The University of Illinois Pavement Test Track—A Tool for Evaluating Highway Pavements

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The behavior and failure modes of highway pavements are being studied through the use of a newly developed research tool, the University of Illinois Pavement Test Track. The test track is used to study behavior of highway pavements and pavement materials under controlled conditions that approximate service conditions. A description of the facilities is presented; the capabilities and limitations of the facilities are discussed; and the testing techniques and procedures employed are outlined. Emphasis is placed on the use of the serviceability-performance concepts in evaluating the rate of pavement deterioration and as a failure criterion. Typical test results of a research program illustrate potential use of the facilities.

• THE THICKNESS DESIGN of pavements is one of the most complex problems facing the engineering profession. The demand for new highways and the limited funds with which to construct them prohibits the inclusion of a large factor of safety in the design procedure. At the same time, highway pavements are subjected to a wide range of loading conditions and extreme exposure. To complicate the problem even further, pavements are constructed with a variety of paving materials ranging from cohesionless aggregates to high strength concrete over all types of subgrades. From all this the pavement designer must select the right materials in correct combination and thickness to give the maximum performance for the paving dollar.

The AASHO Road Test findings have emphasized the need for a greater understanding of factors that influence pavement performance. Current standard laboratory techniques used to measure the strength of paving materials do not, in general, give a satisfactory indication of the performance potential of the material. Some materials which exhibit good results in laboratory tests perform poorly in the field, whereas other materials which react poorly in the laboratory give a satisfactory performance in the field. This leads directly to the important questions of what factors influence the performance of a pavement and to what extent each factor influences this performance.

The ultimate answer to these questions will have to be found in a rigorous analysis of the pavement structure. This analysis must be based not on some assumed ideal properties of the paving materials but on the actual properties of the materials. It must be based on the observed behavior of these materials under realistic loading and climatic conditions. Unfortunately, the completion of the rigorous solution to this problem appears to be years away. In the meantime, a multibillion dollar program of highway construction continues.

Because a rigorous solution to the problem is not available, some procedure for determining the factors that influence pavement performance must be adopted. The procedure adopted must be based on test procedures that simulate the service conditions of a pavement as closely as possible. This reasoning obviously leads to more test roads. However, test roads are expensive and must extend over a long period of time to gather enough data so that all the variables can be sorted out and evaluated. Furthermore, because of the interaction between variables, it may not be possible to determine the extent of the influence of any one variable on pavement performance.

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To facilitate the evaluation of many of the variables, test pavements constructed and tested under rigidly controlled conditions can be employed. For example, if these pavements are tested under simulated traffic loads with the climatic factors held constant the influence of load on behavior and performance of pavements can be evaluated. After the effect of loads on pavement performance has been determined, the next step of evaluating the effect of environment and climate can be properly undertaken.

The University of Illinois pavement test track was developed to evaluate pavement performance and behavior under controlled conditions. It was designed to apply simulated traffic loads at a high frequency to the test pavements.

The idea of a pavement test track is not a new idea. Through the years a number of test track facilities have been developed and some of them are currently in use (1, 2, 3, 4). A survey of the literature during the design stages of the test track indicated that the descriptions presented in the literature were inadequate to evaluate the potential of these facilities. One of the primary objectives of this paper is to describe the facilities so that other engineers and investigators can evaluate its potential in their own terms.

From what limited information is available in the literature, it appears that the test track is unique in several ways. The width of the test pavements is much greater than in any of the other test tracks described. Because of this greater width, the effect of the boundary conditions on the performance of the pavement are held to minimum. The depth of subgrade used is also greater than for other test tracks described in the literature. Finally, it can be programed to distribute the load applications to give a desired load density histogram. This feature allows for more realistic loading than the single-path loading of other test track facilities.

Because a large number of loads can be applied to the test pavements in a short interval of time, and because all but a few of the variables in the test pavement can be held constant, the effect of a particular variable on pavement performance can be determined in a relatively short period of time and at a reasonable cost. The test track facilities are located close to a fully equipped laboratory, so that a program in the test track can be complemented with a thorough laboratory evaluation program for maximum benefit. In this manner the factors influencing pavement performances can be determined.

