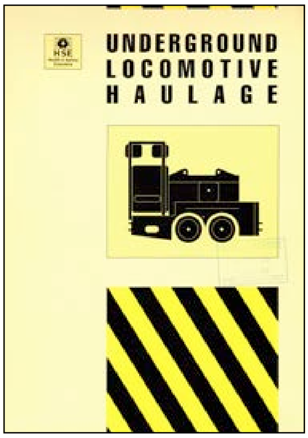
Underground locomotive haulage



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Introduction

1 Locomotives were introduced for underground operation in coal mines in the early 1930s but their use did not become widespread until after the 1939-1945 war. The first diesel powered locomotive with a flameproof engine was introduced in 1939 following its approval by the Mines Department in conjunction with the Safety in Mines Research Board.

2 Following nationalisation of the coal industry in 1947 the use of locomotives spread rapidly, doubling in the first year and after 10 years the numbers in use had increased from 90 to 906. In the early years locomotives were used on existing haulage roadways. Post nationalisation, construction and reconstruction often involved the newly adopted horizon mining principle, in which locomotive haulage roadways were driven at gradients of 1 in 400 or 500 (0.25% or 0.20%) in favour of the load. Since then the use of locomotives has been progressively extended to other parts of the mine and to road ways with variable gradients up to the maximum permitted for the particular form of traction.

3 Since 1949 the design, construction, maintenance and use of underground coal mining locomotives have all been subject to Locomotive Regulations[1,2]. Regulation 3(3) of the 1956 Regulations[2] requires locomotives in use in safety lamp mines to be of an approved type. The authority for the approval is now vested in the Health and Safety Executive (HSE).

4 Section 83 of the Mines and Quarries Act 1954[3] permits the use of an internal combustion engine or a locomotive in mines, only in accordance with the regulations made for that class of mine or with the consent of an inspector.

5 This is the first major review of the use of locomotives as a system of transport underground since the present legislation was established. In 1986 the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR)[4] came into effect and certain incidents involving underground mining locomotives became reportable for the first time to HSE as dangerous occurrences. The statistics subsequently revealed were considered in conjunction with investigations of two previous major accidents. This Topic Report presents an analysis of the findings and proposes principles of design and installation which would improve the safety of locomotive operation.

6 Although the report deals specifically with the underground use of locomotives in coal mines, the principles developed and discussed apply equally to other mines and to tunnelling operations.

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Review of accidents and incidents

Accident history 1947 to 1986

7 Accident statistics for the period 1947 to 1967 did not specifically identify accidents caused by the use of locomotives. The totals presented in Figure 1 show deaths and reportable major injury accidents due to all mechanical haulage activity against the number of locomotives in use. It would appear that their increased use coincided with a general improvement in mechanical haulage statistics over the period.

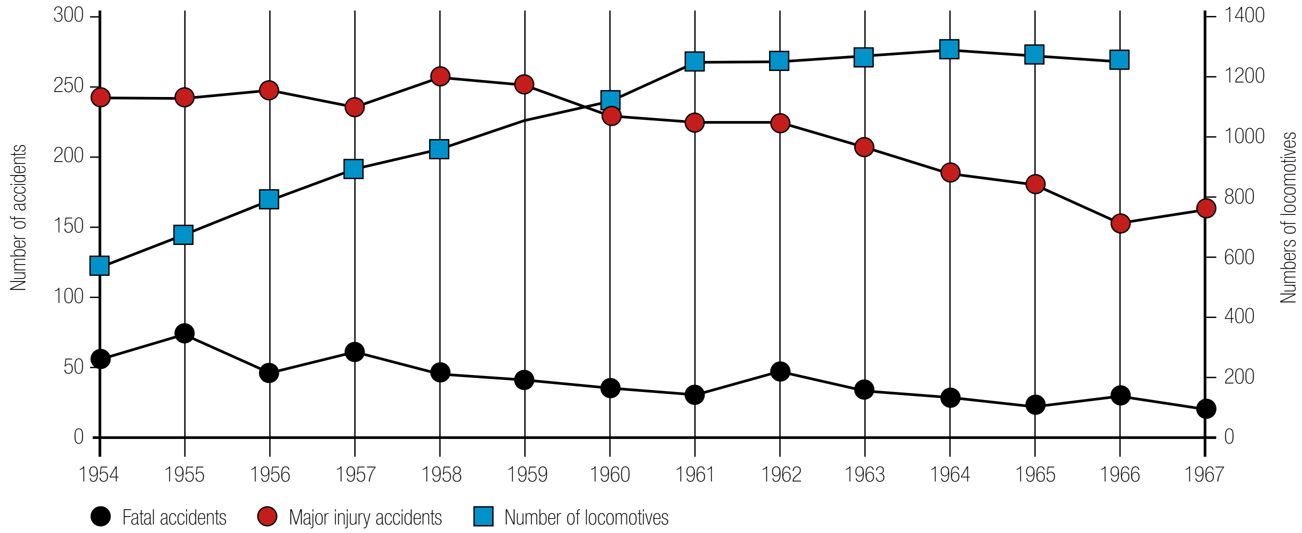

Figure 1 Underground mechanical haulage - fatal and major injury accidents 1954 to 1967 (Figures supplied by British Coal)

8 The first major accident involving the use of locomotives occurred at Silverwood Mine in 1966. The driver of a diesel locomotive, hauling a train of material cars on a descending gradient of 1 in 26 (3.8%) found no retarding response when he applied the service brakes. He resorted to the hand brake but the locomotive and train continued to accelerate out of control and finally collided with the rear of a manriding train carrying 47 passengers. Ten men were killed and another was seriously injured. HM Divisional Inspector revealed in his Annual Report[5] that, although the load being handled on the materials train exceeded that permitted by the manager's transport rules, subsequent tests showed that a similarly loaded locomotive could have been controlled by the skilful use of the service brake. The use of the hand brake would have caused the locomotive wheels to lock and skid, but, before that occurred, another mode of skid would have been induced when the acceleration due to gravity caused the locomotive speed to exceed the governed speed of the engine. The result would be to cause the locomotive wheels to skid while they still rotated and the loss of adhesion would have caused progressive acceleration. The effect would have been made worse by excessive application of the service brakes. This is a condition that the driver would find difficult to recognise and correct unless he had been specifically trained. The same report emphasises the considerable degree of skill required of a locomotive driver. It further points out that the selection of speed limits and hauled loads can only be satisfactory if these are based on the most demanding section of the roadway travelled. There is evidence to suggest that these critical parameters are not always applied.

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9 The second major accident occurred at Bentley Mine in November 1978 and was the subject of an HSE Report[6]. The driver of a locomotive hauling a manriding train on a descending gradient of 1 in 16 (6.25%) lost control and travelled 244 m before the train derailed on a curve. Seven men were killed and three received serious injuries. The investigation concluded that there was no evidence to show that the condition or maintenance of the locomotive contributed to the accident. The report also emphasised the importance of correct control and operation and made eleven recommendations. Potential for such disasters exist where locomotive systems are designed and operated without adequate margins of safety; an analysis of recent incidents indicates that similar circumstances still occur, fortunately without multiple casualties. Since 1968 statistics have made specific reference to locomotive accidents. These are detailed in Figure 2, and are plotted against the number of locomotives in use.

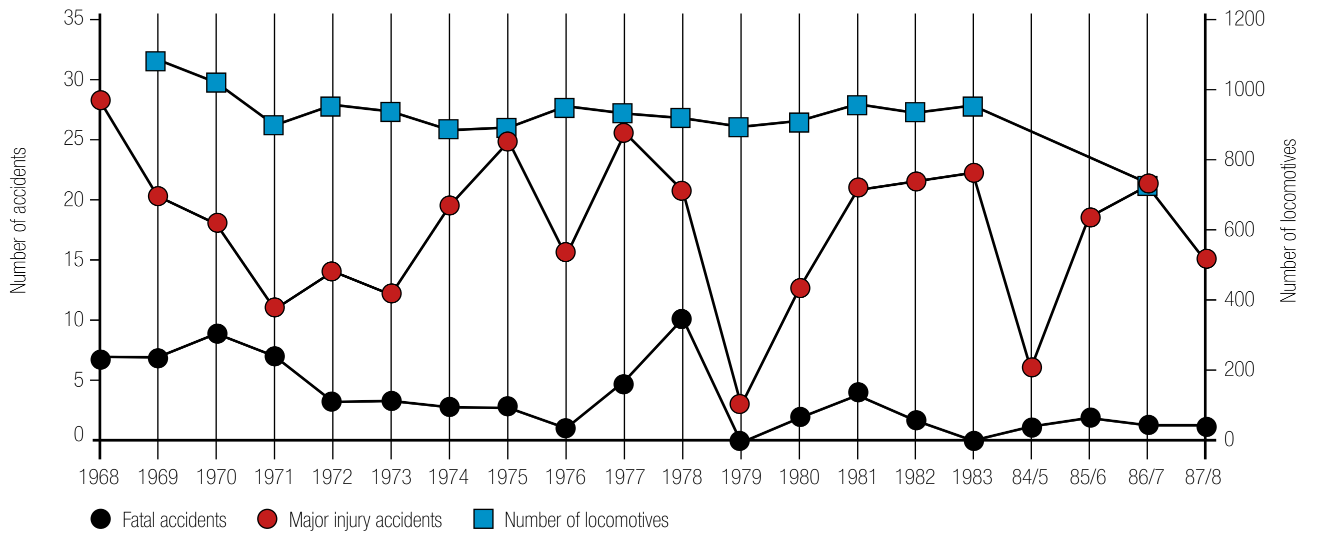

Figure 2 Underground locomotive accidents plotted against numbers of locomotives 1968 to 1987/88 (Figures supplied by British Coal)

10 The number of locomotives remained fairly constant between 1971 and 1983 at around 950. Since 1983 numbers have fallen to about 700; of these, an increasing proportion is formed by small rubber tyred locomotives. The number of fatal accidents has steadily fallen (apart from 1978 when the figures included the Bentley disaster). The number of major injury accidents has been affected by changes in accident reporting procedures but, nevertheless, the overall trend has shown little improvement. In the year following the Bentley incident the number of locomotive accidents was the lowest ever recorded, possibly because of heightened personal awareness on the part of both management and workers. If this attitude could be maintained it would make an important contribution to the improvement in accident figures.

11 Following the Bentley disaster, special inspections by the Mines and Quarries Inspectorate revealed that many of the recommendations of the official accident report had not received the attention they deserved and not all potentially dangerous circumstances had been eliminated. As a result the schedule of reportable dangerous occurrences relating to mines introduced in RIDDOR[4] which came into operation on 1 April 1986, was extended to include, at Part 11.18 of the Schedule 1 of the Regulations, '*any incident where an underground locomotive when not used for shunting or testing purposes is brought to rest by means other than its safety circuit protective devices or normal service brakes'* as being a reportable occurrence.

Analysis of locomotive dangerous occurrences reported under RIDDOR (1986 to 1988)

12 In the 33 months following the introduction of RIDDOR[4] a total of 307 incidents were reported. Remedial action following investigations has decreased the monthly rate significantly.

13 The incidents which occurred can be divided into four groups and the frequency of these is depicted in Figure 3 which also shows the percentage occurrence of the incidents over the period April 1986 to December 1988:

(a) derailment on track (including straight and curved sections);

(b) derailment at points;

(c) runaways;

(d) collisions.

