TRAFFIC ABILITY OF HEAVY VEHICLES ON AN INCLINE

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ABSTRACT

Traffic ability of heavy vehicles on steep hills is of great concern in Norway due to its geography, which is characterized by many mountain passes and inclines. Vehicles stopping in the roadway are a significant problem on many roads in winter time, and this has led the Norwegian Public Roads Administration to implement a project that begins to examine what factors influence the ability of trucks to keep moving under poor driving conditions during the winter season.

Four vehicles with different axle configurations were used in the experiments carried out in February 2009:

1. Bogie truck with 3-axled trailer
2. Semi-trailer with bogie and 3-axled trailer
3. Semi-trailer without bogie, and 3-axled trailer
4. Pusher truck with bogie and 3-axled trailer

The experiments included the following configurations for vehicles 1-3:

- Vehicle and trailer without cargo
- 10 tonnes of cargo
- 20 tonnes of cargo
- With and without use of bogie (vehicles 1 and 2)

The results show that the weight on the driving wheels is decisive with regard to whether the vehicle is able to reach the top of the gradient or not. The tests also demonstrate clearly the great advantage of having a vehicle with bogie. Raising the bogie significantly increases the weight on the driving wheels, and this makes it easier to maintain speed up the gradient. Often it is an advantage to increase the pressure of an axle beyond 10 tonnes, which is the limit on many Norwegian roads.

1. INTRODUCTION

1.1. Background

Traffic ability of heavy vehicles on steep hills is of great concern in Norway due to its geography, which is characterized by many mountain passes and inclines. Vehicles stopping in the roadway are a significant problem on many roads in winter time, and this has led the Norwegian Public Roads Administration to implement a project that begins to examine what factors influence the ability of trucks to keep moving under poor driving conditions during the winter season.

Traffic ability of heavy vehicles is a key issue in the R&D project “Inner Romsdal” [1] and the issue of heavy vehicles on mountain passes was one of the main reasons why the project was initiated. This is also the reason why the district of Nord Møre og Romsdal has taken the initiative to carry out experiments with heavy vehicles on an incline to study in more detail the challenges in relation to different vehicle configurations.

To illustrate the extent of heavy traffic, Figure 1 shows the traffic variation over one day at a traffic recording point on the E136 near Horgheim in Romsdalen. On this particular Wednesday in February 2009, a total of 409 heavy vehicles were recorded in both directions, which constitutes 44 per cent of the total daily traffic. Heavy vehicles are defined as vehicles with a length equal to or greater than 5.6 metres, and are thus a group of vehicles that are not exclusively made up of trucks and trailers.

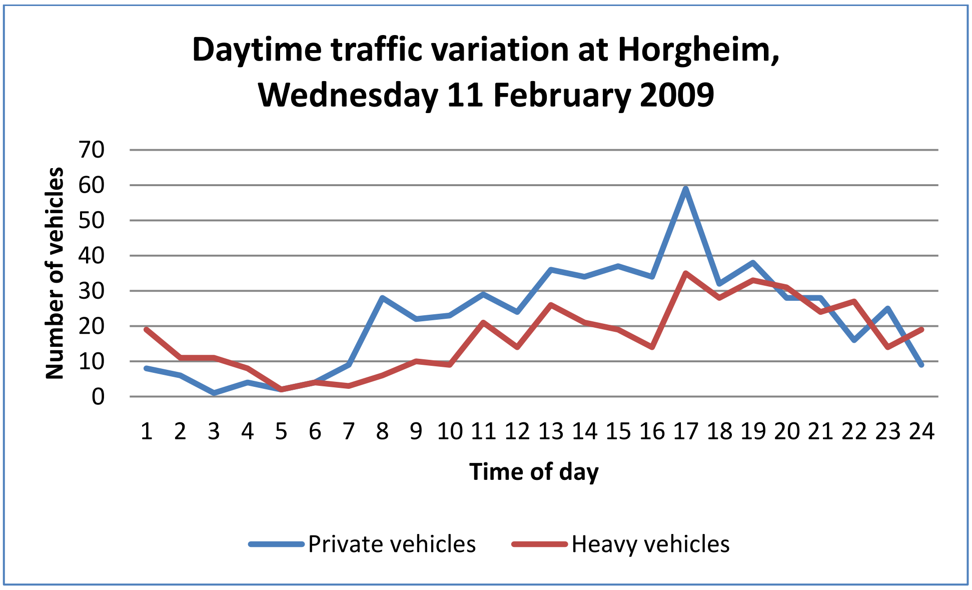

Figure 1 - Daytime traffic variation at Horgheim

2. DESIGN OF THE STUDY

2.1. Study area

As part of the project experiments have been conducted on heavy vehicles on a gradient near Vestnes in Møre og Romsdal County in Mid-Norway. The aim of this sub-project [2] has been to study the traffic flow quality for heavy vehicles on gradients in winter road conditions. Four vehicles with different axle configurations were used in the experiments carried out in February 2009:

