TRAIN HANDLING DEVELOPMENT FOR 21 000 TONNE TRAINS ON THE ERMELO-RICHARDS BAY LINE

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ABSTRACT

The paper discusses issues addressed during development of an integrated braking package to operate trains of 21 000 tonnes gross on the upgraded Ermelo-Richards Bay line. It traverses rugged terrain comprising predominantly descending grades, with an imbalance between ascending and descending ruling grades. The style of train handling demanded and the feel of the train in the driver's hands contribute to the acceptance of these new challenges. Optimisation of parameters relevant to fluent train handling and correct feel are discussed. Descriptions are given of rolling stock systems and components. Test runs are reported on, concluding that a braking package has been developed which can safely operate very heavy loads over difficult terrain without imposing demands on drivers beyond levels they handle at present.

1. INTRODUCTION

The Ermelo-Richards Bay line as commissioned in 1976 was designed with ruling grades in both directions of 1,52 %, for handling trailing loads of 76 CCR-1/3 rotary dump cars, with a permissible axle load of 18,5 tonnes. These trains were sufficient to satisfy traffic demand until 1979. Yet further demand was accommodated by raising permissible axle load to 20 tonnes, so utilizing the reserve cubic capacity of existing CCR-1/3 cars, but fitting radial axle trucks in order to minimize wheel and rail damage. Subsequently, steadily increasing traffic plus anticipated growth precipitated a complete re evaluation of the Ermelo-Richards Bay line. Fortunately, the existing structures and bridges could permit an axle load of 26 tonnes for cars and 28 tonnes for locomotives. A wide range of options could therefore be considered in order to provide the planned capacity.

The design optimization embraced both economic and technical requirements. By happy coincidence, satisfaction of both disciplines' requirements converged on a common solution. On the technical side, major issues such as locomotive adhesion, number of driven axles, number of locomotives per consist, number of cars per train, permissible coupler force and ruling grade were addressed. The result was a train of 200 cars loaded to 26 tonnes per axle, hauled by four Co-Co locomotives of 28 tonnes per axle. This gives a trailing load of 20400 tonnes, a locomotive consist mass of 672 tonnes, and a train length of 2500 m. The new car and locomotive designs were designated respectively CCL-5/7 and class 11E. Four class 11E locomotives are shown hauling 200 CCL-5/7 cars on the front cover page. The CCL-5/7 car is depicted in Illustration 1. It was found possible to retain the ruling descending grades, but that ascending grades against loaded trains would have to be flattened to 0,625%. This paper addresses those parts of the total design package that relate to braking.

To place the operation perspective, the following brief statistics are given. The line traverses rugged terrain, with predominantly descending gradients in the loaded direction for unit trains (see Fig. 1). A relatively intense service is operated, comprising both heavy unit trains as well as general freight trains. This necessitates fairly short block sections. Lineside signals are encountered on average one per 1,9 km, compared for example to one per 13,8 km on the Sishen-Saldanha line. The average speed of heavy unit trains is 46 km/h, and that of returning empties is 64 km/h. A total of thirty trains run each day in each direction. The Ermelo-Richards Bay line therefore demands fluent trainhandling despite the heavy tonnage of the unit trains. Appropriate braking design is thus critically important.

2. DESIGN CONSTRAINTS

The design of a braking system must preferably be considered as a package of parameters which must be optimized within situational constraints. Whereas historical and compatibility constraints are often encountered, 21 000 tonne trains on the Ermelo-Richards Bay line could be designed with new locomotives and cars. The additional constraints discussed below did however influence the design.

Line side signal spacing.

Sections containing predominantly descending grades were not scheduled for regrading, in order to save costs. This implied that most existing lineside signals would be retained. These had been spaced according to current SATS practice which, amongst other, provides braking distance for vacuum braked freight and passenger trains. In addition, train speed is restricted as necessary to respect a braking distance upper limit of 1200 m. On ruling descending grades the available braking distance is thus 1200 m. Practical braking distances between lineside signals are typically in the range 600-1200 m. Except where normal braking distance cannot be provided, warning of a stop signal is given at the previous signal. This situation is a severe constraint on the lowest acceptable brake ratio.

Thermal loading on train wheels.

Optimization of wagon turnaround time demands amongst other the highest practical speed on descending grades. This conflicts with both braking distance constraints and limited thermal input to train wheels. Furthermore, a brake ratio which is high enough to adequately control braking distance may thermally overload wheels on long descending grades. Fortunately this delicate trade off can be optimized by inclusion of appropriate dynamic braking characteristics as a balancing factor.

Because the axle load on CCL-5 cars is 26 tonnes, it was considered desirable to use C class rim quenched cast steel wheels. It was feared that a softer class of wheel would not give acceptable wear rates. For this class of wheel a nominal thermal loading of 12-13 kW per wheel is used on long descending grades. In this context "long" is taken to mean in excess of 20 km or 30 minutes. This may be compared to a loading of 17-18 kW per wheel, at which thermal cracking problems were experienced on the Sishen-Saldanha line, where descending grades may be up to 50 km in length. Although the chosen value is conservative, this is a very critical aspect of brake design, where unreliability is frequently catastrophic and always expensive. It is also wise to allow for abnormally high heat input due to dragging brakes, equalizing reservoir leaks, trains composed of cars with differing brake block forces and drivers who exceed authorized speed limits on descending grades. There are also several situations where thermal loading increases because drivers increase speed in advance of short flatter grades within long descending grades, to avoid releasing, recharging and reapplying the automatic brake.

Thermal loading is interrelated with other parameters, and the potential gain from being less conservative is insignificant. This is because traction motors were rated primarily for drag conditions, and consequently the chosen dynamic brake rating was practically attainable. Furthermore, had wheel thermal loading been increased to reduce dynamic brake rating, trains would feel "sticky" when passing over short flatter grades within long descending grades.

Dynamic braking envelope.

The rating of dynamic brakes customarily assumes that ascending and descending ruling grades are equal. When descending grades are significantly steeper than ascending grades, the situation becomes complex. Heavy haul lines tend to favour the latter approach. In the case under consideration, the difference is large, being 0,625% ascending and 1,52% descending.

Traction motors are normally rated for hauling, and here SATS' 1067 mm track gauge is a severe constraint on motor size. For the unequal ruling grades of the Ermelo-Richards Bay line, the required dynamic braking capacity also proved to be a significant determinant of traction motor rating. In dynamic braking electrical and mechanical inefficiencies work to advantage, and it was therefore possible to specify a slightly higher rating at rail for dynamic braking than for hauling. The traction motor ratings specified could not be met by existing SATS locomotives, and it became necessary to design a new class of electric locomotive, the 11E. It is rated at 3,9 MW in traction and 4,5 MW in dynamic braking, both continuous.

Very high dynamic brake rating may result in excessive compressive coupler forces. It is therefore necessary to limit the peak braking effort which could otherwise be exerted in the lower speed range. The limiting value is not easily defined, but there are favourable factors in the case of the Ermelo-Richards Bay line. Rails are laid on concrete ties with secure fastening devices, and rail turnover is thus not a problem. Rail is all continuous welded. Points are provided with movable frogs and wheels therefore do not traverse any gaps in the running top. All drawgears have alignment control characteristics, which reduces the lateral component of compressive coupler forces. All cars are fitted with radial trucks, which effectively eliminates flange contact in curves. For the class 11E locomotive the consist dynamic braking effort has been limited to an empirically determined value of 1450 kN, which is equivalent to 22 % adhesion.

Traditionally, dynamic braking adhesion is limited to fairly conservative values, typically in the range 16-18 %. When specifying the class 11E locomotives, it was necessary to consider significantly higher values to support the high energy dissipation rate specified. This can be rationalized philosophically by noting that, for design purposes, the dynamic brake is used for energy dissipation only, not for control of braking distance. Previous practical experience with high-tech electric locomotives has provided confidence in practically usable adhesion levels of the order of 24% in drag service. It was therefore concluded that the required 22% adhesion in dynamic braking would be attainable. Dynamic braking is of course useful for control of braking distance, and in principle there is no objection to high dynamic braking adhesion demand provided that train friction brakes can cope with situations of poor adhesion.

