SIDE FRICTION AS A PARAMETER TO OPTIMIZE WINTER OPERATIONS

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ABSTRACT

When measuring the coefficient of friction it is normally focus on friction in the driving direction, i.e. the friction available for stopping a vehicle presuming that all the measured friction can be used for braking. This is however not true when driving in curves where a component of the friction is used to counteract the centrifugal force. The size of this component will depend on the speed, radius and super elevation. It is well known relations between these parameters and the resulting friction available for braking, but it has till now not been possible directly to measure this side friction component. This is however now an option with the friction device of the type Traction Watcher One (TWO) which is a continuous measuring device. A new sensor has been developed combining both gyro and accelerometer. The sensor is placed horizontally in the measuring vehicle and registers both side forces on the vehicle and the angular deflection. Knowing the speed of the vehicle, the radius can be derived from these data and this is furthermore bases for calculation of what is denoted “critical speed”.

The new measuring principle will add important information about the available road grip. At locations where the critical speed is low when driving on winter conditions, this can be compensated by tougher demand for measures to be carried out and reinforced operational effort. Another option will be to give information to the drivers on where and when they should be especially aware of a low safety margin when they exceed a certain speed.

KEYWORDS

FRICTION / SIDE FORCES / SPEED / WINTER MAINTENANCE

1. INTRODUCTION

1.1. Background

One main challenge from a traffic safety point of view is to keep the risk for skidding below a certain threshold value under varying driving conditions. The side friction factor at which skidding can happen depends on several factors, among which the most important are the speed of the vehicle, the type and conditions of the tyres, the type and conditions of the roadway surface, and the horizontal curvature.

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The new sensor has been going through extensive testing the winter season 2008/2009. So far promising results are achieved with regards to getting reliable data. Increased knowledge of how side forces in curves influence the vehicle are important information for the drivers, but also for the dimensioning and construction of roads and need for measures to maintain a certain safety level to counteract the risk for exceeding a critical speed. The problem is that many drivers do not adapt their speed to the prevailing driving conditions and thereby drive with very low safety margin especially in curves.

1.2. Purpose

The new measuring principle will add important information about the available road grip. At locations where the critical speed is low when driving on winter conditions, this can be compensated by tougher demand for measures to be carried out and reinforced operational effort. Another option will be to give information to the drivers on where and when they should be especially aware of a low safety margin when they exceed a certain speed.

One of the main purposes with the approach regarding registration of critical speed is to support the needs for a more adequate decision support in the winter maintenance operations to meet the standard requirements where side friction is included as a parameter.

With more detailed data about the impact of the geometry it will be possible to link operations to the actual safe speed. This can help to assure more predictable road conditions to the drivers. This can be done by taking into account the influence of the side forces in the calculation of the necessary friction improvement to maintain a certain safe margin with regards to the friction. This will especially be valid for roads where sand is used as the main friction improvement measure.

There is a need to increase awareness of how driving in curves influence on the safety margin to avoid that there is a slip due to the fact that the side forces exceed the available road grip. It is mainly a question of compensating more friction changes in curves than on straight segments.

2. FRICTION THEORY

The friction influences on the ability to stop a vehicle (braking), to start a vehicle moving (acceleration), and to manoeuvre (turning) the vehicle. Under low friction conditions, all three abilities are influenced, thus reducing safety.

When a vehicle goes around a curve, it experiences a lateral force known as centrifugal force. This lateral force pushes the vehicle and occupants outward from centre of the circle. The lateral force is caused by the directional change of the vehicle (i.e., directional change of the velocity vector) called centripetal acceleration. This is similar to the acceleration forces from increasing vehicle speed, with the exception that the acceleration is towards the centre of the circle [2].

