Friction coefficients on winter road surfaces using Multi-Axial Sensing system vehicle

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ABSTRACT: The University of Fukui and the Public Works Research Institute, Niigata Experimental Laboratory, have been collecting the sliding friction coefficient data for different winter road surface conditions using a new type of vehicle (MASS-vehicle) since 2000. The MASS-vehicle is a friction-measurement vehicle equipped with a new type of Antilock Braking system, known as the Multi-Axial Sensing system (MASS), invented by one of the coauthors. A joint test using a friction-measurement bus with an instrument-embedded wheel mounted to its body (5th wheel bus) and the MASS-vehicle was conducted in Myoko-Kogen village in Niigata Prefecture, Japan. The test roads include roads over ravines with steep slopes ranging from three to eight percent inclines.

It has been concluded from our test data that the effect of road slope on the sliding friction coefficient is negligible for the MASS-vehicle but significant for the 5th wheel bus, which tends to overestimate the sliding friction coefficient on a downhill road surface.

1 INTRODUCTION

Although it may be clearly seen that the sliding friction coefficient, $\mu$, is one of the primary factors, in quantitatively evaluating hazardous road conditions, $\mu$ is seldom considered in winter road management. One of the main reasons for this may be due to the lack of means to carry out real-time friction measurement at short time intervals. The difficulty of measuring the sliding friction also makes the connection of road surface conditions and $\mu$ insufficient, and therefore hinders the development of a road safety-forecasting model. However, a reliable friction-measurement device could play an important role in the advancement of an intelligent winter road transport operation and could contribute to the curtailment of the maintenance administrative expenses associated with salting, plowing and so forth. Hereafter, the term "sliding friction" will be abbreviated as "friction".

The NCHRP Web Document 53 reports several friction testers and vehicles to measure the friction coefficient (Imad, L. et al. 2002). Both an ABS (Antilock Braking system) based friction-measurement system and an AeroTechTelub MoRRS (Mobile Road Reporting system) are introduced as a more modern version of friction measurement device in this report. However, it should be noted that ABS will only provide friction related data when the system is activated under severe braking conditions.
the test wheel, by which the peak friction coefficient, the slip speed, and so forth, can be computed. Considerable scatter in the friction coefficient was observed in a test section under wet and compacted snow conditions.

The Hokkaido Development Agency and the Public Works Research Institute, Niigata Experimental Laboratory, possess a friction-measurement bus (5th wheel bus), which has an additional wheel (fifth wheel) that can compute the friction coefficient on a road surface and assist in the winter management of national roads. The Japan Highway Public Corporation also has been using the same type of five wheel car for highway road management in winter. The 5th wheel car is more compact than the 5th wheel bus and makes vehicle operation easy. However, the comparative accuracy of these two devices hasn’t been evaluated yet, because friction measurement has never been conducted at the same time and same place to allow meaningful comparison.

A new system in which a driver is provided with continuous road surface information by advanced telecommunications technology has been required to support the movement of people to a snowy region from a non-snow covered area.

From this social background, a joint research team of the University of Fukui and the Public Works Research Institute, Niigata Experimental Laboratory, have been collecting the friction coefficients for different road surface conditions using a new type of vehicle (MASS-vehicle) since 2000. The MASS-vehicle is a friction-measurement vehicle equipped with a new type of Antilock Braking system, known as Multi-Axial Sensing system (MASS), invented by one of the coauthors (Miyazaki, N. et al. 2001). The most notable feature of the MASS-vehicle is that the friction coefficient can be obtained without locking wheels to allow continuous friction measurements in a heavy traffic situation.

The present paper describes the friction coefficients on the winter road surfaces measured using a 5th wheel bus and by a MASS-vehicle.

2 TEST VEHICLES

There is a big difference in the mechanism of friction measurement between the 5th wheel bus (see Figure 1) and the MASS-vehicle (see Figure 2). The former measures the friction coefficient (lock-μ) by locking the fifth wheel but the latter can obtain the friction coefficient even without sliding, in addition to the lock-μ. The MASS-vehicle can detect the friction force during such a short braking action of about 100 milliseconds that an operator doesn't even feel the deceleration of the vehicle. The weight of the MASS-vehicle is about 1.7 tons, while that of the 5th wheel bus is about 9 tons.

