MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

INVESTIGATION OF SLIPPERY CONDITION
of
STONE SAND CONCRETE PAVEMENT

by

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Highway Research Project 48 G-41

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INVESTIGATION OF SLIPPERY CONDITION OF STONE SAND CONCRETE PAVEMENT

At the request of the Maintenance Division, and with their cooperation, an investigation has been made to determine the extent and cause of the unusually slippery-when-wet condition of certain concrete pavement projects located on US-2 and US-41 in the Upper Peninsula.

Project F 52-25, C6 on US-41 at Carp River Hill in Marquette was reported to be very slippery when wet. In July, 1948 steps were taken by the Maintenance Division to correct the condition by surface treatments.

On July 23, 1948, E. S. Anderson, Acting District Maintenance Engineer, reported to the Department that accidents due to skidding on wet concrete pavement were beginning to occur at an alarming rate on US-2, especially in the vicinity of Isabella, Manistique and Gulliver.

An examination of the pavements in these areas by W. W. McLaughlin, Testing and Research Engineer, during the latter part of July, 1948 disclosed the fact that the concrete pavement surfaces were smooth, glossy and quite slippery under foot even when dry. Also it was noted that all of these slippery pavements were constructed with stone sand. Consequently, Mr. McLaughlin authorized a skidding investigation to be made by the Research Laboratory, which was to include all of the stone sand projects in the Upper Peninsula.

The skidding investigation on US-2 was made during the week of August 16, 1948 and included: (1) a visual inspection of all concrete paving projects on US-2 between St. Ignace and Rapid River and a portion of US-41, (2) a number of stopping distance tests on wet pavement surface, (3) a personal interview with the State Police at Gladstone, Manistique and St. Ignace, (4) a summary of traffic accidents from Planning and Traffic Division, and Michigan State Police and (5) the procurement of cores from several locations for visual inspection and for subsequent laboratory studies.

The results from the skidding tests on US-2 were so astonishing that it was deemed advisable to include in the scope of the investigation the three stone sand concrete projects in the lower peninsula and in addition several bituminous resurfacing projects made with Inland limestone coarse aggregates. The results of this phase of the investigation are also included in the report.

The unusually slippery condition which has developed on certain concrete projects on US-2 is definitely associated with the type of fine aggregate used. The aggregate in question is the stone sand produced by the Inland Stone Company at Manistique. Unlike natural sand, the stone sand particles are relatively soft and consequently become smooth and polished under traffic.

The stopping distance tests on the projects constructed with stone sand revealed that their average coefficient of friction when wet was 0.28, as compared to 0.50 for natural sand concrete. This value is considerably under the 0.40 minimum value considered safe for normal driving.

This report presents accident records, results of the stopping distance tests, a general discussion of other factors associated with the problem, and conclusions. The work is supported by illustrations, graphs and maps.

ACCIDENT AND TRAFFIC EXPERIENCES

Through the cooperation of the Planning and Traffic Division and the Michigan State Police it is possible to present accident data for US-2 between St. Ignace and Rapid River. A summary of all reported accidents investigated by State Police from January 1, 1946 through September, 1948 on US-2 is presented in Table I, together with those accidents which can be definitely associated with skidding on wet pavement. The data in Table I has been presented graphically in Figure 1.

In addition, a descriptive summary of accidents reported as being caused by skidding on wet surface is given in Table II. It must be remembered that the data in Table II include only those skidding accidents reported by the State Police, (reports of municipal police and county sheriffs were not available) and will not include many other skidding accidents of minor consequence which, undoubtedly, have taken place and never been reported to the police authorities. Also, it must be understood that the number of skidding accidents is approximate because of the difficulty in recognizing true skidding accidents from the description given on the reporting forms. Additional factual information on traffic volume and accident experience on US-2 is presented in Figure 2.

From these data, several pertinent facts are indicated. The average daily summer traffic has increased from approximately 500 vehicles per day in 1943 to over 3000 vehicles per day in 1948. Accidents due to skidding on wet pavement have also increased in number with the increased daily traffic volume. The skidding accidents from January 1 to September 1, 1948 total 34, as compared to 21 for the entire year of 1947 and 9 for the year of 1946. Approximately one-fourth of the accidents reported on US-2 are in some manner associated with skidding on wet surfaces.

From Table II, the designated residence of the drivers involved in the accidents indicate a preponderance of transient motorists who, no doubt, would not be familiar with the slipperiness of the surface. Also there are more accidents on straight sections of pavement than on curved sections which would indicate that the location of braking areas rather than highway alignment is the predominant factor in the high accident rate.

The high accident rate on US-2 due to slippery-when-wet pavement is believed largely influenced by at least two outstanding factors inherent in location, design, and environment of the highway itself. Route US-2 is virtually a gateway to motorists traveling east or west across the upper part of the United States and, therefore, carries a considerable volume of transient traffic, especially during the tourist and hunting seasons. This fact is clearly illustrated by Figure 2. Also, the highway alignment with its long straight stretches, sweeping curves, flat grades, as well as continuous wooded areas unbroken by crossroads and habitation, encourages high speeds. Consequently, transient as well as local motorists who are unaware that a concrete surface can be slippery when wet are prone to travel at high speeds under a false sense of security.

In Table II there is also presented a summary of skidding accidents which have been reported on the stone sand concrete projects located on US-31 and M-29 in the Lower Peninsula. The projects are located in the cities of Manistee and Petoskey on US-31 and between Marysville and St. Clair on M-29. No accidents due to skidding on wet pavements have been

TABLE I

RURAL TRAFFIC ACCIDENT EXPERIENCE ON US-2
As Reported by Michigan State Police

			1946		1947		1948 to Sept 1		Total	
Route	County	Township	Total Accidents	Accidents due to skidding	Total Accidents	Accidents due to Skidding	Total Accidents	Accidents due to skidding	Total Accidents	Accidents due to skidding
US-2	Mackinaw	Moran	15	2	17	1	10	4	42	7
		Hendricks	2	0	4	0	1	0	7	0
		Hudson	0	0	2	0	3	0	5	0
		Garfield	6	0	5	0	3	0	14	0
		Newton	5	0	2	0	5	0	12	0
	Schoolcraft	Mueller	4	0	12	3	13	5	29	8
		Doyle	4	1	7	0	10	1	21	2
		Manistique	8	3	12	3	7	4	27	10
		Thompson	8	1	6	2	5	2	19	5
		Inwood	1	0	4	1	4	2	9	3
	Delta	Garwood	4	0	10	4	7	5	21	9
		Nahma	6	0	7	0	14	6	27	6
		Ensign	3	0	12	4	7	3	22	7
		Masonville	12	2	13	3	9	2	34	7
		Total	78	9	113	21	98	34	289	64