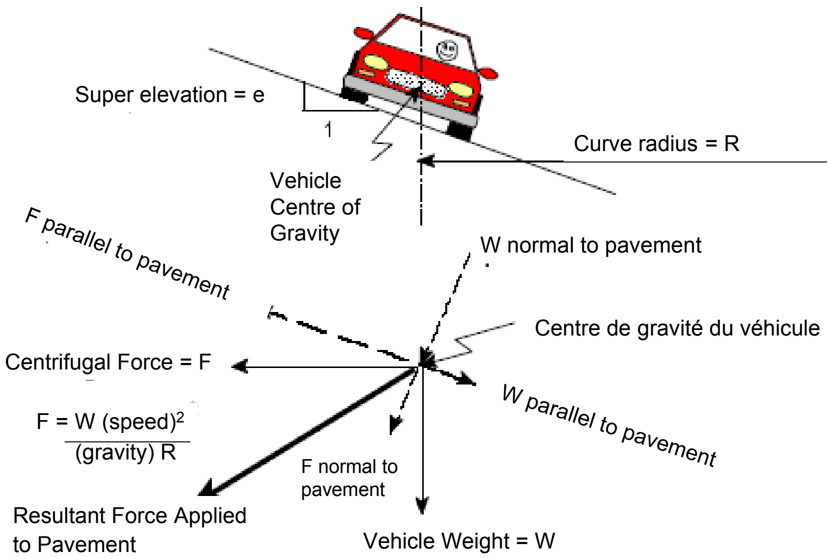

Figure 1 – Forces acting on a vehicle traversing a horizontal curve [2]

Super elevation is defined as the amount of cross slope provided on a horizontal curve to help counterbalance the outward pull of a vehicle traversing the curve.

Super elevation is the banking (rotation) of a highway to counter some of the lateral force [2]. The banking causes a portion of the lateral acceleration to act normal (perpendicular) to the banked pavement. This is felt as a downward (with respect to the vehicle) force by the vehicle occupants. The remaining portion of the lateral force may act one of three ways depending on the banking and speed of the vehicle.

- If the speed is balanced for the banking, the lateral force acting outward on the vehicle will be countered by the forces pushing the vehicle down the slope of the banking. The vehicle and occupants will experience a downward force (perpendicular to the roadway) and the vehicle will travel around the curve with little steering input. This is a neutral or equilibrium condition.

- If the vehicle is travelling faster than the equilibrium speed, the resultant lateral force acts outward on the vehicle and occupants. At excessive speeds, the vehicle will skid or rolls off the road.
- If the speed is lower than the equilibrium speed, the vehicle and occupants are forced inward. Extreme banking can cause top heavy vehicles to rollover towards the inside of the curve. Additionally, icy conditions can cause the vehicle to slide down the banking, particularly when the tires are spinning to accelerate in stop and go traffic.

High levels of super elevation may cause slow moving vehicles to slide down the banking on a snow and ice covered surface, so there is normally set a maximum super elevation rate of 6-8% in areas that frequent experience snow and ice [2].

Friction allows cornering, braking, and acceleration forces to be transmitted from the tires to the pavement. Rather than using the "coefficient of friction" from dynamics, highway engineers use a ratio of the lateral forces that the pavement can resist. This lateral ratio is most commonly referred to as the "friction factor."

The friction factor to counter centrifugal forces is reduced by vehicle braking (decelerating) and accelerating. For example, when most of the friction is used for a panic stop, there is little friction available for cornering. Antilock Braking Systems (ABS) has greatly improved this aspect.

The friction factor also depends on numerous variables, including the vehicle speed, weight, suspension, tire condition (wear, tire pressure, tire temperature), tire design (tread, contact patch, rubber compound, sidewall stiffness), pavement, and any substance between the tire and pavement. Since the friction factor decreases as speed increases, numerous studies have been performed to develop friction factors for various speeds. Note that the friction factor diminishes substantially when the tires are spinning faster or slower than the vehicle speed (e.g., in a skid, spinning tires when attempting to accelerate or stop on ice, and during a "burn out" or "peel-out"). [2].

The simplest and most natural method for determining the friction number is to measure the braking distance to full stop for a vehicle with locked wheels during braking. The coefficient of friction is determined from Equation 1.

$$\mu = \frac{v^2}{2 \times 9.81 \times d}$$

Equation 1 – Calculation of friction number

where v is the vehicle brake application speed, g is the acceleration of gravity, and d is the stopping distance.

Traditionally side friction has been included as a component in the design of roads. I.e. when putting up dimensioning criteria, it is taken into account that the available friction in curves has to be reduced to compensate for the fact that some of the road grip is used to counteract the side forces. This can be illustrated as shown in Figure 2.

