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Measuring bicycle braking friction in winter conditions

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ABSTRACT

Bicycling is considered an attractive way of traveling and is becoming a more and more common mode of transportation in Scandinavia. However, winter conditions create a challenge for providing a high quality, functional bicycle road network. Winter maintenance actions, such as snow removal, gritting and salting, are needed. The Norwegian Public Road Administration (NPRA) sets standards for winter maintenance of cycleways, which includes a friction criterion. Friction measurement devices (FMDs) are used to test whether the conditions are within the specified standard. However, it is not known how well these values describe the friction experienced by bicycles. The two objectives of this study are: 1) to measure actual braking friction of bicycles in winter conditions and 2) to compare the results to friction measurement devices (FMDs). Two methods were used to measure bicycle friction in this study: deceleration and braking distance. Two instrumented bicycles with studded winter tires were tested by all-out braking tests on winter road surfaces. As a comparison, friction of the test stretch was measured by three FMDs. The results showed that both methods are suitable for defining bicycle friction; however, the deceleration was found to be a more accurate method in the given field conditions. The bicycles experienced the same or higher friction than the FMDs. The variability of bicycle friction was also greater than the variability of each individual FMD. This is probably due to lack of slip control of the bicycles and therefore it is uncertain whether maximum friction was in fact attained during the braking tests.

1. Introduction

1.1. Background

Bicycling is considered an attractive way of traveling since it is healthy, flexible and, especially in urban areas, can be faster than other modes of transportation. Several studies have shown a positive correlation between physical activity and health (Tesche et al., 2012; Wang et al., 2004). In addition, walking and cycling can decrease congestion and improve the environment. Accordingly, the Norwegian National Transport Plan states that the growth in local travel in larger urban areas must be absorbed by public transport, cycling and walking (Norwegian Directorate of Public Roads, 2012). To be more precise, the goal is to increase the national bike trip share from 4% in 2009 to 8% in 2023 (Espeland and Amundsen, 2012). To achieve this goal, better and safer infrastructure for pedestrians and cyclists must be provided.

In the cold regions of the world, winter conditions create a challenge for maintaining high-quality biking infrastructure. In Sweden, the number of bicycle trips in the wintertime amounts to only one-third of the bicycle trips in the summertime (Bergström, 2003). Norwegian Public Roads Administration (NPRA) guidelines state that the maintenance level of sidewalks and cycleways should be as good as the standard for the adjacent road (Norwegian Public Roads Administration, 2014a). During the wintertime, this demands the use of winter maintenance actions such as salting, snow removal and gritting. These actions are often performed by private contractors. The Norwegian standards for winter maintenance describe a minimum friction coefficient value for the cycleway (Norwegian Public Roads Administration, 2014b), which is measured using friction measurement devices (FMD) approved by the NPRA. The NPRA has five approved standard FMDs: Road Analyzer and Recorder Mark III (RoAR) by ViaTech AS. In addition, several different FMDs approved by the NPRA are in use by contractors. These FMDs are calibrated to match the RoAR every winter season. However, little is known about how these friction measurement devices correlate with friction experienced by bicycles. A Swedish study measured the friction coefficient value of a cycleway with a portable friction tester developed by the Swedish National Road and Transport Research Institute and found that the tester is suitable for measuring the friction of the cycleways. Nevertheless, the study did not show how accurately this friction tester describes the performance of bicycles (Bergström et al., 2003). Attempts to measure bicycle braking friction in winter conditions appear to be lacking. The two objectives of this study are therefore: 1) to measure actual braking friction of bicycles in winter conditions and 2) to compare the results to FMDs.

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1.2. Measuring bicycle friction in winter conditions

Friction measurements have mainly focused on heavy vehicles such as motorcycles, cars, airplanes and trains (Andresen and Wambold, 1999; Klein-Paste et al., 2012; Lundberg et al., 2015). Slippery and slip-resistant footwear performance has also been studied (Aschan et al., 2009). Computer-based modeling and simulation have developed substantially over the last two decades, which has resulted in an increasing proportion of studies of bicycle dynamics being carried out virtually. Computer-based modeling and simulation are usually inexpensive and time-saving and therefore more attractive than experimental field tests. Nevertheless, experimental testing can yield more accurate results (Day, 2014). The simulation studies for bicycles are focused either on bicycle rider control and motions (Moore et al., 2010; Schwab and Meijaard, 2013) or on braking vibration and analysis (Lie and Sung, 2010; Redfield, 2014). Apart from Bergström et al. (2003), very few friction measurement studies are done on cycleways covered with snow or ice.

Friction is a force between two materials sliding against each other. Friction is always dependent on not only the properties of the two materials but also the ambient environment and the interfacial medium between the materials. This complex interaction is called tribosystem. Generally, friction is expressed by the friction coefficient value, μ, which is a ratio between the friction force, F_μ, and normal force, F_n (Eq. (1)).

$$\mu = \frac{F_\mu}{F_n} \tag{1}$$

Friction is needed to control a bicycle since it enables steering, braking and accelerating. In general, friction of a vehicle can be measured in four different ways: friction force, deceleration, torque or braking distance (Andresen and Wambold, 1999; Day, 2014; Hall et al., 2009). In this study, deceleration and braking distance are used, since they are the most convenient to measure. In addition, measuring friction force or torque requires a fully instrumented bicycle, which was not available for this study. The relationship between deceleration, a, and friction coefficient, μ_a, can be defined from the Eq. (1) and it is:

$$\mu_a = \frac{a}{g} \tag{2}$$

where g is gravity (Lie and Sung, 2010). On a flat road, friction can thus be determined by measuring the deceleration of a fully braking vehicle.

The friction can also be measured by measuring the braking length of a vehicle that came to a complete stop as shown in Eq. (3). This requires measurements of the initial speed. Further, friction is dependent on initial speed and the braking distance as follows:

Fig. 1. The tire of the hybrid bicycle (bicycle 1).

$$\mu_b = \frac{v^2}{2lg}. \tag{3}$$

While measuring bicycle friction, it is important to attain maximum available friction from the road surface. For the case of bicycles, this might be a challenge since bicycles do not have ABS systems to control a slip ratio. The slip ratio, as well as several other factors like speed, water film thickness, test tire state and tire pressure can all cause variation in friction value (Laïmouche and Gerthoffert, 2013). These factors can be hard to control in field test conditions, and therefore friction in emergency braking situation was studied instead.

2. Method

2.1. Test execution

Friction of two ordinary bicycles was measured on winter road conditions in April 2014 through all-out braking experiments. The bicycles were sped up to approximately 25 km/h and braked as hard as safely possible until the bicycle came to a full stop. Red paint was used as a marker at the beginning of the test stretch to indicate where braking should start. The mean friction coefficient was measured both by deceleration of each braking (Eq. (2)) and by braking distance together with initial speed of the bicycle (Eq. (3)). The braking tests were done in series: one series with each bike in the morning and one series with each bike in the afternoon. Friction coefficient values were also measured by FMDs on the test stretch before and after the braking test series as a comparison. There were three FMDs: TWO™ by Pon-Equipment AS, which is a continuous friction measurement device installed behind left wheels of a van; T2GO™ by ASFT Industries AB, a portable continuous friction measurement device; and a passenger car with a deceleration detector by Coralba. The TWO and passenger car with the deceleration detector were calibrated earlier the winter to RoAR, a friction-measuring device standard in Norway.

In Norway, cyclists commonly use studded winter tires on their hybrid or off-road bicycles during the winter season. Therefore, a hybrid- and an off-road-bicycle with studded winter tires were chosen for this study. Both bicycles had standard v-brakes in both tires and a front suspension. The