Skid Resistance of Snow- or Ice-Covered Roads

Kaoru Ichihara and Makoto Mizoguchi

This paper reports skid resistance coefficients obtained on snow- or ice-covered roads. Skid resistance changes according to snow conditions, temperature, kinds of vehicle tires, and chemicals used. Three classifications of skid resistance used are skid resistance in braking condition, skid resistance in driving condition when the tire does not slip and just before it begins to spin, and skid resistance in driving conditions when the tire is spinning. These data are used in discussion of stopping distance, longitudinal gradient, and cross fall of the road.

Under normal conditions, braking force is produced by the friction between road surface and tire. When a snow or ice layer is present on a pavement, we are concerned with the friction between the layer and the tire. The coefficient of friction on a snow- or ice-covered surface is considerably smaller than that on a normal pavement. Because of this low friction, we have many problems, such as longer stopping distances or a limiting longitudinal gradient for a vehicle to start. To solve these problems, we measured and analyzed coefficients of friction on various snow or ice surfaces.

CLASSIFICATION OF COEFFICIENTS OF FRICTION ON SNOW- OR ICE-COVERED ROADS

Usually braking force is measured, and the value obtained is applied to the evaluation of pavements. On snow- or ice-covered pavements, traction force coefficients that define whether vehicles will be able to start from standstill are of as much concern as the braking force coefficients. The braking force coefficient is used not only for calculating stopping distance but also for analyzing the motion of the vehicle in skidding.

When a vehicle starts from a standstill, the traction force increases gradually; but when the tire begins to spin, the traction force drops to a lower value (Fig. 1). This fact leads to complications in the determination of the maximum gradient for starting on snow- or ice-covered surfaces. Furthermore, tire spin can occur not only when the vehicle begins moving but also after the vehicle is in motion.

For these reasons, the authors classified the possible coefficients of friction on snow- or ice-covered roads into 4 categories: braking force coefficient, traction force coefficient of tire immediately before it begins to spin, traction force coefficient of spinning tire with stationary vehicle, and traction force coefficient of spinning tire with moving vehicle.

BRAKING FORCE COEFFICIENT

Skid Resistance Coefficient

Table 1 gives skid resistance coefficients on various snow- or ice-covered roads. On flat ice surfaces, coefficients are around 0.1, sometimes dropping to near zero on completely flat surfaces. On a new snow layer compacted by traffic, coefficients of 0.10 to 0.15 are observed. On a compacted snow or ice surface, which is most frequently observed, coefficients are around 0.2 to 0.3. When a snow layer becomes relatively old and its surface has changed into relatively large ice granules (through melting and freezing processes), coefficients of friction are in the range of 0.3 to 0.5.

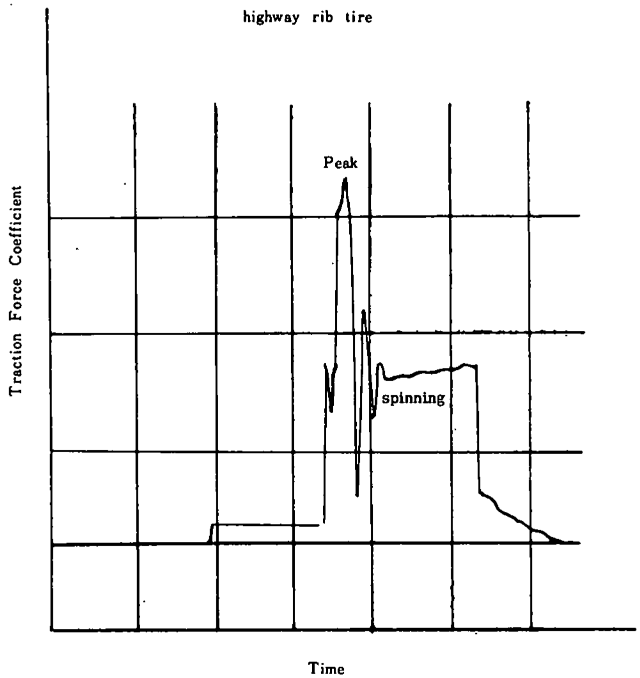

Figure 1. Change of traction force coefficient at starting time.

In this case, the crushing resistance of this old snow layer is included. When sand or small crushed stone or small amounts of chlorides (NaCl, $CaCl_2$, or $MgCl_2$) are spread on snow- or ice-covered roads, coefficients of friction are increased to 0.3 to 0.4. It is obvious that the coefficient of friction increases as snow or ice disappears either by using large amounts of chlorides or by pavement heating.

