

PERFORMANCE OF A 20-YEAR-OLD SECTION OF US 27
Marshall to the Eaton County Line (13072)

Research Laboratory Division
Office of Testing and Research
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Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, March 1959

SYNOPSIS

Concrete pavement built under three contracts between 1932 and 1934, was studied to determine reasons for relatively good riding quality after 20 years under increasingly heavy traffic. The evaluation included a pavement condition survey, roughometer measurement, concrete strength determination, and a detailed soil investigation, attempting to correlate performance with physical features.

Although a large quantity of data was amassed and analyzed, the primary objective was not realized. Roughometer testing verified that the pavement had superior riding quality for its age and general surface condition, but the determining factors could not be established. The analysis was limited because important construction and performance data were not available and because of extensive pavement repairs before the start of this study.

The evaluation indicates that: (a) wire mesh reinforcing controlled surface deterioration better than bar mat or no reinforcing; (b) although substandard, the subgrade materials provided better pavement support than their classification tests would suggest; and (c) "in-use" pavement can be studied successfully only if sufficient data are available concerning construction and performance, to supplement information obtained in subsequent tests.

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For a number of years, the Office of Testing and Research has conducted a program of field research to evaluate the performance of highway pavements. This program includes study of various physical characteristics of the roadway structure during construction and periodically throughout the life of the pavement. In this manner, a continuous record may be obtained concerning pavement performance from construction to any desired time during use. Under properly controlled conditions, a pavement in use may also serve in experimental studies, with the advantage that destructive forces of traffic and weathering are realistic.

In the Fall of 1954, W. W. McLaughlin, Testing and Research Engineer, requested an evaluation of a concrete pavement extending from Marshall north to the Eaton County line. This part of US 27 had been placed between 1932 and 1934, and, in spite of continually increasing traffic, still retained good riding qualities. Although badly cracked in many areas and showing general deterioration, this pavement was believed to be in exceptional condition when its age and method of construction were taken into consideration. By study of soil conditions, pavement quality, and construction procedures, it was hoped that characteristics might be discovered explaining the pavement's good performance, which in turn would be of value in future construction.

It was realized that evaluation of a 20-year-old pavement could not be carried out as thoroughly as for newer pavements. Construction records which might have been of value were no longer available, due to MSHD policy of discarding such material after a reasonable period of storage. The construction methods varied from current standards. Furthermore, sections of the pavement had been resurfaced, replaced, or otherwise altered so that in some areas the condition of the original surface could not be determined. However, certain characteristics were still available for evaluation.

This work was carried out under the direction of William C. Broughton, with substantial contributions by E. A. Dahlman who supervised soil surveys, Onto L. Lindy who performed the concrete testing and analyzed much of the data, and Paul Milliman who conducted the roughness survey. The data was further analyzed and this report prepared in final form by R. C. Mainfort.

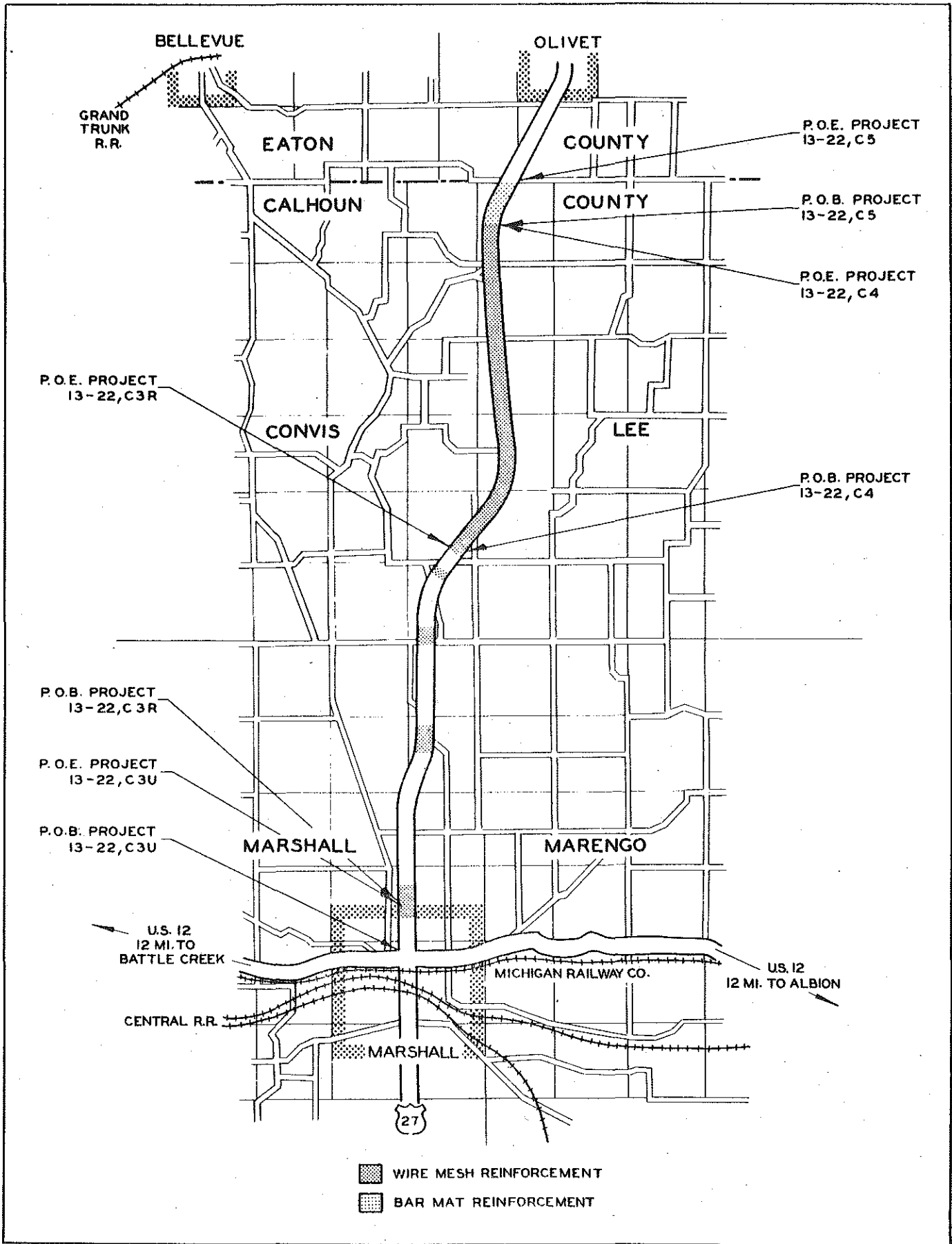


Figure 1. Plan View of the US 27 Projects

PROJECT DESCRIPTION

Although complete construction records were no longer available, considerable information concerning the test area was obtained. The total length of pavement included in this study was 10.9 mi, built incrementally under three contracts in 1932, 1933, and 1934 respectively. The construction was controlled by MSHD 1926 Road and Bridge Specifications, with a supplemental provision specifying the use of as much manual labor as possible.

