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Svendenius, Jacob

2007

Document Version:
Publisher's PDF, also known as Version of record

Link to publication

Citation for published version (APA):
Svendenius, J. (2007). *Validation of the Brush Model towards VTI-measurement data recorded in Arjeplog 2006*. (Technical Reports TFRT-7617). Department of Automatic Control, Lund Institute of Technology, Lund University.

Total number of authors:
1

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

ISSN 0280–5316
ISRN LUTFD2/TFRT--7617--SE

Validation of the Brush Model towards VTI-measurement data recorded in Arjeplog 2006

Jacob Svendenius
IVSS - Road Friction Estimation
February 2007

Department of Automatic Control
Lund University
Box 118
SE-221 00 Lund Sweden

Document name
INTERNAL REPORT

Date of issue
February 2007

Document Number
ISRN LUTFD2/TFRT--7617--SE

Author(s)
Jacob Svendenius

Supervisor
Björn Wittenmark

Sponsoring organisation
Haldex Brake Products AB

Title and subtitle
Validation of the Brush Model towards VTI-measurement data recorded in Arjeplog 2006

Abstract

The report shows a validation of the brush tire-model towards measurement data performed in the RFE-project within the IVSS-framework. The data is recorded by VTI at Colmis Proving Ground in Arjeplog. The winter tire, Continental ContiWinterContact TS810 215/55R16, the summer tire, Continental ContiSportContact 225/45R17 91W, and the studded tire: Gislaved Nordfrost 3 215/55R16 are tested longitudinally and laterally at different conditions. A study of how the braking stiffness, the cornering stiffness and the friction varies with the varying conditions is performed.

Key words
Tire Models, Measurement Data, Arjeplog, Brush Model

Classification system and/or index terms (if any)

Supplementary bibliographical information

ISSN and key title
0280–5316

ISBN

Language
English

Number of pages
23

Recipient's notes

Security classification

The report may be ordered from the Department of Automatic Control or borrowed through:
University Library, Box 134, SE-221 00 Lund, Sweden
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1. Introduction

This report describes measurements of tire characteristics performed in the IVSS-project *Road Friction Estimation* at the Colmis Proving Ground in Arjeplog. It is a continuation of the measurements performed at Hällered, see [3], in that more common road basements now are tested with the prescribed tires and procedures, in the project.

1.1 Equipment

The test vehicle is a Scania truck owned by VTI, further described in [1].

1.2 Measurement Procedure

The longitudinal tire data were generated by applying a braking torque on the wheel as a ramp function from free rolling to complete lock-up of the wheel. The lateral data was in a similar manner obtained by sweeping the wheel axle from zero [deg] to 10 [deg], then to -10 [deg] and back to zero. The load dependence was measured by varying the vertical load between 2, 4 and 6 kN. The winter tire was tested with the three loads on snow and ice for sweeps of the slip in longitudinal and lateral directions. Further, all three tire types were tested both on snow and ice, for the nominal load 4 kN. Data from braking and cornering with the slip angle ± 2 [deg] (*combined slip*) are available for the winter tire on snow and ice. For the summer tire and the studded tire these are only available on ice. The combined slip tests are not further evaluated here. All tested combinations are clearly stated in Table 1.

The tested tire types were:

- Summer tire: Continental ContiSportContact 225/45R17 91W (batch no. DOT LMTY P2B7 1705)
- Winter tire: Continental ContiWinterContact TS810 215/55R16 (batch no. DOT CPT5 AXXE 3005)
- Studded tire: Gislaved Nordfrost 3 215/55R16 (batch no. DOT CPT5 AR17 4105)

The inflation pressure was 2.5 bar.

2. Data Validation

2.1 The Brush Model

Within this project the brush model [2] is considered to be used to describe the tire behavior. One of the main aims with the performed measurements is to verify if the model predicts the tire behavior sufficiently good for friction estimation. The different noise conditions, compared to the Hällered measurements, made it necessary to filter the signals before the parameter optimisation. The filter command `filtfilt` in matlab is used for calculating the floating average of 20 samples without time lag. The sampling time is 0.005 s.

Table 1 List over available test conditions.

Tire type	Road surface	Load	Side slip
Winter tire	Snow	2 kN	0
Winter tire	Snow	4 kN	0
Winter tire	Snow	6 kN	0
Winter tire	Ice	2 kN	0
Winter tire	Ice	4 kN	0
Winter tire	Ice	6 kN	0
Winter tire	Snow	4 kN	$\alpha = \pm 2$ [deg]
Winter tire	Ice	4 kN	$\alpha = \pm 2$ [deg]
Summer tire	Snow	4 kN	0
Summer tire	Ice	4 kN	0
Summer tire	Ice	4 kN	$\alpha = \pm 2$ [deg]
Studded tire	Snow	4 kN	0
Studded tire	Ice	4 kN	0
Studded tire	Ice	4 kN	$\alpha = \pm 2$ [deg]

2.2 Summary of results

The parameters in the brush-model are derived by minimizing the error between the brush-model relation and the measurement data using the Gauss-Newton method. Data points in the low-slip region up to just above the point for fully developed friction force for all repetitions within one test file are used for the optimization. A further restriction for the data points to be used in the optimization is that the absolute value of the slip is increasing. The reason for this is that there is a hysteresis in the measurements when raising and lowering the slip. The results of the lateral data are derived both with and without compensation of the hysteresis. In the case that the hysteresis is compensated, all data within the slip interval are used, even with decreasing absolute slip.

The rolling radius for the tested loads on the different tires was measured by VTI before the tests and the results are shown in Table 2.

Table 2 Rolling radius of the tires, measured by VTI.

Tire	Vertical load		
	2 kN	**4 kN**	**6 kN**
Winter tire	0.3143	0.3120	0.3101
Summer tire	-	0.3096	-
Studded tire	-	0.3129	-

Since the rolling radius may change during the testing, it was necessary to correct for small changes in the data before each test sequence. The identified averaged rolling radius from the slip bias in each test sequence is presented in Table 3. Also comparative results from wet asphalt from the tests in Hällered are included the table. The results are further vizualized in Figure 1.

Table 3 Normal force dependence of the rolling radius, identified from test data.

Tire	Road condition	Loads		
		2 kN	4 kN	6kN
Winter tire	Snow	0.3122	0.3103	0.3095
Winter tire	Ice	0.3123	0.3118	0.3109
Winter tire	Wet Asphalt	0.3079	0.3062	0.3055

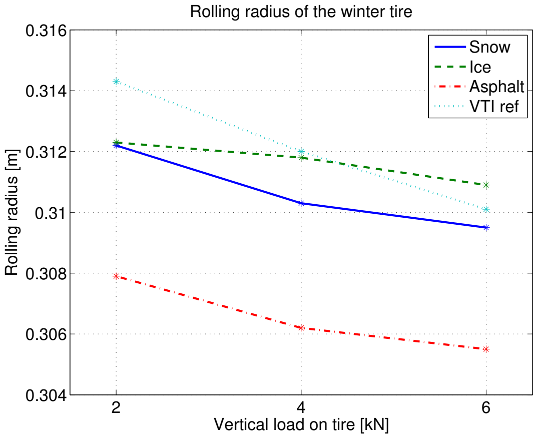

Figure 1 Plot of the load dependence of the rolling radius from Table 2 and 3.