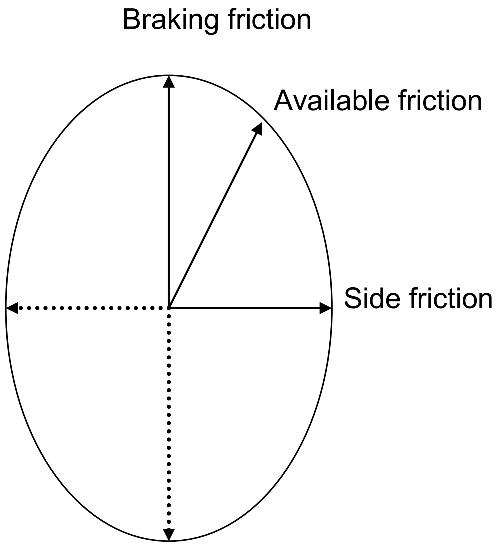

Figure 2 – The connection between side friction and braking friction

According to [4] there is the following physical connection between utilized friction figure and curve speed, see Equation 2:

$$v^2 = R \times \mu \times 9.81 \times 3.6^2$$

Equation 2 – Connection between utilized friction and curve speed

Where V is speed in km/h, R is curve radius and μ is the friction figure. In the tables below is shown the connection between V and μ for R = 100 metres.

Table 1 – Maximum speed for different friction figures at a curve radius of 100 m

Friction figure	0,05	0,10	0,125	0,15	0,175	0,20	0,225	0,25	0,30
Maxiumum speed km/h	25,2	35,7	39,9	43,7	47,2	50,4	53,5	56,4	61,8

The relation between design speed and curvature and also the relation with superelevation and side friction can be represented by Equation 3 according to the AASHTO Design Policy [1].

$$R_{\min} = \frac{V^P}{127(f_{R,perm} + e_{\max})}$$

R_{min}	= Radius of horizontal curve (m)
V	= speed (usually design speed) (km/h)
fR, perm	= permissible side friction factor
emax	= maximum super elevation rate (%/100)

Equation 3 – Relation between design speed, curvature, super elevation and side friction

3. CALCULATION OF CRITICAL SPEED

In the TWO program the critical speed is calculated in two separate ways. This results in different set of values and the lowest speed is the valid speed to determine the critical speed at any time.

The following formula is used to convert friction and braking length to critical speed:

$$v = \sqrt{254.3 \times \mu \times Lb}$$

Where μ=friction and Lb=Braking length (m)

Equation 4 – Calculation of critical speed from friction and braking length

In the TWO program μ is measured while Lb can be chosen by the user.

Converting of friction and curve radius to speed v [km/h]:

$$v = 3.6 \times \sqrt{9.81 \times \mu \times r}$$

Equation 5 – Calculation of speed from friction and curve radius

Where r = curve radius calculated from measured acceleration (centrifugal force) and the speed of the vehicle as shown in Equation 6.

$$r = \frac{\left(\frac{v}{3.6}\right)^2}{a}$$

Equation 6 – Calculation of curve radius

By calculating the critical speed both from Equation 4 and Equation 5 and state the lowest value of those two, one gets the “worst case” speeds.

One main objective by including side friction forces in the friction measuring routines is that this can be important information both to the road users and the road owners and contractors. During slippery conditions this can be an important tool especially as a support to assess the need for actions to improve the friction at critical parts of the road network.

This will also bring knowledge about the correlation between friction and critical speed to maintain a certain level of safety when driving in curves. This type of knowledge can also be used to set criteria for dimensioning new roads. If the speed limit is set, it is possible to calculate the minimum curvature that is safe in the spectre one can have of road conditions.

4. EXAMPLES OF MEASURING RESULTS

There has been made measurements with the new sensor the winter season 2008/2009 as a part of the project “FoU Indre Romsdal” [5], and in the following is shown some examples of what results the new measuring principle gives.