Slip Resistance Coefficient

Figures 2 and 3 show coefficient of friction under slip on various snow- or ice-covered roads. Generally on a wet

TABLE 1

SKID RESISTANCE COEFFICIENTS ON SNOW- OR ICE-COVERED ROADS AT A SPEED OF 30 TO 40 KM/HR

Snow or Ice Condition	Skid Resistance Coefficient
Ice	0.1 to 0.2
New snow	0.2 to 0.25
Old snow	0.25 to 0.30
Refrozen snow	0.30 to 0.40
Chloride-treated snow	0.35 to 0.45
Sand-treated snow	0.30 to 0.40
Chloride-sand mixture	0.30 to 0.50

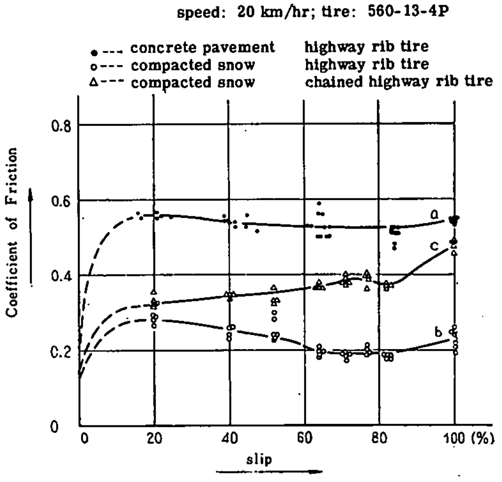

Figure 2. Coefficient of friction under Slip 1, 1967.

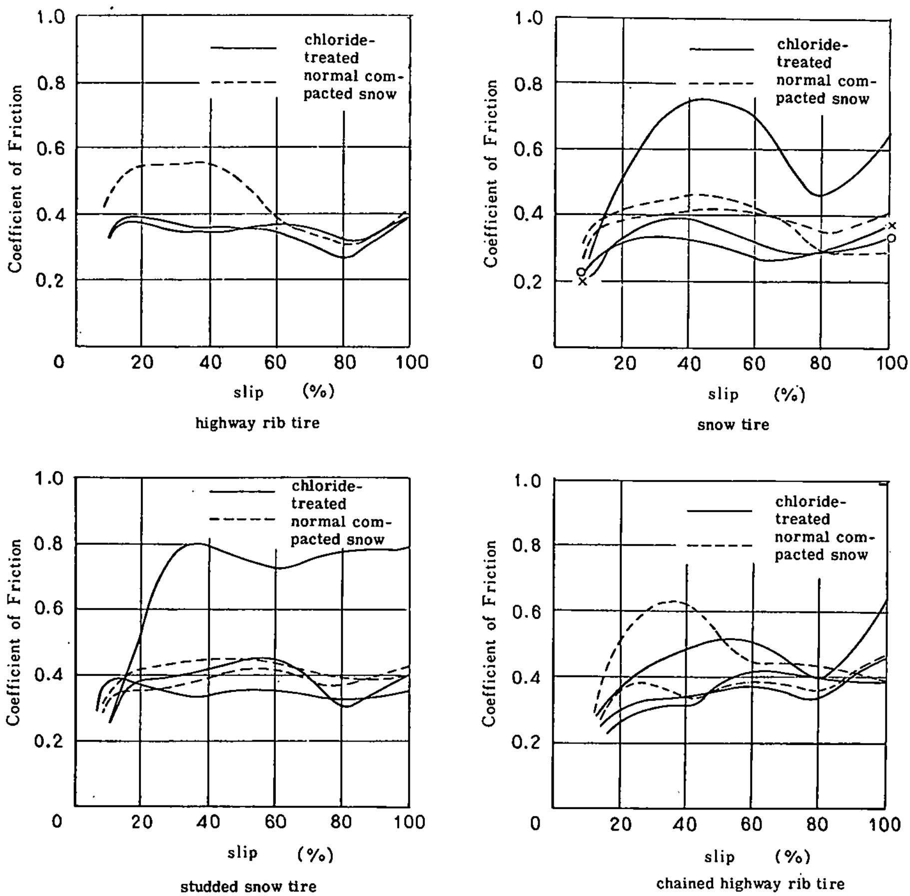

Figure 3. Coefficient of friction under Slip 2, 1968.

pavement, maximum coefficient of friction occurs around 20 percent slip. On snow- or ice-covered roads, however, maximum values were observed at higher slip, and several patterns were seen according to the type of tire and state of the snow.

Maximum values were observed at 20 to 30 percent slip with highway rib tires, at 40 to 60 percent slip with snow tires or studded snow tires, and at 80 to 100 percent slip with chained highway rib tires. This means that the slip ratio at maximum friction moves toward higher slip according to allowable tread deformation of the tire.