Longitudinal properties It is left to the reader to qualitatively judge the validation of the brush model in the comparison to the data. The results for a few of the longitudinal measurements are shown in Plots 3-12. The obtained model parameters at the different test conditions are presented, as averages, in Table 4 and for each test occasion in Table 10. A comparison of the stiffness and the friction coefficient for different normal loads are found in Tables 5 and 6. The results from wet asphalt shown in these tables are collected from [3].

Table 4 Result of the parameter optimization in the longitudinal direction. The horizontal shift s_h is further described in [3].

Tire	Road condition	Load	Tire Stiff.	Friction	s_h [%]
Winter tire	Snow	2 kN	9.04	0.40	0.69
Winter tire	Snow	4 kN	13.55	0.40	0.55
Winter tire	Snow	6 kN	14.35	0.41	0.20
Winter tire	Ice	2 kN	6.27	0.10	0.64
Winter tire	Ice	4 kN	6.25	0.078	0.077
Winter tire	Ice	6 kN	6.72	0.081	-0.25
Summer tire	Snow	4 kN	22.8	0.26	1.1
Summer tire	Ice	4 kN	3.6	0.077	1.35
Studded tire	Snow	4 kN	11.4	0.51	0.77
Studded tire	Ice	4 kN	5.6	0.16	-0.70

Table 5 The longitudinal tire stiffness for different tires and vertical loads.

Tire	**Road condition**	**Loads**		
		2 kN	4 kN	6kN
Winter tire	Snow	9.04	13.55	14.35
Winter tire	Ice	6.27	6.25	6.72
Winter tire	Wet Asphalt	23.8	27.6	28

Table 6 The friction coefficient for different tires and vertical loads, measured in the longitudinal direction.

Tire	**Road condition**	**Loads**		
		2 kN	4 kN	6kN
Winter tire	Snow	0.40	0.40	0.41
Winter tire	Ice	0.10	0.078	0.081
Winter tire	Wet Asphalt	0.977	1.02	1.05

Lateral properties The agreement of the brush model to the data is shown in Figure 13-22 and the obtained brush-model parameters are collected, as averages in Table 7 and for each test occasion in Table 11. As mentioned in [3] the lateral data show a large hysteresis between increasing and decreasing slip angles, which affected the possibilities to analys the data. An empirical proposal to handle the hyseteresis was proposed. Further testing showed that one reason for the hysteresis may be related to the measurement of the lateral drift of the vehicle that arises due to the lateral force created by the tested tire.

The slip angle of the test truck is measured by an extra wheel rolling behind the vehicle. Due to the geometry, see Figure 2, the lateral velocity of the test vehicle is not measured instantly and it takes a short rolling distance for it to adjust correctly. A somewhat simplified approach becomes

$$\hat{\alpha}_v = \frac{1}{\frac{L_R}{v}s + 1}\alpha_v = G_\alpha(s)\alpha_v \qquad (1)$$

where L_R is estimated to minimize the hystereses and may not necessarily equalize the physical length of the lever holding the extra wheel. The angles, α_1 and α_2 are measured and the slip angle of the truck is calulated as $\hat{\alpha}_v = \alpha_1 - \alpha_2$. By smoothing $\hat{\alpha}_v$ and applying G_α backwards the slip angle of the tire can be corrected as $\alpha_{corr} = \alpha_1 - G_\alpha^{-1}(s)\hat{\alpha}_v$. The hysteresis in the measurements is largely diminished by setting $L_R = 5$ m. In the reality the length of the lever is significantly shorter than 5 m. This indicates that there might be even further sources for the hysteresis.

In Tables 8 and 9 a summary of the result is shown, emphazising on how the parameters vary with the load. The results from asphalt are gathered from [3], but the correction of the hysteresis is performed as stated in this article, see (1) and not as proposed originally. Both the results without (Norm) and with (Corr) the hysteresis correction are presented. The recalculated results are shown in Table 12

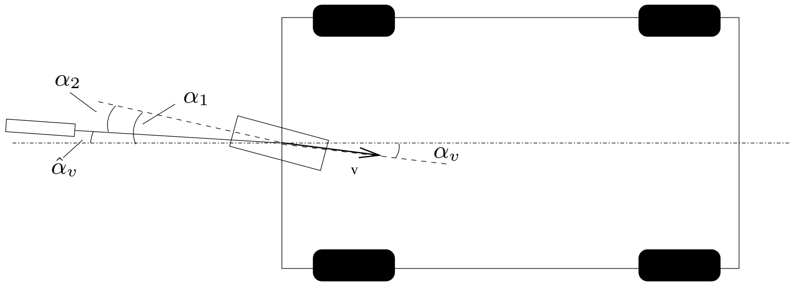

Figure 2 Schematic figure of the slip angle measurement arrangement on the test truck.

Table 7 Result of the parameter optimization in the lateral direction.

Tire	**Road condition**	**Load**	**Tire Stiff.**		**Friction**	
			Norm	**Corr**	**Norm**	**Corr**
Winter tire	Snow	2 kN	11.9	13	0.36	0.369
Winter tire	Snow	4 kN	13.4	12.3	0.387	0.379
Winter tire	Snow	6 kN	13.7	12.7	0.411	0.412
Winter tire	Ice	2 kN	9.12	8.81	0.0873	0.0952
Winter tire	Ice	4 kN	7.63	9.36	0.0775	0.076
Winter tire	Ice	6 kN	5.48	4.64	0.073	0.0796
Summer tire	Snow	4 kN	22.8	18	0.296	0.297
Summer tire	Ice	4 kN	9.01	9.51	0.0916	0.0943
Studded tire	Snow	4 kN	11.8	11.5	0.448	0.449
Studded tire	Ice	4 kN	5.19	4.16	0.113	0.113

2.3 Conclusions and remarks

The measurements are more difficult to evaluate than the results from Hällered due to the larger noise level on the wheel speed signal caused by the unevenness of the snow. There are deviations from the brush model. For the winter tire and the studded tire on snow there is an increase of the friction for higher slip. This means the there is no particular force peak for those tire/road combinations. The same combinations also showed a more rounded form on the tire curve compared to the brush model. It is supposed that the material abrasion/deformation is affecting the behavior, since these tires grip the snow in a different way than the summer tire. Further evaluation is necessary to determine how the disagreement affects the friction estimation and if special treatment is necessary for snow.

The results on ice are hard to evaluate due to the very low friction force. The spread of data points is large, which makes it difficult to discern the tire characteristics..

By comparison between the parameter optimization from the different test conditions the following statements can be done:

- It is clear the the tire stiffness both depend on the tire and the road. The summer tire is stiffer than the winter tire, except for ice. However, the ice measurements are hard to evaluate well.
- The normalized longitudinal tire stiffness of the winter tires on snow is

Table 8 The cornering stiffness for different tires and vertical loads. The results for wet asphalt come from [3].

