MICHIGAN
STATE HIGHWAY DEPARTMENT
Charles M. Ziegler
State Highway Commissioner

ABSTRACTS FROM MICHIGAN'S STUDIES OF SLIPPERINESS OF CONCRETE PAVEMENTS CONSTRUCTED WITH STONE SAND AS THE FINE AGGREGATE

Prepared for ASTM Committee C-9
On Concrete and Concrete Aggregate

Highway Research Project 48 G-41

Special Report No. 242

Research Laboratory
Testing and Research Division
October 20, 1955

INTRODUCTION

This report contains abstracts of Departmental investigations dealing with the slipperiness of concrete pavements in Michigan, and particularly those constructed with stone sand as the fine aggregate material.

This report has been specially prepared for distribution to members of ASTM Committee C-9 at the request of Mr. W. W. McLaughlin, Testing and Research Engineer.

SLIPPERINESS OF STONE SAND CONCRETE PAVEMENTS

In the past the Michigan State Highway Department has constructed on the state trunk line system 121.6 miles of stone sand concrete pavement. The longest section of contiguous stone sand projects (82.5 miles) is located on US-2 in the Upper Peninsula between St. Ignace and Rapid River. Route US-2 is virtually a gateway to motorists traveling east and west across the upper part of the United States and, therefore, carries a considerable volume of transient traffic as well as local traffic. Peak traffic during the tourist season reaches at least 3500 vehicles per day.

With the resumption of normal traffic conditions after World War II, a considerable number of accidents due to skidding on wet concrete pavement on US-2 were reported by State Police. The situation became so severe that an investigation was deemed advisable to determine the cause of these unusual skidding accidents. A preliminary examination of the pavement in this area by W. W. McLaughlin, Testing and Research Engineer, disclosed the fact that the surfaces of the concrete pavement involved were smooth, glossy, and quite slippery under foot even when dry. It was also noted that all of such slippery pavements were constructed with stone sand as fine aggregate. In view of these facts, a complete investigation was authorized covering all concrete pavements in Michigan constructed with stone sand. The investigation included: 1) visual inspection of all pavements, 2) skidding tests on wet surfaces, 3) study of accident records, and 4) laboratory physical examination of cores from pavement surfaces.

The information presented under the above subject has been abstracted from Departmental Research Laboratory Report No. 117.

SKIDDING STUDIES ON US-2

This abstract includes a summary of skidding accident experience, stopping distance test data, and photomicrographs of stone sand concrete surfaces, pertinent to route US-2, and to projects in the Lower Peninsula containing stone sand aggregates. Also included in the abstract is an explanation of the cause of slipperiness and conclusions from the complete investigation.