On the other hand, on a normal compacted snow surface maximum values were observed at 20 to 40 percent slip, and at higher slip on a chloride-treated surface. Maximum values occur at relatively low slip on a hard snow surface and at higher slip on a soft snow surface. However, the differences between these maximum values and skid resistance coefficients at 100 percent slip are small.

Effect of Chemicals and Sand

Chloride—Changes of skid resistance on chloride-treated roads are shown in Figure 4. In these cases, 50 g/m^2 of chloride were spread prior to skid measurements. Higher coefficients of friction were observed on treated surfaces. Chlorides improved skid resistance by about 0.05 to 0.15, producing skid resistance values of about 0.4

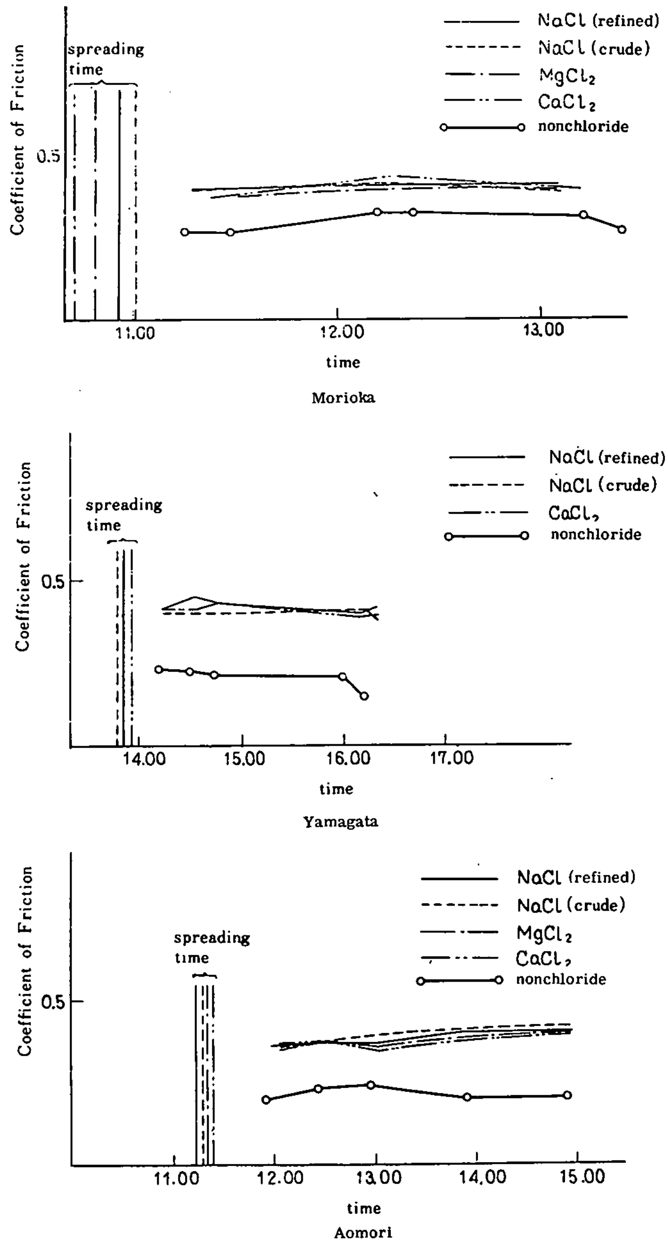

Figure 4. Effect of chlorides.

(with snow tires) regardless of original values. No difference among the chlorides was observed.

Sand—Figure 5 shows the effects of sand and sand-chloride mixtures. These tests were conducted by the Civil Engineering Experimental Laboratory, Hokkaido Development Bureau. The effect of sand was relatively small. High coefficients of friction (0.4 for snow tires) were observed with high chloride content. This is considered to be an effect of the chloride itself.