Tire	**Road condition**	**Stiffness** (Norm;Corr)		
		2 kN	4 kN	6kN
Winter tire	Snow	11.9; 13	13.4; 12.3	13.7; 12.7
Winter tire	Ice	8.9; 8.3	7.6; 9.4	5.5; 4.6
Winter tire	Wet Asphalt	29.6; 21.7	28.6; 16.8	22.38; 15.2

Table 9 The friction coefficient for different tires and vertical loads, measured in the lateral direction. The results for wet asphalt come from [3].

Tire	**Road condition**	**Friction** (Norm;Corr)		
		2 kN	4 kN	6kN
Winter tire	Snow	0.36; 0.37	0.39; 0.38	0.41; 0.41
Winter tire	Ice	0.088; 0.092	0.078; 0.076	0.073; 0.08
Winter tire	Wet Asphalt	1.01; 0.99	1.04; 1.02	1.04; 1.02

significantly smaller for 2 kN than for 4 kN and 6 kN.

- The rolling radius of the tires changes with the load. It is clear that higher load gives smaller radius.

2.4 Acknowledgements

Many thanks to the test team from VTI that during a short, but intensive time slot provided the project with the great amount of valuable measurement data. Also, many thanks to the partners in the RFE-project for good planning and interesting cooperative work. Special acknowledgements to the participants in the RFE sub-project “Model-based road friction estimation” for careful proofreading and valuable opinions on this report.

A. Data Plots and Parameter Tables

In this section plots of comparisons between the data and the tire model are shown for selected tests. There are also tables presenting the optimal choice of parameters for each test sequence. Results from one test sequence at each test condition are shown in the plots. Mostly there are three sequences for each condition. The plots to the left show the measurement data in the force–slip plane together with the brush model with the optimized parameters. Data from the different slip excitation occasions are denoted by different marks, which are indexed in the figure legend. The numbering corresponds to the slip excitations phases shown in the right figure, which covers the data from the entire test sequence.

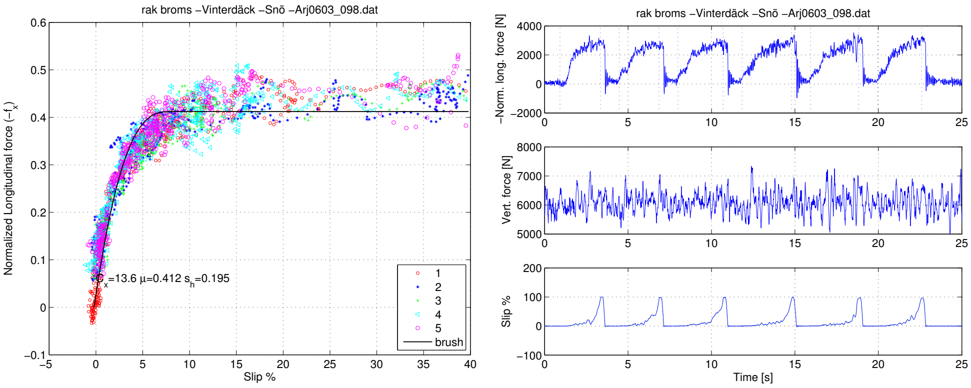

Figure 3 Results from braking test with winter tire on snow. Vertical load 6 kN.

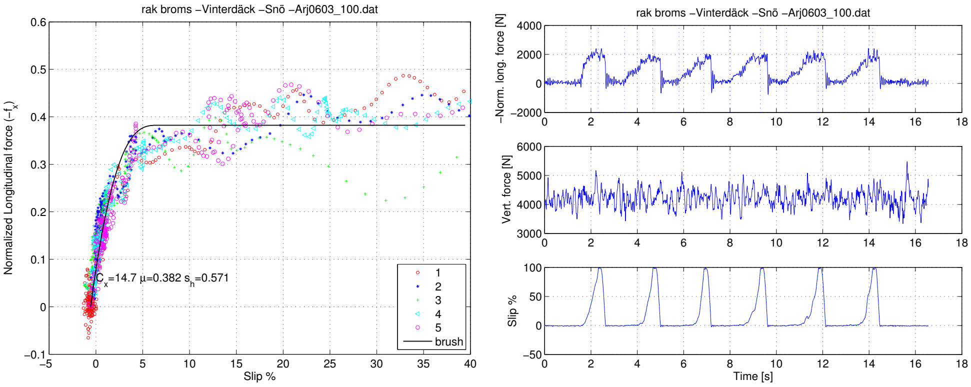

Figure 4 Results from braking test with winter tire on snow. Vertical load 4 kN.

