Production of Skid Testing Vehicle and Skidding Resistance of Variable Tread Patterns of Tires on Snow Covered Road Surface

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Abstract

A new bus type skid testig vehicle which is adapted for modern traffic was designed and produced. This skid testing vehicle can measure the slip number, skid number and sideway force number by means of a torque meter which is attached to the axle of the test wheel directly. Perfomance test of this skid testing vehicle was made on dry, wet and snow covered road surfaces. Test results showed the sufficiency of this test vehicle.

The slip number was measured to determine the tread pattern effect of tires, using 13 specially designed tires which have various tread patterns on snow covered road surface by the newly produced skid testing vehicle. The analysis of variance of field test resulte was made to determine the most effective tread pattern for skid resistance of snow covered road surface. It has been difinitely shown by this analysis that the tread pattern angle is the most effective for the skid resistance on snow coverd road surface.

1. Prefece

In recent yeas, snow removal from the road surface has been extensively increased, as a result winter traffic does not differ from that in summer.

On the other hand, traffic accidents due to the decrease of skidding resistance between tire and snow covered road surface have been increasing gradually year to year. The research on the skidding resistance of snow and ice covered road surface has been conducted extensively by various workers. But the research by other workers are conducted by the locked wheel method. Alone, this paper, with the background mentioned avove, reports or the production of a skid testing vehicle which can measure slip number at a speed of 90 km/h on wet road surface, 50 km/h for snow covered road surface and can determine the type of tread pattarn which is the best for skidding resistance on snow covered road surface using specially made tires which have various pattarns such as rib pattern only, rug pattern only etc.

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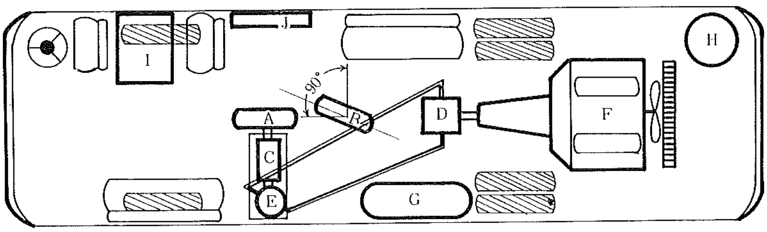
2. Production of skid testing vehicle

A skid testing vehicle which can measure slip number, skid number and sideway force number at maximum testing speed of 100 km/h for wet road surface, 60 km/h for snow covered road surface was designed and produced using a large bus in order to fit modern road trafic. The prototype of this skid testing vehicle is a trailer type testing vehicle which was originally designed and produced by the authors. The special features of this skid testing vehicle are that the skidding resistance is measured by a torque meter which is attached to the axle of the skid testing wheel directly and that the rotation of test wheel and the slip ratio are given by the oil motor and oil pump which is operated by the gasolin engine mounted in the bus cabin. Both skidding resistance measuring apparatus for srip number and sideway force number are operated by air cylinders which apply a



A: tire for skid No. and slip No., B: tire for sideway force, C: torque meter, D: oil pump, E: oil moter, F: gas engin, G: air compressor, H: A. C. power generater, I: measuring instruments, J: operatig panel

Fig. 1 General view of test vehicle

Table 1 Test vehicle

Body	
Type of vehicle	ISUZU BK 32 Bus
Length	820 cm
Width	230 cm
Height	277 cm
Wheel base	378 cm
Max. engine power	145 PS/3,200 rpm
Max. engine torque	35 kg-m/2,000 rpm
Crew	6 persons
Gross weight	6,950 kg
Max. speed	110 km/h
Measuring apparatus	
Torque meter	KYOWA DENGYO TP-200 KMSA 16 200 kg-m
Load cell for sideway	KYOWA DENGYO LCH 500 KDS 500 kg
Load cell for vertical load	KYOWA DENGYO LU 1 TE 1,000 kg
Speed detecter	TAKEDA RIKEN TR-0221 Magnetic type
System of drive and brake of test wheel	AMERICAN FORD V-8 GAS ENG. DAIKIN-SANDSTRAND HYDROSTATIC TRANSMISSION 23 PV and 23 MF
Test tire	Rim size 13, 14, 15 inch
Vertical load	100 to 500 kg
Max. speed of test	100 km/h
A. C. power supply	ISUZU MOTOR GX 15 1.5 KW
Compressor	BANZAI MOTOR LS-107 NA-1 750 W

vertical load on the test wheel and rise and fall of the apparatus. The torque developed from the locked or slipped tire friction is measured by an electric straingauge type torque meter and recorded by the measuring instruments. The sideway force number is measured by the electric straingauge type load cell installed at the end of the test wheel axle directry. The range of slip angle is from 0 degree to 90 degrees. This test vehicle can be equipped with 13. 14 and 15 inch rim sized tires.

The vertical load which can be applied to the test tire ranges up to 500 kg.

