Focus on Tomorrow

Research funded by WorkSafeBC

Development of Descent Guidelines for Log-hauling Vehicles (Highway Legal Configurations)

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Development of descent guidelines for log-hauling vehicles (highway legal configurations)

Final Report

WorkSafeBC INNOVATION AT WORK grant RS2007-IG02

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January 13, 2010

Overview

- Field testing showed that trailer brakes exhibited the maximum brake temperatures for both the 6-axle and 7-axle tests of 400 °C and 480 °C respectively. Higher brake temperatures occurred during the 7-axle tests due to the greater payloads carried by the 7-axles (off-highway haul) compared to the 6-axle study.
- Field testing showed that gear selection, braking technique, and speed variations throughout the descent can result in large differences in service brake temperatures. On long descents where excessive service brake use can lead to ‘brake fade’, drivers will tend to use their service brakes sparingly and primarily utilize their engine retarder to control descent speed.
- A computer model was developed and showed relatively good correlation with the test data. The model predicted similar temperature profiles to those measured during testing with peak average temperatures within 15 °C of the test results. These deviations are relatively low suggesting that the model can be expected to yield fairly accurate results in terms of predicting peak temperature levels.
- A sensitivity analysis demonstrated that stopping performance on steep grades is degraded at increased brake temperatures, increased descent speeds, and decreased traction. Stopping performance is further exacerbated when brakes are out of adjustment particularly at high temperatures and descent speeds.
- For each traction level a critical grade exists beyond which stopping distances increase exponentially to the point that the configuration will be unable to stop. There is little improvement in stopping distance at moderate or better traction levels (coefficient of friction/traction above 0.45) as the configuration’s braking capacity is fully utilized once this traction level is reached. As the traction surface declines below a coefficient of friction level of 0.30 (low) the maximum grades on which the configuration can safely stop declines rapidly.
- The influence of load on configuration stopping performance is traction dependent. On moderate or better surfaces an increase in load will reduce stopping performance, while on poor (low) traction surfaces an increase in load will reduce the tendency of wheel lockup thereby improving stopping performance.
- The 6-axle tractor jeep/pole trailer showed superior steep grade stopping performance relative to other configurations under all traction conditions at both legal and off-highway loads. Stopping performance is generally degraded for off-highway loads and consequently the maximum grade that can be safely descended is reduced at increased loads.
- Appropriate gear selection combined with engine brake use maximizes the driveline retardation available and reduces service brake demand. As a general rule the optimum gear selection is the lowest gear and the highest engine brake setting combination without inducing wheel lockup.
- The following parameters all need to be considered when evaluating the risk of hauling on steep grades: traction level, engine brake capacity, service brake condition and adjustment, service brake temperature, horizontal and vertical road alignment, configuration type, load and distribution, length of haul, grade and descent speed.
- Guidelines have been developed to assist road planners in assessing haul risk (report Appendices and/or spreadsheet tool available from FPInnovations Feric division).

Executive Summary

The descent of steep forest roads has been a long standing safety issue in the mountainous terrain of British Columbia. Road grades often exceed 20% and in some cases 25%, levels that can seriously impact hauling safety. Since 2003, FPInnovations Feric division has investigated this issue with the cooperation of WorkSafeBC, and the forest industry. Initial research focused on the operation of purpose built off-highway log truck configurations in coastal British Columbia, and guidelines were developed specifically for these configurations in 2006. These guidelines are not directly applicable to highway size logging trucks due to differences in load sizes, truck configurations, and retardation capacity. So in 2007, Feric initiated a study to address the specific descent requirements for highway truck applications.

Field testing of two instrumented truck configurations operating on steep grades demonstrated that high service brake temperatures of up to 480 °C could be achieved, which can seriously degrade stopping performance. This emphasizes the importance of controlling service brake temperatures so that adequate stopping performance is maintained in the event of an emergency. Comparison of similar descents showed that gear selection, braking technique, and speed variations throughout the descent can result in large differences in service brake temperatures throughout the descent. On long descents, drivers will tend to use their service brakes sparingly and primarily utilize their engine retarder to control descent speed through appropriate gear selection.

A computer model was developed and showed relatively good correlation with the test data. The computer model was run at the test parameters for a number of the study descents. The model predicted similar temperature profiles to those measured during testing, predicting peak average temperatures within 15 °C of the test results. These deviations are relatively low suggesting that the model can be expected to yield fairly accurate results in terms of predicting maximum temperature levels. However,

at highway speeds, the model was less capable of predicting brake temperature fluctuations possibly a result of increased heat transfer complexity under these conditions and additional variable factors not accounted for in the model.

A sensitivity analysis was conducted using the computer model which demonstrated that stopping performance on steep grades is severely degraded at high service brake temperatures, high descent speeds, and at reduced traction levels. Stopping performance is further exacerbated when brakes are out of adjustment particularly at high temperatures and descent speeds. For each traction level a critical grade exists beyond which stopping distances increase exponentially to the point that the configuration will runaway and be unable to stop. For a 6-axle tractor/jeep/pole trailer at a descent speed of 20 km/h and initial brake temperature of 250 °C, this maximum grade is approximately 26% for moderate traction (coefficient of friction/traction 0.45) or better surfaces. At a lower descent speed of 10 km/h, the critical grade level may be extended to 27% and 28% for moderate and high (coefficient of friction/traction 0.60) traction surfaces respectively. As the traction surface declines below a level of 0.30 (low) the maximum grades on which the configuration can safely stop declines rapidly.

Gear selection is also a very important parameter influencing the safe descent on steep grades. Appropriate gear selection combined with engine brake use maximizes the driveline retardation available and reduces service brake demand. Gear selection is also influenced by traction level, as the tendency for wheel lockup increases at reduced traction levels at low gears. As a general rule the optimum gear selection is the lowest gear and the highest engine brake setting combination without inducing wheel lockup. At the reduced levels of engine retardation that are often necessary at reduced traction levels, service brakes must be used to a greater extent to control descent speed potentially overheating the brakes and consequently further degrading stopping performance.

The safe descent of steep grades with a loaded logging truck is a challenging task, requiring considerable driver expertise and knowledge. The risk associated with descending steep grades may be alleviated through diligent road design, haul planning and the development of safe operating procedures (SOPs). The following parameters all need to be considered when evaluating the risk of hauling on steep grades: traction level, engine brake capacity, service brake condition and adjustment, service brake temperature, horizontal and vertical road alignment, configuration type, load and distribution, length of haul, critical grade and descent speed. Guidelines have been developed to assist road planners in assessing haul risk (report Appendices and/or spreadsheet tool available from FPInnovations Feric division).

Project Report

Project problem and context

The descent of steep forest roads has been a long standing safety issue in the mountainous terrain of British Columbia. Previous research on steep grade descents has been limited to highway applications where the maximum grades are limited to 12%, and the design and location of runaway lanes (Yee, 1996). Forest road grades often exceed 20% and in some cases 25%, levels which are significantly steeper than highway grades which can seriously impact hauling safety. In 2003, FPInnovations Feric[1] division initiated research to investigate this issue with the cooperation of WorkSafeBC, and the forest industry. This initial research focused on the operation of log truck configurations specifically designed for off-highway hauling with gross combination weights of up to 160 tonnes (Parker, 2007). Safe descent of steep forest roads depends on the careful management of many factors, including braking capacity, brake adjustment, brake thermal characteristics, road surface traction, descent speed, hauling configuration, payload, grade, grade length, and horizontal road alignment. As a result of the study, guidelines were developed which specify maximum load, speed and traction level required for the safe descent of steep grades.

In September 2005, WorkSafeBC issued an official guideline (G 26.2-2) (WorkSafeBC 2005). This guideline separated the hauling requirements into two categories: grades less than 18%, and grades greater than 18%. This separation was based on the assumption that reasonably maintained equipment is designed for grades up to 18%, which is the maximum allowable grade specified in the Ministry of Forests Engineering Guidebook (BC Ministry of Forests 2002). On grades above 18%, a risk

[1] FPInnovations was formed in 2008, an amalgamation of three forest industry research institutes: Paprican, Forintek and FERIC (Forest Engineering Institute of Canada). The Feric division was formerly FERIC.

assessment must be conducted prior to hauling on these grades and a safe descent procedure with specific conditions for haul suspension must be developed. The guidelines developed in the Feric off-highway study may be used where warranted (i.e. coastal off-highway trucks) in the risk assessment.

In 2006, the BC Forest Safety Council in cooperation with industry stakeholders developed a specific safe operating procedure (SOP) for descending steep forest roads for the coastal off-highway application based on the Feric off-highway study. These guidelines are not directly applicable to highway size logging trucks due to differences in load sizes, truck configurations, and retardation capacity. So in 2007, Feric initiated a study to address the specific descent requirements for highway "legal" truck applications. While these trucks are designed to meet the dimensional and loading constraints of the public road infrastructure, they are commonly utilized in off-highway applications where the axle loads are often increased above the legal allowances. Highway "legal" truck payload capacity is considerably less than the coastal off-highway truck applications previously evaluated, even when hauling off-highway loads. In addition braking capacity of the service brakes and engine retarders also differ between these truck types, making specific descent guidelines for highway "legal" configurations necessary. The proposed guidelines will establish the criteria required to safely descend these steep roads (e.g. maximum speed, maximum load, minimum traction level), thereby improving the safety for drivers of these vehicles. The project was divided into the following four phases:

1. Measurement of typical retardation requirements and operating conditions
2. Computer model development and validation
3. Identification of critical operating parameters
4. Descent guideline development

Methodology

1. Measurement of typical retardation requirements and operating conditions

Feric installed instrumentation to measure retardation levels for two highway "legal" truck configurations. The first trial was conducted in the summer of 2007 at Western Forest Products Woss operations (south of Port McNeill, BC on Vancouver Island) on a 7-axle tridem tractor/ tridem pole trailer (Figure 1). This haul was an exclusively off-highway operation with a GCW of approximately 63 tonnes (8 tonnes above legal loads). The second trial was conducted the following summer (2008) at Island Timberlands Northwest Bay operations (Parksville, BC) on a 6-axle tractor/ jeep/ pole trailer (Figure 2). A large proportion of this haul was conducted on the highway and was limited to legal loads of approximately 48 tonnes GCW. The installed instrumentation measured the following parameters:

- Vehicle speed
- Distance travelled
- Engine RPM
- Service brake air application pressure
- Engine brake use
- Road grade
- Vehicle accelerations (lateral, vertical, and longitudinal)
- Individual brake drum temperatures

Figure 1. 7-axle test truck – Woss

Figure 2. 6-axle test truck – Northwest Bay

Data were for a total of 46 descents (25 descents for 7-axle, 21 descents for 6-axle). A Feric researcher was present to observe descent conditions, and periodically measure brake adjustment and calibrate the instrumentation. Gross loads were measured using electronic scales prior to unloading.

The following information was summarized for each descent:

- Number of brake applications
- Average and maximum brake application pressure (psi)
- Average and maximum brake engine speed (RPM)
- Average and maximum speed (km/h)
- Maximum brake temperatures by axle group (°C)
- Length of descent (km)
- Maximum and average road grade (%)

Stopping distance tests were also conducted with the engine brake disengaged for the loaded 7-axle configuration to evaluate the service brake stopping capacity. These tests were conducted on level grade from a speed of 50 km/h. The severity of the brake application (pressure variation during application) was left to the driver's discretion so that the truck could come to a controlled stop.

2. Computer model development and validation

The computer model developed for the previous off-highway study (Parker, 2007) was modified for highway truck configurations. This model incorporates the main variables influencing retardation on steep grades including configuration dynamics, individual brake mechanical and heat transfer properties (including fade due to drum expansion), drive train and tire properties, traction conditions and road horizontal and vertical alignment. Separate models were developed for the following three log-hauling configurations:

- Tandem tractor/tandem pole trailer (5-axle)
- Tandem tractor/jeep/ tandem pole trailer (6-axle)
- Tridem tractor/ tridem pole trailer (7-axle)

Model validation was accomplished by running the model for selected steep grade descents and comparing the resulting service brake temperatures between the field-test data and model predictions. The model runs of each descent were conducted using the same gear selections, and speed as measured during the tests. Road traction levels and rolling resistance were estimated and assumed constant over selected road segments. The model speed controller achieved the target speed levels (as measured in tests) by applying the service brakes, engine brake and throttle accordingly.

Confidence limits of temperature deviations were calculated between the measured and model estimates for peak values for each axle group. In addition the coefficient of determination was calculated for each axle group temperature to compare the simulation model output with the observed temperatures throughout each descent. This statistical measure provides a means evaluating the ability of the model to predict temperatures accurately throughout the descent. The coefficient of determination (R^2) is defined as:

$$R^2 = 1 - \frac{\left[\sum (Y_{obs} - Y_{est})^2\right]}{\left[\sum (Y_{obs} - Y_{mean})^2\right]}$$

Where Y_{obs} = observed temperature in field test

Y_{est} = predicted temperature from model

Y_{mean} = mean observed temperature for field test

3. *Identification of critical operating parameters*

An analysis was conducted using the computer model to investigate the sensitivity of the following parameters on steep grade descent performance:

- Brake adjustment
- Initial brake temperature
- Traction
- Load
- Load distribution
- Speed and gear selection
- Configuration type

- Curve radius

The performance measure primarily used in this analysis was stopping capability (stopping distance) using only the service brakes. The sensitivity of each parameter was evaluated by maintaining all parameters at the same level and varying the parameter of interest. For example to determine the sensitivity of load, all parameters (e.g. initial brake temperature, speed, brake adjustment level, traction) were kept the same while varying the load and computing the stopping distances.

Gear selection influences retardation levels and service brake demand which in turn affects brake temperature and consequently the stopping capability of these configurations. Therefore it would be useful to better understand the impact of gear selection on potential brake performance when descending steep grades. The sensitivity of gear selection was accomplished by determining average brake temperatures following a 3 km descent on grades ranging between 10 and 28% for a combination of different gear selections, speeds and traction conditions.

4. Descent guideline development

Descent guidelines were developed through the application of the computer model for 5, 6, and 7-axle configurations under the following traction conditions:

- Very low (ice/snow coefficient of traction = 0.20)
- Low (or poor) (loose gravel/wet hardpan coefficient of traction = 0.30)
- Moderate (compact gravel coefficient of traction = 0.45)
- High (smooth dry compact gravel coefficient of traction = 0.60)

For each of these operating conditions, the maximum payload and descent speed were determined for a range of descent scenarios under which the specific configuration can be safely operated. In this analysis for safe operation, the configuration was required to stop within 50 m following a driveline failure (i.e. service brakes only) [2]. These descent scenarios are characterized by the following parameters which are included in the tables:

- Grade (%) of pitch where driveline failure occurs
- Length (m) of pitch
- Distance (km) prior to pitch
- Average grade (%) of descent prior to pitch

The following assumptions were made in the development of these guidelines:

- On the steer axle 15” x 4” drum brakes, 5 ½” slack adjusters, and type[3] 20 air chamber are used. All other axles utilize 16 ½” x 7” drum brakes, 5 ½” slack adjusters, and type 30 air chambers.
- All brakes adjustment levels are at the adjustment limit (i.e. 1 ¾” and 2” for types 20 and 30 chambers respectively). Brake lining friction coefficient varies between 0.30 and 0.40.
- The driveline retarder is engaged to maximize engine retardation at an engine speed of between 1400 and 1800 RPM during the descent. The retarder and transmission are disengaged during the emergency stop.
- There is a rolling resistance of 1.5%. This means that for each 100 kN vertical load, there is a horizontal resisting force of 1.5 kN acting at the tire toad interface.
- Loads are placed on the log bunks to achieve target legal axle loads on level ground and are maintained at the same load distribution at higher and lower payloads. The load length and width are 15 m and 2.4 m respectively. The block load density[4] is 450 kg/m^3.

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[2] 50 m maximum stopping distance based on maximum speed of 30 km/h, 1.5 second reaction time and a minimum deceleration of 0.1 g. This low deceleration is to allow for the increased acceleration that needs to be overcome on steep grades.

[3] The type number of an air chamber identifies the piston cross-sectional area in square inches. A Type 20 air chamber with a 20 psi application provides 400 lbs force to the slack adjuster.

[4] Block load density is the load mass (kg) divided by the block volume of the load including air voids (m^3). Air voids typically make up 40% of this volume. Therefore block load density is not equivalent to log density.

- The initial brake temperature at the start of the descent is 40 °C for the drive and steer axles, and 20 °C for the trailer[5] axles. The ambient temperature is also 20 °C.
- There is a delay time of 1.5 seconds for the service brakes to be engaged during an emergency stop. This delay includes the reaction time of the driver (1 sec) and the actuation time (pressure buildup) of the braking system (0.5 sec). During this time the grade will cause the truck/trailer to accelerate to a higher speed before the brakes are applied.

Project Findings

1. Measurement of typical retardation requirements and operating conditions

The descents monitored for both the 6-axle and 7-axle studies are summarized in
Table 1. The 6-axle descents were monitored over a longer distances relative to the 7-axle tests resulting in very low average grades. Therefore the 6-axle descents were divided into shorter sections of steep grade to allow for comparisons with the 7-axle tests. Over the steep grade sections, both the 6-axle and 7-axle test units were subjected to similar test conditions (length of grade, grade, and speed), with the exception of the 7-axle unit hauling greater payload. The increased load per axle of the 7-axle off-highway haul resulted in increased service brake use and hence higher peak brake temperatures. Further details of each descent may be obtained in Appendix I (6-axle) and Appendix II (7-axle). In both studies the prevalence of steep grades was low with grades averaging approximately 11% over 2.5 km, with maximum grades up to 23% for short pitches (up to 100 m). Road sections with average grades above 18% were generally limited to less than 800 m. Average descent speeds were approximately 20 to 25 km/h with engine speeds approximately 1400 RPM. Despite the low average grades experienced during the field tests, peak temperatures were very high with temperatures up to 480 °C.

[5] Throughout this report trailer axles may also include jeep axles unless otherwise stated

Table 1. Descent summary

Parameter	6-axle all	6-axle Steep sections	7-axle
Number of Descents	21	15	25
GCW (tonnes)	43.7	42.8	63.2
Distance (km)	20.0	2.3	2.5
Average grade (%)	2.3	10.5	11.4
Maximum grade (%)	23	23	23
Average Engine RPM	1427	1425	1358
Maximum Engine RPM	2017	1906	2077
Average Speed (km/h)	43.3	24.4	19.3
Maximum Speed (km/h)	110.7	46.1	49
Average number of brake applications	31	26	52
Average application pressure (psi)	14	15	15
Peak brake temperature (°C)	400	400	480

It would have been desirable to have tested these truck configurations under longer and steeper road grades. However, forest road grades are generally limited to less than 18% where possible and extended distances (greater than 1 km) on steep grades are rare. It would be useful to further validate this work in the future by locating steeper roads and conducting further tests.

The trailer brakes exhibited the maximum brake temperatures for both the 6-axle (Figure 3) and 7-axle (Figure 4) tests of 400 °C and 480 °C respectively. The average peak trailer brake temperatures were relatively close for both series of tests with the 7-axle exhibiting a marginally higher trailer temperature of 284 °C relative to 261 °C for the 6-axle. The 7-axle tests also exhibited higher brake temperatures for both the drive and steer axle groups. The steer axle brakes on the 7-axle units achieved average peak temperatures almost twice the level as measured for the 6-axle units. This suggests that the steer axle brakes absorb a significant proportion of the braking energy relative to the 6-axle units likely due to the increased load carried by the steer axles on these configurations.

