Tram Braking Distances under the Influence of $MgCl_2$ as a Dust Binding Agent

K.A. Skoglund
SINTEF Building and Infrastructure, Trondheim, Norway

ABSTRACT: A field study of friction loss during tram braking under the influence of $MgCl_2$ has been carried out. The work was initiated after a collision in Trondheim, Norway, where a tram ran into a stagnant bus from behind. During the studded tyre season, an $MgCl_2$ solution was regularly applied to the street surface as a dust binding agent, and was applied only hours before the incident. The objective of the project was to determine whether the use of this $MgCl_2$ solution for dust attenuation may have contributed to a reduced top-of-rail friction at the moment of the accident. The study comprised of a literature survey, brake tests with trams and analyses to determine the friction conditions at four different top-of-rail conditions, i.e. dry, wet by water, wet by $MgCl_2$ solution and dried/moist $MgCl_2$, three braking modes, i.e. with friction controlled disk brakes, electromagnetic track brakes, and with one of four track brakes deactivated and three levels of target speed, i.e. 5 km/h, 15 km/h and 30km/h. Around 110 individual tests were carried out. A main conclusion was that the use of $MgCl_2$ resulted in significantly longer braking distances, especially for normal braking. Dried $MgCl_2$ induced the longest braking distances, followed by wet $MgCl_2$ applied to the track. The third longest braking distances went to the track wet by water, and the fourth, with the best friction, was for the dry track. One disabled magnetic track brake did not seem to have a major impact on the stopping length compared with all four magnetic track brakes activated. As a result of the investigation, Trondheim municipality has stopped the use of the $MgCl_2$ solution as dust binding agent in streets where there is tram traffic.

KEY WORDS: Tram track, friction, braking distance, magnesium chloride.

1 INTRODUCTION

The background for the work was an investigation initiated after a collision in November 2009 in Trondheim, Norway, where a tram ran into a stagnant bus from behind injuring 4 people. As a part of the investigation, The Accident Investigation Board Norway (AIBN), wanted to examine whether the use of a magnesium chloride ($MgCl_2$) solution as a dust binding and dust attenuating agent was connected to a suspected lowering of the wheel-rail friction. AIBN appointed SINTEF Building and Infrastructure to carry out some field tests to clarify whether this mechanism could be a part of the explanation of the collision.

There have been some studies carried out to investigate frictional properties when using liquids of different composition for dust attenuation and for ice and snow melt on roads. However, these studies have solely been dealing with the surface friction of road pavements, hence not so relevant for trams or other railway applications. A Swedish study (Gustavsson 2009) reports a 24 % reduction in friction between the tyre and the asphalt pavement when using a 25 % $MgCl_2$ solution. The same study also indicates a 22 % friction loss for a 0.5 mm thick film of water on the pavement surface. Thus it seems that the wetting effect is the biggest one. In a large study carried out by Montana State University, USA (Xianming et al. 2009) 14 different substances, including a 26 % $MgCl_2$ solution, were tested in connection with ice and snow removal from concrete road pavements. Here, a friction reduction of 20 % is reported for the $MgCl_2$ solution in comparison with wet (water film) conditions. Other studies (Martinez and Poecker 2009, Vaa 2004, Vaa 2005a, Vaa 2005b) indicates either no significant loss of friction or even an increase in friction, the latter result was a comparison with a NaCl solution applied to the pavement. To conclude, it seems that for road pavements there is a moderate loss of friction when applying an $MgCl_2$ solution on top of the pavement.

The high level of contact stresses that exists between the rail and the wheel are also found in extrusion of metals. In such brute metal forming processes lubrication is applied to the die where the plastic deformation of the metal occurs. In a study of cold extrusion of aluminium (Syahrullail et al. 2009), it was found that a lubricant with a higher viscosity required the lowest necessary extrusion loads. In metal extrusion it is well known that a too low lubricant viscosity may lead to a higher friction than for more viscous lubricants. This is due to break down of the resulting thin lubricant film of the low viscosity lubricant, and also to a higher influence of any surface roughness. Although not entirely comparable, one should expect higher top-of-rail friction for a low viscosity liquid as water, than for an $MgCl_2$ solution.

2 THE FIELD TEST PROGRAMME

The purpose of the field test programme was to measure breaking distances under various track and tram conditions in order to map any differences in breaking distances, and hence map the braking performance under various conditions. Since braking performance is closely related to wheel-rail friction, not to forget the influence from the tram braking equipment, the test programme was expected to also illuminate these frictional aspects.