Values recorded are the number of revolutions of the test wheel, vertical load applied to the test wheel, torque and sideway force.

There are only two skid testing vehicles at present which can measure slip number although there are over 21 skid testing vehicles in Japan. One is the skid testing vehicle described in this paper, another is the skid testing vehicle of the Yokohama Rubber Co. which is operated based on the same principle as the authors. Fig. 1 and Table 1 show the rough outline of the skid testing vehicle.

3. Performance test of skid testing vehicle

The performance test of the skid testing vehicle was made by measuring the slip number at the test course of Japan Automobile Research Institute (JARI) on asphalt and concrete road surfaces as compared with the skid testing vehicle of the Yokohama Rubber Co. using smooth tires, regular tires, radial tires and ASTM standard tires on both dry and wet road surfaces at a maximum speed up to 80 km/h. The performance test of the skid testing vehicle on snow coverd road surfaces was made by masuring slip numbers, skid numbers and sideway force numbers at the test course of Hokkaido Development Bureau near Sapporo

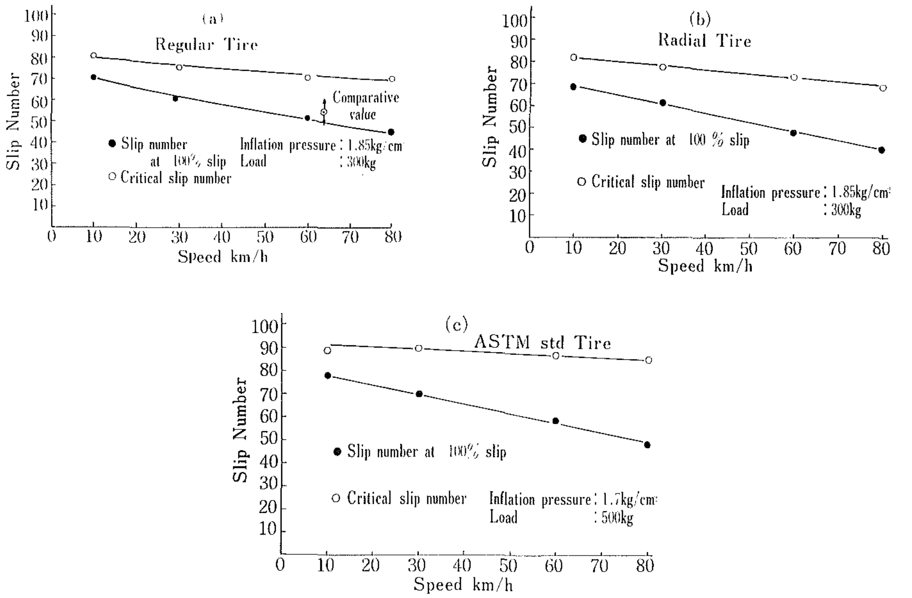


Fig. 2 Slip number on wet asphalt road surface

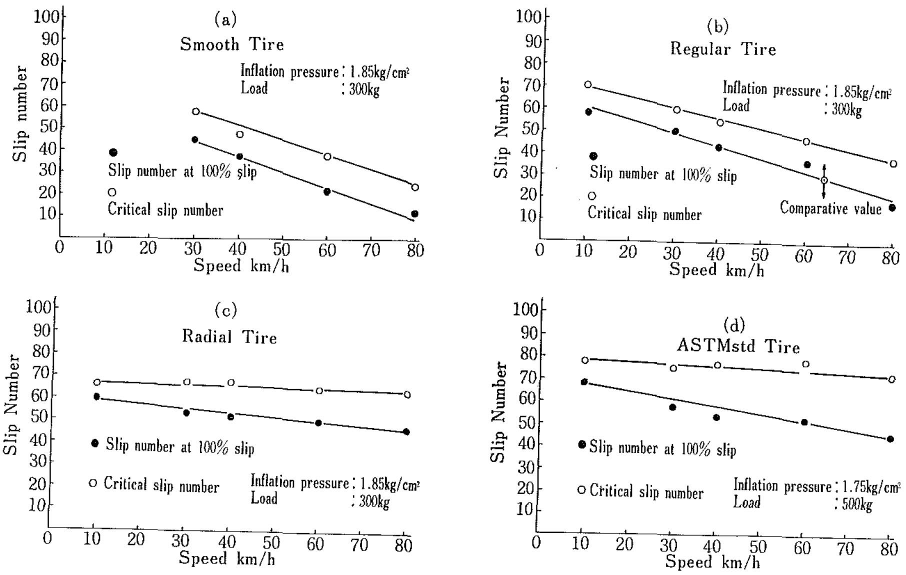


Fig. 3 Slip number on wet concrete road surface

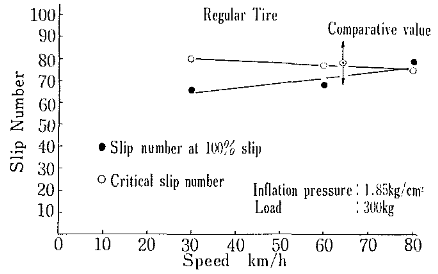


Fig. 4 Slip number by speed on dry asphalt road

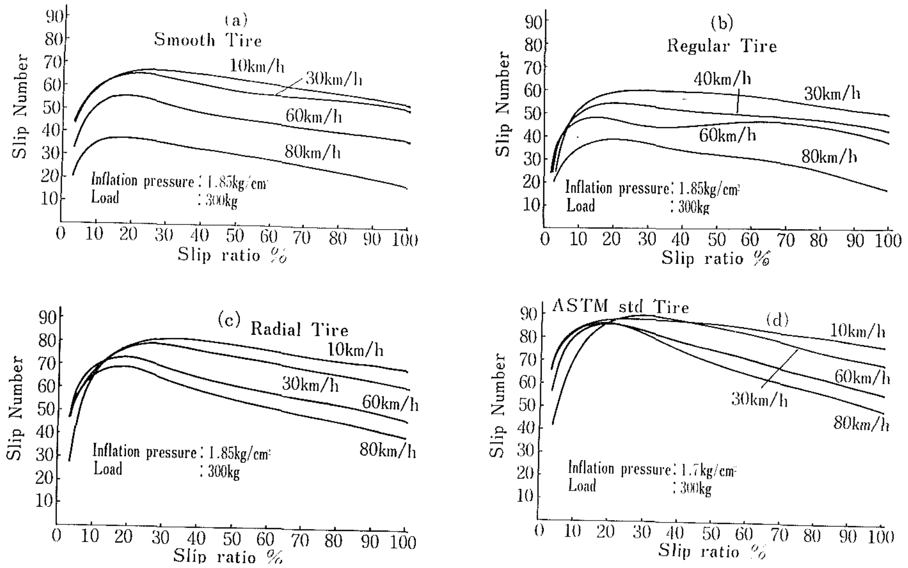


Fig. 5 Slip number by speed on wet asphalt road surface

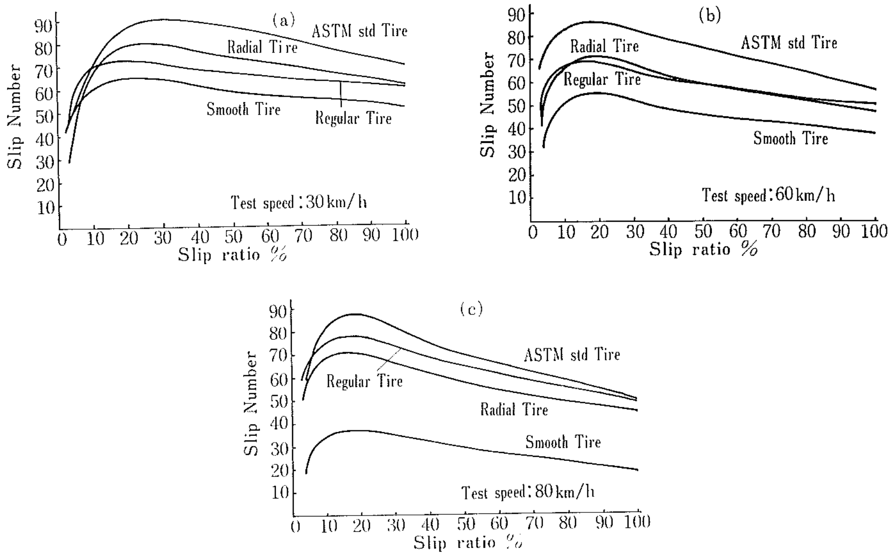


Fig. 6 Slip number by tire on wet asphlt road surface

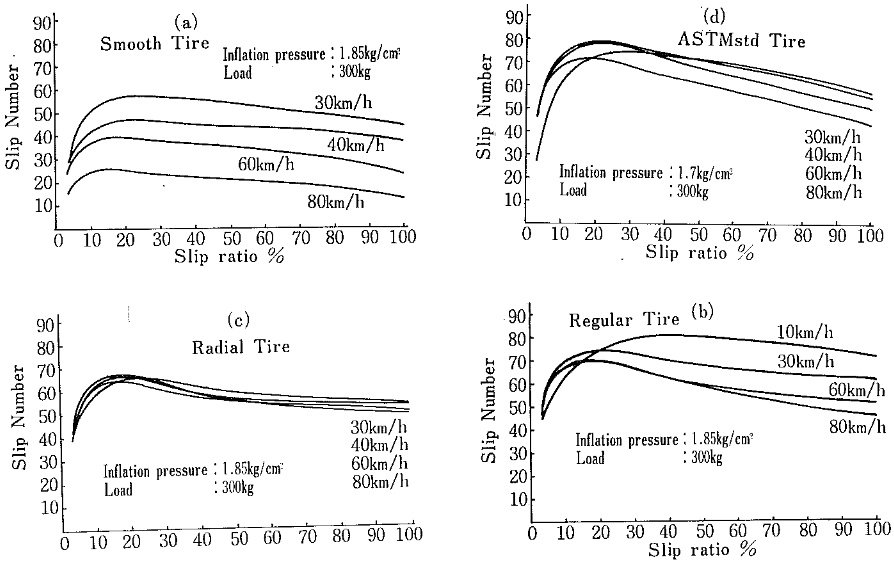


Fig. 7 Slip number by speed on wet concrete road surface

using smooth tires, radial tires, stud tires and snow tires at a maximum speed up to 45 km/h. The test results for wet road surfaces are shown in Fig. 2 to Fig. 12. Fig. 2 to Fig. 4 show the critical skid numbers and slip numbers at