A. Bogie truck with 3-axled trailer
B. Semi-trailer with bogie and 3-axled trailer
C. Semi-trailer without bogie, and 3-axled trailer
D. Pusher truck with bogie and 3-axled trailer

The experiments included the following configurations for vehicles 1-3:

- Vehicle and trailer without cargo
- 10 tonnes of cargo
- 20 tonnes of cargo
- With and without use of bogie (vehicles 1 and 2)

Vehicle 4 was only tested with 20 tonnes of cargo and without bogie. The experiments were mainly carried out on compact snow partly covered with some loose snow.

During a field test of this kind it is important to have appropriate test conditions that maintain safety standards and the incline at Heggelia near Vestnes was found to be a suitable place for carrying out the experiments. Heggelia, which is the steepest road section between Oslo and Ålesund, is closed during difficult periods in the winter. It is therefore easy to use this section of road for controlled experiments with trucks.

Figure 2 - Test area

Figure 2 provides an overview of the test area with the diversion option via the E39. Figure **3** provides an overview of the test section and identifies various parts of the route. From km 18,017 to km 18,604 there is a height difference of 42 metres. This represents an incline of 7.2 per cent. As can be seen from the profile in Figure 4, there is a fairly steady increase in the incline, but it is somewhat flatter for the first 150 metres (6.3 per cent).

Figure 3 - Overview of the test section at Heggelia

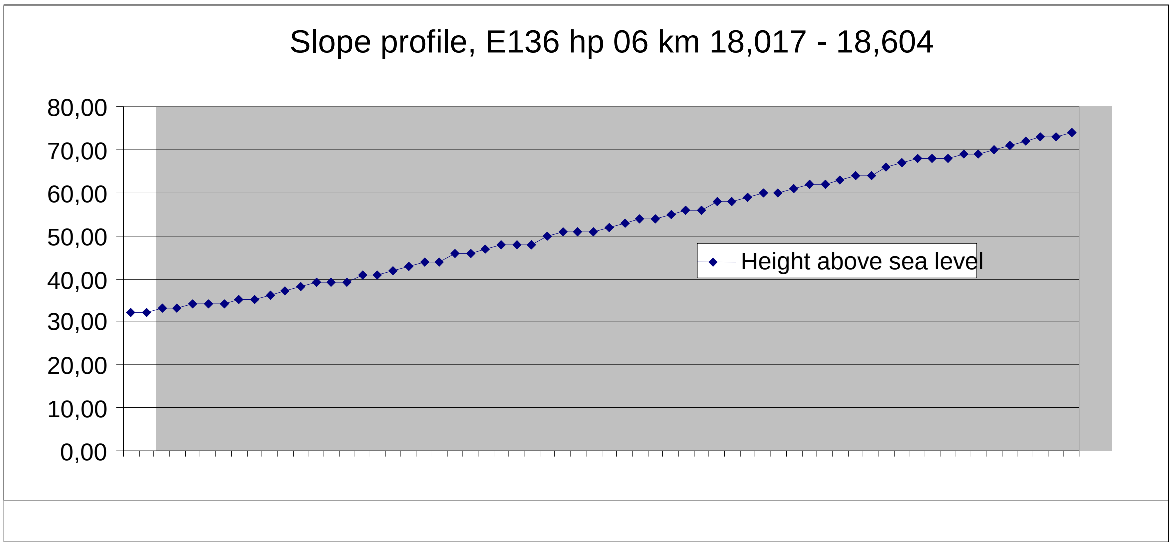

Figure 4 - Slope profile at Heggelia

The starting point of Heggelia is visible to the left of the image in Figure 5. The test section was closed to other traffic during the experiments, and security was ensured through manual traffic routing in addition to the signs.

Figure 5 - The starting point on the test road can been seen to the left

Figure 6 shows the vehicles included in the experiment, and Table 1 shows the load distribution without cargo and loaded with 10 and 20 tonnes respectively.