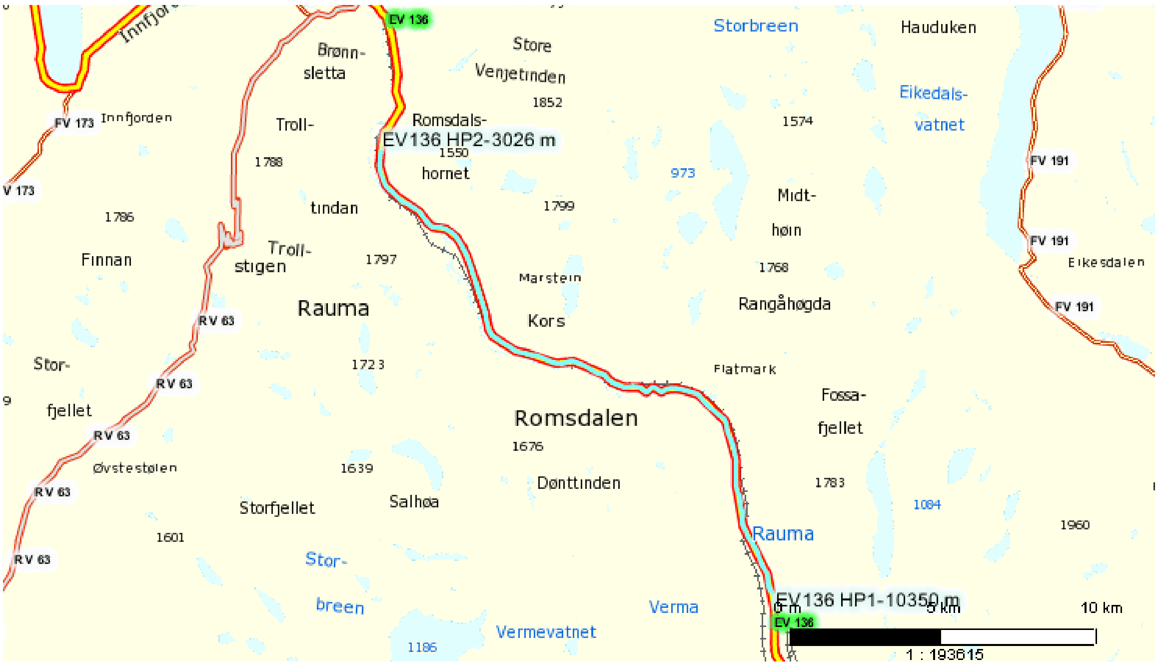

Figure 3 – Road section 5, Sæterbø - Trollveggen

The example is from road section 5 in a follow up study of the winter standard on the trunk road E136 in Romsdalen [5], see Figure 3. This road section has some sharp bends as shown in Figure 4.

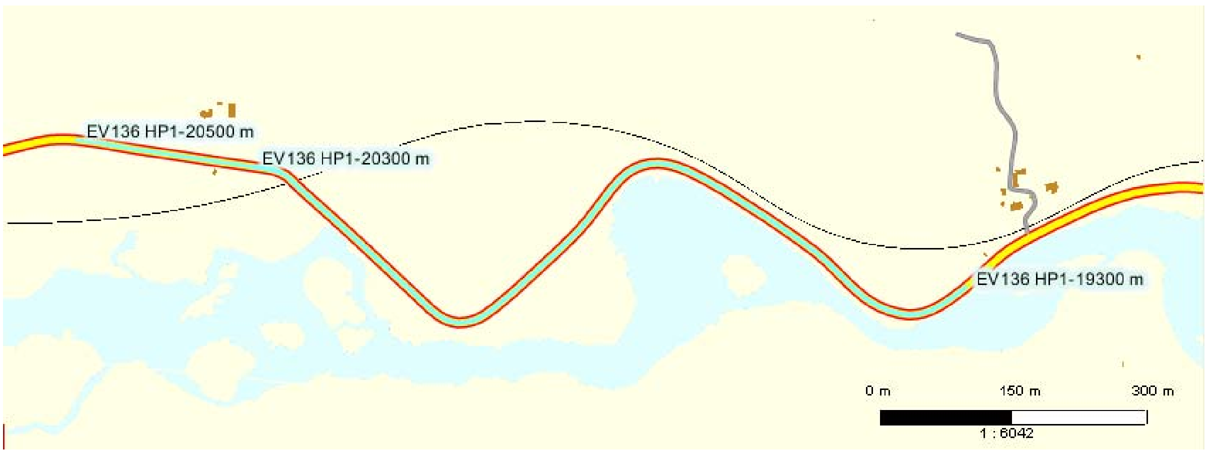

Figure 4 – Road section with sharp bends

Figure 5 show the road condition on 9th of February 2009 at 16:46 p.m. There was a snow and ice cover on the road, and the mean value of the coefficient of friction was 0.22 on the whole road section, see Figure 6.