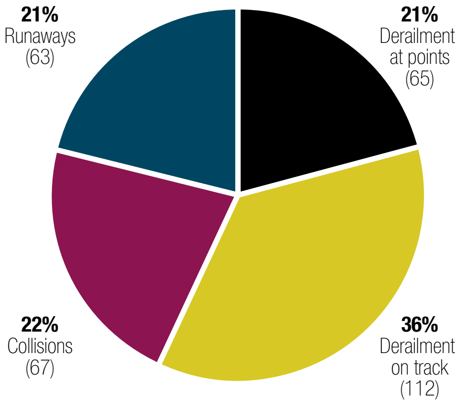

Figure 3 Analysis of underground locomotive incidents April 1986 to December 1988

14 The four groups of incidents have been subdivided into various primary causes and Figures 4, 5, 6 and 7 illustrate the apportionment of these and the types of locomotive involved. The causes in each case are expressed as percentages; it should be noted that in some incidents more than one primary cause was considered to apply and in such cases the occurrence is listed in each applicable category.

Derailments

15 Derailments on straight track and at points accounted for 36% and 21 % respectively of all locomotive dangerous occurrences. During 1988 and 1989 there was a substantial reduction in the number of derailments on straight track, probably the result of improved track standards and maintenance. Most derailments are associated with poor standards of installation and maintenance and the improvements made in these directions should be maintained (see Figures 4a and 4b).

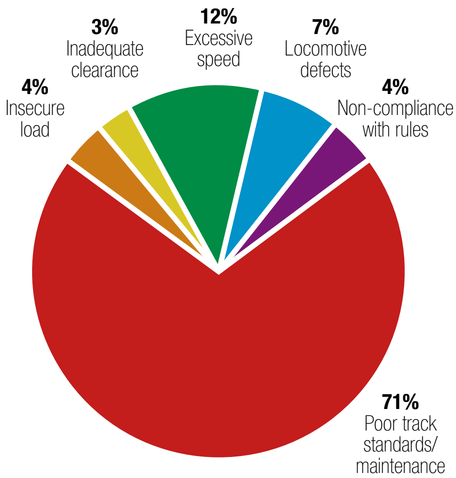

Figure 4a Primary cause of derailments on track 1986 to 1988

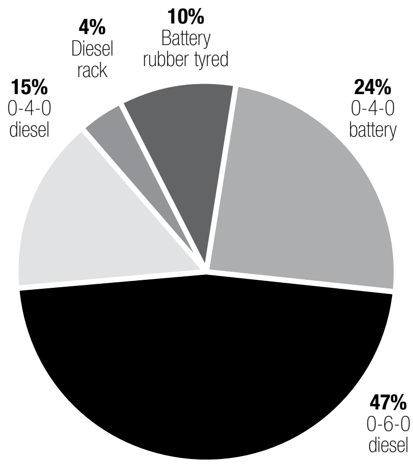

Figure 4b Analysis of locomotive types 1986 to 1988

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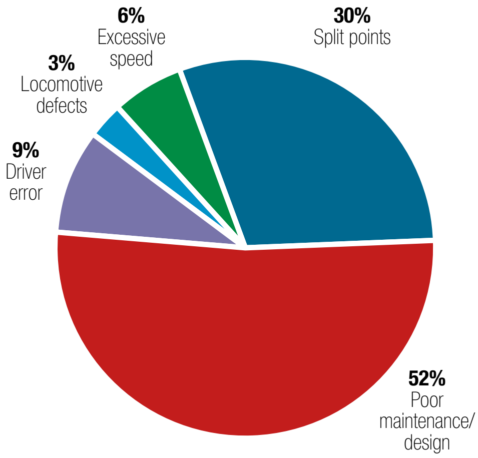

Figure 5a Primary cause of derailments on points 1986 to 1988

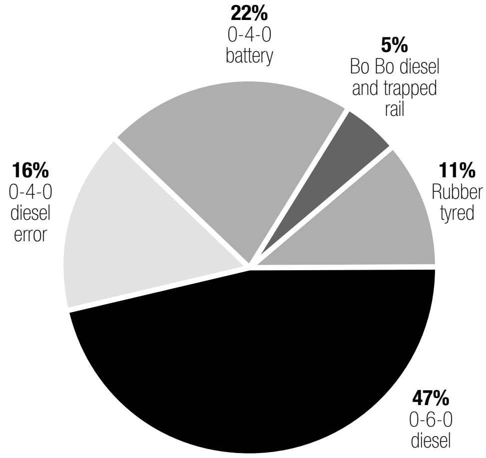

Figure 5b Analysis of underground locomotive incidents April 1986 to December 1988

Runaways and collisions

16 Runaways and collisions, which are considered to have the highest accident potential, together account for 43% of incidents. Many collisions were caused by operational shortcomings and might have been avoided by better management of the haulage system and a more disciplined approach by workers. In one example, a 225 kW bogie locomotive hauling a manriding train containing 200 men collided head on with a 76 kW single-ended locomotive hauling a manriding car and eight empty vehicles. This occurred at a 45º bend on a section of single track fitted with traffic light signals and controlled from a locomotive control cabin. Fortunately, no one suffered major injury, but nine men reported to the mine medical centre. The driver of the train transporting the 200 men failed to comply with the manager's instructions which required him to obtain permission from the control room before entering the single track section. Following the incident an automatic signalling system was installed (see Figures 6 and 7).

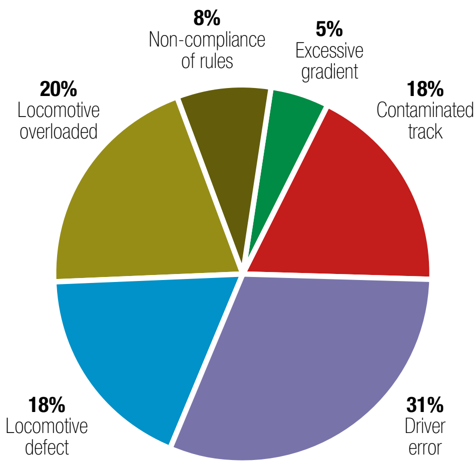

Figure 6a Primary causes of runaways 1986 to 1988

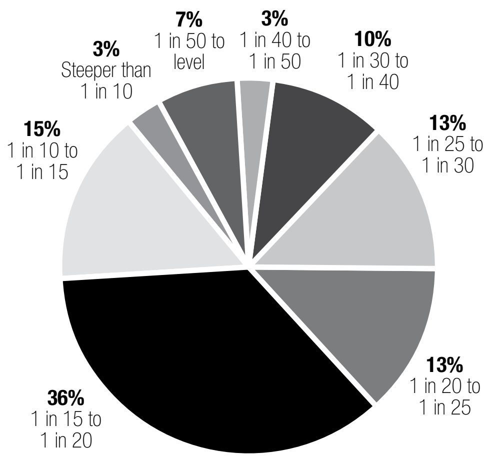

Figure 6b Analysis of gradients on which runaways occurred 1986 to 1988

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17 Analysis of the runaways highlights the inherent dangers associated with operating locomotives on steep gradients in that 80% of the incidents occurred on gradients of 1 in 30 (3.3%) or steeper. This report provides practical guidance which should reduce the number of such incidents. The factors involved include the general principles of locomotive design and particularly those aspects which affect braking performance.

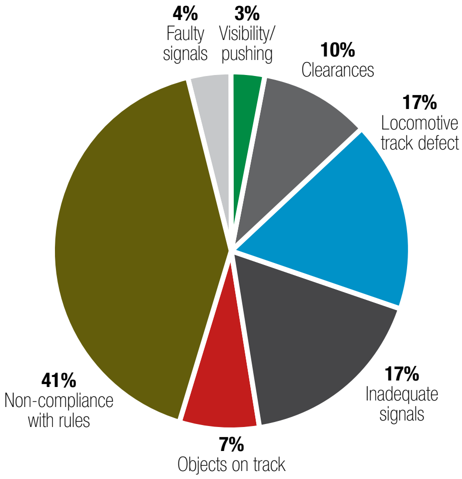

Figure 7 Primary cause of collisions 1986 to 1988

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Principles of locomotive design

18 In a paper[7] delivered in 1947 to the Institution of Mining Engineers, AE Crook, HM Engineering Inspector of Mines, set basic standards of design for locomotives and these are still in use today. Most locomotives used in mines haul unbraked rolling stock. They depend on the coefficient of adhesion between the wheel and the rail to transmit the force necessary to move, or more significant for safety, to brake the locomotive and any attached load.

19 The coefficient of adhesion is a measure of the ability of a locomotive to utilise the static coefficient of friction between its wheels and the rails. Theoretically, the maximum coefficient of adhesion is the coefficient of static friction but in practice this cannot be achieved because of the small relative motion (creepage) always present between the wheel and the rail during traction (hauling) or braking. In this report the coefficient of adhesion is referred to in the context of braking.

20 Adhesion locomotives used in mines are fitted with either steel or rubber tyres and operate on gradients much steeper than most surface applications. The maximum gradient on which underground locomotives may operate is set by Regulations2 at 1 in 15 (6.7%) although exemptions have been issued to allow locomotives fitted with rubber tyres to operate, with limited loads, on gradients as steep as 1 in 10 (10%). Two other types of locomotive, which run on rack or captive rail track, are not dependent on the adhesion produced by the weight of the locomotive to provide braking and are allowed by exemption to operate on steeper gradients.

21 The design and type of locomotive should be considered as an integral part of the design of the overall transport system. When new installations are being planned, the roadway gradient, size and minimum curve radii of the track should be based on the locomotive design and ensuing system requirements.

22 Where locomotives are used on existing roadways, it is important to match the type of locomotive to the gradients on which they are to be used. It is necessary to establish loads that locomotives can safely haul on gradients varying between level and the statutory gradient limit Further to this, the duty cycle must be taken into account and for battery locomotives this may be a limiting factor. The manufacturer normally supplies performance data for each type of locomotive together with details of the braking system. It is essential for the user to examine and interpret these details carefully in calculating the maximum load which can be braked safely on the proposed gradient The maximum load so obtained will be a limiting operational factor for that type of locomotive. The design of any transport system should be based on the loads which the locomotive can safely brake. A locomotive should never be used to haul up-gradient a load greater than that which it can safely control down-gradient Under no circumstances should engine braking be considered as part of the brake effort when calculating permissible trailing loads.

23 The force that can be developed by a locomotive or vehicle to retard its motion is termed the 'brake effort" or the 'brake ratio' when expressed as a percentage or fraction respectively of its weight The brake effort should be so applied that the maximum retardation can be achieved without loss of adhesion and therefore without skidding. This controlled use of the brake effort becomes more critical as the inclination of the track increases and is further emphasised where a locomotive is operating with unbraked rolling stock, In this case the brake effort is limited only by the frictional forces which can be maintained between the locomotive's wheels and the rails. An 'overbraked' locomotive, being one where excessive brake effort is applied, is just as dangerous as one which is 'underbraked' by inadequate

application of braking effort Excessive braking can result in the locomotive's wheels locking and then skidding on the rails causing a reduction of the brake effort to the value of the dynamic frictional force between the wheels and rails. Rather than being a function of the static frictional force which applies when the wheels rotate. In these circumstances unless control can be regained by skilled regulation of the brakes, the skidding locomotive may accelerate down the gradient.

24 The 'coefficient of adhesion', the 'design demand' and the 'operational demand', are three important terms used extensively in this report. The underlying philosophy was introduced by C Pritchard in 1979[8] The phrases may be defined as follows:

Coefficient of adhesion the coefficient of friction equivalent to the ratio of the locomotive brake effort, just before the onset of slip, to the weight of the locomotive;

Design adhesion demand (design demand) the coefficient of adhesion necessary to allow full application of the brakes without any slip;

Operational adhesion demand (operational demand) the coefficient of adhesion necessary to allow the brakes, when applied, to achieve the specified minimum retardation and safe stopping distances for specific operational loads and gradients.

