBLE DEVIATION

Yes = recommended. N/r = no recommendation. N/a = not advised. No = not permitted.

ITEM	CLASS OF TRACK					ADDITIONAL INFORMATION
	1	2	3	4	5	
From design level in mm	± 5	± 7	± 10	± 20	± 30	(Over length 5 m)
Cross slack	3mm	3mm	5mm	8mm	15mm	(Over length <2 m)
Straightness in mm	5mm	7mm	10mm	20mm	30mm	(Over length 5 m) measured on gauge face
Gauge (nominal)	+ 5 - 2	+ 5 - 2	+ 10 - 3	+ 15 - 3	+ 25 - 5	
Gauge (widening)	+ 3 - 2	+ 3 - 2	+ 5 - 2	+ 5 - 2	N/r	See note 2
Sleeper spacing (nominal)	± 20	± 20	± 50	± 50	± 75	
Sleeper spacing (joint)	± 10	± 10	± 20	± 20	± 50	
Circular curves	± 5	± 5	± 10	± 15	± 25	(Over length 5 m)
Super elevation on straight	5mm	5mm	8mm	10mm	20mm	(Over length > 2 m)
Height differential at joint	0	<1	<2	<5	<10	
Lateral differential at joint	0	<2	<3	<3	<5	
Joint gap	0	<2	<6	<6	<10	

Notes:

1. Should track conditions fall outside the parameters of the class, remedial measures shall be instituted.
2. Gauge widening deviation limits are based on design widening values.

ANNEXURE H : PROPOSED PROCEDURE FOR DYNAMIC TESTING OF BATTERY LOCOMOTIVE BRAKES

1 Preamble

The purpose of the test is to determine the dynamic braking performance of a battery locomotive. The locomotive and hauled test load will be weighed. Physical stopping tests will be conducted. The tests will take place under the direct supervision of a person, in a manner approved by the employer.

2 Preparation work

The following work must be carried out in preparation for the tests:

- Inspect the test site to ensure that the rail condition and rail length may be used for dynamic tests.
- Obtain the test track gradient.
- Determine the maximum hauling speed in terms of the classification criteria. (Refer Annexure F) in conjunction with the permissible deviation (Refer Annexure G) of SABS 0339.

Note: The speed referred to above must not be less than the maximum speed under which the locomotive is operating or intended to be operating.

- The locomotive mass must be known.
- The hauled test load mass which may include an emergency locomotive referred to in later must be known.
- The above hauled test load must be as close as possible to 6 times the test locomotive mass. It should, however, not be less than 6 times or more than 7 times the locomotive mass.

3 Requirements of dynamic testing

The following equipment and systems are required for the tests:

- Two locomotives in good working order, one of which being the locomotive to be tested and the other one which mass must not be less than that of the test locomotive.
- Two licensed and experienced locomotive drivers capable of taking instructions from the person in charge of the tests.
- Approved test equipment complete with spare batteries.
- A method of restricting access to the test site and providing suitable resources so that track bound equipment, other vehicles and pedestrians cannot interfere with or be endangered by brake tests.

4 Testing procedure

All work will be done under the direct supervision of the person in charge. The following procedures will apply:

- Inspection check lists for the locomotives and train shall be scrutinised before any test is conducted.
- Locomotives must pass the static brake tests before any dynamic tests are conducted.
- All the wheels of the hauled equipment must be checked to ensure that they are not rubbing against a chassis or brake linings.
- Where possible, at least one other means of brake application will be kept available. Should this not be possible to apply, then a second locomotive of which the mechanical brakes have been statically tested will be placed between the locomotive under test and the rest of the hauled load to act as a fall back should the locomotive under test fail to stop safely.
- All dynamic testing will start off in a low risk mode, ie half speed.
- Tests where wheel skidding occurs should be noted.
- The furthest end of the test track will be sanded and demarcated if the person in charge

deems it necessary.