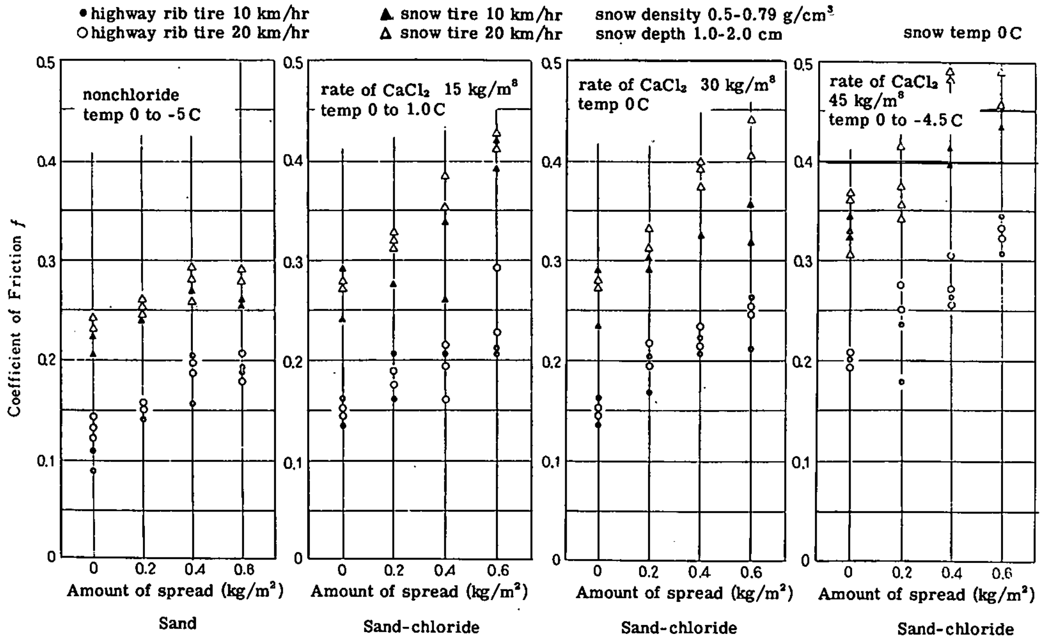

Figure 5. Effects of sand and sand-chloride mixtures.

Effect of Speed and Temperature

Figure 6 shows the relationship between coefficient of friction and speed on snow- or ice-covered roads. Coefficient of friction is low at low speed and does not change much with increasing speed. As speed increases the crushing resistance of the snow layer also increases. These facts are completely different from those for wet skidding.

Skid resistance coefficients on snow- or ice-covered roads were measured at 5 locations in northern Japan during the 1968-1969 winter. Table 2 gives these data tabulated by temperature. Coefficients of friction were observed to be relatively low at temperatures around 0 C and higher at temperatures both above and below the freezing point. But characteristics of skid resistance on snow- or ice-covered roads are not classified by temperature only.

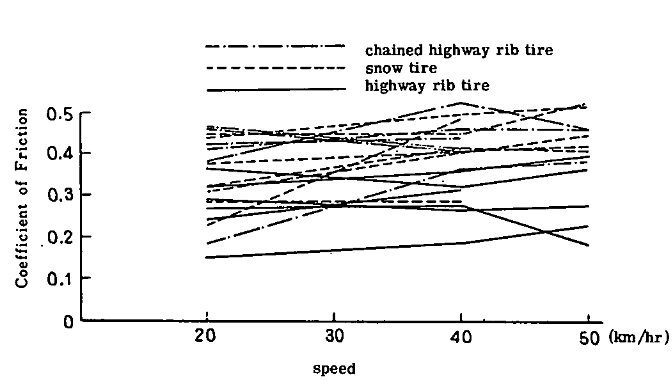

Figure 6. Coefficient of friction and speed.

TABLE 2

TEMPERATURE AND SKID RESISTANCE COEFFICIENTS

Temperature (deg C)	Hokkaido	Tōhoku	Hokuriku	Joetsu	Average
Highway Rib Tire					
-5					
-5 to 0				0.272 0.392	0.272-0.392 0.332(2)
0 to +2.5					
+2.5 to +5.0					
Snow Tire					
-5	0.301 0.232				0.232-0.301 0.266(2)
-5 to 0	0.333 0.250 0.290	0.369	0.208 0.399 0.379 0.209	0.261 0.372 0.422	0.208-0.422 0.317(11)
0 to +2.5		0.262 0.328 0.392	0.436 0.917	0.558 0.502	0.197-0.558 0.382(7)
+2.5 to +5.0		0.259 0.211 0.245 0.178 0.439		0.593	0.178-0.593 0.321(6)
Studded Snow Tire					
-5	0.298 0.260				0.260-0.298 0.279(2)
-5 to 0	0.324 0.335 0.325			0.296	0.296-0.335 0.320(4)
0 to +2.5		0.433 0.439			0.433-0.439 0.436(2)
+2.5 to +5.0					
Chained Highway Rib Tire					
-5	0.323 0.248				0.248-0.323 0.286(2)
-5 to 0	0.365 0.215 0.340		0.337 0.365 0.317 0.282	0.480	0.215-0.480 0.337(8)
0 to +2.5	0.195	0.217 0.220 0.223 0.202 0.247 0.240 0.280	0.401 0.315		0.195-0.401 0.254(10)
+2.5 to +5.0		0.215 0.204			0.204-0.215 0.210(2)