25 Incident investigation, and a review of locomotive haulage systems operating on gradients steeper than 1 in 33 (3%), indicate that some installations were operating with retardation so low as to give little margin of safety. The reports on the accidents at Silverwood and Bentley demonstrate the possible consequences of such installations.

26 A typical incident occurred on an underground roadway in a mine where the manager's transport rules[9] specified that a maximum of 12 vehicles could be hauled. However there were no set limits for the maximum load to be hauled. A 15 tonne diesel locomotive operating in first gear with a maximum speed of 5 km/h (3 mph), was hauling a train of six unbraked vehicles having an approximate mass of 26 tonnes down a roadway with an average gradient of 1 in 30 (3.3%), and a maximum gradient of 1 in 18 (5.6%). The driver received a signal to stop and applied the service brakes but sensed no deceleration. He applied sand and braked again, but still did not slow down. At this stage he abandoned the locomotive which travelled a further 100 m before colliding with a materials car. Tests on the locomotive brakes revealed that they were capable of producing a brake effort equivalent to 17.5% of the locomotive weight, ie a design demand of 0.175. The majority of this brake effort was used to counteract the gravitational component due to the 1 in 18 (5.6%) gradient acting on the train. This left a brake force of 0.35 kN to retard the train which was capable of producing a retardation of only 0.85% g. The transport rules have been revised to specify the maximum load based on an operational demand of 0.12 and a minimum retardation of 2% g.

Factors affecting locomotive brake design

Locomotive approvals

27 Before any new type of locomotive is introduced underground, it is submitted to HSE for tests to confirm that it complies with the requirements of TM 12 (1977)[10]. This document, presently under review, specifies the minimum requirements relating to the design of brakes which are given in Appendix 1. However, many of the locomotives still in use were designed and manufactured before TM 12 was first published in 1969.

28 TM 12 requires that any locomotive intended for use underground should meet the following design requirements:

(a) the service brake should be used as the primary braking system. It should be capable of developing a brake effort of at least 16% of the locomotive weight for locomotives fitted with steel tyres, and at least 30% of that weight for locomotives fitted with rubber tyres;

(b) the emergency brakes should be used in the event of a failure of the service brake. They should be capable of developing a brake performance of not less than half that required for the service brake on the appropriate class of locomotive; and

(c) a parking brake should be fitted which is capable of holding the locomotive stationary on the maximum gradient for which it is designed to operate, when the locomotive is coupled to the maximum permissible load for that gradient.

Recommended design demand for service wheel brakes

29 When TM 12 was introduced the main concern was that some locomotives did not produce sufficient brake effort to make full use of the available coefficient of adhesion and therefore it did not specify an upper design limit. Recently, some locomotives tested for approval purposes have been found to have excessively high design demands and have needed modification to reduce the brake effort before being introduced underground. In view of this and other developments the approval requirements are to be updated to take account of the tests carried out by the Research and Laboratory Services Division (RLSD) of HSE which are covered in paragraph 34. From the limited data available the combined retarding force of the service brake and the rolling resistance of the locomotive (ie the brake effort of the locomotive) should be designed to produce a design demand within the following limits:

(a) for steel tyred locomotives with coupled axles 16 to 20% of the gross locomotive weight, ie a design demand of 0.16 to 0.20;

(b) for steel tyred locomotives with uncoupled axles 13 to 18% of the gross locomotive weight, ie a design demand of 0.13 to 0.18; and

(c) for rubber tyred locomotives 30 to 35% of the gross locomotive weight, ie a design demand of 0.30 to 0.35.

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Tests to establish brake design demand of existing locomotives

30 HSE has recently undertaken a project with the co-operation of British Coal and manufacturers, to establish the design demand of new and existing locomotives. The tests were mainly carried out on surface test tracks with an unbraked trailing load at least equal to the locomotive weight. To date, 12 locomotives have been tested and further tests are planned with rigid frame battery locomotives having uncoupled axles. This work has been supplemented by inspections and tests carried out by HM Inspectors of Mines on locomotives operating underground using the SIMRET retardometer. This instrument was developed by RLSD and is based on a microprocessor containing a torque-balanced accelerometer.

The brake effort obtained from the digital read-out is independent of the inclination of the track and enables the locomotive brakes to be monitored accurately. The results of these tests suggests that the brake effort required in TM 12 is generally appropriate for fixed frame steel tyred locomotives with fully coupled axles and wheel braking.

Design factors affecting adhesion

31 The wheel and linking configuration of a locomotive can have a significant effect on the limiting coefficient of adhesion it can achieve.

32 Ideally, to achieve the best brake performance all wheels should have exactly the same diameter and be coupled; for uncoupled wheels the braking torque applied to each wheel should be proportional to the locomotive weight on the wheel. This is an ideal design standard which is seldom achieved due to other design limitations. In addition, the following design parameters have also been found to affect the coefficient of adhesion.

(a) the force in the draw bar coupler;

(b) the position of the centre of gravity;

(c) the height of the draw bar coupler;

(d) the resilience and damping between couplers of the train; and

(e) the suspension characteristics of the locomotive.

33 Certain combinations of these parameters make it possible for locomotives with uncoupled wheels to develop a better coefficient of adhesion than those with fully coupled wheels.

34 Work carried out by RLSD has attempted to determine the coefficient of adhesion by measuring the retardation produced by the brakes at the onset of wheel slip. The results are summarised at Figure 8. Most tests were made on surface track of a high standard. Underground tests may reveal a reduction in adhesion values due to variable track conditions. The values should be used as guidance only and not as design data. The following conclusions may be drawn from the limited tests:

(a) coefficients of adhesion are variable, even for locomotives with the same wheel and coupling arrangements;

(b) coefficients of adhesion developed on wet rails are usually less than those developed on dry rails;

(c) initial tests support the view that fixed-frame steel tyred locomotives with uncoupled wheels and block/wheel brakes develop lower coefficients of adhesion than the fully coupled type;

(d) bogie-mounted locomotives with braked uncoupled wheels can develop higher coefficients of adhesion than those developed by similar classes of fixed frame locomotives; and

(e) bogie-mounted locomotives with braked wheels which are coupled within the bogie can develop coefficients of adhesion which are similar or better than those obtained from fixed frame locomotives with fully coupled wheels.

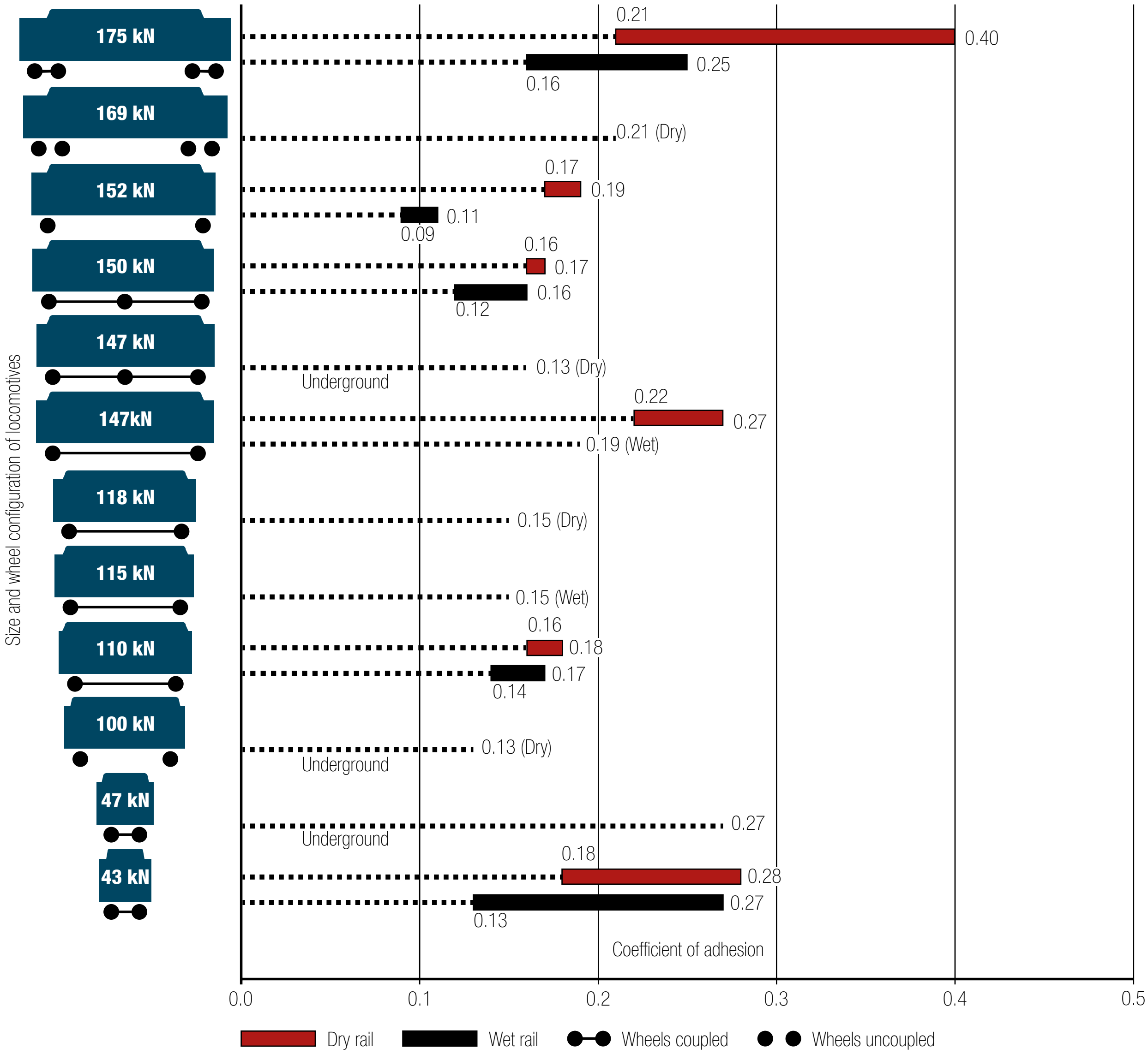

Figure 8 Variation in coefficient of adhesion of underground locomotives

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Steel tyred locomotives

35 AE Crook[7] in his paper on the use of locomotives underground modified the values of rolling resistance to those associated with underground rolling stock. He recommended that trailing loads should be calculated using an operational demand of not more than 0.16 when the wheels are not locked and the rails are dry with a minimum retardation of 0.2 mph/s (0.91 % g) in order to ensure reliable and safe braking. These values are still used by the mining industry for calculating the stopping distances of steel tyred locomotives with coupled wheels. Crook used a value of 0.225 for operational demands associated with traction calculations. It is possible to achieve this higher value but it should not be considered in braking calculations in which an adequate margin of safety must by maintained to reduce the likelihood of skidding when the brakes are fully applied.

36 Most of the original underground locomotive haulage installations were designed for mineral haulage using long, heavy trains on very slight gradients. Trailing loads and conditions of use were generally constant and the values used by Crook were appropriate. Today, locomotives are seldom used for large scale mineral haulage in purpose driven roads. They are more often required to operate throughout the mine, on variable gradients up to the maximum permitted for adhesion working and with trailing loads of supply vehicles having wide variations in composition and weight. These circumstances require much higher margins of safety than was previously thought to be appropriate. A retardation of 2% *g* is recommended as an acceptable minimum for current locomotive haulage systems.