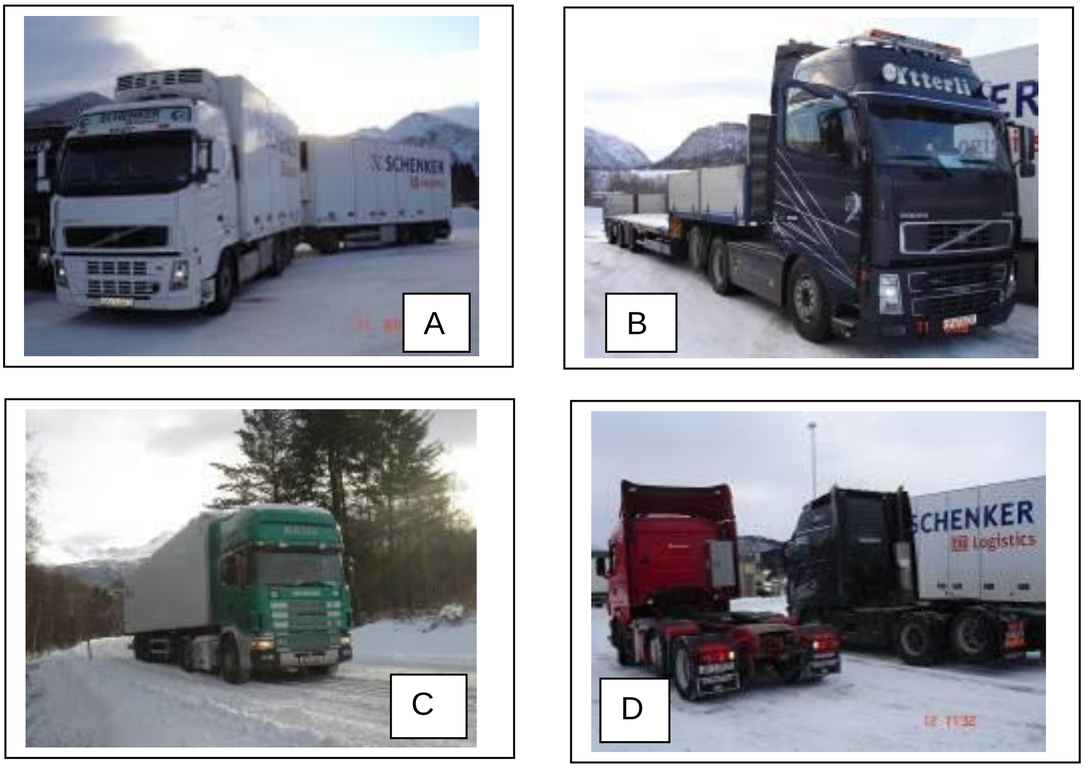

Figure 6 - Vehicles included in the experiment

Table 1 - Load distribution in kg without cargo and loaded with 20 tonnes

Load, use of bogie, Truck A, 460 HP	**Tractor**			**Trailer**			**Gross weight**		
	Axle weight			Axle weight			Load distribution on units		
	Front	Rear 1	Rear 2	Axle 1	Axle 2	Axle 3	Tractor	Trailer	Vehicle combination
0 tonnes									
Bogie down	6 050	4 750	2 400	4 600		4 600	13 050	9 200	22 250
Bogie up	5 300	7 750		4 600		4 600	13 050	9 200	22 250
10 tonnes									
Bogie down	7 600	6 300	4 050	7 700		7 000	17 950	14 700	32 650
Bogie up	6 400	10 900		7 700		7 000	17 950	14 700	32 650
20 tonnes									
Bogie down	8 000	9 500	6 600	9 600	4 950	5 150	24 100	19 700	43 800
Bogie up	5 900	17 800		9 600	4 950	5 150	24 100	19 700	43 800

Load, use of bogie, Truck B, 550 HP	**Tractor**			**Trailer**			**Gross weight**		
	Axle weight			Axle weight			Load distribution on units		
	Front	Rear 1	Rear 2	Axle 1	Axle 2	Axle 3	Tractor	Trailer	Vehicle combination
0 tonnes									
Bogie down	6 500	5 110	2 200	2 450	2 450	2 550	13 810	7 450	21 260
Bogie up	5 550	8 100			3 810	3 800	13 650	7 610	21 260
10 tonnes									
Bogie down	7 000	7 100	3 800	4 150	4 050	4 100	17 900	12 300	30 200
Bogie up	5 450	12 250		4 200	4 100	4 200	17 700	12 500	30 200
20 tonnes									
Bogie down	7 500	8 100	4 750	6 300	6 350	6 450	20 350	19 100	39 450
Bogie up	5 450	14 900		6 300	6 350	6 450	20 350	19 100	39 450
Bogie partially up	5 450	16 550			8 700	8 750	22 000	17 450	39 450

Load, use of bogie, Truck C, 530 HP	**Tractor**			**Trailer**			**Gross weight**		
	Axle weight			Axle weight			Load distribution on units		
	Front	Rear 1	Rear 2	Axle 1	Axle 2	Axle 3	Tractor	Trailer	Vehicle combination
0 tonnes									
No bogie	6 850	5 350	-	-	-	-	12 200	7 850	20 050
10 tonnes									
No bogie	7 500	9 000	-	-	-	-	16 500	12 850	29 350
20 tonnes									
No bogie	8 000	11 700	-	6 900	6 850	6 600	19 700	20 350	40 050

Load, use of pusher function, Truck D, 400 HP	**Tractor**			**Trailer**			**Gross weight**		
	Axle weight			Axle weight			Load distribution on units		
	Front	Rear 1	Rear 2	Axle 1	Axle 2	Axle 3	Tractor	Trailer	Vehicle combination
20 tonnes									
Pusher up	-	8 000	-	6 300	6 350	6 450	-	19 100	-
Pusher down	-	11 700		6 300	6 350	6 450		19 100	

On the second day, the tyres were changed on the drive wheels on truck C. The original tyres were fairly worn Norwegian winter tyres with a shore value of 64, see Figure 7. The tyres that were mounted were “foreign” crunched tyres with a shore value of 72 and with good tread depth, see Figure 8.