5 Method of Testing

- With the train parked at start off point of the test track the car carrying the data acquisition unit must be hooked onto the rear end of the train.
- The operation of the trigger switch for the driver shall be tested.
- After assuring that the test equipment is firmly strapped to the car and the test track is clear, the locomotive driver may be signaled to drive the locomotive up to the desired test speed.
- Depending upon the type of test to be carried out he will, once attaining the desired test speed, flick the trigger switch immediately before switching off the driver power and applying the appropriate brake.
- The locomotive driver will observe the slowing down of the train and may not apply alternative braking unless he notices a failure of the brake under test when he will, without delay, apply other means of braking or signal to the driver on the second locomotive to apply brakes.
- At the successful completion of a test the test car must be unhooked from the train and pulled back to the start off point, the train must be taken back to the same point from where the above must be repeated for the next test.
- A test that has failed may not be repeated unless the reason for the failure has been identified and attended to.
- The results of the tests must be logged in the log sheet in the Table below.

Test Results : Battery Locomotive

LOCOMOTIVE NUMBER:..... DATE:

LOCOMOTIVE MASS:..... kg HAULED MASS: kg

RATIO OF UNBRAKED HAULED MASS TO LOCOMOTIVE MASS:..... :1

TEST SITE:.....

GRADIENT OF TEST TRACK: 1 : DIRECTION OF TEST: Downgrade / Upgrade

GRADIENT OF TRACK WHERE LOCOMOTIVE WILL BE USED: 1 :

NAME OF PERSON IN CHARGE: SIGNATURE:

TEST	MEASURED SPEED	STOPPING DISTANCE IN METRES	CALCULATED RATE OF RETARDATION AGAINST DISTANCE	MODIFIED RATE OF RETARDATION AGAINST DISTANCE FOR GRADIENT
Dynamic Braking: Half speed Comments Full speed Comments				
Reverse Power: Half speed Comments Full speed Comments				
Mechanical Braking: Half speed Comments Full speed Comments				
Mechanical and Dynamic Braking: Half speed Comments Full speed Comments				
Emergency Electrical Braking: Half speed Comments Full speed Comments				

Note: The gradient of the test track must be as close as possible to that of the tracks where the locomotive is being or intended to be used. Where this is not possible, a modification to the rate of retardation is to be calculated for the maximum gradient at which the locomotive will be operating.

6 Approval

Approved by persons as required by the respective mine's procedures.

ANNEXURE I : PROPOSED PROCEDURE FOR DYNAMIC TESTING OF HYDROSTATICALLY DRIVEN LOCOMOTIVE BRAKES

1 Preamble

The purpose of the test is to determine the dynamic braking performance of a hydrostatically driven diesel locomotive. The locomotive and hauled test load will be weighed. Physical stopping tests will be conducted. The tests will take place under the direct supervision of a competent person, in a manner approved by the employer.

2 Preparation work

The following work must be carried out in preparation for the tests:

- Inspect the test site to ensure that the rail condition and rail length may be used for dynamic tests.
- Obtain the test track gradient.
- Determine the maximum hauling speed in terms of the classification criteria (Refer Annexure F) in conjunction with the permissible deviation (Refer Annexure G) of SABS 0339.
Note: The speed referred to above must not be less than the maximum speed under which the locomotive is operating or intended to be operating.
- The locomotive mass must be known.
- The hauled test load mass which will include an emergency locomotive, referred to later, must be known.
- The above hauled test load must be as close as possible to 6 times the test locomotive mass. It should, however, not be less than 6 times or more than 7 times the locomotive mass.

3 Requirements of dynamic testing

The following equipment and systems are required for the tests:

- Three locomotives, in good working condition, one of which being the locomotive to be tested and the other two of which individual mass must not be less than that of the test locomotive.
- Three licensed and experienced locomotive drivers capable of taking instructions from the person in charge of the tests.
- A competent person to remove and refit drive chains on locomotives.
- A suitably rated long link with an elongated hole on the one end to pull a train up to the required test speed.
- Approved test equipment complete with spare batteries.
- A method of restricting access to the test site and providing suitable resources so that track bound equipment, other vehicles and pedestrians cannot interfere with or be endangered by brake tests.