At the time of construction, subgrade materials were not selected to conform to the rigid specifications now required by the Department. Proper compaction was not specified and that obtained here would hardly be satisfactory by current standards, considering the emphasis placed on manual labor. In fact, construction records refer to frequent stoppage of concrete placement due to delays in shaping the subgrade ahead of the paver.

Under the 1926 Specifications, contraction joints were not required in concrete pavement, but expansion joints were specified at 100-ft intervals with no provision for load transfer. Butt-end construction joints were used when concrete pouring was halted for periods of 30 min or more. In accordance with practice of the period, steel reinforcement was not used in the concrete placed during 1932 (Contract 3), except where the subgrade was considered too weak to support the anticipated traffic load--less than one-third of this 5-mi section was reinforced. Conforming to a design change effective in 1933, concrete placed that year was reinforced throughout with wire mesh (Contract 4), and in 1934 with bar mat (Contract 5).

Figure 1 shows the area involved, indicating the position and length of each contract and the type of concrete reinforcing used. Contract 3 is divided in two portions: urban (3U) and rural (3R). The 481-ft urban portion of this contract is part of the Marshall street system and consequently in some respects is not comparable to the pavement in a rural area which constitutes the major portion of the mileage studied. For this reason, and because certain records could not be obtained for this portion of the pavement, the rural and urban sections of this contract were analyzed separately.

Additional information concerning these projects is presented in Table 1, which lists contractors, materials sources for each contract, and certain physical characteristics of the pavement and its foundation.

TABLE 1
CONSTRUCTION INFORMATION

Characteristic	Contract Number		
	3	4	5
Year Built	1932	1933	1934
Contractor	Grace Construction & Supply Co	Brook Construction Co	W. H. Friedrich & Co
Cement Source	Wolverine-Quincy	Peninsular-Cement City	Wolverine-Coldwater
Aggregate Source	American Aggregate, Kalamazoo	Jonesville Sand and Gravel, Jonesville	Brown & Rosenberger, Coldwater
Length, feet	27,572	23,079	4,752
Width, feet	20*	20	20
Thickness, inches	9-7-9*	9-7-9	9-7-9
Reinforcement	Unreinforced, with short sections of wire mesh.	Wire Mesh	Bar Mat
Drainage	Poor*	Poor	Poor
Water Table	Variable*	High	High
Grade Line	Low*	Low	Low

*481 ft of Contract 3 lies within the city limits of Marshall and had the following characteristics which differ from the rural sections: width - 30 ft; thickness - 8 in. uniform; drainage - good; water table - low; and grade line - fair.

Traffic volumes and the flow pattern for the project are shown in Figure 2. These data indicate that total traffic increased over 400 percent between 1936 and 1955, and that the contracts may be considered part of a heavily travelled highway system.

General soil conditions under the pavement are included with other information in Figure 3.