Therefore, an extensive field test programme with realistic tram braking tests was carried out. Such types of tests were believed to correspond more directly to the conditions at the accident than more standardised friction tests as for instance friction pendulum tests. An ordinary, single car tram with two bogies was used during the tests, i.e. a tram of the same type as the one involved in the accident.

The test site chosen was a 280 m long straight and horizontal section adjacent to the accident site. The tram line is double tracked here, and is placed in a street reserved for buses and trams. During the two nights of testing, one in March 2010 and one in May 2010, the street was closed allowing traffic only for the test tram. The weather during the test nights was comparable to that of the accident in terms of temperature and relative air humidity.

In order to investigate the effect of differences in track condition, testing under four distinct track conditions were executed:

- Dry track
- Wet track (water only)
- Track wet with $MgCl_2$ in the same way as for dust binding, followed by immediate testing.
- Dried $MgCl_2$, allowing some half day of traffic and of drying before testing. Resembled the track conditions at the moment of the accident.

The $MgCl_2$ solution that was used was at a concentration of 20 % and was applied to the street surface at an amount of 25 g/m^2. Both the concentration and the amount spread were the same as prior to the accident.

To study the effect of various velocities, the tests were carried out with three different target velocities, namely 5 km/h, 15 km/h and 30 km/h. An additional reason to vary the velocity was the fact the actual velocity at the accident impact was not known accurately.

Also, since there was some doubt about the functioning of the emergency electromagnetic track brakes, three braking modes were tested:

- Normal braking, i.e. with friction controlled disk brakes.
- Emergency braking, i.e. using electromagnetic track brakes.
- Reduced emergency braking, i.e. with one out of four track brakes deactivated.

During emergency braking, also the normal disk brakes were operating.

In combination all these test conditions gave 36 different test combinations, but in order to get some reliability, repeated tests with intentionally the same test conditions were run. Consequently, about 110 individual tests were conducted in total.

3 DATA CAPTURE AND INTERPRETING

3.1 Data capture

The braking distance was the primary parameter to measure, and was simply measured by measuring tape from the point where braking action was initiated to the point where the tram came to a complete halt. The point of braking initiation was the point in the track where a signal was given to the tram driver to activate the brakes.

In addition, the velocity at the instant of initiating the brakes was important to measure. It was decided that the tram speedometer was too inaccurate, so a GPS data logger was used instead. This was a 100 Hz GPS data logger from Racelogic, model VBOX 3i, see Figure 1.

Figure 1: Racelogic VBOX 3i, 100 Hz GPS data logger. From: www.racelogic.co.uk

The antenna for the GPS data logger was easily mounted on top of the tram by means of a magnetic footing, allowing registration of signals from multiple satellites. GPS data recordings were stored at an SD card, and the data was processed by the help of the accompanying software VBOX Tools ran on a PC.

3.2 Data interpreting

Large quantities of data were logged as the log frequency was 100 Hz. In combination with the accuracy of the equipment this unfortunately gave very rugged GPS curves for the tram velocity as can be seen from Figure 2.