The above considerations contributed to specification of the dynamic brake characteristic depicted in Fig. 2.

Dimensional constraints on cars

The new design CCL-5/7 cars share existing loading and dumping facilities with old CCL-1/3 cars (CCR-1/3 cars which have had their brake ratio reduced and L-1 equipment removed are redesignated CCL-1/3) and they therefore have to be dimensionally compatible. An additional 20 cubic meters capacity had however to be found within the length of the old car, to utilize the increased axle load of 26 tonnes. The additional volume was obtained by broadening and lowering the bathtub portion of the car, placing stanchions inside the car instead of outside, and increasing the overall height, as illustrated in Fig. 3. Full use of the permitted vehicle profile on the new CCL-5 car thus ruled out conventional underframe-mounted foundation brake rigging. Alternative brake gear configurations had therefore to be considered.

3 DRIVING FEEL

Analogous to fine handling contributing to the pleasure and safety of driving a motorcar, the authors' experience is that a similar approach to trains enhances drivers' acceptance of new challenges. It was therefore set as an objective that 21000 tonne trains on the Ermelo-Richards Bay line should handle at least as well as, and preferably better than, previous trains. Driving feel is dominated by braking characteristics. Any benefits which can be engineered in respect of feel will therefore enhance train handle ability, and hence also the drivers' perception of the operation as a whole. The factors which are taken into account are now discussed.

Brake block material.

Composition brake blocks are regarded as a prerequisite for successful operation of very heavy trains over rugged terrain with tight signal spacing. In particular, a coefficient of friction as constant as possible is preferred. To the driver it is important that once a train has been set up on a descending grade, subsequent speed variations should not result in a significant change in friction braking force. When speed is reduced at temporary speed restrictions for track maintenance on long descending grades with direct release brakes, it may be inopportune to make a release, yet without the release a train may stall. If the coefficient of friction increases as speed decreases, an undesirably high brake force can result. This characteristic is present in the extreme in cast-iron brake blocks, and can also be present if an unsuitable composition material is chosen. Drivers deal with this situation by applying power against the brake application, but obviously this wastes energy, and may overheat wheels.

This problem is aggravated on the Ermelo-Richards Bay line by relatively high brake ratios which provide adequate brake power for stopping at signals. The nominal brake ratio on CCL-5/7 cars is 13,3 %. In practice this means that a minimum plus no more than 15 kPa brake pipe reduction in conjunction with dynamic braking is sufficient to hold speed constant on long descending grades. It is thus critical not to get too much brake pipe reduction during normal speed control on long descending grades. The situation would be somewhat easier with longer signal spacing and consequently lower brake ratios. The situation could be more manageable with a greater contribution from dynamic braking, but this is an expensive solution which would probably also incur excessively high compressive coupler forces.

Brake Ratio

It is important to a driver that he should be able to modulate braking force sufficiently. For this reason the lowest possible brake ratio consistent with stopping ability is preferred. This enables brake pipe pressure reductions in excess of minimum to be made as required. If the brake ratio is too high, it is seldom possible to make more than a minimum brake pipe reduction, and even this may be too much. A low brake ratio also enables long, gliding speed reductions to be made with a small brake application. This facilitates the mental process of judging stopping position accurately. Braking distance simulations were undertaken on a train dynamics analyser in order to establish a viable brake ratio range. The results of this simulation are shown in Fig. 4.The simulations were made from an initial condition of speed balanced on a downgrade against a wheel energy dissipation limited brake application, supplemented by sufficient dynamic braking to hold speed constant. This is the normal situation when approaching lineside signals on descending grades. This does imply that a fallible dynamic brake is used to contribute to safe control of braking distance. Fig. 4 shows to what extent the dynamic brake contributes. In the event of dynamic brake failure whilst approaching a signal, the driver would have to make an emergency brake application. In practice the dynamic brake has proven acceptably reliable. It is the authors' contention that traditional reliance on the automatic brake only for control of braking distance is not beyond criticism. It is not practical to control stopping distance with the required degree of accuracy using the automatic brake only, and the combined use of dynamic braking is unavoidable.

Based on the above considerations a brake ratio in the range 13- 14 % appeared viable. An associated cost reduction target was to avoid empty/load equipment. This was not easy to achieve because CCL-5/7 cars have a very high load to tare ratio at 4,15 to 1. Exploiting the smooth characteristics of the high friction composition brake blocks chosen, and pushing brake ratio to the lowest acceptable limit, it was found just possible to get away with single capacity brakes.

Curve compensation

Grades in curves are customarily compensated, so that locomotive loading in the ascending direction can be optimized. However, in the descending direction the flatter grades in curves show up as a reduction in total brake force demand. This increases the range of brake force modulation that the brake designer must provide. With direct release brakes it is advantageous to minimize this variation in resultant grade force felt by a train as it descends a grade, so that variation in total brake force demand is minimized. On a line designed only for heavy traffic in one direction, curves on descending grades could be uncompensated, because returning trains are normally empty and thus easily hauled by available locomotives. The Ermelo - Richards Bay line is however also designed for significant traffic in the nominally empty direction, and this option was avoided. However, when radial trucks are used, as on the CCL-1/3 and CCL-5/7 cars, curve resistance is reduced to practically zero. This in turn minimizes the amount of dynamic braking required to match the range within which total available brake force can be modulated, to the range within which total brake force demand varies.

Dynamic braking contribution

Dynamic braking characteristics are arguably the greatest single contributor to train driving feel. These can be placed in two categories, namely the ratio of dynamic brake force to automatic brake force when descending long grades, and the characteristics of the dynamic brake itself.

When descending long grades, on which it is not normally desirable to release and recharge the automatic brake, it is important to ensure that the range within which total braking force can be modulated is at least as large as the range within which total brake force demand varies. If not enough, excessive speed variation is unavoidable. If speed drops too low drivers tend to apply power against a brake application. If speed rises too high, the dynamic braking contribution diminishes to the extent that additional friction braking is required. This is a difficult situation to handle correctly, and frequently leads to either a stalled train or excessive heat input to wheels. It has been found empirically on the Ermelo-Richards Bay line that this criterion can be satisfied if the proportion of friction braking does not exceed 50 %, or 60 % at the utmost, of the required total braking effort.

It is also essential that adequate dynamic braking must be available down to very low speeds, to handle three distinct situations. Firstly, when approaching an accurate stop, it is convenient to be able to release the automatic brake at relatively low speed and control the train with dynamic brake only, whilst recharging the brake pipe. A final automatic brake application is then made shortly before the desired stopping point is reached. If this technique cannot be applied, drivers tend to creep up to signals at very low speed, or to stop far short of the required point, or to drag the train against a brake application. None of these techniques are desirable. Secondly, adequate low speed dynamic braking effort enables train speed to be reduced to a low value where the ruling downgrade is slightly eased, and automatic brake to be released and recharged whilst holding the train with dynamic brake only. This is useful when too large a brake pipe reduction has been made for whatever reason. Thirdly, it is advantageous to be able to slow a train approaching a temporary speed restriction on a long ruling descending grade by means of dynamic braking only, so that speed can later be regained by reduction of dynamic braking effort.

It was calculated and verified by tests that the design adhesion of 22% and extended range down to 15 km/h, as depicted in Fig. 2, provide the optimum characteristics. These characteristics are very easily met by high-tech electric locomotives such as the class 11E.