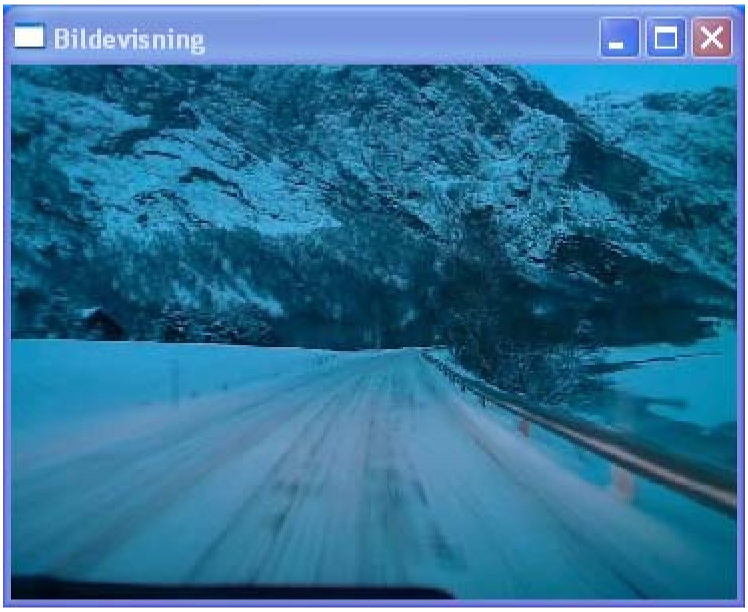

Figure 5 – Surface condition on the road section between Sæterbø and Trollveggen, 9th of February 2009 at 16:46 p.m.

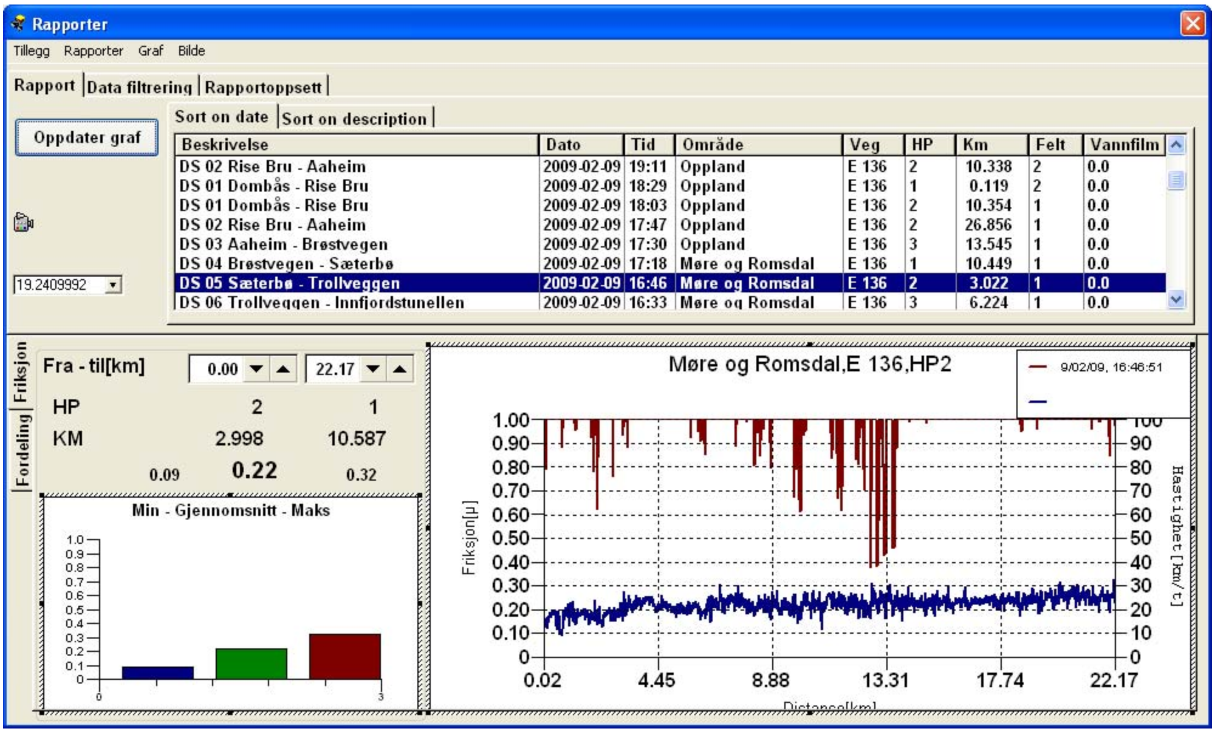

Figure 6 – Measured friction and calculated critical speed on the road section between Sæterbø and Trollveggen, 9th of February 2009 at 16:46 p.m.