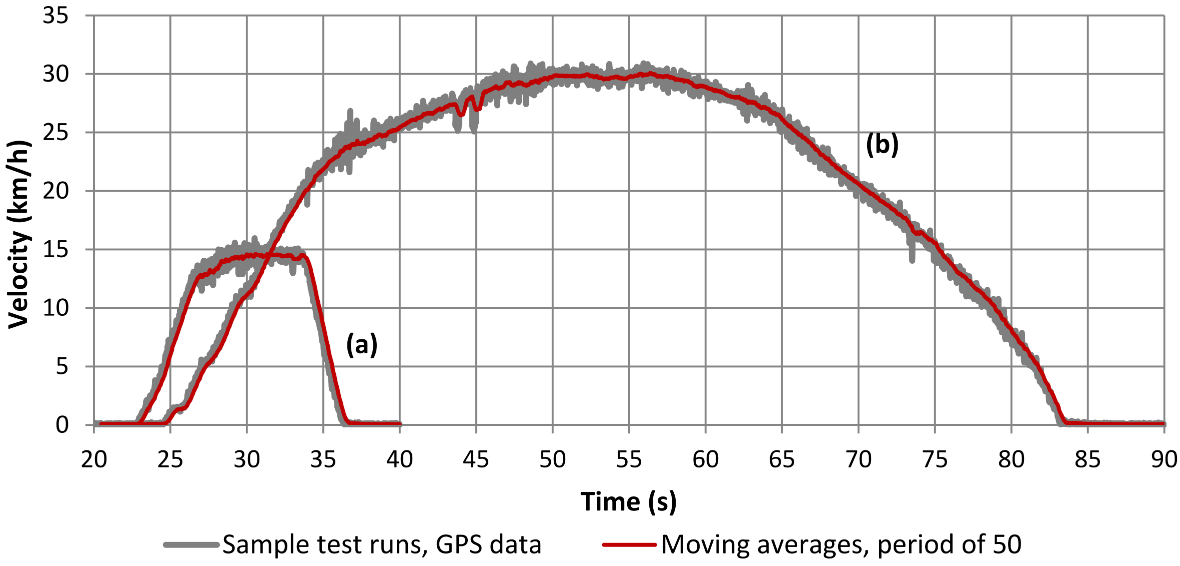

Figure 2: Tram velocities logged with GPS for two of the test runs. Curve (a): Test at dry track conditions, normal braking and target velocity 15 km/h. Curve (b): Test at dried $MgCl_2$ track conditions, normal braking and target velocity 30 km/h.

In order to interpret the velocities more accurately from the GPS data, a moving average of a period of 50 was imposed. This corresponds to averaging the velocity measurements over the last 0.5 second for every data point. As can be seen from Figure 2, this made a smoother curve and made it possible to find the velocity more accurately at which the braking was initiated.

The velocity at the activation of the brakes was in most cases easily found by searching for an abrupt decline in the tram velocity curves, corresponding to curve (a) in Figure 2. In some cases, where friction was low and braking did not have much effect, it was not so obvious when the brakes were applied, confer curve (b) in Figure 2. In such cases a braking criterion was introduced, noting that the deceleration of the free rolling of the tram was around 0.5 km/h per second. Hence, it was postulated that the brakes were activated when the deceleration steadily was around 1.0 km/h or more per second.

4 RESULTS FROM THE TESTS

Each test produced a braking distance and a velocity for braking initiation. For each track condition the results are depicted in Figure 3.