37 This recommended retardation is twice that suggested by Crook, but considerably lower than the value used on most surface railways. The operational demand currently used for underground locomotives in coal mines is much higher than that of other users of locomotives. The use of any lower retardation reduces the margin of safety even more, and in fact the driver may be unable to detect that he is slowing down. Locomotive drivers have been known to jump out and abandon their train thinking it to be out of control or skidding simply because the brakes have been unable to achieve detectable retardation. This is quite likely if low retardation rates are accepted for heavily loaded trains.

38 The safe trailing load for most installations has been based on a formula developed by British Coal to calculate the stopping distance for locomotives under test. Details of the formula are given in their *Codes and Rules*[11], The trailing load is expressed as the ratio of the weight of the attached load to the weight of the locomotive. To calculate the appropriate trailing load for a particular gradient it has been the practice to transpose the formula and make assumptions regarding the locomotive brake effort, stopping distance and rolling resistance. In most cases, the stopping distance is assumed to be 60 m and the rolling resistance factor to be either 29 N/Tonne (3 kg/tonne) or 147 N/Tonne (15 kg/tonne) for vehicles with rolling bearings and plain bearings respectively.

39 In calculating the trailing load for locomotives fitted with steel tyres this formula assumes an operational demand of 0.16 for coupled axles and 0.135 for uncoupled axles. These values do not differ significantly from the minimum design demand already referred to in paragraph 29 and provide no margin of safety to cater for variations in conditions of use or for deterioration in braking performance. A further weakness in the application of the formula is the erroneous assumption that the range of 60 m required by the existing Locomotive Regulations for a locomotive headlight is a safe stopping distance. The driver should be able to stop the locomotive within the sight line for any particular section of track. On curves, a shorter distance will be required and the speed reduced accordingly. At normal

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speeds, the use of the formula is generally appropriate when used correctly, but it may have serious consequences if transposed to determine trailing loads based on stopping distance only. This is particularly so if severe speed restrictions are intended to be imposed by the transport rules and these are taken account of in the calculations. The effect of calculating the trailing load, using a 60 m stopping distance, results in a very low retardation for locomotives with a low initial speed.

40 To ensure a safe system of work the maximum trailing load should take account of the minimum locomotive brake effort which can be reliably maintained between statutory brake tests and with varying track conditions. This is likely to be lower than the design demand. It should also enable the train to be brought to rest safely at an acceptable retardation under the most onerous braking conditions, and should include a margin of safety to cater for unforeseen changes in critical operating parameters.

41 A recent HSE survey of locomotive hauled trains operating on gradients of 1 in 33 (3.0%) or steeper, highlighted the potentially dangerous situations which can exist. Assuming that the service brake is capable of producing an operational demand of 0.16, only about half of the locomotives could achieve the recommended minimum retardation of 2% 9 (0.196 m/s^2). The retardation is calculated using an RLSD formula derived from first principles; details in Appendix 2. Figure 9 also shows that several installations of locomotives with coupled axles with an operational demand of 0.16 would not be capable of achieving a 0.5% 9 retardation if used to the limit permitted by the managers transport rules and remedial action has been recommended.

42 Retardation curves of 2% *g* have been plotted to show the effect of a reduced brake effort equivalent to operational demands of 0.14 and 0.12 (Figure 9). Generally, the mining industry operates machinery to higher factors of safety than those found in other industries because of the adverse conditions experienced. Yet in the case of most steel tyred locomotive haulage systems no formal margin of safety exists between the design demand and the operational demand used for calculation of the trailing loads.

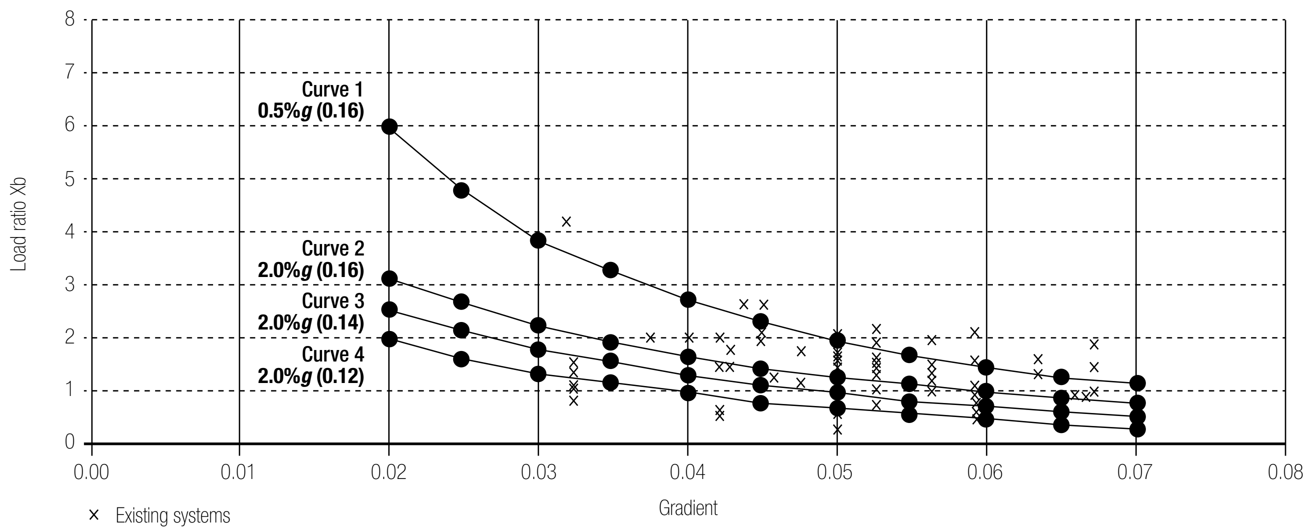

Figure 9 Effect of load/gradient on deceleration of locomotives with coupled axles

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43 Tests carried out on some of the older diesel locomotives have shown that although they are capable of achieving a design demand of 0.16, they require frequent maintenance and adjustment. The operational demand selected should recognise that braking performance may fall significantly between routine testing

and needs to be based on the condition in which the locomotive brakes can be consistently maintained. It is recommended that the operational demand used in brake calculation should not exceed 80% of the proven design demand. However, at some mines where there is regular contamination of track and wheels a lower value should be adopted.

44 Retardation curves have been plotted in Figure 10 for battery locomotives with uncoupled axles, assuming operational demands of 0.13 and 0.11. These curves are assessed against existing installation designs. It is generally accepted that this type of locomotive cannot produce coefficients of adhesion as high as those locomotives with coupled axles.

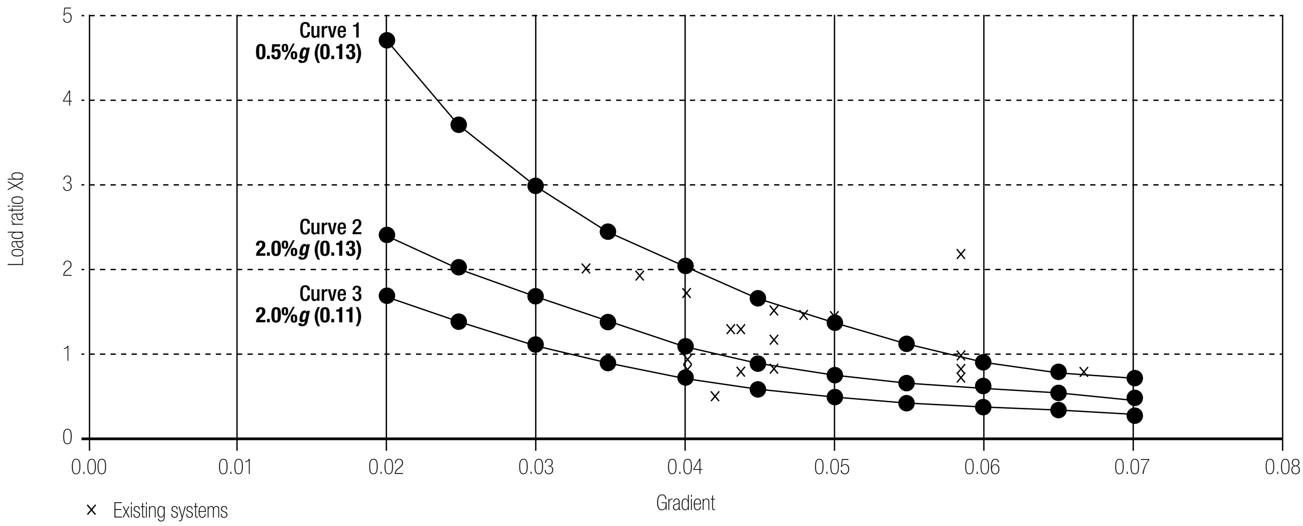

Figure 10 Effect of load/gradient on deceleration of locomotives with uncoupled axles

Rubber tyred locomotives

45 Rubber tyred locomotives introduced in the 1970s now account for 27% of the locomotives in use. The majority are of the smaller type, often referred to as pony locomotives, typically having a mass of 3 to 4 tonnes and powered by a battery producing approximately 11 kW. They are usually equipped with electrical service braking and a solenoid operated emergency disc brake. Other types of rubber tyred locomotives are fitted with conventional wheel brakes. Normally a rubber tyre running on dry steel rails will produce coefficients of adhesion of over 50%. Following a potentially serious runaway due to loss of adhesion on a gradient steeper than 1 in 15 (6.7%), tests were carried out with the cooperation of British Coal and manufacturers.

46 It was agreed that for rubber tyred locomotives the design demand should be limited to between 0.35 and 0.30 and the operational demand limited to 0.21, a value used by the British Coal braking formula. This ensures two margins of safety:

(a) the margin between limiting coefficient of adhesion (0.50) and design demand (0.30 to 0.35); and

(b) the margin between design demand (0.30 to 0.35) and operational demand (0.21).

47 The first is the margin of safety to prevent skidding under normal operating conditions. The second recognises that the coefficient of adhesion can, under

abnormal operating conditions, fall to 0.21 and includes a margin of safety to cater for a reduction in brake effort, due to wear or maladjustment between weekly brake tests. It also allows the driver to call on a higher level of braking than normal if circumstances demand it. The driver has in effect 'something up his sleeve' to cater for the unforeseen problems when working at maximum limits. This safety margin is not usually provided on steel tyred installations and may account for many operational problems on conventional systems which are described as being due to driver error.

48 The tests also highlighted the importance of retaining the use of sand for recovery from a skidding condition. When rubber tyred locomotives were introduced it was considered that the provision of sand would not be necessary; but since these tests all new locomotives have been fitted with sand boxes and some earlier locomotives have been modified.

49 The principles that brakes on steel tyred locomotives should provide safe stopping distances and a minimum retardation of 2% *g* are also applicable to rubber tyred locomotives. Permissible trailing loads should be based on these limiting factors and a normally attainable operational demand.

50 Installations operating on gradients steeper than 1 in 15 (6.7%) do so under exemption from the Locomotive Regulations[2], and the conditions attached to those exemptions by HM Chief Inspector of Mines stipulate the maximum trailing load.

Comparison with other users of locomotive systems

51 Although surface railways operate at much faster speeds it is worth comparing the brake design demand and operational demand for various installations with those presently used underground. Table 1 shows that surface railways use much lower operational demand requirements and allow a suitable margin between design and operational figures.