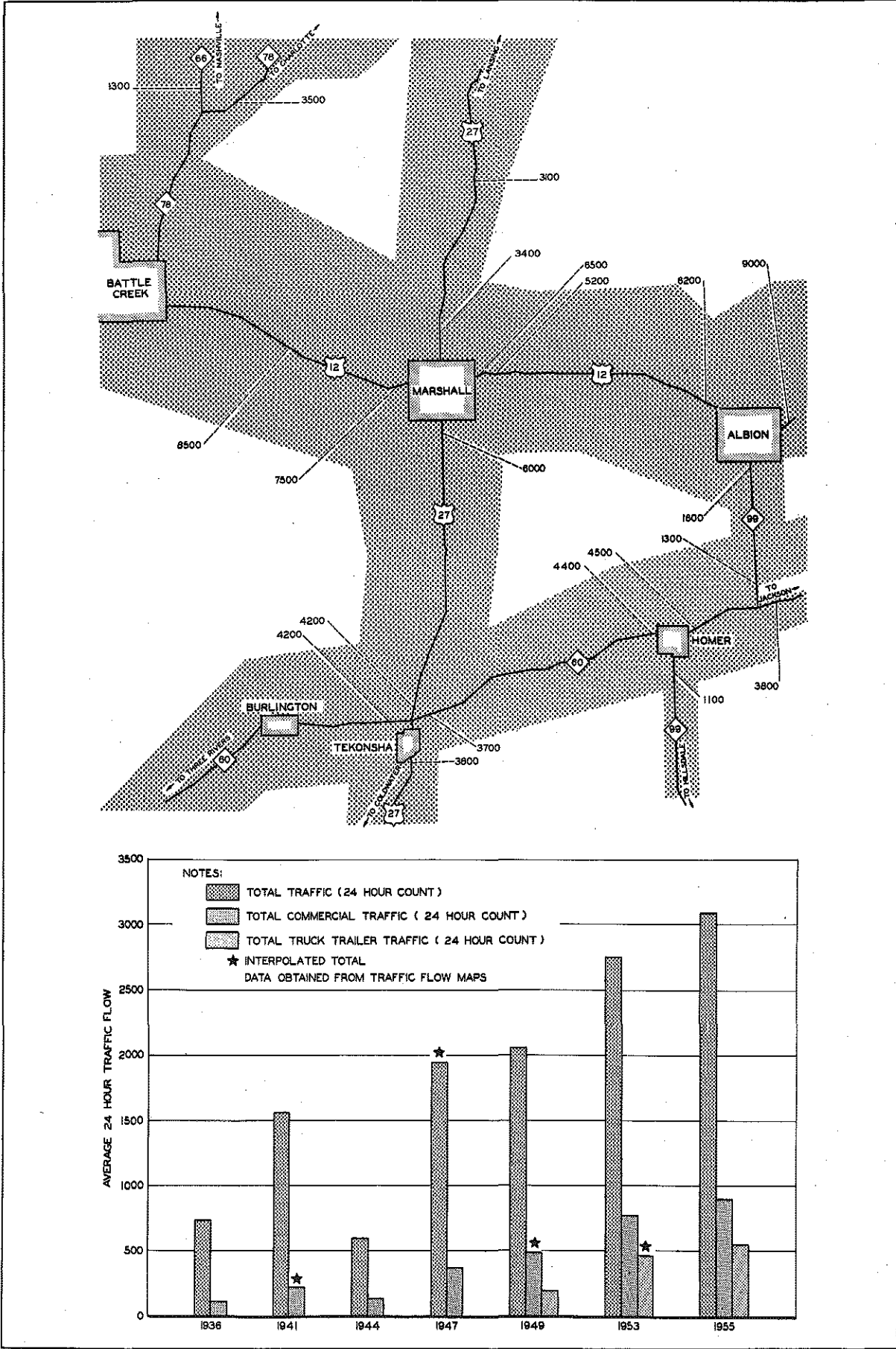


Figure 2. Traffic Volumes and Flow Pattern

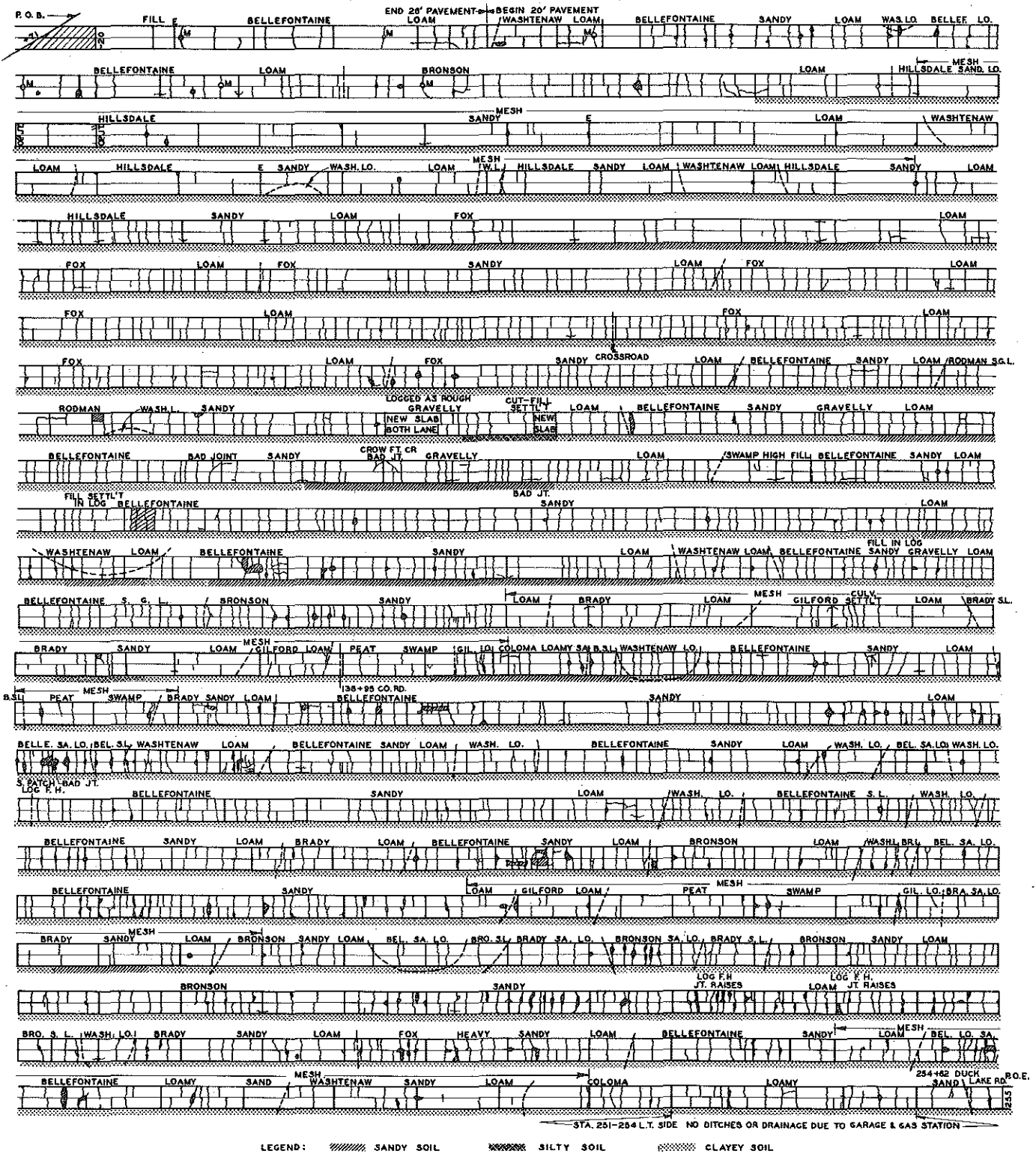
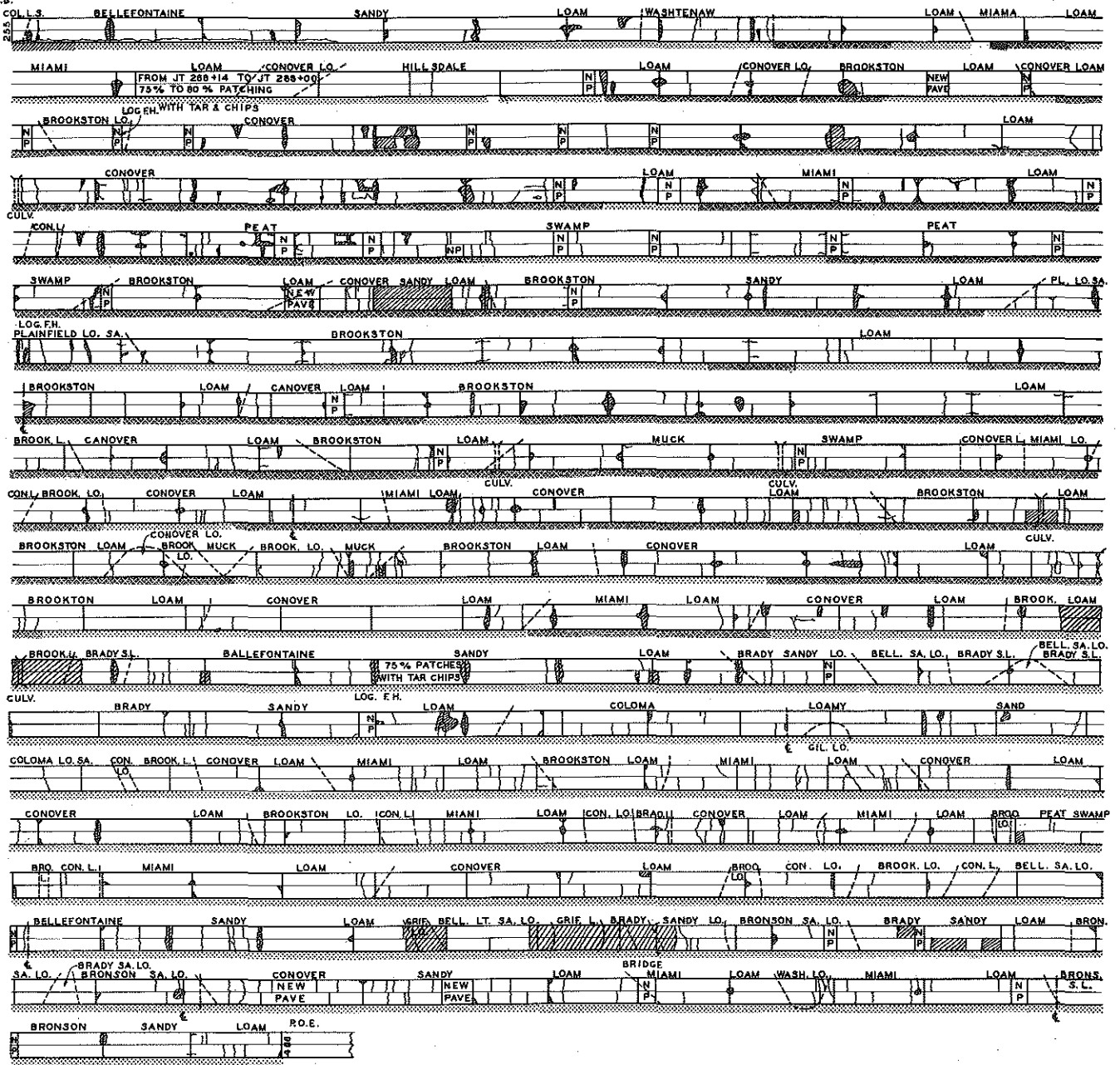