Traffic Accident Experience

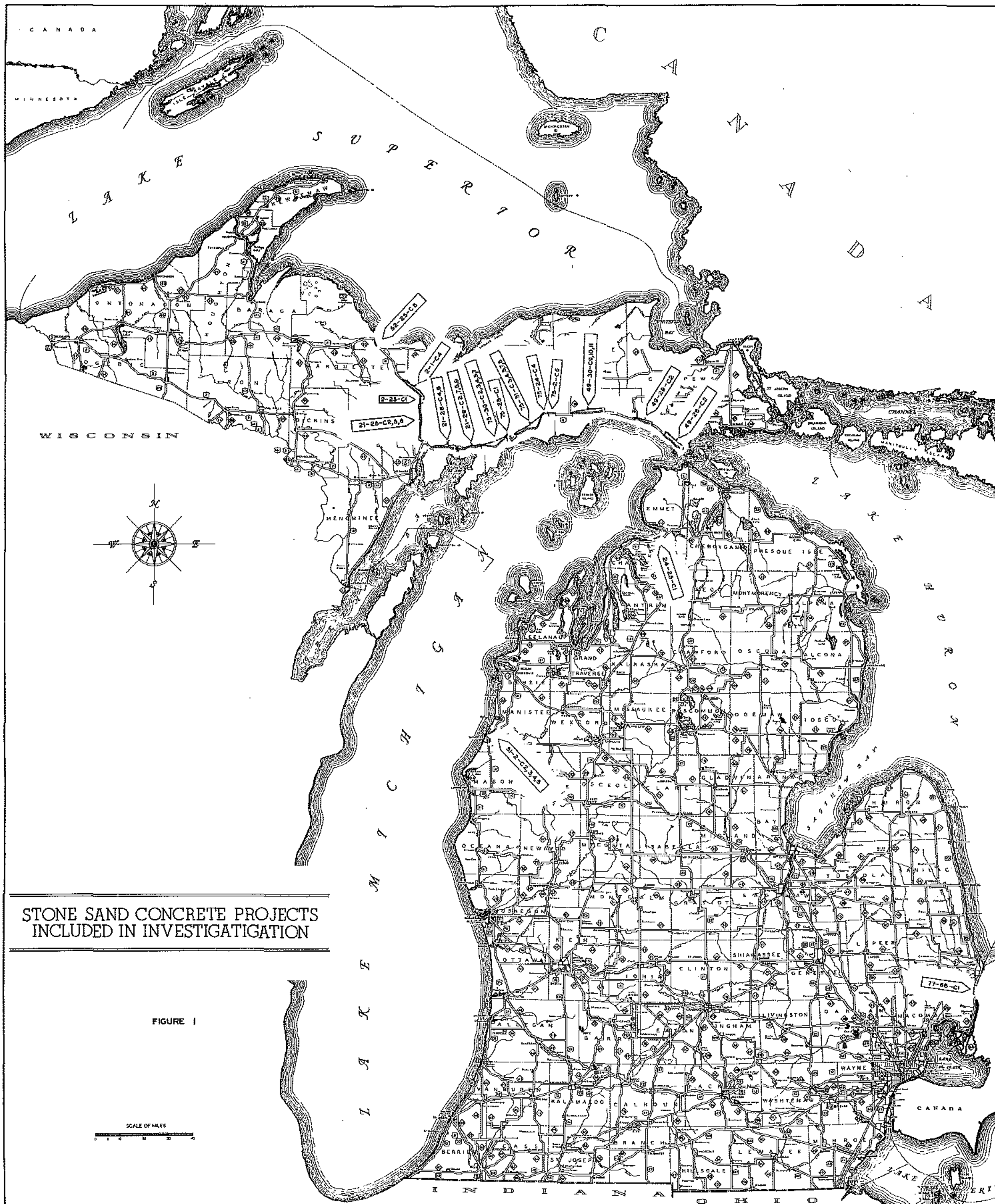
The average daily summer traffic on US-2 has increased from approximately 500 vehicles in 1943 to over 3500 in 1950. Accident experience due to skidding on wet pavement is shown below, by years:

	Accidents
Aug. to Aug., 1946	8
Aug. to Aug., 1947	20
Aug. to Aug., 1948	33
Aug. to Aug., 1949	39
Aug. to Aug., 1950	64

The location of concrete projects included in the investigation are shown on the map in Figure 1.

Stopping Distance Tests

The relative slipperiness of the different types of concrete pavements was determined by the stopping distance method using a 1942 Pontiac passenger car weighing 3,300 pounds and equipped with 6.10 x 16 in., 4 ply tires at 30 pounds pressure. All tests were made on wet pavement at a speed of 20 miles per hour. Coefficient of sliding friction was determined from the formula $f = \frac{V^2}{20S}$ where V = velocity of vehicle in miles per hour and S = stopping distance in feet.



STONE SAND CONCRETE PROJECTS
INCLUDED IN INVESTIGATIGATION

FIGURE I

Stopping distance measurements, together with average coefficients of friction and pertinent project information for projects on US-2 are given in Table II. The stone sand projects tested had friction coefficients ranging from 0.20 to 0.35 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.

Stone sand concrete pavements are also slippery when dry. Although no physical measurements of slipperiness of dry pavements were made during the skidding studies, it was quite obvious upon inspection that the stone sand concrete pavements were slippery under foot when dry and it was easily possible to skid tires during rapid acceleration of a vehicle under dry pavement conditions.

Physical Characteristics of Stone Sand Concrete Surfaces

Photomicrographs shown in Figure 2 illustrate typical surface conditions found on several stone sand concrete pavement projects.

From the photographs in Figure 2 it may be observed that, in some cases, the stone sand particles extend slightly above the cement mortar, but are well rounded and polished. In other instances, the aggregates and matrix have become equally polished to a smooth, glossy surface which offers practically no mechanical interlocking for the tires.