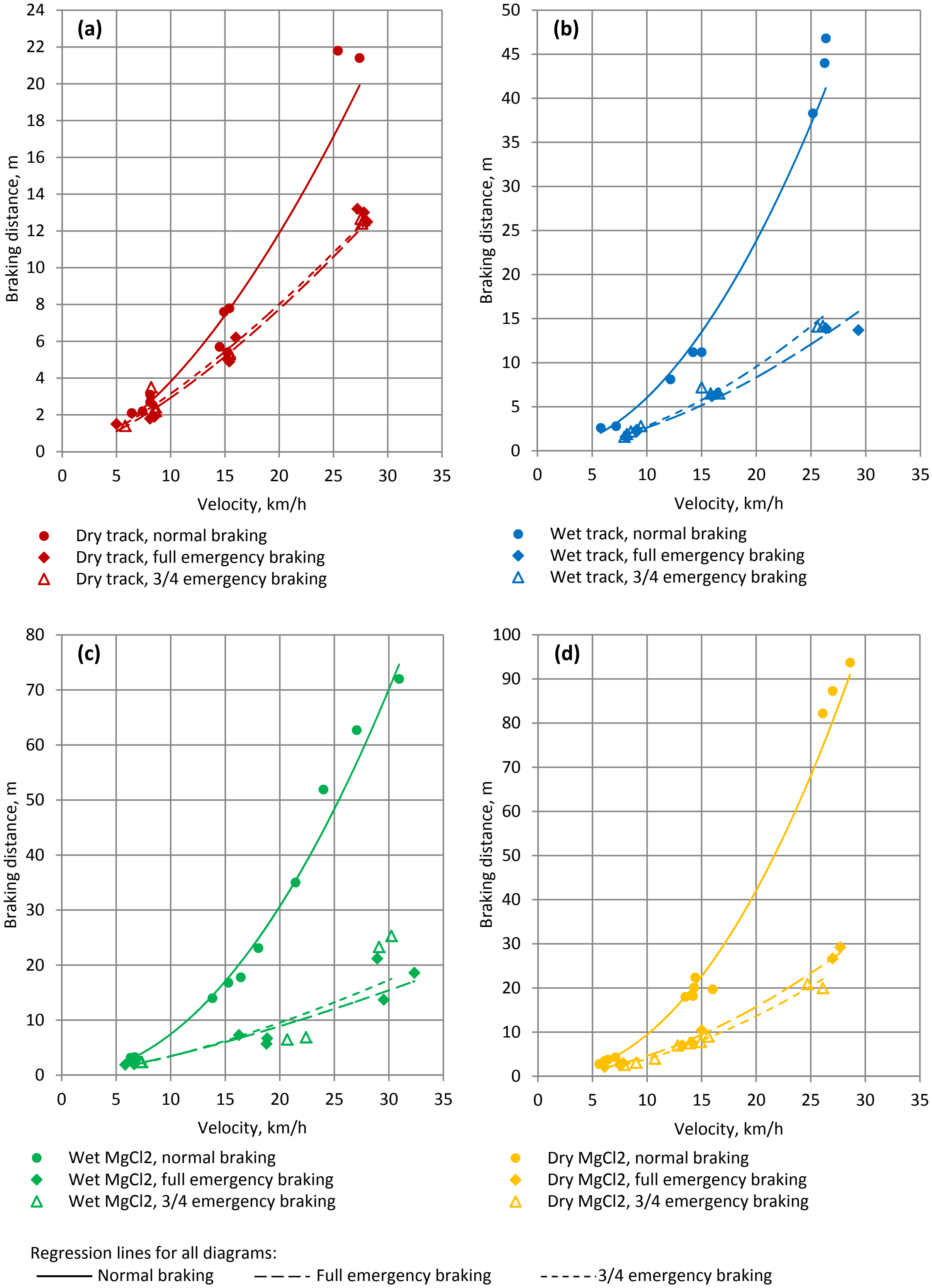

Figure 3: Braking distances for four track conditions, (a) dry track, (b) wet track, (c) wet $MgCl_2$ and (d) dry $MgCl_2$, and three braking modes as a function of velocity. Note the different scales on the vertical axes.

As can be seen from Figure 3, the braking distance at normal braking mode approximately doubles from dry track to wet track, and almost doubles once again for dry $MgCl_2$, leaving wet $MgCl_2$ in between at the second longest braking distance. The emergency braking modes are not affected by track conditions to the same extent as the normal braking mode, although almost a doubling of the braking distance is seen going from a dry track to a track subjected to dry $MgCl_2$.

CONCLUSIONS

- $MgCl_2$ added to the track gives substantial longer braking distances.
- Dried $MgCl_2$ generates the longest braking distances – longer than for wet $MgCl_2$.
- Electromagnetic emergency braking substantially reduce the braking distances, and also the differences in braking distances, for all track conditions.
- The relative differences in braking distances are less for all track conditions when using emergency braking as opposed to normal braking – emergency braking compensates somewhat the adverse effect of $MgCl_2$.
- If one out of four emergency brakes is out of operation, the effect on the braking distance is notable, but not substantial.
- The exact mechanism behind the effect of $MgCl_2$ was not investigated, but is believed to be connected to the amount of bonded water in the layer containing $MgCl_2$.
- Lab tests of the black layer on top of the rails were inconclusive.

A recommendation is therefore that $MgCl_2$ should not be applied in streets where there is tram traffic.

ACKNOWLEDGEMENTS

Financing of the study was provided by Accident Investigation Board Norway (AIBN). Henning Johansen was the primary contact within AIBN.

REFERENCES

Gustafsson, M., 2009. Dust binding: Practical trials in Sweden. *Air Quality Alongside Motorways*, Rotterdam, The Netherlands.

Martinez, F.C. and Poecker, R.A, 2006. *Evaluation of Deicer Applications on Open Graded Pavements*, Oregon Department of Transportation, Salem, Oregon, USA.

Syahrullail, S., et al., 2009. The Effect of Lubricant Viscosity in Cold Forward Plane Strain Extrusion Test, *European Journal of Scientific Research*, vol. 38, no. 4, p. 545-555, Victoria Mahé, Seychelles.

Vaa, T., 2004. Norwegian Experience with Use of Magnesium Chloride, *Sixth International Symposium on Snow Removal and Ice Control Technology*, Transportation Research Board Spokane, Washington, USA.

Vaa, T., 2005a. *Forsøk med befuktning med magnesiumkloridløsning på Gjøvik/Toten. Sesongen 2004/2005*, The Norwegian Public Roads Administration, Oslo, Norway.

Vaa, T., 2005b. *Forsøk med befuktning med magnesiumkloridløsning i Oslo. Sesongene 2001/2002–2004/2005. Sluttrapport*, The Norwegian Public Roads Administration, Oslo, Norway.

Xianming Shi, et al., 2009. *Evaluation of AlternativeAnti-icing and Deicing Compounds Using Sodium Chloride and Magnesium Chloride as Baseline Deicers - Phase I*, Western Transportation Institute, Montana State University, Bozeman, Montana, USA, 294 p.