As Figure 3 indicates, the longitudinal force \( F_x \), lateral force \( F_y \) and braking force \( F_b \) are detected from the 5th wheel, in addition to the vertical force \( F_z \). The braking force, \( F_b \), acts on the wheel axle structure. The accuracy of \( \mu \) was verified by the slippery friction test carried out by the Japan Automobile Research Institute, Inc. The maximum of \( F_z \) applied on the 5th wheel (test wheel) is 5kN and the maximum yaw angle is 30 degrees.

Figure 4 shows a four-axial direction sensing device, mounted in the suspension of the MASS-vehicle. The device, i.e., \( \mu \)-sensor can measure the three-directional forces \( F_x, F_y, F_z \) and braking force \( F_b \).

Figure 3. Longitudinal force, lateral force, vertical force, and braking force detected from an instrument-embedded wheel mounted to the 5th wheel bus.

Figure 4. Four-axial direction sensing device, installed at a "neutral spot" in the suspension of the MASS-vehicle.
The $\mu$-sensor is installed at a “neutral spot” where only the shear stress can be obtained for the desired directional load, while the stress caused by other directional force can’t be detected. The value of $\mu$ can be obtained at an interval of 0.1 milliseconds, so that the time response of $\mu$ after braking is more sensitive than conventional ABS devices and enables the measurement at the peak of $\mu$, $\mu_{\text{max}}$, which occurs just right after braking.

The joint test using the 5th wheel bus and the MASS-vehicle was conducted from February 7 to February 8, 2001 in Myoko-Kogen village, Niigata Prefecture, Japan, and the measurement sites are shown in Figure 5. The test roads cross ravines and there are steep slopes ranging from three to eight percent inclines. The MASS-vehicle and the 5th wheel bus were driven by turns quickly on the uphill and downhill lanes at the three test sites. The friction measurements were repeated three times at the same place.

In this test, the lock-$\mu$ is set as the comparative object, because the 5th wheel bus measures the lock-$\mu$ only. Hereafter, the lock-$\mu$ is simply expressed as the friction coefficient, $\mu$. In this paper the subscript of $\mu$, m and b mean the MASS-vehicle and the 5th wheel bus, respectively.

3 FIELD TEST RESULTS

Figure 6 show the comparison of $\mu$ ($\mu_b$) measured by the 5th wheel bus and $\mu$ ($\mu_m$) measured by the MASS-vehicle in a test course in Tomakomai, Hokkaido. These measurements were conducted on a level test road covered with a thick compacted snow layer and on an ice-plate surface. It is seen that $\mu_m$ agrees well with $\mu_b$.

Figures 7 and 8 show road surface conditions at different times at test site 0 on February 7, 2001 and on February 8, respectively. A layer of fresh snow, compacted snow, and frozen ice was observed after snowfall and the road surface condition was very changeable during the test period.

Figures 9 (a) to (f) show the time variations of $\mu_b$ and $\mu_m$ at three different test sites from 1 a.m. to 6 a.m. on February 7, 2001. Figures 9 (a), (b) and (c) represent the results measured on uphill lanes at the three test sites and Figures 9 (d), (e) and (f) show the results measured on downhill lanes at the same test sites. The weather on that day was cloudy and it sometimes snowed during the test period. An icy layer formed on the road surface due to a heavy snowfall after 4 a.m.

Looking at the results at test site 0 (see Figure 9 (a)), both $\mu_m$ and $\mu_b$ on the uphill lane range from about 0.3 to 0.5 and the difference in $\mu_m$ and $\mu_b$, $\Delta \mu$, is small. However, $\Delta \mu$ on the downhill lane, $\Delta \mu_b$, is larger than that on the uphill lane, $\Delta \mu_m$, as shown in Figure 9 (d) and is as much as about 0.35. The value of $\mu_b$ is obviously higher than that of $\mu_m$ for the entire test period for the downhill lane. The value of $\mu_b$ ($=0.7-0.8$) may belong to the category of a wet road surface, but the downhill and uphill lanes were apparently covered by a thin compacted or new snow layer or an ice base.