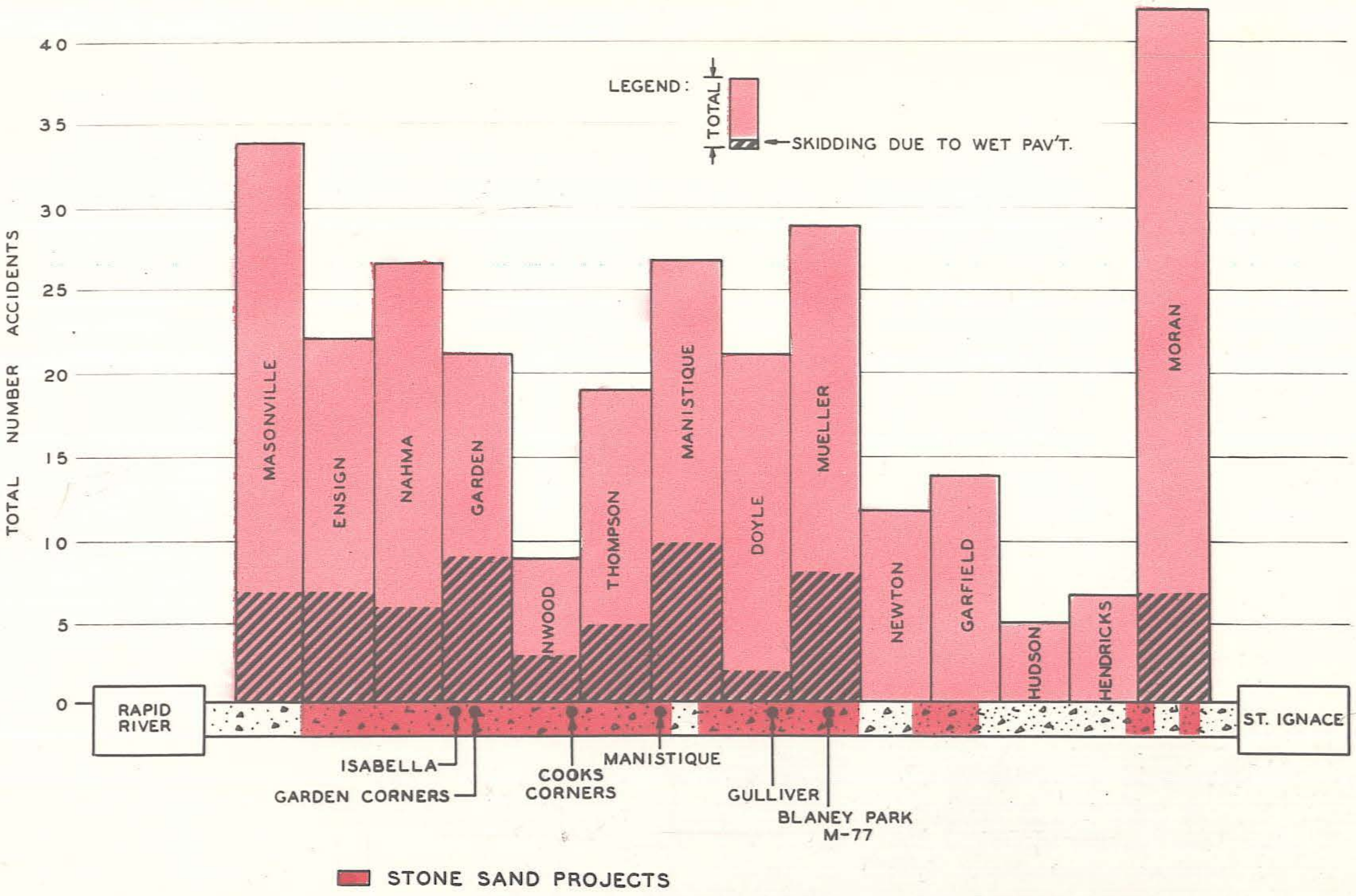


Figure 1

ACCIDENT RECORD for U.S. 2

ST. IGNACE TO RAPID RIVER - 1946 TO SEPT. 1948

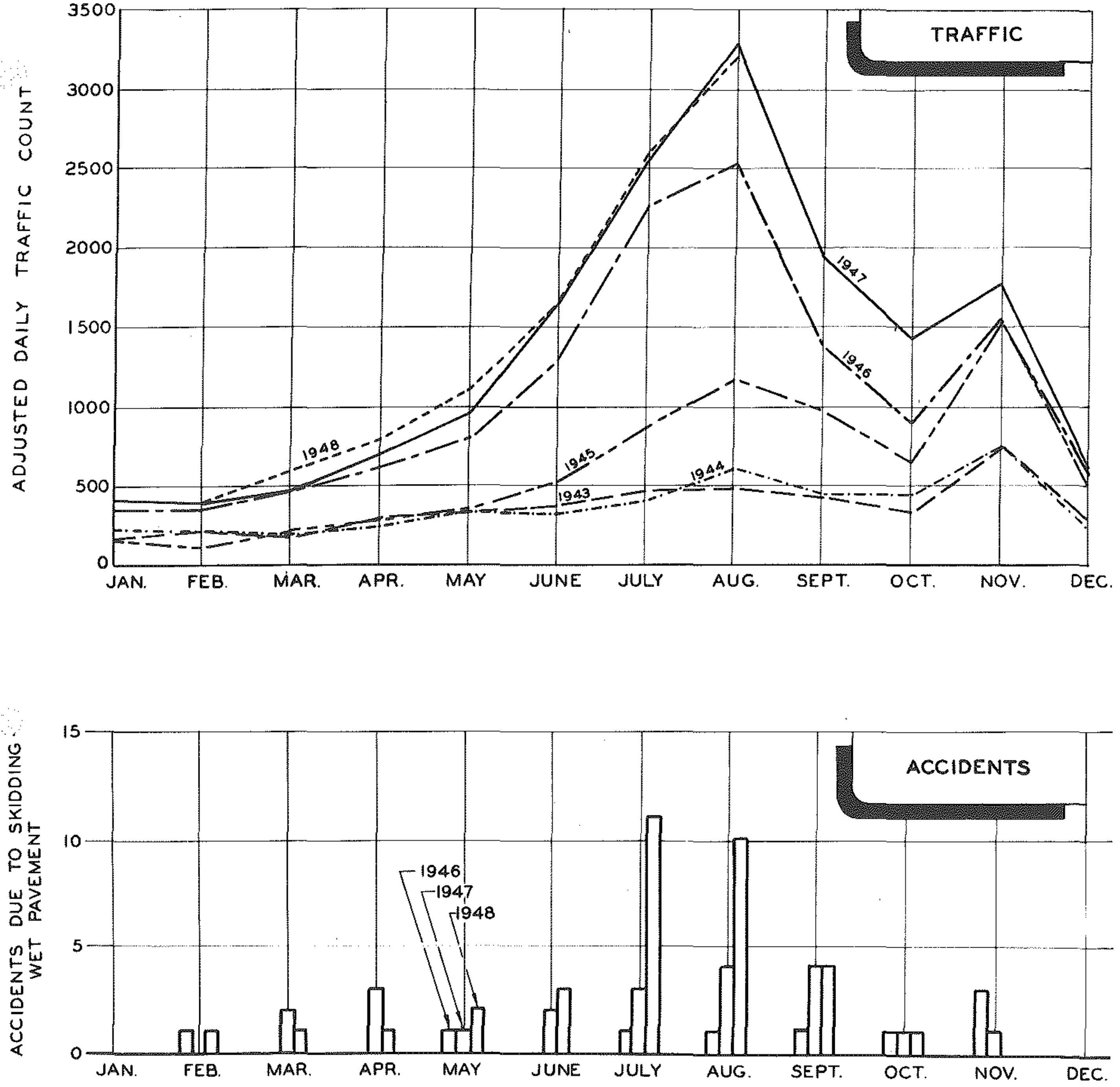
TABLE II

SUMMARY OF SKIDDING ACCIDENTS FROM 1946 TO SEPTEMBER 1948*

Complaint No.	Date	County	Township	Route	Location	Residence of Driver	Speed	Project No.	Construction Date	Pavement		
										Type	Condition	Alignment
					UPPER PENINSULA - US-2							
83-2376	7-28-46	Mackinac	Moran	US-2	.3 Miles North from St. Ignace City Limits	Rudyard, Michigan	40	49-28, C2	1936	A	Dry	Straight
83-2600	10-27-46	Mackinac	Moran	US-2	4 Miles West from South City Limits (Gros Cap Road)	Marquette, Michigan	50	49-28, C2	1936	A	Wet	Curves
83-3349	8-31-47	Mackinac	Moran	US-2	500 Ft. East from Brevort Lake Road	Flint, Michigan	70	49-28, C2	1936	A	Dry	Straight
83-126-48	3-29-48	Mackinac	Moran	US-2	2.2 Miles West from City Limits	Lake Linden, Michigan	45	49-28, C2	1936	A	Wet	Straight
83-451-48	7-22-48	Mackinac	Moran	US-2	1 Block West from West End of Gros Cap Road	Nashville, Tennessee	50-55	49-28, C2	1936	A	Wet	Curves
83-545-48	8-12-48	Mackinac	Moran	US-2	Gros Cap Road	Lansing, Michigan	45	49-28, C2	1936	A	Dry	Straight
83-661-48	9-11-48	Mackinac	Moran	US-2	1-1/2 Mile East from Brevort	Detroit, Michigan	40	49-28, C4	1936	N	Wet	Straight
84-1582	7-20-47	Schoolcraft	Mueller	US-2	3-1/2 Miles West from M-77	Green Bay, Wisconsin	50	75-31, C4	1939	A	Wet	Curves
84-1670	9-17-47	Schoolcraft	Mueller	US-2	2-3/4 Miles West from M-77	Gulliver, Michigan	50	75-31, C4	1939	A	Dry	Straight
84-1618	8-16-47	Schoolcraft	Mueller	US-2	3.5 Miles West from Blainey Park	Stephenson, Michigan	50	75-31, C4	1939	A	Dry	Curves
84-125-48	5-6-40	Schoolcraft	Mueller	US-2	100 Ft. West from Port Inland Road	Newberry, Michigan	45	75-31, C5	1936	A	Wet	Curves
84-247-48	7-20-48	Schoolcraft	Mueller	US-2	1 Mile East from Junction of Old US-2	Grand Rapids, Michigan	45	75-31, C3	1939	A	Wet	Straight
84-251-48	7-22-48	Schoolcraft	Mueller	US-2	3 Miles West from M-77 (Blainey Park)	Dearborn, Michigan	40	75-31, C4	1939	A	Wet	Straight
84-258-48	7-25-48	Schoolcraft	Mueller	US-2	1-1/2 Miles West from M-77 and US-2	Calumet, Michigan	50	75-31, C3	1939	A	Wet	Curves
84-318-48	8-21-48	Schoolcraft	Mueller	US-2	15 Miles West from Manistique	Washington, D.C.	60	75-30, C5	1936	A	Wet	Straight
84-1232	11-23-46	Schoolcraft	Doyle	US-2	2 Miles West of Gulliver	Chicago, Illinois	50	75-31, C8	1940	A	Wet	Straight
84-332-48	8-28-48	Schoolcraft	Doyle	US-2	1/2 Mile East from Gulliver at 720 plus 00	Grand Rapids, Michigan	60	75-31, C4	1939	A	Wet	Curve
None	2-6-46	Schoolcraft	Manistique	US-2	Intersection US-2 & 219	Escanaba, Michigan	20	75-30, C3	1935	A	Wet	Straight
84-1046	5-19-46	Schoolcraft	Manistique	US-2	(Deer Street) at West Avenue	Manistique, Michigan	30	75-28, C2	1941	A	Wet	Curve
84-1125	8-3-46	Schoolcraft	Manistique	US-2	1-1/2 Miles East from Manistique City Limits	Detroit, Michigan	50	75-31, C7	1939	A	Wet	Straight
84-1381	3-5-47	Schoolcraft	Manistique	US-2	2 Miles East of Manistique	Grand Rapids, Michigan	50	75-31, C7	1939	A	Wet	Straight
84-1427	4-20-47	Schoolcraft	Manistique	US-2	1 Mile East of Manistique	Soo, Michigan	70	75-31, C7	1940	A	Dry	Curves
84-1487	5-27-47	Schoolcraft	Manistique	US-2	Ann Arbor Railroad Crossing	Green Bay, Wisconsin	50	75-30, C3	1935	A	Wet	Straight
None	3-18-47	Schoolcraft	Manistique	US-2	(Chippewa Ave.,) M. & L.S.R.R. Crossing, 200 Block	Manistique, Michigan	20	75-28, C2	1941	A	Wet	Straight
84-208-48	6-30-48	Schoolcraft	Manistique	US-2	500 Ft. East from West City Limits	Escanaba, Michigan	45	75-28, C1	1941	A	Wet	Straight
None	7-12-48	Schoolcraft	Manistique	US-2	(Chippewa Ave.) 75 yds. South from Ottes St.	Toledo, Ohio	-	75-28, C2	1941	A	Wet	Straight
84-319-48	8-21-48	Schoolcraft	Manistique	US-2	300 Ft. West from M-149	Rodney, Michigan	45	75-30, C5	1936	A	Wet	Grade
84-1214	11-14-46	Schoolcraft	Thompson	US-2	1-1/2 Miles West from Manistique	Detroit, Michigan	40-50	75-31, C7	1940	A	Wet	Straight
84-1783	10-22-47	Schoolcraft	Thompson	US-2	5.6 Miles West from 149	Escanaba, Michigan	50	75-30, C5	1936	A	Wet	Straight
84-1742	11-5 -47	Schoolcraft	Thompson	US-2	.3 Mile West from M-219	Guelph, Ontario	40	75-30, C5	1936	A	Wet	Straight
84-211-48	7-3-48	Schoolcraft	Thompson	US-2	1/2 Mile West of Thompson	Milwaukee, Wisconsin	55	75-30, C5	1936	A	Wet	Straight
84-225-48	7-10-48	Schoolcraft	Thompson	US-2	2.9 Miles East from M-149	Portland, Michigan	40	75-30, C5	1936	A	Wet	Straight
84-1581	7-20-47	Schoolcraft	Inwood	US-2	100 yds. West from Cook's Corner	Pontiac, Michigan	45	75-30, C4	1936	A	Wet	Straight
84-322-48	8-22-48	Schoolcraft	Inwood	US-2	300 yds. West from Cook's Junction	Eben Junction, Mich.	50	75-30, C4	1936	A	Dry	Curves
84-346-48	9-4-48	Schoolcraft	Inwood	US-2	.2 Mile East of Cook's Junction	Plymouth, Michigan	40	75-30, C4	1936	A	Wet	Straight
84-417-48	10-11-48	Schoolcraft	Inwood	US-2	4.2 Miles West from Thompson M-149	Fayette, Michigan	60	75-30, C4	1936	A	Wet	Straight
84-1514	6-13-47	Delta	Garden	US-2	Isabella Junction R-18 W, T-41 N	Detroit, Michigan	35	21-29, C8	1937	A	Wet	Straight
85-2333	7-26-47	Delta	Garden	US-2	At No. 7 County Road	Marinette, Wisconsin	45	21-28, C4	1937	A	Wet	Straight
84-1624	8-10-47	Delta	Garden	US-2	1000 Ft. East from Isabella	Washington, D.C.	50	21-29, C8	1937	A	Wet	Downgrade
84-1671	9-13-47	Delta	Garden	US-2	500 Ft. East from Delta County Road #495	Rodgers City, Mich.	55-60	21-29, C8	1937	A	Wet	Straight
84-124-48	5-4-48	Delta	Garden	US-2	1 Mile West from Schoolcraft County Line	E. Detroit, Michigan	45	21-29, C9	1937	A	Wet	Curve
84-246-48	7-21-48	Delta	Garden	US-2	On US-2 at Delta County Road No. 483	Marquette, Michigan	45	21-29, C8	1937	A	Wet	Straight
84-148-48	7-21-48	Delta	Garden	US-2	Junction of Co. Rd. 483 and US-2	Peck, Michigan	55	21-29, C8	1937	A	Wet	Curves
84-282-48	8-7-48	Delta	Garden	US-2	1/4 Mile West from Garden Corners	Miami, Florida	50	21-29, C8	1937	A	Wet	Straight
84-284-48	8-7-48	Delta-	Garden	US-2	1/4 Mile East from Delta County Road No. 483	Lenox, Iowa	50	21-29, C9	1937	A	Wet	Straight
85-415-48	6-28-48	Delta	Nahma	US-2	528 Ft. West from Nahma Line Railroad	Gaylord, Michigan	60	21-28, C6	1936	A	Wet	Straight
84-229-48	7-12-48	Delta	Nahma	US-2	500 Feet West of Isabella	Cincinnatti	50	21-29, C8	1937	A	Wet	Straight
85-545-48	8-7-48	Delta	Nahma	US-2	100 Ft. West from County Road 497	Norway, Michigan	40	21-29, C7	1937	A	Wet	Straight
85-627-48	8-28-48	Delta	Nahma	US-2	1/8 Mile West from County Road L 7	Detroit, Michigan	60	21-28, C4	1937	A	Wet	Straight
85-633-48	8-29-48	Delta	Nahma	US-2	Intersection of US-2 & County Road 497	Warren, Ohio	45	21-29, C7	1937	A	Dry	Straight
85-697-48	9-19-48	Delta	Nahma	US-2	1.5 Miles Northeast from Isabella	Manistique, Mich.	45	21-29, C9	1937	A	Dry	Straight
85-2068	4-1-47	Delta	Ensign	US-2	.6 Miles East from Intersection of Co. Rd. 422	Garden, Michigan	30	21-28, C6	1936	A	Wet	Straight
85-2383	8-18-47	Delta	Ensign	US-2	Ownsis Tavern T-41-N & R-20-W	Detroit, Michigan	60	21-28, C4	1937	A	Dry	Straight
85-2451	9-15-47	Delta	Ensign	US-2	1/2 Mile West from Magnusson's Store	Verona, Wisconsin	50	21-28, C4	1937	A	Wet	Straight
85-82-48	2-23-48	Delta	Ensign	US-2	2.2 Miles East from Village of Ensign	Powers, Michigan	45	21-28, C6	1936	A	Dry	Straight
85-430-48	7-3-48	Delta	Ensign	US-2	4-1/2 Miles East of Rapid River	W. Toledo, Ohio	40	21-28, C4	1937	A	Wet	Straight
89-591-48	6-21-48	Delta	Ensign	US-2	3.3 Miles east from Ensign	Manistique, Michigan	65	21-28, C6	1936	A	Wet	Straight
85-1646	9-1-46	Delta	Masonville	US-2	2 Miles East from Rapid River	Marquette, Michigan	50	21-28, C2	1935	N	Dry	Straight
85-1802	11-2-46	Delta	Masonville	US-2	Intersection of Main Street (Rapid River)	Baraga, Michigan	25	21-20, C5	1934	C	Wet	Straight
85-2130	4-27-47	Delta	Masonville	US-2	30 Feet W. of Intersection of old US-41 & US-2 in Rapid River	Chicago, Illinois	30	21-28, C2	1935	N	Dry	Straight
85-2281	6-5-47	Delta	Masonville	US-2	Junction US-2 and US-41	Rapid River, Michigan	35	21-25, C4	1938	A	Wet	Curve
None	9-19-47	Delta	Masonville	US-2	On US-41, 1/5 Mile West from Ford River Bridge	Rhinelander, Wisconsin	50	21-9 , C5	1942	C	Wet	Straight
85-235-48	4-25-48	Delta	Masonville	US-2	Intersection of US-41	Negaunee, Michigan	45	21-25, C4	1938	A	Wet	Curve
85-638-48	9-14-48	Delta	Masonville	US-2	1/10 Mile East from US-41	Ensign, Michigan	30	21-28, C2	1935	N	Wet	Straight
					LOWER PENINSULA - US-31							
77-1657	7-10-46	Manistee	Manistee	US-31	At US-31 and M-110 Peanut Junction			51-2, C3	1944	A	Wet	Curve
None	4-4-47	Manistee	Manistee	US-31	1-1/2 - 2 Miles East from M-55 and village of Parkdale at the edge of the City of Manistee			51-2, C3	1944	A	Wet	Straight
77-2355	9-1-47	Manistee	Manistee	US-31	.2 Miles from North M-110			51-2, C3	1944	A	Wet	Curve
77-2390	9-16-47	Manistee	Manistee	US-31	1/10 Mile East from Manistee City Limits			51-2, C3	1944	A	Wet	Curve
77-750-48	6-18-48	Manistee	Manistee	US-31	5 Miles East from intersection of M-110	Antigo, Wisconsin	30	51-2, C3	1944	A	Wet	Curve
56	8-17-48	Manistee	Manistee	US-31	At M-110 - Peanut Junction	Holland, Michigan	25	51-2, C3	1944	A	Wet	Curve
55	8-17-48	Manistee	Manistee	US-31	At M-110 - Peanut Junction	Evanston, Illinois		51-2, C3	1944	A	Wet	Curve
					LOWER PENINSULA - M-29							
19154	8-11-46	St. Clair	St. Clair	M-29	1/4 Mile South From Davis Road at Guardrail			77-66, C1	1944	A	Wet	Straight
23-2616	8-28-46	St. Clair	St. Clair	M-29	1/4 Mile North from Parkers Boat House			77-66, C1	1944	A	Wet	Straight
23-3018	2-12-47	St. Clair	St. Clair	M-29	.3 Mile North from Neuman Road	Marine City, Michigan	60	77-66, C1	1944	A	Dry	Straight
23-3187	4-30-47	St. Clair	St. Clair	M-29	.2 Mile South from Davis Road			77-66, C1	1944	A	Wet	Straight
23-112	2-19-48	St. Clair	St. Clair	M-29	.2 Mile North from Neuman Road	St. Clair, Michigan	50	77-66, C1	1944	A	Dry	Straight
23-773-48	8-4-48	St. Clair	St. Clair	M-29	At 1335 - M-29 in St. Clair Twp.	Marysville, Michigan	35	77-66, C1	1944	A	Dry	Straight
None	8-13-48	St. Clair	St. Clair	M-29	1/4 Mile North from Yankee	St. Clair, Michigan	35	77-66, C1	1944	A	Dry	Straight
23-873-48	8-26-48	St. Clair	St. Clair	M-29	4 Miles North from Neuman Road	Detroit, Michigan	50	77-66, C1	1944	A	Dry	Straight