TABLE 3

TRACTION FORCE COEFFICIENTS AT START AND ROLLING RESISTANCE, 1968

Location	Condition	Waiting Time (sec)	Test Tire: Highway Rib Tire Range	Highway Rib Tire Avg.	Snow Tire Range	Snow Tire Avg.	Studded Snow Tire Range	Studded Snow Tire Avg.	Chained Highway Rib Tire Range	Chained Highway Rib Tire Avg.
Kurikara[a]	Spinning[e]		0.093-0.117	0.106(3)					0.426-0.461	0.444(2)
	Spinning[f]	30	0.119-0.157	0.134(3)					0.405-0.536	0.455(5)
	Spinning[f]	300	0.111-0.152	0.127(3)						
Amada[a]	Spinning[e]		0.040-0.085	0.070(3).	0.039-0.404	0.322(2)	0.419-0.440	0.430(2)		
					0.369-0.432	0.400(2)				
	Spinning[f]	30	0.064-0.086	0.070(4)	0.145-0.204	0.184(3)	0.558-0.678	0.617(3)		
					0.258-0.377	0.324(3)				
Amada[b]	Spinning[e]		0.337-0.365	0.349(3)	0.309-0.506	0.396(3)	0.361-0.453	0.398(3)	0.452-0.471	0.460(3)
	Spinning[f]	30	0.043-0.187	0.133(3)	0.383-0.517	0.460(4)	0.367-0.481	0.448(4)	0.269-0.418	0.351(3)
	Rolling resistance		0.066-0.089	0.083(4)	0.075-0.108	0.092(8)	0.060-0.101	0.084(6)	0.079-0.113	0.090(5)
Kanazawa Un.[c]	Spinning[e]		0.210-0.240	0.223(3)	0.318	0.318(1)	0.449-0.469	0.459(3)	0.345-0.387	0.370(3)
	Peak value	30	0.166-0.601	0.307(5)	0.507-0.743	0.665(5)	0.713-0.888	0.778(9)	0.689-0.805	0.753(4)
	Spinning[f]	30	0.052-0.221	0.149(5)	0.333-0.593	0.442(5)	0.149-0.645	0.484(9)	0.489-0.563	0.525(4)
	Peak value	120	0.269-0.398	0.334(2)	0.593-0.716	0.662(4)	0.820-0.962	0.872(4)	0.646-0.844	0.747(4)
	Spinning[f]	120	0.097-0.137	0.117(2)	0.194-0.426	0.274(4)	0.429-0.512	0.474(4)	0.453-0.576	0.519(4)
	Rolling resistance		0.043-0.058	0.049(4)	0.0574-0.082	0.069(2)	0.054-0.064	0.603(4)	0.0509-0.0679	0.057(4)
Izumigaoka[c]	Spinning[e]		0.184-0.190	0.188(5)	0.288-0.312	0.306(5)	0.365-0.379	0.373(3)	0.424-0.462	0.445(3)
	Peak value	30	0.209-0.246	0.230(3)	0.372-0.568	0.500(4)	0.543-0.760	0.628(6)	0.626-0.667	0.647(4)
	Spinning[f]	30	0.141-0.205	0.170(3)	0.073-0.153	0.122(4)	0.113-0.212	0.152(6)	0.489-0.531	0.504(4)
	Peak value	120	0.200-0.227	0.209(3)	0.490-0.578	0.537(3)	0.568-0.578	0.573(3)	0.667-0.722	0.698(5)
	Spinning[f]	120	0.108-0.145	0.131(3)	0.148-0.173	0.158(3)	0.103-0.133	0.118(3)	0.489-0.571	0.517(5)
	Rolling resistance		0.031-0.040	0.036(5)	0.039-0.049	0.044(5)	0.061-0.063	0.062(5)	0.049-0.053	0.052(5)
Yuzawa[d]	Spinning[e]		0.118-0.130	0.124(2)	0.289-0.324	0.307(2)	0.262-0.300	0.281(2)	0.307-0.332	0.319(2)
	Peak value	30			0.23-0.26	0.252(5)	0.38-0.48	0.43 (7)	0.347-0.417	0.383(4)
	Spinning[f]	30	0.12-0.16	0.142(5)	0.09-0.15	0.124(5)	0.15-0.28	0.21 (7)	0.301-0.352	0.326(4)
	Peak value	80			0.36-0.42	0.402(5)	0.42-0.48	0.452(5)	0.471-0.501	0.487(5)
	Spinning[f]	300	0.13-0.15	0.14 (5)	0.12-0.18	0.158(5)	0.17-0.31	0.224(5)	0.373-0.358	0.376(5)
	Peak value	300			0.28-0.39	0.357(3)	0.43-0.50	0.462(4)	0.45-0.48	0.460(4)
	Spinning[f]	300	0.12-0.14	0.125(4)	0.14-0.16	0.153(3)	0.18-0.20	0.187(4)	0.32-0.37	0.345(4)
	Rolling resistance		0.026-0.028	0.027(2)	0.035-0.037	0.036(2)	0.035-0.042	0.038(2)	0.031-0.034	0.032(3)
Mitsumata[d]	Spinning[e]		0.10-0.112	0.107(3)	0.10-0.112	0.107(3)	0.08-0.14	0.11 (5)	0.381-0.385	0.383(2)
	Peak value	30	0.21-0.30	0.236(4)	0.21-0.30	0.248(7)	0.36-0.39	0.378(5)		
	Spinning[f]	30	0.10-0.12	0.11 (4)	0.08-0.11	0.09 (7)	0.12-0.17	0.144(5)	0.33-0.37	0.346(5)
	Peak value	60	0.18-0.22	0.196(5)	0.21-0.26	0.232(5)	0.32-0.41	0.356(5)		
	Spinning[f]	60	0.10	0.10 (5)	0.07-0.11	0.09 (5)	0.11-0.15	0.128(5)		
	Rolling resistance		0.20-0.22	0.020(3)	0.019-0.022	0.020(3)	0.015	0.015(3)	0.022-0.025	0.023(3)