Consequently, comparing the difference in $\mu$, ($\delta \mu$) between the downhill and uphill lanes for each test vehicle, it is known that $\delta \mu$ for the 5th wheel bus, $\delta \mu_b$, is considerably larger than that for the MASS-vehicle, $\delta \mu_m$, although the road surface conditions on the downhill and uphill lanes are not consistent due to the difference in the density of vehicular traffic.
Figures 7 and 8 show the road surface conditions at test sites 0 and 2 on February 7 and 8, 2001, respectively. The figures indicate that the road surface conditions varied throughout the day, with some sections appearing wet and others dry.

Similar results are also obtained at test site 1 (see Figures 9 (b) and (e)). For example, $\delta \mu_b$ is larger than $\delta \mu_m$ and $\Delta \mu_d$ is larger than $\Delta \mu_u$. Especially note that $\Delta \mu_d$ ranges from 0.2 to 0.3. These results are also attributed to the fact that $\mu_b$ is higher than $\mu_m$ on the downhill lane.

The lowest friction coefficient is measured at test site 2 (see Figures 9 (c) and (f)). In fact, there was an ice base or a compacted snow layer at test site 2. An agreement of $\mu$ on the uphill and downhill lanes is seen for not only the MASS-vehicle but also for the 5th wheel bus. However, $\mu_b$ on the downhill lane ranges from 0.3 to 0.4 and is about 0.2 higher than $\mu_m$. The value of $\mu_b$ is somewhat high for a friction coefficient on an ice base or on a compacted snow surface.

From Figure 9, it is seen that the effect of road slope on the friction coefficient is hardly different for the MASS-vehicle but is obvious for the 5th wheel bus.

Figures 10 (a) to (f) show the time variations of $\mu$ at the three different test sites on February 8. The friction measurement procedure is the same as on the previous day. The value of $\Delta \mu_u$ is negligible for all test sites, while $\Delta \mu_d$ is sufficiently large to be of significance except on the uphill lane at test site 2. The value of $\delta \mu_b$ is larger than $\delta \mu_m$ for all test sites, especially at test site 0. It can be seen that the results drawn from Figure 10 are almost the same as those drawn from Figure 9.

The difference of $\mu_m$ and $\mu_b$ on the downhill lanes may be caused by vertical force, $F_z$, because braked wheels more or less destroy snow/ice composite road surface and the destruction of a snow/ice layer on the road surface depends on the vertical force, $F_z$. Therefore, it remains to be distinguished whether the friction coefficient, $\mu_b$, measured by a heavy vehicle such as the 5th wheel bus, represents the friction on the snow/ice layer or that on the road surface under the snow/ice layer. Judging from the fact that $\mu_b$ is larger than 0.7 even on a snow/ice layer (see Figures 9(d), 10(d) and 10(e)), the 5th wheel bus may detect the friction force on the road surface rather than that on the snow/ice layer. Consequently, the relation of $\mu_b > \mu_m$ tends to appear on a downhill road compared with an uphill road.
4 CONCLUSIONS

The University of Fukui and the Public Works Research Institute, Niigata Experimental Laboratory, have been collecting sliding friction coefficient data for different winter road surface conditions using a new type of vehicle (MASS-vehicle) since 2000. The MASS-vehicle is a friction-measurement vehicle equipped with a new type of Anti-lock Braking system, known as the Multi-Axial Sensing system (MASS), invented by one of the coauthors. A joint test using a friction-measurement bus with an instrument-embedded wheel mounted to its body (5th wheel bus) and the MASS-vehicle was conducted from February 7 to February 8, 2001 in Myoko-Kogen village, Niigata Prefecture, Japan.

The main results and conclusions drawn from the present test are as follows:

(1) The sliding friction coefficient obtained by the MASS-vehicle agrees with that obtained by the 5th wheel bus as far as uphill and level roads are concerned.

(2) However, the sliding friction coefficient obtained by the 5th wheel bus is larger than that obtained by the MASS-vehicle on downhill lanes. The 5th wheel bus tends to overestimate the sliding friction coefficient on a downhill road surface.

(3) The effect of road slope on the sliding friction coefficient is negligible for the MASS-vehicle but significant for the 5th wheel bus.

Figure 9. Time variations of friction coefficients at three different test sites from 1 a.m. to 6 a.m. on February 7, 2001.
Figure 10. Time variations of friction coefficients at three different test sites from 1 a.m. to 6 a.m. on February 8, 2001.

REFERENCES