Figure 7 - Norwegian winter tyre. Shore value: 64

Figure 8 - “Foreign” crunched tyre. Shore value: 72

2.2. Registration of the speed profile

All vehicles were equipped with a GPS unit that was set up to log position twice a second. The signals from the GPS device were transmitted wirelessly to a PDA that acted as a data logger. The records provided a detailed speed profile over the test section.

2.3. Weighing procedures

All weighing was carried out by personnel from the road users and vehicles department (TK) using mobile scales. The set-up for weighing with mobile scales is shown in Figure 9. This is a flexible weighing system which gives detailed weights for all axles on both the tractor and trailer.

Figure 9 - Set-up for weighing with mobile scales

2.4. Friction measurements

Measurements of type TWO (Traction Watcher One) were used for friction measurements, see Figure **10**. The friction measurements were run simultaneously with two trailers of the same type each day.

Figure 10 - Friction measurement with the type TWO friction trailer

3. RESULTS

3.1. Driving conditions

Figure 11 shows how the situation looked on the morning of 11 February. There was a large quantity of loose snow of a consistency that was clearly influenced by residual salt from the salting that was carried out before a major snowfall a few days earlier.

Figure 11 - Driving conditions on the morning of 11 February 2009

Figure 12 and Figure 13 show the average friction from the individual measurements that were made on the two test days. The friction value is based on the average of all the measurements on a 600 m long stretch from the start of the climb at km 18.0 and past the curve at km 18.6. The friction values presented are the average of the values of both friction trailers. Temperature data were obtained from one of the measuring vehicles.

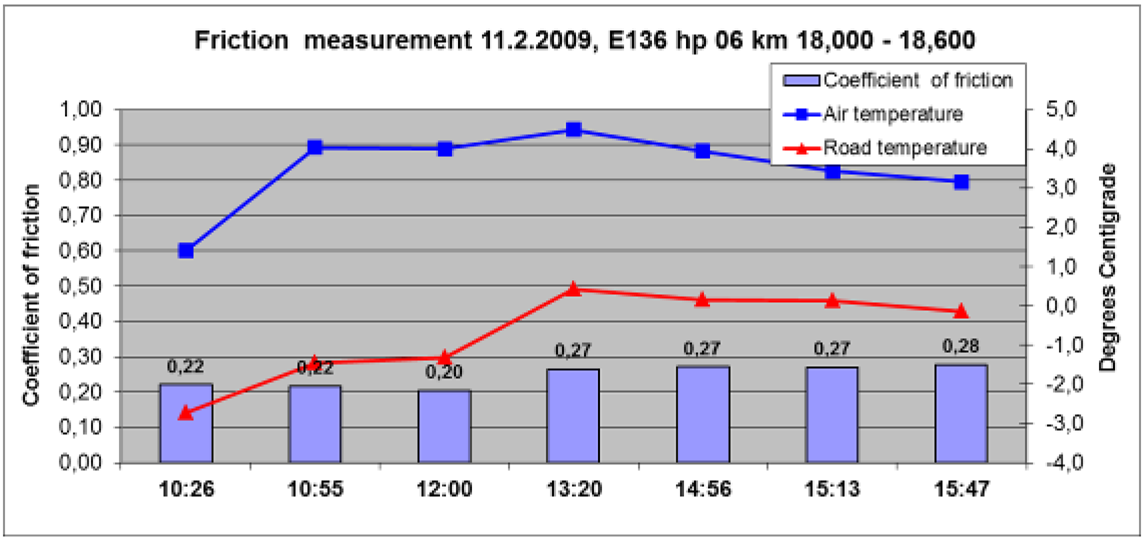

Figure 12 - Mean value for the coefficient of friction on the test section 11.2.2009