* From State Police Reports via Planning and Traffic Division

A - Inland Coarse Aggregate and Stone Sand
B - Bituminous Surface
C - Natural Aggregate
D - Limestone Coarse Aggregate - Natural Sand



TOTAL TRAFFIC *and* ACCIDENT EXPERIENCES *on* U.S. 2 *between* RAPID RIVER *and* ST. IGNACE

Figure 2

reported for the stone sand project in Petoskey. No doubt many have occurred which have been taken care of by municipal police. At Manistee the section of pavement having the most accidents includes the sharp curve where US-31 and M-110 meet and that portion of pavement between M-110 and M-55. In the case of the stone sand project on M-29 the skidding accidents seemed to be well-distributed along the entire project.

SKIDDING STUDIES IN THE UPPER PENINSULA

According to Departmental records, there are approximately 121.6 miles of stone sand concrete pavements on the State Trunkline system of which 112.6 miles are in the Upper Peninsula and 9.0 miles in the Lower Peninsula. There are 82.5 miles of such pavements on US-2 between St. Ignace and Rapid River.

The location of all concrete projects in the Upper Peninsula containing Inland stone sand are shown on the map in Figure 3. The locations of Inland stone sand projects in the Lower Peninsula are shown in Figure 16, together with those bituminous concrete recapping projects containing Inland stone aggregate on which skidding tests were made.

The concrete pavements made with Inland stone sand are readily distinguished from other concrete surfaces in that they are light gray in color and possess a high gloss or sheen indicative of smoothness. Examples of such conditions are shown in Figures 4 and 5. The light areas seen in Figure 4 represent spots on the concrete surface which have been polished to a high degree of smoothness by the action of traffic and grader blades used for ice removal. These areas are exceedingly slippery even when dry. Figure 5 shows a stone sand pavement under reflected light.

Sections of several of the projects on US-2 made with stone sand have scaled completely exposing the limestone coarse aggregate particles of the parent concrete. See Figure 6. In such cases the coarse aggregate particles have become smooth and glazed under the action of the traffic. See Figure 7. These areas proved to be exceedingly slippery when wet. The completely scaled areas are generally found at curves and intersections where chloride salts applied for ice control have encouraged scaling action.

The seriousness of the situation warranted the making of numerous skidding tests on the several projects in order to obtain sufficient data on frictional coefficients for use as a basis for comparative study with other types of highway surfaces.

Method of Determining Stopping Distance

The relative slipperiness of the different types of concrete pavements included in the survey were determined by the stopping distance method. A 1942 Pontiac passenger car weighing 3,300 pounds and equipped with 6.10 X 16 inch, 4 ply tires at 30 pounds air pressure was used throughout the skidding tests. All tests were made on wet pavement at a speed of 20 miles per hour. In performing the tests, the car was brought to an initial uniform speed of 20 miles per hour, the clutch disengaged, and the brakes applied hard instantly to lock all four wheels. Simultaneously with the action of the brake pedal a special pavement marking gun located on the rear bumper was discharged electrically to mark the pavement. The stopping distance was measured between the mark on the pavement and the gun on the car. This method of determining the skid resistance of highway surfaces has been used with success by other State Highway Organizations. Figures 8 and 9 illustrate equipment employed in the study.

Usually three or more skidding tests were made in a certain area, either

U.P. STONE SAND CONCRETE PROJECTS
INCLUDED IN INVESTIGATION

Figure 3

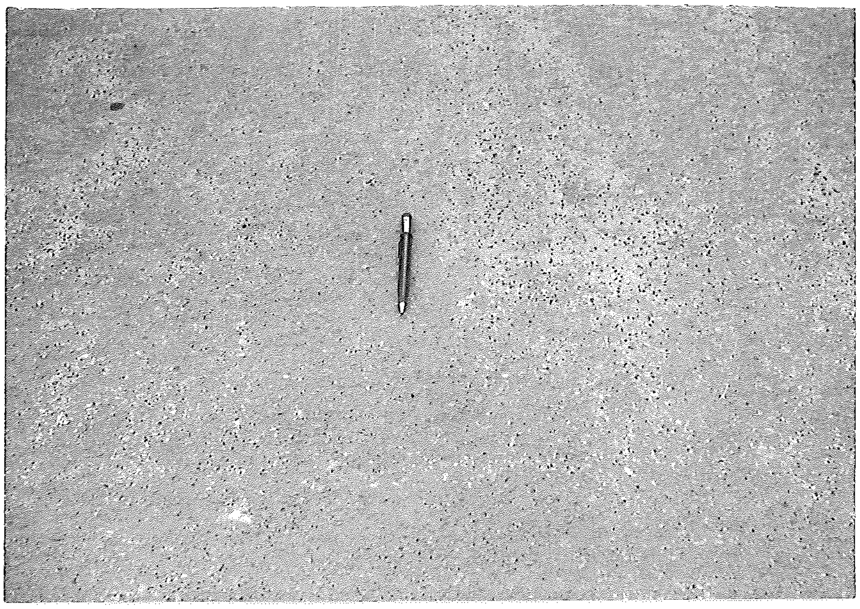


Figure 4. Stone sand concrete. Light gray areas have become exceedingly smooth and polished under service.

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Figure 5. Stone sand concrete. Typical appearance of smooth surfaces under reflected light.

Figure 6. View of Inland stone sand concrete. Completely scaled area. US-2 in Manistique.

Figure 7. Glose view of scaled surface. Note smooth texture of coarse aggregate particles.

Figure 8. View showing water truck, skidding car and measurement of stopping distance.

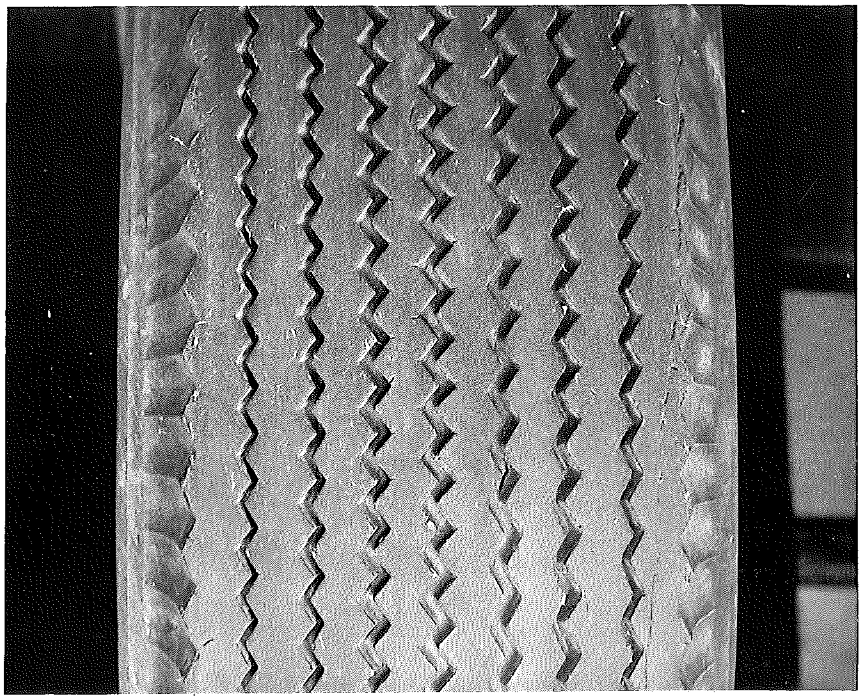

Figure 9. Typical tread pattern of all tires on test car.

in the same direction or in opposite directions, depending upon the gradient of the pavement. Prior to performing tests, the surface of the pavement was thoroughly wetted by means of a water truck. If necessary, additional water was applied during tests to maintain uniform conditions. The location and designation of test areas are shown by encircled numbers on the maps in Figures 3 and 4. Knowing the stopping distance and the velocity of the vehicle, the coefficient of sliding friction may be calculated in the following manner.

Determination of Coefficient of Sliding Friction

The skid resistance of a pavement surface can be readily determined by the principle that the work done by the external forces acting on a rigid body in any displacement is equal to the change in the kinetic energy of the body in the same displacement. This principle may be expressed by the equation:

$$F \cdot S = 1/2 \frac{W}{g} v^2 \qquad (1)$$

where $F \cdot S$ equals work and $1/2 \frac{W}{g} v^2$ equals the kinetic energy of a body when

F = frictional resistance force in pounds,
S = displacement of body in feet,
W = weight of body in pounds,
g = 32.2 acceleration of gravity, and
v = velocity of body in feet per second.

Applying the principle of work and energy to a skidding vehicle on a highway, it is possible to determine the approximate coefficient of friction between concrete and tires in the following manner. When skidding with all wheels locked, the total kinetic energy of a moving vehicle ($1/2 \frac{W}{g} v^2$) is dissipated by the frictional resistance force (F) created between tires and surface acting through the stopping distance (S). The frictional force (F is equal to the weight of the vehicle (W) times the coefficient of friction (f),

$$f = \frac{F}{W} \text{ or } F = f \cdot W$$

Substituting in the above equation (1) we have

$$f \cdot W \cdot S = \frac{W}{2g} v^2$$

by changing (v) in feet per second to miles per hour, substituting 32.3 for g, and cancelling the weight (w), the formula becomes

$$f = \frac{V^2}{30S}$$

where f = coefficient of sliding friction,

V = velocity of vehicle in miles per hour, and

S = stopping distance in feet

This method assumes that the coefficient of friction throughout the stopping distance is uniform which is not strictly true because it is known that the coefficient varies slightly with speed of deceleration. However, for all practical purposes the uniform coefficient determined by this method is considered satisfactory for comparative study of pavement surfaces.

Stopping Distance Tests on US-2

In all cases the stopping distance tests were conducted as nearly as possible under identical climatic conditions and wetness of the pavement surface in order to minimize as much as possible the influence of such factors on the coefficient of the friction. The stopping distance tests include not only certain stone sand projects on US-2 but also other concrete and bituminous projects containing Inland stone aggregate located in the Lower Peninsula.