a 100% slip ratio of each test tire, namely the skid number. The comparative values in Fig. 2 (a), Fig. 3 (b) and Fig. 4 were obtained by a comparative study of skid testing vehicles in Japan at JARI test course in 1971. This comparative study was made at only one speed, 60 km/h, and all of these value are skid numbers.

It is clear from Fig. 5 to Fig. 7 that the slip number curves show a transition to low values with speed and the critical slip ratio which gives the maximum

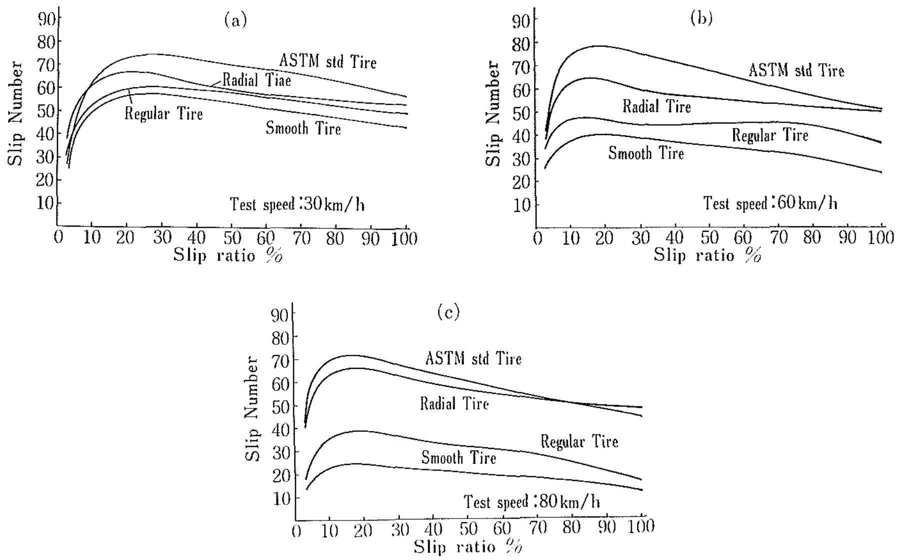


Fig. 8 Slip number by tire on wet concrete road surface

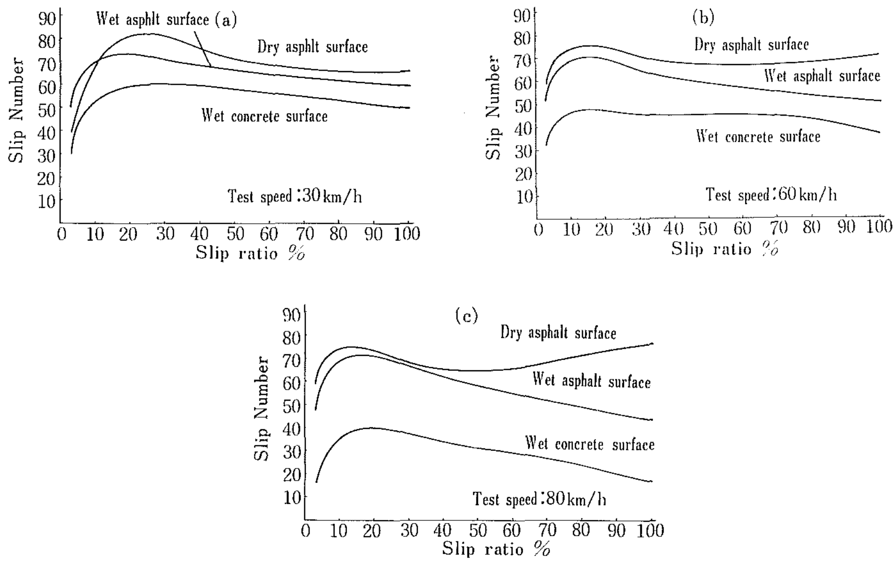


Fig. 9 Slip number by road surface (Regular Tire)

slip number moves to a small ratio. In this case, when the tire and road surface vary, and the absolute slip number changes as the tire and road surface varies, the relationship above does not show any change. We can see from Fig. 6 and Fig. 8 that the slip number of smooth tires is quite lower than those of other tires.