The test track can also be used effectively to measure the relative performance of a paving material. With new paving materials being introduced it is important that there be a procedure or tool that can make a preliminary evaluation of the material quickly and inexpensively. The test track effectively serves this function. By comparing the performance of a proposed material with the known performance of a standard material, the relative performance of the proposed materials can be determined.

SCOPE

It is the purpose of this presentation to illustrate how a tool such as the University of Illinois pavement test track can be used for evaluating the factors that influence pavement performance and in developing highway materials. This presentation describes the test track in detail, explains the concepts and limitations of its use, and illustrates through typical results the information that can be gained by the use of this too. The results of the test program presented are typical results but do not include all of the data gathered. Furthermore, the results presented have not been discussed and interpreted, as this is not the purpose of this paper. However, the results are typical and accurately reflect the type of information that can be obtained through the proper use of the facilities.

TEST TRACK FACILITIES

A quonset-type building with 2,400 sq ft of floor space was provided by the University of Illinois to house the test track. Figure 1 is a plan of the building showing the general layout of the testing facilities. Outside storage area has been provided for stockpiling the large quantities of materials required. Figures 2 and 3 show the test track and loading frame.

Physical Dimensions

A detailed cross-section of the test track is shown in Figure 4. The test pavements are placed in the form of an annulus with an outside diameter of 25 ft and an inside diameter of 9 ft, leaving a pavement width of 8 ft. The test pavements rest on a prepared subgrade having a minimum thickness of 3 ft. The center of the wheelpath has a diameter of 16 ft, placing it 3.5 ft from the inside edge and 4.5 ft from the outside edge of the test pavements.

The test track may be divided radially so that several test pavements may be evaluated concurrently. The test pavements that are tested simultaneously are designated

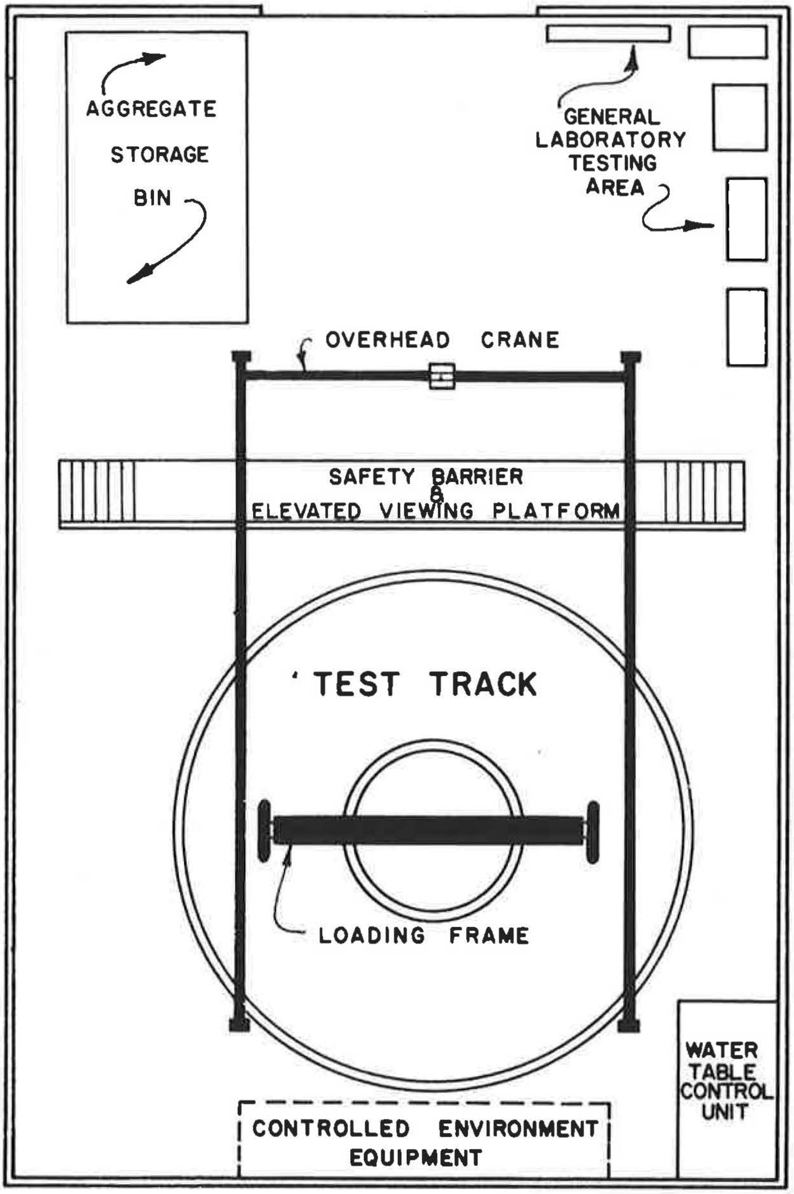

Figure 1. Test track, general layout.