Figure 3. Pavement Condition and Soil Survey Information

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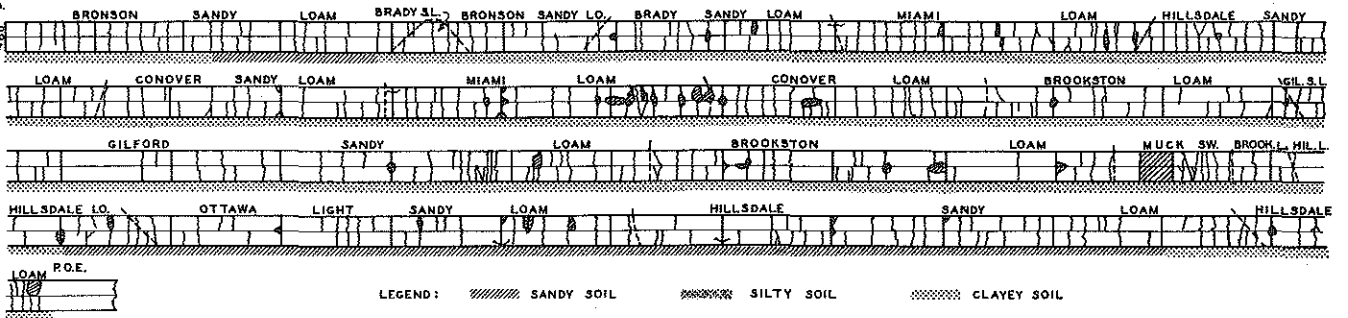


Figure 3., (Continued)

EVALUATION METHODS

The field evaluation surveys of this project began in 1954. Prior to that time, extensive patching, and in some cases complete slab replacement, had taken place, so that certain sections could not be considered in all phases of the analysis. The surveys included the following basic procedures:

- (a) General condition survey and mapping of pavement cracks, patching, slab replacement, and other surface characteristics;
- (b) Soil survey of existing subgrade conditions and correlation of the results with the different soil series found in the area;
- (c) Determination of pavement riding quality using roughometer techniques;
- (d) Measurement of concrete quality by means of compressive strengths obtained by the Swiss Hammer method.

The desired objective was to find some correlation between pavement behavior and one or more of the conditions analyzed.

Condition Survey

Pavement surface condition was determined by field parties and plotted to scale on a base map, as shown in Figure 3, according to standard procedures of the Research Laboratory Division. In addition, a photographic record was made of the most important pavement features and others considered typical of these contracts (Figs. 4-6). In analyzing data from a pavement condition survey, any crack whose length exceeds half a lane-width, forming an angle less than 45 deg with a perpendicular to the slab centerline, is considered one crack. A crack extending across two lanes is considered two cracks. Repairs included surface patching, deep patching, and slab replacement.

Soil Survey

The soil series designations for this area were obtained from original construction maps, and where necessary were revised to conform to current designations. In addition, borings were made along each shoulder, 12 ft from the pavement centerline at 100-ft intervals, by hand augering to a depth of 3 ft. Even-numbered stations were used on the east shoulder,



▲ Station -20+17 looking north. The widened urban section of US 27, built by part-width construction, has a generally smooth-riding surface. Slight faulting occurred at the transverse joint in foreground.



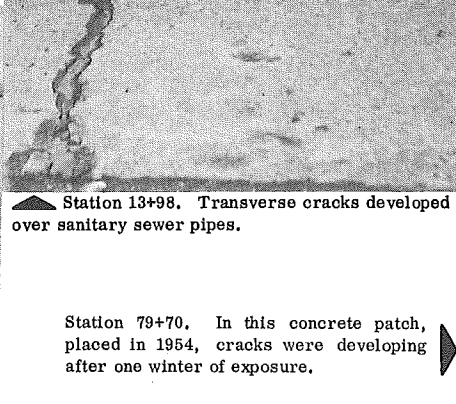
▲ Station 13+98. Transverse cracks developed over sanitary sewer pipes.



▲ Station 48, looking north. Drainage was blocked along much of the route, with tire ruts crossing shoulders and ditches.



▲ Station 49+78. Typical of cracks in non-reinforced concrete sections.



Station 79+70. In this concrete patch, placed in 1954, cracks were developing after one winter of exposure.



Station 113+50 looking south. On this Contract, deterioration was often found over inadequately compacted soil and where heaving occurred at a point of transition from cut to fill.

Station 89+49. The condition of this expansion joint was typical of those in Contract 3; note longitudinal cracking (top). occasionally found in this project.