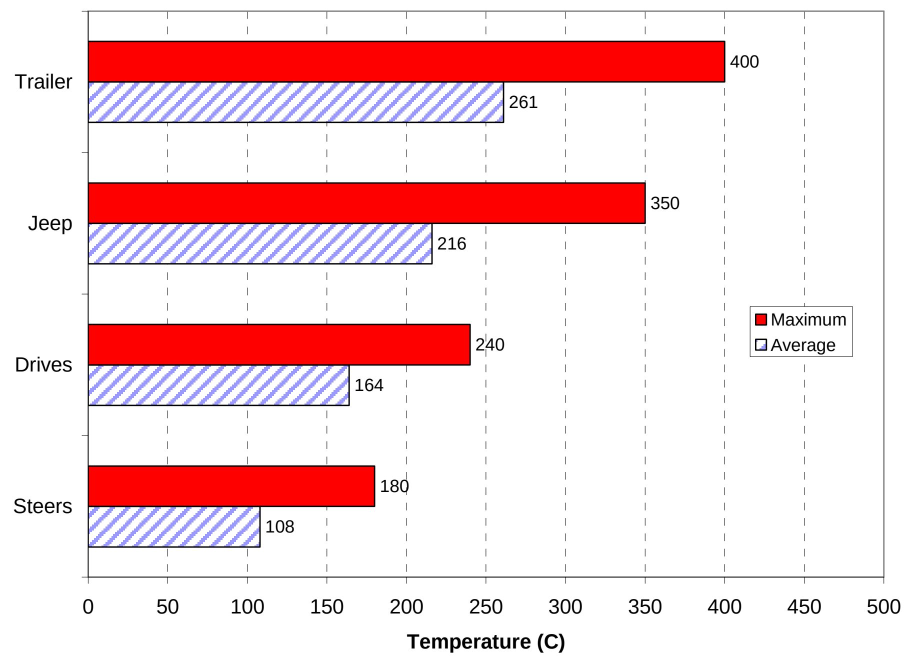


Figure 3. Peak brake temperatures – 6-axle tests

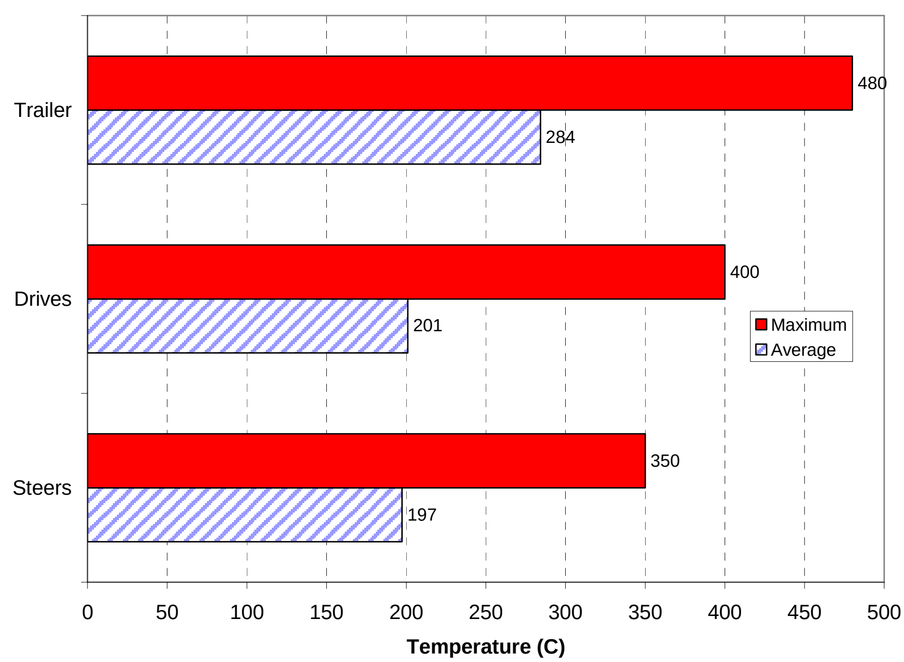


Figure 4. Peak brake temperatures – 7-axle tests

Sample descents for the 6-axle and 7-axle tests are presented to illustrate the influence of the various parameters on resulting brake temperatures. These descents were similar in length and grade (12% average grade over 5 kilometers) with a number of steep pitches separated by sections of lesser grades. The main difference between these examples is the increased GCW of 20.6 tonnes carried during the 7-axle test relative to the 6-axle test. Both descents were conducted at similar speeds, but the speed variation during the 7-axle descent was greater (Figure 5), possibly a result of the road alignment with tighter switchbacks encountered in this descent. There was also an increased frequency of gear changes during the 7-axle descent particularly during the latter half of the descent, which coincides with the speed variations and switchbacks. In order to prevent the drive wheels from locking up while negotiating the switchback, the driver would gear up just prior to entering the switchback as well as applying the service brakes. The service brakes were utilized almost continuously for the 7-axle example with a relatively high average application pressure of 9.1 psi throughout the 5 kilometer descent and a peak pressure of 35.3 psi (Figure 6). In contrast the service brakes were only applied for the 6-axle example on the steeper sections of the descent resulting in a much lower average application pressure throughout the descent of 5.6 psi and a lower peak pressure of 25.3 psi. The increased service brake use observed for the 7-axle test is primarily a result of the higher payload carried by this configuration requiring more retardation above that provided by the engine brake to maintain the configuration at a safe speed. In addition the frequent gear changing and speed variations observed during the latter half of the 7-axle descent also contributed to the increased service brake use.

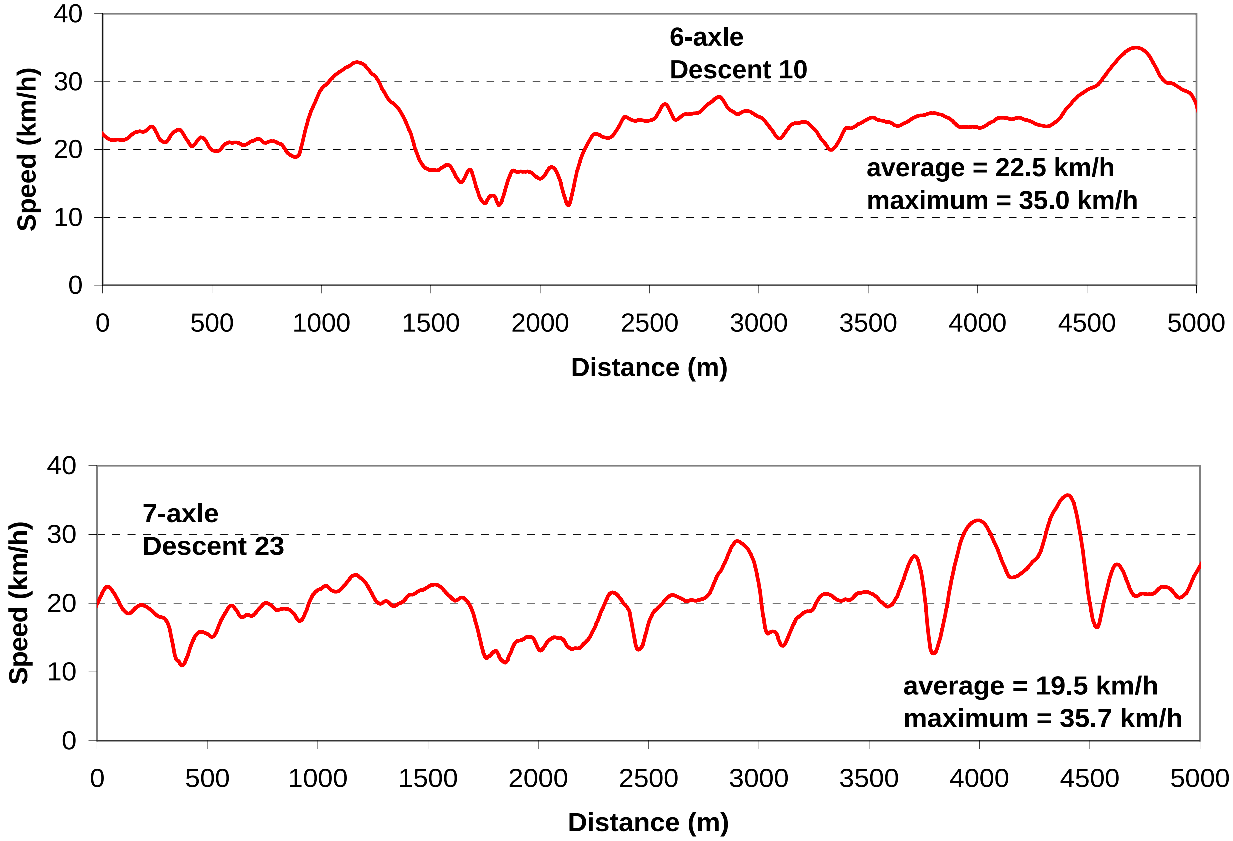


Figure 5. Descent comparison – speed

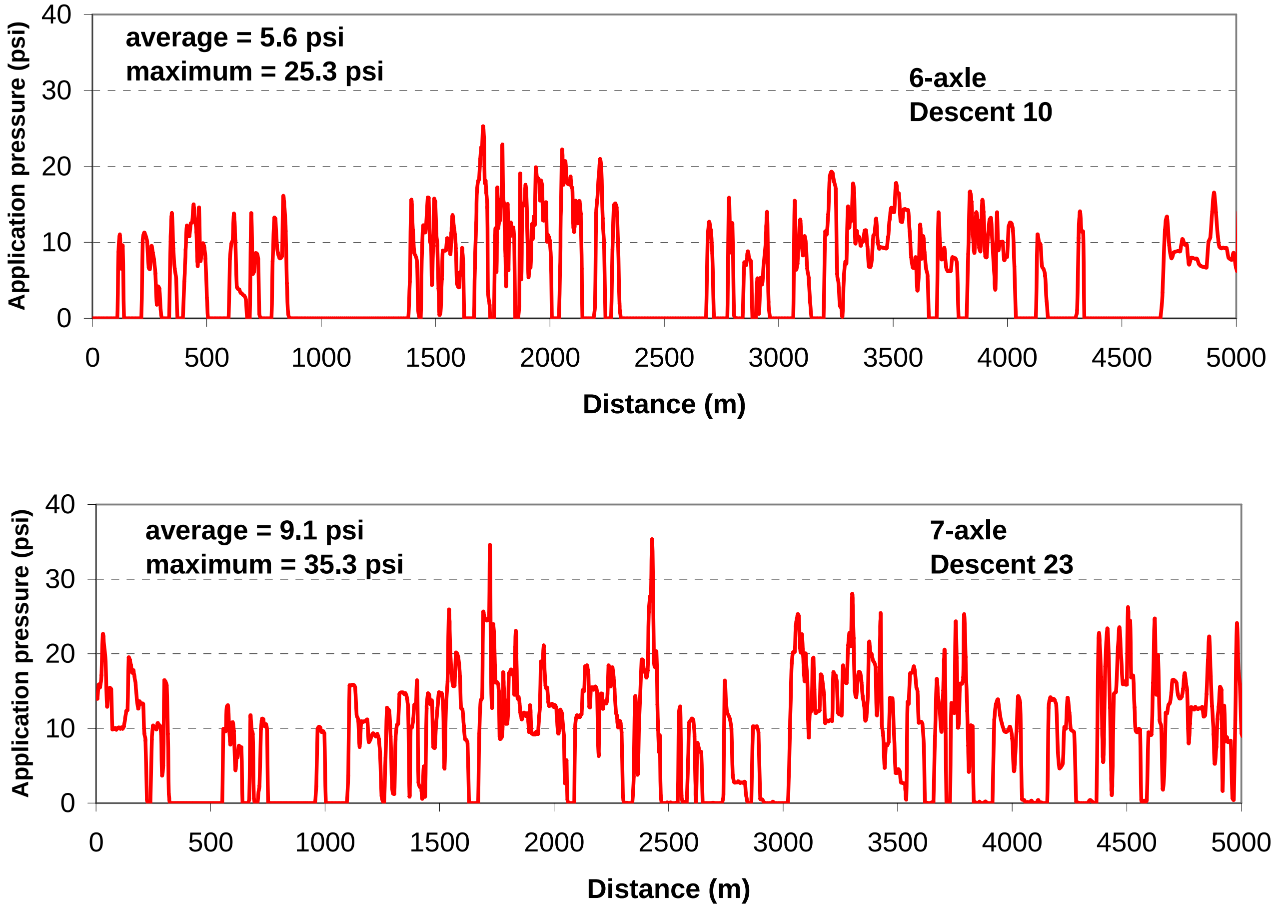
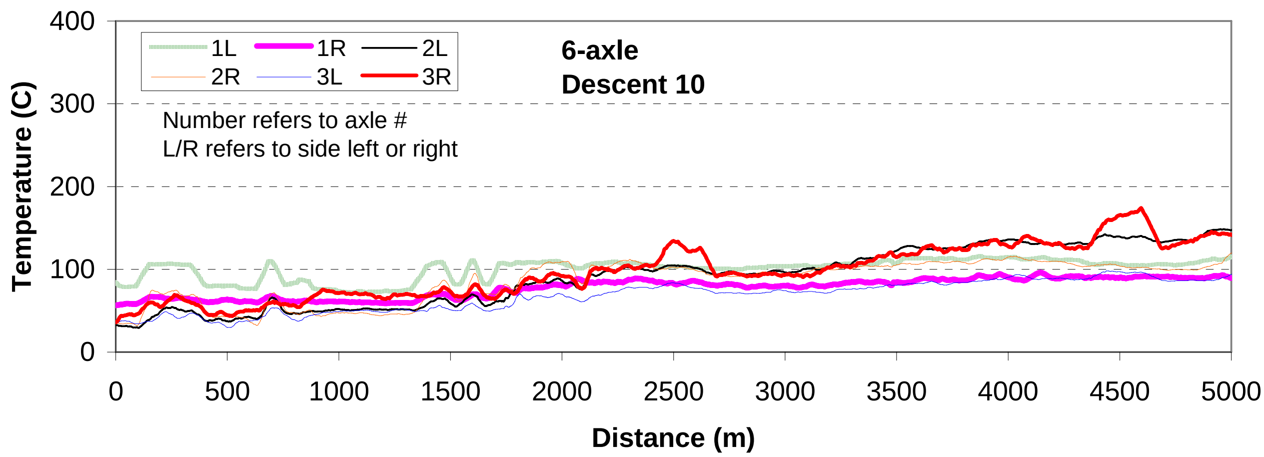


Figure 6. Descent comparison – service brake use

The increased service brake use observed for the 7-axle descent resulted in higher truck (Figure 7) and trailer (Figure 8) brake temperatures relative to the 6-axle descent. The peak drive brake temperature achieved for the 7-axle descent was 300°C compared with 165°C for the 6-axle descent. Trailer brake temperatures were relatively higher with peak temperatures of 370°C and 290°C for the 7-axle and 6-axle descents respectively. It should be noted that in each test, the driver used the treadle valve consistently so that both the truck and trailer brakes had the same duty cycle, but despite this the trailer brakes reached higher temperatures. Generally the temperature variation for both the truck and trailer brakes was within 100°C, with the exception of one 7-axle trailer brake which deviated 200°C below the peak trailer temperature. These two examples show that the trailer brakes absorb a greater proportion of the service brake energy which is likely due to the high proportion of retardation provided by the engine brake often saturating the braking force at the drive tires so that the tire lockup and service brake provide reduced energy absorption. Ideally the engine brake level should be set to minimize wheel lockup while maximizing energy absorption so that service brake use is minimized. This is often a challenging task requiring appropriate gear selection, engine brake level setting as well as anticipation of road conditions (traction, grade and alignment).



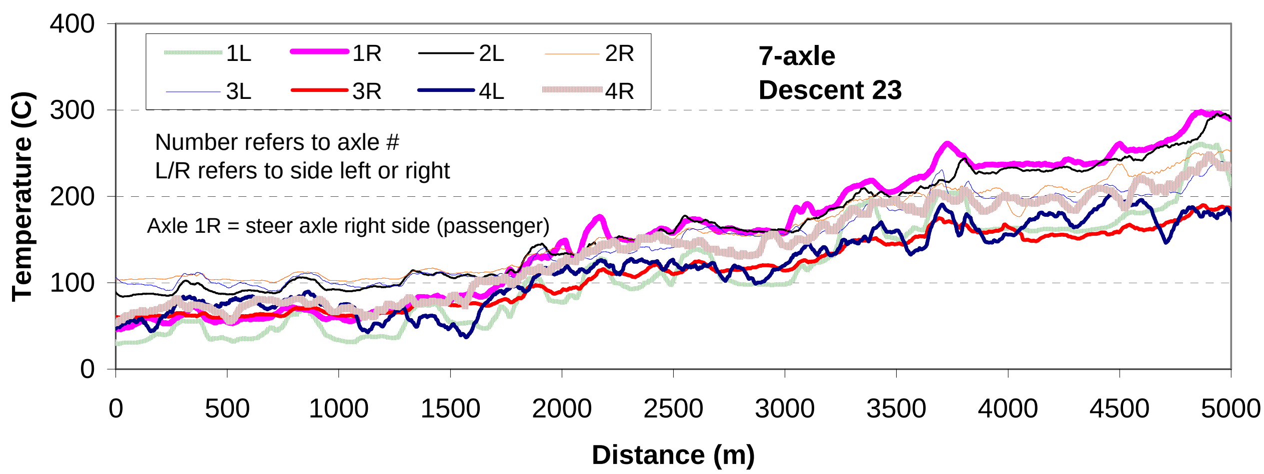
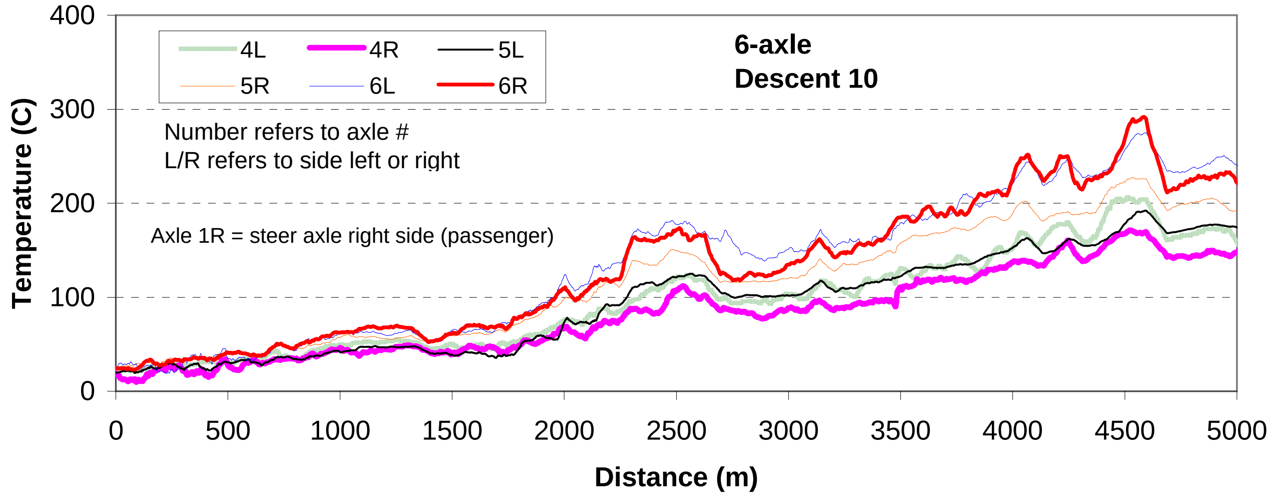


Figure 7. Descent comparison – truck brake temperatures



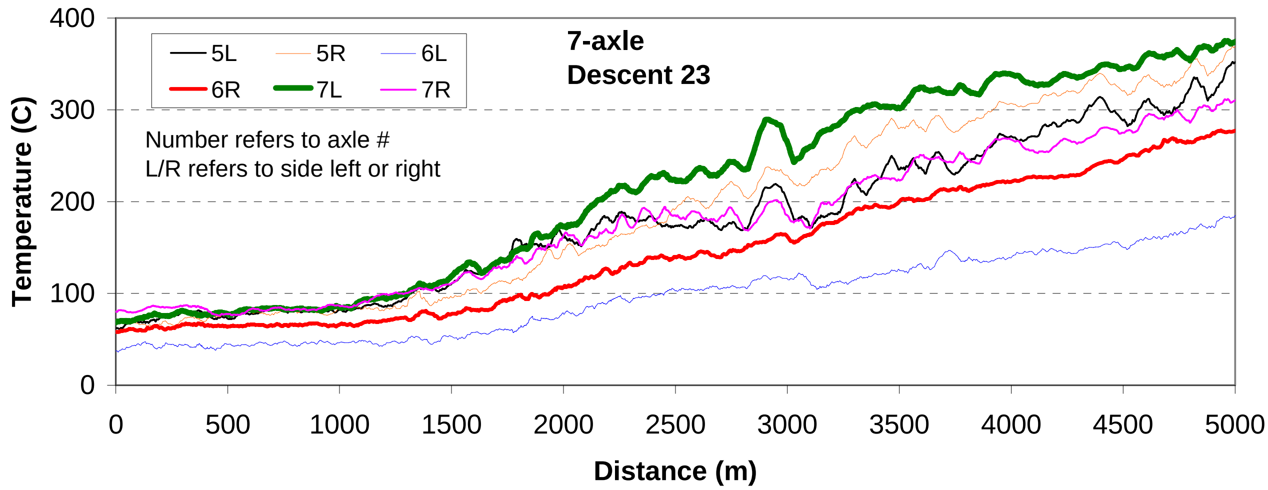
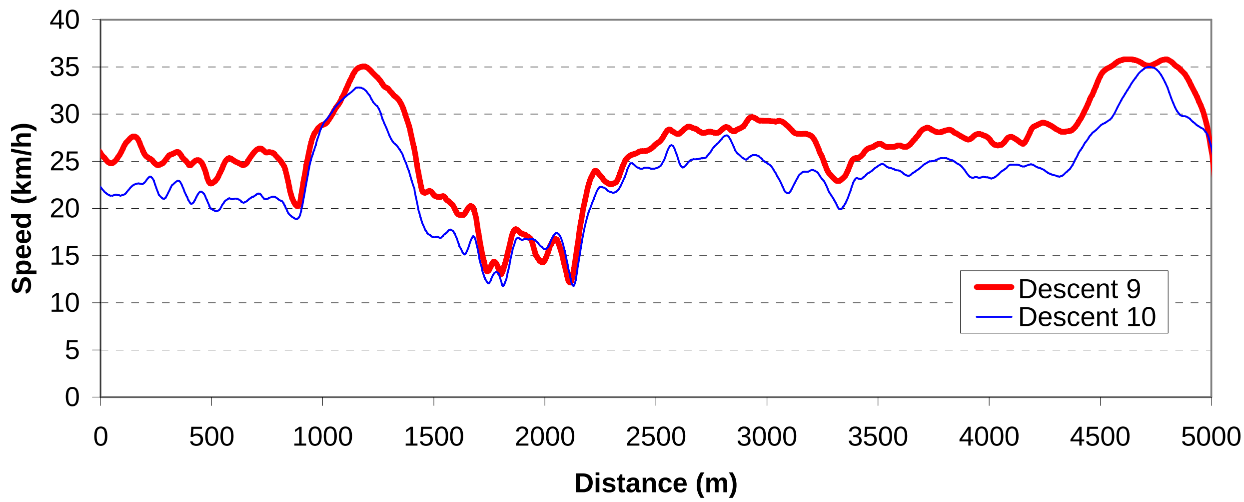


Figure 8. Descent comparison – trailer brake temperatures

The influence of gear selection is further illustrated by comparing two 6-axle descents over the same road section with essentially the same payload. Descent 9 was conducted at an increased speed of approximately 4 km/h over pitches 1 and 3 using a higher gear relative to descent 10 (Figure 9). The driver opted for an increased speed for descent 9 since water cooling[6] of the brake drums was active for this descent. However only the drive and jeep axles had water delivered to the brake drums since the

[6] Water cooling of brake drums is commonly used for coastal off-highway trucks, but not usually installed on highway hauling operations. This was the only descent where water cooling was active.

water supply to the trailer axles had inadvertently been disengaged. The increased descent speed and the absence of water cooling resulted in a marked increase of the trailer brake temperatures of 100 °C, with a peak temperature exceeding 400 °C (Figure 10). The water did however succeed in reducing the jeep axle brake temperatures by approximately 50 °C despite the increase in speed. The higher gear used for descent 9 resulted in a reduction in available engine retardation, thereby increasing service brake demand to maintain a controlled descent. This example shows that water cooling of legal loads is not essential provided an appropriate gear is chosen. However the use of water does provide a better means of controlling brake temperatures under more extreme circumstances (off-highway loads, longer steeper descents).