Table 1 Comparison of design and operational demands adopted by various locomotive users

Type of installation	Maximum speed kM/h	Design demand	Operational demand
European main line passenger trains*	140 160 200	0.074 - 0.096 0.06 - 0.085 0.067 - 0.096	0.059 - 0.085 0.052 - 0.078 0.061 - 0.083
London transport*	95	0.11†	0.096
British coal**	-	-	-
Steel tyred (coupled)	-	0.16†	0.16†
Steel tyred (uncoupled)	-	0.16†	0.135
Rubber tyred	-	0.30 - 0.35†	0.21

*Sources: * Brake, wheel adhesion. C Pritchard [8]*

*** HSE*

† Full service brake

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Calculation of trailing load -summary

52 The use of the formula to calculate the stopping distance given in the British Coal Codes and Rules for the various classes of locomotives is not a sound basis on which to calculate acceptable trailing loads. At low speeds the use of a 60 m stopping distance can lead to a dangerously low retardation. The RLSD formula (Equation 7, Appendix 2) offers a better basis on which to calculate acceptable unbraked trailing loads. It is recommended that under normal circumstances the operational demand brake ratio (Kl) for steel tyred locomotives should not exceed 80% of the design demand brake ratio. The effectiveness of the emergency brake should not be neglected and it is recommended that the operational demand of the service brake should not exceed the design demand of the emergency brake. It is important that in addition to a safe stopping distance, an acceptable retardation ‘f’ is established for all locomotive systems operating underground. It is recommended that this should be at least 2% *g* (0.196 m/s^2). (See paragraphs 35 to 44)

53 These basic principles should be adopted on all underground locomotive installations. The graphs shown in Figure 11 provide a quick method of calculating the trailing load for selected operational brake demands which will produce a retardation of 2% *g*.

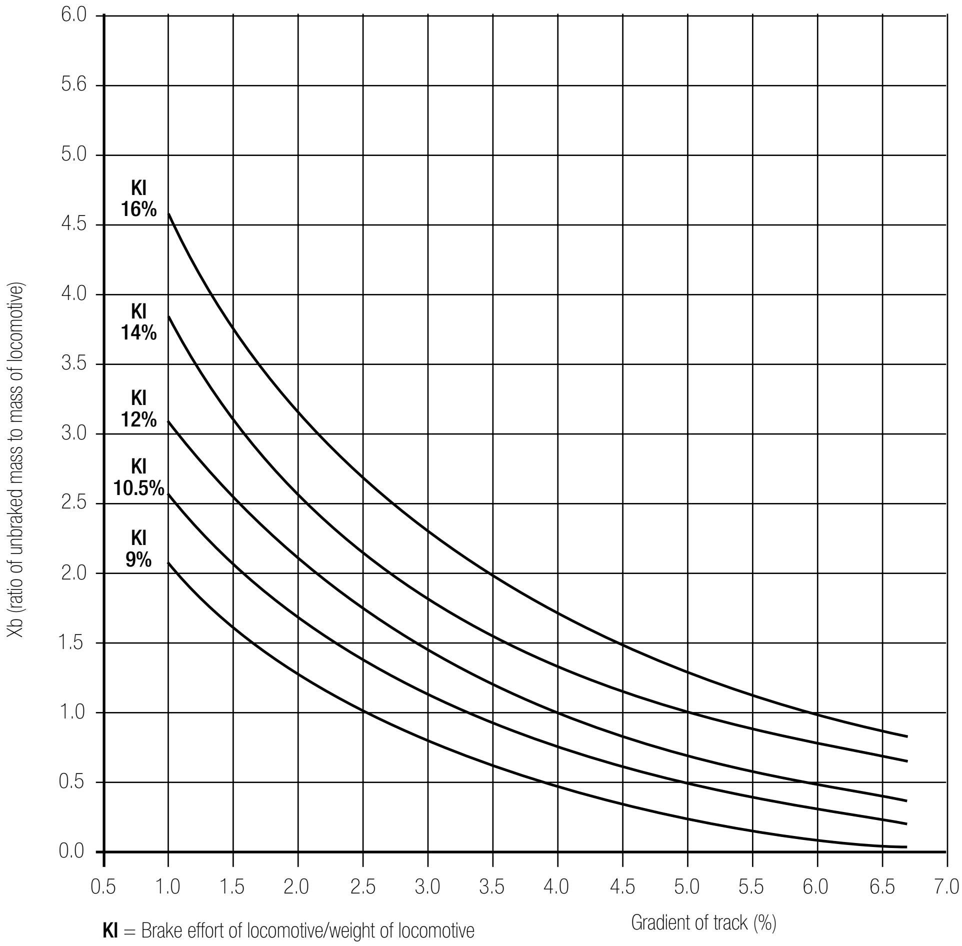

Figure 11 Graphical method of calculating trailing load for selected operational brake demands to produce retardation of 2% *g*

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The effect of track contamination on adhesion coefficient

54 The coefficient of adhesion can be adversely affected by track conditions, especially track contamination. This was the primary cause of 18% of the runaways (Figure 6) between April 1986 and December 1988. Analysis of these incidents showed the primary causes to be:

(a) oil or water leaking from vehicles during transportation;

(b) water dripping from the roadway roof and from defective or badly sited equipment.

55 These incidents could have been avoided by simple remedial action and in some cases should have been highlighted by the statutory daily examination of the locomotive roadway. The basic training of haulage workers and those responsible for inspection should stress the importance of prompt remedial action and the potentially tragic consequences of any locomotive runaway.

56 It is well known that either oil or grease on rails results in loss of adhesion, but it is not clear how much is required to be significant. Following one incident, samples of debris were taken from the rail running surface. Analysis revealed that the oil content was only 0.5% (by weight) and that the main constituents were quartz 11%, carbon 4% and, to a lesser extent, rust.

57 The results of tests carried out by British Rail and published in 1979[8] indicated that water is more likely to be the prime cause of low adhesion than either oil or grease deposits. It was found that very small amounts of water with solid debris or rust could form a surface film that was not readily squeezed from under the wheels, but provided low resistance to shear. Where greater amounts of water were present the film was squeezed from under the wheel and the coefficient of adhesion remained high. The tests also indicated that wheel slip (low adhesion) was more frequent on dirty or little used track, which is a significant factor with regard to underground use. In normal circumstances, the coefficient of adhesion encountered was at least 0.12 which gave an adequate margin of safety when compared with the operational demand for signal stopping distances required by British Rail. It was significant, however, that one line repeatedly exhibited results lower than others and the only reason appeared to be that the track was contaminated on a regular basis by coal dust.

58 The coefficient of adhesion of 0.12 would not be suitable for the high operational demand presently required by many underground locomotive systems. It should be emphasised that tests on adhesion values for steel tyred locomotives have been carried out on the surface. How similar locomotives perform underground should be considered for further investigation.

Brake shoes acting on locomotive wheel treads

59 A constant coefficient of friction between the brake and the wheel would make it possible to design wheel brakes which produce a constant brake effort. However, in practice, the coefficient varies with operating conditions, with the wheel speed and with the period of brake application. The coefficient of friction decreases as the wheel speed and period of brake application increases. Underground locomotives operate at much slower speeds than surface railways, the majority at speeds of 22 km/h (14 mph) or less. At these speeds the effect on the coefficient of braking friction is critical. The optimum brake effort should be just less than the maximum possible for the limiting coefficient of adhesion but, because the coefficient of

adhesion and the coefficient of friction between the brake block and the wheel are variable, the only way this can be achieved is by varying the brake force applied to the wheel. In underground locomotives this is achieved by manual control of the compressed air brake valve and requires considerable skill on the part of the driver.

60 An additional limiting factor in the design of underground locomotive brake blocks, currently supplied to several standards, is that there should be no risk of incendive sparking capable of igniting a methane/air mixture. The results of tests carried out by RLSD on six different materials published in a paper by Moreton and Powell in 1984[12] recommended the use of 0.5% chromium alloy cast iron. Although the material has a low wear rate and does not produce incendive sparking during braking, it does have a lower coefficient of friction than some of the materials presently used.

61 The type of brake shoe adopted is an important design consideration. Neither design nor material should be changed without consulting the manufacturer for a proper reassessment of the locomotive braking characteristics carried out before and after the replacement. Work on surface main line railways indicates that cast iron brake blocks which act on the wheel treads also tend to improve adhesion conditions, probably by a gradual cleaning action rather than any instantaneous effect. This is sometimes referred to as conditioning and is reflected in the results obtained from tests on underground locomotives.

Emergency wheel brakes

62 The ideal locomotive emergency brake is one which will not cause a skid but is adequate to bring a train to rest safely in the event of the service brake failing. Emergency brakes are usually designed to operate from a secondary pressure source which is separated from the supply to the service brakes, but spring application is becoming more common. Drivers do not have variable control of the emergency brake effort and on some locomotives cannot release the brakes quickly enough to correct a skid. Paragraph 39 of TM 12 requires the emergency brake effort to be capable of producing not less than 50% of the service brake performance. Tests have shown the emergency brakes of many locomotives to be considerably better and in some cases exceeded the effort provided by the service brakes. This report acknowledges that TM 12 should be amended and recommends that designed emergency brake efforts of steel tyred locomotives should not be less than 12%. Also emergency wheel brakes should never be designed to be greater than the service brake and in most cases should be less to prevent the likelihood of a skid being induced.

63 The recommendation that emergency wheel brake effort should not be sufficient to induce a skid imposes a severe restriction on steel tyred locomotives used on steep gradients and serious consideration should be given to equipping such locomotives used on gradients of 1 in 30 or steeper with another form of reliable emergency brake such as track brakes (paragraphs 65 to 69).

Parking brakes

64 Any parking brake, whether fitted to a locomotive or a vehicle should be either designed to fail safe or be applied by manual means through direct mechanical linkage. No application should be by fluid pressure.

Slipper pad track brakes

65 Slipper pad track brakes are simple brake pads which are usually fitted to the frame or bogie of a vehicle and when operated apply a large proportion of its weight directly to the top of the rail. The brakes can be lined with various materials but copper or copper alloys which produce reliable coefficients of friction up to 0.3 for most operating conditions are recommended. This value allows the achievement of higher and more reliable emergency brake efforts than those normally obtained from wheel brakes fitted to steel tyred locomotives.

66 Track brakes should fail to safety and can be designed to be applied by partially collapsing the vehicle or locomotive suspension, or by using springs to extend the brake pad. However, it is important that the force developed on the rails by spring applied track brakes still allows the wheels of the vehicles or locomotive to provide sufficient guidance to prevent derailment.

67 The Bentley Report[6] recommended that "Each carriage of locomotive hauled manriding trains should be provided with brakes arranged for service and emergency operation. Emergency brakes should operate automatically in the event of overspeed, and readily accessible means of applying them manually, clearly marked with the method of operation, should be provided on each carriage. Where such trains operate on gradients steeper than 1 in 30 (3.3%) the emergency system should comprise fail to safety track brakes". Track brakes are used extensively in the coal mining industry on manriding carriages on rope hauled installations and they have been well proved over the years.

68 An HSE survey carried out ten years after the publication of the Bentley Report, of locomotive installations operating on gradients steeper than 1 in 33 (3.0%), revealed that of the 64 manriding installations 62 trains were fitted with wheel brakes. Two were fitted with track brakes only and eleven were fitted with both. All installations had some form of carriage braking but the two fitted with track brakes only were provided with no service braking and 51 still required the provision of track brakes to comply with the recommendations.

69 Track brakes are now being fitted to some recently designed locomotives as additional emergency/ parking brakes. They can be expected to produce design demands in excess of 0.2 giving better performance than wheel brakes on virtually all steel tyred locomotives. The design of this type of brake should therefore be pursued for existing locomotives.

Braked rolling stock

70 Unbraked vehicles used to transport material loads underground impose considerable restrictions on the number and weight of vehicles which can be attached to the locomotive at anyone time. Only one out of 63 runaways involved braked rolling stock. In the single case the train was brought to rest by a friction arrestor before the brakes had time to take effect. The efficiency and safety of haulage systems would be considerably improved if all vehicles were fitted with brakes. Virtually all manriding carriages have effective brakes but few material cars are similarly equipped.