Train length

It is SATS' policy to fit AAR-type direct release brakes on all unit train cars. For the train length and mass, and terrain under consideration, this is the only brake system that will provide adequately fast and uniform response. Experience with 210-car trains on the Sishen-Saldanha line suggested that trains of the order of 200 cars could be handled on the Ermelo-Richards Bay line. This conclusion was reinforced by previous tests which had been run on the latter line for other purposes, using trains of 160 cars loaded to 74 tonnes gross. This was also a reasoned step of faith, because it was not possible with the analytical tools available at the time to adequately predict the feel of the final train. The original fleet of cars on the Sishen-Saldanha line are fitted with ABD equipment, which gives acceptable response with short cars (10 500 mm over coupling lines), long grades (very much longer than train length between reversals), long signal spacing, infrequent temporary speed restrictions for maintenance and easy terrain. Nevertheless, application response subjectively felt more sluggish than would be desirable on the Ermelo-Richards Bay line. However, the latter line uses longer cars, (12 070 mm over coupling lines), short grades (less than train length between reversals in many instances), tight signal spacing, relatively more frequent temporary speed restrictions and generally difficult terrain. It was therefore essential to sharpen application response. Fortunately, before freezing the design of the cars, it had become policy to fit brake control valves featuring an accelerated application valve. The improved response at brake pipe reductions greater than minimum has proven acceptable on 21000 ton trains.

Energy balance on ruling descending grades

A graphical energy dissipation balance is a convenient check on correct performance of a brake system over the design speed range. Brake force multiplied by train speed equals energy dissipation rate. All energy flows are balanced out as depicted in Fig. 5. From this diagram the correct distribution between dynamic and friction braking is clearly evident. The high risk of thermal damage to wheels, if authorized descending grade speed restrictions are exceeded when the dynamic brake is on the constant power portion of its characteristic, is also clearly evident. A speed limit of 40 km/h is at present applied to long 1,52 % descending grades. From the data in this paper there obviously is reserve capacity to increase this speed to 50 km/h. This provides a reserve for speeding up turnaround time when required.

4. LAYOUT OF BRAKE GEAR ON CARS

Due to the impracticality of conventional underframe mounted foundation brake rigging, two alternative configurations were initially investigated. These were truck mounted and carbody mounted systems.

Truck mounted brake systems customarily use two 7" (178 mm) diameter cylinders per truck. Since the effective brake ratio may only be varied by varying brake pipe pressure, brake cylinder forces attainable with this system were found to be marginal in certain circumstances. Increasing the brake pipe pressure to overcome this problem was considered, but ruled out because of doubt regarding brake hose reliability at high pressures. Use of four 10" (254 mm) diameter brake cylinders per car could have provided sufficient braking force, but introduces the problem that the combined brake cylinder volume is too large for a single control valve to handle. This necessitates the complexity of an additional air reservoir and relay valve. Furthermore, due to the 1065 mm track gauge and the use of radial trucks, a modified bolster would have had to be designed to accommodate a truck mounted system. Space restrictions on the radial trucks, inflexibility of brake ratio, together with the hardware development required, all reduced the attractiveness of this alternative. Due to a lack of first hand experience with truck mounted systems and the reservations mentioned, SATS opted for a body mounted system.

A brake system comprising a 7" ABU cylinder, a slack adjuster and └ suitable rigging fitted to each end wall of each car to brake └ each truck was eventually designed. The auxiliary and emergency reservoirs, control valve and holding brake control valve are └ fitted to one end of a car only. The handbrake is also fitted to one end only. The layout is depicted in Illustrations 2, 3, 4 and 5. The drawgear is standard F type, with a nominal distance between striker castings of 800 mm. This accommodates the brake gear even at the minimum design curve of 91 m radius. This arrangement thus utilizes volume which would otherwise have been wasted. Since the cars are semi-permanently coupled in pairs to reduce free slack, the use of one control valve per two cars was initially considered in an effort to reduce car mass and cost. This option would however also require the use of an additional air reservoir and relay valve. A further disadvantage is that the brakes of two cars could be rendered inoperative in case of car equipment failure.

5. HOLDING BRAKE

Due to the imbalance between ascending and descending grades and the severity of the latter, the locomotive independent brake alone is incapable of holding a train whilst recharging the automatic brake after stopping on a descending grade steeper than approximately 0,8 %. The automatic brake can also not be sufficiently recharged in the short time before the authorized descending grade speed limit is reached. Consequently, a holding brake system had to be developed to hold the train whilst recharging the automatic brake. The following alternatives were considered.

Electromagnetic track brakes on the locomotives appeared to be a relatively simple means to supplement the independent brake. Calculations showed that a total braking force of 1345 KN had to be provided by electromagnetic braking, in addition to the 1565 kN provided by the independent brake, giving a total force of 2910 kN per consist. Although at the time of the investigation the track structure was considered capable of sustaining such high forces, subsequent longitudinal track movement in areas where tractive forces of 2000 kN are sometimes exerted has cast doubt on this capability.

A test was conducted to ascertain the in train effect of very high localized head end brake forces. The intended train was simulated by a test train consisting of six 111-tonne locomotives at the head end, followed by 100 cars loaded to 80 tonnes gross, followed by four locomotives of 125 tonnes each, followed by 88 cars loaded to 20 tonnes gross, followed by six locomotives of 125 tonnes each, followed by a final 88 cars loaded to 80 tons gross. This train was stopped with slack bunched on a 1,52 % descending grade. The independent brake of the leading locomotive consist, plus a hand brake application on top of an air brake application on the first 30 cars, provided the abovementioned head end braking force. The automatic brake was then released. After a short initial period, during which the train remained stable due to stick slip, the friction drawgears of some of the cars closed solid. The resulting movement set off a chain reaction throughout the train which overcame the head end brake force. The leading locomotive consists and thirty braked cars were simply pushed out of the way. In addition, very high structural stresses were induced in some of the vehicles. By this time parallel tests had demonstrated that commercially available brake magnets could not deliver adequate brake forces under local conditions. The idea of using electromagnetic brakes was therefore abandoned after the abovementioned test.

The use of retainers to retain or delay release of brake cylinder pressure whilst recharging the automatic brake was considered. This alternative offers the advantage that minimum additional equipment is required, but impairs handle-ability. Setting retainers was also considered to be a potential nuisance in undulating terrain. This alternative was therefore also rejected.

A straight air brake for the front portion of the train was also considered. This would have comprised an additional holding brake pipe teed on each car to a double check valve between the brake cylinder and control valve. The double check valve would compare the pressure from the control valve with that of the holding brake pipe, and allow the higher pressure to enter the brake cylinder. This would positively hold the train whilst the automatic brake is being recharged. The concept was rejected because the integrity of the car brake equipment would be compromised by interposition of fallible components between control valve and brake cylinder.

Retaining valves fitted to the brake cylinder exhaust port on the pipe bracket on a prescribed number of cars, under control of a second holding brake pipe. This system shuts off the exhaust port of the control valve and so holds the train positively on └ descending grades whilst recharging the automatic brake, without affecting normal train brake functioning. This is the system for └ which SATS opted.

Functioning of holding brake

The holding brake chosen is in essence a remote controlled retainer. A separate holding brake pipe is connected through the trailing locomotives to the first 100 cars on the train. This system is independent of the automatic brake, except that a prior automatic brake application must have been made so that the holding brake has an application which it can hold. It can only be applied or released by the holding brake driver's valve from the leading locomotive in the consist. The holding function is selected by moving the holding brake driver's valve to the application position, thereby charging the holding brake pipe. The automatic brake may then be recharged without having any influence on the holding brake. After the train brake pipe has been fully charged the driver's holding brake valve is held in the application position until the train is ready to depart. When placed in the running position, the holding brake pipe discharges through a switching valve on the lead locomotive, resulting in the brake cylinders releasing from the front of the train. The train is brought into motion against full dynamic brake, with initial assistance from the independent brake, so that slack does not run out.

Locomotive portion

The locomotive portion of the holding brake consists of a holding brake driver's valve, holding brake pipe pressure gauge and flow meter, plus associated control and interlocking equipment. The holding brake driver's valve is conveniently installed in the driver's cab (see Illustration 6). It has application and running positions and is inoperative unless a full service automatic brake application has been made and the locomotive independent brake is fully applied. These interlocks are intended to discourage use of the holding brake whilst the train is in motion.