In Figure 6 is shown the critical speed calculated by use of Equation 5. The speed limit is 80 km/h and there are several sections where the critical speed is calculated to be considerable lower than the speed limit. A few spots have a critical speed below 50 km/t, see Table 2. The four spots in Table 2 have all a radius less than 100 metres according to the National road data bank. Even if the calculated radius from the sensor readings is largely congruent with the road data values there are some deviations that should be investigated further.

Table 2 – Comparison between calculated curvature and curvature according to National road data bank

Curve	Distance	Radius according to National road data bank	Calculated radius (m)	Coefficient of friction (km/)	Critical speed
1	12.68	96	57	0.19	38
2	12.94	46	51	0.22	38
3	13.23	69	74	0.21	43
4	13.60	66	80	0.21	46

Figure 7 shows the same measurement as in Figure 6 where the braking length is included in the calculation of the critical speed.

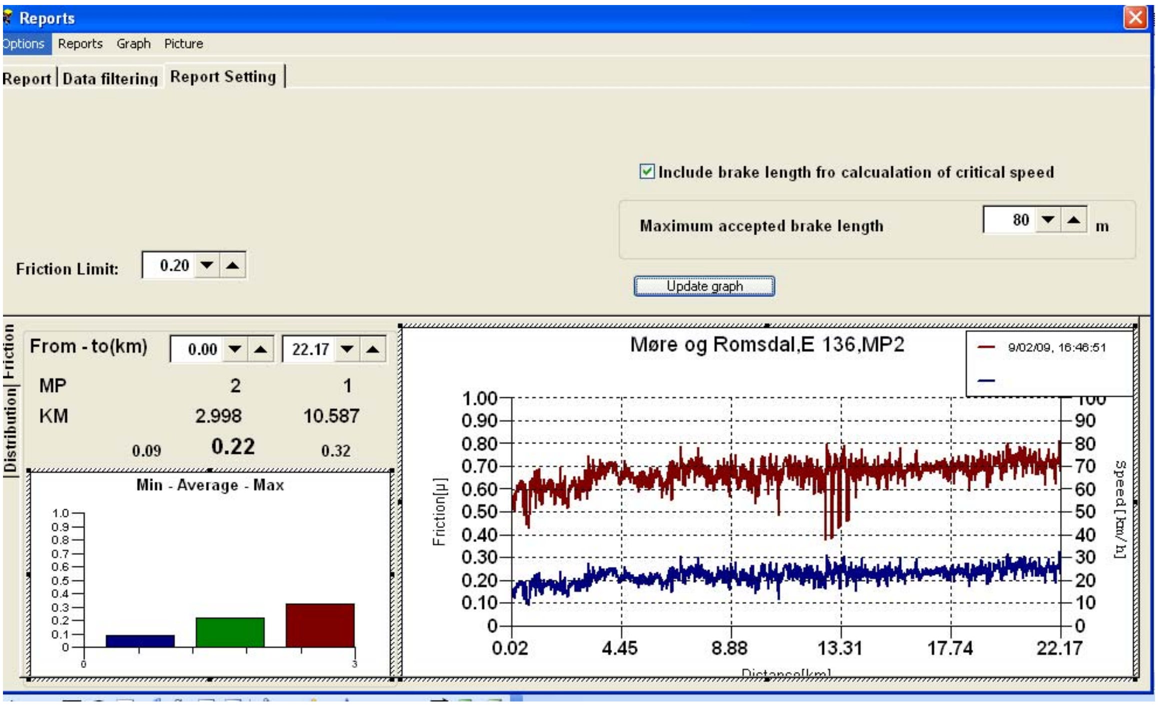

Figure 7 – Including braking length in calculation of critical speed on road section between Sæterbø and Trollveggen, 9th of February 2009 at 16:46 p.m.

The breaking length is in the example in Figure 6 set to 80 metres and it can be seen that the critical speed varies throughout the road section.

5. OPTIMIZING WINTER OPERATIONS

5.1. In general

Information about how the curvature influence on the road grip and calculation of critical speed in curves will have several areas of application. This type of information is already being used in the design criteria for highways. New areas for use of this type of information will be:

- More focus in the driver education of how curvature influence on the driving task.
- Information to the road users about the actual road grip.
- Friction requirements adjusted for the side friction factor, i.e. the actual road grip can be reflected in the winter standard requirements.
- Support to the contractors in their daily operations.