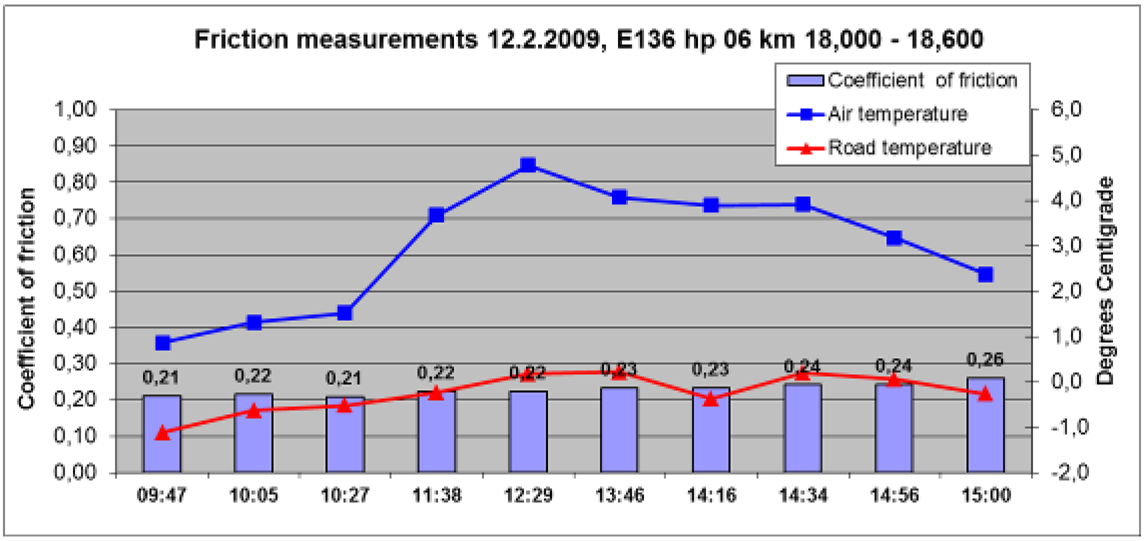

Figure 13 - Mean value for the coefficient of friction on the test section 12.2.2009

A marked change is evident in the friction level between 12:00 and 1:20 p.m. the first day of the experiment, and this seems to be clearly associated with a treatment (grading) of the snow-cover to create a more compact surface. Also the change in friction conditions on the second day of the experiment can be explained by a mechanical treatment of the snow and ice surface.

3.2. Driving tests, both days combined

Figure 14 - Figure 18 compile the results from ordinary driving without provoking a stop for the three main units that participated in the experiments. The main results show that:

3.2.1. Trucks with bogie

- With the bogie up, there were no significant problems in driving without stopping, and the amount of load had no significant impact on accessibility
- With the bogie down, both vehicles stopped on the rise regardless of whether they were loaded with cargo or not

- For trucks with bogies, the vehicle with the lowest engine power had greater problems than that with the highest engine power in that the stoppage generally occurred further down the incline, to the vehicle with the weakest engine
- With no load it did not help to raise the bogie, and both trucks with bogie needed towing assistance to get up the incline
- With both 10 and 20 tonnes of cargo it was sufficient to raise the bogie to start up after stopping

3.2.2. Semi-trailer without bogie

- With no load and a starting speed of 40 km/h the truck without bogie did not manage to drive up the incline without stopping. 50 km/h was sufficient for it to drive up the incline without stopping.
- The truck without bogie had no problems driving up the incline with 10 and 20 tonnes of cargo.