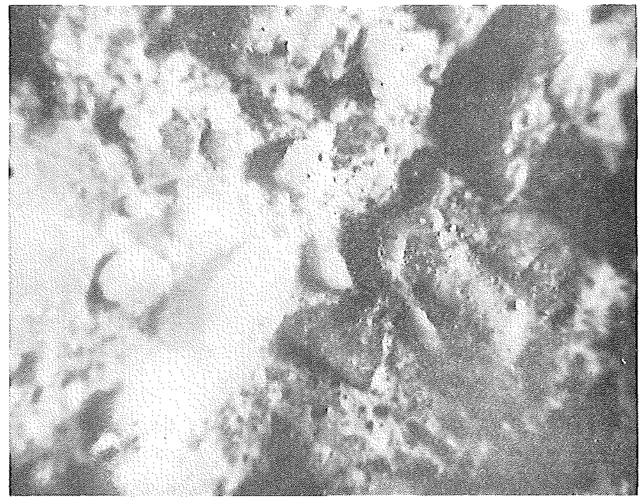
TABLE II

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

UPPER PENINSULA, US-2

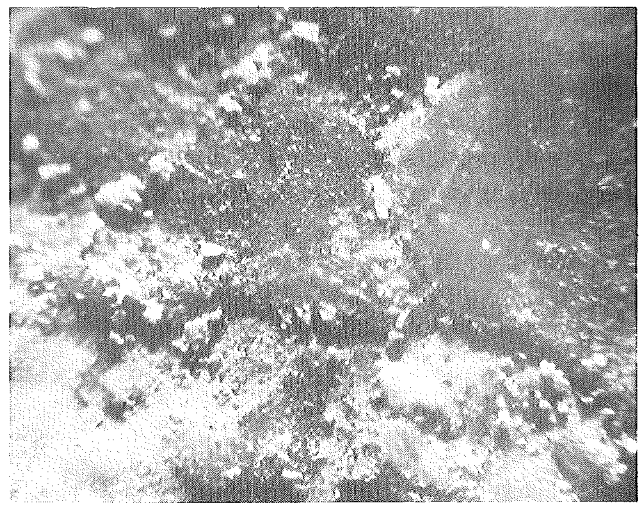
Test No.	Project No.	Aver. Stopping Distance in ft.	Coef. of Friction	Date Constructed	Concrete Aggregates	
					Coarse Agg.	Fine Agg.
7	75-30, C7	31.7	.42	1936	Limestone	Stone sand
2	75-30, C3	37.7	.35	1935	Limestone	Stone sand
5	Manistique	38.6	.35	1938	Limestone	Stone sand
18	49-28, C2	37.7	.35	1937	Limestone	Stone sand
1	75-30, C3	41.5	.32	1935	Limestone	Stone sand
3	75-30, C3	43.6	.31	1935	Limestone	Stone sand
16	75- 2, C6	46.3	.29	1943	Limestone	Stone sand
13	75-31, C7	51.9	.26	1941	Limestone	Stone sand
11	21-29, C7	53.0	.25	1937	Limestone	Stone sand
8	75-30, C5	56.2	.24	1936	Limestone	Stone sand
9	21-29, C8	59.1	.23	1937	Limestone	Stone sand
10	21-29, C7	58.0	.23	1937	Limestone	Stone sand
14	75-31, C4	61.7	.22	1938	Limestone	Stone sand
15	75-31, C3	67.0	.20	1933	Limestone	Stone sand
17	49-28, C4	17.3	.77	1937	Gravel	Natural sand
6	Manistique	22.8	.58	1926	Gravel	Natural sand
4	75- 6, C4	29.5	.45	1930	Limestone	Natural sand
12	75- 6, C4	38.1	.35	1930	Limestone	Natural sand