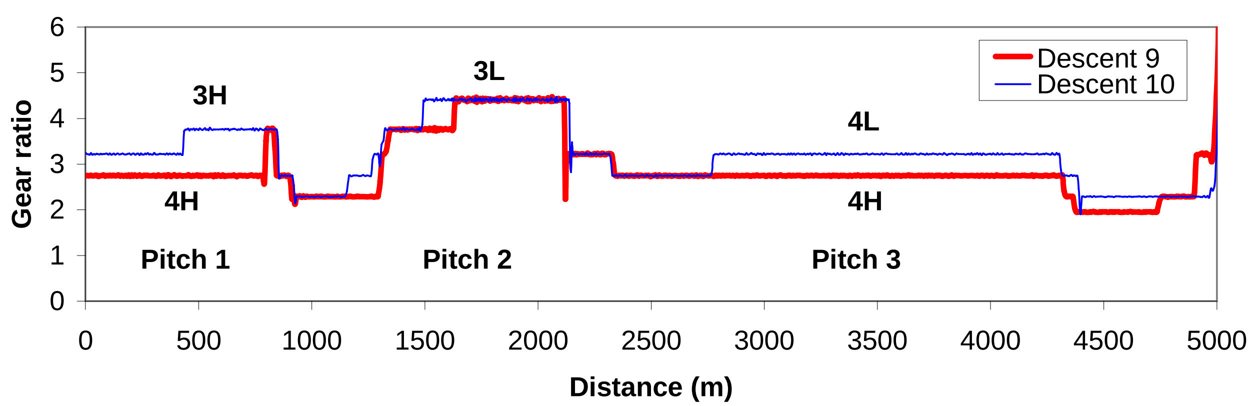


Figure 9. 6-axle descent comparison – descent speed and gear selection

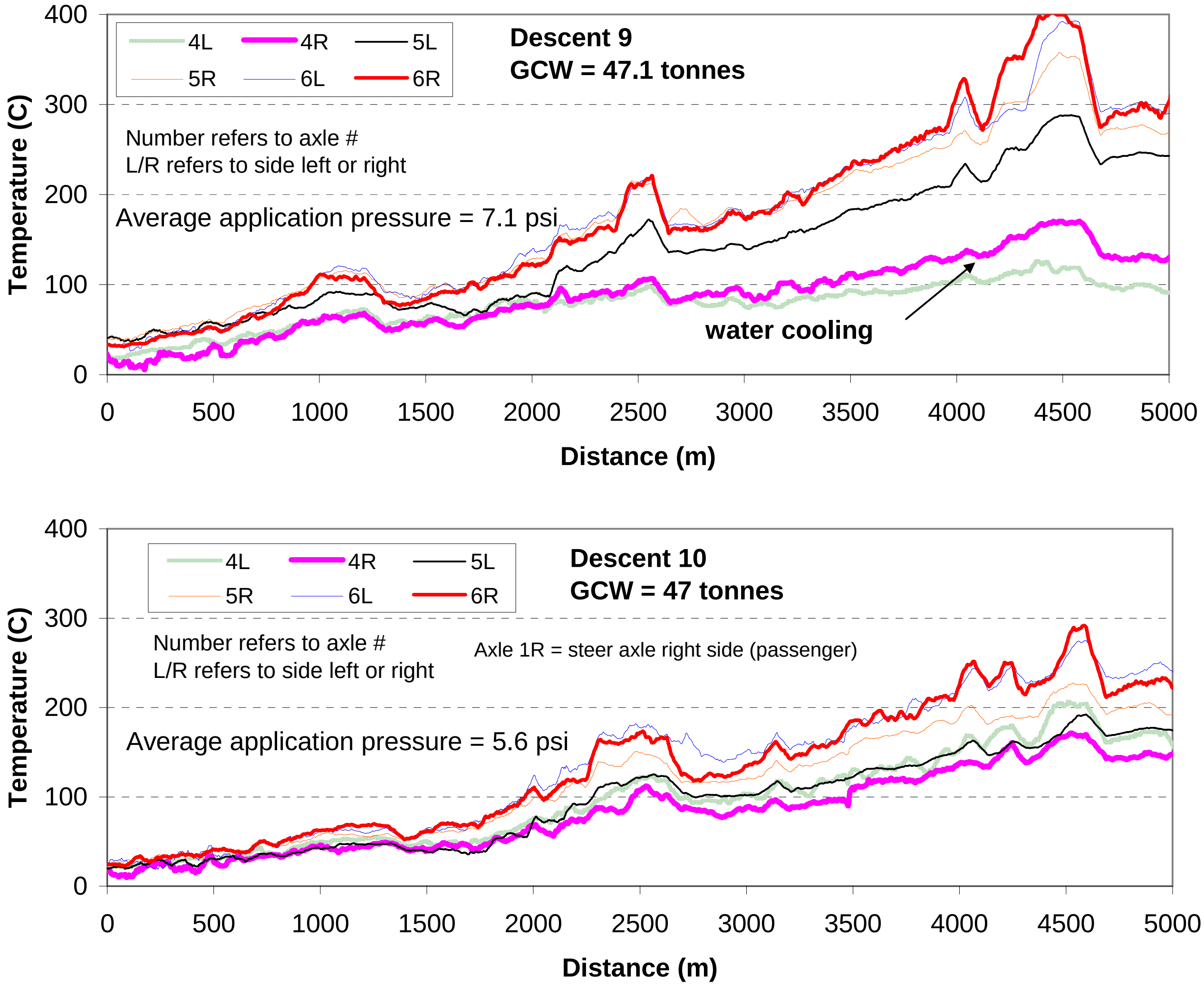
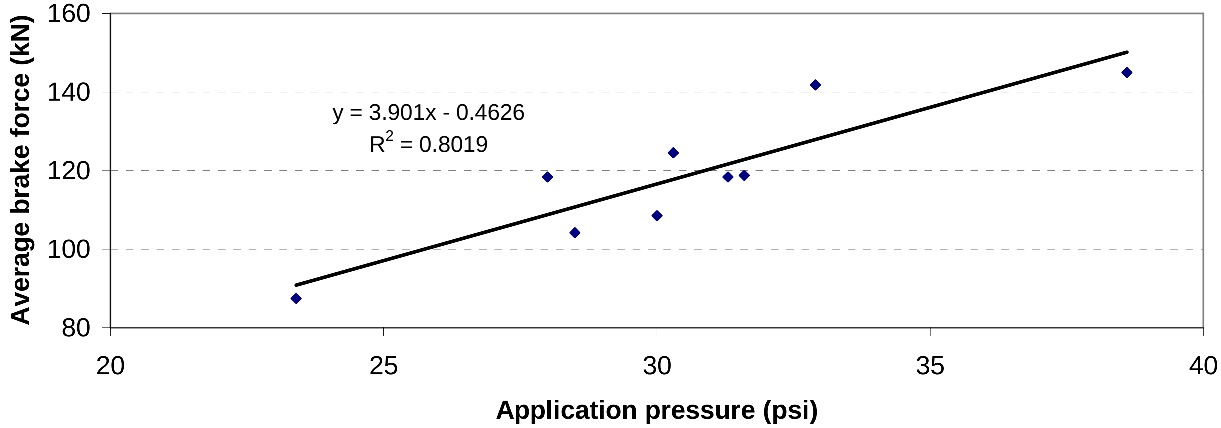


Figure 10. 6-axle descent comparison – trailer brake temperatures

Driving skill is an important parameter which was not directly addressed in this study. The drivers of both the 6 and 7-axle units were experienced and had descended the test grades on many occasions prior to the tests, and therefore had become accustomed to the nuances of each descent (grade changes, curves). This experience allowed the drivers to optimize their gear selections and service brake applications accordingly to ensure descents could be made safely. Despite prior knowledge of the descent, both drivers often commented that each descent was different due to different loads, load distribution, surface condition, and brake condition. It is particularly important for drivers to constantly monitor the condition of the brakes and ensure that the service brakes are adjusted correctly. It is equally important to select the right gear for the descent conditions, so that the service brakes are not overused and a relatively steady speed is maintained. Experienced drivers have the necessary skills to meet the challenges of descending steep grades, but need to remain vigilant to changing conditions. Less experienced drivers should be mentored by the experienced drivers prior to operating on grades in excess of 18%.

A series of stopping distance tests were conducted for the 7-axle configuration (GCW 63 to 65 tonnes) on relatively level grades. These tests were controlled stops from initial speeds of between 40 and 50 km/h and consequently the average application pressure rarely exceeded 30 psi, with peak levels all below 50 psi. Stopping distances were typically between 50 and 65 m. Average brake force and brake power were computed from the data and showed a direct relationship with application pressure with both measures increasing at increasing pressure (Figure 11). There was some variability in the computed measures which are likely as result of variations in the road grade, surface rolling resistance as well as brake fade at increased temperatures as these tests were conducted at brake temperatures between 200 and 350 °C. Both brake force and power can be expected to increase at increased application pressures until the road surface adhesion limit is reached.



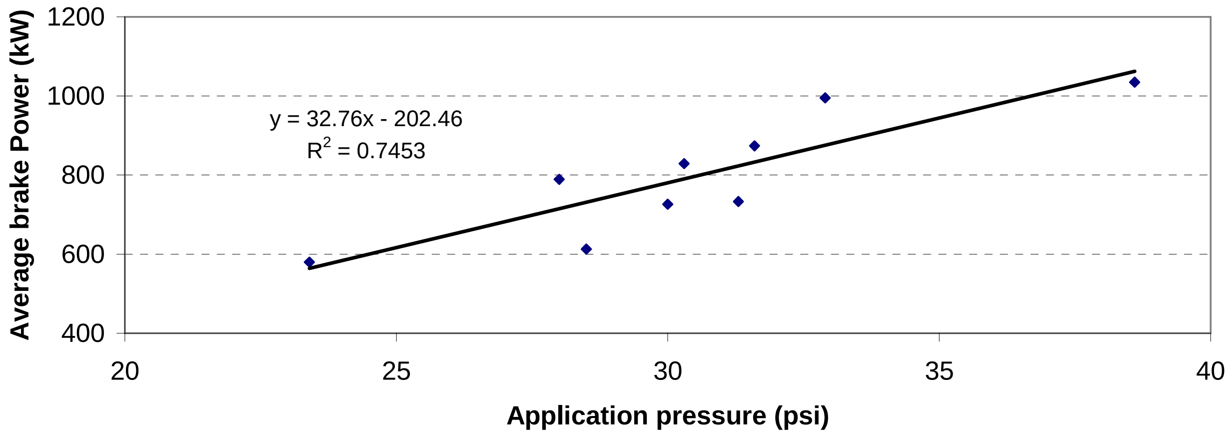


Figure 11. Service brake stopping force and power – 7-axle

2. Computer model development and validation

A total of 16 descents were compared using the 6 and 7-axle models and both models correlated very closely with the field-test results (Parker 2010). On average, both the 6-axle and 7-axle models estimated peak average temperatures within 15 °C of the test results (Figure 12). The highest variation in peak temperatures occurred for the trailer group of the 6-axle with the temperature deviation (95% confidence limits) ranging from -27 (model underestimate) to +28 °C (model overestimate). Generally there was a slight tendency for the 6-axle model to underestimate peak jeep temperatures, while the 7-axle model tended to underestimate steer axle peak temperatures. Despite this, the temperature deviations are relatively low and the model can be expected to yield accurate results in terms of peak temperature levels.

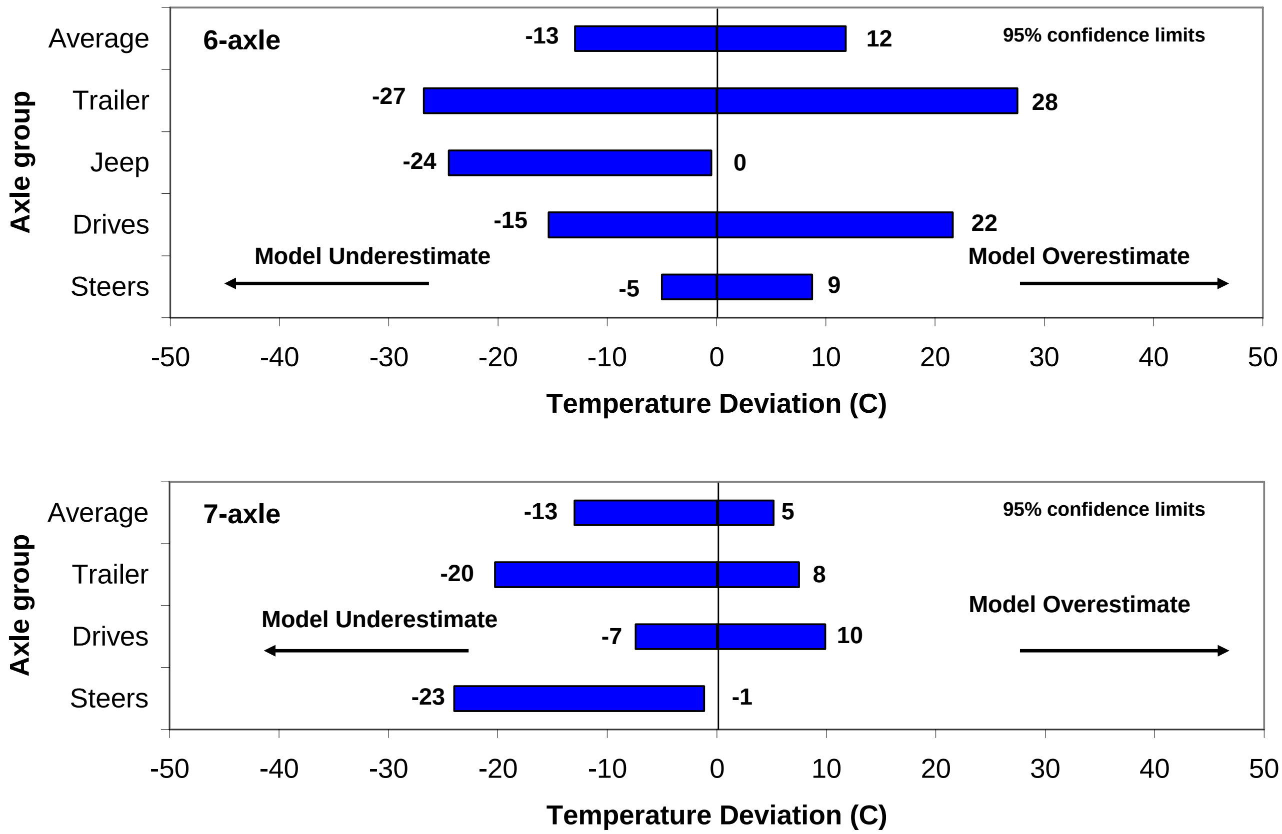


Figure 12. Model temperature deviations – peak temperatures

The comparison of the model predictions with the field-test data may be best illustrated by reviewing a sample descent. The sample descent illustrated is for the off-highway portion of a 6-axle configuration (descent 10). In this descent the simulation steer and drive axle brake temperatures followed the field-test results reasonably closely but the jeep and trailer axle temperatures deviated to greater extent (Figure 13). The simulation estimated higher jeep axle temperatures during the steep grade section

(5000 to 10 000 m), while the trailer temperatures were estimated to be lower relative to the field-test data by approximately 40 °C for most of the descent. This discrepancy may be due to differences in lining friction or load distribution between these two axle groups. There was also less temperature variation shown by the model for all axle groups likely due to the many variations in brake condition, and road conditions (traction level and rolling resistance) that were not accounted for in the simulation. The simulation followed the actual descent speeds relatively closely resulting in a similar service brake duty cycle as observed during the test (Figure 14). However the simulation application brake pressures tended to be slightly increased and of a longer duration indicating that either the service brake performance or engine brake performance used in the model deviated below the actual performance. Differences in application pressures between the model and test data result from the inability of the model speed controller to exactly match each individual driver's driving and braking strategy. However overall the model and field-test data comparisons illustrate that the model predicts brake temperatures and required service brake duty cycle on steep grades reasonably well.