4 Testing procedure

All work will be done under the direct supervision of the person in charge. The following procedures will apply:

- Inspection check lists for the locomotives and train shall be scrutinised before any test is conducted.
- Locomotives must pass the static brake tests before any dynamic tests are conducted.
- All the wheels of the hauled equipment must be checked to ensure that they are not rubbing against a chassis or brake linings.
- The drive chains of the locomotive under test will be disconnected while mechanical brake

tests are being conducted. This will ensure that the hydrostatic braking will not interfere with the mechanical brake performance.

- Where possible, at least one other means of brake application will be kept available. A second locomotive of which the mechanical brakes have been tested and the drive chains have been removed will be placed between the locomotive under test and the rest of the hauled load to act as a fall back should the locomotive under test fail to stop safely.
- The train with two locomotives' drive chains removed will be pulled up to the desired speed by a third locomotive which will be disconnected in motion for brake tests on the test locomotive.
- Dynamic testing must start off in a low risk mode, ie half speed.
- Tests where wheel skidding occurs should be noted.
- The furthest end of the track will be sanded and demarcated if the person in charge deems it necessary.

5 Method of Testing

- With the train parked at start off point of the test track the car carrying the data acquisition unit must be hooked onto the rear end of the train.
- The operation of the trigger switch for the driver shall be tested.
- After assuring that the test equipment is firmly strapped to the car and the test track is clear, the locomotive driver may be signaled to drive the locomotive up to the desired test speed.
- Depending upon the type of test to be carried out he will, once attaining the desired test speed, flick the trigger switch immediately before switching off the driver power and applying the appropriate brake.
- The locomotive driver will observe the slowing down of the train and may not apply alternative braking unless he notices a failure of the brake under test when he will, without delay, apply other means of braking or signal to the driver on the second locomotive to apply brakes.
- At the successful completion of a test the test car must be unhooked from the train and pulled back to the start off point, the train must be taken back to the same point from where the above must be repeated for the next test.
- A test that has failed may not be repeated unless the reason for the failure has been identified and attended to.
- The results of the tests must be logged in the log sheet in the Table below.

Test Results : Hydrostatically Driven Locomotive

LOCOMOTIVE NUMBER:..... DATE:

LOCOMOTIVE MASS:..... kg HAULED MASS: kg

RATIO OF UNBRAKED HAULED MASS TO LOCOMOTIVE MASS:..... :1

TEST SITE:.....

GRADIENT OF TEST TRACK: 1 : DIRECTION OF TEST: Downgrade / Upgrade

GRADIENT OF TRACK WHERE LOCOMOTIVE WILL BE USED: 1 :

NAME OF PERSON IN CHARGE: SIGNATURE:

TEST	MEASURED SPEED	STOPPING DISTANCE IN METRES	CALCULATED RATE OF RETARDATION AGAINST DISTANCE	MODIFIED RATE OF RETARDATION AGAINST DISTANCE FOR GRADIENT
Hydrostatic Braking: Half speed Comments Full speed Comments				
Hydrostatic and Mechanical Braking: Half speed Comments Full speed Comments				
Mechanical Braking only: Half speed Comments Full speed Comments				
Emergency Electrical Braking: Half speed Comments Full speed Comments				

Note: The gradient of the test track must be as close as possible to that of the tracks where the locomotive is being or intended to be used. Where this is not possible, a modification to the rate of retardation is to be calculated for the maximum gradient at which the locomotive will be operating.

6 Approval

Approval by persons as required by the respective mine's procedures.

ANNEXURE J : SCHEMATIC DIAGRAM OF A MECHANICAL-BRAKE SYSTEM

**ANNEXURE K : DOWNGRADE BRAKING DISTANCE FOR A
5-TON LOCOMOTIVE WITH A FULLY-LOADED TRAIN OF 4-
TON CARS**

**ANNEXURE L : BRAKE DISTANCE MEASUREMENTS
CONDUCTED ON LOCOMOTIVES AT MINE NO. 1**

**ANNEXURE M :BRAKE DISTANCE MEASUREMENTS
CONDUCTED AT MINE NO. 2**

**ANNEXURE N : BRAKE DISTANCE MEASUREMENTS
CONDUCTED AT MINE NO. 3**