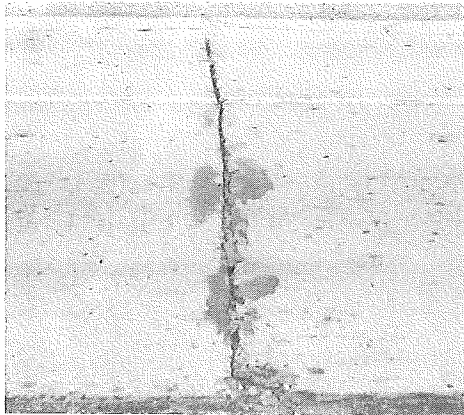


Figure 4. Surface Condition: Contract 3.



▲ Station 249 looking South. Edge disintegration without presence of serious cracking was frequently found in Contract 4. Built in 1934, this section's wire mesh reinforcement seemed to have effectively controlled cracking for more than 20 years (POB at top of Figure).

▲ Station 267+80, looking North. Here more severe surface disintegration was apparent, but again without cracking. This pavement was 75 to 80 percent patched in 1954, and when this picture was taken in 1955, most of the route's length lacked adequate side drainage.



▲ Station 278+20. This patch, placed in 1954 by part-width construction, was subject to pumping along its transverse, center, and shoulder edges; note differential slab elevation at centerline.



▲ Station 288. In 1955, a blowup developed at a tar-patched joint on this badly disintegrated and multipatched slab.

Station 318+50. This crack developed in a patch which replaced a failed expansion joint in the original pavement. Advanced disintegration is visible at the centerline and at the shoulder edges.

Station 319 looking North. The pavement settled and the surface disintegrated over this skewed transitional section, presumably because of poor soil conditions uncorrected during original construction.

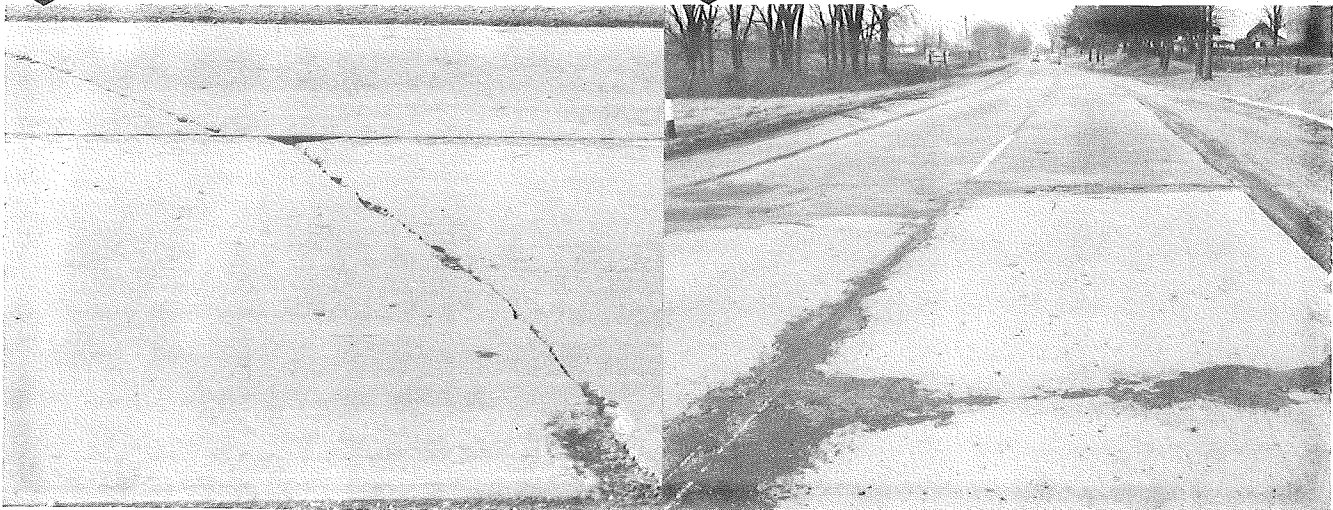


Figure 5. Surface Condition: Contract 4.



▲ Station 487 looking north. Popouts and frequent transverse cracks were encountered on even the best sections of Contract 5.

Station 509+50. Pavement deterioration and bituminous patching on this Contract almost completely obliterated station markings and dating placed in 1934 by construction crews. Showing more severe deterioration than the other Contracts, C5 may have been harmed by overfinishing during construction, which led to surface scaling upon application of winter maintenance chemicals.



▲ Station 469. This joint subject to pumping, showed disintegration typical on Contract 5, with heavy spalling and corner breakage.



Figure 6. Surface Condition: Contract 5.

and odd on the west. The average soil type for each boring was determined by visual inspection, supplemented by analysis of selected samples at the Testing Laboratory Division in Ann Arbor. Although for convenience these samples were taken from the shoulders, they were assumed to represent soils beneath a pavement which is only 20 ft wide. For convenience in reporting, soils encountered were classified in the following general categories:

(a) Sandy soil, representing a combination of sand and gravelly material which nearly meets requirements for current subbase construction;

(b) Clayey soil, representing a rather wide range of heavier clay soils considered unsusceptible to frost action due to their low permeability. These include loams and sandy loams, materials considerably below current standards for subbase construction;

(c) Silty soil, representing the more silty clay soils which are potentially frost active or located in areas where frost action has been noted. These soils, too, are much below present standards for subbase use.

The soil types determined by shoulder borings are shown in Figure 3, plotted by stations on the same base map used for the surface survey. From this notation a general picture may be developed, relating pavement condition and soil type.

Physical characteristics of the shoulder soils selected for laboratory analysis are shown in Table 2. Classifications obtained in these tests did not agree in all cases with those obtained by visual inspection. In this

TABLE 2
PHYSICAL CHARACTERISTICS OF SELECTED SUBGRADE SOILS

Station	Gradation-Percent				Consistency		Bureau of Public Roads Classification	Highway Research Board Classification	
	Gravel	Sand	Silt	Clay	L. L.	P. I.		Group	Subgrade Rating
51	22	54	20	4	22	9	Gravelly Sandy Loam	A-2-4 (0)	Good
195	2	45	43	10	21	8	Loam	A-4 (4)	Fair
310	5	55	31	9	20	8	Sandy Loam	A-4 (1)	Fair
347	4	26	49	21	34	16	Clay Loam	A-6 (10)	Poor
477	8	57	28	7	25	13	Sandy Loam	A-6 (2)	Fair-Poor
487	1	32	48	19	30	14	Loam	A-6 (8)	Poor
495	7	43	38	12	21	9	Sandy Loam	A-4 (3)	Fair
500	25	48	22	5	16	4	Sandy Loam	A-2-4 (0)	Good
514	10	63	22	5	14	0.6	Sandy Loam	A-2-4 (0)	Good
518	2	56	34	8	26	7	Sandy Loam	A-4 (1)	Fair
524	10	85	4	1	N. P.	N. P.	Sand	A-3 (0)	Good

connection it should be noted that a soil classification assigned visually represented average conditions over a given area and as a consequence was quite general, whereas the detailed analysis was made on one sample from a given point on the shoulder, within that area.