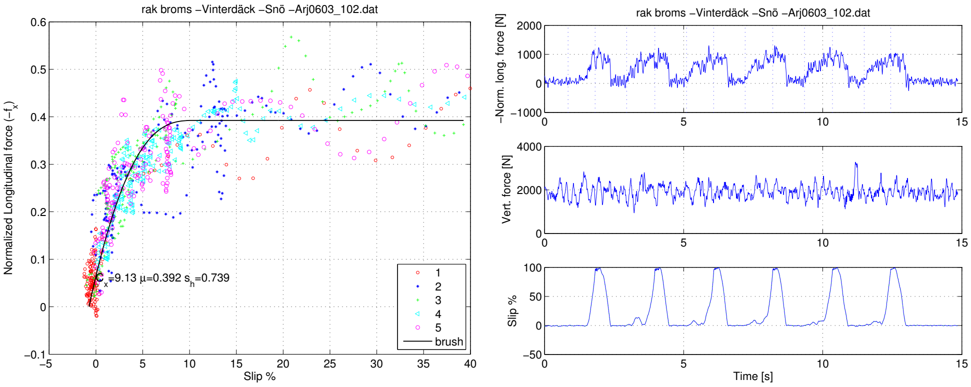

Figure 5 Results from braking test with winter tire on snow. Vertical load 2 kN

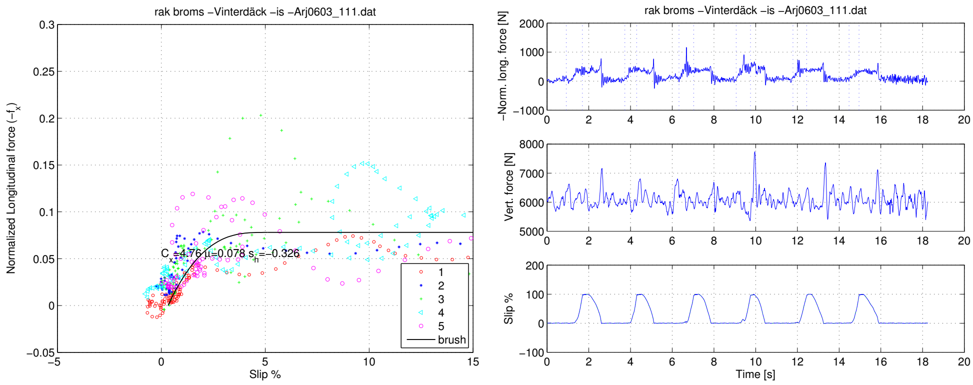

Figure 6 Results from braking test with winter tire on ice. Vertical load 6 kN

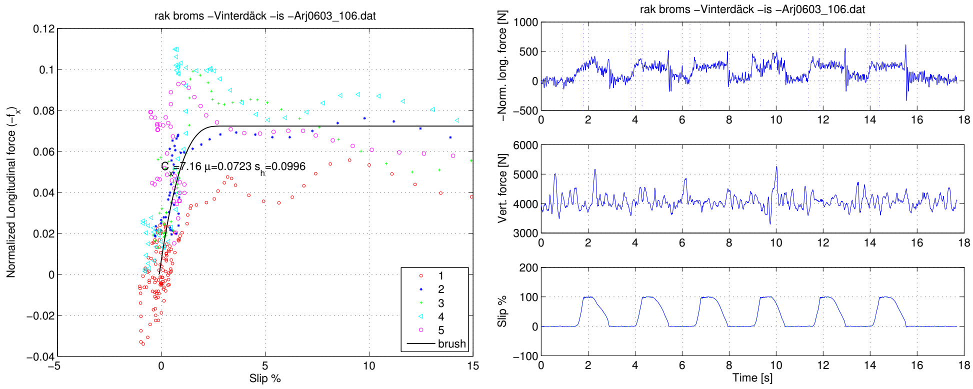

Figure 7 Results from braking test with winter tire on ice. Vertical load 4 kN

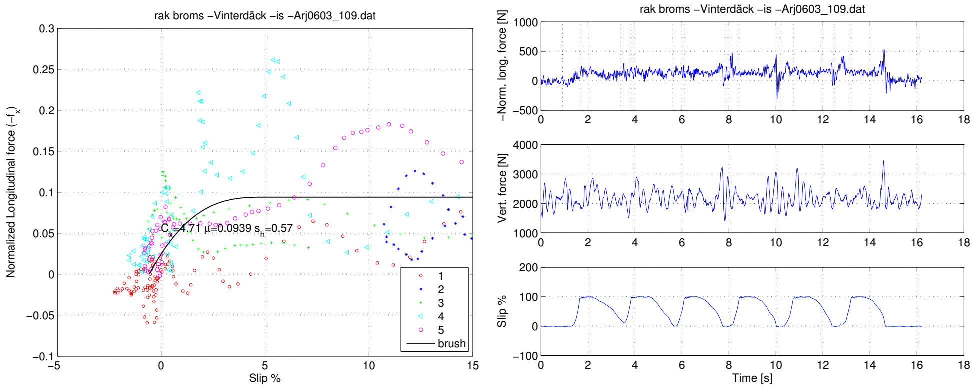

Figure 8 Results from braking test with winter tire on ice. Vertical load 2 kN

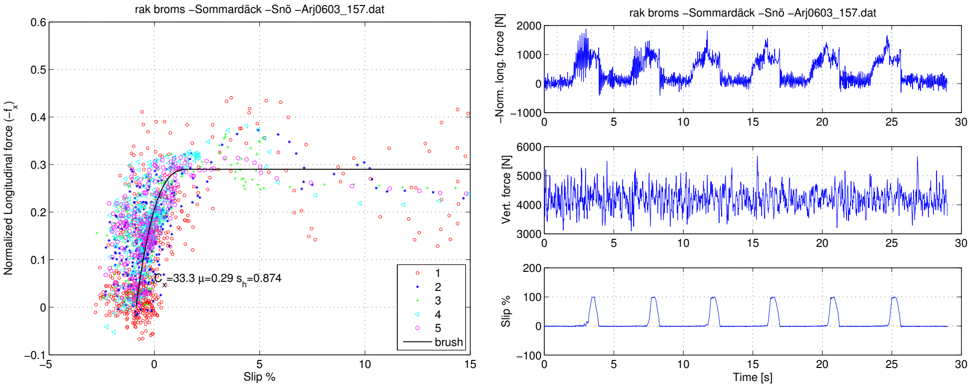

Figure 9 Results from braking test with summer tire on snow. Vertical load 4 kN

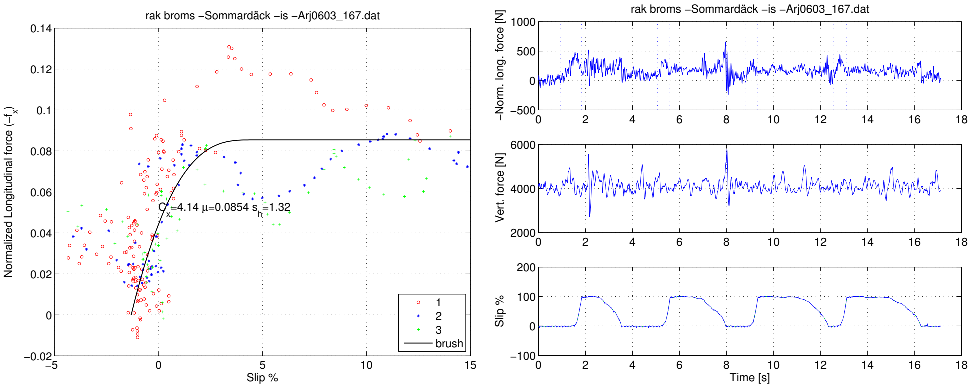

Figure 10 Results from braking test with summer tire on ice. Vertical load 4 kN

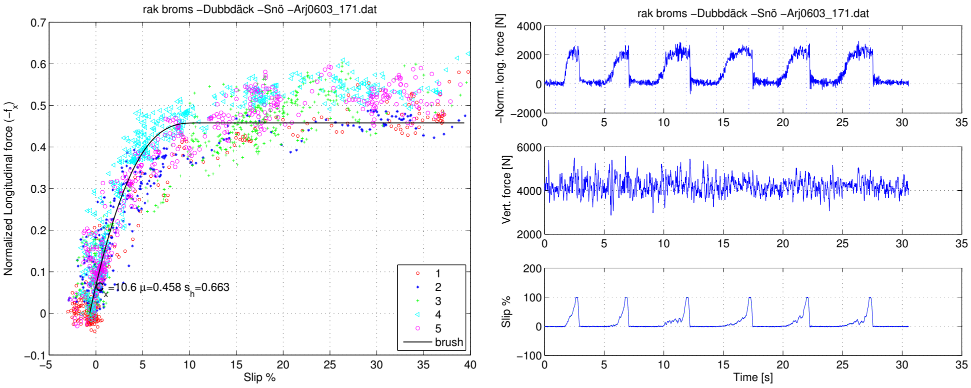

Figure 11 Results from braking test with studded tire on snow. Vertical load 4 kN