The slip number by road surface decrease in the order of dry asphalt surface, wet asphalt surface and wet concrete surface. (From Fig. 9 to Fig. 11)

This difference may be due to the concrete surface itself which is constructed as a slippery road surface although there are little differences in skid resistance

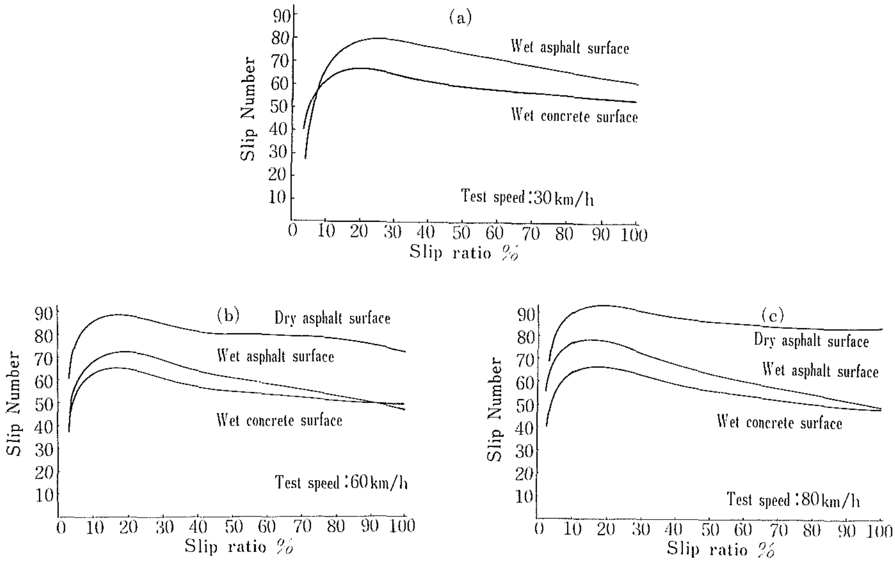


Fig. 10 Slip number by road surface (Radial Tire)

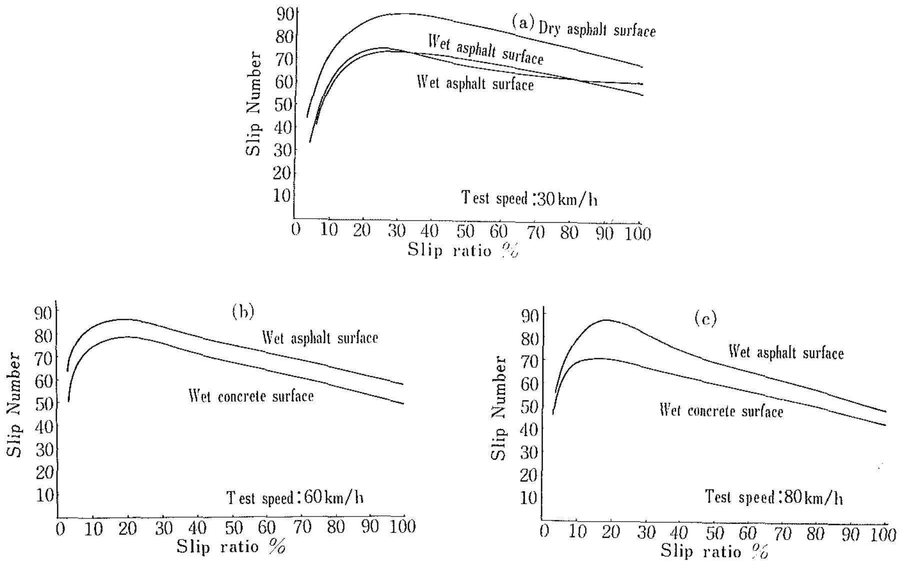


Fig. 11 Slip number by road surface (ASTM std Tire)

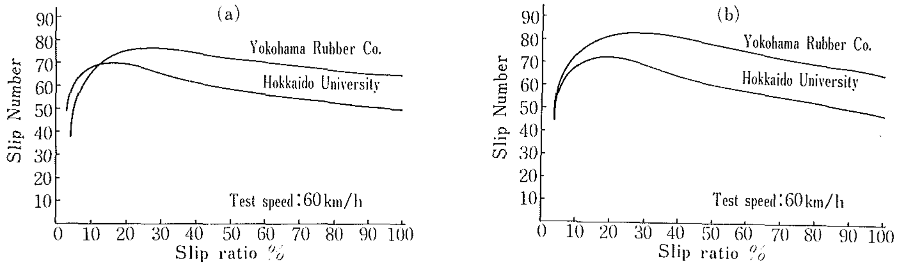


Fig. 12 Comparison of slip number between test vehicles on wet asphalt road surface

between these two wet road surface generally.