71 Ideally, the vehicle braking system should be designed to ensure that the brake effort increases in proportion to the vehicle's load. Two level braking, which requires manual selection for full and empty manriding carriages has been used, but it is seldom employed now because of doubts about the reliability of the design. Many mines with only shallow gradients or light manriding loads ignore

available carriage braking when calculating the permissible manriding load. The carriage brakes are therefore a bonus and ensure an additional factor of safety.

72 Where mines operate heavy manriding trains or have steep gradients a formula which includes the brake effort of the carriages has to be used to determine a permissible trailing load. The British Coal *Codes and Rules* braking formula for braked trailing loads uses a service brake effort of 18% of the unladen weight of the vehicles. Testing of one manriding carriage has shown that on dry rails such a design demand can be achieved, but it is strongly recommended that the design demand for each type of braked vehicle is determined by instrumented test. An acceptable method for calculating permissible braked trailing loads is given in the RLSD Equation 5, Appendix 2. The recommended margin of safety philosophy of using a lower locomotive operational brake demand, (paragraph 52), should also be adopted for braked vehicles and this should not be greater than 80% of the design demand.

Maintenance

Locomotive maintenance

73 Locomotive maintenance requirements are generally well understood and good advice is given in British Coal *Codes and Rules*. It is important that equipment is maintained in accordance with the requirements of the HSE approval granted to the manufacturer. The manufacturer has a duty to ensure that adequate information is provided to the user to enable this to be done. Similarly the wear limit on some components is critical as it can affect the safe operation of the locomotive. The manufacturer of any locomotive should clearly identify critical components and provide sufficient information regarding the limits of their safe use. Where possible the component should be designed so that the wear limit can be observed without reference to drawings.

74 Eighteen per cent of the 63 dangerous occurrences involving runaways were attributed to defects on the locomotive. The majority of these were associated with brake faults, particularly on battery locomotives which accounted for seven out of the eleven runaways due to this cause. Some small locomotives are not fitted with either service or emergency wheel brakes; they rely on electrical braking for control and a fail to safety emergency transmission brake which can be operated either manually or by an overspeed trip. Defects on the transmission brake were the primary cause of three runaways. The type and frequency of examination, specified in the scheme of maintenance, must be adequate to prevent this type of failure.

Locomotive brake testing

75 Regulation 24 of the Coal and Other Mines (Locomotives) Regulations 1956[2] requires the thorough examination and dynamic brake testing of locomotives every seven days. It requires "that brakes shall be applied when the locomotive is in motion, by direct mechanical action and by any other means provided". To meet this requirement the accepted practice has been to test in accordance with British Coal Codes and Rules, which specify a formula referred to in paragraphs 35 to 44 for calculating the maximum permissible stopping distance. Before 1986 the *Codes and Rules* also detailed the minimum test load to be used. However, the most recent version allows two alternative procedures:

(a) for non-instrumented deceleration testing of locomotive brakes the trailing load to be used shall be equivalent to the most onerous braking conditions;

(b) for fully instrumented deceleration testing either a light locomotive or a locomotive hauling a test vehicle may be used.

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76 To satisfy the test requirement a locomotive must come to rest within the calculated distance and the brakes must be applied for a minimum period of five seconds. Recent tests have been carried out on underground locomotives using the SIMRET retardometer. These have revealed a significant aspect of locomotive brake testing. Several locomotives, some of which had been involved in incidents were able to satisfy the requirements' of the *Codes and Rules* concerning stopping distance, but were only developing a brake design demand of 0.12, and in one case only 0.11.

77 The formula used in the current version of the *Codes and Rules* is based on the locomotive achieving a brake effort equivalent to a design demand of 0.16. However, the stopping distance also makes allowance for both driver and brake system reaction time. In most locomotive tests the driver knows the point at which he is required to apply the brakes, and therefore the reaction time is probably considerably less than the allowance made. In tests which require only short stopping distances this can mask a locomotive brake defect.

78 The present test requirement in British Coal *Codes and Rules* does not adequately assess the braking performance of the locomotive. Brake testing using the SIMRET device has indicated that in some cases the full brake effort is not developed before the locomotive comes to rest. Trailing load and speed should be sufficient to allow maximum brake effort to develop before the train is brought to rest. The measured brake effort can then be compared with the recommended design demand.

79 It is recommended that instrumented commissioning tests are carried out on all locomotive service and emergency brakes to establish that they are capable of achieving the design demand recommended in paragraphs 29, 62 and 63, and where appropriate, paragraphs 65 to 69. Subsequent routine testing should also be by instrument, but exceptionally, if a test is by measured stopping distance, then the distance should be compared with that measured at the time of the instrumented commissioning test.

80 The statutory weekly brake test is intended to assess the braking capability of the locomotive. If skidding occurs at any stage in the test the results should be disregarded. It is permissible to sand the track by hand provided that the complete section where the test is carried out is swept clean before further testing is started. If sand is allowed to remain on the rails and picked up by the locomotive wheels it can lead to an enhanced coefficient of friction between the brake blocks and the wheels, thus giving a false impression of improved brake performance. Where a particular type of locomotive frequently skids during brake testing, further investigation should be carried out to ascertain whether the locomotive is overbraked, whether the configuration prevents an acceptable coefficient of adhesion being achieved, or whether the running gear or suspension requires overhaul.

Management of track maintenance

81 The Coal and Other Mines (Mechanics and Electricians) Regulations 1965[13] include permanent haulage track and rolling stock in the definition of mechanical apparatus. All locomotive track and points should be included in the mine manager's scheme of maintenance required by those regulations. It is the responsibility of the mechanical engineer to ensure that the mechanical engineering staff supervise or effect the installation, examination and maintenance in safe working order of all permanent track. Sufficient competent staff should be available to allow this to be done.

Track standards and maintenance

82 Locomotive derailments accounted for 57% of all reportable incidents and by far the majority were caused by poor standards of installation and maintenance of track. The construction and inspection of locomotive track is covered by Regulation 6 and 10 respectively of the Coal and Other Mines (Locomotives) Regulations 1956. More detailed information on the design and maintenance requirements is available in the British Coal publication *Tracklaying for Underground Haulage*[14]:

83 Investigation of incidents revealed that on several occasions the basic requirements of regulations were not being met. Poor track standards not only increase the risk of derailment but also result in the need for more locomotive maintenance and an increased risk of loss of adhesion. When the normal loads on the locomotive wheels are reduced by cross gradient, cant or poor ballasting of the track, the risk of skidding is increased - this applies specially to locomotives with uncoupled wheels.

84 The same effect can also occur due to mis-aligned rail joints which cause a locomotive wheel to leave the track. Similarly, poorly laid out and tightly curved sections of track can increase the risk of rotational skidding. This occurs when the taper on the treads of fixed wheel sets is insufficient to compensate for the unequal distances which the wheels are required to travel.

85 Steep gradients have a critical effect on safe operation and therefore it is important that they are regularly checked as part of the manager's scheme of maintenance[13]. The examination frequency should reflect the roadway conditions and the severity of the gradient. It is recommended that on gradients steeper than 1 in 30 (3.3%) the slope of each individual rail should be checked.

86 Many of the derailments at points could have been avoided by better design. 'Split points', due to design deficiency rather than poor maintenance, were the primary cause of 30% of incidents.

87 All points should be fitted with an operating mechanism, preferably of a type which has a two way switch lever and unobtrusive handle. Point mechanism should normally lock the blades in position, and monitoring should be provided to indicate the position of both blades, particularly if these are not directly connected.

88 The risk of serious injury arising from a locomotive derailment increases with operating speed. Some locomotive installations now operate at speeds over 32 km/h (20 mph). Improved track standards should be specified for any installations with an operating speed in excess of 16 km/h (10 mph). Similarly, more use should be made of specially designed high speed turnouts, which give a much smoother transition from one track to another and usually incorporate the locking devices referred to above.

89 Analysis of the locomotive types involved in derailments, detailed in Figures 4 and 5, indicate that the 0-6-0 configuration has a much greater propensity for derailment than any other locomotive. This locomotive accounts for approximately 22% of the locomotives in use but 47% of the derailments, and requires even better track standards, especially at points, to achieve the same level of safety.

90 Track monitoring equipment should be used in conjunction with normal visual inspection to improve standards of examination. Such monitoring and recording equipment mounted on a purpose built car towed by a locomotive is used by some mines. A few recently manufactured locomotives have had similar track monitoring transducers fitted. Transducers to detect inadequate clearances are available but

this necessary periodic examination can be carried out using a flexible template attached to a locomotive or trailing vehicle.

91 The use of specialist track laying companies for both installation and maintenance contracts is becoming more widespread, especially on high speed installations. There is evidence to suggest that the expert knowledge which they apply has led to a significant and sustained improvement in track standards.

Systems of operation

Safe system of work

92 The Health and Safety at Work etc Act 1974[15] requires in Section 2(2)(a) "the provision and maintenance of plant and systems of work that are, so far as reasonably practicable, safe and without risk to health". Where locomotives are used the system of work is of prime importance. Rules should be established to cover all aspects of locomotive operation. These should be issued to all involved and should also be displayed on each haulage system. Specific provisions relating to managers rules are set out in Section 37 of the Mines and Quarries Act 1954[3].

Managers transport rules and regulation of the system

93 The guidance given in paragraphs 52, 53 and 72 of this report should be used as a basis for calculating the permissible trailing load for the various gradients on which locomotives are required to operate. Where adverse local conditions exist, it may be necessary to apply more stringent standards. The calculation should be based on the steepest gradient which exists continuously for more than 10 m. Before any locomotive haulage is used for the first time the complete system should be checked by competent people and a commissioning report prepared stating whether the installation is in a condition to enable operations to start. The system should not be used until they are satisfied that it is safe.

Maximum speed

94 Notices should be posted to advise the driver of the maximum speed and any speed change which is necessary should be achieved gradually.

95 When specifying the maximum speed it is necessary to consider the locomotive type and gearing. Locomotive manufacturers should be consulted to establish the engine output torque for the various gears and speeds and under what conditions engine braking is available. Speeds should be selected that are compatible with track conditions and allow the driver under normal circumstances to bring the train to a controlled stop without full application of the services brake. Speeds may vary for different sections of the track.

Trailing loads

96 Transport rules[9] should specify the maximum trailing load with sufficient information provided to enable haulage workers to assess the gross weight of individual vehicles. Transport rules used at most mines specify the weights of various combinations of loads and vehicle, but 20% of all runaways are still caused by overloading. Where there is any doubt, the weight of the vehicle and its attached load should be established before it is sent underground. When unusual loads are being transported underground the engineering staff should be consulted. Where locomotives are used on gradients steeper than 1 in 30 (3.3%) consideration should be given to installing small weigh-bridges at strategic places, eg pit bottom, so that the accurate weight can be established and marked on the vehicle.

Notices

97 The driver of any locomotive needs to be given clear information and instructions about the safe operation of the locomotive system. In the tight confines of underground roadways it is often difficult to judge distance. The investigation of incidents involving the collision of locomotives has revealed several cases where the driver completely underestimated the stopping distance, especially when heavy trailing loads were being braked. It is recommended that reflective notices are placed in all locomotive roadways to indicate;

(a) the gradient;

(b) the maximum speed;

(c) the gear to be selected; and

(d) the point at which braking should start in order to stop safely at a predetermined point.

98 This is particularly necessary when approaching ventilation doors, runaway devices and any turnout or points where a lower limiting speed is specified.

99 In addition to the notices relating to locomotive control, information should also be displayed detailing the correct sequence of operation for runaway devices and ventilation doors.