All stopping distance measurements, together with average coefficients of friction and pertinent project information for projects on US-2, are given in Table III. The stone sand projects tested possessed friction

TABLE III

SUMMARY OF SKIDDING TEST DATA ON CONCRETE PAVEMENT CONSTRUCTED WITH STONE OR NATURAL SANDS

UPPER PENINSULA US-2

Test No.	Project No.	Location	Condition - Concrete Surface	Stopping Distance Tests - in Feet						Coef. of Friction	Date Constructed	Concrete Materials		
				1	2	3	4	5	Average			Cement	Coarse A	Fine A
7	75-30, C7	US 2 Just East of Thompson's Corners	Not Scaled	30.6	28.0	36.6	-	-	31.7	.42	1936	Universal, Ind.	Inland	Inland
2	75-30, C3	US 2 300 Ft. East R.R.Crossing and West of M-94 in Manistique	Partially Scaled	50.8	37.1	42.1	27.9	30.5	37.7	.35	1935	Universal, Ind.	"	"
5	Manistique	US 2 At intersection of Elk and Maple Streets in Manistique	Completely Scaled and Pitted	35.2	50.7	29.8	-	-	38.6	.35	1938	Universal, Minn. Petoskey	"	"
18	49-28, C2	US 2 1/2 Mile East of Brevoort River Bridge	No Scaling	*^{e}29.3	^{w}41.3	^{e}35.7	^{w}44.6	-	37.7	.35	1937	Universal, Ind.	"	"
1	75-30, C3	US 2 200 Ft. South of Intersection with M-94 in Manistique	Completely Scaled and Pitted	43.5	36.9	47.9	37.6	-	41.5	.32	1935	Universal, Ind. Petoskey	"	"
3	75-30, C3	US 2 On Curve N. of R.R.Crossing and S. of M-94 in Manistique	Partially Scaled	47.1	51.9	39.4	36.1	-	43.6	.31	1935	"	"	"
16	75-2, C6	US 2 100 Ft. E. of M-77 Blaney Park	No Scaling	^{e}43.5	^{w}50.5	^{e}40.8	^{w}50.3	-	46.3	.29	1943	Petoskey with Orvus	"	" "
13	75-31, C7	US 2 E. of Curve Opposite Marble Head Lake	No Scaling	59.6	55.8	49.8	41.3	52.9	51.9	.26	1941	Huron, Alpena	"	"
11	21-29, C7	US 2 W. of Isabella at Moss Lake Curve	No Scaling	54.0	52.0	-	-	-	53.0	.25	1937	Petoskey	"	"
8	75-30, C5	US 2 Just E. of Curve at Cook's Corners	Completely Scaled and Pitted	59.0	58.6	47.4	59.6	-	56.2	.24	1936	Petoskey	"	"
9	21-29, C8	US 2 On Curve at Garden Road Corners	Badly Scaled and Pitted	54.8	59.0	63.6	-	-	59.1	.23	1937	Universal, Ind.	"	"
10	21-29, C7	US 2 At east Limits of Isabella	No Scaling but Cracked and Rough	63.9	52.0	-	-	-	58.0	.23	1937	Petoskey	"	"
14	75-31, C4	US 2 Just East of Curve at Gulliver Corner	No Scaling	71.1	59.9	52.4	63.5	-	61.7	.22	1938	Petoskey	"	"
15	75-31, C3	US 2 At Bear Creek 3.5 Miles W. of M-77 Blaney Park	Partially Scaled Badly Cracked, Rough	60.8	67.9	69.6	69.7	-	67.0	.20	1933	Petoskey	"	"
17	49-28, C4	US 2 Just W. of Brevoort River Bridge	No Scaling	^{e}16.6	^{e}16.5	^{e}16.5	^{w}18.1	^{w}18.1	17.3	.77	1937	Huron, Alpena	Moran, Pit-St. Ignace	Moran, Pit-St. Ignace
6	Manistique	US 2 N. end Maple St. at Elk St. in Manistique	Not Scaled	24.9	20.7	-	-	-	22.8	.58	1938	- -	-	Natural
4	75-6, C4	US 2 Just E. of State Police Post in Manistique	No Scaling	34.1	28.0	26.7	29.1	-	29.5	.45	1930	Huron, Alpena	Sturgeon Bay	Sarnia
12	75-6, C4	US 2 ½ Mile E. of State Police Post in Manistique	No Scaling	37.8	34.5	42.0	-	-	38.1	.35	1930	Huron, Alpena	Sturgeon Bay	Sarnia

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* e - East w - West

coefficients ranging from 0.35 to 0.20 with an average of 0.28. This is below the minimum value of 0.4 recommended by the American Association of State Highway officials for safe driving under all conditions. This point is fully discussed further on in the text. No definite correlation between pavement age, construction procedure or brand of cement is indicated. Tests on concrete using natural sand gave results ranging from 0.77 to 0.35, or an average of 0.50. A more complete account of each skidding test area follows:

Test Areas 1, 2, and 3: The first three skidding tests were conducted on different sections of pavement Project 75-30, C3 in the City of Manistique, starting at the intersection with M-94 and extending to the south about 1 1/2 miles. This particular section was reported to be extremely bad because, in addition to being slippery when wet, it contains a sharp curve, a railroad crossing and a traffic stop at M-94. The pavement surface in this area is completely scaled in most places and partially so in others, as may be observed in Figure 6. Many accidents have occurred in this area during the past two years. The average coefficients of friction for the three tests were 0.32, 0.35, and 0.31, respectively.

Test Areas 4, 6, and 12: Test areas 4, 6 and 12 were selected on a pavement constructed with natural sand to obtain comparative skidding data. Tests 4 and 12 were made on Project 75-6, C4 on US-2 at the east limits of Manistique. Sturgeon Bay limestone, natural sand, and Huron cement were used in the concrete. Test No. 6 was made on Maple St. at the intersection with Elk St. in Manistique. This pavement is believed to contain the same materials as in test area 4. The average coefficient of friction for the three surfaces was 0.44. The concrete surface of the three areas was not scaled.

Test Area 5: This area is also located at the intersection of Maple and Elk Streets in Manistique, but is on a project containing stone sand. At this point US-2 makes a 90 degree turn. The surface of the stone sand concrete has become completely scaled and the exposed coarse aggregate particles are worn smooth and glossy under the turning action of traffic. The coefficient of friction for this area was 0.35.

Test Area 7: Test No. 7 was made on a straight section of pavement just east of Thompson Corners on Project 75-30,C7. This particular stone sand pavement surface had no scale and appeared less glossy than other stone sand projects. The coefficient of friction was 0.42, which was the highest value found on any of the stone sand projects tested. Figure 10 presents a view of the texture of the surface. You will note in Figure 10 that the pavement surface has a large amount of small indentations. These surface voids may account for the fact that the friction factor is higher on this stone sand project than on others, since they provide drainage space for displaced water by passing tires.

Test Area 8: Test No. 8 was made on a straight section of pavement just east of a curve at Cook's Corners on Project 75-30, C5. See Figure 11. The concrete surface in this area was badly scaled and apparently very smooth. This location was reported to be dangerously slippery when wet. The coefficient of friction was very low, 0.24.

Test Area 9: Test No. 9 was made on the curve at Garden Corners on Project 21-29, C8. This area was reported by State Police to be one of the extremely bad spots. The concrete surface was badly scaled and the exposed coarse aggregate was worn smooth. The coefficient of friction was very low, being 0.23.

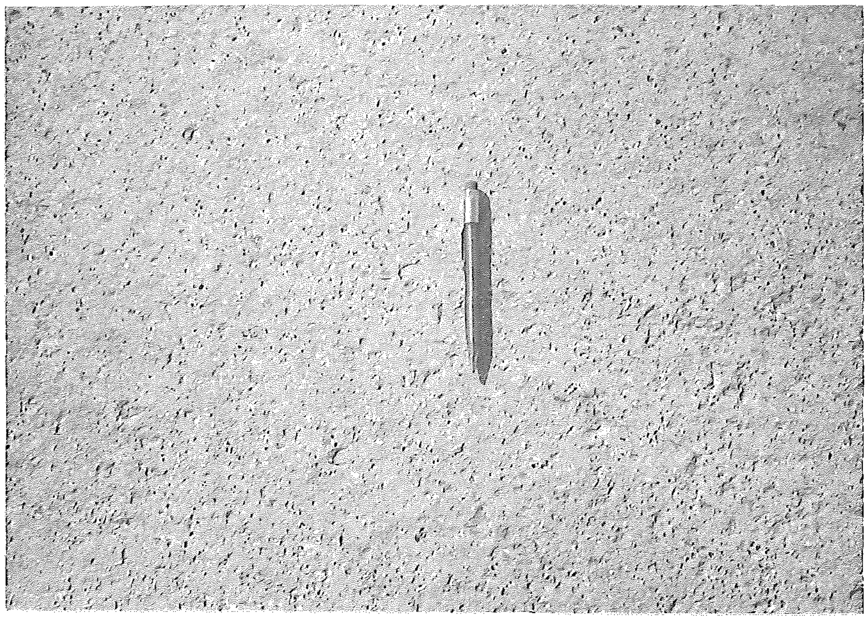


Figure 10. Texture of stone sand surface Project 75-30, C7.

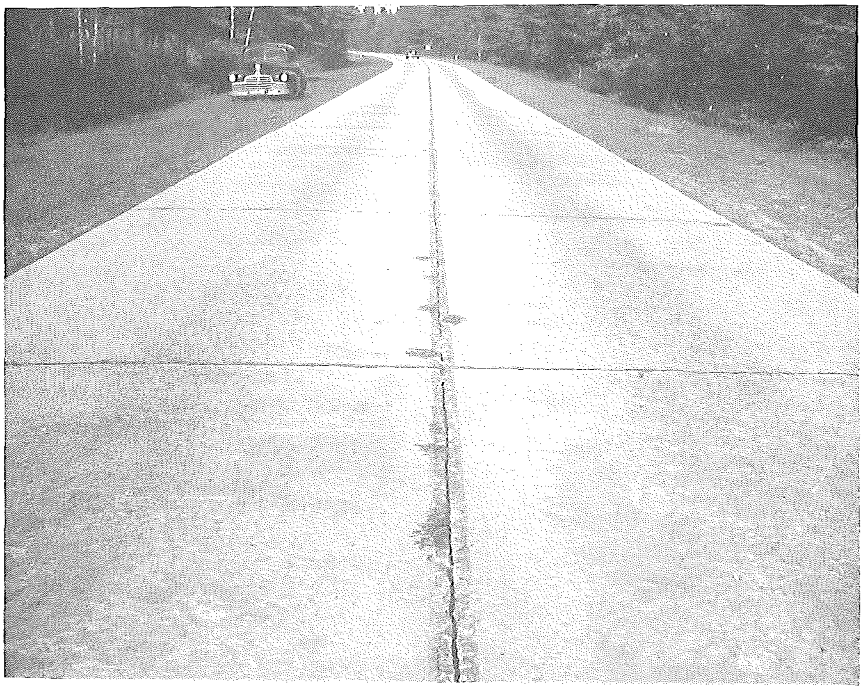


Figure 11. General view of curve at Cooks Corners. F 75-30, C5.

There are certain design features which could influence skidding accidents at this point. In the first place, the curve is superelevated .07 foot per foot of width, which is sufficient to cause any skidding car in the east bound lane to skid sideways into the oncoming westbound traffic. During the skidding tests the test car invariably would skid from the high side to the low side of the curve before coming to a stop. Furthermore, the curve is intersected near its east tangent by Garden Road. If fast-moving vehicles on US-2 are suddenly required to reduce speed due to the entrance of slow traffic from the Garden Road, the results are obvious. The tracking of dust onto the highway from the gravel side road and shoulders at the intersection will also tend to lower the friction factor. A picture of this area is shown in Figure 12.

Test Areas 10 and 11: Test areas 10 and 11 are located just east and west, respectively, of the store at Isabella on Project 21-29, C7. These areas were also reported by the State Police to be very slippery when wet. In both cases the surfaces were smooth and glossy with no scaled areas.

The pavement at test area 10 has undergone considerable transverse cracking in spots due to settlement of the subgrade. The roughness of the surface created by the cracks and settled pavement may be instrumental in conjunction with the slippery surface in causing many skidding accidents in this area. The coefficients of friction of the two areas were 0.23 and 0.25, respectively.

Test Area 13: This area is located on a straight section of pavement just east of the curve opposite Marblehead Lake, Project 75-31, C7. The surface had a coefficient of friction of 0.26. This area was also reported by the State Police to be extremely slippery when wet. See Figure 13.

Test Area 14: Test No. 14 was made on a straight section just east of the curve at Gulliver Village on Project 75-31, C4. The curve at Gulliver was reported as being very dangerous when wet. The coefficient of friction at this area was very low, 0.22.

Other factors besides slippery pavement may influence the accident rate in this particular area. The curve is superelevated at .06 per foot of width and there is a cross road near the center of the curve. Also this is a local trading community and consequently local traffic cutting in and off the highway could create a hazard to fast-moving traffic on US-2 when pavement is wet. A general view of the curve at Gulliver Village is shown in Figure 14.

Test Area 15: This area is located at Bear Creek approximately 3 1/2 miles west of Blaney Park on Project 75-31, C3. The coefficient of friction was .20, the lowest value obtained on any of the stone sand projects tested. The pavement surface on the entire project extending from just west of M-77 at Blaney Park to the end of the curve west of Bear Creek was badly cracked transversely. The surface was scaled sporadically and especially at cracks. State Police stated that this was an unusually bad area for skidding accidents, and it is believed that the abnormal roughness of the pavement due to cracking may increase the tendency for cars to skid on the wet surface. The curve is also partially obscured by trees as well as a cross road at the center of the curve. See Figure 15.

Test Area 16: Tests were made on a comparatively recent stone sand project, Project 75-2, C6, constructed in 1943. It is located just east of M-77 at Blaney Park. This section has not been reported as dangerous, but we were interested in the age factor on skidding results. The coefficient of friction was found to be 0.29, which is exceedingly low. The surface of the pavement

Figure 12. General view of road conditions at Garden Corners.