Fig. 12 shows a comparison of the slip number which was measured by the test vehicle of Yokohama Rubber Co. and our test vehicle. In this comparision, ther were some differences of slip number obtained from these two test vehicles. The reason of this difference mey have arisen from the 15°C difference of road surface temperature when the two test were made.

All tests were made on the standerd usage conditions of tires: the tire loads are 500 kg for ASTM standard tires, and 300 kg for other tires; tire sizes are 7.50–14 for ASTM standard tire and 5.60–13 (165–13) for other tires; inflation pressures are 1.70 kg/cm² for ASTM standard tire and 1.85 kg/cm² for other tires.

From our test results for dry and wet road surfaces, it is possible to take the view that the present test vehicle gives sufficient perfomance from the curves of slip ratio and slip number, critical slip ratio and the maximum test speed although there are some difference in absolute value of slip number. The variance in absolute value of slip number may have arisen from the stabilizing time of the load and lack of smoothness of the measuring system because the milage of the test vehicle was a mere 1,000 km when the tests were made.

Next, the results for snow coverd road surfaces are shown in Fig. 13 to Fig. 18.

Usually, the variation of the skid resistance of the snow covered road surface varies widely due to the variety of snow properties but in the present measurement the skid resistance obtained from these tests showed a variation less than 3% of the average value of slip number. These results show the stability of the test vehicle operatig under low temperatures and the effectiveness of the grading operation on snow surfaces by each skidding test using a snow removal truck. Fig. 13 and Fig. 14 show that the critical slip ratio for the snow covered road surface is smaller than that for wet road surfaces, in particular, the critical slip ratio of smooth tires is under 5% and the slip number is very low.

In case of snow patterned tires which are available on the market, both the critical slip number and critical slip ratio are larger than those of smooth tires and these results show the effectiveness of snow tread tires on the snow covered road surface clearly.

The slip number for snow covered road surfaces were not affected by speed but it shows a tendency to increase with the speed and with the slip ratio. From

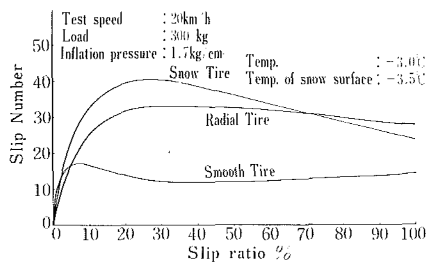


Fig. 13 Slip number by tire on snow covered road surface

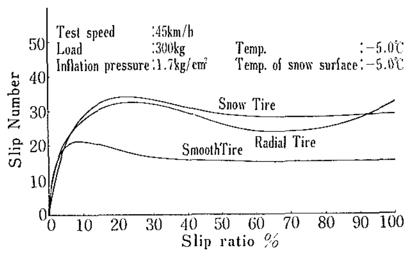


Fig. 14 Slip number by tire on snow covered road surface

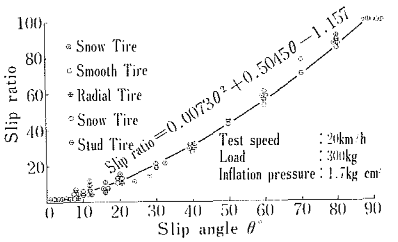


Fig. 15 Relation between slip angle and slip ratio on snow covered road surface

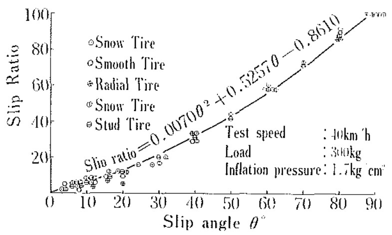


Fig. 16 Relation between slip angle and slip ratio on snow covered roed surface

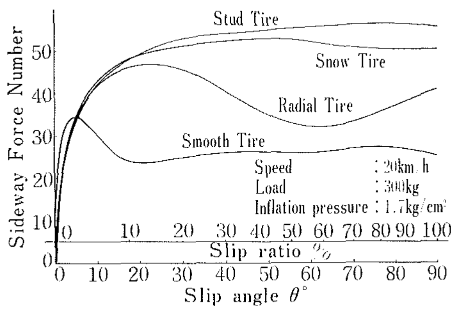


Fig. 17 Slip number and sideway force number

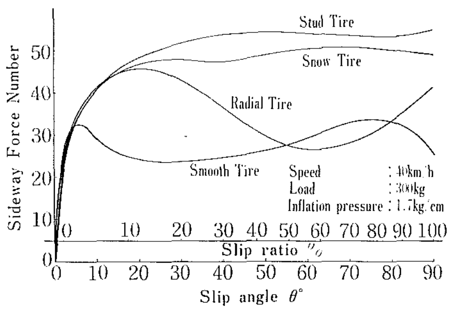


Fig. 18 Slip number and sideway force number

Fig. 15 to Fig. 18 the test results of sideway force numbers are shown. Fig. 15 and Fig. 16 show the relationship between slip angles and slip ratio which has not previously been measured. The slip ratio in these figures are the same as those in the figures of slip numbers. It was shown definitely that the reiationship between slip ratio and slip angle when the tire rotates freely, is expressed by the quadratic equation. Fig. 17 and Fig. 18 show the relationship between slip number and the sideway force number.