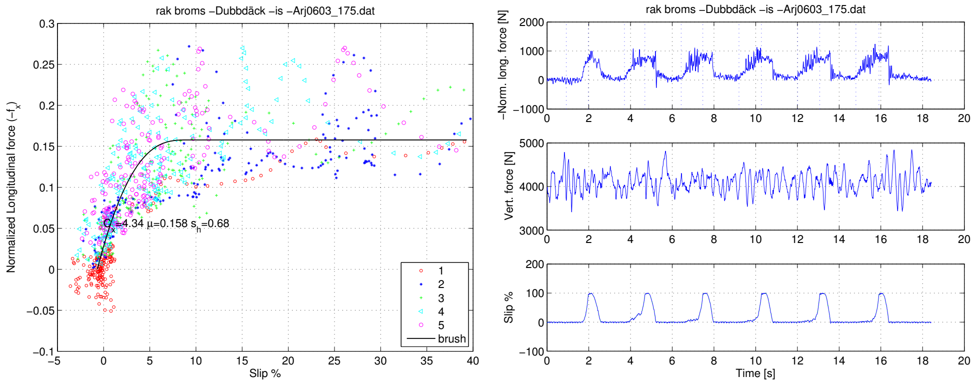

Figure 12 Results from braking test with studded tire on ice. Vertical load 4 kN

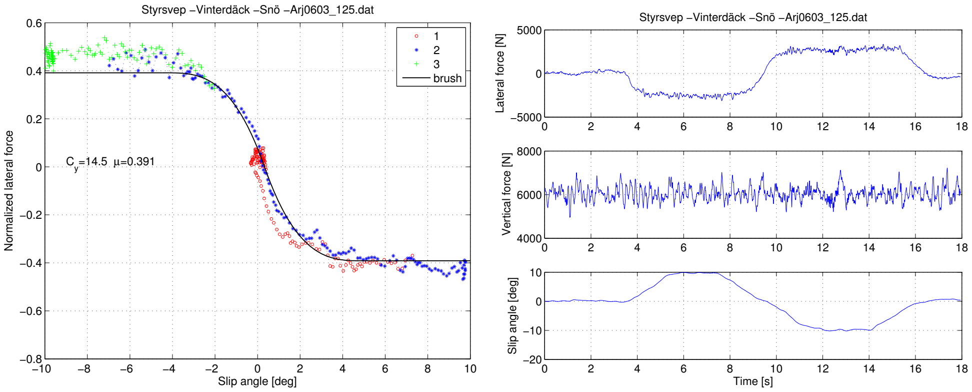

Figure 13 Results from steering test with winter tire on snow. Vertical load 6 kN

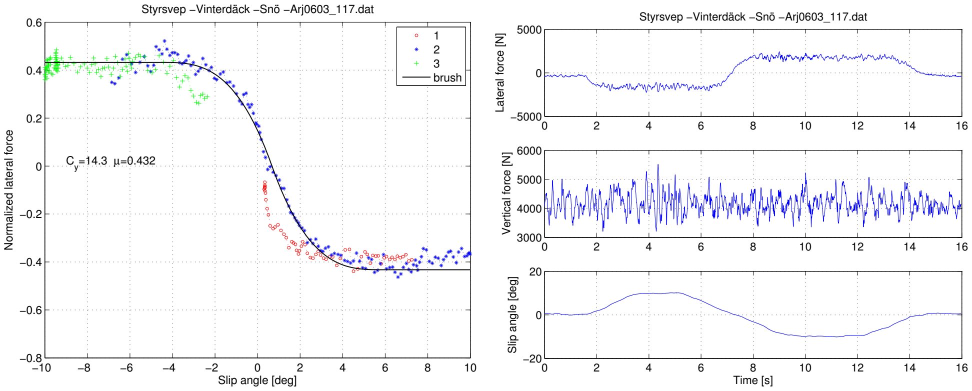

Figure 14 Results from steering test with winter tire on snow. Vertical load 4 kN

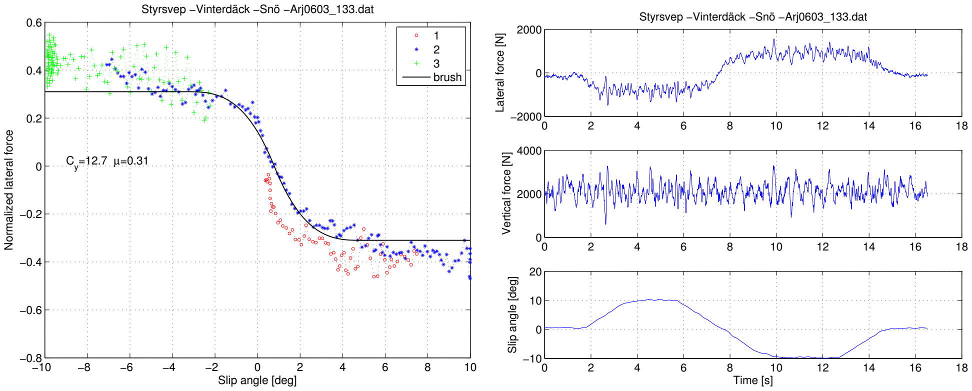

Figure 15 Results from steering test with winter tire on snow. Vertical load 2 kN