One important aspect with more focus on side friction is that the general awareness can rise and thereby result in safer driving in the winter time. This will also be useful in the education of new drivers.

The first step seems however to be to concentrate on how the calculation of critical speed can be used to optimize winter operations on roads with a winter road strategy, i.e. where sand is used to improve the friction.

5.2. Optimizing winter operations

The main idea is that the driving condition with regards to level of safety should be predictable. To compensate for the influence of side forces, the friction level should be higher in curves than on straight sections even if the friction measured by the friction trailer is the same.

This will result in a more flexible way of doing the winter operations and can also be a guideline to select road segments where the maintenance actions should be reinforced to keep a stable safety margin throughout a route. One way of doing this and to have “fresh” data is to mount a friction device on the truck. This will also in general help the contractors to do their actions more correctly according to the friction requirements.

The system can be illustrated as show in Figure 8. There can be calculated a necessary level of safety in each curve based on radius, friction and super elevation.

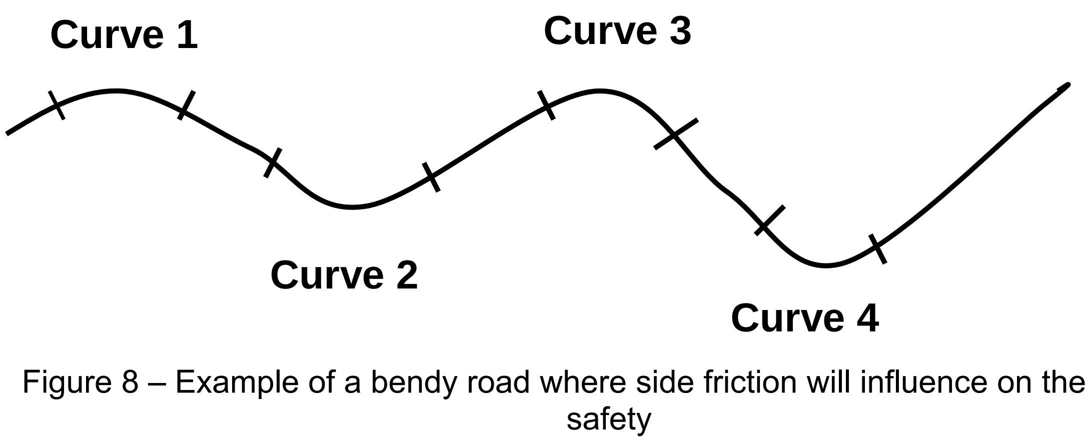

Figure 8 – Example of a bendy road where side friction will influence on the level of safety

If one assumes that Figure 8 illustrates the same curves as in Table 2 and that the coefficient of friction is as measured on the different spots, this will give the need for friction improvement as shown in Table 3 to if the level of safety is set 10 km/h above the critical speed.

Table 3 – Needed friction level to maintain a certain level of safety

Curve	Distance	Calculated radius	Coefficient of friction	Critical speed (km/h)	Safety level (km/h)	Needed friction level
1	12.68	57	0.19	38	48	0.33
2	12.94	51	0.22	38	48	0.36
3	13.23	74	0.21	43	53	0.30
4	13.60	80	0.21	46	56	0.31

Table 3 illustrates that the need for friction improvement will vary with the geometry and a friction measure raising the friction up to 0.30 will not be satisfactory in the sharpest curves in the example. If possible there should be put extra effort in those curves for additional friction improvement, or other actions like information to the drivers should be considered.

6. FURTHER STUDIES

So far the project has concentrated on the development of the friction measuring device with the basic functions in the new sensor. The next steps will be to develop the measuring system further and to come up with recommendations for how information about side friction can be utilized in the winter operations.

Regarding the measuring system there will be made more comprehensive verification of the accuracy of the sensor readings. The calculation of the critical speed will also be further elaborated by including the super elevation in the formula.

The Norwegian winter standard requirements contains a rule that there shall be executed reinforced gritting in curves and in hills but without specifying any criteria for a triggering factor which in curves can be what is denoted as critical speed or level of safety. This will therefore naturally be one of the aspects that will be investigated more thoroughly in the continuation of the project.

Other areas of application like driver information and driver education will also be considered when the project is finally reported after the winter season 2010/2011.

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