A holding brake pipe pressure gauge is mounted on the fascia of the driver's cab and its dial is divided into red and green zones. The green zone indicates a sufficient pressure in the holding brake pipe to close the holding brake valve on the cars. Because of the flow characteristics in a relatively small bore pipe, a green indication at the head end of the train is not a conclusive indication that the holding brake control valves on all cars will function. For this reason the pressure gauge is supplemented by a flow meter (also see Illustration 6). The holding brake pipe flow meter is an analog gauge positioned adjacent to the pressure gauge. It indicates the rate of air flow into the holding brake pipe on a dial divided into red and green zones. While the pipe is being charged the pointer is in the red zone. When the pressure differential across a measuring orifice is small enough, the pointer moves into the green zone. This indicates that the holding brake pipe is sufficiently charged and that all the car mounted holding brake control valves are by implication in a closed position. The pressure differential at the red/green boundary allows for acceptable air leaks in the holding brake system, but discriminates against an open pipe at the rear end of the block of cars through which the holding brake pipe has been coupled.

Car portion

The car portion of the holding brake system comprises a holding brake pipe, teed on each car to a holding brake control valve attached to the exhaust port on the pipe bracket. The 3/4" nominal diameter steel holding brake pipe runs the length of the car, and is connected between cars by means of rubber hoses. These hoses are fitted with gladhands at the outer ends of each semi-└ permanently coupled pair of cars, at which location a dummy gladhand is also attached to the car body. The holding brake pipe is shut off behind the required number of cars by coupling the rubber hose to the dummy gladhand. The holding brake control valve controls the exhaust port of the control valve. When the holding brake pipe is charged from the lead locomotive, the holding brake control valves on the cars shut off the exhaust ports of the control valves. When this is done after an automatic brake application, the air pressure in the car brake cylinders is trapped, thus maintaining the brake application. Subsequent release of the holding brake pipe pressure by means of the driver's holding brake valve opens the holding brake control valves on the cars and so vents the pressure in the brake cylinders to atmosphere.

To ensure convenient marshalling it was decided that every CCL-5/7 car should be fitted with the complete holding brake system. The holding brake must be applied on slightly less than half the cars in order to hold a train on the steepest descending grades. It would thus also have been possible to fit a holding brake control valve to one car out of each pair. However, CCL-1/3 cars which have never been fitted with holding brakes are also used on the Ermelo-Richards Bay line. It was therefore decided to fit holding brake control valves to all the CCL-5/7 cars so that, when required, a 100-car block of CCL-1/3 cars may be conveyed at the rear of a block of CCL-5/7 cars. This arrangement has the further benefit that the holding brake pipe is only coupled through the first 100 cars, which benefits response time.

6. PROVING THE DESIGN

The braking system design was verified by means of practical tests, in preparation for introduction of revenue service. At the time of testing, civil engineering work to reduce ascending grades against loaded trains was not yet complete. This necessitated assisting the 200-car test trains by means of six 125 tonne rear helper locomotives over those portions of the line that still have 1,52% ascending grades. Train handling on the rest of the predominantly descending route was achieved by employing four class 11E locomotives at the head end of the train only. The following are some of the insights gained during testing and run up operation.

System response.

The holding brake control valves on the cars were originally designed to include a self propagating release feature. The feature initially did not perform as intended, and was later found not to be essential in practice. Further development was therefore aborted. The response times of the holding brake system were found to be as follows. It takes 5 minutes to charge the holding brake pipe to set the holding brake control valves to the retain position. Thereafter it takes approximately 11 minutes to recharge the brake pipe after the full service application which has to be made before the holding brake may be applied. When the holding brake is released it takes approximately 4 minutes before the train starts rolling, and approximately another minute before the holding brake is completely released. The train thus rolls for about one minute before the holding brake is fully released. This is not sufficient to damage wheels. The abovementioned times indicate that heavy trains should not be stopped without good reason on descending grades, because it requires at least 20 minutes to get them moving again.

Car brake equipment.

To date the car brake equipment has performed satisfactorily. Because of its exposed location on the end walls of the cars, corrosion is somewhat greater than normal. This configuration initially caused water to accumulate in the slack adjusters, causing them to fail after a short period in service. A minor modification to the slack adjuster design rectified this problem. Although the drooping automatic and holding brake pipes do not conform to recommended practice, there was no other route possible because the car fills the permitted vehicle profile. No problems have however been experienced with water trapped in these pipes.

The brake ratio chosen has met all expectations. Whereas many SATS cars have brake ratios which are so high that only a minimum brake pipe reduction can be used for speed control on descending grades, the CCL-5/7 cars permit a wider choice of reduction for this purpose.

Dynamic braking.

During dynamic braking it has been found that unusually frequent wheelsliding occurs on the leading truck of the leading locomotive under conditions of poor adhesion. This results in frequent automatic corrections. This phenomenon has only been observed at the very high adhesion demanded by the dynamic brake of the class 11E locomotive. It has been found that notching down slightly eliminates this sliding, but with the disadvantage that the reduced braking level applies to the entire consist. It has therefore been concluded that control logic which reduces the adhesion demand on the leading truck of the leading locomotive only during dynamic braking should permit optimum exploitation of the adhesion available to the consist as a whole.

Certain of the dynamic brake responses of the class 11E locomotives have proven to be less than perfect under certain circumstances. Due to the positive slope of the intermediate notch characteristics (see Fig. 2), there is dead handle movement through most of the normal speed range. When a driver follows the response to handle movement on his loadmeter there is no problem. However, when driving by seat of the pants, this characteristic interposes an illogical link between the driver's intentions and the response of the locomotive to those intentions. At the higher end of the speed range this characteristic makes the └ intermediate notches extremely coarse. At a speed of 80 km/h for example, which is used through dips for energy saving, the driver effectively has a choice between only two notches. The minimum dynamic braking in notch 1 is also rather high. Whilst it is often desirable to keep the locomotives against the load, there are also occasions when it is desirable to allow a train to accelerate on a descending grade against a light dynamic brake force. The authors are of the opinion that trainhandling feel can be optimized by shaping intermediate dynamic brake notch characteristics to be miniatures of the outer envelope. This eliminates the detractors discussed above.

The substantial dynamic brake rating has proven of great value in building up the confidence of drivers, because it minimizes the negative attributes of direct release brakes. It has been found that recharging time in particular needs to be watched carefully, to avoid kick-offs. The class 11E locomotives are fitted with flowmeters so that by planned use of the dynamic brake it is possible to control speed after running releases on easy descending grades until the brake pipe is sufficiently recharged.

The longest tunnel on the Ermelo - Richards Bay line is 3,7 km long, on a 1,52 % descending grade. Most of, and occasionally all of, the locomotive consists full 18 MW dynamic brake rating is used in this tunnel. Because the train substantially plugs the single track tunnel profile, airflow past the locomotives is sluggish. Under these conditions ambient air temperature rises to around 150 deg. C at the fourth locomotive. Two fixes were needed to make this situation workable. Firstly, the dynamic brake resistors had to be uprated. Secondly, the overtemperature protection of the auxiliary equipment cooling system was modified so as not to trip if the overtemperature was caused by high inlet air temperature, as would be encountered in a tunnel during dynamic braking.

The CCL-5/7 cars are fitted with standard friction drawgear. Under the relatively high compressive coupler forces encountered on the Ermelo-Richards Bay line, they are sensitive to the rate of change of dynamic braking force. Above a threshold level rough wave action can be induced within the train. It has been found that this action does not occur with constant friction drawgear, and it is therefore intended to change out the standard friction drawgears in due course.