[a]Compacted snow on road. [b]Hard compacted snow on road. [c]New snow on road. [d]Normal snow on road.
[e]Vehicle moving. [f]Vehicle not moving.

Lateral Force Coefficient

Maximum values of lateral force coefficients on snow- or ice-covered roads are about the same or slightly larger than skid resistance values. On a flat ice surface, the maximum lateral force coefficient is approximately equal to the skid resistance coefficient. On a snow layer or a chloride-treated snow surface, however, the maximum lateral force coefficient is higher than the skid resistance coefficient. Probably the effect of crushing resistance of the snow layer increases under sideslip conditions.

TRACTION FORCE COEFFICIENT

The basic idea of traction force coefficient was discussed earlier. Tables 3 and 4 give traction force coefficients under various conditions. Traction force coefficients are influenced by the state of snow or ice on the road and by the type of tire.

Traction Force Coefficient and Type of Tire

A highway rib tire develops its maximum coefficient of 0.17 or more immediately before spinning, but while spinning this drops to around 0.1 (minimum observed was 0.04). On the other hand, the peak value with snow tires is 0.21 or more (normally 0.35 or more), and minimum while spinning is 0.07.

As for peak values, a highway rib tire develops much less traction than the other 3 types of tires, which develop more than 0.35. Differences among these 3 types of tires are small. As for traction force coefficient upon spinning, however, the chained rib tire develops the highest value, followed by the studded snow tire. These high values of the chained tire are considered to be a result of the scratching action of the chain.

Waiting Time and Traction Force Coefficient

Once we bring a car to a stop on a slippery snow or ice road, we sometimes have difficulty starting it again. To investigate the influence of waiting time on such a surface, the authors measured a change of traction force coefficient due to time elapsed between stopping the vehicle and starting again. Figure 7 shows these results. Little change due to waiting time was seen.

TABLE 4

TRACTION FORCE COEFFICIENTS AT START AND ROLLING RESISTANCE, 1969 AT MITSUMATA

Condition	Waiting Time (sec)	Test Tire					
		Highway Rib Tire		Snow Tire		Studded Snow Tire	
		Range	Avg	Range	Avg	Range	Avg
Spinning (nonmoving)	0	0.136 (0.101-0.112)	0.136(3) 0.108(3)	0.126-0.136 (0.167-0.171)	0.130(3) 0.168(3)	0.243-0.298 (0.267-0.324)	0.278(6) 0.301(6)
Peak value	30	0.270-0.369 (0.257-0.302)	0.322(5) 0.307(5)	0.314-0.379 (0.319-0.371)	0.337(5) 0.334(5)	0.550-0.605 (0.497-0.505)	0.571(3) 0.499(3)
Spinning (nonmoving)	30	0.125-0.189 (0.089-0.114)	0.160(5) 0.104(5)	0.140-0.153 (0.121-0.136)	0.148(5) 0.135(5)	0.413-0.443 (0.424-0.438)	0.427(3) 0.428(3)
Peak value	60	0.238-0.311 (0.274-0.333)	0.278(5) 0.307(5)	0.348-0.379 (0.343-0.417)	0.387(3) 0.373(3)	0.547-0.649 (0.497-0.531)	0.598(4) 0.515(4)
Spinning (nonmoving)	60	0.108-0.152 (0.100-0.121)	0.131(5) 0.111(5)	0.136-0.170 (0.129-0.144)	0.150(3) 0.139(3)		
Peak value	300	0.246-0.292 (0.279-0.288)	0.275(3) 0.282(3)	0.373-0.452 (0.367-0.474)	0.406(3) 0.414(3)	0.575-0.633 (0.526-0.538)	0.604(2) 0.532(2)
Spinning (nonmoving)	300	0.112-0.126 (0.101-0.112)	0.119(3) 0.104(3)	0.126-0.143 (0.099-0.150)	0.135(3) 0.121(3)		
Rolling resistance		0.025	0.025(3)	0.022-0.023	0.023(3)	0.022-0.031	0.025(3)

Note: Road temperature was 0 C; road condition was compacted snow; and the temperature was -0.5 to 0 C.