It is noted that these curves are similar to those of the slip number and the slip ratio and that there are peak value of sideway force number in some tires.

This is the point on which shows a clear difference on wet road surfaces but the reason remains to be clarified.

4. Skidding resistance and the tread pattern of tire on snow covered road sufaces

Oo snow covered road surfaces, skidding resistance of tires are affected largely by the tread patterns of tire. Tread patterns of tires are decided mainly by trial and error under the present conditions, and basic research of the effectiveness of tread patterns of tires are limited in the literature today.

In the present peper the results of tire tread pattern effect obtained from field measurements of skidding resistance and analysis of variance, using 13 types of model tires especially made with different patterns on snow covered road surface are presented.

All of the model tires are 5.60–13 and other factors of model tires are as follows and showed in Table 2 :

tread groove depth ; two levels of 4 and 8 mm,
tread pattern angle ; five levels of 0, 30, 45, 60 and 90 degrees,
tread groove width ; four levels of 5, 10, 15 and 20 mm,
tread pattern width ; three levels of 4, 5, 9 and 18 mm.

Table 2 Model tires

Factors under consideration		other factors				Tire No.
Item	Level	Tread groove width	Tread groove width	Tread pattern width	Tread groove angle	
Tread groove depth G. D.	8 mm	5 mm	–	9 mm	90°	1
	4 mm					2
Tread groove angle θ	0°	5 mm	8 mm	9 mm	–	3
	30°					4
	45°					5
	60°					6
	90°					1
Tread groove width G. W.	5 mm	–	8 mm	9 mm	90°	1
	10 mm					7
	15 mm					8
	20 mm					9
Tread pattern width M. W.	4.5 mm	5 mm	8 mm	–	90°	10
	9 mm					1
	18 mm					11
Block type		5 mm	8 mm	9×9 mm	90° 0°	12
Snow design model			8 mm			13

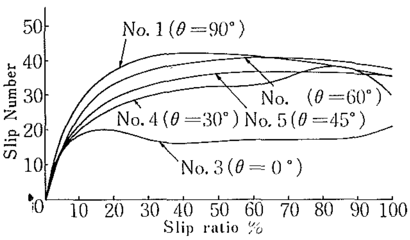


Fig. 19 Slip number and tread pattern angle

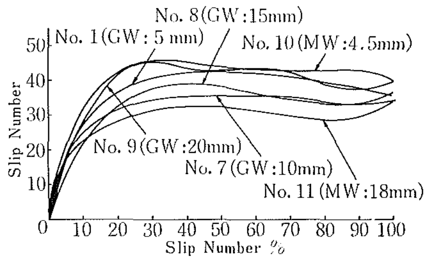


Fig. 20 Sl!p number, tread pattern width and tread groove width

Table 3 Factors and levels

Factor	Levels				
	level 1	level 2	level 3	level 4	level 5
A : slip ratio	20%	40%	60%	80%	100%
B : tread grrve depth	4 mm	8 mm			
C : Tread groove angle	0°	30°	45°	60°	90°
D : tread groove width	5 mm	10 mm	15 mm	20 mm	
E : tread pattern width	4.5 mm	9 mm	18 mm		