as a set. Adjacent edges of test pavements are merged by the use of transition zones. Because of dimensional limitations discussed later, the maximum number of test pavements considered practical in one test set is six. Additional test pavements may be included in a set by replacing underdesigned test pavements which fail after a few applications of load with new test pavements.

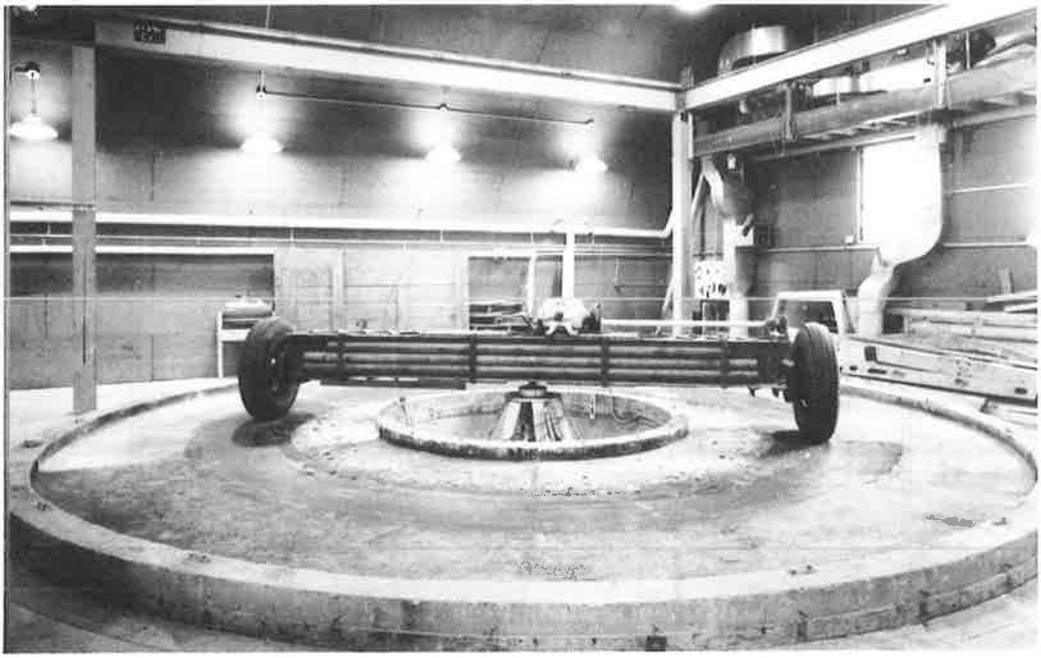

Figure 2. Test track.