Traffic control - fixed light signals

100 The standard of traffic control on many underground locomotive installations is inadequate and accounted for 21 % of the reported collisions. A survey of 639 points on manriding track in one coalfield showed that only 226 were fitted with any form of monitoring. Many installations of single line working relied on verbal communication and written instructions rather than a system combining both written instruction and automatic signalling systems.

101 All points should be monitored and arranged so as to provide indication of their position, priority being given to all manriding installations and those which operate at speeds over 13 km/h (8 mph). Monitoring and indication should also be provided at ventilation doors, runaway devices and terminal stations. The positioning of the indicator signals should allow the driver time to bring the train to a safe controlled stop within the available distance.

102 Where locomotives are required to travel through ventilation doors the monitoring and signalling systems should be interlocked with the door control circuit so as to prevent the locomotive advancing into a closed door.

103 Single line working should be avoided wherever possible; however, where it is unavoidable, signalling systems should be used in which the track is divided into ‘zones’ or ‘blocks’. Such systems should be arranged so that only one locomotive is allowed to operate in a zone or block at any instant in time. Entry into a zone should cause a red light to be displayed at all entrances thereby warning other locomotives not to enter an occupied zone. Automatic systems should fail to the safe state (ie red signal) and should be considered as the minimum requirement for manriding installations. For mineral and material haulage non-automatic block signalling systems, which require manual operation of either a key or pull cord, are

preferred to those installations which rely on the driver communicating either with other locomotive drivers or a control room.

Communication

104 The latest designs of radio systems, eg the VHF leaky feeder or the LF inductive systems sending digital data, allow good communication between locomotive drivers and any control room. Such systems are likely to lead to a more efficient operation and better utilisation of locomotives. Ideally, these should be used in conjunction with properly designed signalling systems.

Energy absorbing arrestors

105 The HSE Report on the Bentley incident recommended the use of retractable energy absorbing arrestors. This type of device can bring a runaway train to a controlled stop without injuring people. In 23 of the 63 runaway incidents, the locomotive was brought to rest by a friction arrestor and there were no reports of injury or serious damage to equipment. Only in one case did the arrestor fail to operate as designed.

106 The arrestor should be designed to assume its safe operating position at all times, except when lowered to allow a train to pass. Where powered operation is considered, a safety assessment should be carried out to ensure no fault in the logic circuit could lead to the arrestor head moving inadvertently. Powered operation should require a signal from the locomotive driver while the train is within prescribed track limits. Where more than one type of locomotive is used care should be taken to ensure that the arrestor is compatible with the differing designs. On long downhill gradients it is sometimes difficult to estimate the impact speeds on which to design the arrestor.

107 It is recommended that the impact speed at an arrestor should be based on either the normal operational speed of the locomotive or the calculated speed of a locomotive which develops a skid at the top of the incline at that normal operational speed, whichever is the greater. It should be assumed that a skidding locomotive develops a brake effort equivalent to 7% of its weight.

Training and discipline

Locomotive driver training

108 Locomotive handling requires considerable skill on the part of the driver especially when descending steep gradients with large unbraked trailing loads. Under no circumstances should anyone, including officials and maintenance personnel, be allowed to drive a locomotive unless they have been suitably trained on the type of locomotive they are required to drive, and passed as being competent by an authorised locomotive instructor.

109 Analysis of the runaway incidents (Figure 6a) revealed that 31 % were caused by driver error. Immediate improvements should be sought in the standard of selection, training and supervision. The reliance placed on the skill of a locomotive driver is much greater than in any other type of haulage or transportation system in mines.

110 The existing training scheme covers most aspects of locomotive driving and is probably too detailed to be fully absorbed in one training course. Where possible all aspects of training other than locomotive control should be dealt with separately, and the driver given an opportunity to become familiar with these activities before undergoing training on control aspects.

111 The scheme covers skid correction techniques on steep gradients, the skid normally being initiated by contaminated (greased) track. Investigation of runaways has revealed that on several occasions the wheels were not locked and that loss of control was due to either rotational skidding or retardation so slow that the driver was unable to detect it. The existing training programme should be extended to give drivers ample experience in the control of heavy trailing loads which require long stopping distances. They should also have experience in correcting skids in both forward and reverse directions, due to either excessive speed or load.

112 Training centre test tracks should be designed to simulate, as near as possible, the conditions likely to be experienced underground. In particular, they should be long enough to allow skid correction techniques to be fully experienced. The British Coal booklet *Underground locomotive driving*[16] provides appropriate advice and should be followed. The use now being made of micro-computer programmes as part of a programmed learning technique for locomotive drivers should be extended with the aim of allowing learner drivers to undergo basic training in locomotive control on some form of locomotive simulator. This should help to overcome the problem of providing training on numerous types of locomotives.

Management awareness

113 For locomotives to be used safely and efficiently management at the mine must appreciate the limitations of their control and use. Some coalfields have recognised this need and arranged suitable appreciation courses for management grades. It is recommended that this initiative is adopted in mines on a national basis.

Supervision and discipline

114 However well a locomotive system is designed dangerous incidents can happen when drivers and supervisors do not comply with instructions. The analysis of incident causes given below is extracted from Figures 4 to 7 and is a matter for serious concern.

(a) 41% of collisions, 8% of runaways and 4% of derailments on straight track were due to non-compliance with rules.

(b) 20% of runaways were due to overloading.

(c) 12% of derailments on straight track and 6% of derailments on points were due to excessive speed.

115 These incidents represent 21% of the total and could have been avoided by better supervision and a more disciplined approach by drivers.

116 To conclude this section it is worth repeating the first recommendation of the Bentley Report which stated “Strict discipline and adherence to the manager’s transport rules are fundamental requirements in all manriding operations. Management and Trade Unions should take firm action to ensure full compliance with operational procedures”. These fundamentals are applicable to all locomotive operations and should be adopted forthwith.

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Conclusion and recommendations

117 This report has considered underground locomotive operation across a wide range, reiterating many of the recommendations made following major incidents and reviewing some fundamental principles which should be reconsidered in the light of current locomotive practices.

Fundamental Principles

118 **Recommendation 1:** The design of any transport system should be based on the load which the locomotive can safely brake. A locomotive should never be used to haul up-gradient a load greater than that which it can safely brake down that gradient. Under no circumstances should engine braking be considered as part of the brake effort to calculate permissible trailing loads. (See paragraph 22).

Margin of safety.

119 Throughout this report the need for adequate margins of safety has been emphasised. These are necessary not only to cater for a reduction in brake effort between weekly testing but also to recognise that the conditions of use may vary either deliberately or inadvertently from those prescribed at the planning stage. Allowances must be made for speeds marginally higher than specified, for trailing loads which may have been incorrectly assessed, for gradients which may have increased due to ground movement between repairs and for a reduction in available adhesion due to rail contamination or track defects. The margin of safety must also recognise that it is unreasonable to expect locomotive drivers always to perform to the limits of their ability or to impose this heavy burden on them. Many of the incidents in which driver error has been perceived as a primary cause could have been avoided if an adequate margin of safety had been built into the system at the design stage.

120 Margins of safety may be achieved by setting limits to the brake design demand so as to provide adequate braking with minimum risk of skidding, and by reducing the operational demand to not more than 80% of the design demand.

121 **Recommendation 2:** It is recommended that locomotives be designed to produce a design demand for the service brakes within the following limits (paragraph 29):

(a) for steel tyred locomotives with coupled axles 16 to 20% of the gross locomotive weight, ie a design demand of 0.16 to 0.20;

(b) for steel tyred locomotives with uncoupled axles 13 to 18% of the gross locomotive weight, ie a design demand of 0.13 to 0.18; and

(c) for rubber tyred locomotives 30 to 35% of the gross locomotive weight, ie a design demand of 0.30 to 0.35.

Trailing loads

122 The customary practice of determining permissible trailing loads by use of a formula intended to calculate only a stopping distance is not satisfactory. This is particularly so if low speeds are specified and used in the formula. The criteria for determining whether a locomotive can control an unbraked train is that full

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application of the brakes should produce both an acceptable retardation and halt the train in a safe stopping distance which will normally be within the 60 m range of the locomotive headlight (paragraphs 35 to 44 and 52 to 53).

123 **Recommendation 3:** The formula developed by RLSD at Equation 7, Appendix 2, should be used to determine the limiting unbraked trailing load which may be handled safely on the gradients concerned. It is recommended that a retardation of 2% g should be accepted as a satisfactory minimum for safe operation but a second calculation should be made to ensure the train will stop in a safe distance which will normally be within the 60 m range of the locomotive headlight.

124 In calculating the trailing load due account should be taken of the need for a margin of safety and the formula should be based on a locomotive's operational demand not greater than 80% of the designed demand brake effort (paragraph 52 and 53). Due account should also be taken of the design demand of the emergency brake. The operational demand of the service brake should not be greater than the design demand of the emergency brakes.

Emergency braking

125 **Recommendation 4:** Emergency wheel brakes on steel tyred locomotives should have a designed brake effort of not less than 12%, but should not be capable of inducing a skid. Serious consideration should be given to fitting another form of reliable emergency brake such as track brakes to steel tyred locomotives used on gradients of 1 in 30 (3.3%) or steeper (paragraphs 62 to 63).

Locomotive brake testing

126 The current method of testing locomotive brakes does not necessarily assess their true braking performance. Brakes which have deteriorated considerably below their acceptable limit may enable a light locomotive to pass the simple stopping distance test. It is important that regular tests require the locomotive to develop full brake effort and this may only be possible if sufficient input energy is applied by realistic setting of the loads and speeds specified for the test (paragraphs 75 to 80).

127 Recommendation 5: Instrumented tests should be carried out on all locomotives to establish that they are capable of achieving their specified design demand. Exceptionally, if a subsequent test is to use measured stopping distances then those distances should be compared with the distance measured at the time of the instrumented commissioning test for that locomotive. Test conditions must be established to ensure that locomotives continue to achieve their full braking potential for both service and emergency braking (paragraphs 75 to 80).

Other recommendations

128 **Recommendation 6:** Each carriage of locomotive hauled manriding trains should be provided with brakes arranged for service and emergency operation. The emergency brakes should operate automatically in the event of overspeed, and readily accessible means of applying them manually should be provided on each carriage (paragraph 67).

129 **Recommendation 7:** Vehicle wheel brakes should be designed to produce a brake effort of 18% of the unladen vehicle weight, ie a design demand of 0.18.

Brake efforts of some types of existing vehicles may be less than this level and should be determined by an instrumented test (paragraphs 70 to 72).

130 **Recommendation 8:** The formula developed by RLSD at Appendix 2, Equation 5 should be used to determine the maximum permissible trailing braked load. In calculating the trailing braked load due account should be taken of the need for a margin of safety and the calculation should be based on an operational demand brake effort from the vehicle that is not greater than 80% of the measured design demand brake effort (paragraphs 70 to 72).

131 **Recommendation 9:** Locomotive track and points should be included in the manager's scheme of maintenance and a duty placed on the mechanical engineer to ensure that they are maintained in a safe condition. Sufficient competent persons should be made available to allow this requirement to be fulfilled (paragraph 81).

132 **Recommendation 10:** All points should be fitted with an operating mechanism, preferably of a type which has a two-way switch lever and unobtrusive handle. Normally the point mechanism should lock the blades in position and monitoring should be provided to indicate the position of both blades (paragraphs 82 to 91).

133 **Recommendation 11:** Reflective notices should be placed on all locomotive roadways to indicate the gradient, the maximum speed, the gear to be selected and the point at which braking should start in order to stop safely at a predetermined place (paragraphs 97 to 99).

134 **Recommendation 12:** Single line working should be avoided wherever possible, but where it is necessary block signalling systems should be used. Automatic fail-safe systems should be considered as the minimum requirement for manriding installations (paragraphs 100 to 103).