Figure 7 shows relationships between amount of pavement cracking, soil type, and kind of concrete reinforcing used, for the three contracts. Similar relationships are shown in Figure 8, in which soil type and reinforcing are compared with the amount of pavement patching; here, the patched areas included both surface and deep patching as well as replaced slabs.

Roughometer Survey

The roughness survey conformed to standard MSHD procedures, expressing riding quality of the surface in terms suited to engineering analysis. Three runs were made for each lane at a forward speed of 20 mph. The average roughness value for the entire project was 161. Roughness values for the north- and southbound lanes did not differ significantly. Roughness of the individual contracts ranged from 156 for Contract 4 to 166 for Contract 3. Contract 5 was intermediate with 162 in. per mi average.

Considering the pavement's age, the values obtained compare favorably with average rideability values on pavement constructed during recent years.

Concrete Testing

To determine the quality of the concrete used in these projects, compressive strengths found for cores taken shortly after construction were compared with strengths obtained in 1957 using the Swiss Hammer method (Figure 9). In both cases, these were average values based on numerous tests made throughout the length of the different contracts. Concrete core data were not available for the urban section of Contract 3. The Swiss Hammer method is not a standard MSHD test procedure. It does not give absolute values of compressive strength, but is a non-destructive device suitable for obtaining relative values for concrete and other materials. Compressive strength in various portions of the test area was relatively constant.

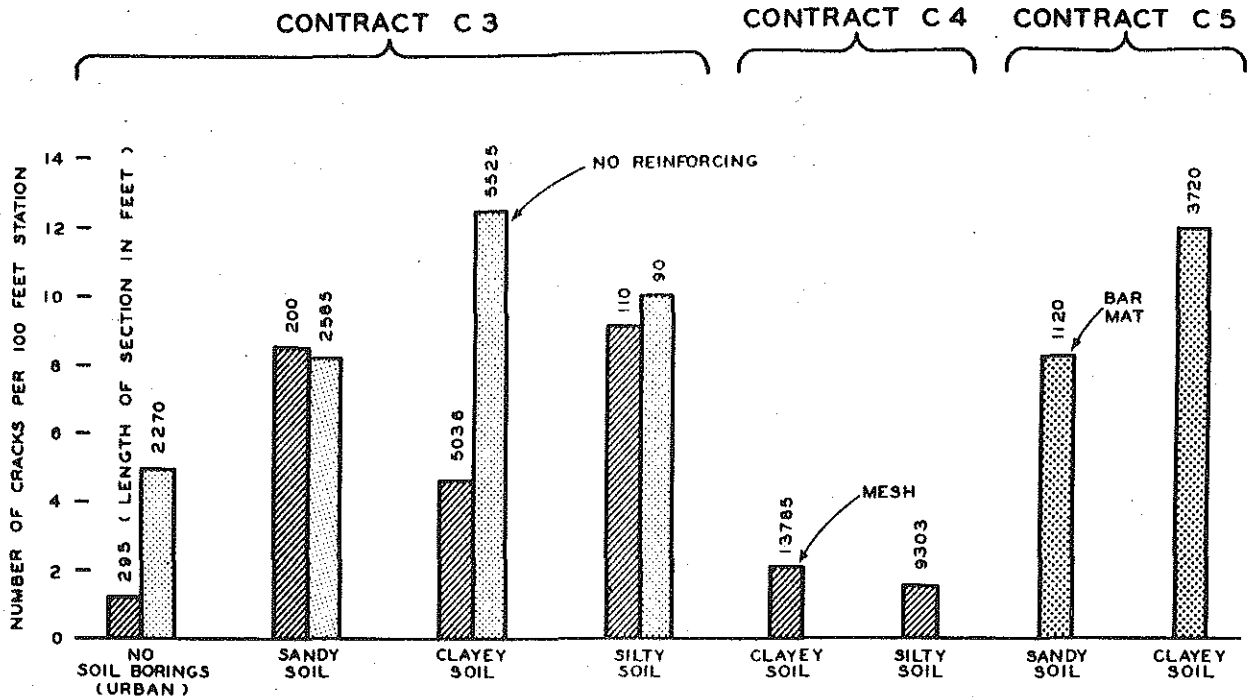


Figure 7. Comparison of Soil Type and Concrete Reinforcing with Pavement Cracking