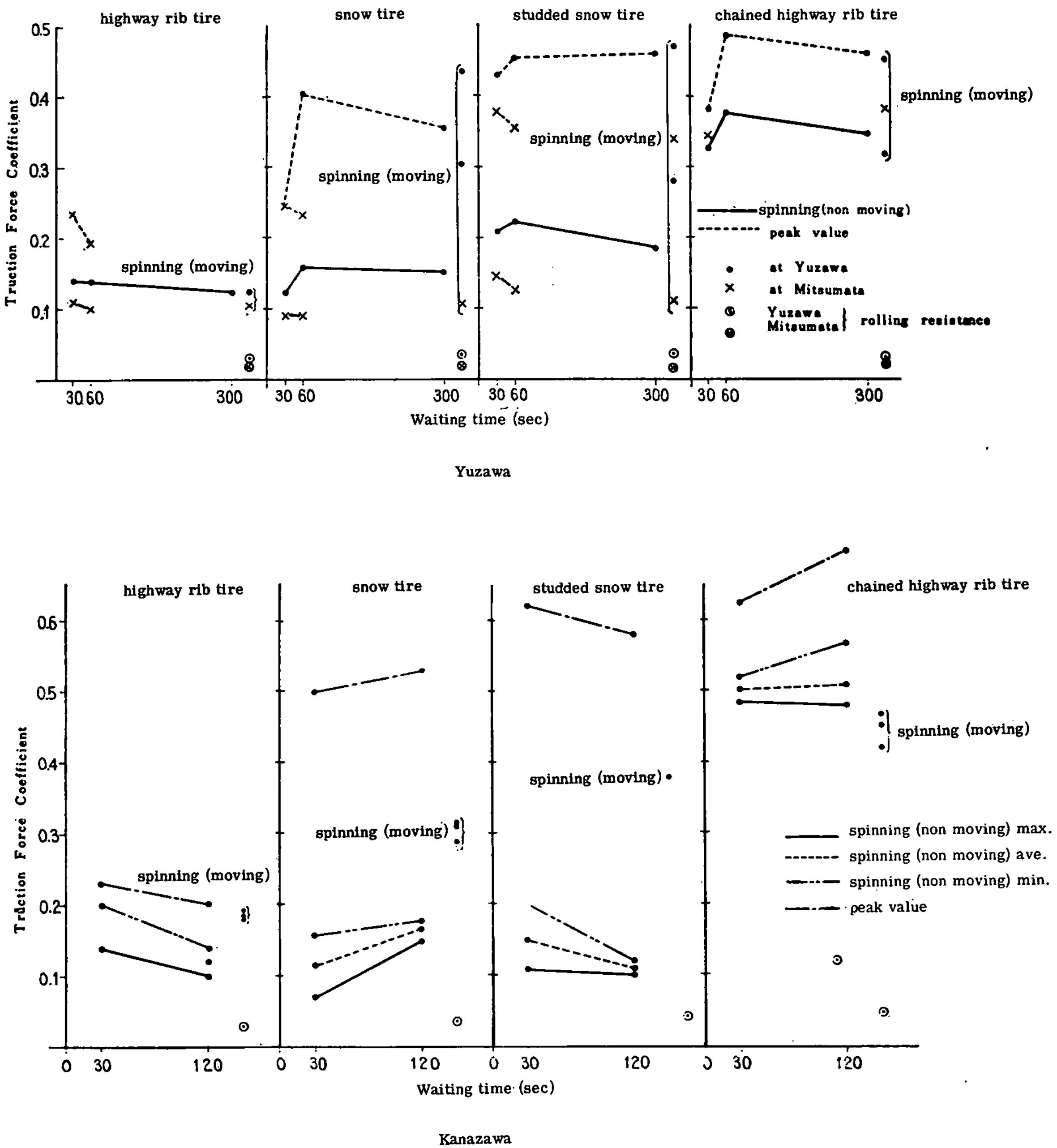

Figure 7. Traction force coefficients at start versus waiting time.