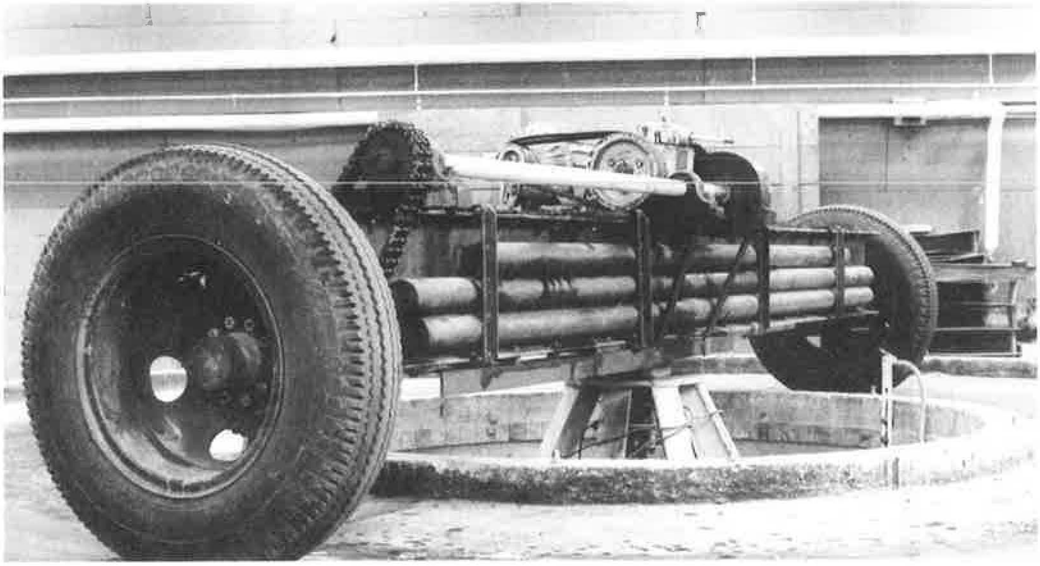

Figure 3. Test track loading frame.

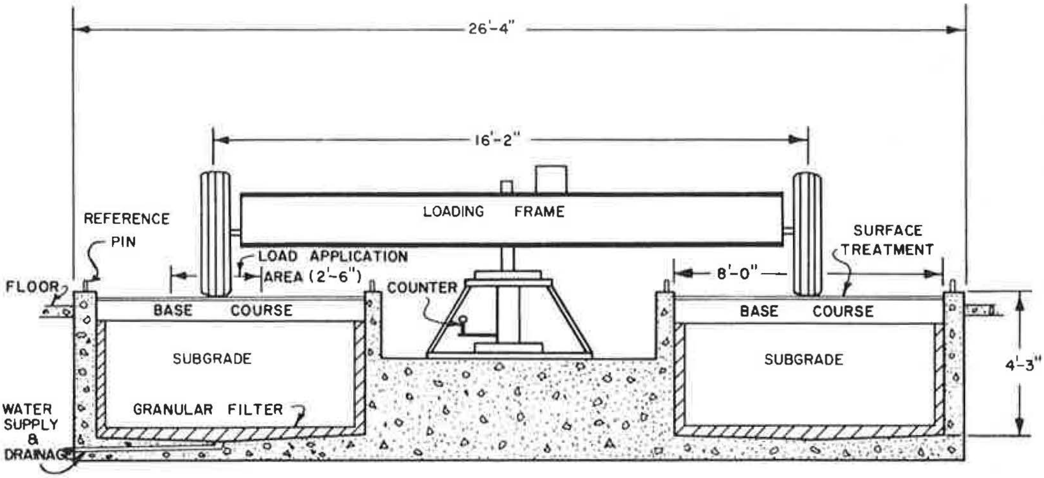

Figure 4. Test track, sectional view.

The base and the walls of the test track pit will affect the behavior of the test pavements because of their influence on the pavement boundary conditions. The dimensions of the test track are such that the effects of these boundary conditions are held to a minimum. A quantitative discussion of the effects of the boundary conditions is not possible because of the many factors that influence them. A quantitative discussion of the boundary conditions that seem most significant is given next.

The effect of boundary conditions on the behavior and performance of a pavement depends, among other factors, on the type of paving material and thickness of the pavement. For the purposes of this discussion the pavements are broken into two classifications: (a) pavements that distribute the load over a large area because of the ability of the paving material to develop relatively large tensile stresses (rigid pavements); and (b) pavements composed principally of cohensionless aggregates (flexible pavements). The terminology is arbitrary and does not necessarily connote the physical behavior of the pavement. Because the effect of the boundary conditions on the two classes of pavements is so different, the effects on each class of pavements is discussed separately.

The effects of the boundary conditions on the rigid pavements are dependent on the physical properties of the paving material as well as the pavement thickness. Therefore, it is convenient to discuss the significant dimensions of the test pavements in terms of a parameter that is a function of both material properties and pavement thickness. Such a parameter is Westergaard's (5) radius of relative stiffness denoted by the symbol L. The parameter L is given by

$$L = \sqrt[4]{\frac{Eh^3}{12\ (1-m^2)k}}$$

in which

E = modulus of elasticity of paving material;
h = thickness of pavement;
m = Poisson's ratio;
k = modulus of subgrade reaction.

The parameter L has a dimension of length and is usually given in inches.