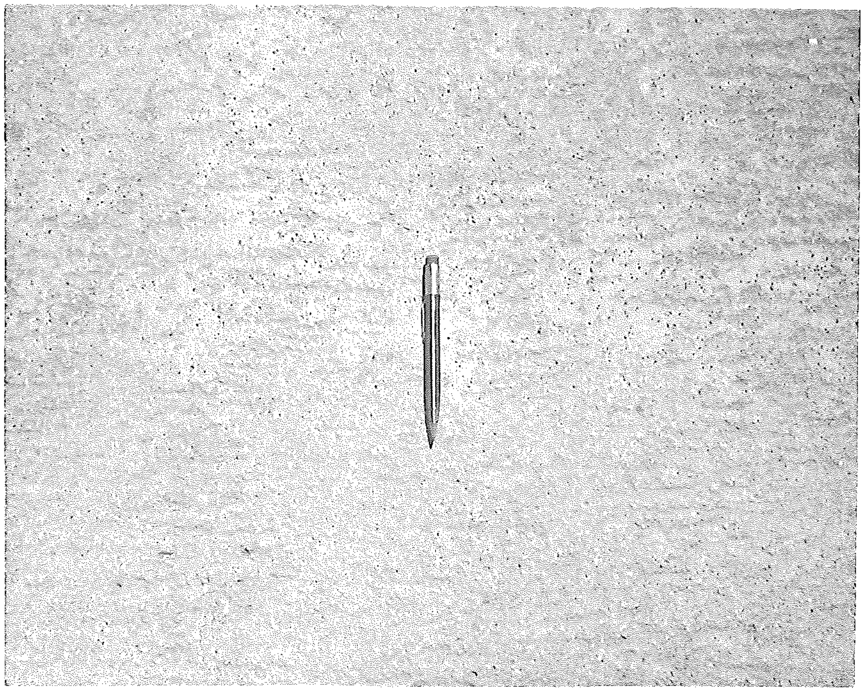


Figure 13. Texture of surface project 75-31, C7. Test area 13. Note smooth condition of concrete.

Figure 14. General view of test area 14 on Project 75-31, C4. Gulliver Village.

Figure 15. General view of curve at Bear Creek test area 15, Project 75-31, C3.

was free from scale.

Test Area 17: Test area 17 is on Project 49-28, C4, constructed with both fine and coarse natural aggregates. This project was selected as a control for comparison with the stone sand projects. The coefficient of friction on this project was 0.77, the highest value obtained on any project tested.

Test Area 18: This test area is on pavement project F 49-28, C2, constructed with stone sand and abutting the natural sand project containing test area 17. These projects meet at the Brevort River Bridge. This area was selected because of its proximity to Project 49-28, C4. Both areas could have the same traffic and climatic conditions. The coefficient of friction was 0.35.

Stone Sand Projects on US-41

As may be seen in Figure 3, stone sand concrete pavement extends continuously on US-41 from Rapid River to the west line of Alger County. Also there is a short project within the city limits of Marquette on the east side. No skidding studies were conducted on US-41. Measurements of stopping distance were not deemed necessary on US-41 because a visual inspection indicated that the condition of the pavement surface was similar to that of the stone sand projects on US-2. At the time of this investigation, the department was fully aware of the very slippery-when-wet pavement on US-41 in the City of Marquette and had already taken action.

Intersection at US-2 and US-41:

A visual examination was made of pavement conditions at US-2 and US-41 at the request of the State Police at Gladstone. They stated that the pavement on the two legs of the wye intersection on US-41 was very slippery when wet and that many skidding accidents have taken place when motorists, traveling south on US-41, attempted to make the stop at US-2 when it is raining or foggy.

The stone sand concrete surfaces on the two wye segments are badly scaled, evidently due to repeated applications of chloride salts for ice removal. In addition, the existing surface of the concrete has worn smooth under traffic action and evidently has the same skidding characteristics as other stone sand concrete in the same physical condition as shown in Figures 6 and 7.

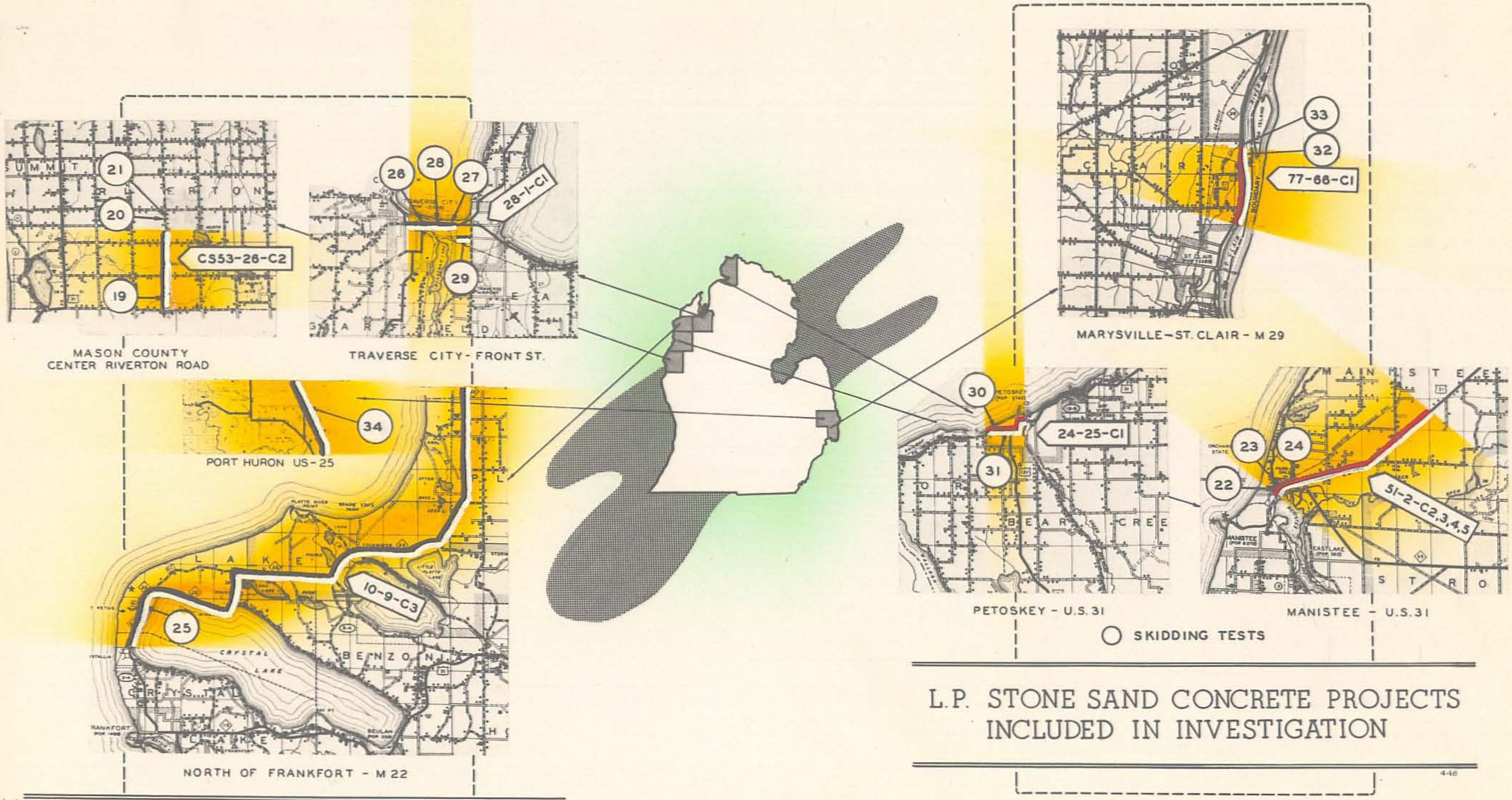
SKIDDING STUDIES ON LOWER PENINSULA PROJECTS CONTAINING INLAND LIMESTONE AGGREGATES

Upon completion of the skidding studies on US-2, it was decided to secure more skidding data by increasing the scope of the investigation to include the three stone sand concrete projects in the lower peninsula and several bituminous resurfacing projects in which Inland limestone aggregates were used. The projects covered in this phase of the investigation are shown in Figure 16 together with the location of the skidding tests. A summary of skidding test data will be found in Table IV. A detailed account of each test area follows.

Stopping Distance Tests

Test Area 19: This test area is on Project CS 53-26, C2 in Mason County on Center Riverton Road. The surface consists of a bituminous double seal with Inland stone chips over oil aggregate. This test area was selected as one of several bituminous resurfacing projects to determine the influence of Inland limestone aggregates on the skidding properties of bituminous surfaces. The average coefficient of friction was 0.55. The surface was unusually rough textured due to the fact that the coarse stone was exposed.

Figure 16



L.P. STONE SAND CONCRETE PROJECTS INCLUDED IN INVESTIGATION

L.P. BITUMINOUS SURFACE TREATMENT PROJECTS CONTAINING INLAND STONE

TABLE IV

SUMMARY OF SKIDDING TEST DATA ON CONCRETE PAVEMENTS AND BITUMINOUS SURFACE TREATMENTS CONSTRUCTED WITH INLAND STONE AGGREGATES, LOWER PENINSULA

Test No.	Project No.	Location	Condition of Surface	Stopping Distance Tests, in feet						Coef. of Friction	Date Const.	Materials		
				1	2	3	4	5	Ave.			Cement	Coarse Aggregate	Fine Aggregate
26	Traverse City	US-31, W. Front St. at Oak and Maple, Traverse City.	Bituminous Concrete Resurface, Good Condition.	20.0	23.0	20.0	22.0	--	21.2	0.63	1945	Asphalt	Inland	Nat. Sand
27	Traverse City	US-31, E. Front St., 800 block, Traverse City.	Bituminous Concrete Resurface, Fair Condition.	22.3	21.5	--	--	--	21.9	0.61	1942	Asphalt	Inland	Nat. Sand
33	77-15,C2	M-29, S. Limits of Marysville.	Concrete Surface, No Scale.	22.5	22.2	29.4	22.8	23.7	24.1	0.55	1939	Peerless	Inland	Nat. Sand
19	CS 53-26,C2	Center Riverton Road, Mason County.	Double Seal, Rough Texture.	26.7	24.4	22.1	--	--	24.4	0.55	1942	M.C. Asphalt	Inland	Inland
34	77-10,C4	US-25, North of Port Huron.	Bituminous Concrete Resurface, Good Condition.	24.7	26.5	23.9	24.1	--	24.8	0.54	1947	Asphalt	Inland	Nat. Sand
20	Mason County	Center Riverton Rd. just north of CS 53-26,C2.	Single Seal, Smooth.	25.6	29.0	30.4	--	--	28.3	0.47	1942	Bituminous	--	Inland
28	Traverse City	US-31, E. Front St., 400 block, Traverse City.	Bituminous Concrete, Good Condition.	32.0	27.0	27.5	26.8	--	28.3	0.47	1945	Asphalt	Inland	Nat. Sand
31	24-25,C1	US-31 at US-131, Petoskey.	Bituminous Retread, Good Condition.	32.3	31.5	34.3	--	--	32.7	0.41	1942	Bituminous	Petoskey	Nat. Sand
25	F 10-9,C3	M-22, Crystallia north to County Line.	Double Seal, Good Condition.	37.2	26.3	38.2	31.4	--	33.3	0.40	1945	Bituminous	Inland	Inland
29	Traverse City	East 8th St. at Garfield Road.	Concrete Smooth & Pitted.	34.0	36.3	36.7	--	--	35.6	0.37	--	Petoskey	Gravel	Nat. Sand
21	Mason County	Center Riverton Road north of CS 53-26,C2.	Single Seal, New, Good Condition.	41.3	34.1	36.6	--	--	37.3	0.36	1948	Bituminous	--	Inland
32	77-66,C1	M-29, Between Marysville and St. Clair.	Concrete, No Scaling.	39.3	44.3	36.4	45.0	41.0	41.2	0.32	1944	Peerless V.R.	Inland	Inland
24	51-2,C3-5	US-31 in Manistee at M-55.	Concrete, No Scaling.	46.0	51.2	42.2	--	--	46.5	0.29	1944	Petoskey	Inland	Inland
23	51-2,C3-5	US-31 in Manistee on curve west of M-55.	Concrete, No Scaling.	63.7	43.0	46.8	42.6	--	49.0	0.27	1944	Petoskey	Inland	Inland
30	24-25,C1	US-31 in Petoskey Front of County Garage.	Concrete Partially Scaled.	51.5	61.2	56.8	53.9	--	55.8	0.24	1939	Petoskey	Inland	Inland
22	51-2,C3-5	US-31 in Manistee at M-110.	Concrete, No Scaling.	41.8	82.8	35.0	64.9	--	56.1	0.24	1944	Petoskey	Inland	Inland

We would consider this surface too open to be typical of a well-constructed double seal resurfacing job. See Figure 17.

Test Area 20: This test area lies a short distance north of Project CS 53-26, C2 on Center Riverton Road. The surface consists of an old single seal job using Inland limestone chips. The surface was well worn, smooth and typical of such surfaces. See Figure 18. The average coefficient of friction was 0.47.

Test Area 21: This test area is also on Center Riverton Road, approximately 200 feet north of test area 20. The road surface in this particular area was recently treated with a single bituminous seal and Inland stone chips. The surface was so loaded with chips that no bituminous material was exposed. See Figure 19. Skidding tests were made at this location to determine the effect of age and influence of construction conditions. The coefficient of friction was 0.36.

Test Area 22: This area is on a curve on US-31 in the City of Manistee at the intersection with M-110, Project 51-2, C 3-5. As may be seen in Figure 20, this area has several undesirable features which enhance the seriousness of the slippery pavement. They include the sharp curvature and down grade of US-31 at this point, the short sight distance due to adjacent buildings and converging traffic from M-110. The surface of the pavement was smooth and slippery as in the case of the other stone sand projects. See Figure 21. The average coefficient of friction was 0.24. According to local State Police there are many accidents on this spot.

Test Areas 23 and 24: Additional skidding tests were made on US-31 on the same project as test area 22, F 51-2, C 3-5, but nearer to M-55. Coefficients of 0.27 and 0.29 were obtained.