7 CONCLUSION

It is concluded that a braking package has been developed which enables safe operation of very heavy trains over very rugged terrain within tight constraints. The design does not impose demands on drivers beyond the levels which they handle at present. In fact, they have been pleasantly surprised at the ease with which the 200-car trains handle. This was dramatically demonstrated during an early test run, which is normally driven by specially prepared test drivers. One of the local drivers expressed great interest in driving a train, and as a check on the handle-ability he was given the opportunity, without any training. He handled the train virtually faultlessly, which was taken as confirmation that the braking design is on target.

8. Acknowledgement

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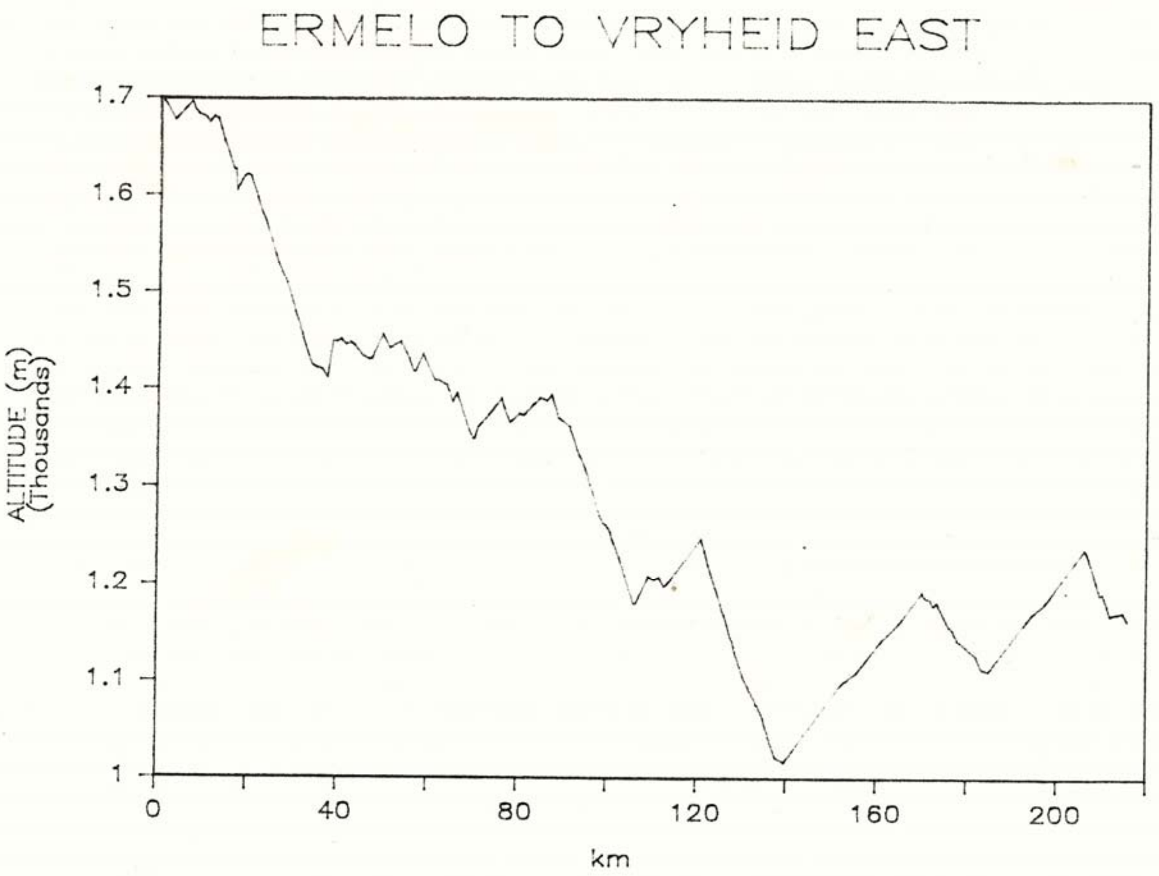

ERMELO TO VRYHEID EAST
ALTITUDE (m)
(Thousands)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
40
80
120
160
200
km