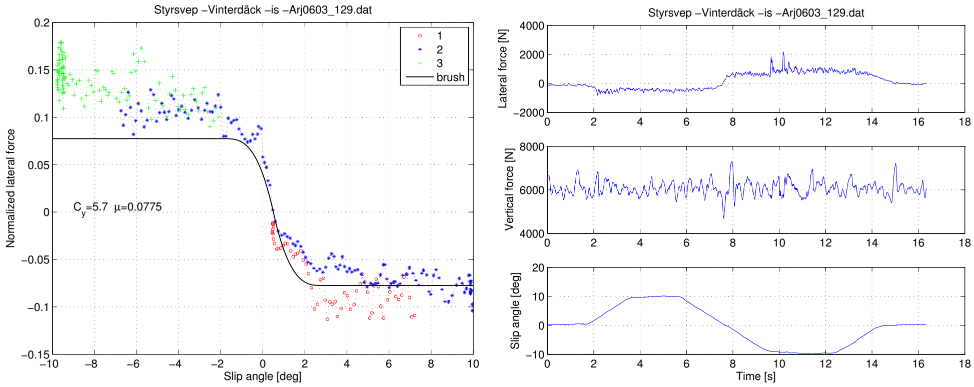

Figure 16 Results from steering test with winter tire on ice. Vertical load 6 kN

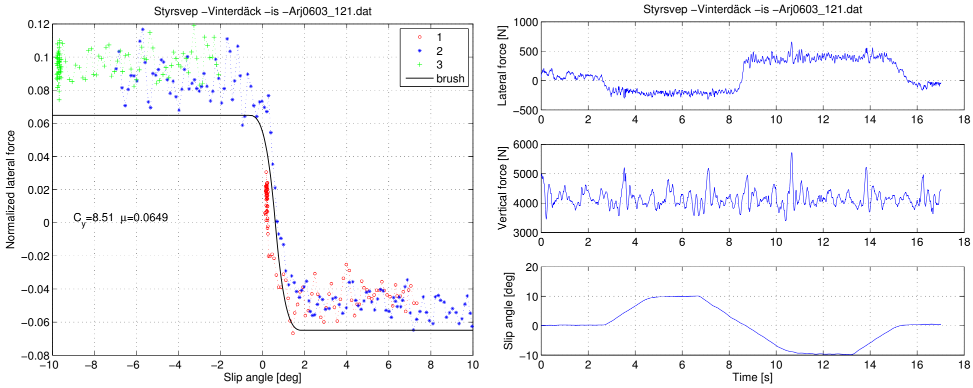

Figure 17 Results from steering test with winter tire on ice. Vertical load 4 kN

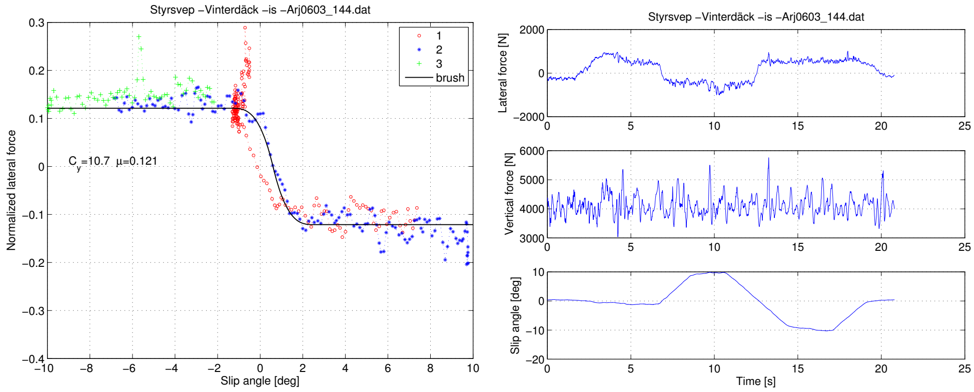

Figure 18 Results from steering test with winter tire on ice. Vertical load 2 kN

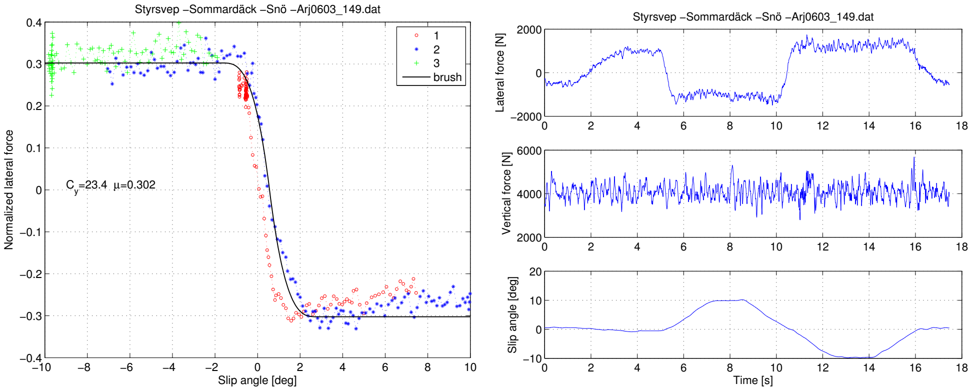

Figure 19 Results from steering test with summer tire on snow. Vertical load 4 kN

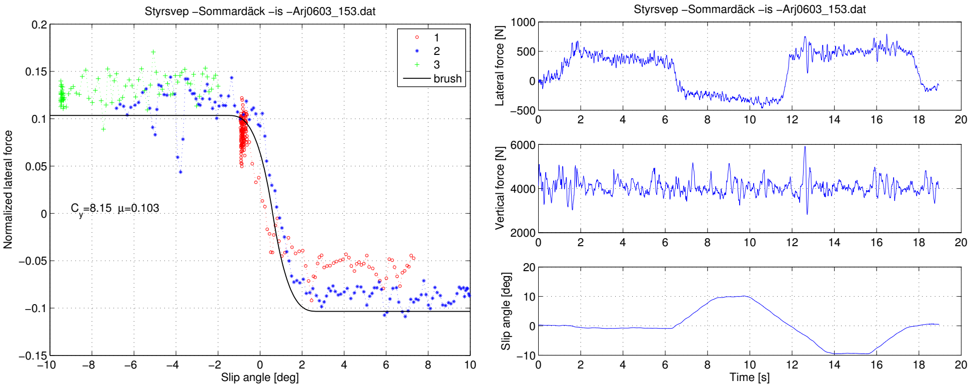

Figure 20 Results from steering test with summer tire on ice. Vertical load 4 kN

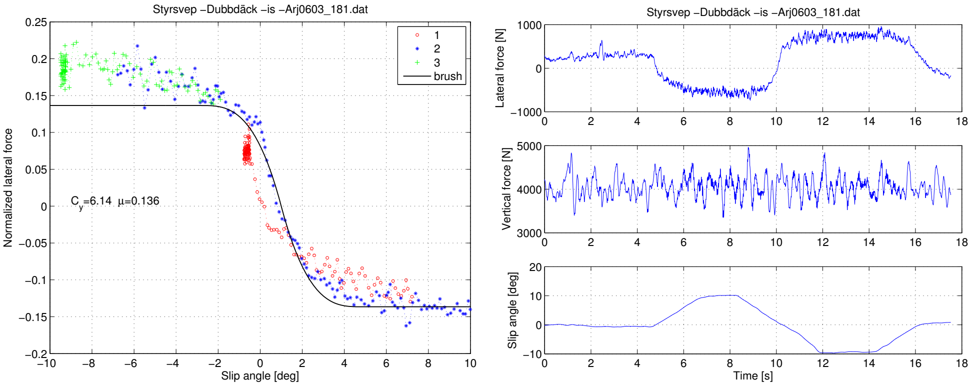

Figure 21 Results from steering test with studded tire on ice. Vertical load 4 kN

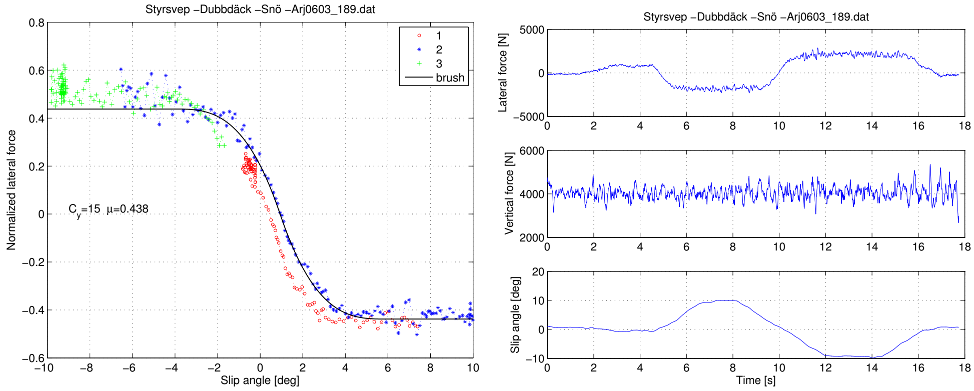

Figure 22 Results from steering test with studded tire on snow. Vertical load 4 kN

Table 10: Parameter estimations from all longitudinal tests. The rolling radius R_e is here the values from Table 2 with correction from the estimated horisontal shift s_H.