Test Area 25: This test area includes another bituminous resurfacing project located on M-22 just north of Crystallia, and designated Project F 10-9, C3. The surface consists of a double seal with Inland stone chips. The surface is in good condition. The coefficient of friction was 0.40.

Test Area 26 and 28: These test areas are on new bituminous concrete resurfacing on Front Street in Traverse City placed in 1945. The skidding tests were made early in the morning and, therefore, the skidding factor may be somewhat lower than might be expected at summer temperatures. The pavement surface was 45° F. at the time of tests. Coefficients of friction for the areas were respectively 0.63 and 0.47. Conditions of surfaces may be seen in Figures 22 and 23. Although the pavement represented by test areas 26 and 28 was supposedly the same, the friction data and photographs in Figures 22 and 23 disclose that the respective surfaces have undergone different changes no doubt due to local traffic conditions.

Test Area 27: This test area was also on Front Street in Traverse City, but on old bituminous concrete resurfacing project put down by the City in 1942. The coefficient of friction was 0.61. The texture of the surface was rough. See Figure 24.

Test Area 29: At the suggestion of the Traverse City Police a skidding test was made on a natural sand project on East 8th Street at Garfield Road which they claimed was very slippery when wet. As may be seen in Figure 25 the surface is smooth and glossy. The average coefficient of friction for this Traverse City concrete project was 0.37.

Test Area 30: This are is located on US-31 on concrete pavement project 24-25, C1 in the city of Petoskey just west of the intersection at M-131. Inland coarse and fine aggregate and Petoskey cement were used in the construction of this con-

Figure 17. Texture of surface at last area 19.
Project CS 53-26, C2.

Figure 18. Texture of surface at test area 20.

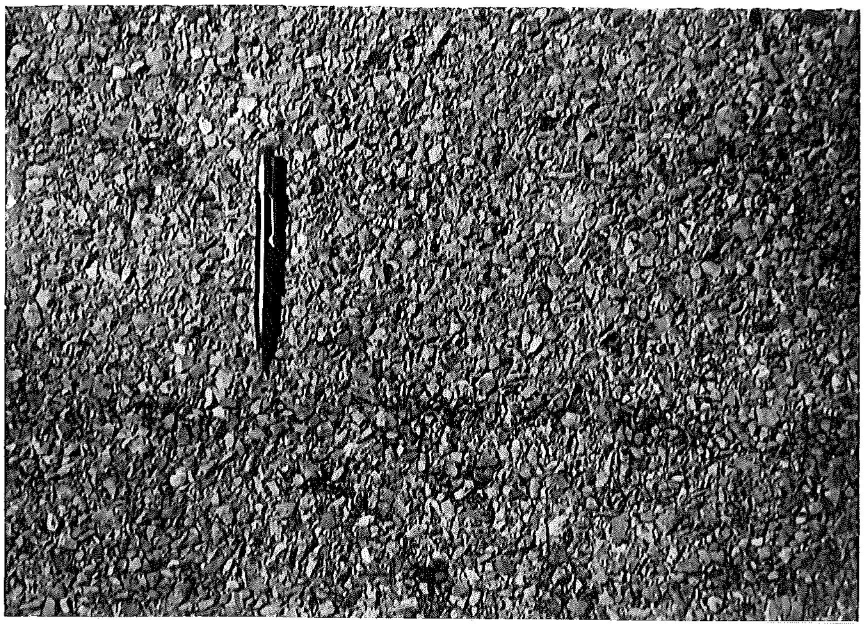


Figure 19. Texture of surface at test area 21.

Figure 20. General view at US-31 and M-110. City of Manistique. Project 51-2, C3-5, test area 22.

Figure 21. Stone sand concrete on US-31 at M-110, Manistee, Project 51-2, C3-5.

Figure 22. Bituminous concrete resurfacing on Front Street, Traverse City, between Oak and Maple Sts. Test area 26. Laid in 1945.

Figure 23. Bituminous concrete resurfacing on Front Street, Traverse City, 400 block. New pavement put down in 1945. Test area 28.

Figure 24. Bituminous concrete resurfacing at Front Street, Traverse City. 800 block, laid in 1942. Test area 27. Note rough texture of surface.

Figure 25. Natural sand concrete surface on 8th St. in Traverse City. Test area 29, City Project.

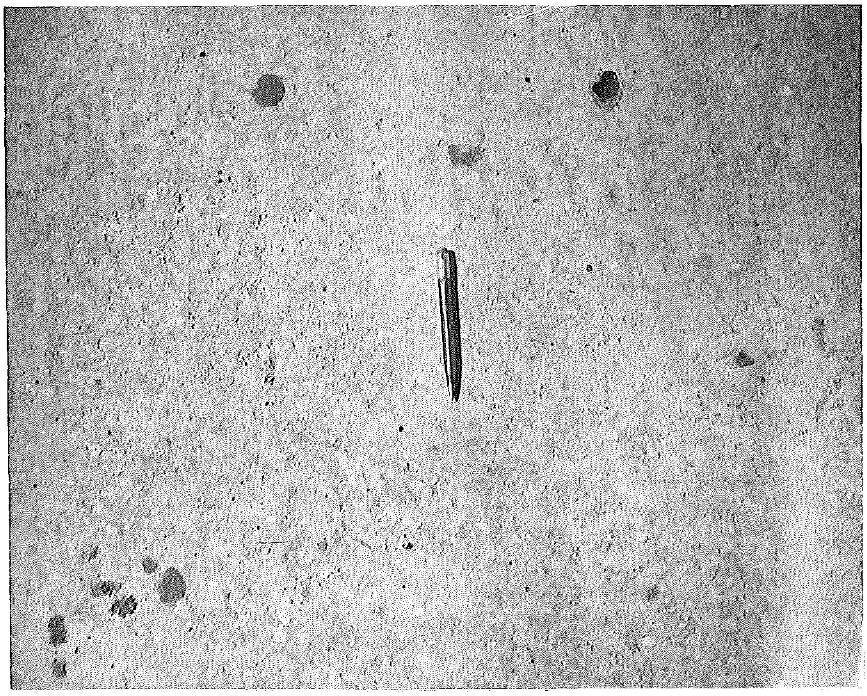


Figure 26. Stone sand surface, Project 24-25, C1, Test area 30. Note smooth texture of surface.

SUMMARY OF STOPPING DISTANCE TEST DATA

In summary, the average skidding properties of the various surfaces tested are presented in the following table:

TABLE V

SUMMARY OF COEFFICIENT OF FRICTION DATA

Type of Surface	Number Tests	Type of Fine Aggregate	Coefficient of Friction Max. f	Min. f	Avg. f
Concrete	19	Inland Stone Sand	0.42	0.20	0.28
Concrete	6	Natural Sand	0.77	0.35	0.50
Bituminous Concrete	4	Inland Stone-Natural Sand	0.62	0.47	0.56
Seal Coat	4	Inland Stone Chips	0.55	0.36	0.45

A graphical presentation of the average skid resistance by stopping distance measurements on all surfaces tested is given in Figure 27. Note that the bituminous concrete resurfacing material has very good resistant properties when wet which is contradictory to popular belief. Also note that natural sand concrete pavements are not totally immune to becoming exceedingly slippery when wet. However, as a group the stone sand projects greatly outweigh any other group of pavement surfaces in regard to being dangerously slippery when wet.

RECOMMENDED COEFFICIENT OF SLIDING FRICTION FOR SAFE DRIVING

In view of modern traffic requirements, a pavement should be designed and constructed with the utmost thought to materials and workmanship in order to insure a riding surface with skid resistant characteristics when wet as close as possible to those when dry, and one which will not change materially with age or traffic wear.

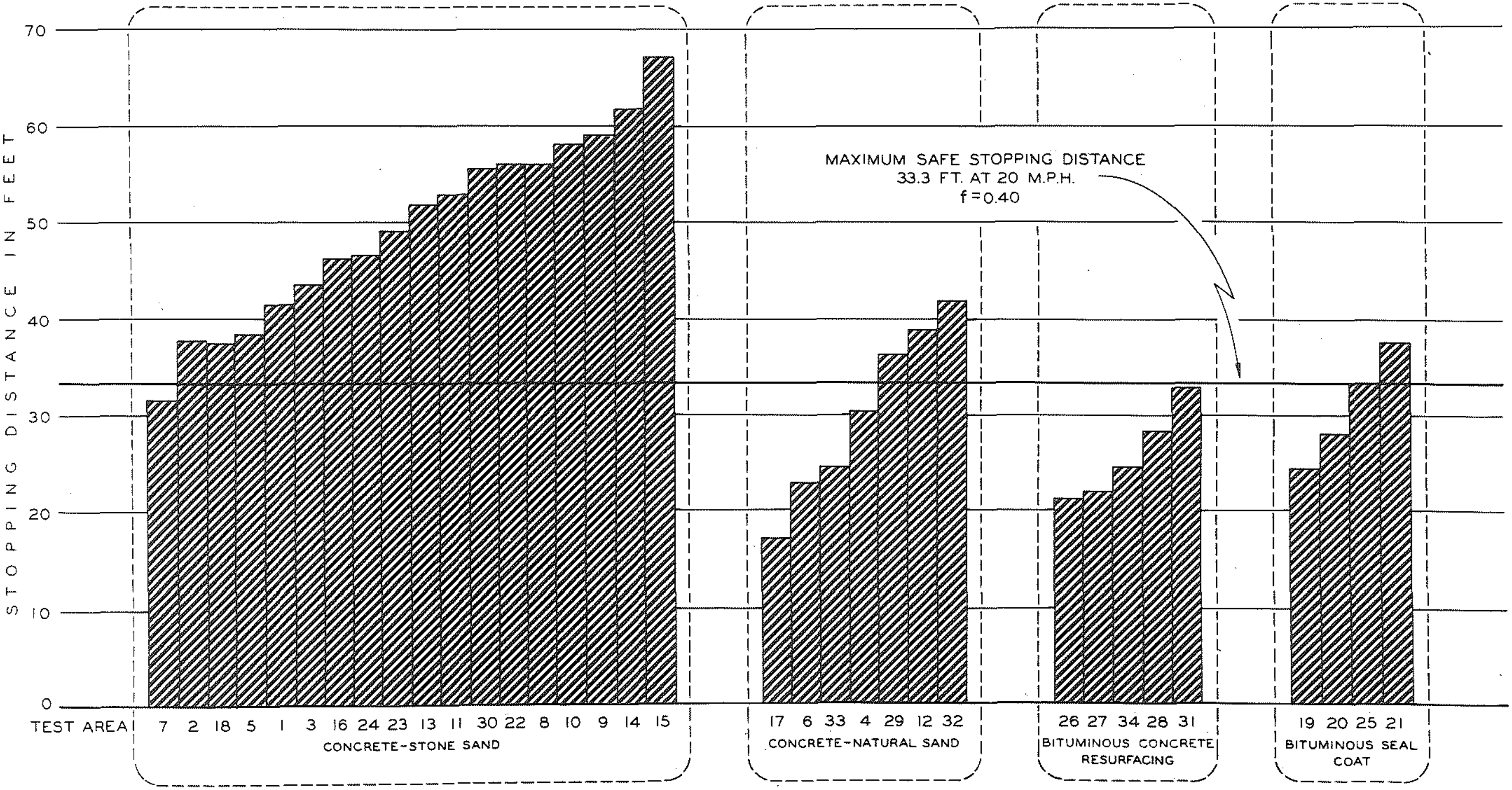


Figure 27

SKID RESISTANCE MEASUREMENTS *on* VARIOUS PAVEMENT SURFACES CONTAINING INLAND LIMESTONE AGGREGATES

BASED ON DATA IN TABLES 3 AND 4 — VEHICLE SPEED, 20 M.P.H.-WET PAVEMENT

At the present time a minimum coefficient of friction value of 0.40 is being used by highway officials for determining safe stopping distance. In their bulletin entitled, "A Policy on Sight Distance for Highways" (1940) (2), the Special Committee on Administrative Design Policies of the American Association of State Highway Officials has established a policy for non-passing minimum sight distance for different speeds. <u>The non-passing minimum sight distance is defined as being a distance long enough to permit a vehicle traveling at the assumed design speed of the highway to stop before reaching a stationary object in the same lane</u>. This sight distance is the sum of two distances: (1) The distance traversed by a vehicle from the time the stationary object is visible to the instant that the brakes are applied, which is termed the perception and brake reaction time, and (2) the distance required to stop a vehicle after the brakes are applied.

The minimum non-passing sight distance is also the safe stopping distance. These distances for various assumed design speeds as developed by the Committee are presented in Table VI, taking into account the safe rate of deceleration for comfort which for most passengers is around 16 feet per second. It is to be noted in Table VI that the safe coefficient of friction varies between 0.4 and 0.5.

In figure 28 a graph is presented which shows the stopping distance in feet for different values of coefficient of friction and for different vehicle speeds. In addition, the graph shows the skidding characteristics for various surface conditions. Note that stone sand concrete surfaces fall below the recommended minimum value of 0.40.

PHYSICAL CHARACTERISTICS OF NATURAL SAND AND STONE SAND CONCRETE SURFACES

Incidental to the stopping distance tests, cores were taken from many of the stone sand projects which were tested for skidding properties. The tops of the cores were subjected to a microscopic examination. The results of the examinations are disclosed pictorially in Figures 29 to 40, inclusive.