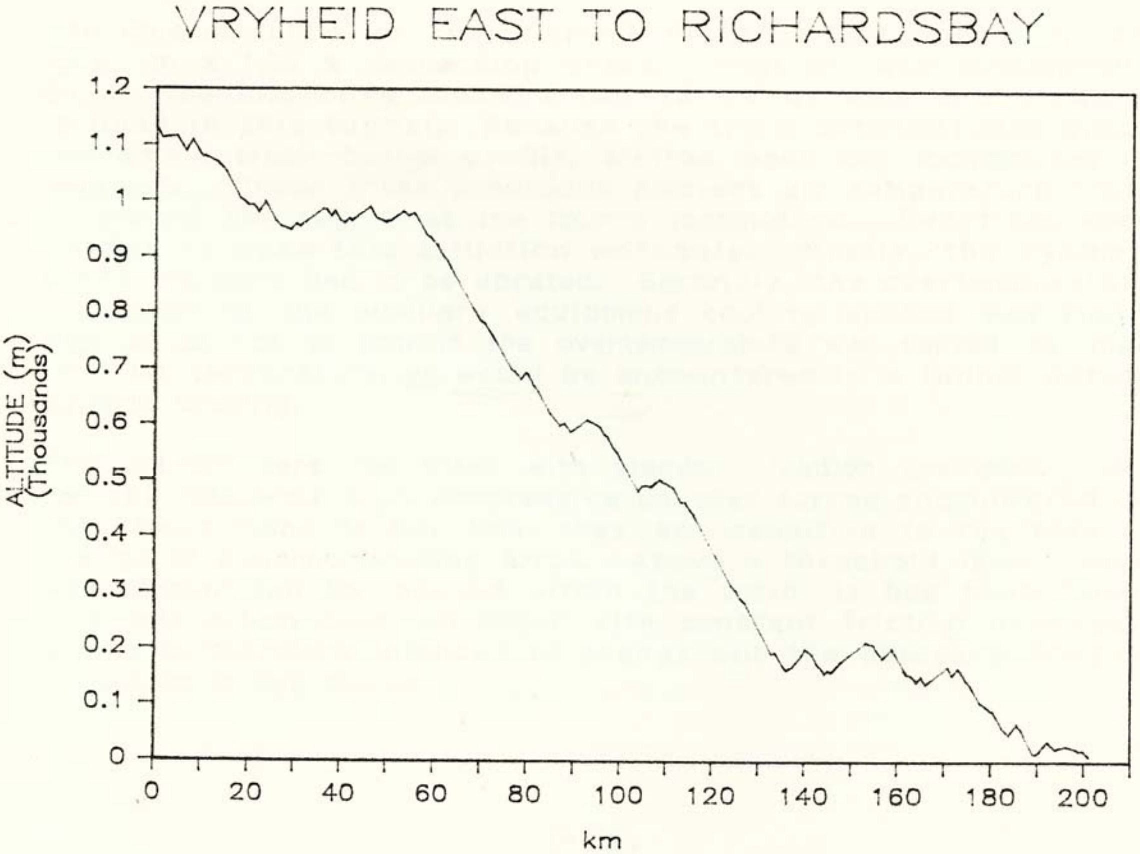


FIGURE 1 : CONDENSED LINE PROFILE

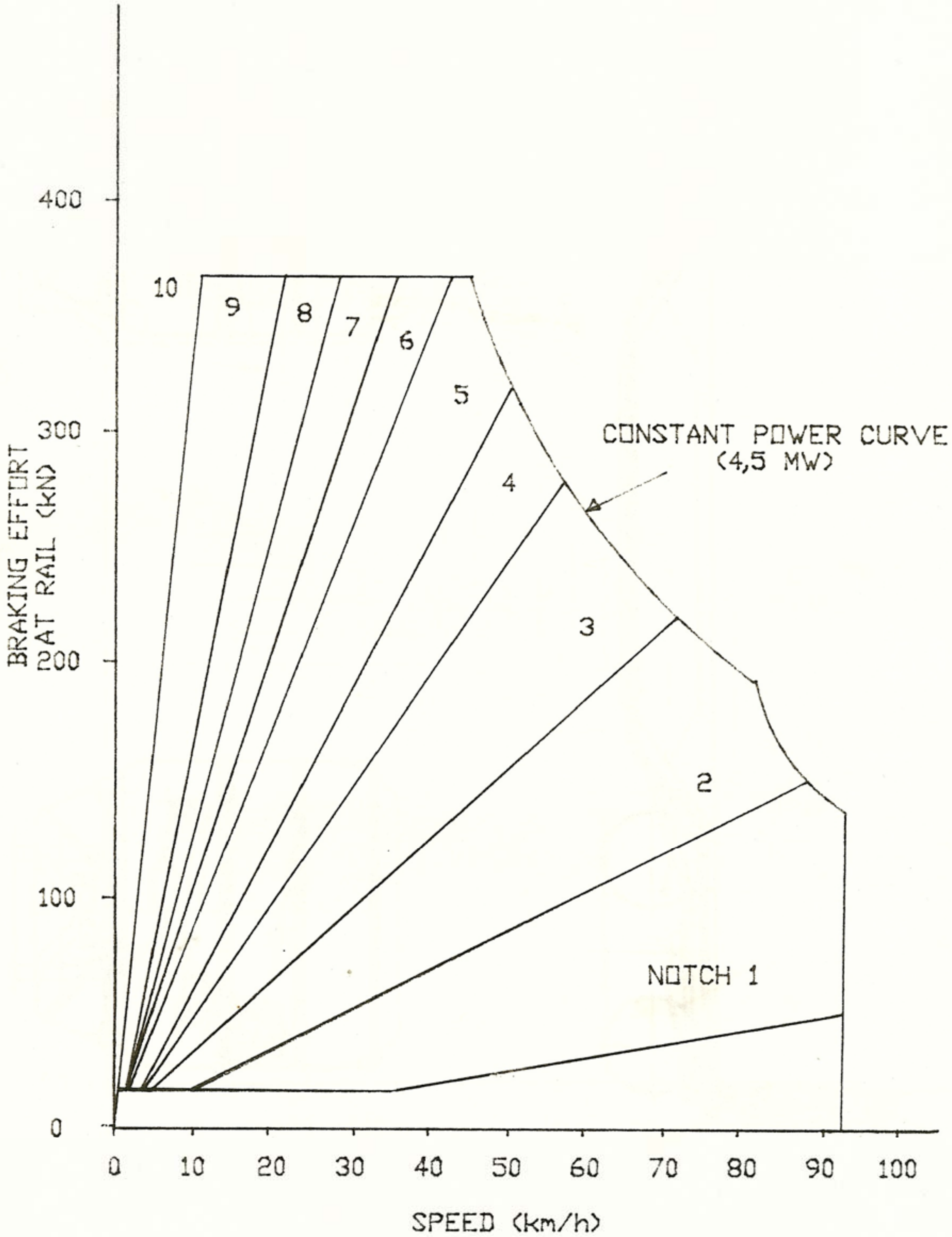


FIGURE 2 : CLASS 11E LOCOMOTIVE DYNAMIC BRAKE CHARACTERISTICS

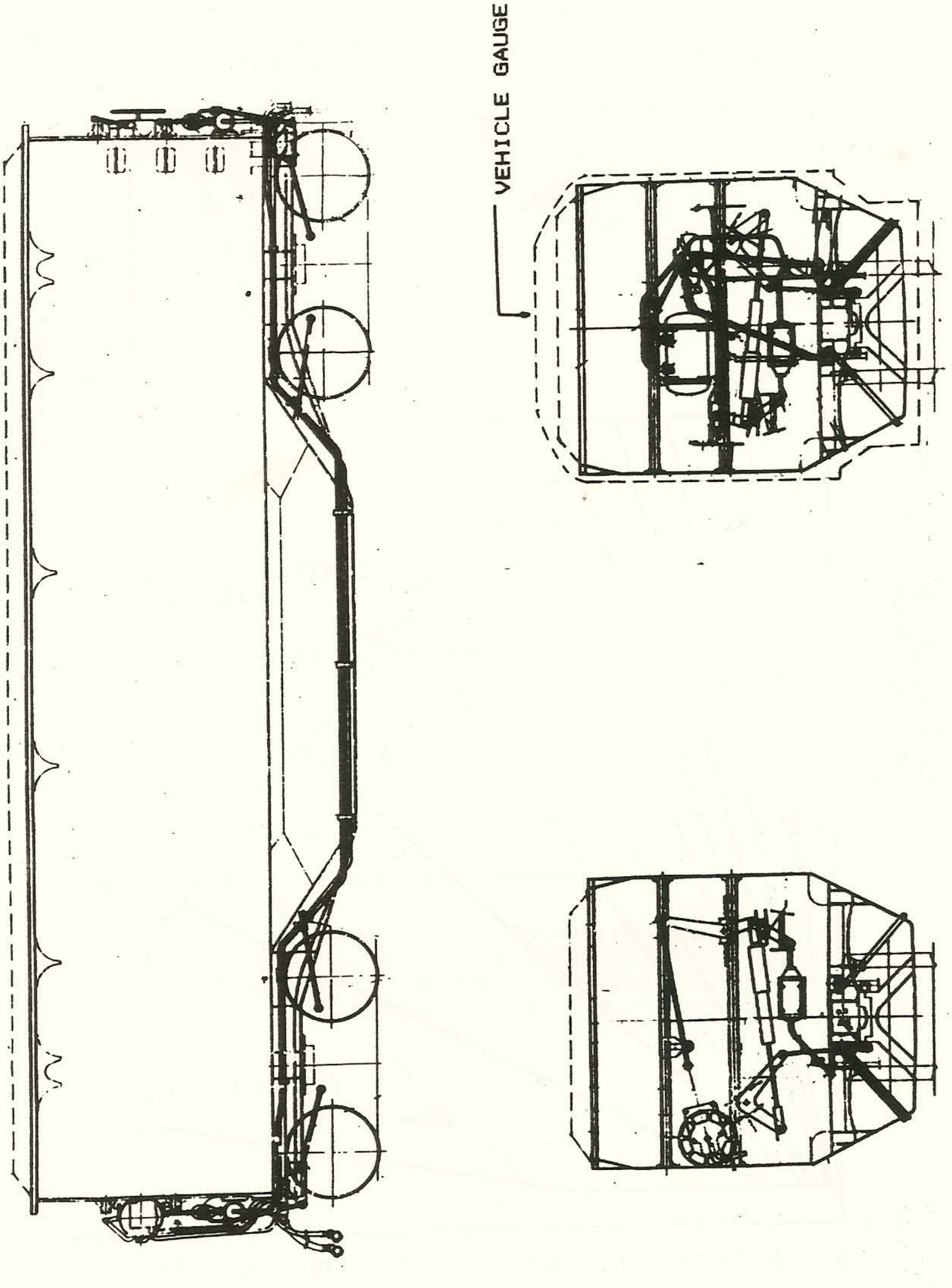


FIGURE 3 : CCL-5/7 CAR

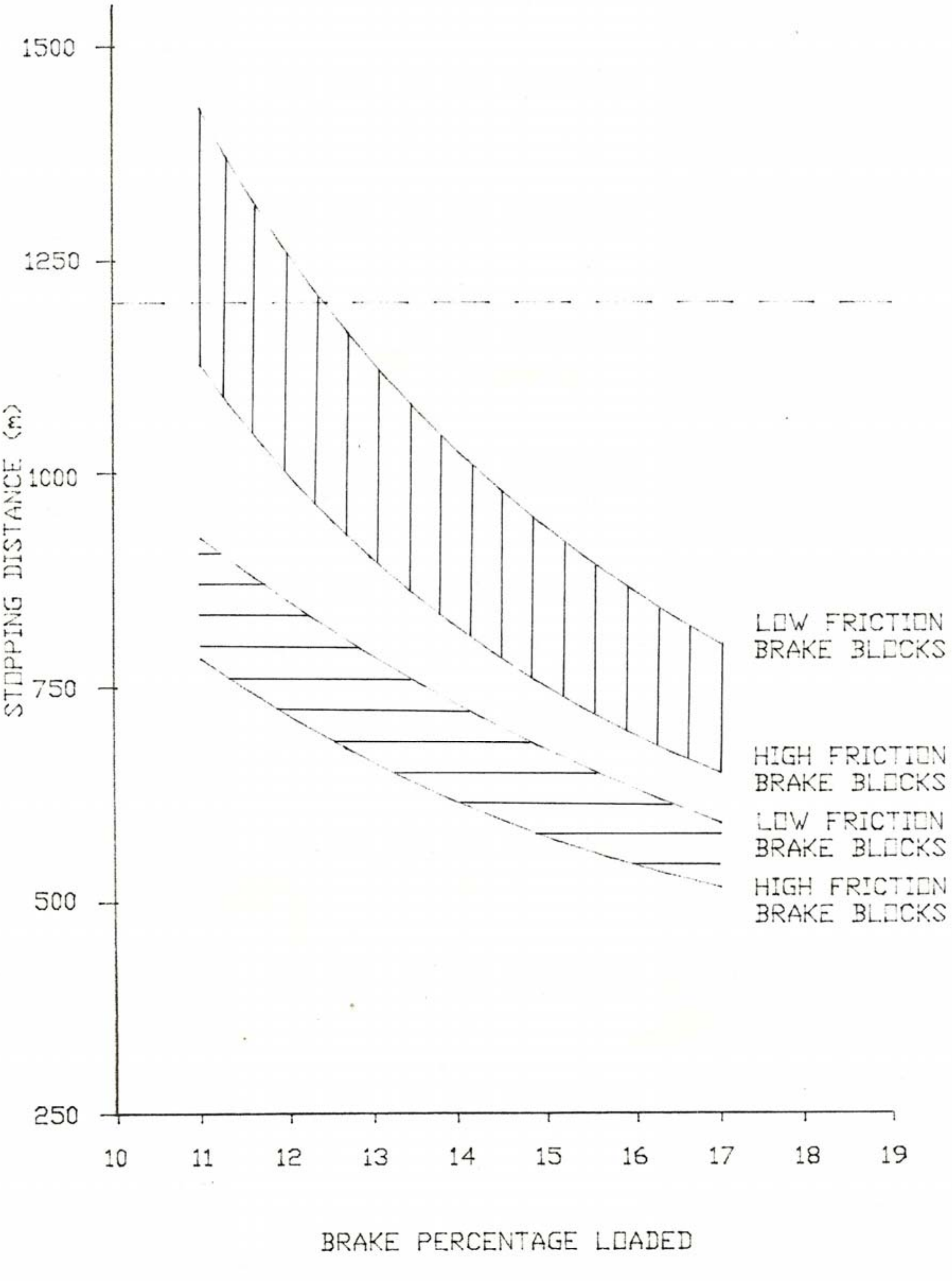