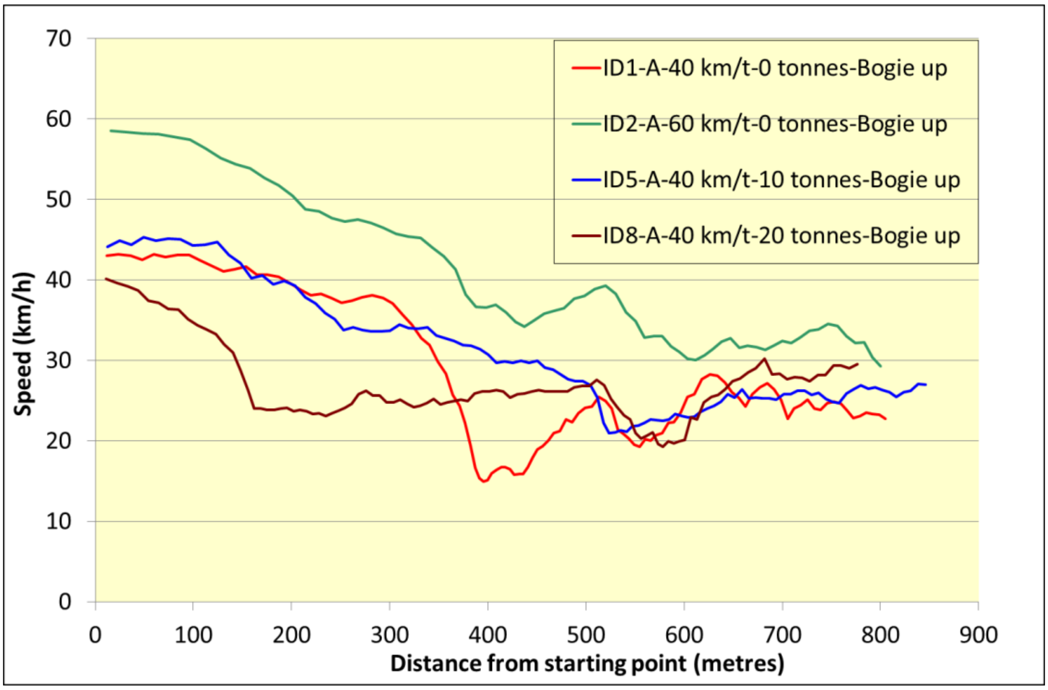

Figure 14 - Truck A, truck with bogie and trailer with different loads, bogie up

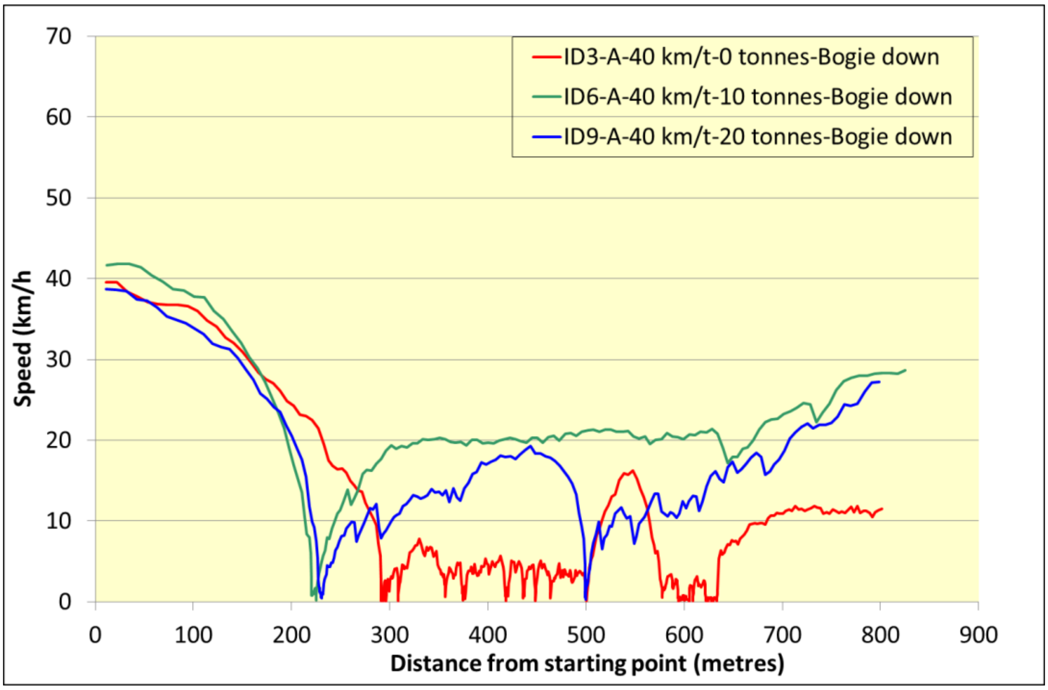

Figure 15 - Truck A, truck with bogie and trailer with different loads, bogie down