Figures 29 and 30 illustrate the typical surface condition of two pavements constructed with natural sand. Note how the fine quartz aggregate particles are firmly embedded in the cement mortar and offer a sand-papery surface which encourages mechanical interlocking of the tire tread with the road surface. Also the surfaces contain minute depressions which provide recesses for water to escape from under passing tires; thereby reducing the water film thickness and thus its lubricating effect.

Typical examples of stone sand surfaces are presented in Figures 31 to 40. In Figures 31, 32, 33 it may be observed that the stone sand particles extend slightly above the cement mortar, but are well-rounded and polished by traffic action. This condition of aggregate had no noticeable effect on skid-resistant characteristics of the different limestone surfaces. Figures 34, 35, and 36 present views of scaled and unscaled areas of stone sand concrete. In both instances the aggregates and matrix are quite smooth in appearance, much unlike natural sand concrete. Figures 37 to 40 show that the aggregates and matrix have become equally polished to a smooth glossy surface which offers pratically no mechanical interlocking for the tires.

TABLE VI

NON-PASSING MINIMUM SIGHT DISTANCE BASED ON SAFE STOPPING DISTANCE

American Association of State Highway Officials (2)

Assumed Design Speed, M.P.H.	Speed, Ft./S.	Perception and Brake Reaction Time, Sec.	Reaction Distance, Feet	Coefficient of Friction Skidding	Factor of Safety	Safe Coefficient of Friction	Braking Distance on Level, Feet	Total Braking and Reaction Distance, Feet	Approved Minimum Sight Distance, Feet
30	44	3.0	132	0.62	1.25	0.50	60	192	200
40	59	2.75	162	0.59	1.25	0.47	113	275	275
50	73	2.5	183	0.56	1.25	0.45	185	368	350
60	88	2.25	198	0.53	1.25	0.42	286	484	475
70	103	2.0	206	0.50	1.25	0.40	408	614	600

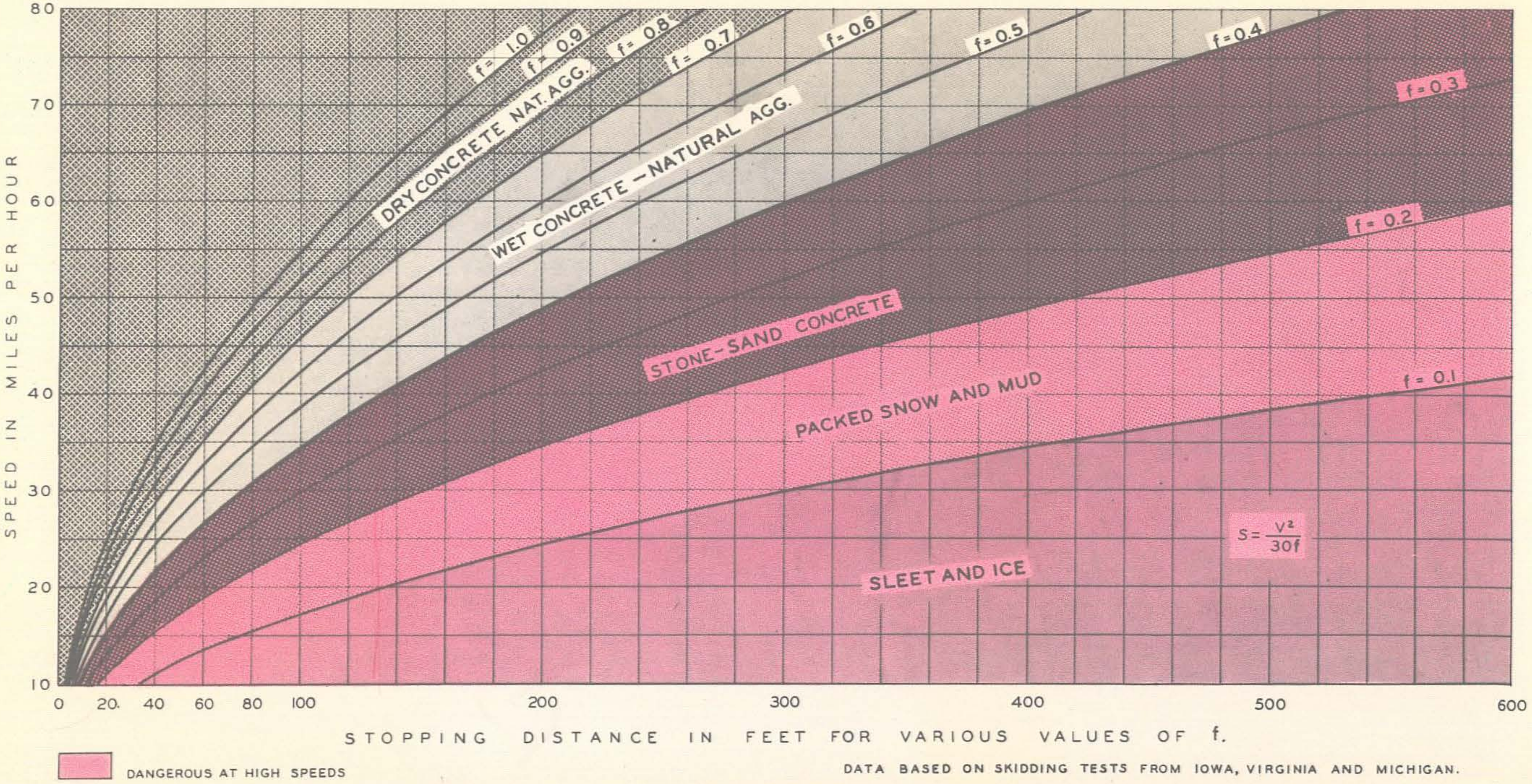


Figure 28

STOPPING DISTANCE *in* RELATION *to* SPEED *of* VEHICLE *and* COEFFICIENT *of* FRICTION *for* VARIOUS SURFACES

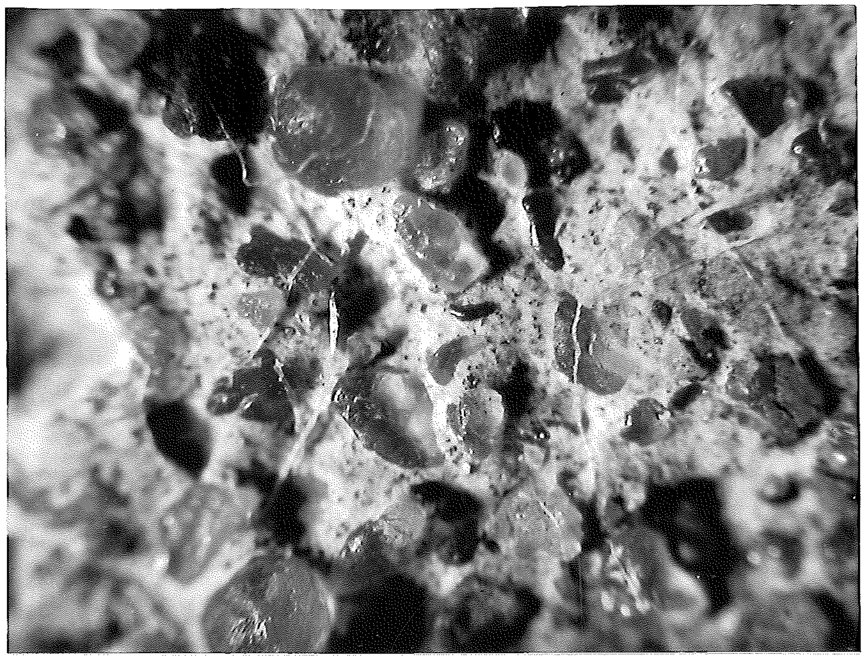


Figure 29. Texture of natural sand concrete surface. Project 49-28, C4. Core 671. Note rough, uneven surface and sand grains. Magnification, 24X.

mean [illegible]
[illegible]

mean [illegible]
[illegible]

Figure 30. Texture of natural sand concrete surface. Project 75-6, C4. Core 637. Note rough, uneven surface and sand grains. Magnification, 24X.

[illegible]
2880

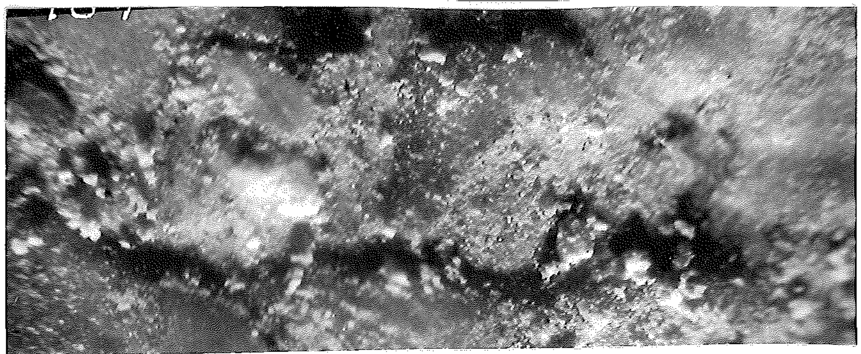
Figure 31. Texture of stone sand concrete surface. Project 75-30, C3. Note smoothness of exposed aggregate. Magnification, 24X. Core 635.

[illegible]

Figure 32. Texture of stone sand concrete. Project 21-29, C7. Core 633. Similar to Figure 31. Magnification, 24X.

[illegible]

Figure 33. Texture of stone sand concrete surface. Project 75-31, C4. Core 668. Similar to Figures 31 and 32. Magnification, 24X.

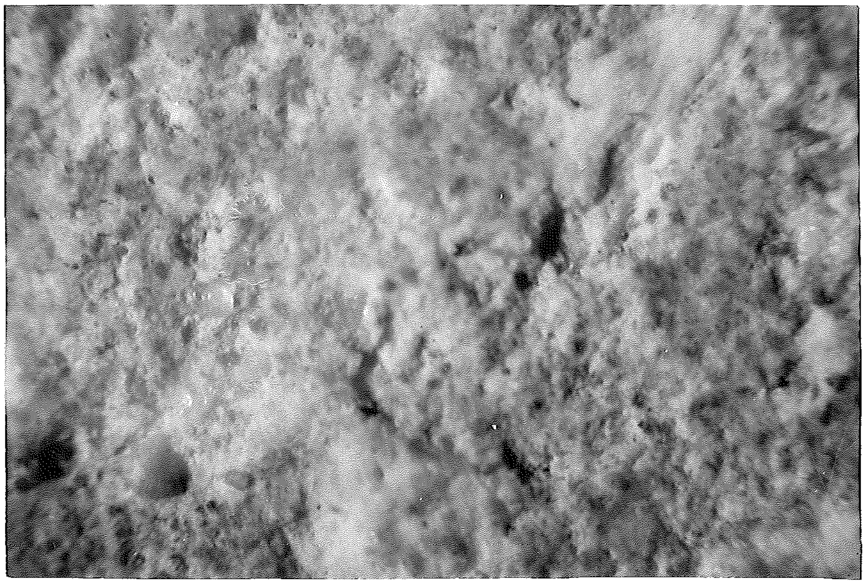


Mag. no. 2867

Figure 34. Texture stone sand concrete surface project 25-30, C3. Core 634. Magnification, 24X.

Mag. no. 2865

Figure 35. Texture of stone sand concrete surface project 21-29, C7. Core 630. Scaled area. Magnification, 24X.



Mag. no. 2865

Figure 36. Texture of stone sand concrete surface, project 21-29, C7. Core 631. Unscaled area. Magnification, 24X.

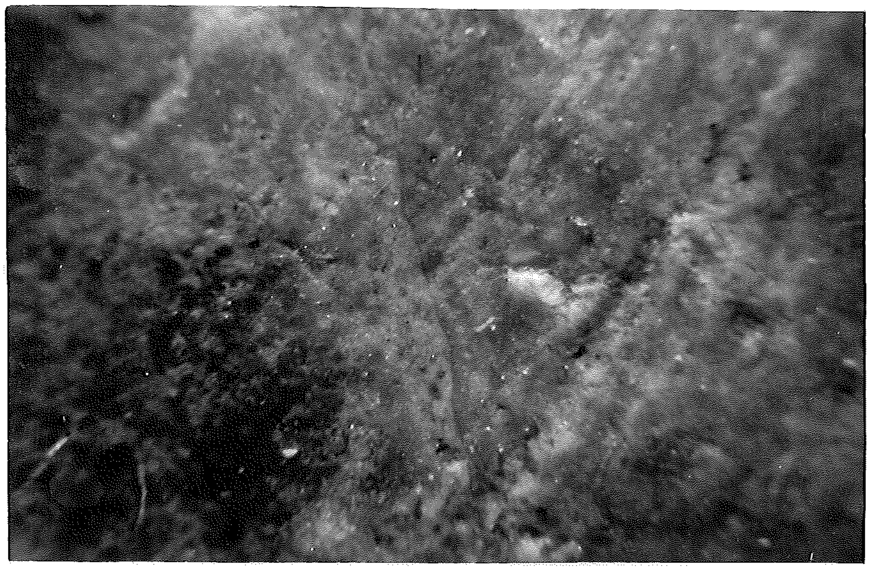


Figure 37. Texture of stone sand concrete pavement project 75-31, C3. Core 669. Note smooth condition of matrix and stone particles. Unscaled surface. Magnification, 24X.