Description	C_x	μ [%]	s_H	R_e **[mm]**	F_z **[kN]**
rak broms -Vinterdäck -Snö -Arj0603_098	13.6	0.412	0.195	309.5	6
rak broms -Vinterdäck -Snö -Arj0603_099	15.1	0.414	0.211	309.4	6
rak broms -Vinterdäck -Snö -Arj0603_100	14.7	0.382	0.571	310.2	4
rak broms -Vinterdäck -Snö -Arj0603_101	12.4	0.423	0.534	310.3	4
rak broms -Vinterdäck -Snö -Arj0603_102	9.13	0.392	0.739	312	2
rak broms -Vinterdäck -Snö -Arj0603_103	8.95	0.41	0.634	312.3	2
rak broms -Vinterdäck -is -Arj0603_106	7.16	0.0723	0.0996	311.7	4
rak broms -Vinterdäck -is -Arj0603_107	6.3	0.0796	0.105	311.7	4
rak broms -Vinterdäck -is -Arj0603_108	5.13	0.0823	0.0262	311.9	4
rak broms -Vinterdäck -is -Arj0603_109	4.71	0.0939	0.57	312.5	2
rak broms -Vinterdäck -is -Arj0603_110	7.82	0.114	0.711	312.1	2
rak broms -Vinterdäck -is -Arj0603_111	4.76	0.078	-0.326	311.1	6
rak broms -Vinterdäck -is -Arj0603_112	8.69	0.0853	-0.182	310.6	6
Kombinerad broms med vinkel -Vinterdäck -Snö -Arj0603_113	9.24	0.432	0.43	310.7	4
Kombinerad broms med vinkel -Vinterdäck -Snö -Arj0603_114	9.02	0.425	0.434	310.6	4
Kombinerad broms med vinkel -Vinterdäck -Snö -Arj0603_115	8.01	0.396	0.562	310.3	4
Kombinerad broms med vinkel -Vinterdäck -Snö -Arj0603_116	9.11	0.42	0.342	310.9	4
rak broms -Sommardäck -Snö -Arj0603_157	33.3	0.29	0.874	306.9	4
rak broms -Sommardäck -Snö -Arj0603_158	25.1	0.271	1.05	306.3	4
rak broms -Sommardäck -Snö -Arj0603_159	19.2	0.252	-0.365	310.7	4
rak broms -Sommardäck -Snö -Arj0603_160	12.2	0.246	0.777	307.2	4
rak broms -Sommardäck -Snö -Arj0603_161	24.3	0.245	1.7	305.9	4
Kombinerad broms med vinkel -Sommardäck -Snö -Arj0603_162	8.58	0.256	1.76	305.7	4
Kombinerad broms med vinkel -Sommardäck -Snö -Arj0603_163	9.05	0.277	1.77	305.7	4
Kombinerad broms med vinkel -Sommardäck -Snö -Arj0603_164	9.81	0.257	1.69	305.9	4

Table 10: Parameter estimations from all longitudinal tests. The rolling radius R_e is here the values from Table 2 with correction from the estimated horisontal shift s_H.

Description	C_x	μ [%]	s_H	R_e **[mm]**	F_z **[kN]**
Kombinerad broms med vinkel -Sommardäck -Snö -Arj0603_165	9.63	0.237	1.74	305.8	4
rak broms -Sommardäck -is -Arj0603_167	4.14	0.0854	1.32	307.1	4
rak broms -Sommardäck -is -Arj0603_168	2.97	0.0587	1.29	307.2	4
rak broms -Sommardäck -is -Arj0603_169	3.68	0.0864	1.45	306.7	4
rak broms -Sommardäck -Snö -Arj0603_170	20.9	0.278	1.8	305.6	4
rak broms -Dubbdäck -Snö -Arj0603_171	10.6	0.458	0.663	309.1	4
rak broms -Dubbdäck -Snö -Arj0603_172	11.8	0.466	-9.47	342.4	4
rak broms -Dubbdäck -is -Arj0603_175	4.34	0.158	0.68	310.7	4
rak broms -Dubbdäck -is -Arj0603_176	6.86	0.163	0.719	310.6	4
Kombinerad broms med vinkel -Dubbdäck -is -Arj0603_185	9.53	0.461	0.756	310.5	4
Kombinerad broms med vinkel -Dubbdäck -is -Arj0603_186	7.59	0.434	0.693	310.7	4
Kombinerad broms med vinkel -Dubbdäck -is -Arj0603_187	8.7	0.475	0.751	310.5	4
Kombinerad broms med vinkel -Dubbdäck -is -Arj0603_188	7.3	0.452	0.667	310.8	4
rak broms -Dubbdäck -Snö -Arj0603_193	11.4	0.507	0.776	310.4	4

Table 11: Parameter estimations from all lateral tests.

Description	**Normal**		**Adjusted**		
	C_x	μ	C_x	μ	
Styrsvep -Vinterdäck -Snö -Arj0603_117	14.3	0.432	14.9	0.401	4
Styrsvep -Vinterdäck -Snö -Arj0603_118	11.3	0.355	7.78	0.355	4
Styrsvep -Vinterdäck -Snö -Arj0603_119	15	0.378	13	0.377	4
Styrsvep -Vinterdäck -Snö -Arj0603_120	12.9	0.383	13.6	0.385	4
Styrsvep -Vinterdäck -is -Arj0603_121	8.51	0.0649	4.42	0.0678	4
Styrsvep -Vinterdäck -is -Arj0603_122	7.71	0.0933	16	0.0873	4
Styrsvep -Vinterdäck -is -Arj0603_123	6.15	0.0713	8.3	0.0625	4
Styrsvep -Vinterdäck -is -Arj0603_124	8.16	0.0804	8.7	0.0865	4

Table 11: Parameter estimations from all lateral tests.