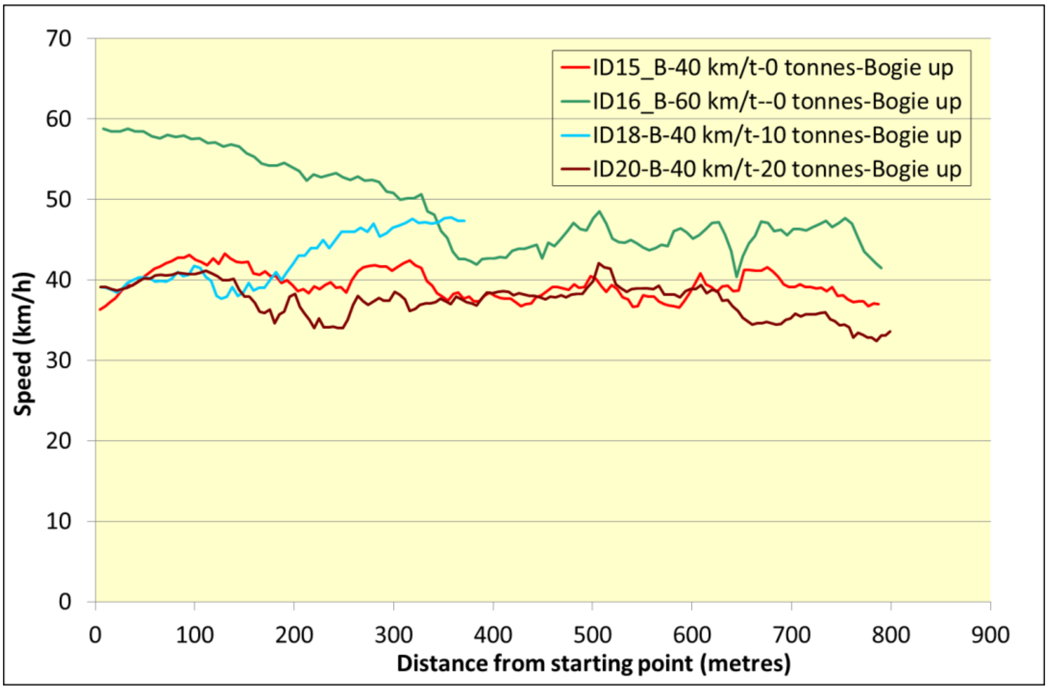

Figure 16 - Truck B, truck with bogie and trailer with different loads, bogie up

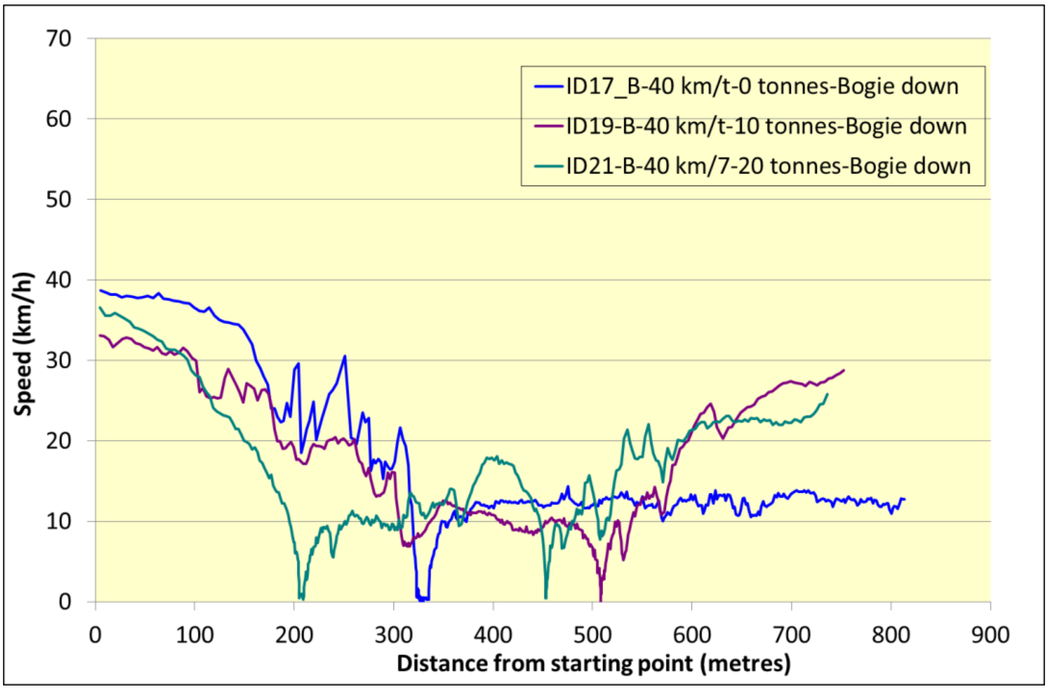

Figure 17 - Truck B, truck with bogie and trailer with different loads, bogie down