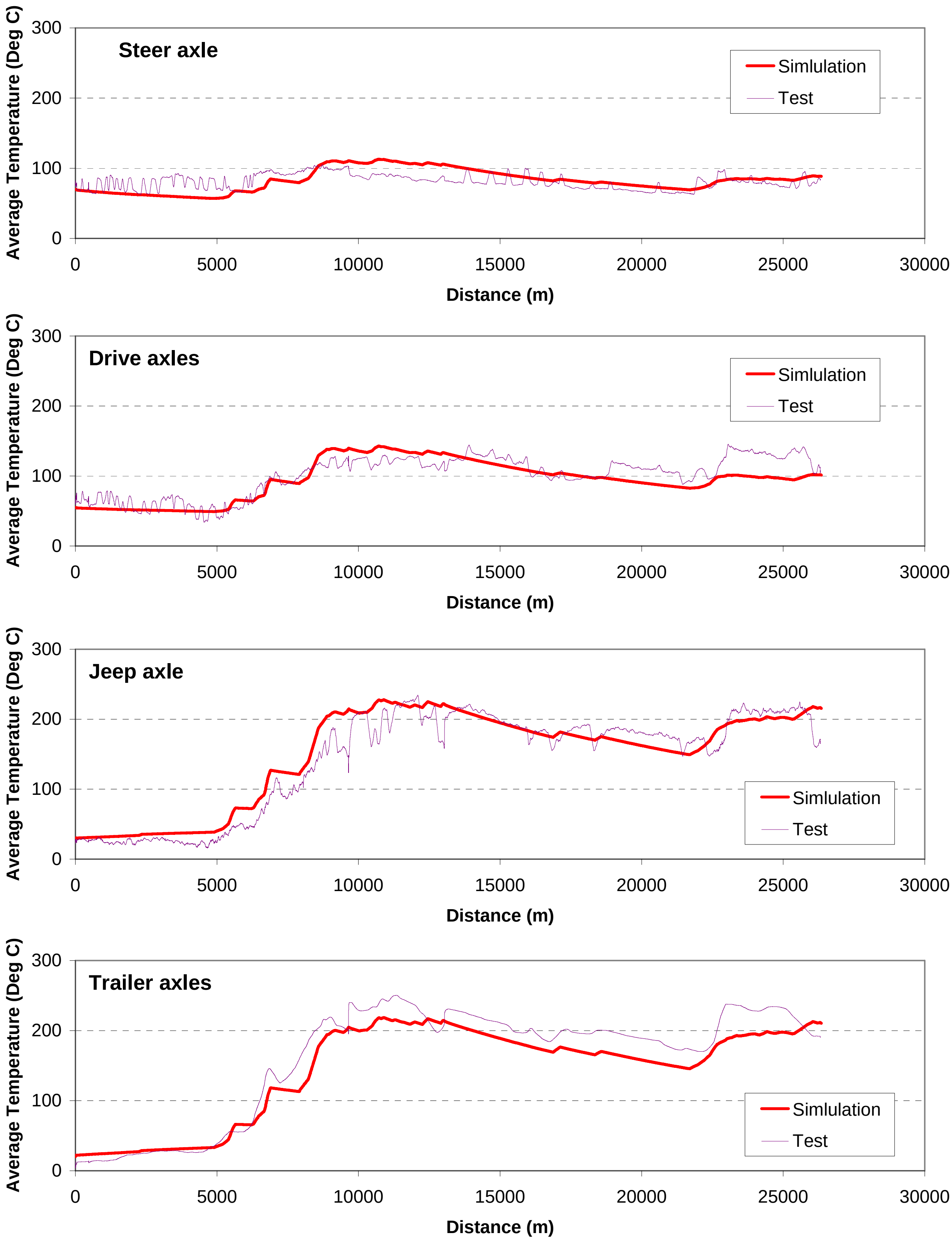


Figure 13. Simulation and test data temperature comparison – 6axle

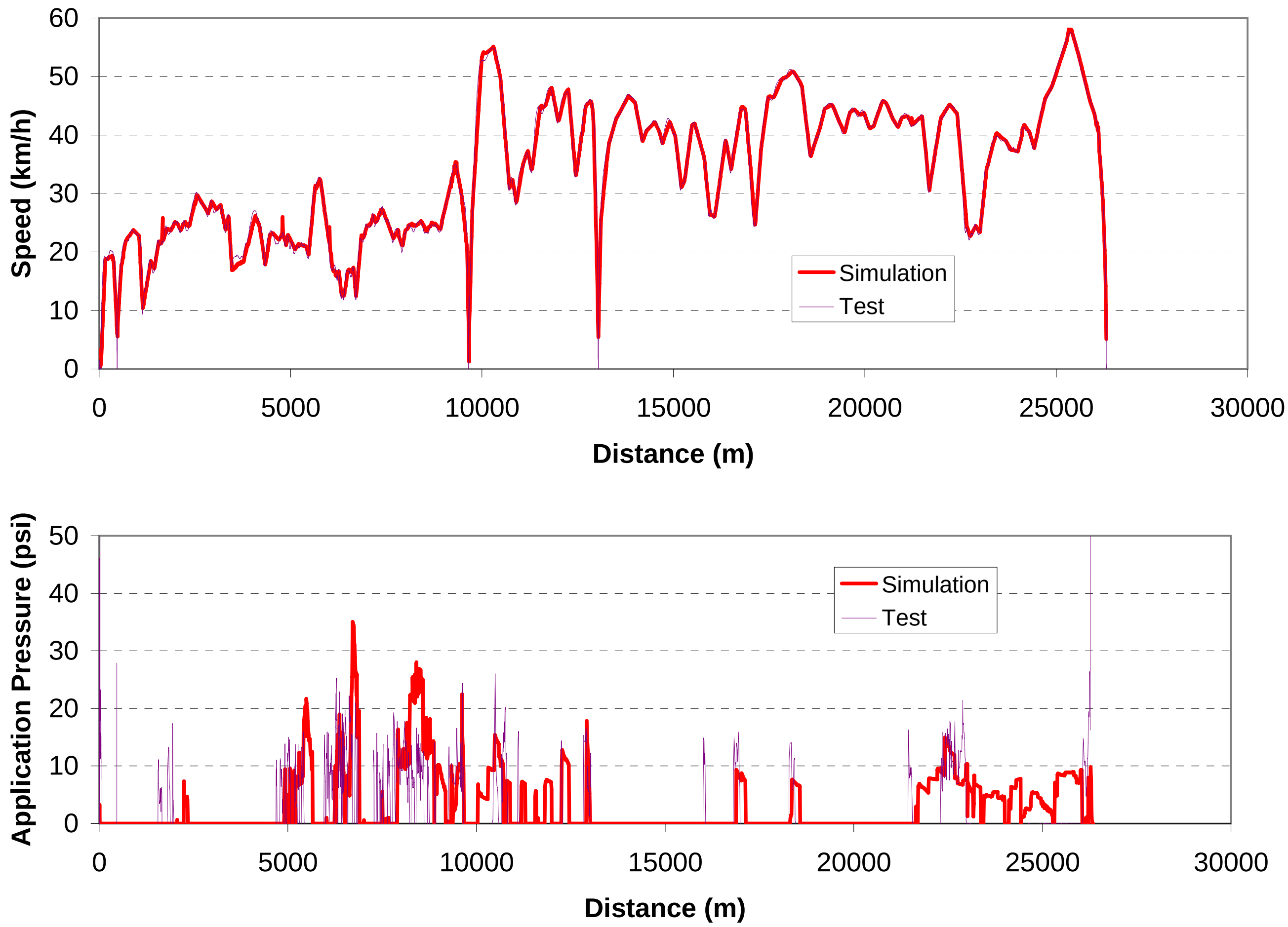


Figure 14. Simulation and test data speed/pressure comparison – 6axle

The model predictions of brake temperature for each axle group were statistically correlated with the field test data for 16 descents by calculating the coefficient of determination (Table 2). Generally the model predicted jeep and trailer axle brake temperatures very close to the field test data as shown by high R^2 values. The predictions of steer axle and drive axle temperatures showed a weaker correlation particularly for the 6-axle descents. The relatively poor correlation of the steer axle for some descents is believed to be primarily a result of erratic temperature sensors at this location. In addition there may be other factors that were not sufficiently accounted for in the model brakes such as variable air pressure, dragging brakes, varying heat transfer properties particularly at the steer axle as well as variations in rolling resistance and traction level. The correlation for descent #7 (6-axle) was relatively poor, where the majority of the haul was on-highway at speeds above 50 km/h. In this descent, the model predicted brake temperatures were generally 20 °C higher than the observed temperatures and the model did not predict the large variations observed during the test. This consistent temperature offset resulted in poor correlation under these conditions possibly a result of more complicated heat transfer at highway speeds, suggesting that further model refinement is required at highway speeds.

Table 2. Descent temperature correlation-coefficient of determination

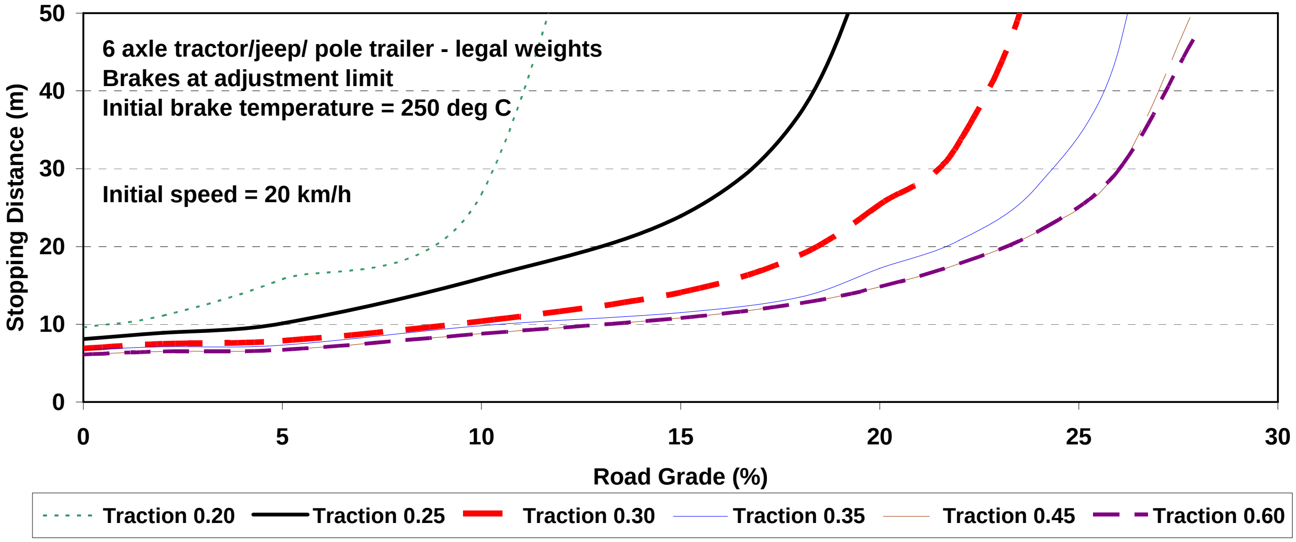
Descent#	**Coefficient of determination[1] (R^2)**			
	Steer axle	Drive axles	Jeep axle	Trailer axles
6-axle				
1a	0.786	0.682	0.917	0.945
2	-0.632	0.177	0.907	0.716
3	0.731	0.694	0.774	0.519
5c	-0.237	0.497	0.917	0.659
7	-11.039	-0.380	-0.210	0.418
8	-1.089	0.085	0.845	0.850
9	0.499	0.563	0.566	0.903
10	0.461	0.745	0.904	0.890
7-axle				
1	0.858	0.794	NA	0.769
7	0.833	0.872	NA	0.939
9	-0.925	0.181	NA	0.675
13	-1.692	0.793	NA	0.778
16	0.389	0.964	NA	0.949
19	0.334	0.415	NA	0.742
21	0.942	0.944	NA	0.970
23	0.896	0.974	NA	0.958

3. Identification of critical operating parameters

The safe descent of steep grades with a loaded logging truck is a challenging task, requiring considerable driver expertise and knowledge. The risk associated with descending steep grades may be alleviated through diligent road design, haul planning and the development of safe operating procedures (SOPs). A sensitivity analysis was conducted of the many parameters using the computer model and identified the following parameters which are critical for steep grade descents:

- Traction level
- Service brake condition and adjustment
- Service brake temperature
- Engine brake capacity
- Horizontal alignment (curves)
- Vertical alignment (road grade)
- Load and distribution
- Configuration type
- Speed

Traction level determines the maximum grades on which a truck configuration can safely descend and if necessary come to a stop. For a given grade and load there is a minimum retardation force that must be constantly applied to control the vehicle's descent speed. If the required retardation force exceeds the available force then the truck will accelerate and potentially runaway. The influence of traction on stopping distance for a legally loaded 6-axle tractor jeep/ pole trailer is illustrated in Figure 15. For each traction level a critical grade exists above which stopping distance increases exponentially, and this essentially is the limit at which the brakes will safely stop the configuration. At a descent speed of 20 km/h and initial brake temperature of 250 °C, this maximum grade is approximately 26% for moderate traction (level 0.45) or better surfaces. There is little improvement in stopping distance at traction levels above 0.45 as all the configuration's braking capacity is utilized once this traction level is reached. At a lower descent speed of 10 km/h, the critical grade level may be extended to 27% and 28% for moderate (0.45) and high (0.60) traction surfaces respectively. As the traction surface declines below a level of 0.30 (low) the maximum grades on which the configuration can safely stop declines rapidly. For example on a very low traction level of 0.20 (ice/snow) the maximum grade that this configuration can safely operate is 10%.



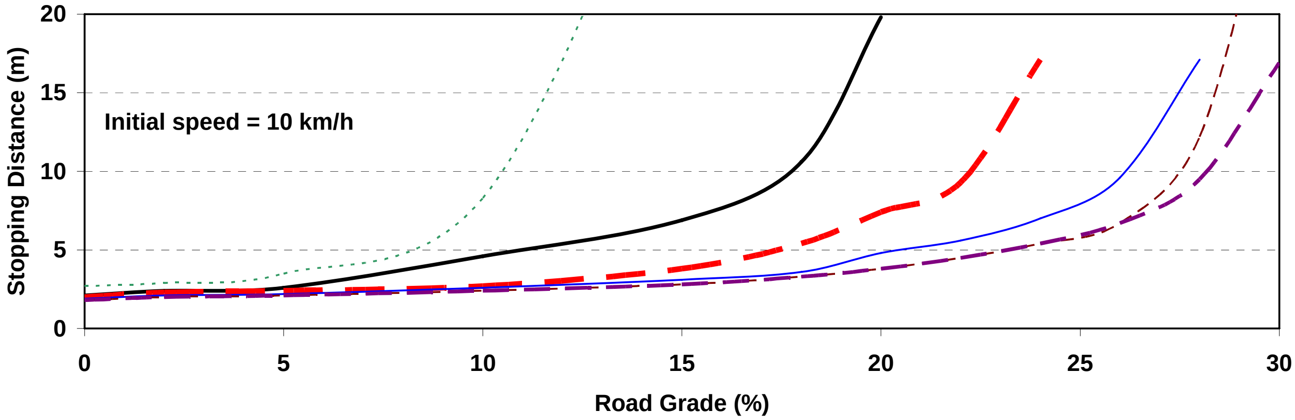


Figure 15. Influence of traction on stopping performance – 6-axle – initial speed variation

Service brakes have sufficient capacity to handle emergency stopping requirements at highway speeds and grades. However air actuated drum brake performance can vary considerably due to component condition, brake adjustment, and brake temperature. Brake system components need to be maintained and inspected regularly to ensure they are operating according to manufacturer specifications. Brake adjustment together with brake temperature has a major impact on the configuration's ability to stop on steep grades (Figure 16). There is a marked difference in stopping distance on grades above 18% when the brakes are out of adjustment. For example on a road grade of 20%, at an initial speed of 20 km/h and initial brake temperature of 250 °C, a 6-axle legally loaded tractor/jeep/pole trailer with brakes out of adjustment (1/4” over adjustment limit) will take twice the distance (31.5 m) to stop compared to when all the brakes are at the adjustment limit (14.8 m). Stopping performance is improved further when the brakes adjustment is ¼” under the adjustment limit. Brake temperature has a major influence on stopping performance particularly when the brake adjustment is at or beyond the adjustment limit. At low brake temperatures (150 °C), even the configuration with all brakes out of adjustment may stop at a road grade of 24%. However, as brake temperatures increase to 350 °C stopping performance is degraded to the point that even when all the brakes are at the adjustment limit the configuration may have difficulty stopping at grades above 20% at a descent speed of 20 km/h.

Initial speed also has a major influence on stopping distances as illustrated in Figure 17. At low descent speeds of 10 km/h and moderate brake temperatures (250 °C), even brakes which are ¼” above the adjustment limit may stop on grades up to 24%. However as the initial speed is increased to 30 km/h, even well adjusted brakes will be challenged to stop on grades above 24%. The phenomenon illustrated in this section is known as “brake fade” and shows the importance of managing brake temperature, and speed through appropriate descent procedures as well as ensuring that the brakes are within prescribed adjustment limits.

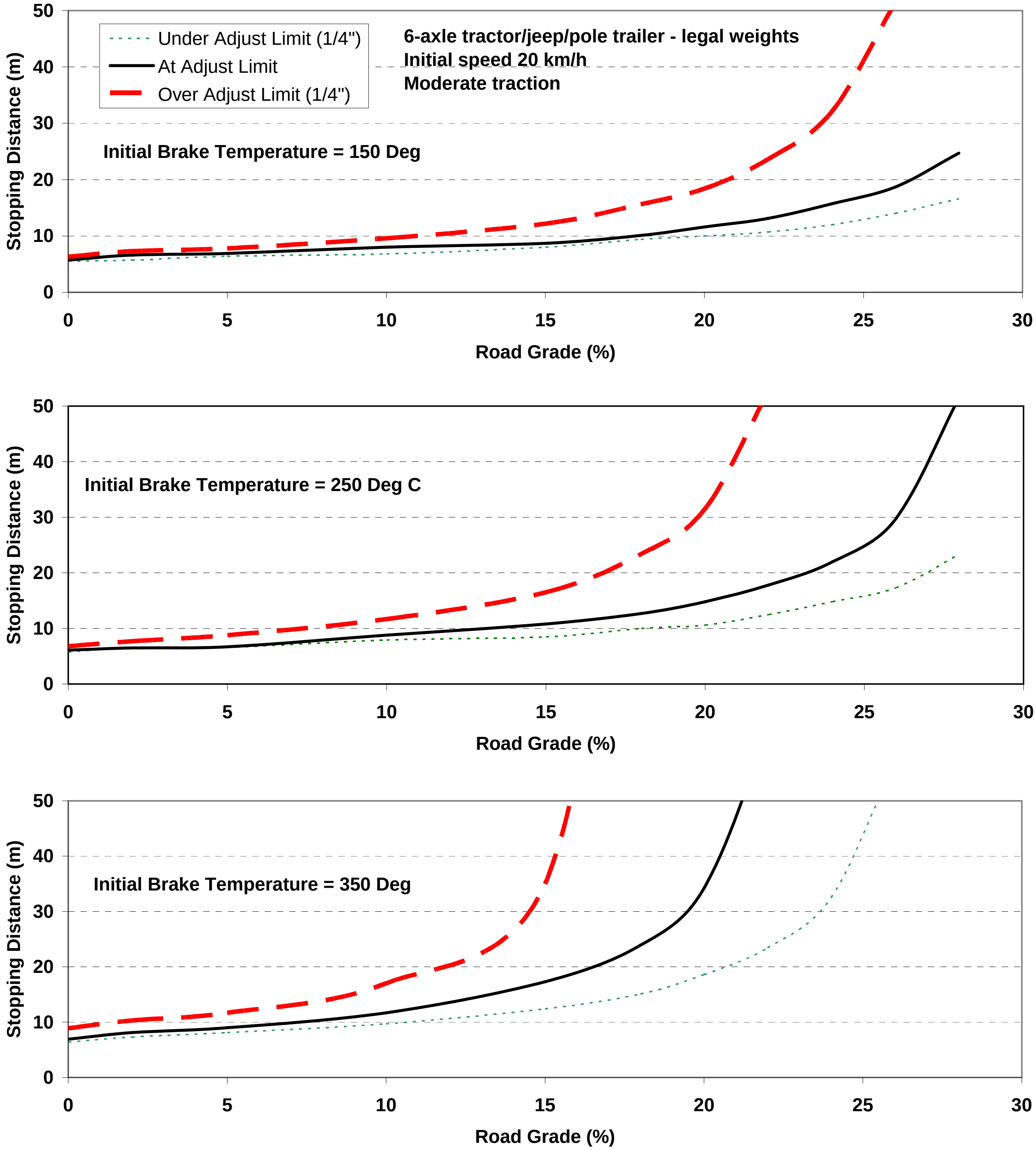


Figure 16. Influence of brake adjustment and temperature on stopping performance

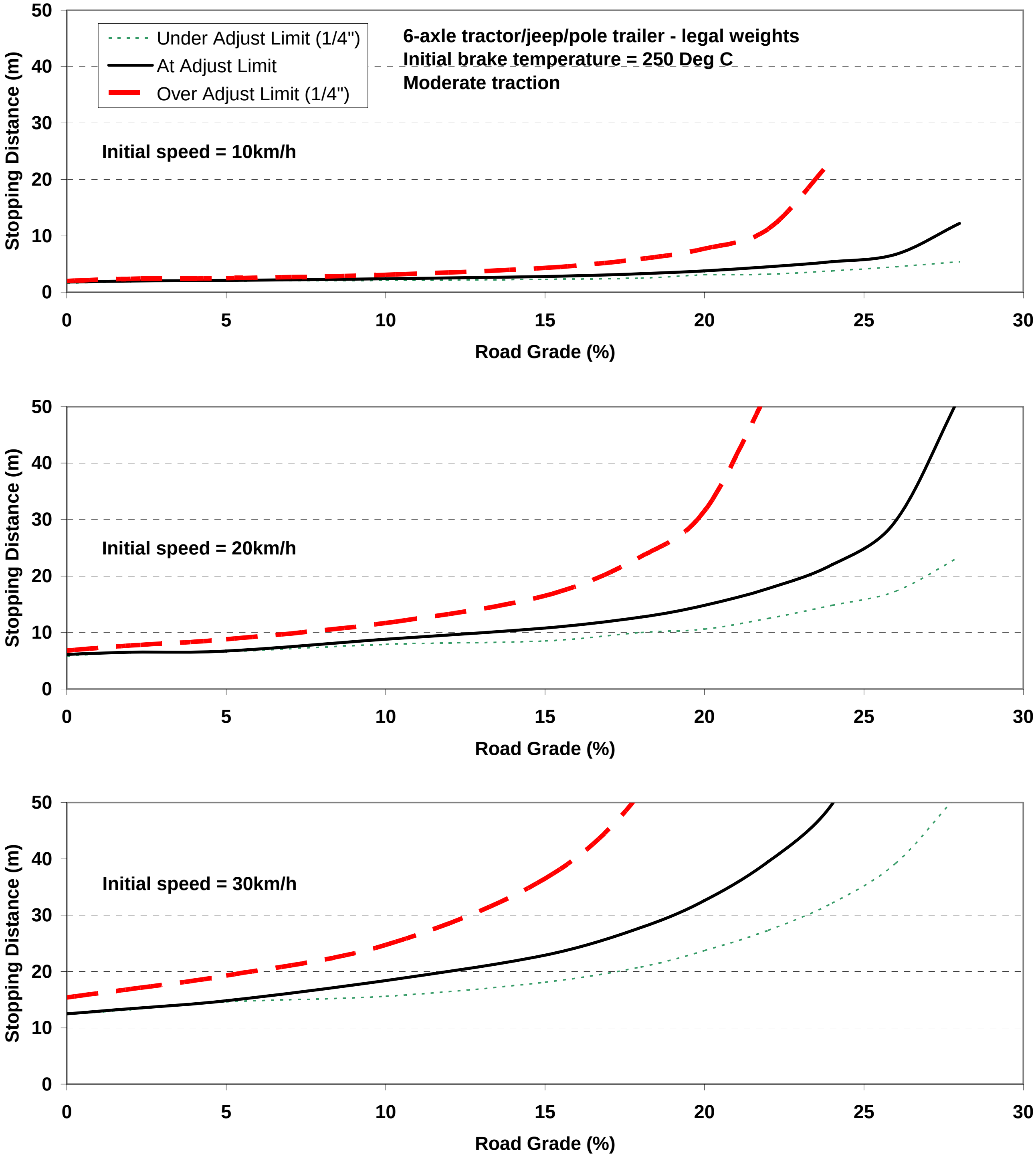


Figure 17. Influence of brake adjustment and initial speed on stopping performance

Most highway trucks are equipped with automatic slack-adjusters, which usually consistently stay within adjustment limits. However their adjustment should be checked at regular intervals to ensure they are operating as intended. Many older trailers are still equipped with manual slack-adjusters which require more frequent adjustment. Regardless of slack-adjuster type, all slack-adjusters should be checked daily when hauling on steep grades. At high temperatures, the combined effect of drum expansion and declining lining friction leads to reduced stopping capability, which can be further exacerbated when brakes are out of adjustment. In order to haul on steep grades, a good brake maintenance program, frequent inspection, and conservative brake use on long steep grades will ensure that the service brakes will continue to perform as intended when needed in an emergency.