PROJECT 75-30,C3, CORE 635



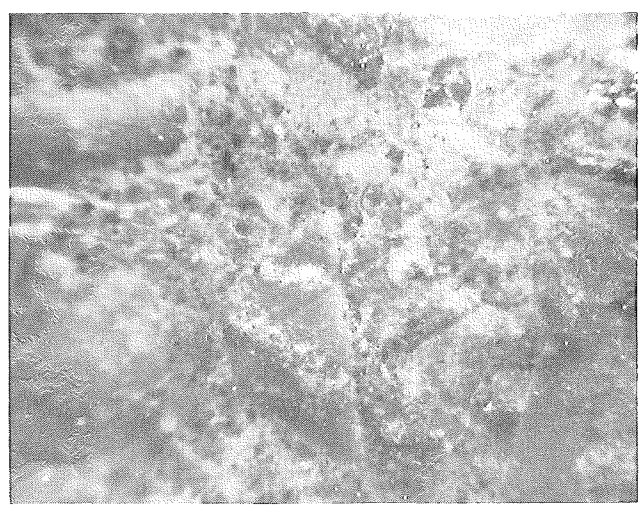
PROJECT 21-29,C7, CORE 633

PROJECT 75-31,C4, CORE 668



PROJECT 25-30,C3, CORE 634

PROJECT 21-29,C7, CORE 630



IN THE CITY OF MANISTIQUE, CORE 636

EXAMPLES OF SURFACE TEXTURE OF STONE SAND CONCRETE PAVEMENT FROM DIFFERENT PROJECTS ON US 2 - MAGNIFICATION 24X.

FIGURE 2

SKIDDING STUDIES ON LOWER PENINSULA PROJECTS CONTAINING STONE SAND AGGREGATES

Upon completion of the studies on US-2, the scope of the investigation was increased to include stone sand concrete pavement projects located in the Lower Peninsula. The location of the projects studied are shown in Figure 1. A summary of the skidding test data will be found in Table III.

TABLE III

SUMMARY OF SKIDDING TEST DATA ON CONCRETE PAVEMENTS CONSTRUCTED WITH STONE OR NATURAL SANDS - LOWER PENINSULA

Test No.	Project No.	Date Const.	Aver. Stopping Distance in ft.	Coef. of Friction	Concrete Aggregates	
					Coarse Agg.	Fine Agg.
22	51-2, C3-5	1944	56.1	0.24	Limestone	Stone sand
23	51-2, C3-5	1944	49.0	0.27	Limestone	Stone sand
24	51-2, C3-5	1944	46.5	0.29	Limestone	Stone sand
29	Traverse City	--	35.6	0.37	Gravel	Natural sand
30	24-25, C1	1939	55.8	0.24	Limestone	Stone sand
32	77-66, C1	1944	41.2	0.32	Limestone	Stone sand
33	77-15, C2	1937	24.1	0.55	Limestone	Natural sand

EXPLANATION FOR LOW SKID RESISTANCE OF STONE SAND CONCRETE

The unusually low skid resistance of wet concrete pavements made with manufactured stone sand can be definitely attributed to the presence of the small stone sand par particles. Stopping distance tests have proved that concrete made with limestone coarse aggregate and natural sand or bituminous mixtures with limestone aggregates and natural sand have satisfactory skid resistance when wet. A possible explanation of this phenomenon follows:

In general, the coefficient of friction between tires and pavement depends on the nature of the surfaces in contact, on their condition as to smoothness or roughness, and on the presence or absence of a lubricant.

Gravel aggregates are the result of the disintegration of various rocks and, therefore, the individual aggregate particles both coarse and fine may vary considerably in physical properties. The predominant quartz particles which appear in natural sand have a hardness factor of 7. Limestone, on the other hand, is a sedimentary rock having a hardness of 3 in Moh's hardness scale. In view of these facts, it is only reasonable to suspect that the small limestone particles comprising the stone sand will rapidly abrade under the action of traffic and soon become smooth, thus offering very little mechanical resistance to skidding. On the other hand, the small quartz grains and other hard stone particles found in natural sand apparently remain intact and firmly embedded in the mortar with sufficient resistance to abrasion to remain jutting above the mortar, thus offering a high mechanical resistance to skidding. Furthermore, since the coarse and fine limestone aggregates are from the same parent material in stone sand pavements, the resulting concrete is more or less homogeneous in character as far as aggregates are concerned. Consequently, as observed on all stone sand projects, the pavement surface tends to wear uniformly 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 consequences, 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.

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 resurfaced in 1947.

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 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 limestone 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 homogeneous and, consequently, they will tend to abrade or wear in a uniform manner, thus creating a smooth terrazzo-lie surface. 3) 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. On the basis of this study all stone sand concrete pavements were resurfaced with bituminous concrete.