FIGURE 4 : BRAKING DISTANCE AGAINST SPEED FROM INITIAL SPEED OF 50 km/h ON 1,52% DESCENDING GRADE

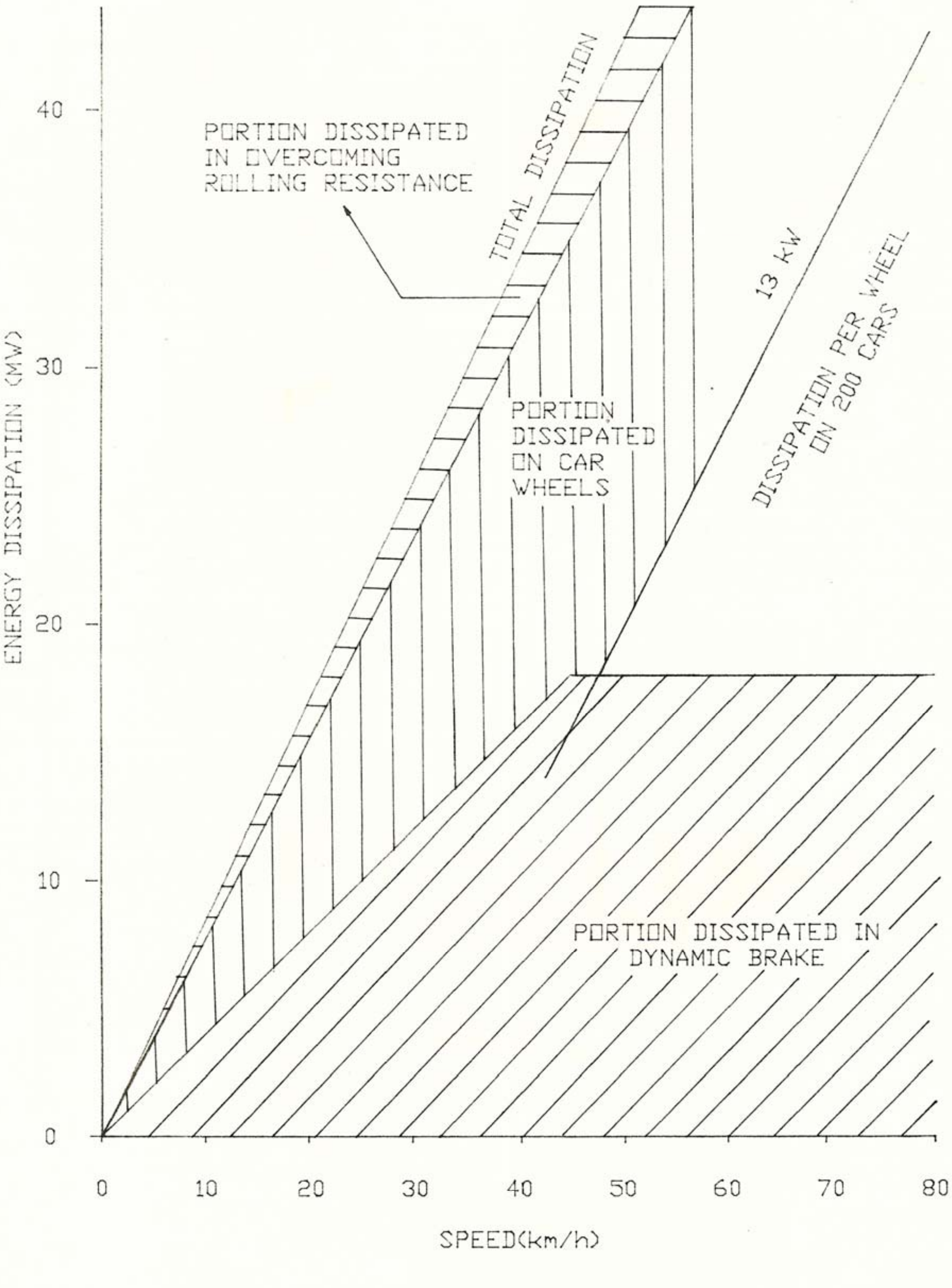


FIGURE 5 : ENERGY BALANCE ON DESCENDING GRADE

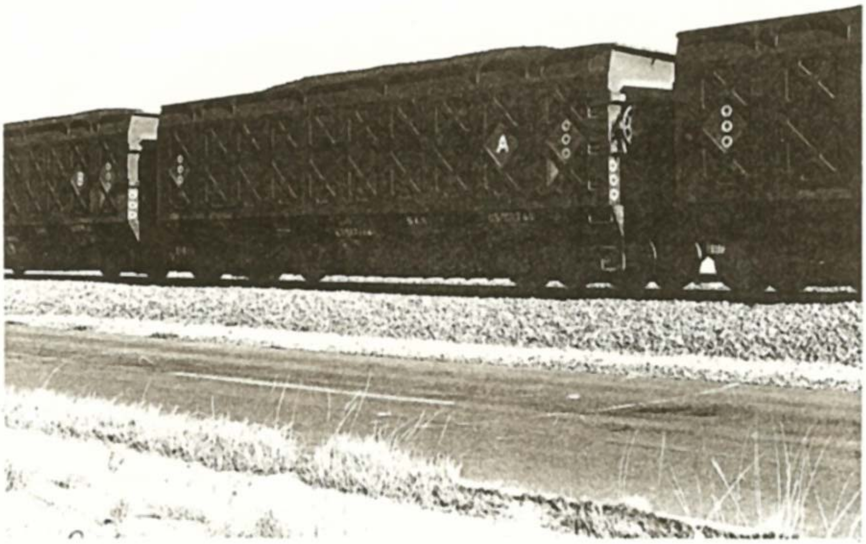


ILLUSTRATION 1

ILLUSTRATION 6