Sufficient engine brake capacity is essential for descending grades above 18%, particularly for extended distances. The engine brake develops retardation only at the drive tires, which is often sufficient to satisfy the retardation requirements on grades up to 13%. As grades increase beyond this level service brake use becomes necessary to maintain control. There are typically three levels of engine brake engagement, allowing for operation under varying traction conditions. If too high an engine brake setting is applied the drive wheels will lockup and the retardation available will decline potentially allowing the truck to accelerate and lose control. Therefore, under low traction conditions, a low engine brake setting must be applied making it necessary for the service brakes to provide a greater proportion of the retardation. As a general rule, engine brake retardation should be maximized as much as possible by using the highest available engine brake setting in combination with the appropriate gear to maintain an engine speed of between 1400 and 1800 RPM without causing wheel lockup. This should prevent the service brakes from overheating so that they will perform as desired if needed in an emergency such as a driveline failure.

Appropriate gear selection and engine brake use influences service brake temperatures as illustrated in **Figure 18** for a 6-axle tractor/jeep/pole trailer under moderate traction conditions. Up to grades of

13%, the majority of the retardation may be accomplished by the driveline, provided that the traction at the drive tires can support the retardation forces. However as grades exceed 15% additional retardation is required at the non-drive tires from the service brakes to maintain the descent speed. As grades increase above this level service brake temperatures increase due to increased service brake retardation requirements. Therefore at grades above 15%, gear selection becomes more critical to maximize the driveline retardation so that service brake use is minimized as much as possible. The optimum gear is not necessarily the lowest as illustrated in the case of a 20 km/h descent on a 15% grade. In this example, in gear 3L a lower engine brake setting must be used to prevent the drive wheels from locking up thereby requiring more service brake use. The highest engine brake setting may be used without wheel lockup when in gear 3H requiring less service brake use. In some cases reduced service brake use may be achieved at higher descent speeds, but descent speeds above 20 km/h on grades above 18% are not recommended due to the difficulty of stopping on steep grades with hot brakes at these speeds.

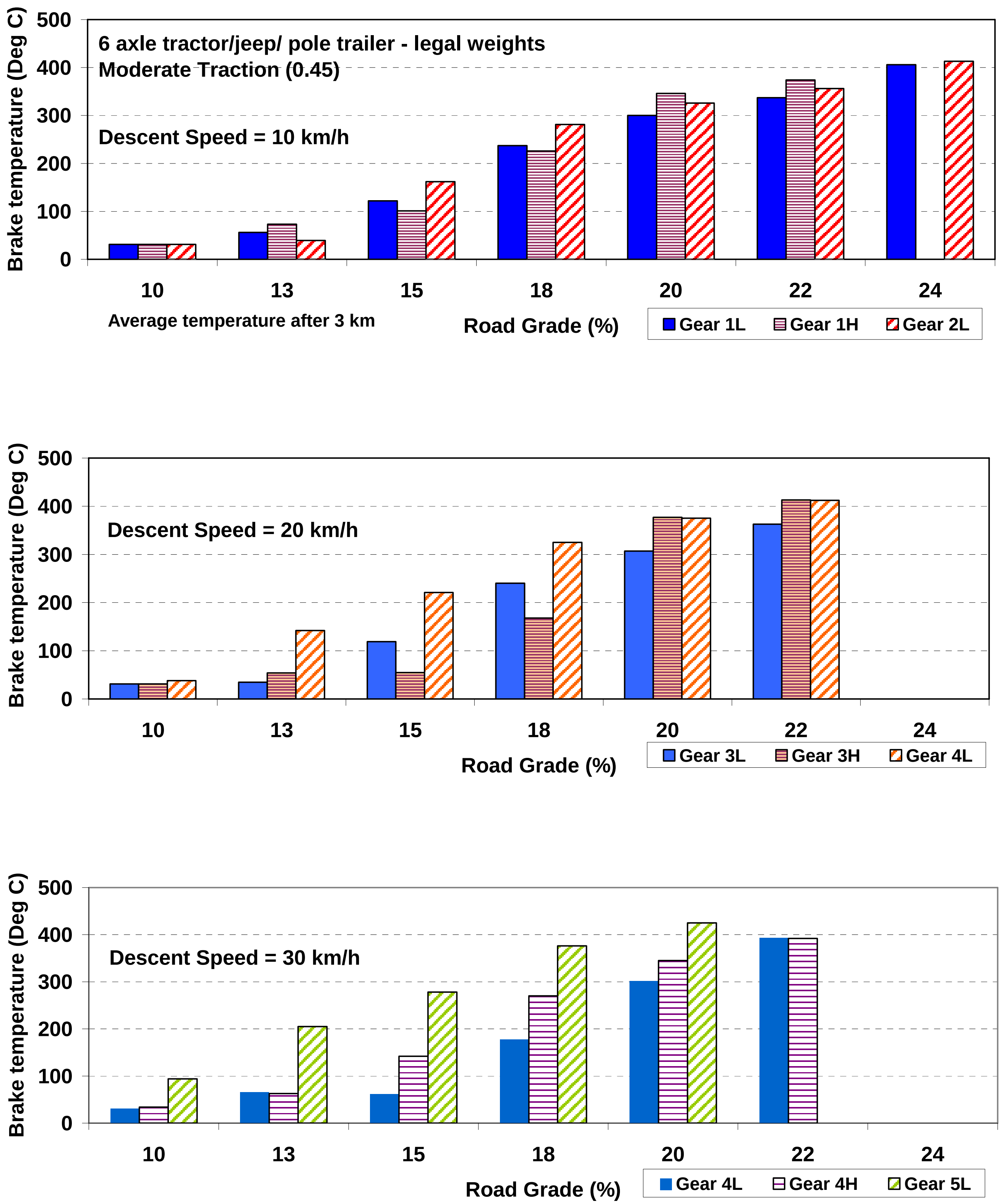


Figure 18. Influence of gear selection and speed on brake temperature – 6 axle (legal loads)

Road geometric specifications have a major influence on hauling safety and are often determined by topography. The vertical alignment (grade) dictates the necessary retardation to maintain a controlled descent speed for a particular truck load. Horizontal alignment also influences retardation requirements as trucks must generally reduce speed when travelling in curves to maintain control. This reduction in speed often involves gearing down and adjusting engine brake settings so that the drive tires will not lose traction in the curve. The effect of horizontal alignment on brake performance only becomes an issue on tight curves (radius of curvature less than 20 m) on grades above 20%, and therefore road designers should endeavor to keep switchback grades below this level.

Load and grade together determine the required retardation force to maintain a controlled descent, with retardation requirements increasing at increased loads and grades. The influence of load on stopping performance is very dependent on traction level as illustrated in **Figure 19** for a legally load 6–axle tractor/jeep/pole trailer. On moderate traction surfaces, an increase in load results in an increase in stopping distance while on poor traction surfaces stopping performance may be marginally improved. On poor (low) traction surfaces a reduction in axle loads leads to increased wheel lockup and markedly reduced braking forces transmitted to the road and consequently less effective braking. On moderate and higher traction surfaces the brake capacity has already been reached but must decelerate a greater mass leading to increased stopping distances.

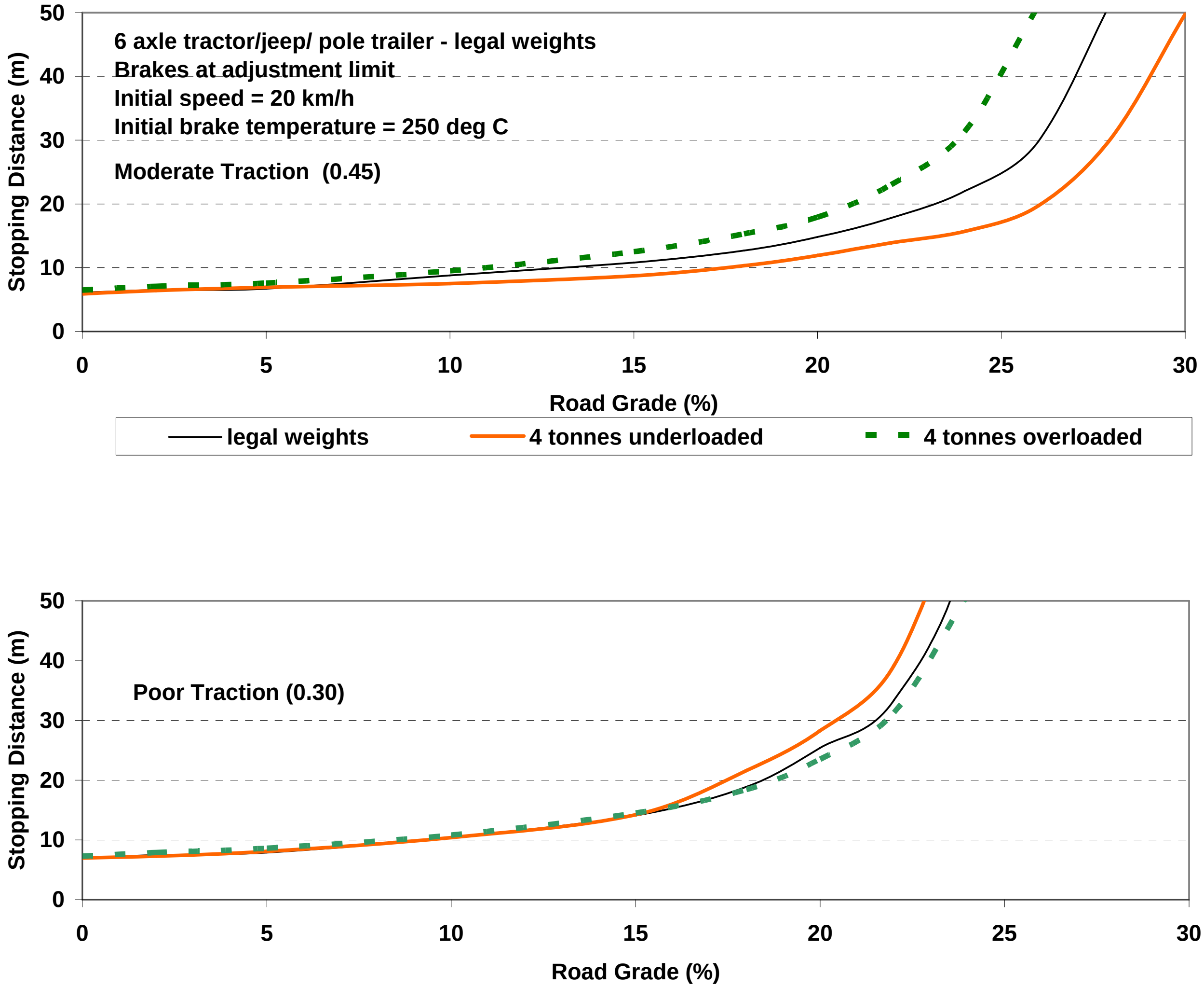


Figure 19. Influence of load on stopping performance – 6-axle – moderate and poor traction

Ideally the load should be distributed to provide a relatively balanced load to each axle, so that each brake absorbs a similar energy level and the risk of wheel lockup is reduced, thereby optimizing the configuration's stopping capability. For increased loads (off-highway applications) and grades, the load carried by the drive axles can be increased to allow the highest engine brake setting to be applied so that driveline retardation is maximized.

The 6-axle tractor jeep/pole trailer showed superior steep grade stopping performance under all traction conditions (**Figure 20**). Under legal loads, the 7-axle configuration has the lowest load per axle and therefore would be expected to have the best stopping performance under moderate traction conditions. However on grades above 20%, the 6-axle configuration showed improved stopping performance relative to the 7-axle. The relatively improved stopping performance of the 6-axle under these traction conditions is likely a result of two factors: less load carried by the steering axle brakes (which have less brake capacity) and a more efficient load transfer between axles. Under poor traction conditions, the combined effect of the lower load per axle and increased relative load transfer for the 7-axle configuration results in an increased tendency for wheel lockup and consequently less effective braking.

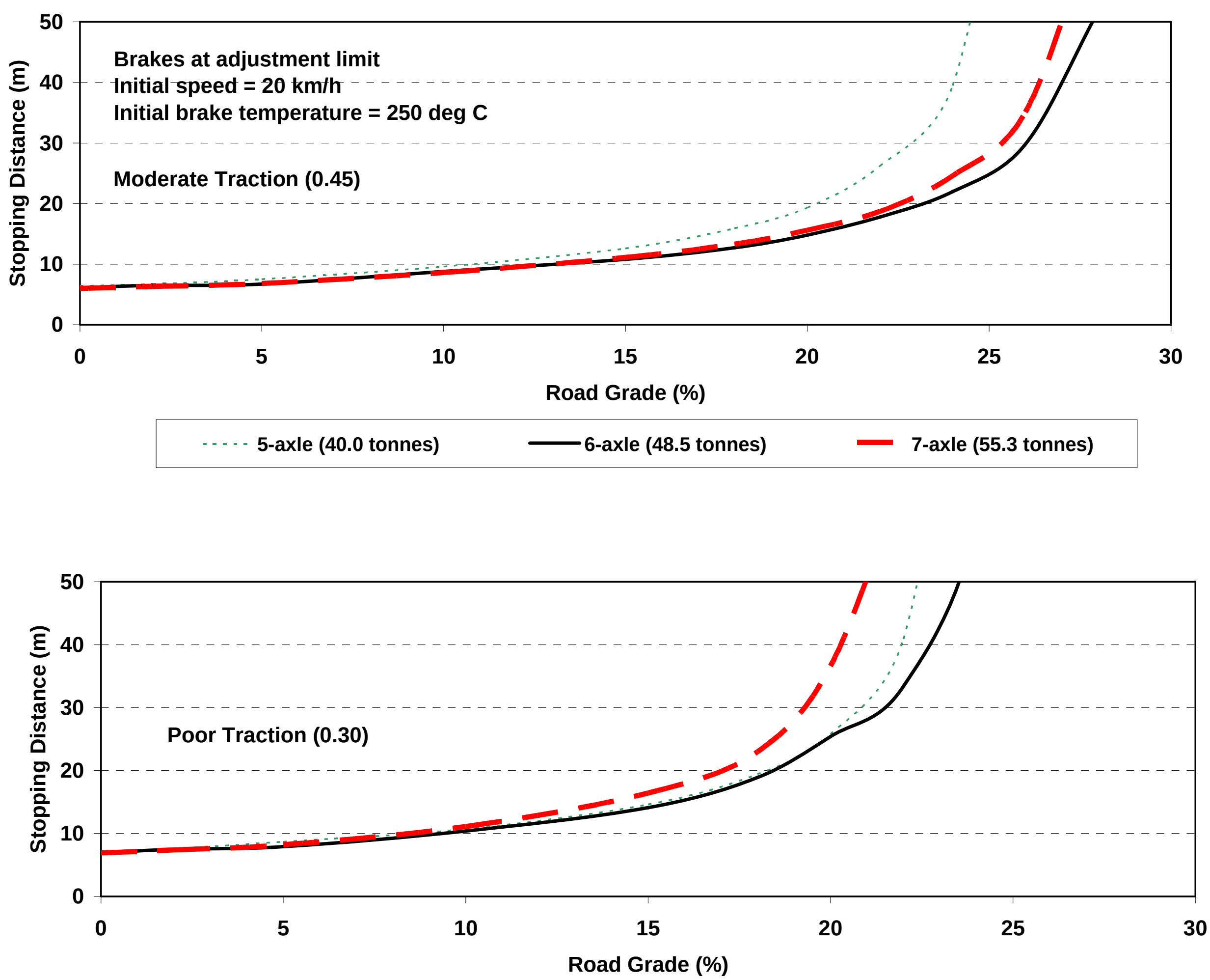


Figure 20. Influence of configuration on stopping performance – legal loads

Speed is a very important factor due to the increased energy[7] that must be absorbed should the truck configuration need to be stopped from a high speed on a steep grade. A low descent speed reduces the stopping distance and energy absorption requirements thereby reducing the risk of a runaway. However on a lower traction surface a lower speed may increase the risk of drive wheel lockup due to the lower gear used at low speeds which increases the drive wheel retardation forces. This is where the driver's skill and experience play the greatest role in their ability to adjust the descent speed through appropriate gear selection, engine brake use, and service brake application to constantly changing road conditions.

4. Descent guideline development

Descent guidelines have been developed which take into account the critical parameters for three configuration types. The parameters that can be most easily controlled for given road and traction conditions are load, load distribution, and descent speed. The guidelines provide maximum speeds and loads (Appendix III) for specified road conditions (traction, grade, distance) for three configurations (5-axle, 6-axle, and 7-axle). These guidelines will also be available as a spreadsheet lookup tool (available from FPInnovations – Feric website (www.feric.ca) under the solutions tab) which expedites speed and payload estimation.

Application of these guidelines may be best understood by reviewing a sample descent profile (**Figure 21**) for a 7-axle off-highway application. The maximum speeds and loads are determined separately by dividing the descent into different road sections based on grade and traction condition.

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[7] Energy = $\frac{1}{2} mv^2 + mgh$ (where m = mass, v=velocity, g= gravitational constant (9.81m/s2) , h = vertical distance) First component ($\frac{1}{2} mv^2$) is kinetic energy, second component (mgh)is potential energy. In addition to the increase in kinetic energy, at higher speeds the increased stopping distance results in increased vertical distance and potential energy that must be absorbed.

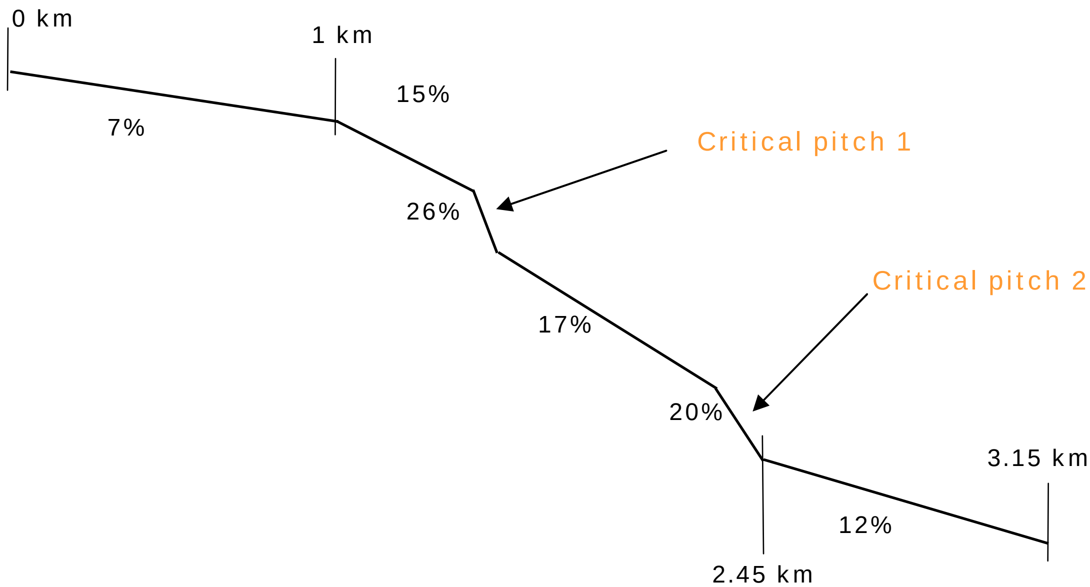

Figure 21. Sample descent profile

The sample descent has six segments to review for maximum speed as summarized in Table 3. The descent distance for each segment is the distance to the end of that segment unless the particular segment is considered a pitch[8]. For a pitch the descent distance is considered the start of the road segment. The maximum speeds are essentially broken down into four sections, an initial section of 45 km/h (km 0 to 1.0), followed by a sections of 25 km/h (km 1 to 1.4), 10 km/h (km 1.4 to 2.45), and 20 km/h (km 2.45 to 3.15). If the initial section (km 0 to 1.0) had been less than 5%, this section would be neglected in the calculation as the service brakes are unlikely to be used to any great extent at this grade. This would result in a reduced descent distances and consequently potentially increased descent speeds.

[8] Pitch is where the road segment is less than 300 m and the grade is greater than or equal to 20%

Table 3- Speed guidelines for sample descent

Road section (km)	Traction level (minimum)	Section distance (m)	Maximum grade (%)	Descent distance (km)	Speed (km/h)	Table reference (Appendix III)
0 – 1.0	Moderate	1000	7	1.0	45	Figure III-4
1.0 - 1.4	Moderate	400	15	1.4	25	Figure III-4
1.4 – 1.6	Moderate	200	26	1.4	10	Figure III-4
1.6 – 2.2	Low	600	17	2.2	10	Figure III-3
2.2 – 2.45	Low	250	20	2.2	10	Figure III-3
2.45 – 3.15	Moderate	700	12	3.15	20	Figure III-4

The maximum load capacity is determined at critical locations usually occurring on the steepest sections of the descent. In this example (Table 4) the critical sections evaluated are at 1.4 km (26% pitch, 200 m, moderate traction), and 2.2 km (20% pitch, 250 m, low traction). Interestingly, the load capacity of these two critical sections is very similar at 48 and 50 tonnes respectively. However critical pitch 1 determines the load capacity for the entire descent at 48 tonnes. If the traction level at critical pitch 1 is low instead of moderate, hauling on this grade is not possible (see Appendix III, Table III-16). The load capacity determination requires an estimate of average grade preceding the critical pitch. This grade estimate involves a two stage calculation with an initial estimate based on a weighted average followed by an adjustment if the grade just preceding the critical pitch is greater than the weighted average calculation. The most conservative estimate would be to use the maximum grade occurring at any point in the road section preceding the critical pitch as the average for the section.