To reduce the effects of the boundary conditions on pavement behavior, the load should be placed as far as possible from the edge, the distance being measured in terms of the relative stiffness L. The position of the load on the test pavements is controlled by the loading frame. Thus, to increase the effective distance of the load from the pavement edge, the L value for the pavement must be reduced. Conversely, to obtain the maximum effect of the boundary conditions the load should be placed relatively nearer the edge. The relative distance of the load in a fixed position from the edge of the pavement is at a minimum when the L for the pavement is at a maximum. Thus, for maximum effect of the boundary conditions the pavement with the greatest L value should be considered. Because the L of the pavement increases with pavement thickness, the maximum effect of the boundary conditions will occur with the thickest pavements.

Based on the AASHO Road Test findings and the maximum load used with the loading frame, the maximum anticipated thickness for a plain concrete test pavement is 4 in. With a subgrade having a modulus of subgrade reaction (k) of 100, the radius of relative stiffness for the 4-in. concrete pavement is approximately 21.5 in. The center of the wheelpath is 42 and 54 in. from the inside and outside edges, respectively, of the test pavements. Thus, the minimum distance from the center of the wheelpath to the edge of the test pavements is approximately 2L.

Meyerhof (6) in his analysis of the ultimate capacity of pavements has shown that the ultimate interior load capacity of a plain concrete slab would be developed if the load is placed a minimum distance of 2L from the edge. In other words, 2L is the minimum distance a load must be placed from the edge to develop the maximum interior loading capacity of the slab. Similarly, to develop the ultimate capacity of an edge-loaded pavement, the load must be placed a minimum distance at 2L from an intersecting edge.

Although the boundary conditions encountered in the test track may not influence the ultimate strength of the test pavements it would be premature to say that these same boundary conditions to not affect the stress in elastic slabs. That is, the stress in the slab before yielding may be influenced by the size of the slab even though the dimensions of the slab are great enough so that the ultimate strength is not influenced. The solution of a finite elastic slab on an elastic foundation is extremely complex. The analysis for a slab with the boundary conditions as imposed by the test track is not currently available.

The thickness of the elastic subgrade will affect the stress in the pavement. An analysis of 4-in. concrete pavement by means of the influence charts prepared by Pickett (7) et al., indicates that the stress in the pavement is reduced by less than 5 percent when the subgrade thickness is reduced from infinite thickness to a thickness of 2L. The depth of the subgrade in the test track under a 4-in. pavement is between 43 and 45 in. The L for the 4-in. concrete pavement with a relatively soft subgrade is between 21 and 25 in. Thus, the subgrade depth is approximately 2L, a depth that was shown to have an insignificant effect on pavement stress. Obviously, if the subgrade is assumed to be a dense liquid, the stress in the pavement is not a function of the subgrade depth.

The influence of the boundary conditions on the behavior and performance of flexible pavements is not known. This is mainly because the factors that influence the behavior and performance of the flexible pavements are not clearly established. There are some data, and theoretical justification, to support the theory that a cohesionless aggregate base will not distribute the load to any greater extent than predicted by the Boussinesq equation (8). If this is so, the Boussinesq equation can be used to estimate the influence of the test track pit on the behavior and performance of a flexible pavement.

The performance of a flexible pavement has been correlated with the pavement deflection under loads (9, 10, 11). Hence, a good indication of the effect of boundary conditions on behavior and performance of the test pavements would be the influence of the boundaries on the pavement deflection.

To illustrate the influence of the test track pit on the pavement deflection the bulb of pressure concept can be used. The bulb of pressure is defined by Terzaghi (12) as "the space within which the vertical normal stress in the subgrade is greater than one-fourth of the normal pressure on the surface of load application. The value of one-fourth has been selected because the major portion of the settlement of a loaded plate resting on a fairly homogeneous subgrade is due to the compression and deformation of the soil located with the space defined by this value."

In Figure 5, the bulbs of pressure for 12- and 30-in. plates are shown on a typical cross-section of the test track. The bulb of pressure for the 30-in. plate does not touch the bottom of the test track pit and for the 12-in. plate it reaches to less than the mid-depth of the pit. Also, the bulbs of pressure do not intersect the walls of the test track pit. The pressure bulbs shown are those as defined by Terzaghi and were calculated from the Boussinesq equations.

The test track pit is wide enough so that the log spiral failure plane proposed by McLeod (13) can form under all anticipated test conditions.