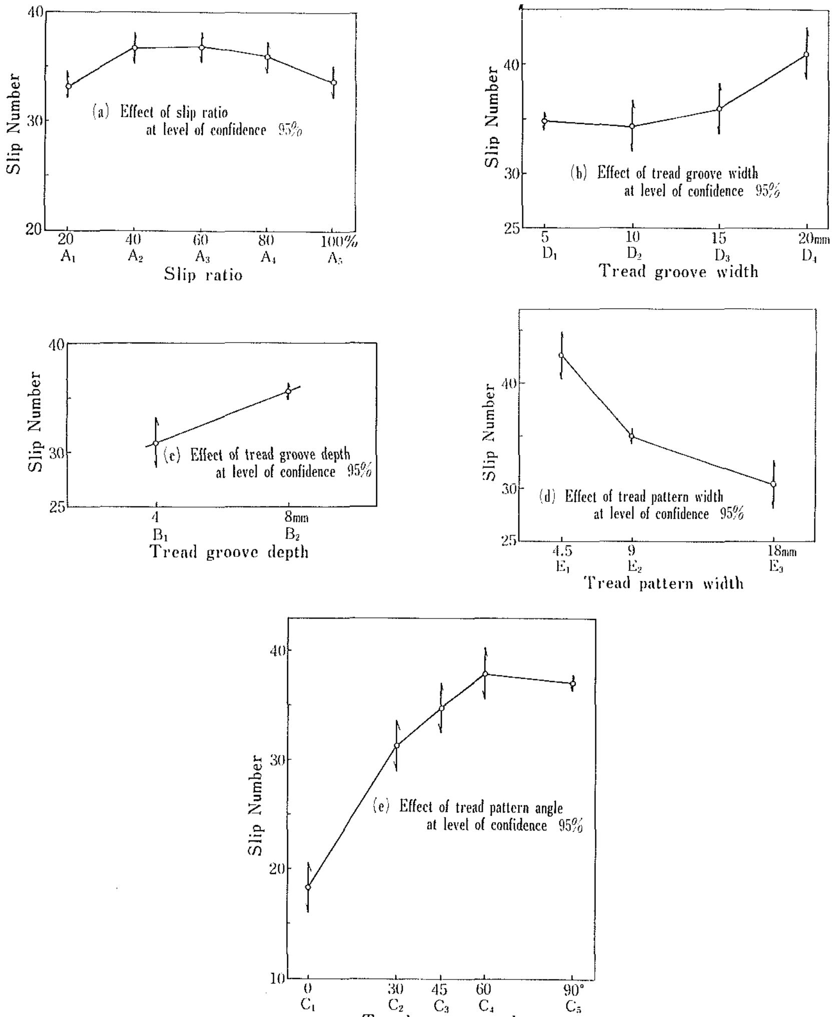


Fig. 21 Slip number and factors

Table 4 Analysis of variance

Factor	SS	df	mS	ρ%	F
A	16,337	4	4,084	4.68	6.2831**
B	10,227	1	10,224	3.26	15.7262**
C	172,737	4	43,184	57.98	66.4369**
D	18,613	3	6,204	5.67	9.5446**
E	39,772	2	19,886	13.11	30.5938**
e	35,756	55	650	15.30	
T	293,437	69			

** level of conffdence 95%

Slip number on snow covered road surface measured using model tires in Table 2 by the skid testing vihicle described in the preceeding chapter at speeds up to 40 km/h under the conditions of inflation pressure of 1.7 kg/cm² and wheel load of 300 kg. Fig. 19 and 20 show the test results collectively by each factor.

Fig. 19 shows the tread pattern angle and Fig. 20 gives the tread groove depth and the tread pattern width. In Fig. 19, the slip number for 60° and 90° of the tread pattern angle are nearly equal and decrease in the order of 45°, 30° and 0°. 0 degree tread pattern angle indicates a rib tread pattern and 90 degree indicates a rug tread pattern. For tread groove width, slip number of the tire No. 9 which has 20 mm tread groove width is the largest but there are less differences between tires. For the tread pattern width, when the tread groove is constant, the slip number increases to higher values while the tread depth decreases to smaller values.

From the above test results, an analysis of variance was made to determine the effectiveness of the tread pattern of tires which affect the slip number on snow coverd road surfaces. Table 3 shows the factors and levels alloted.

Table 4 shows the results of the analysis of variance. From this Table, the factor with the largest coefficient of determination ρ is the tread groove angle, and its value is about 58%. Next in order to the tread pattern angle, the effect of the tread pattern width is larger. It is estimated that the skidding resistance on snow covered road surfaces is controlled mainly by the tread pattern angle. The coefficient of determination for error is as high as 15% next that of the tread pattern angle. It is surmised that the heterogeneous surface of snow affected the test results.

Fig. 21 shows the relationship between factors and slip numbers at 95% of the level of confidence. The conbination of the factors, A_3, B_1, C_3, D_3 and E_1 gives the most optimum condition to the factors A to E, from Fig. 21. The estimation of population mean is 50.6 to 55.4 under these optimum factors combined at the level of confidence of 95%.

As the results obtained are for the effect of tread composition only, we connot apply these results to determine the tread pattern of actual tires but it seems that the test results are sufficient for a basal analysis of tread patterns of tires on snow covered road surface.

5. Conclusion

The performance test of the new test vehicle showed sufficient results in outline.

At first, the test was intended to be carried out at higher speeds but this was not possible because the engine power of test vehicle was insufficient in comparison with the gross weight of test vehicle on wet road surfaces, and the test course was affected largely by weather conditions on snow coved road surfaces.

The present experiment was conduced to solve problems described above and to determine or clarify the mechanism of slip numbers using the skid testing vehicle. The results of the experiments will be presented shortly.

The effect which the tread pattern of tire has on the skidding resistance on snow coverd road suface was clarified. The results of skidding ristance on wet road surface and ice covered road surfaces will be applied to clarify or investigate unresolved problems.

References

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2) T. Kaku and Y. Onodera: The Tread Pattern of Tire and the Skidding Resistance of Snow Covered Road Surface, Proc. 11th annual conference of JRC, 1973.