135 **Recommendation 13:** The provision of energy absorbing arrestors is recommended. Their design should be based on an impact speed equal to either the normal operational speed or the calculated speed attained by a locomotive which develops a skid at the top of the incline at that normal operational speed, whichever is greater. It should be assumed that a skidding locomotive develops a brake effort equivalent to 7% of its weight (paragraphs 105 to 107).

136 **Recommendation 14:** The existing training programme for locomotive drivers should be extended to give them ample experience in controlling heavy trailing loads which require long stopping distances. They should also be given experience in correcting skids, particularly rotational skids in both forward and reverse directions (paragraph 108 to 112).

137 **Recommendation 15:** Strict discipline and adherence to the manager's transport rules are fundamental requirements on all locomotive systems. Management and trade unions should take firm action to ensure full compliance with operational procedures (paragraphs 114 to 116).

References

1 *Coal Mines (Locomotives) General Regulations 1949.* SI 1949 No.530

2 *The Coal and Other Mines (Locomotives) Regulations 1956.* SI 1956 No.1771

3 *Mines and Quarries Act 1954. The law relating to safety and health in mines and quarries Part 1*, HMSO ISBN 11 410073 X

4 *The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1985.* SI 1985 No.2023, HMSO ISBN 0 11 058023 0

5 Reports of HM Inspectors of Mines and Quarries for 1966 - North Eastern Division

6 *The accident at Bentley Colliery, South Yorkshire, 21 November 1978*, HSE report

7 *Some fundamentals of under-ground haulage by locomotives.* A E Cook. Transactions of the Institute of Mining Engineers Vol 106, 1947, pp 498-528.

8 *Brakes and wheel/rail adhesion. International conference on railway braking 1979.* C Pritchard. Paper C155/79 - The Institution of Mechanical Engineers.

9 Managers Transport Rules. Section 37 Mines and Quarries Act 1954 Ch 70 HMSO ISBN 0 10 850389 5

10 TM 12 (1977) - *Testing Memorandum: test and approval of diesel and storage battery powered locomotives and trackless vehicle and diesel powered equipment for use underground* HSE

11 National Coal Board (Technical) Code and Rules *Underground haulage by diesel and storage battery locomotive* (CR/3) revised 1 March 1986

12 *An evaluation of brake block materials for underground locomotives.* G Moreton and F Powell. International Conference on Tribology in Mineral Extraction 1984. Paper C349/84 - Institution of Mechanical Engineers.

13 The Coal and Other Mines (Mechanics and Electricians) Regulations 1965. SI 1965 No.1559. Scheme of Maintenance - Regulation 10. Interpretation - Regulation 2

14 *Tracklaying for underground haulage.* National Coal Board Mining Department (Revised 1973)

15 Health and Safety at Work etc Act 1974. HMSO ISBN 0 10 543774 3

16 *Underground locomotive driving.* NCB Industrial Training Branch.

17 *Derivation of formulae for the braking of underground mining locomotives* HSE. RLSD Internal Report No IR/L/ME/89/04 - GAC Games

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Appendix 1

TM 12 requirements for locomotive brakes

1 Braking systems for locomotives and vehicles should consist of:

(a) service brakes - to be used as the primary braking system;

(b) emergency brakes - to be used in the event of a failure of the service brakes; and

(c) parking brakes.

2 These systems may use common components, but any one failure in the common components shall not reduce the capability of the emergency brakes to stop the locomotive or vehicle safely. At least one of the braking systems must be operated by direct mechanical action by the driver. Brakes applied by springs on the release of fluid pressure may, exceptionally and at the discretion of the Executive, be permitted in lieu of this requirement on the understanding that In the case of locomotives and vehicles for use in mines where regulations are applicable, such systems may not be used without exemption from the relevant regulations. Nothing in this paragraph shall prevent the service brakes or the emergency brakes being used as parking brakes provided they meet the requirements in paragraph 40[10].

3 Braking systems must be designed to eliminate or minimise so far as practicable, the generation, in any part of the system, of temperatures capable of igniting combustible material likely to be present in the vicinity of that part. Brake blocks and/or brake linings must be of a type designed to minimise incendive sparking by frictional contact.

4 All braking systems should be designed to eliminate, or minimise so far as practicable, locking of the wheels.

5 No power assisted braking systems shall be rendered ineffective by non-rotation of the engine.

6 Where the operation of a braking system depends on accumulated hydraulic or pneumatic power, the system must include a reservoir capable of sustaining at least five consecutive applications of the brakes with the power source inoperative. Devices shall be provided to prevent the locomotive or vehicle being moved under its own power unless any power operated braking system is in an operating condition.

7 Service and emergency braking systems shall be so designed that the response time between initiation and commencement of braking does not exceed 0.7 seconds for automatic (eg operation of safety trip) or manual operation. This requirement will not apply to ‘screwdown’ types of brakes.

8 Service braking systems must be capable of developing the following brake effort:

(a) for locomotives with steel tyres 16% of the maximum gross weight of the locomotive;

(b) for locomotives with rubber tyres 30% of the maximum gross weight of the locomotive;

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(c) for trackless vehicles 50% of the maximum gross weight of the vehicle; and

(d) for locomotives designed for use with captive rail traction systems the braking system must be capable of providing a braking effort at least equal to the maximum tractive effort which the locomotive is capable of developing.

9 Emergency braking systems must be capable of developing a braking efficiency of not less than half that required for the service brakes of the appropriate class of locomotive or vehicle.

10 Parking brakes must be capable of holding the locomotive or vehicle stationary on the maximum gradient on which that locomotive or vehicle is designed to operate when the locomotive or vehicle is carrying or hauling the maximum load which it may carry or haul on that gradient.

Appendix 2

Derivation of the 'RLSD formula' in System International (SI) Units

Symbols and Units

Bl brake effort of the locomotive (including the locomotive rolling resistance) in newtons

Kl brake ratio of the locomotive (dimensionless), ie ratio of locomotive brake effort to locomotive weight

Ml mass of locomotive in kilograms

m/s^2 metres per second per second

g gravitational acceleration in $m/s^2 = 9.80665$

Be brake effort of the unladen vehicles (including the unladen vehicle rolling resistance) in newtons

Ke brake ratio of the unladen vehicles (dimensionless) ie ratio of brake effort of the vehicles to the weight of the unladen vehicles. For unbraked vehicles the rolling resistance factor Kr of the vehicles should be used

Me mass of unladen vehicles in kilograms

Gs gradient expressed as the sine of the incline (eg 0.02 is equivalent to a gradient of 2% or 1 in 50). Positive values indicate that the train is travelling downhill

Mt mass of attached load in kilograms (including mass of vehicles)

Kr rolling resistance factor of the vehicles (dimensionless) ie ratio of rolling resistance to the weight of the vehicles. The factor indicates that a mass '*m*' having a weight '*m x g*' resists constant velocity motion on a level track with a force equal to *m x g x* Kr newtons

P net force retarding the train in newtons

c a dimension less constant to allow for the effect of the rotating parts of the train

f retardation of a train with braked vehicles in m/s2

Xe ratio of mass of the unladen vehicles to the mass of the locomotive (dimension less) ie Me = Xe (Ml)

Xb ratio of mass of attached load (including mass of the vehicles) to the mass of the locomotive (dimension less) ie Mt = Xb (Ml)

fu retardation of train having unbraked vehicles in m/s2

s braking distance of the train in metres

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v velocity of the train in metres per second when a retardation f (or fu) commences

Assumptions

i) Let the rolling resistance of the locomotive be considered as part of the locomotive brake effort.

ii) Let the rolling resistance of the unladen vehicles be considered as part of the vehicles brake effort.

iii) Let the brake effort Bl of the locomotive be constant and proportional to the weight of the locomotive (the cosine of a slope of 1 :15 is 0.998 and hence the force normal to the track does not change appreciably for the range of gradients considered here).

ie Bl = [Kl (Ml)] *g* newtons

iv) Similarly the brake effort of the vehicles is

Be = [Ke (Me)] *g* newtons

Forces acting on the train

i) The effect of the gradient is to apply an accelerating force =

[Gs (Ml + Mt)] *g* newtons

ii) The effect of the brake effort on the locomotive is to apply a retarding force, Bl.

Bi = [Kl (Ml)] *g* newtons

iii) The effect of the brake effort of the vehicles is to apply a retarding force, Be.

Be = [Ke (Me)] *g* newtons

iv) The effect of the additional rolling resistance of the vehicles due to being laden is to apply an additional retarding force - [Kr (Mt - Me)] g

v) The net force P retarding the train is therefore

P = Bl + Be + [Kr (Mt - Me)] *g* - [Gs (Ml + Mt)] *g*

= [Kl (Ml)] *g* + [Ke (Me)] *g* + [Kr (Mt - Me)] *g* - [Gs (Ml + Mt)] *g*

= [Kl (Ml) + Ke (Me) + Kr (Mt - Me) - Gs (Ml + Mt)] g newtons...............**Equation 1**

However, not all this force will produce linear deceleration of the train; a portion of the force will be used to decelerate the rotating parts.

Let ‘c’ be the fraction of ‘P’ that produces the linear deceleration ‘f’; ie a force c x P must be used in calculating the retardation of the train, this being the parameter measured in instrumented tests. It is recommended that the value of ‘c’ should be 0.94 if no other information is available.

Deceleration of the train

The product of a mass multiplied by an acceleration is force. Therefore the linear deceleration of the train is obtained from (Ml + Mt) f - c x P

$$\text{ie } f = \left[\frac{c \times P}{(Ml + Mt)}\right] \text{ m/s}^2 \quad \text{.......... Equation 2}$$

substituting for ‘P’ from Equation 1 in Equation 2

$$f = c \times g\left[\frac{Kl\,(Ml) + Ke\,(Me) + Kr\,(Mt - Me) - Gs\,(Ml + Mt)}{(Ml + Mt)}\right] \text{ m/s}^2$$

dividing numerator and denominator by Ml

$$f = c \times g\left[\frac{Kl + Ke\,(Xe) + Kr\,(Xb - Xe) - Gs\,(1 + Xb)}{(1 + Xb)}\right] \text{ m/s}^2 \quad \text{.......... Equation 3}$$

‘RLSD Formula’ for Xb with braked trailing load

Equation 3 may be rearranged and expressed in terms of the fractional retardation f/g

$$\frac{f}{g} = c\left[\frac{(Kl - Kr) + Xe\,(Ke - Kr)}{(1 + Xb)} + Kr - Gs\right] \quad \text{.......... Equation 4}$$

and Equation 4 may be used to express Xb explicitly

$$Xb = \left[\frac{(Kl - Kr) + Xe\,(Ke - Kr)}{\left[\frac{f}{g + c}\right] - Kr + Gs}\right] - 1 \quad \text{.......... Equation 5}$$

‘RLSD Formula’ for Xb with unbraked trailing load

substituting Ke for Kr in Equation 4

$$\frac{fu}{g} = c\left[\left[\frac{(Kl - Kr)}{1 + Xb)}\right] + Kr - Gs\right] \quad \text{.......... Equation 6}$$

and substituting Ke for Kr in Equation 5

$$Xb = \left[\frac{Kl - Kr}{\left[\frac{fu}{g + c}\right] - Kr + Gs}\right] - 1 \quad \text{.......... Equation 7}$$

The braking distance should then be calculated by substituting the value of ‘f’ or ‘fu’ into the formula $v^2 = 2 \times f \times s$. The value of ‘f’ should always be at least 0.196 m/s^2 for the reasons explained in paragraphs 36 and 52.

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