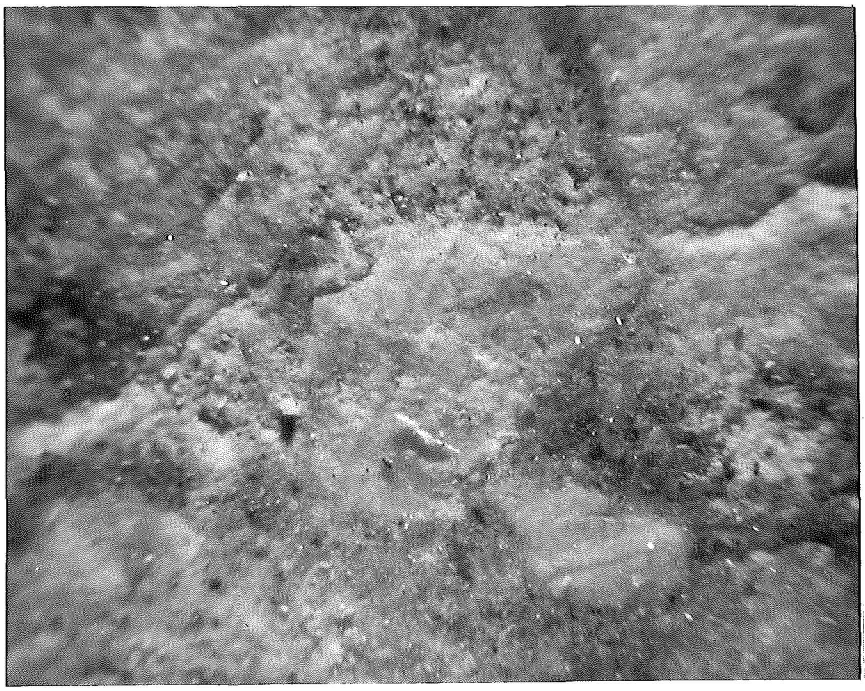
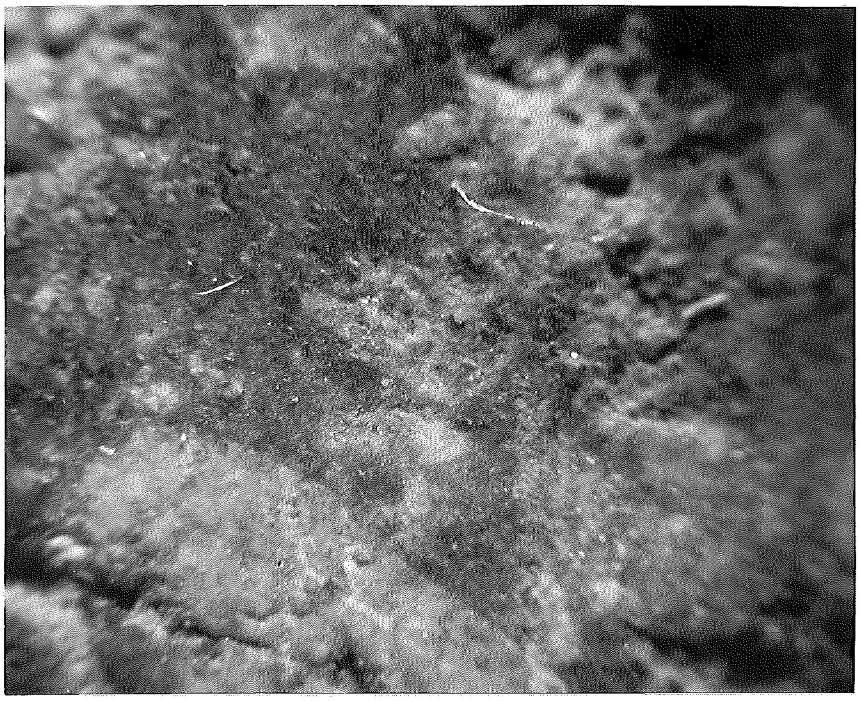
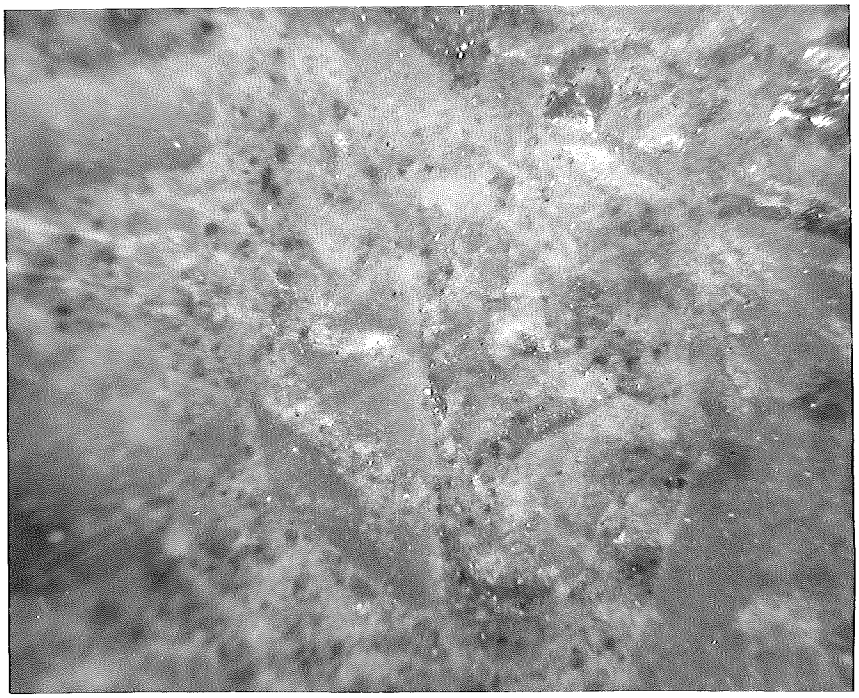


Figure 38. Texture of stone sand concrete pavement project 49-30, C9. Core 670. Unscaled surface. Magnification, 24X.



neg. no.
28 60

Figure 39. Texture of stone sand concrete pavement project 49-28, C2. Core 672. Unscaled surface. Magnification, 24X.



neg. no.
28 61

Figure 40. Texture of stone sand concrete surface at Elk and Maple St. in Manistique. Core 636. Scaled surface. Magnification, 24X.

and eventually become smooth, since all aggregate particles will offer approximately the same resistance to abrasion. Pavements constructed with gravel aggregates do not become smooth in the manner of stone sand pavements because the individual aggregate particles, due to their origin, have different degrees of hardness as well as other physical characteristics which prevent uniform surface wear.

Furthermore, stone sand is a "by-product" stone or residue resulting from the manufacture of large size fluxing stone. It is well recognized that the resultant aggregate of smaller sizes is of a quality much inferior to that of the large uncrushed pieces because the rock from the harder and sounder ledges is less inclined to break down to small sizes in the crusher, while the rock from the softer ledges breaks down easily. In consequence, the stone sand will contain the larger percentage of softer, less durable stone particles.

In addition, it has been observed that limestone aggregates are coated with a fine dust due to processing which it is practically impossible to remove by repeated washings. This material when combined with water forms a greasy film on the aggregates. This same condition no doubt takes place on the surface of the pavements due to the wearing away of the fine limestone particles.

On wet surfaces, water acts as a lubricant between the tires and road surface. The tires in motion act as a squeegee in removing water. Therefore, any combination of tire and surface condition which reduces the lubricating effect of the water by creating a thinner film will increase both the true frictional resistance and mechanical resistance for the two materials. On high skid-resistant surfaces, the excess water is more easily removed at the points of contact, and consequently, the tire has a greater opportunity to grip the surface and develop high mechanical resistance against skidding.

There are several factors in modern construction practice which might be thought to influence the skidding factor on stone sand surfaces. They include air-entraining agents, membrane-curing compounds and chemicals used in ice removal. These factors appear in all pavements constructed in Michigan at the present time, regardless of the source of aggregates. The fact that pavements constructed with natural sand of approximately the same age and subject to the same traffic and salt treatment exhibit much better skid resistant characteristics than stone sand surfaces would indicate that these factors have very little influence, if any, on slipperiness of concrete pavement surfaces. In regard to the stone sand projects on US-2 all except one of the projects tested were constructed before air-entraining agents or membrane-curing compounds were employed in concrete practice and they were all found to be very slippery when wet.

There is some possibility of a chemical reaction involving the silicates and alkali oxides of the cement on the other hand, and the magnesium carbonate of the stone on the other, to produce a hydrous magnesium silicate during the setting and early hardening period of the concrete. In the hydration of Portland cement, the cement compounds temporarily pass through the solution phase before being deposited in the hydrated form, thus affording an opportunity for ionic reactions with the minerals of the aggregate. These reactions between cement and aggregate constituents if they took place at all would, of course, proceed more rapidly and progress further with decreasing particle size of the reacting substance. The small particle sizes in stone sand fines and stone dust would promote such reactions.

It is well recognized and there is much evidence to support the fact that the older stone sand pavements without air-entrainment have scaled excessively under the action of chloride salts used in ice control. However, skidding tests have proved conclusively that once the surface mortar is removed exposing the limestone coarse aggregate underneath, the limestone coarse aggregate also abrades and becomes exceedingly smooth resulting in a surface with skidding characteristics not unlike those of the unscaled areas. To the best of our knowledge no rock salt has been used on these stone sand surfaces.

The unusually slippery condition of pavements constructed with stone sand was observed and reported as far back as 1941, when trouble developed in Petoskey at US-31 and M-131. The intersection was eventually resurfaced. The Chief of Police of Manistique reports that a section of US-2 just west of the bridge, known as Deer Street, was very slippery when wet for several years until re-surfaced a year ago. (See appendix).

Through an interview with Mr. Goldbeck, Research Director of the National Crushed Stone Association, it was learned that other States using stone sand for fine aggregate in concrete pavements have encountered the same slippery-when-wet condition which prevails in Michigan. The Association has no explanation for the phenomena other than that the stone particles are soft and homogeneous in character, a condition which causes them to abrade rapidly and uniformly under traffic to form a smooth terrazzo-like surface. The problem has their immediate attention at the present time.

CONCLUSIONS

1. The investigation disclosed that concrete pavements may become unusually slippery when wet dependent upon the texture of surface, and the materials used. The slippery-when-wet condition of certain concrete pavements in the Upper Peninsula, which prompted this investigation, is due entirely to the use of Inland stone sand.

2. Evidence supports the fact that this phenomenon is due entirely to the use of stone sand fine aggregate because pavement surfaces constructed with Inland coarse aggregates and natural sand are not abnormally slippery when wet.

3. The reason why stone sand alone contributes to the slippery condition of limestone pavements is attributed to certain inherent physical properties of the material which cannot be changed. (1) In contrast to natural sand aggregate, the stone sand particles are relatively soft and, therefore, offer very little resistance to the abrasive action of traffic; (2) in addition to being soft, the particles of limestone are homogenous and, consequently, they will tend to abrade or wear in a uniform manner, thus creating a smooth terrazzo-like surface. (3) Inland limestone aggregates have a coating of limestone dust formed during processing which is practically impossible to remove entirely, even by repeated washings. This coating of extremely fine material is ever present on the surface of the pavement due to aggregate wear and creates a greasy film on the pavement surface, which when wet accentuates the slippery condition of the surface. (4) The smooth texture of limestone surfaces promotes thicker water films to form on the pavement surface with their increased lubricating effect between tires and pavements.

4. The influence of such factors as air-entraining materials, membrane curing compounds and chloride salts used in ice control have no material influence on the end point, that is the slippery-when-wet or characteristically smooth surface of stone sand pavements. They may retard or accelerate to a small degree the time at which the surface will become dangerously slippery but, in the end, the same slippery condition will prevail.

5. Traffic volume and accident experience on US-2 for the past years indicate that the slippery condition has prevailed for some time. However, unusually heavy post-war traffic volume and high speeds have been instrumental in accentuating the seriousness of the condition.

6. In regard to corrective measures, the use of stone sand was discontinued for concrete pavements August 1, 1948 on the basis of preliminary reports of this investigation. In the case of existing stone sand concrete pavements, it is recommended that (1) traffic control measures be considered and (2) stone sand concrete pavements be covered with bituminous concrete.

ACKNOWLEDGEMENT

The work of this investigation was facilitated materially through the generous assistance of the Michigan State Police. Personnel were provided to direct traffic during stopping distance tests. Mr. O. M. Lucas, Traffic Analyst, Safety and Traffic Bureau, furnished data relative to reported skidding accidents; Sergeant Kenneth White, Post Commander at Manistique rendered valuable assistance relative to spotting slippery areas for testing and in describing accident conditions on US-2.

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APPENDIX

Manistique, Mich.
Nov. 14th, 1948

Subject: Highway US-2, "Slippery when wet conditions".

To: Commanding Officer, Safety & Traffic Division

Reply is made to your letter of Nov. 12 on the above subject. We cannot recall of any "unusually slippery when wet conditions" on US-2 prior to the date mentioned in your letter.

On checking the files I find one accident in 1945 that might indicate this condition then existed, Com. 84-719, June 24th, 1945, it happened in an area now very slippery - two miles West of Cooks Corners. It may be also that due to the conservative driving in that year, this condition did not become apparent.

There is a location in the City of Manistique that was very slippery when wet, until it was re-surfaced a year ago. It is on US-2 just West of the bridge, known as Deer St. This location was slippery for several years according to the Chief of Police.

It is interesting to note that since the installation of "slippery when wet signs" in this area, the accidents occurring during a rain have been reduced about 90%. The last two weeks of October and the first week of November have been very wet in this area, and I do not think we have had over one accident caused by skidding. This is unusual based on past experience.

Respectfully submitted,

Kenneth White
Sgt. Kenneth White
Post Commander
Manistique