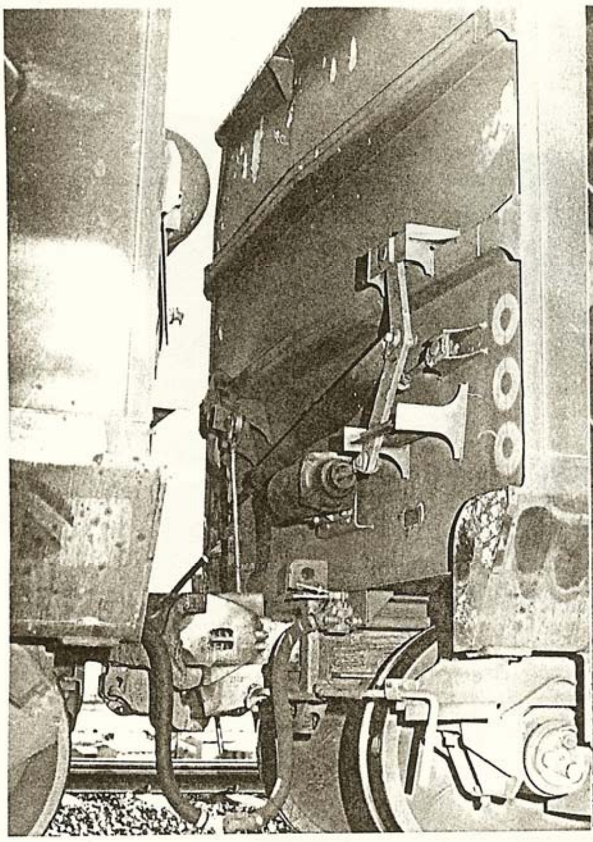
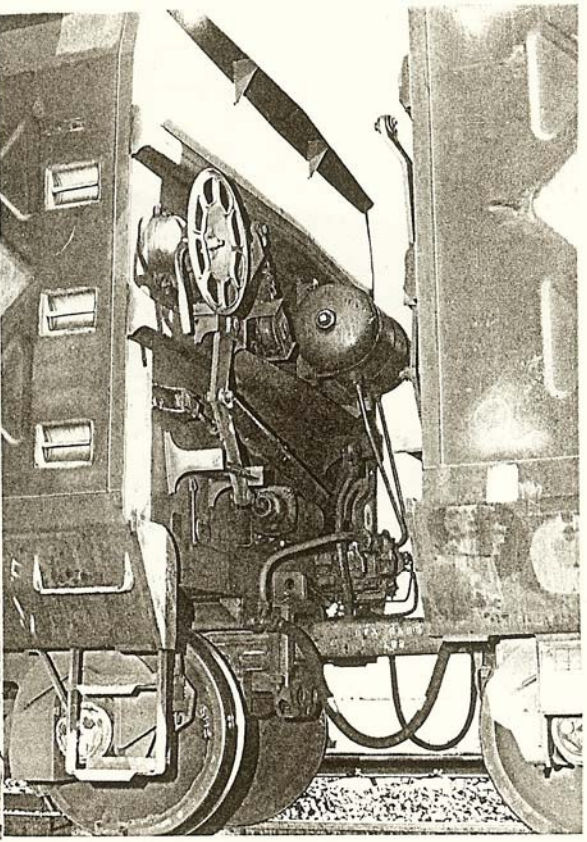


ILLUSTRATION 2



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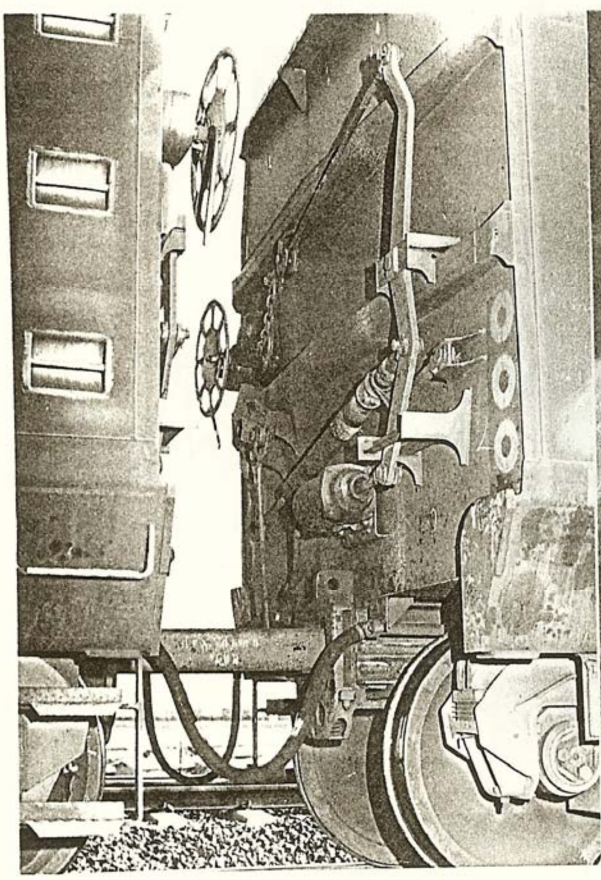

ILLUSTRATION 4

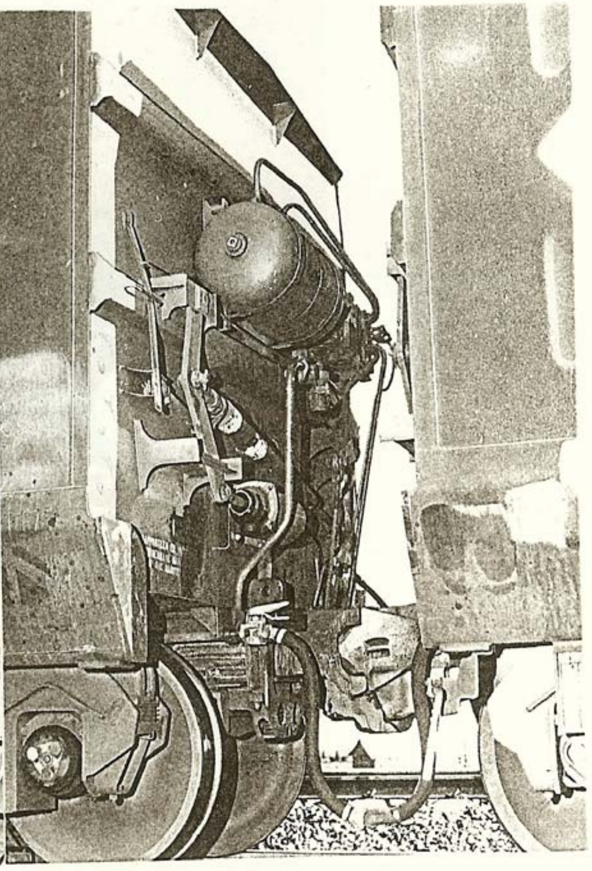

ILLUSTRATION 5