On the basis of the arguments just presented it is apparent that neither rigid nor flexible pavements will be significantly affected by the walls and base of the test track pit.

Water-Table Control Unit

The testing facility is equipped with a water-control unit so that the water table can be controlled to any desired level. A graded granular filter is provided on the bottom

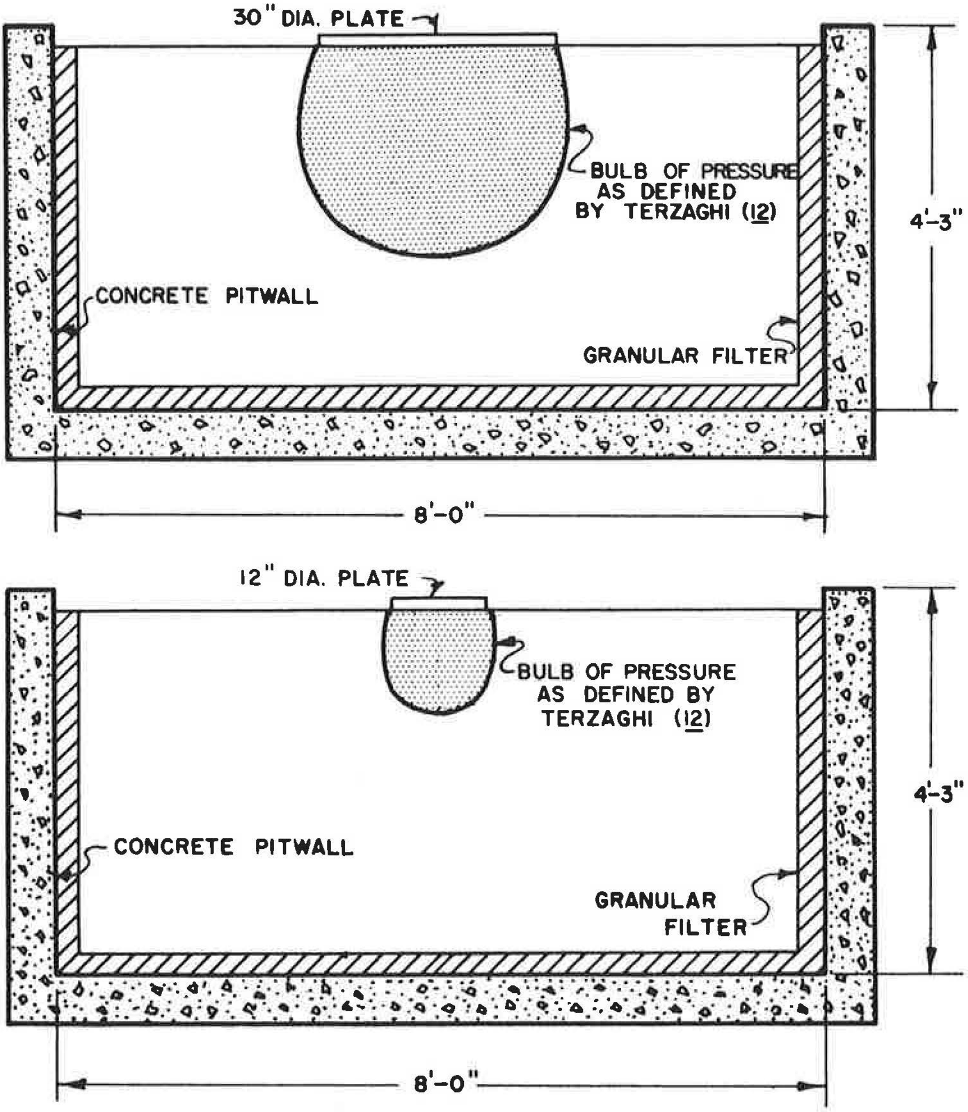

Figure 5. Bulb of pressure under rigid plates.

and along each vertical wall of the test track. A water supply and drainage system is connected to the granular filter. An automatic float system controls the position of the water table.

Controlled Environment Equipment

Controlled environment equipment has been incorporated into the plans for the test track. At the present time, the equipment is limited to producing temperatures on the surface of the track up to 140 F with a lower limit of ambient conditions. The relative humidity can be controlled in the range of 30 to 100 percent. Plans include the addition of refrigeration units so that lower temperatures can be produced. If environment conditions other than ambient are desired, a hood is placed over the test track and air of the desired temperature and humidity is circulated over the surface of the pavements being tested.