Table 4- Load guidelines for sample descent (7-axle)

Location (km)	Critical Pitch Distance (m)	Grade (%)	Traction	Road section preceding pitch Distance (km)	Average[a] Grade (%)	Adjusted[b] Grade (%)	Maximum Load (tonnes)	Table reference
1.4	200	26	Moderate	1.4	9.3	12.2	$\boxed{48}$	Table III-18
2.2	250	20	Low	2.2	12.9	15.0	50	Table III-17

a Weighted average grade by distance (i.e. critical pitch 1: 7% x 1000/1400 + 15% x 400/1400 = 9.3%)
b When grade section preceding critical grade is greater than weighted average adjust average grade, for critical pitch 1 average of 15% and 9.3% = 12.2%. When the preceding grade is less than the weighted average, the adjusted average will be the same as the weighted average.

Implications for future research on workplace health and safety

The study has highlighted four potential areas for future research relating to steep road descent safety:

1. Service brake monitoring system to alert drivers of service brake adjustment and condition.
2. Traction monitoring and enhancement of steep grade sections.
3. Guideline enhancement to include all log truck configurations.
4. Training of drivers and road planners.

FPInnovations is currently evaluating a brake monitoring system, which monitors brake adjustment and temperature. These two parameters were identified as critical to ensuring acceptable stopping performance in the study.

Traction was also identified as a critical parameter to ensuring safe descent on steep grades. It would be therefore useful to develop a simplified means of measuring traction for operational personnel and develop methods of improving traction through road maintenance techniques or technological advancements (e.g. tire pressure control system).

The descent guidelines presented in this report include three of the most widely used log truck configurations for log hauling. There are minor differences in load transfer that occur between configurations that affect braking performance. The inclusion of other configurations in the guidelines would further enhance this planning tool.

Driving technique (gear selection and speed control) was identified in the study for controlling service brake temperatures and hence their stopping capability. Experienced drivers are well aware of these driving techniques, but further training of less experienced drivers in these techniques should be implemented. In addition forest road planners should be trained in the use of the guidelines as a planning tool to ensure that the safest road systems are developed.

Identification of immediate and longterm benefits of project findings

The main immediate benefit of this study is the production of guidelines that provide operational planners with a means of assessing the relative safety of their haul routes. The guidelines will enable planners to investigate a number of route options that provide the safest alternative and assist in the development of safe operating procedures (SOPs). The study also identified the critical factors for drivers and operational staff to review on an ongoing basis. Much of the material presented in this report can be used to develop a training module for drivers hauling on steep grades.

Identification of relevant user groups for project results

There are two broad user groups who will benefit from the study findings:

1. Forest road planners – this includes all operational staff involved in the design, construction and maintenance of forest road networks.
2. Truck drivers – all drivers involved hauling logs on steep forest roads (grades greater than 18%)

Dissemination/knowledge transfer

Dissemination of the study findings is anticipated to be conducted over two phases:

In the first phase, FPInnovations will visit all the main stakeholders involved in steep road hauling to review the study findings. Forest engineers, road construction and haul supervisory staff will be trained in the application of the guidelines and the critical parameters influencing steep grade descents.

In the second phase, a workshop will be scheduled to review the study findings from a driver's perspective. The workshop will focus on driving technique and the importance of service brake maintenance, gear selection and load size on steep grade braking performance. Additional workshops will be scheduled depending on demand from stakeholders and availability of additional funding.

References

British Columbia Ministry of Forests 2002. *Forest Road Engineering Guidebook.* Forest Practices Branch, BC Ministry of Forests, Victoria, BC. Forest Practices Code of British Columbia Guidebook. http://www.for.gov.bc.ca/TASB/LEGSREGS/FPC/FPCGUIDE/Road/FRE.pdf

WorkSafeBC 2005. *OH&S Guideline 26.2-2:Planning Log hauling operations for varying road grades.* WorkSafeBC (the Workers Compensation Board of British Columbia), Vancouver. http://www2.worksafebc.com/Publications/OHSRegulation/GuidelinePart26.asp

Parker S.P.S. 2007. Development of guidelines for descending steep grades: coastal British Columbia off-highway truck applications. Advantage Report Vol 8 No. 5, FERIC Vancouver.

Parker S.P.S. 2010. Development of guidelines for descending steep grades: highway legal log hauling configurations. FPInnovations Feric Internal Report

Yee H.W. 1996 A review to determine the need, location and design of runaway lanes in British Columbia. Masters Thesis Department of Civil Engineering University of British Columbia

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Appendix III – Descent Guidelines

Traction Estimation

The following methods[1] provide simplified means of estimating traction and may be conducted with either an empty logging truck or pickup truck:

Stopping Distance Test

Stopping distance tests should be conducted on a level grade on the road surface material of interest. Several tests should be conducted at several application pressures until wheel lockup occurs. The traction can be estimated from the following formula:

$$Traction\_coefficient = \frac{V^2}{254 * S} \qquad \text{(III-1)}$$

Where V = initial speed (km/h)
S = stopping distance (m)

It will be important to measure the stopping distance from the point where the brakes are applied.

Gradeability Test

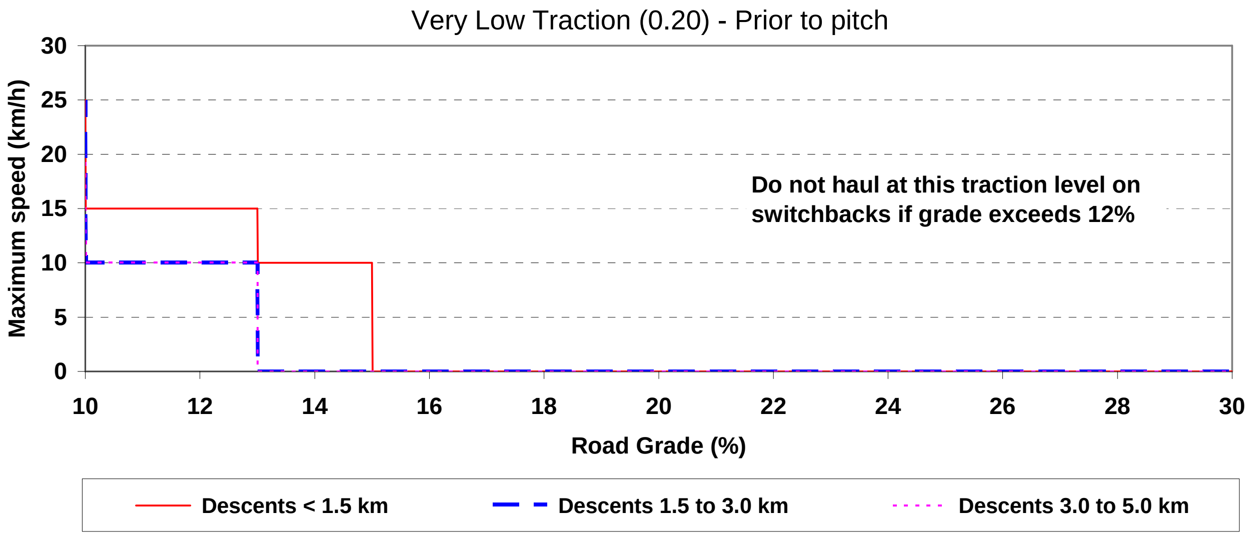
The gradeability test is best accomplished with a rear-wheel drive pickup truck. The test needs to be conducted on the road surface material of interest on an uphill grade steep enough to challenge the truck's gradeability. If the truck easily makes it up the test section, the load distribution may be adjusted by reducing weight on the rear (driven axle) or adding weight to the front axles (non-driven axle). The traction can then be estimated from the following formula:

$$Traction\_coefficient = \frac{M * p}{100 * R} \qquad \text{(III-2)}$$

Where M = Total truck mass (kg)
R = Rear axle load (kg)
p = road grade (%)

Note that this method provides the minimum traction required to achieve the desired gradeability. In order to get the best estimate of traction, the conditions (axle weights or road grade) must be adjusted until the truck can just make it up the grade while maintaining a steady speed.

[1] Only one of these tests need to be conducted to estimate the coefficient of friction/traction



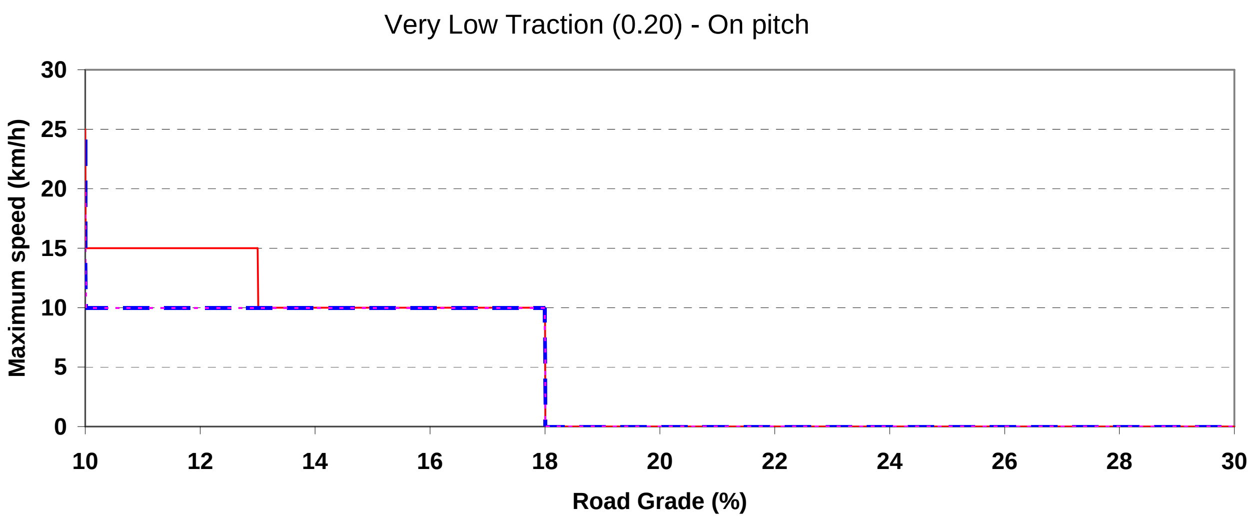


Figure III- 1. Maximum speed – very low traction (traction coefficient 0.20)

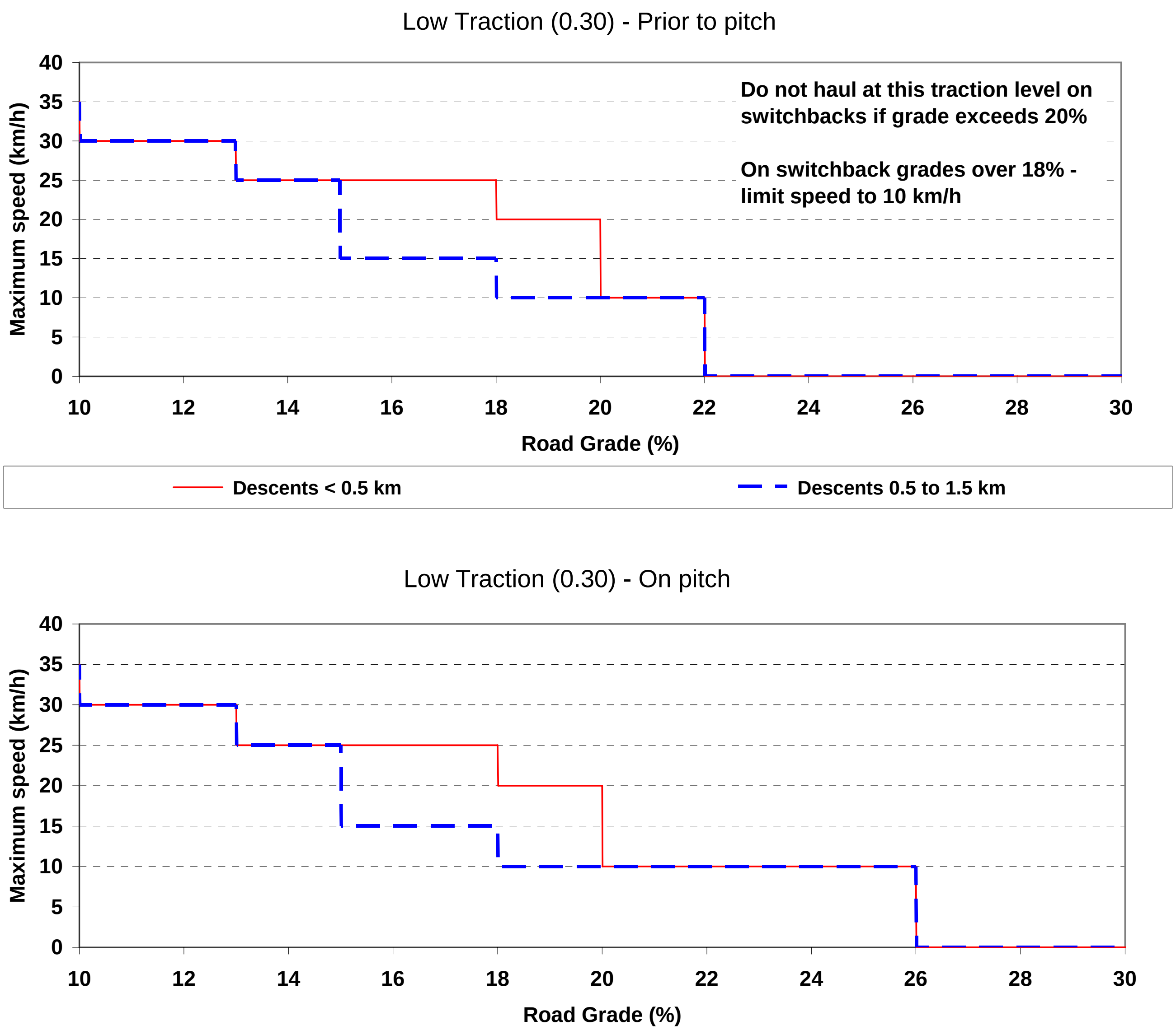
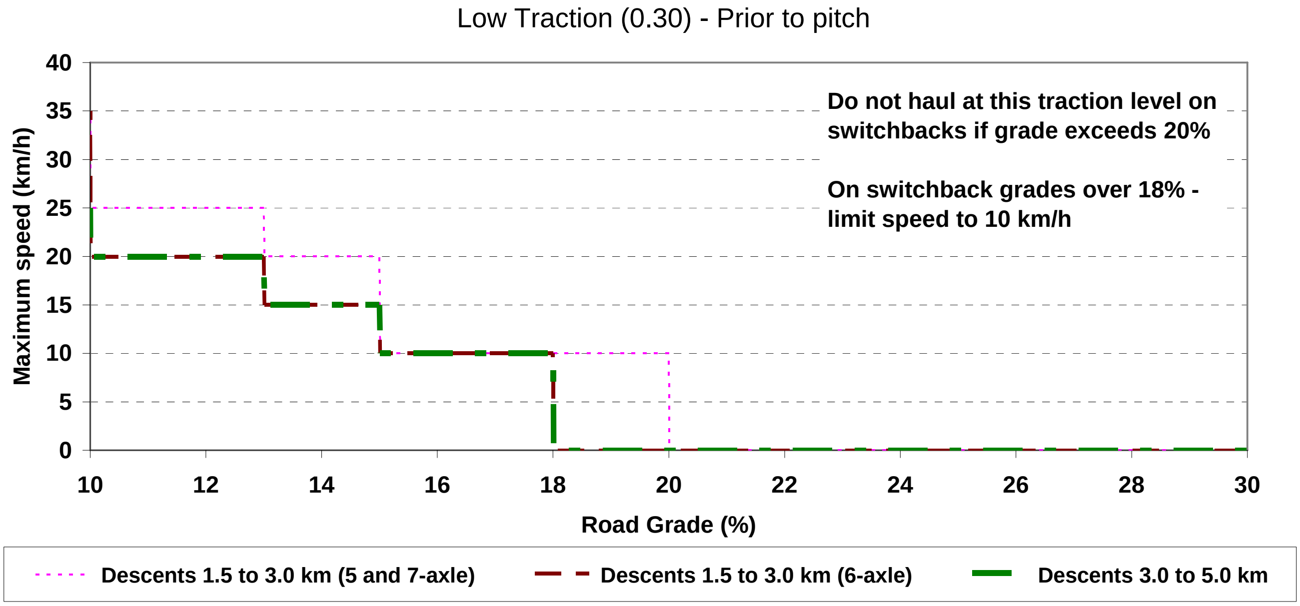


Figure III- 2. Maximum speed – low traction (traction coefficient 0.30) – descent distances less than 1.5 kilometres



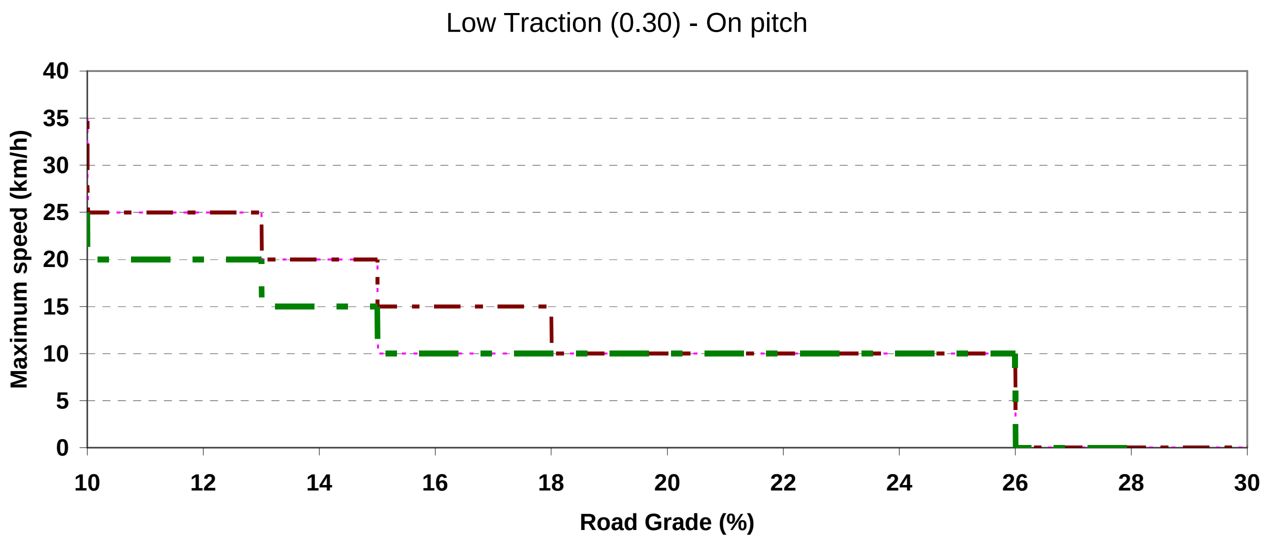


Figure III- 3. Maximum speed – low traction (traction coefficient 0.30) – descent distances greater than 1.5 kilometres