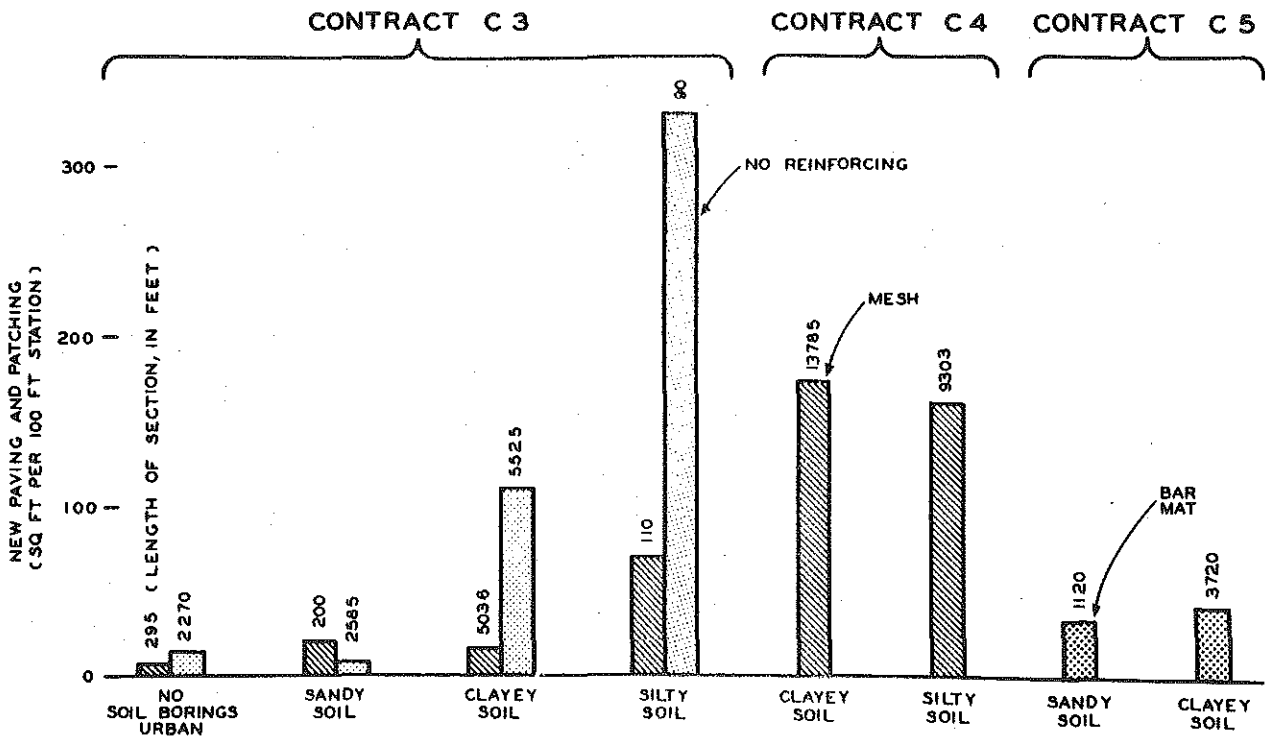


Figure 8. Comparison of Soil Type and Concrete Reinforcing with Pavement Repairs

DISCUSSION OF RESULTS

The objectives of this study may be divided in two general categories: (1) determination and evaluation of pavement quality by condition and roughness surveys, and (2) efforts to find some explanation for the present condition by soil analysis, concrete strength determination, and study of related construction and topographic features. With this information, it was hoped that cause-and-effect relationships might be found among the variables, and that information could be developed which might be of value in future highway construction.

From a performance standpoint, the pavement was considered to be in better than average condition considering the number of years it had been in service and the increasing traffic loads it carried. This was supported by the roughometer survey in which the riding quality of the pavement was found to be comparable to average conditions found for new pavements. Although the pavement had deteriorated considerably, this did not appear to have affected riding quality seriously.

A study of patching and cracking patterns showed that the pavement condition was not a function of concrete quality alone. Compressive strengths of the concrete, taken at various locations, did not indicate a correlation between concrete quality and pavement condition. This left only the supporting power of the subgrade or the concrete reinforcement to account for any unusual elements in pavement performance. From the data available for this study, neither the foundation nor reinforcing could be entirely eliminated from consideration, nor could either be selected as the principal cause of the pavement's performance.

For example, Figure 7 indicates that for conditions of comparable test (where significant lengths are involved), considerably less cracking occurred in those areas where the concrete was reinforced with wire mesh. A study of the variable soil types in the areas involved leaves little doubt that this reinforcement contributed considerably to good surface condition. This is also shown in Figure 8, where a relative absence of patching may be noted in those areas of Contract 3 where wire mesh reinforcement was used. Although performance of the reinforcement was not always clearly related to the supporting soil type, sandy soil generally gave the best results, other variables being equal.

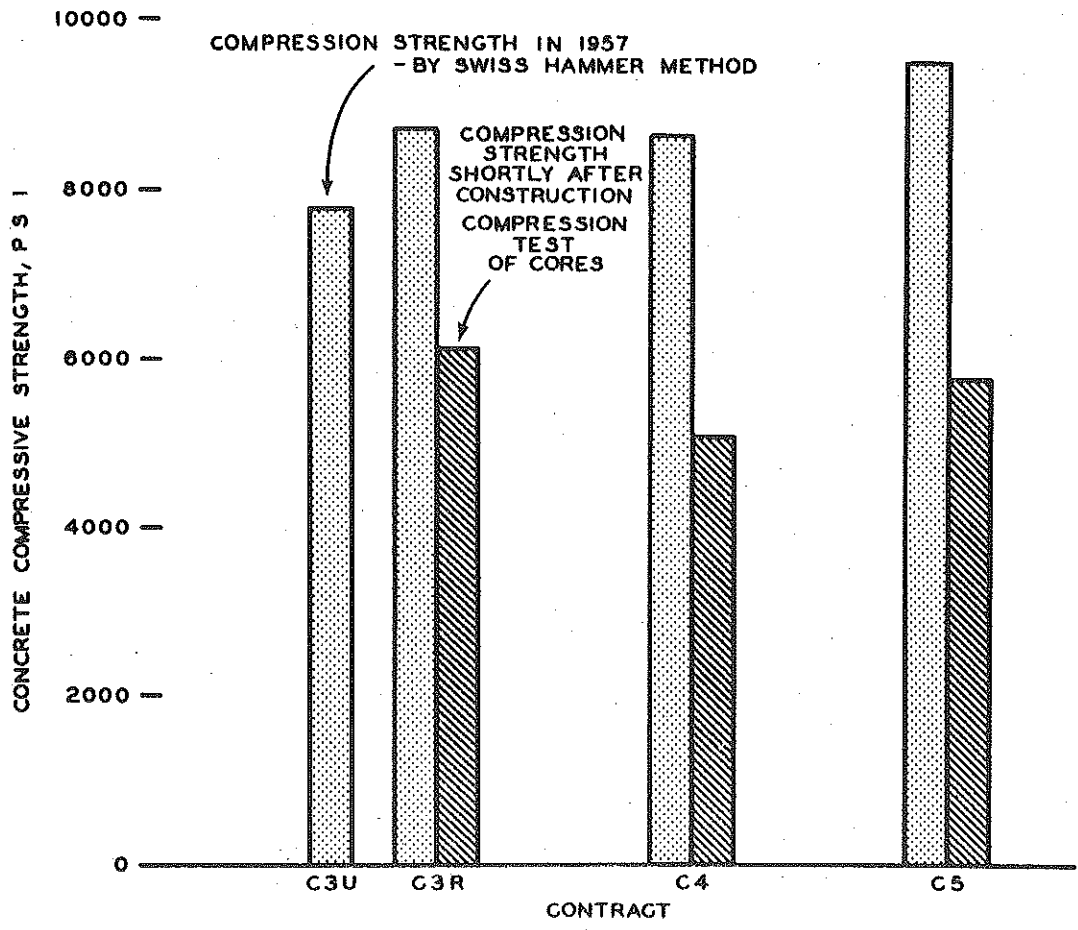


Figure 9. Compressive Strength of Concrete Pavement

However, the above average performance of this pavement cannot be attributed entirely to the type of reinforcement. Although wire-mesh-reinforced Contract 4 showed the least surface deterioration, the riding quality of this section as determined by the roughometer survey was not much better than that of the other sections, all of which rated above average. Furthermore, other, similarly reinforced pavements have not performed as well as the sections under study. This would indicate that the subgrade soils, in spite of generally poor quality, supported the pavement better than might be expected. The soil characteristics shown in Table 2 help to explain this--although the soils used do not meet current subbase requirements for concrete pavement support, some are within current standards for good subgrade material. Only three samples had

a plasticity index greater than 10 and most contained an appreciable amount of sand and gravel. A grain-size analysis of the soils showed that they were generally well graded, indicating that they should readily compact to a satisfactory density. This is of particular value in cases where compaction is not controlled, as was the case here.