TABLE 5

MINIMUM COEFFICIENT OF FRICTION

Type of Tire	Traction Force Coefficient	Skid Resistance Coefficient	Rolling Resistance
Highway rib	0.04 to 0.17	0.15	0.02 (0.05)
Snow	0.07 to 0.21	0.16	0.02
Snow studded	0.08 to 0.27	0.20	0.02
Chained highway rib	0.02 to 0.35	—	0.03

TABLE 6

PERCENT MAXIMUM STARTING GRADIENT

Type of Tire	Passenger Car	Truck	Semitrailer
Highway rib	-0.4 to 4.9 (1.9)	-0.3 to 5.3	-0.5 to 4.1
Snow	0.9 to 6.6	1.0 to 7.0	0.6 to 6.0
Studded snow	1.3 to 9.1	1.4 to 9.6	1.0 to 8.3
Chained highway rib	9.1 to 12.3	9.6 to 13.1	8.3 to 11.3

TRACTION FORCE COEFFICIENT AND MAXIMUM STARTING GRADIENT

Maximum longitudinal gradient of roads, which is influenced by snow or ice, should be determined by gradient at the start. These gradients are calculated by traction force coefficients and resistances at time of starting.

When we take as a distribution coefficient, β, the ratio of driving axle load to full load of vehicle, then the ratio of traction force to full load of this vehicle becomes β times traction force coefficient. Values of β, which are considered conservative for highway design for various vehicles are as follows:

Vehicle	β
Passenger car	0.41
Truck	0.43
Semitrailer	0.38

On the other hand, generalized minimum traction force coefficients on a snow- or ice-covered road are given in Table 5. In this table, lower and higher values correspond to the spinning state and the state immediately before this respectively.

The values of β and Table 5 were used to compute maximum starting gradients. These are shown in Table 6. The lower values correspond to traction force coefficients at spin and are considered the starting gradients for least skilled drivers with the worst snow or ice conditions. The higher values show gradients computed from maximum traction force coefficients immediately before spinning, and only the most skilled drivers can start on these gradients with the worst road condition. Because acceleration resistance is not accounted for in these computations, actual starting gradients might be somewhat lower than the values listed.

When we determine maximum starting gradient for highway design, the decision should be based on the type of tire that would be used.

CONCLUSIONS

Generally, because coefficients of friction on snow- or ice-covered roads are much lower than those on wet pavements, special attention must be given to them. On a snow- or ice-covered road, coefficient of friction varies over a wide range according to snow or ice conditions, type of tire, and driving conditions. Further, considerable difference exists between braking force and traction force coefficients, so it is important to consider these 2 conditions separately.

When we determine geometric design standards for highways that will be influenced by snow or ice, special considerations must be taken, such as maintenance level and the type of tire that will be most used.

Informal Discussion

Glenn G. Balmer

I have done work with the Committee on Winter Driving Hazards of the National Safety Council and I would like to emphasize one point that was made in this paper, that is, the temperature of the ice at the time the skid resistance is measured. The ice is most slippery when it is near the melting point, and the skid resistance increases as the ice becomes colder. At 32 deg on glare ice, you may get a skid resistance value between 0.05 and 0.1. As the temperature gets colder and drops to 0 F, the skid resistance value may increase to 0.2 or 0.25.

J. W. Renahan

What happens if it gets colder?

Balmer

There is a gradual decrease in the skid resistance as the temperature increases up to the melting point of the ice. At temperatures below 0 F, it seems to level out, and there is not too much change in the skid resistance as it gets considerably colder.

Renahan

At fifty below, driving is good.

Balmer

I have never measured the skid resistance at temperatures that low. We have measured it at 0 and about 5 below, and it seems to be leveling out. I do not know too much about it at really cold temperatures.

Renahan

Is there a stage at which your tires stick to the ice?

J. L. Smith

The closer you get to the melting point, then the closer you get to a hydroplaning stage. Is that what it is?

Balmer

Above 32 deg the ice begins to melt on the surface and the water lubricates the remaining ice. That is the reason it becomes very slick. There is another factor that comes into play, and that is the type or texture of the ice. Rough-textured ice is not as slick as glare ice. There are also other factors such as the type of tire you use—highway tires, studded tires, or tires with chains.

Ichihara

I previously showed that the same results were observed in Japan. At the freezing point the friction coefficient is lowest.

William D. Glauz

In the tests where the vehicle was stopped then started later and you measured the change (in friction coefficient), can you say anything about the tire temperatures? Were the tires cold or warm?

Ichihara

We did not measure the tire temperature at that time.

Glauz

Do you think that tire temperature might be important?

Ichihara

I think so. If the tire temperature is high, the snow layer melts between the tire and snow surface, and this contributes to the lower friction coefficient.

Lawerence H. Chenault

Some years ago I did a great deal of work on skid resistance with tires. It might be of interest that the durometer of the tire rubber had a great deal of effect, that is, the softer durometer gave better skid resistance. Tire pressure did not seem to have so great an effect. Tire tread pattern was a very great factor.