Description	**Normal**		**Adjusted**		
	C_x	μ	C_x	μ	
Styrsvep -Vinterdäck -Snö -Arj0603_125	14.5	0.391	11.6	0.422	6
Styrsvep -Vinterdäck -Snö -Arj0603_126	13.5	0.431	12.4	0.419	6
Styrsvep -Vinterdäck -Snö -Arj0603_127	11.6	0.401	11.9	0.399	6
Styrsvep -Vinterdäck -Snö -Arj0603_128	15.2	0.42	14.7	0.408	6
Styrsvep -Vinterdäck -is -Arj0603_129	5.7	0.0775	3.58	0.0932	6
Styrsvep -Vinterdäck -is -Arj0603_130	4.95	0.074	4.18	0.0814	6
Styrsvep -Vinterdäck -is -Arj0603_131	5.81	0.0782	5.89	0.0794	6
Styrsvep -Vinterdäck -is -Arj0603_132	5.48	0.0625	4.89	0.0646	6
Styrsvep -Vinterdäck -Snö -Arj0603_133	12.7	0.31	14.4	0.332	2
Styrsvep -Vinterdäck -Snö -Arj0603_134	9.87	0.383	10.3	0.377	2
Styrsvep -Vinterdäck -Snö -Arj0603_135	12.3	0.354	13.6	0.362	2
Styrsvep -Vinterdäck -Snö -Arj0603_136	12.7	0.394	13.8	0.403	2
Styrsvep -Vinterdäck -is -Arj0603_137	11.5	0.078	4.8	0.0711	2
Styrsvep -Vinterdäck -is -Arj0603_138	9.52	0.0737	5.51	0.0727	2
Styrsvep -Vinterdäck -is -Arj0603_139	9.2	0.0561	4.24	0.069	2
Styrsvep -Vinterdäck -is -Arj0603_140	7.45	0.069	6.15	0.0899	2
Styrsvep -Vinterdäck -is -Arj0603_144	10.7	0.121	17.7	0.124	2
Styrsvep -Vinterdäck -is -Arj0603_145	8.08	0.0891	-152	0.0966	2
Styrsvep -Vinterdäck -is -Arj0603_146	7.99	0.112	10.4	0.126	2
Styrsvep -Vinterdäck -is -Arj0603_147	7.79	0.108	-13.4	0.0915	2
Styrsvep -Vinterdäck -is -Arj0603_148	7.95	0.0873	9.56	0.0915	2
Styrsvep -Sommardäck -Snö -Arj0603_149	23.4	0.302	21.3	0.302	4
Styrsvep -Sommardäck -Snö -Arj0603_150	20.6	0.291	18.6	0.291	4
Styrsvep -Sommardäck -Snö -Arj0603_151	27.9	0.295	16.4	0.299	4
Styrsvep -Sommardäck -Snö -Arj0603_152	19.5	0.295	15.8	0.296	4
Styrsvep -Sommardäck -is -Arj0603_153	8.15	0.103	6.87	0.0976	4
Styrsvep -Sommardäck -is -Arj0603_154	8.77	0.0878	10.2	0.0941	4
Styrsvep -Sommardäck -is -Arj0603_155	11.3	0.0909	12.4	0.0982	4
Styrsvep -Sommardäck -is -Arj0603_156	7.87	0.084	8.57	0.0875	4
Styrsvep -Dubbdäck -is -Arj0603_181	6.14	0.136	4.98	0.131	4
Styrsvep -Dubbdäck -is -Arj0603_182	6.44	0.111	4.19	0.111	4
Styrsvep -Dubbdäck -is -Arj0603_183	4.28	0.105	3.8	0.109	4

Table 11: Parameter estimations from all lateral tests.

Description	**Normal**		**Adjusted**		
	C_x	μ	C_x	μ	
Styrsvep -Dubbdäck -is -Arj0603_184	3.88	0.098	3.68	0.1	4
Styrsvep -Dubbdäck -Snö -Arj0603_189	15	0.438	12.1	0.463	4
Styrsvep -Dubbdäck -Snö -Arj0603_190	10.6	0.414	11.8	0.424	4
Styrsvep -Dubbdäck -Snö -Arj0603_191	11.9	0.476	12.5	0.442	4
Styrsvep -Dubbdäck -Snö -Arj0603_192	9.65	0.466	9.73	0.467	4

Table 12: Parameter estimations from all lateral tests in Hällered with new correlation calculations according to this report.

Description	**Normal**		**Adjusted**		
	C_x	μ	C_x	μ	F_z **kN**
Cornering -Winter tire -Low friction -H0511_127	33.1	0.37	11.3	0.34	4
Cornering -Winter tire -Low friction -H0511_128	30.2	0.264	27.5	0.237	4
Cornering -Winter tire -Low friction -H0511_129	36.7	0.304	20.1	0.287	4
Cornering -Winter tire -Low friction -H0511_130	38.5	0.274	32.4	0.241	4
Cornering -Winter tire -Low friction -H0511_131	52.4	0.316	21.5	0.304	4
Cornering -Winter tire -Low friction -H0511_132	28	0.301	15.4	0.27	4
Cornering -Winter tire -Wet asphalt -H0511_133	31.9	1.1	19	0.992	4
Cornering -Winter tire -Wet asphalt -H0511_134	31.1	1.07	16.6	1.01	4
Cornering -Winter tire -Wet asphalt -H0511_135	26.7	1	15.8	1.02	4
Cornering -Winter tire -Wet asphalt -H0511_136	27.5	1.02	16.3	1.03	4
Cornering -Winter tire -Wet asphalt -H0511_137	25.6	1.05	16.9	1.03	4
Cornering -Winter tire -Wet asphalt -H0511_138	28.6	1.05	16.1	1.04	4
Cornering -Winter tire -Dry asphalt -H0511_139	28.6	1.15	17.9	1.1	4
Cornering -Winter tire -Dry asphalt -H0511_140	27.3	1.16	17.5	1.09	4
Cornering -Winter tire -Dry asphalt -H0511_141	24.3	1.16	16.6	1.12	4
Cornering -Summer Tire -Dry asphalt -H0511_142	35.6	1.04	21.7	1.05	4
Cornering -Summer Tire -Dry asphalt -H0511_143	32.1	1.13	20.2	1.08	4

Table 12: Parameter estimations from all lateral tests in Hällered with new correlation calculations according to this report.

Description	**Normal**		**Adjusted**		
	C_x	μ	C_x	μ	F_z **kN**
Cornering -Summer Tire -Dry asphalt -H0511_144	29.6	1.16	19.2	1.1	4
Cornering -Summer Tire -Wet asphalt -H0511_155	30.4	1.03	22.1	1.02	4
Cornering -Summer Tire -Wet asphalt -H0511_156	29.6	1.06	22.3	1.03	4
Cornering -Summer Tire -Wet asphalt -H0511_157	32.9	1.05	21.4	1.04	4
Cornering -Winter tire -Wet asphalt -H0511_158	27	1.03	18.9	1.01	4
Cornering -Winter tire -Wet asphalt -H0511_159	27	1.02	19.2	1.01	4
Cornering -Winter tire -Wet asphalt -H0511_160	26.8	1.02	19.2	1.01	4
Cornering -Winter tire -Wet asphalt -H0511_161	29.6	1.01	21.8	0.988	2
Cornering -Winter tire -Wet asphalt -H0511_162	29.9	1.01	21.4	0.994	2
Cornering -Winter tire -Wet asphalt -H0511_163	29.3	1.01	21.8	0.997	2
Cornering -Winter tire -Wet asphalt -H0511_164	23.3	1.04	15.4	1.02	6
Cornering -Winter tire -Wet asphalt -H0511_165	21.8	1.04	15.3	1.02	6
Cornering -Winter tire -Wet asphalt -H0511_166	22.1	1.05	15	1.03	6

B. References

[1] O Nordström and H Áström. Upgrading of VTI friction test vehicle BV12 for combined braking and steering tests under aquaplaning and winter conditions. In *2ND INTERNATIONAL COLLOQUIUM ON VEHICLE TYRE ROAD INTERACTION*, Florence, Italy, February 2001.

[2] Jacob Svendenius. Tire models for use in braking applications. Licentiate thesis ISRN LUTFD2/TFRT--3232--SE, Department of Automatic Control, Lund University, Sweden, nov 2003.

[3] Jacob Svendenius. Validation of the brush model towards VTI-measurement data recorded at hällered 2005. Technical report, RFE-IVSS, 2007.