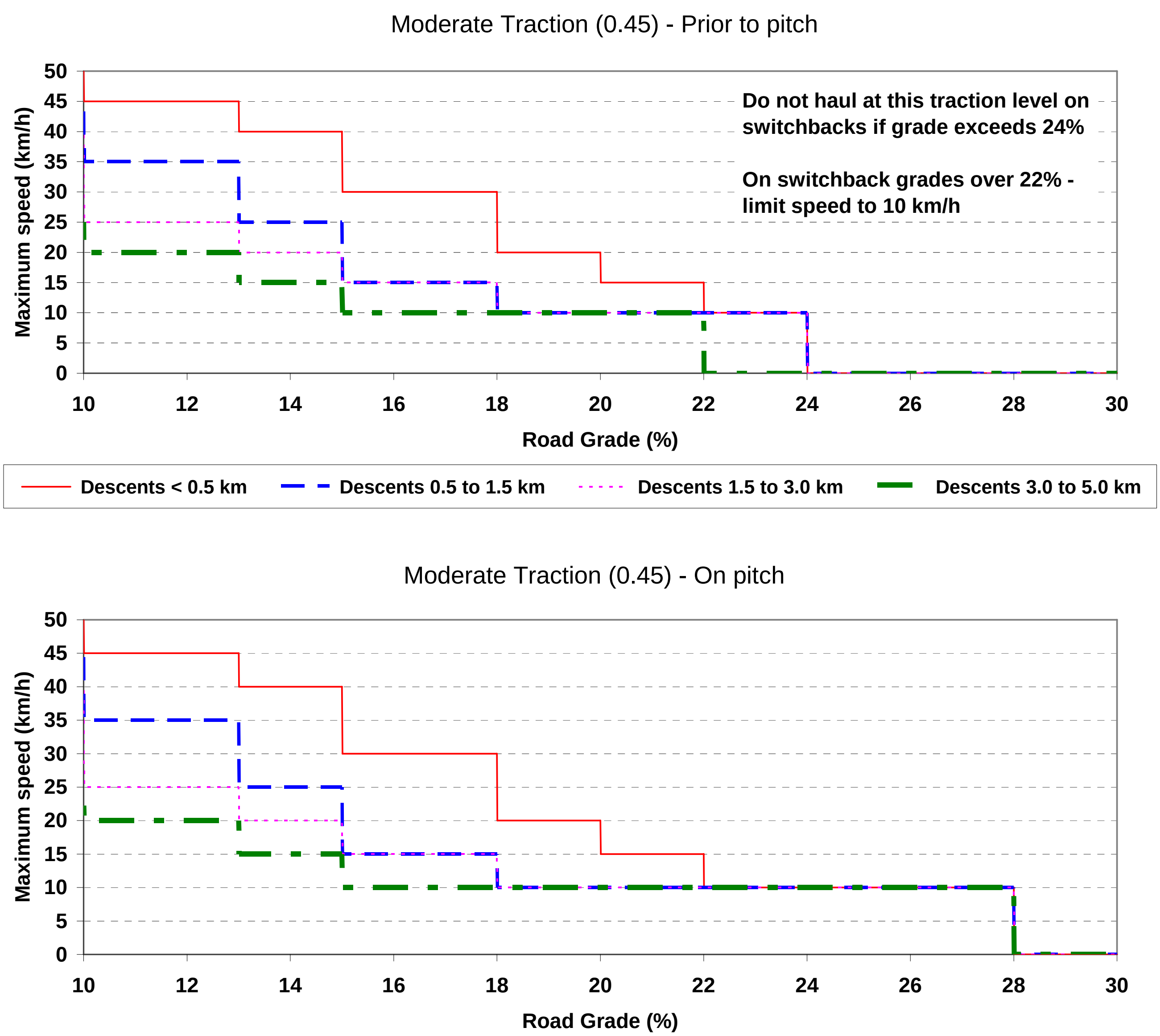
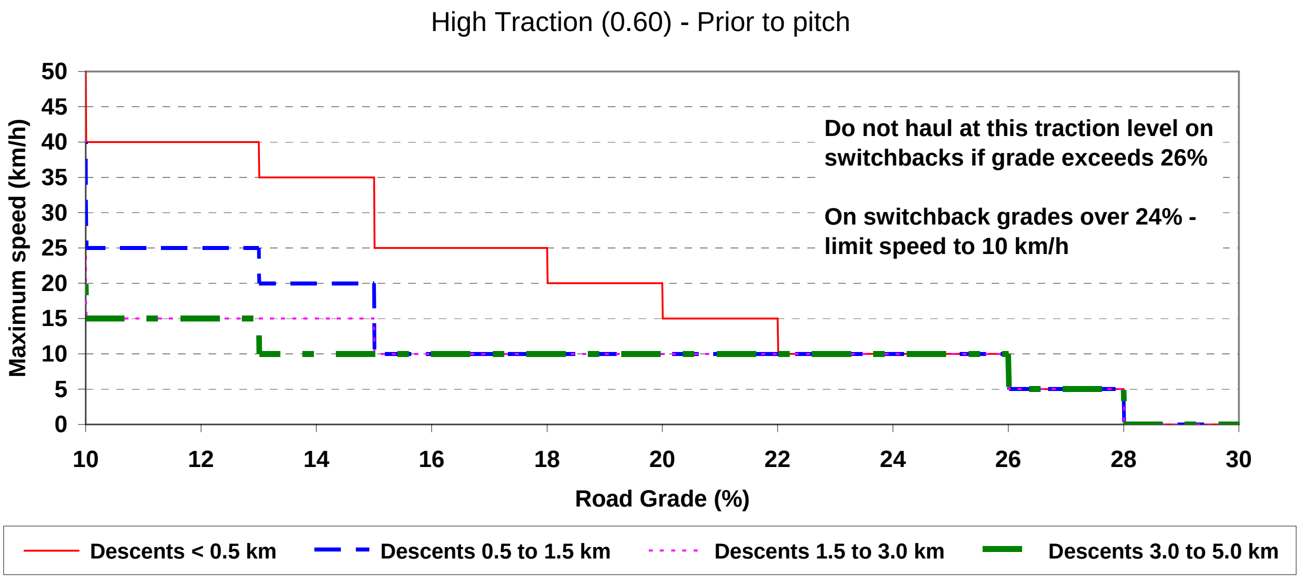


Figure III- 4. Maximum speed – moderate traction (traction coefficient 0.45)



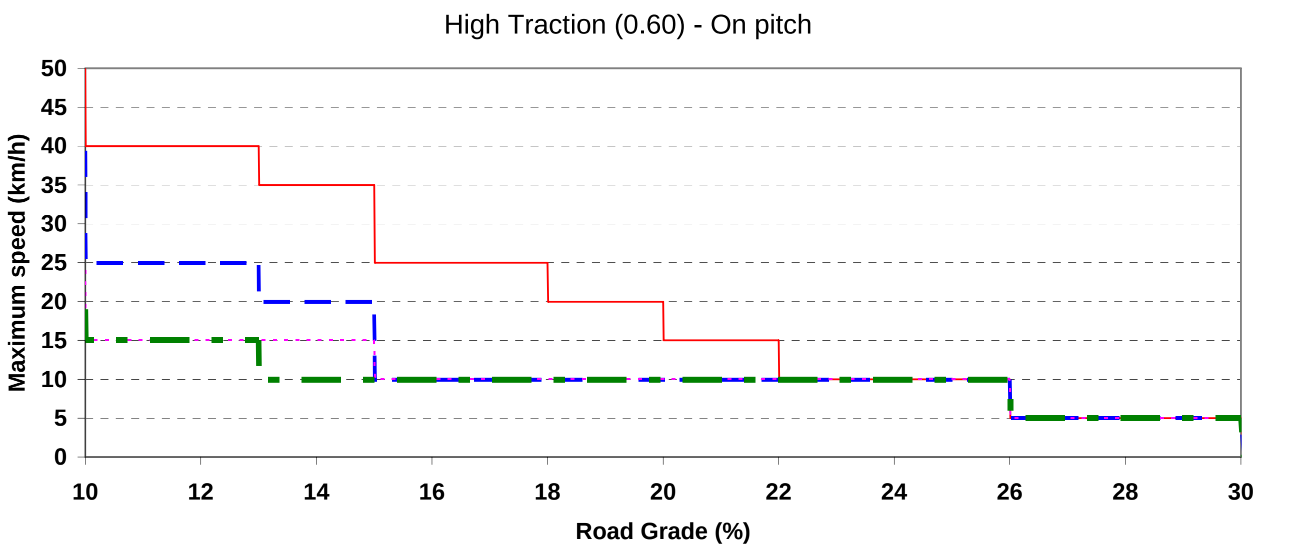


Figure III- 5. Maximum speed – high traction (traction coefficient 0.60)

Table III- 1. Maximum payload (tonnes) – 5-axle –very low traction (snow/ice :traction coefficient 0.20)

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	10	46	46	46	46	1.5	10	10	46	46	46	46
		12	46	46	46	46			12	46	46	46	46
		14	46	46	46	46			14	46	46	46	46
		16	46	46	44	44			16	46	46	44	44
		18	-	-	-	-			18	-	-	-	-
0.5	13	14	46	46	46	46	1.5	13	14	46	46	46	46
		16	46	46	44	44			16	46	46	44	44
		18	-	-	-	-			18	-	-	-	-
0.5	15	16	46	46	44	44	1.5	15	16	42	42	42	40
		18	-	-	-	-			18	-	-	-	-
3	10	10	46	46	46	46	5	10	10	46	46	46	46
		12	46	46	46	46			12	46	46	46	46
		14	46	46	46	46			14	46	46	46	46
		16	46	46	44	44			16	46	46	44	44
		18	-	-	-	-			18	-	-	-	-
3	13	14	36	36	36	36	5	13	14	28	28	28	28
		16	36	36	36	36			16	28	28	28	28
		18	-	-	-	-			18	-	-	-	-
3	15	16	-	-	-	-	5	15	16	-	-	-	-
		18	-	-	-	-			18	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 2. Maximum payload (tonnes) – 5-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents less than 1.5 kilometers

Cummulative distance prior to pitch (km)	Average grade prior to pitch (%)	Critical pitch grade (%)	Critical pitch length (m) 50	100	200	300
0.5	10	20	46	44	44	44
		22	46	44	42	42
		24	42	38	38	38
		26	38	-	-	-
		28	-	-	-	-
0.5	13	20	46	44	44	44
		22	46	44	42	42
		24	42	38	38	38
		26	36	-	-	-
		28	-	-	-	-
0.5	15	20	44	44	44	44
		22	44	44	44	42
		24	40	38	38	36
		26	36	-	-	-
		28	-	-	-	-
1.5	10	20	46	44	44	44
		22	46	44	42	42
		24	42	38	36	36
		26	36	-	-	-
		28	-	-	-	-
1.5	13	20	46	44	42	42
		22	44	40	38	38
		24	40	36	34	34
		26	36	-	-	-
		28	-	-	-	-
1.5	15	20	44	42	42	40
		22	42	38	38	36
		24	38	34	34	32
		26	32	-	-	-
		28	-	-	-	-

Cummulative distance prior to pitch (km)	Average grade prior to pitch (%)	Critical pitch grade (%)	Critical pitch length (m) 50	100	200	300
0.5	18	20	44	42	42	42
		22	44	42	40	40
		24	40	38	36	36
		26	34	-	-	-
		28	-	-	-	-
0.5	20	20	38	38	38	38
		22	38	38	38	38
		24	36	34	34	34
		26	32	-	-	-
		28	-	-	-	-
0.5	22	22	38	38	38	36
		24	36	34	32	32
		26	-	-	-	-
		28	-	-	-	-
0.5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	18	20	32	32	30	30
		22	30	30	28	28
		24	28	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	20	20	28	26	24	24
		22	26	24	22	22
		24	24	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 3. Maximum payload (tonnes) – 5-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
3.0	10	20	44	42	40	40	3.0	18	20	22	22	22	22
		22	40	38	38	38			22	22	22	22	22
		24	38	36	34	34			24	22	-	-	-
		26	36	-	-	-			26	-	-	-	-
		28	-	-	-	-			28	-	-	-	-
3.0	13	20	40	40	38	38	3.0	20	20	-	-	-	-
		22	38	36	36	36			22	-	-	-	-
		24	36	34	32	32			24	-	-	-	-
		26	34	-	-	-			26	-	-	-	-
		28	-	-	-	-			28	-	-	-	-
3.0	15	20	36	34	34	34	3.0	22	22	-	-	-	-
		22	34	32	32	32			24	-	-	-	-
		24	32	30	30	30			26	-	-	-	-
		26	30	-	-	-			28	-	-	-	-
		28	-	-	-	-	3.0	24	24	-	-	-	-
									26	-	-	-	-
									28	-	-	-	-
5.0	10	20	44	42	40	40	5.0	18	20	-	-	-	-
		22	40	38	38	38			22	-	-	-	-
		24	38	36	34	34			24	-	-	-	-
		26	36	-	-	-			26	-	-	-	-
		28	-	-	-	-			28	-	-	-	-
5.0	13	20	40	40	38	38	5.0	20	20	-	-	-	-
		22	38	36	36	36			22	-	-	-	-
		24	36	32	32	32			24	-	-	-	-
		26	32	-	-	-			26	-	-	-	-
		28	-	-	-	-			28	-	-	-	-
5.0	15	20	30	30	30	30	5.0	22	22	-	-	-	-
		22	30	30	30	30			24	-	-	-	-
		24	30	-	-	-			26	-	-	-	-
		26	-	-	-	-			28	-	-	-	-
		28	-	-	-	-	5.0	24	24	-	-	-	-
									26	-	-	-	-
									28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 4. Maximum payload (tonnes) – 5-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	20	46	44	44	44	0.5	18	20	42	42	40	40
		22	46	44	42	42			22	42	42	40	40
		24	44	42	40	40			24	40	40	38	38
		26	40	38	36	36			26	38	36	36	36
		28	36	34	34	34			28	36	34	32	32
0.5	13	20	44	42	42	42	0.5	20	20	42	42	40	40
		22	44	42	42	42			22	42	42	40	40
		24	42	40	40	40			24	40	40	38	38
		26	40	38	36	36			26	38	36	36	36
		28	36	34	34	34			28	36	34	32	32
0.5	15	20	42	42	42	40	0.5	22	22	40	40	38	38
		22	42	42	40	40			24	40	40	38	38
		24	42	40	40	40			26	38	36	36	34
		26	40	36	36	36			28	34	34	32	32
		28	36	34	34	32	0.5	24	24	38	38	36	36
									26	36	34	34	34
									28	34	32	30	30
1.5	10	20	46	44	44	44	1.5	18	20	42	42	40	40
		22	46	42	42	42			22	40	38	38	38
		24	42	38	38	38			24	38	36	36	36
		26	38	36	36	34			26	36	34	34	32
		28	34	32	32	32			28	34	32	30	30
1.5	13	20	42	42	42	42	1.5	20	20	42	42	40	40
		22	40	38	38	38			22	40	38	38	38
		24	38	36	36	36			24	38	36	36	36
		26	36	34	34	32			26	36	34	26	26
		28	34	32	30	30			28	34	28	26	26
1.5	15	20	42	42	42	40	1.5	22	22	40	38	38	38
		22	40	38	38	38			24	38	36	36	36
		24	38	36	36	36			26	36	28	26	26
		26	36	34	34	32			28	28	26	24	24
		28	34	32	30	30	1.5	24	24	28	28	26	26
									26	26	26	26	26
									28	26	24	22	22

Note : Legal payload : 26 tonnes

Table III- 5. Maximum payload (tonnes) – 5-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	10	20	46	44	42	42
		22	44	40	40	40
		24	42	38	36	36
		26	38	36	34	34
		28	34	32	32	32
3.0	13	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30
3.0	15	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30
5.0	10	20	46	44	42	42
		22	44	40	40	40
		24	42	38	36	36
		26	38	36	34	34
		28	34	32	32	32
5.0	13	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30
5.0	15	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	18	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30
3.0	20	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	24	24	24
		28	34	22	22	22
3.0	22	22	24	24	24	24
		24	24	24	22	22
		26	22	22	22	22
		28	22	20	20	20
3.0	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5.0	18	20	40	38	38	38
		22	38	36	36	36
		24	36	34	34	34
		26	36	32	32	32
		28	34	32	30	30
5.0	20	20	40	38	38	38
		22	38	36	36	36
		24	36	22	22	22
		26	36	22	22	22
		28	34	20	20	20
5.0	22	22	20	20	20	20
		24	20	20	20	20
		26	20	20	20	20
		28	20	-	-	-
5.0	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : '-' indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 6. Maximum payload (tonnes) – 5-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	10	20	46	44	44	44
		22	46	44	42	42
		24	44	42	40	40
		26	40	38	36	36
		28	38	36	36	36
		30	34	32	-	-
0.5	13	20	44	44	44	44
		22	44	42	42	42
		24	44	42	40	40
		26	40	38	36	36
		28	38	36	34	34
		30	34	32	-	-
0.5	15	20	42	42	42	40
		22	42	42	40	40
		24	42	40	40	40
		26	40	36	36	36
		28	38	34	34	34
		30	34	32	-	-
0.5	26	26	36	34	34	34
		28	36	34	34	34
		30	34	32	-	-
1.5	10	20	46	44	44	44
		22	46	44	42	42
		24	44	40	40	40
		26	40	36	36	36
		28	38	34	34	34
		30	34	32	-	-
1.5	13	20	44	44	44	44
		22	44	42	42	40
		24	42	38	38	38
		26	40	36	34	34
		28	38	34	34	34
		30	34	32	-	-
1.5	15	20	42	42	42	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
1.5	26	26	32	32	32	32
		28	32	32	30	30
		30	30	30	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	18	20	42	42	40	40
		22	42	42	40	40
		24	40	40	38	38
		26	38	36	36	36
		28	36	34	34	34
		30	34	32	-	-
0.5	20	20	42	42	40	40
		22	42	42	40	40
		24	40	40	38	38
		26	38	36	36	36
		28	36	34	34	34
		30	34	32	-	-
0.5	22	22	40	40	38	38
		24	40	40	38	38
		26	38	36	36	34
		28	36	34	34	34
		30	34	32	-	-
0.5	24	24	38	38	36	36
		26	36	34	34	34
		28	36	34	34	34
		30	34	32	-	-
0.5	28	28	34	34	34	34
		30	32	32	-	-
1.5	18	20	42	42	40	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
1.5	20	20	42	42	40	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
1.5	22	22	40	40	38	38
		24	38	38	36	36
		26	36	36	34	34
		28	36	34	34	34
		30	32	30	-	-
1.5	24	24	36	36	34	34
		26	34	34	32	32
		28	34	32	32	32
		30	32	30	-	-
1.5	28	28	32	30	30	30
		30	30	30	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 7. Maximum payload (tonnes) – 5-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	10	20	46	44	44	44
		22	46	44	42	42
		24	44	40	40	40
		26	40	36	36	36
		28	38	34	34	34
		30	34	32	-	-
3.0	13	20	44	44	44	44
		22	44	42	42	40
		24	42	38	38	38
		26	40	36	34	34
		28	38	34	34	34
		30	34	30	-	-
3.0	15	20	42	42	42	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
3.0	26	26	28	28	28	28
		28	28	28	28	28
		30	28	26	-	-
5.0	10	20	46	44	44	44
		22	46	44	42	42
		24	44	40	40	40
		26	40	36	36	36
		28	38	34	34	34
		30	34	30	-	-
5.0	13	20	44	44	44	44
		22	44	42	42	40
		24	42	38	38	38
		26	40	36	34	34
		28	38	34	34	34
		30	34	30	-	-
5.0	15	20	42	42	42	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	18	20	42	42	40	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
3.0	20	20	42	42	40	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
3.0	22	22	36	36	36	36
		24	36	34	34	34
		26	34	34	32	32
		28	34	32	32	32
		30	32	30	-	-
3.0	24	24	34	32	32	32
		26	32	30	30	30
		28	32	30	30	30
		30	30	28	-	-
5.0	18	20	42	42	42	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
5.0	20	20	42	42	40	40
		22	42	42	40	40
		24	40	38	38	38
		26	38	36	34	34
		28	36	34	34	34
		30	32	30	-	-
5.0	22	22	34	34	34	34
		24	34	34	32	32
		26	32	32	32	32
		28	32	32	30	30
		30	32	30	-	-
5.0	24	24	30	30	30	30
		26	30	30	28	28
		28	30	28	28	28
		30	28	26	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 26 tonnes

Table III- 8. Maximum payload (tonnes) – 6-axle – very low traction (snow/ice :traction coefficient 0.20)

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	10	52	52	52	52	1.5	10	10	52	52	52	52
		12	52	52	52	52			12	52	52	52	52
		14	52	52	52	52			14	52	52	52	52
		16	52	-	-	-			16	52	-	-	-
		18	-	-	-	-			18	-	-	-	-
0.5	13	14	52	52	52	52	1.5	13	14	44	44	42	42
		16	48	-	-	-			16	44	-	-	-
		18	-	-	-	-			18	-	-	-	-
0.5	15	16	-	-	-	-	1.5	15	16	-	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	10	10	40	38	38	38	5	10	10	32	32	32	32
		12	40	38	38	38			12	32	32	32	32
		14	38	38	38	38			14	32	32	32	32
		16	38	-	-	-			16	32	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	13	14	32	32	32	32	5	13	14	28	28	28	28
		16	32	-	-	-			16	28	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	15	16	-	-	-	-	5	15	16	-	-	-	-
		18	-	-	-	-			18	-	-	-	-

Note : '-' indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 9. Maximum payload (tonnes) – 6-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	52	-	-	-
		28	-	-	-	-
0.5	13	20	52	52	52	52
		22	52	52	52	52
		24	52	50	50	50
		26	48	-	-	-
		28	-	-	-	-
0.5	15	20	52	52	52	52
		22	52	52	52	52
		24	52	50	48	48
		26	48	-	-	-
		28	-	-	-	-
1.5	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	50	48
		26	50	-	-	-
		28	-	-	-	-
1.5	13	20	52	52	52	52
		22	52	52	50	50
		24	50	48	46	46
		26	46	-	-	-
		28	-	-	-	-
1.5	15	20	48	48	48	46
		22	48	44	44	42
		24	44	42	40	38
		26	40	-	-	-
		28	-	-	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	18	20	52	52	50	50
		22	52	52	50	50
		24	50	46	44	44
		26	46	-	-	-
		28	-	-	-	-
0.5	20	20	50	50	48	46
		22	50	48	46	46
		24	48	44	42	42
		26	44	-	-	-
		28	-	-	-	-
0.5	22	22	50	48	46	46
		24	46	44	42	42
		26	-	-	-	-
		28	-	-	-	-
0.5	24	24	44	44	42	42
		26	-	-	-	-
		28	-	-	-	-
1.5	18	20	36	32	32	32
		22	34	32	32	32
		24	32	30	30	30
		26	-	-	-	-
		28	-	-	-	-
1.5	20	20	28	26	26	26
		22	26	26	26	26
		24	26	24	24	24
		26	-	-	-	-
		28	-	-	-	-
1.5	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 10. Maximum payload (tonnes) – 6-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	10	20	52	52	52	52
		22	52	48	48	48
		24	50	46	46	44
		26	46	-	-	-
		28	-	-	-	-
3.0	13	20	44	42	42	42
		22	42	40	40	40
		24	40	40	38	38
		26	38	-	-	-
		28	-	-	-	-
3.0	15	20	30	30	30	30
		22	30	30	30	30
		24	30	30	28	28
		26	30	-	-	-
		28	-	-	-	-
5	10	20	52	52	52	52
		22	52	48	48	48
		24	50	46	40	40
		26	46	-	-	-
		28	-	-	-	-
5	13	20	38	38	36	36
		22	38	36	34	34
		24	36	34	32	32
		26	34	-	-	-
		28	-	-	-	-
5	15	20	24	24	24	24
		22	24	24	22	22
		24	24	22	-	-
		26	-	-	-	-
		28	-	-	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	18	20	20	20	20	20
		22	20	20	20	20
		24	20	20	20	20
		26	-	-	-	-
		28	-	-	-	-
3.0	20	20	-	-	-	-
		22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
3.0	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
3.0	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	18	20	-	-	-	-
		22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	20	20	-	-	-	-
		22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : '-' indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 11. Maximum payload (tonnes) – 6-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	20	52	52	52	52	0.5	18	20	52	52	52	52
		22	52	52	52	52			22	52	52	52	50
		24	52	52	52	52			24	52	50	50	48
		26	52	48	48	48			26	50	46	46	44
		28	52	46	46	44			28	46	42	42	40
0.5	13	20	52	52	52	52	0.5	20	20	52	52	52	52
		22	52	52	52	52			22	52	52	52	50
		24	52	52	52	52			24	52	50	50	48
		26	52	48	48	46			26	50	46	46	44
		28	50	44	44	42			28	46	42	42	40
0.5	15	20	52	52	52	52	0.5	22	22	50	50	50	50
		22	52	52	52	52			24	50	50	48	48
		24	52	52	52	50			26	48	46	44	44
		26	52	48	48	46			28	44	42	42	40
		28	48	44	44	42	0.5	24	24	48	46	46	44
									26	44	44	42	42
									28	42	40	40	38
1.5	10	20	52	52	52	52	1.5	18	20	46	46	46	46
		22	52	52	52	52			22	46	46	44	44
		24	52	50	48	48			24	44	42	42	42
		26	50	46	44	44			26	42	40	38	38
		28	46	42	42	40			28	40	38	36	36
1.5	13	20	52	52	52	52	1.5	20	20	38	38	36	36
		22	52	52	50	50			22	38	36	36	36
		24	52	48	46	46			24	36	36	34	34
		26	48	44	42	42			26	34	32	30	30
		28	44	42	40	40			28	32	30	30	30
1.5	15	20	52	52	52	52	1.5	22	22	34	32	32	32
		22	52	52	50	50			24	34	32	30	30
		24	52	48	46	46			26	32	30	28	28
		26	48	44	42	42			28	30	28	26	26
		28	44	42	40	40	1.5	24	24	24	22	22	22
									26	24	22	22	22
									28	24	22	20	20