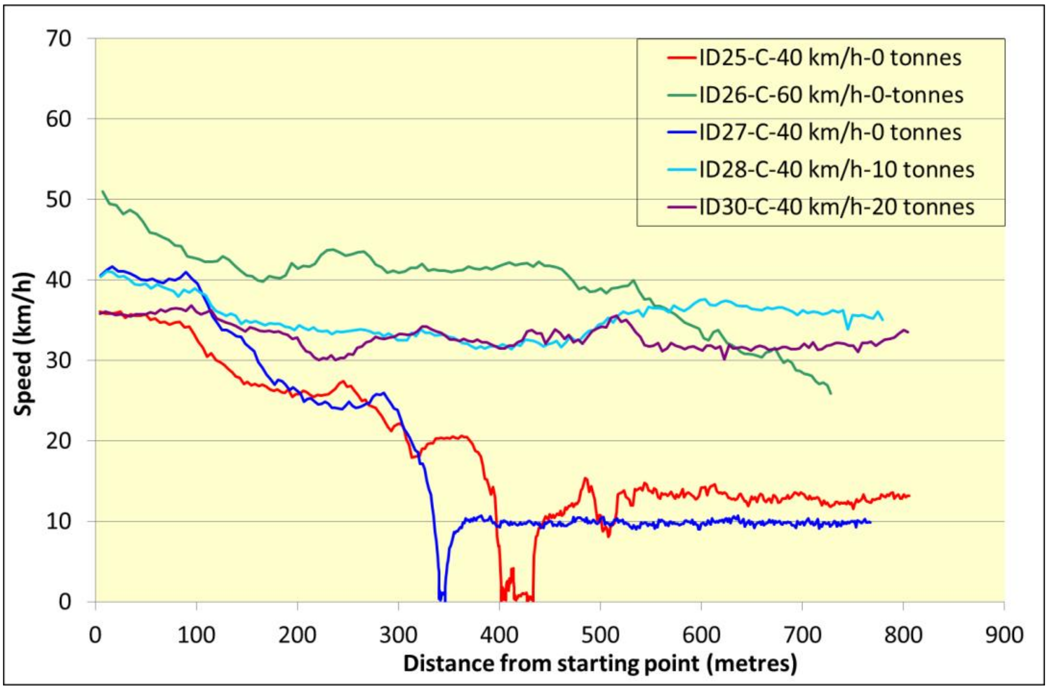

Figure 18 - Truck C, semi-trailer without bogie and different loads

4. CONCLUSIONS

The results from the experiments show that the weight on the driving wheels determines whether the vehicle is able to reach the top of the gradient or not. The tests also demonstrate clearly the advantage of having a vehicle with bogie. By lifting the bogie, the weight on the driving wheels is significantly increased, and this makes it easier to maintain speed when ascending the gradient. Often it is beneficial to increase the pressure of an axle beyond 10 tonnes, which is the limit on many Norwegian roads.

The experiments show that the properties of the tyres are important. Tyres made from hard rubber (high shore value) reduce the possibility to maintain speed when ascending the gradient compared with ordinary tyres.

As expected, the relationship between the power of the engine and the total weight of the vehicle can be significant. Vehicles with a high ratio of engine power to total weight have the highest speed when ascending the gradient. However, if the weight on the driving wheels is relatively low, the power of the engine has no or limited importance.

Semi-trailer without bogie is a common vehicle type among foreign trucks on Norwegian roads. With little or no cargo these vehicles often have problems on gradients during winter conditions. The problems are increased by using tyres made from hard rubber.

The results of the experiments are not surprising, but they document how different factors influence traffic flow quality for heavy vehicles on gradients during winter road conditions. To illustrate the problems for heavy vehicles more broadly, further experiments need to be conducted under different road conditions, with more tyre combinations and including the use of snow chains.

The results of the experiments show that the weight on the drive wheels has a significant and decisive impact on the ability to drive up a steep hill. The experiments also demonstrate quite clearly that it can be very advantageous to have a bogie on the tractor. In this way the weight on the drive wheels can be substantially increased, and thus significantly better traction can be achieved. Often it will also be advantageous to increase the axle pressure beyond the 10 tonnes which is the limit permissible.

The experiments also show that choice of tyre could affect the vehicle's traction qualities. Hard tyres have poorer performance than regular tyres. Although few runs were made with the hard tyres, it was shown that tyre choice had an impact on whether they managed to start moving after the imposed stop on the rise. It also appears that a friction of 0.25 is sufficient to reduce the problem of hard tyres in relation to traffic flow on inclines.

The test at Heggelia confirms that vehicle configuration is decisive with regard to accessibility for truck trailers on inclines. Single-axle semi-trailer, which is a common foreign truck type, depends on load in order to drive up an incline like Heggelia. Empty vehicles of that type are not able to start moving again after shutdown. The problem is amplified by the fact that the tyres on those vehicles will normally be of the crunched type and with high shore value.

To illustrate the magnitude of the problem of traffic ability of trucks on inclines, one can use the number of car rescue actions as an indicator. A total of approximately 1000 rescue actions are carried out every winter season in Norway to assist trucks which has stopped on an incline.

It can be mentioned that there are taken an initiative to warn drivers about difficult driving conditions on inclines. This will be linked to dynamic signage at the chain places and will hopefully reduce the problem for trucks on inclines.

5. FURTHER STUDIES TO BE CARRIED OUT

The results of the experiments are not surprising, but they document how different factors influence traffic flow quality for heavy vehicles on gradients during winter road conditions. To illustrate the problems for heavy vehicles more broadly, further experiments need to be conducted under different road conditions, with more tyre combinations and including the use of snow chains.

A truck with bogie is completely dependent on being able to lift the suspension to take it up an incline such as that at Heggelia. With the load over a certain weight and full lifting of suspension, this would violate the regulation regarding axle load. The experiments at Heggelia suggest that it is not necessary to run at full speed on the suspension, but how much pressure can be reduced without compromising accessibility needs to be investigated.

It is also desirable to conduct further testing including several different tyre combinations, and to study the effects of using chains.

The tires were not run hot during the tests at Heggelia, so there was no melting effect and the subsequent sliding that usually occurs when stopping on a snow-covered incline. It the tests are to be repeated, they should therefore also include tests using warm tyres.

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