According to the classification system recommended by the Highway Research Board, four of these soils rate "good" as subgrade material, four rate "fair," and three may be considered "poor." The fair soils fall into the A-4 group, which includes the frost-susceptible soils, and frost action has been noted in some areas of this project. These soils may well be of a gradation and plasticity generally sufficient to support a rigid surface. This could be verified only by a detailed soil investigation beneath the pavement, including determination of soil density, moisture content, and bearing value, in addition to the usual classification tests. Attempts to obtain a significant correlation between soil conditions and pavement performance were generally unsuccessful, whether analysis was based on soil series or on soil type.

Arbitrary classification of subgrade soils in three general categories by visual inspection alone might be open to some question. Laboratory testing of selected samples did not always give the same classifications obtained by visual inspection. For example, soils designated as "clayey" by visual inspection varied in plasticity index from 0.6 to 14, in clay content from 4 to 19 percent, and in amount of minus-200 material from 21 to 67 percent. Within such a wide range of properties, considerable variation could be expected in performance of supposedly similar materials, and was found when correlations were attempted.

In some cases, pavement performance followed a predictable pattern relative to soil conditions, but in most cases did not. One of the better sections studied, insofar as pavement cracking was concerned, was located in the Hillsdale soil series between Sta 2 and 26. Here, the pavement was reinforced with wire mesh and very little cracking was noted. However, where the same soil supported unreinforced pavement, as was the case between Sta 26 and 31, considerable cracking occurred. This seems logical and can be explained by the presence or absence of concrete reinforcing. Over the adjoining soil, of the Fox series, unreinforced pavement placed over a sandy subgrade soil cracked very little (Sta 32 to 38), but as the subgrade changed to a clayey soil, cracking increased. This also is logical on the basis that better support was obtained from better subgrade material.

Unfortunately, such logical and predictable relationships are rare on these projects, resulting in such apparent anomalies as that where pave-

ment located over swamp areas and poorer soils of the Brady, Conover, Brookton, and Washtenaw series performed better than pavement supported by the more granular, better drained soils of the Hillsdale, Rodman, Bellefontaine, Coloma, and Fox series. This may be explained partially by the movement and manipulation of the soils which took place during construction operations, and by the position of the grade line relative to a particular horizon of the soil series. Nevertheless, no general trend or outstanding correlations between soil series and pavement performance could be found.

Variations in pavement performance also might be due to certain local conditions and construction procedures. Some of these were noted by E. A. Dahlman during his soil surveys⁽¹⁾, the more important of which were:

1. Subgrade soils throughout this project were variable but could be divided into three general groups: (a) granular soils of loamy sand and sandy loam (POB to Sta 263); (b) loam, sandy clay, and clay (Sta 263 to 400); and (c) combinations of these soils in short lengths (Sta 263 to 534).

2. There were numerous areas of high water table and of swamp soils, which affected pavement performance.

3. Some sections which settled were located over large culverts, where backfill was not consolidated properly. This condition existed at Sta 100+50, 133, 403 to 404, and 565 to 566. At Sta 520+50, muck was not excavated prior to culvert construction.

4. Numerous "V-type" fill sections, as well as some zero grade points, caused pavement cracking, notably at Sta 79+50 to 80+20, and 81+50.

5. Numerous poor pavement areas resulted from the presence of topsoil and shallow grading sections, as from Sta 149+25 to 85, 169 to 173, 188 to 191, 214 to 215, 225 to 226, 227 to 228, and 261 to 262.

6. Pavement between Sta 2 and 27 was placed over an older road surface of unknown composition, which probably increased the support offered to the concrete pavement.

7. Pumping action occurred in several areas, particularly in the Brookston-Conover soils between Sta 268 and 288.

(1) Letters to W. W. McLaughlin (12-20-54) and E. A. Finney (4-14-55).

8. Surface drainage was generally good throughout the area. However, at certain locations, such as Sta 132 to 138 and 202 and 207, the existing grade was too low. A "no-ditch" section was found to the right of Sta 320 to 329, into which heavy seepage came from a sand bank.

CONCLUSIONS

The primary objective of this study was not realized in that no consistent relationships could be found between pavement condition and physical characteristics. A large amount of information was obtained and analyzed concerning various features of the pavement and subgrade, by means of which several trends and assumptions are indicated. The most significant of these are:

1. Roughometer surveys showed that the pavement possessed riding qualities relatively equal to those of average newly placed concrete.

2. Compressive strength tests of the concrete showed no significant variation or weakness in the pavement structure.

3. Surface cracking and general deterioration were controlled better in sections with wire mesh reinforcement than in sections with bar mat or no reinforcement. Roughometer readings showed that pavement reinforced with wire mesh possessed slightly better riding qualities.

4. No consistent relationship could be found between pavement performance and the supporting soil series.

5. Although the subgrade soils used were below present day standards for subbase construction, their physical characteristics may be such as to enable them to support distributed loads better than expected.

6. Additional and more detailed soil testing would be necessary before definite correlations between soil condition and pavement performance could be established.

7. The surface condition of a pavement is not necessarily a measure of the supporting quality of a subgrade.

8. Additional information is required concerning threshold quality of subgrade materials used to support rigid pavements. This study indicates that unknown factors are involved and that a pavement structure

acting as a whole may perform somewhat differently than a study of the component parts would indicate.

9. No findings pertinent to future construction procedures were obtained from this study. The fact that this pavement performed better than expected does not, of course, suggest that present standards be lowered, particularly in the face of increasing traffic loads. Poor construction techniques encountered during this investigation have long since been improved and these changes incorporated in newer design procedures.