Note : Legal payload : 33 tonnes

Table III- 12. Maximum payload (tonnes) – 6-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
3.0	10	20	52	52	52	52	3.0	18	20	38	38	36	36
		22	52	48	48	48			22	38	36	36	34
		24	50	46	46	44			24	36	36	34	34
		26	46	44	42	42			26	36	34	34	34
		28	44	40	40	38			28	34	32	32	32
3.0	13	20	52	52	50	50	3.0	20	20	26	26	26	26
		22	50	48	48	48			22	26	26	26	26
		24	48	46	46	44			24	26	26	24	24
		26	46	44	42	42			26	26	24	24	24
		28	44	40	40	38			28	26	24	24	24
3.0	15	20	50	48	48	48	3.0	22	22	-	-	-	-
		22	48	46	44	44			24	-	-	-	-
		24	46	44	42	42			26	-	-	-	-
		26	44	42	42	40			28	-	-	-	-
		28	42	40	40	38	3.0	24	24	-	-	-	-
									26	-	-	-	-
									28	-	-	-	-
5	10	20	52	52	52	52	5	18	20	26	26	24	24
		22	52	48	48	48			22	26	26	24	24
		24	50	46	46	44			24	26	24	24	24
		26	46	44	42	42			26	26	24	24	24
		28	44	40	40	38			28	26	24	24	24
5	13	20	52	50	50	50	5	20	20	-	-	-	-
		22	50	48	48	48			22	-	-	-	-
		24	48	46	46	44			24	-	-	-	-
		26	46	44	42	42			26	-	-	-	-
		28	44	40	40	38			28	-	-	-	-
5	15	20	44	42	40	40	5	22	22	-	-	-	-
		22	42	40	40	38			24	-	-	-	-
		24	40	38	38	38			26	-	-	-	-
		26	38	38	36	36			28	-	-	-	-
		28	38	36	34	34	5	24	24	-	-	-	-
									26	-	-	-	-
									28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 13. Maximum payload (tonnes) – 6-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	52	48	48	48
		28	52	46	46	46
		30	52	44	-	-
0.5	13	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	52	48	48	48
		28	52	46	46	46
		30	52	44	-	-
0.5	15	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	52	48	48	48
		28	52	46	46	46
		30	50	42	-	-
0.5	26	26	46	46	44	44
		28	46	44	42	42
		30	42	40	-	-
1.5	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	48	42	-	-
1.5	13	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	46	42	-	-
1.5	15	20	52	52	52	52
		22	52	52	50	50
		24	52	50	50	48
		26	50	46	44	44
		28	48	44	44	42
		30	44	42	-	-
1.5	26	26	26	26	26	26
		28	26	26	26	26
		30	26	26	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	18	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	50	48	48	48
		28	50	46	46	44
		30	48	42	-	-
0.5	20	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	52
		26	50	48	46	46
		28	50	46	46	44
		30	46	42	-	-
0.5	22	22	52	52	52	52
		24	52	52	52	50
		26	50	48	48	46
		28	50	46	46	44
		30	46	42	-	-
0.5	24	24	52	52	50	50
		26	48	46	46	46
		28	46	44	44	44
		30	44	42	-	-
0.5	28	28	44	44	42	42
		30	42	40	-	-
1.5	18	20	48	48	46	46
		22	46	46	46	46
		24	46	44	44	44
		26	44	42	42	40
		28	42	40	40	38
		30	40	38	-	-
1.5	20	20	44	44	44	44
		22	44	44	42	42
		24	42	42	40	40
		26	42	40	38	38
		28	40	38	38	36
		30	38	36	-	-
1.5	22	22	44	44	42	42
		24	42	42	40	40
		26	42	40	38	38
		28	40	38	38	36
		30	38	36	-	-
1.5	24	24	40	40	40	38
		26	38	38	38	36
		28	38	36	36	36
		30	36	34	-	-
1.5	28	28	24	24	24	24
		30	24	24	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 14. Maximum payload (tonnes) – 6-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	48	42	-	-
3.0	13	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	46	42	-	-
3.0	15	20	52	52	52	52
		22	52	52	50	50
		24	52	50	50	48
		26	50	46	44	44
		28	48	44	44	42
		30	44	42	-	-
3.0	26	26	-	-	-	-
		28	-	-	-	-
		30	-	-	-	-
5.0	10	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	48	42	-	-
5.0	13	20	52	52	52	52
		22	52	52	52	52
		24	52	52	52	50
		26	52	48	46	46
		28	50	46	44	44
		30	46	42	-	-
5.0	15	20	52	52	52	52
		22	52	52	50	50
		24	52	50	50	48
		26	50	46	44	44
		28	48	44	44	42
		30	44	42	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	18	20	48	48	46	46
		22	46	46	44	44
		24	44	44	42	42
		26	44	42	40	40
		28	42	40	40	38
		30	40	38	-	-
3.0	20	20	44	44	42	42
		22	44	42	40	40
		24	42	40	38	38
		26	40	38	36	36
		28	40	38	36	36
		30	38	36	-	-
3.0	22	22	38	38	38	38
		24	36	36	36	36
		26	36	34	34	34
		28	36	34	34	34
		30	34	32	-	-
3.0	24	24	20	20	20	20
		26	20	20	20	20
		28	20	20	20	20
		30	20	20	-	-
5.0	18	20	44	44	42	42
		22	44	42	40	40
		24	42	40	40	40
		26	40	38	38	38
		28	40	38	38	38
		30	38	36	-	-
5.0	20	20	40	38	38	38
		22	38	38	38	38
		24	38	36	36	36
		26	36	36	34	34
		28	36	34	34	34
		30	34	32	-	-
5.0	22	22	34	34	34	34
		24	34	34	32	32
		26	32	32	30	30
		28	32	32	30	30
		30	32	30	-	-
5.0	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
		30	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 33 tonnes

Table III- 15. Maximum payload (tonnes) – 7-axle – very low traction (snow/ice :traction coefficient 0.20)

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	10	60	60	60	60	1.5	10	10	60	60	60	60
		12	60	60	60	60			12	60	60	60	60
		14	60	60	60	60			14	60	60	60	60
		16	52	-	-	-			16	52	-	-	-
		18	-	-	-	-			18	-	-	-	-
0.5	13	14	60	60	60	60	1.5	13	14	60	60	60	60
		16	52	-	-	-			16	52	-	-	-
		18	-	-	-	-			18	-	-	-	-
0.5	15	16	50	-	-	-	1.5	15	16	48	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	10	10	60	60	60	60	5	10	10	60	60	60	60
		12	60	60	60	60			12	60	60	60	60
		14	60	60	60	60			14	60	60	60	60
		16	52	-	-	-			16	52	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	13	14	50	50	50	50	5	13	14	38	38	38	38
		16	46	-	-	-			16	34	-	-	-
		18	-	-	-	-			18	-	-	-	-
3	15	16	-	-	-	-	5	15	16	-	-	-	-
		18	-	-	-	-			18	-	-	-	-

Note : '-' indicates no safe payload for this application
Legal payload : 40 tonnes

Table III- 16. Maximum payload (tonnes) – 7-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	10	20	60	60	60	60
		22	60	60	60	60
		24	60	56	54	52
		26	50	-	-	-
		28	-	-	-	-
0.5	13	20	60	60	60	60
		22	60	60	60	60
		24	60	56	54	52
		26	50	-	-	-
		28	-	-	-	-
0.5	15	20	60	60	60	60
		22	60	60	60	60
		24	60	56	54	52
		26	-	-	-	-
		28	-	-	-	-
1.5	10	20	60	60	60	60
		22	60	60	60	60
		24	60	56	54	52
		26	50	-	-	-
		28	-	-	-	-
1.5	13	20	60	60	60	60
		22	60	58	56	56
		24	56	52	50	50
		26	50	-	-	-
		28	-	-	-	-
1.5	15	20	60	60	58	58
		22	60	56	54	54
		24	56	50	48	48
		26	-	-	-	-
		28	-	-	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	18	20	60	60	60	60
		22	60	60	60	60
		24	60	56	54	52
		26	-	-	-	-
		28	-	-	-	-
0.5	20	20	60	60	58	58
		22	60	60	58	58
		24	58	54	54	52
		26	-	-	-	-
		28	-	-	-	-
0.5	22	22	60	60	58	58
		24	56	54	52	52
		26	-	-	-	-
		28	-	-	-	-
0.5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	18	20	58	56	54	54
		22	54	52	50	50
		24	52	48	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	20	20	48	48	46	46
		22	46	44	42	42
		24	44	42	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	22	22	34	34	32	32
		24	34	32	-	-
		26	-	-	-	-
		28	-	-	-	-
1.5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 40 tonnes

Table III- 17. Maximum payload (tonnes) – 7-axle –low traction (loose gravel/wet hardpan :traction coefficient 0.30) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch (km)	Average grade prior to pitch (%)	Critical pitch grade (%)	Critical pitch length (m) 50	100	200	300
3.0	10	20	60	58	56	56
		22	58	54	52	52
		24	54	50	48	48
		26	-	-	-	-
		28	-	-	-	-
3.0	13	20	54	52	50	50
		22	52	50	48	48
		24	50	46	44	44
		26	-	-	-	-
		28	-	-	-	-
3.0	15	20	54	52	50	50
		22	52	50	48	48
		24	48	46	44	44
		26	-	-	-	-
		28	-	-	-	-
5	10	20	60	58	56	56
		22	58	54	52	52
		24	54	50	48	48
		26	-	-	-	-
		28	-	-	-	-
5	13	20	54	52	50	50
		22	52	50	48	48
		24	50	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	15	20	50	48	46	46
		22	48	46	44	44
		24	46	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Cummulative distance prior to pitch (km)	Average grade prior to pitch (%)	Critical pitch grade (%)	Critical pitch length (m) 50	100	200	300
3.0	18	20	28	28	28	28
		22	28	28	26	26
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
3.0	20	20	22	22	22	22
		22	22	22	20	20
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
3.0	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
3.0	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	18	20	20	20	20	20
		22	20	20	20	20
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	20	20	-	-	-	-
		22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	22	22	-	-	-	-
		24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-
5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : '-' indicates no safe payload for this application
Legal payload : 40 tonnes

Table III- 18. Maximum payload (tonnes) – 7-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
0.5	10	20	60	60	60	60	0.5	18	20	60	60	60	60
		22	60	60	60	60			22	60	60	60	60
		24	60	60	60	60			24	60	60	58	58
		26	58	56	56	56			26	56	54	54	54
		28	54	52	52	50			28	52	50	48	48
0.5	13	20	60	60	60	60	0.5	20	20	60	60	60	60
		22	60	60	60	60			22	60	60	60	60
		24	60	60	60	60			24	60	60	58	58
		26	58	56	56	56			26	56	54	54	54
		28	52	50	50	50			28	52	50	48	48
0.5	15	20	60	60	60	60	0.5	22	22	60	60	60	60
		22	60	60	60	60			24	60	60	58	58
		24	60	60	60	60			26	56	54	54	54
		26	58	56	54	54			28	52	50	48	48
		28	52	50	50	50	0.5	24	24	60	60	58	58
									26	56	54	54	54
									28	52	50	48	48
1.5	10	20	60	60	60	60	1.5	18	20	60	60	60	60
		22	60	60	60	60			22	60	56	56	56
		24	60	58	56	56			24	56	52	52	52
		26	56	54	52	52			26	52	50	48	48
		28	50	48	48	48			28	48	46	44	44
1.5	13	20	60	60	60	60	1.5	20	20	60	60	58	58
		22	60	58	56	56			22	58	56	54	54
		24	56	54	52	52			24	54	52	50	50
		26	52	50	48	48			26	50	50	48	48
		28	48	46	44	44			28	48	46	44	44
1.5	15	20	60	60	60	60	1.5	22	22	52	52	52	52
		22	60	56	56	56			24	50	50	48	48
		24	56	52	52	52			26	48	46	46	46
		26	52	50	48	48			28	46	44	42	42
		28	48	46	44	44	1.5	24	24	38	38	36	36
									26	36	36	34	34
									28	34	34	32	32

Note : Legal payload : 40 tonnes

Table III- 19. Maximum payload (tonnes) – 7-axle –moderate traction (compact gravel :traction coefficient 0.45) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	10	20	60	60	60	60
		22	60	56	56	56
		24	56	52	52	52
		26	52	50	48	48
		28	48	46	44	44
3.0	13	20	56	54	52	52
		22	54	52	50	50
		24	52	48	48	48
		26	48	46	44	44
		28	44	42	40	40
3.0	15	20	56	54	52	52
		22	54	52	50	50
		24	52	48	48	48
		26	48	46	44	44
		28	44	42	40	40
5	10	20	60	58	58	58
		22	58	56	56	54
		24	54	52	52	52
		26	52	50	48	48
		28	48	46	44	44
5	13	20	56	54	52	52
		22	54	52	50	50
		24	52	48	48	48
		26	48	46	44	44
		28	44	42	40	40
5	15	20	56	54	52	52
		22	54	52	50	50
		24	52	48	48	48
		26	48	46	44	44
		28	44	42	40	40

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
3.0	18	20	52	52	52	52
		22	50	50	50	50
		24	50	48	48	48
		26	48	46	44	44
		28	44	42	40	40
3.0	20	20	50	50	50	50
		22	48	48	48	48
		24	48	46	46	46
		26	46	44	44	44
		28	44	42	40	40
3.0	22	22	44	44	44	44
		24	42	42	42	42
		26	42	40	40	40
		28	40	40	38	38
3.0	24	24	24	24	24	24
		26	24	24	22	22
		28	24	22	20	20
5	18	20	52	52	50	50
		22	50	50	48	48
		24	48	48	46	46
		26	46	46	44	44
		28	44	42	40	40
5	20	20	46	46	46	46
		22	46	46	44	44
		24	44	44	42	42
		26	40	40	40	40
		28	40	40	38	38
5	22	22	40	40	40	40
		24	40	40	38	38
		26	38	38	36	36
		28	38	36	36	36
5	24	24	-	-	-	-
		26	-	-	-	-
		28	-	-	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 40 tonnes

Table III- 20. Maximum payload (tonnes) – 7-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents less than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	10	20	60	60	60	60
		22	60	60	60	60
		24	60	60	60	60
		26	60	56	56	56
		28	58	54	54	52
		30	52	48	-	-
0.5	13	20	60	60	60	60
		22	60	60	60	60
		24	60	60	60	60
		26	60	56	56	56
		28	58	54	54	52
		30	52	48	-	-
0.5	15	20	60	60	60	60
		22	60	60	60	60
		24	60	60	60	60
		26	60	56	54	54
		28	58	52	52	52
		30	52	48	-	-
0.5	26	26	56	56	54	54
		28	52	52	52	52
		30	48	48	-	-
1.5	10	20	60	60	60	60
		22	60	60	60	60
		24	60	60	58	58
		26	60	54	54	54
		28	56	52	52	50
		30	52	48	-	-
1.5	13	20	60	60	60	60
		22	60	60	58	58
		24	60	56	54	54
		26	56	52	52	52
		28	54	50	50	48
		30	50	46	-	-
1.5	15	20	60	60	60	60
		22	60	60	58	58
		24	60	56	54	54
		26	56	52	50	50
		28	54	50	50	48
		30	50	46	-	-
1.5	26	26	52	52	50	50
		28	50	50	50	48
		30	48	46	-	-

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300
0.5	18	20	60	60	60	60
		22	60	60	60	60
		24	60	60	58	58
		26	58	56	54	54
		28	58	52	52	52
		30	52	48	-	-
0.5	20	20	60	60	60	60
		22	60	60	60	60
		24	60	60	58	58
		26	58	56	54	54
		28	56	52	52	52
		30	52	48	-	-
0.5	22	22	60	60	60	60
		24	60	60	58	58
		26	58	56	54	54
		28	54	52	52	52
		30	50	48	-	-
0.5	24	24	60	60	58	58
		26	56	56	54	54
		28	52	52	52	52
		30	48	48	-	-
0.5	28	28	50	50	50	50
		30	48	48	-	-
1.5	18	20	60	60	60	60
		22	60	60	58	58
		24	60	56	54	54
		26	56	52	50	50
		28	54	50	50	48
		30	50	46	-	-
1.5	20	20	60	60	60	60
		22	60	60	58	58
		24	60	56	54	54
		26	56	52	50	50
		28	54	50	50	48
		30	50	46	-	-
1.5	22	22	60	60	58	58
		24	60	56	54	54
		26	56	52	50	50
		28	54	50	50	48
		30	50	46	-	-
1.5	24	24	56	56	54	54
		26	54	52	50	50
		28	52	50	50	48
		30	48	46	-	-
1.5	28	28	40	40	40	40
		30	38	38	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 40 tonnes

Table III- 21. Maximum payload (tonnes) – 7-axle –high traction (smooth compact gravel :traction coefficient 0.60) for descents greater than 1.5 kilometers

Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)				Cummulative distance prior to pitch	Average grade prior to pitch	Critical pitch grade	Critical pitch length (m)			
(km)	(%)	(%)	50	100	200	300	(km)	(%)	(%)	50	100	200	300
3.0	10	20	60	60	60	60	3.0	18	20	60	60	60	60
		22	60	60	60	60			22	60	60	58	58
		24	60	56	56	56			24	60	56	54	54
		26	58	52	52	52			26	56	52	50	50
		28	56	50	50	50			28	54	50	50	48
		30	52	48	-	-			30	50	46	-	-
3.0	13	20	60	60	60	60	3.0	20	20	60	60	60	60
		22	60	60	60	60			22	60	60	58	58
		24	60	56	56	56			24	60	56	54	54
		26	58	52	52	52			26	56	52	50	50
		28	54	50	50	50			28	54	50	50	48
		30	52	48	-	-			30	50	46	-	-
3.0	15	20	60	60	60	60	3.0	22	22	58	58	58	58
		22	60	60	60	60			24	56	56	54	54
		24	60	56	56	56			26	54	52	50	50
		26	56	52	52	52			28	54	50	50	48
		28	54	50	50	50			30	50	46	-	-
		30	50	46	-	-	3.0	24	24	52	52	52	52
3.0	26	26	46	46	46	46			26	50	50	48	48
		28	46	46	44	44			28	50	48	48	48
		30	44	44	-	-			30	48	46	-	-
5.0	10	20	60	60	60	60	5.0	18	20	60	60	60	60
		22	60	60	60	60			22	60	60	58	58
		24	60	56	56	56			24	60	56	54	54
		26	58	52	52	52			26	56	52	50	50
		28	56	50	50	50			28	54	50	50	48
		30	52	48	-	-			30	50	46	-	-
5.0	13	20	60	60	60	60	5.0	20	20	60	60	60	60
		22	60	60	60	60			22	60	60	58	58
		24	60	56	56	56			24	58	56	54	54
		26	58	52	52	52			26	56	52	50	50
		28	54	50	50	50			28	54	50	50	48
		30	52	48	-	-			30	50	46	-	-
5.0	15	20	60	60	60	60	5.0	22	22	54	56	54	54
		22	60	60	60	60			24	54	54	52	52
		24	60	56	56	56			26	52	52	50	50
		26	56	52	52	52			28	52	50	50	48
		28	54	50	50	50			30	50	46	-	-
		30	50	46	-	-	5.0	24	24	50	50	48	48
									26	48	48	46	46
									28	48	46	46	46
									30	46	44	-	-

Note : ‘-‘ indicates no safe payload for this application
Legal payload : 40 tonnes