Loading Frame

The loading frame with appurtenances weighs approximately 3,700 lb. Provisions have been made for adding ballast to bring the total load to 6,500 lb. The total weight of the loading frame is carried by two wheels with the load evenly distributed between them. The loading frame is prevented from rotating about the wheel axles by a vertical guide which protrudes through the central portion of the loading frame. The frame is free to slide on the vertical guide and can rotate in a vertical plane about a horizontal axis perpendicular to the axles of the wheels, so that each wheel carries its proportionate share of the load at all times.

One of the loading frame wheels acts as a drive wheel, the other is a floating wheel which operates the oscillating mechanism on the frame. Power is supplied to the frame by means of a three-phase electric motor. A pulley system transmits the power from the motor to a four-speed gear box, through a drive shaft to the wheel. With the present pulley system and the four-speed gear box the drive wheel speed can be adjusted between 3 and 15 mph.

The oscillating mechanism controlled by the floating wheel causes the loading frame to oscillate radially as the frame rotates. The amplitude of the oscillation is controlled by a reversing mechanism. When the loading frame has moved to its most extreme position in one direction, a lever system activates the reversing mechanism causing the frame to start in the opposite direction. The amplitude of the oscillations can be adjusted by setting the stops which engage the lever on the reversing mechanism. The maximum amplitude of the loading frame is approximately 30 in. Approximately 100 revolutions of the frame, or 1 mi of wheel travel, is required for a complete cycle across the 30-in. path. By setting the stops and controlling the running time for each amplitude of the oscillation, various traffic patterns in the form of load density histograms can be produced. An automatic counter records the number of revolutions of the loading frame. Skewed distribution patterns can be obtained as conveniently as the symmetrical patterns.

Reference and Anchor Pins

In the design of the test track, permanent reference pins were included for use in measuring changes in the surface profile. These reference pins provide a base for accurate and expedient measuring of changes in the surface profile of the test pavement caused by the applied loads.

Anchors to which frames can be fastened were placed at various points in both concrete walls. These allow static bearing tests to be performed at any location in the track.

CONCEPTS AND LIMITATIONS

The design and analysis of a pavement must include a study of the soils and paving materials, their behavior under load, and the destructive effects of traffic and exposure. Few structures are subjected to as severe conditions of loading and exposure as highway pavements. The effects of both the loading conditions and exposure have been observed in all layers of highway pavements as well as in the supporting subgrade.

The performance of a pavement is the end result of the effects of a number of interrelated variables. Some of the variables that influence the performance of a pavement are traffic density, magnitude of load, load distribution, paving materials, subgrade soil, climatic conditions, drainage, etc. The quantitative effect of any of these variables on pavement performance has not been clearly established. This is mainly due to the difficulty in isolating the effect of any given variable under the fluctuating conditions to which a highway pavement is subjected. There is a danger of misinterpretating the results if one of a number of interrelated variables is isolated and studied independent of the others. If only one variable is studied and all others are suppressed, the results will not be the same as if all variables are acting. However, the variables that affect the pavement performance must be isolated and analyzed independently if the effects of each are to be put into proper perspective. Once the effects of the variables have been established, they can then be integrated into pavement design procedures.

The test track can be used as a tool for evaluating the performance and behavior of pavements. Loads that simulate traffic loads can be applied at a high frequency to the test pavements. Because of the controlled climate, subgrade, and loading conditions it is possible to isolate many of the variables and to study their effect on pavement performance without the confusing influence of other variables.

The test track can serve a useful purpose by spanning the gap between laboratory studies of material properties and field test roads. A logical and economical procedure for developing a design procedure for paving materials is as follows:

1. Conducting laboratory studies on the basic properties of the materials to be incorporated into the pavement.
2. Rationalizing the behavior of the pavement under service conditions and predicting the performance of the pavement.
3. Verifying and/or modifying the theory of behavior and performance by use of results from a test track.
4. Conducting road tests and studying the pavement under service conditions.
5. Observing the performance of the pavement over an extended period of time under actual service conditions.

All five steps must be used if new paving materials and new concepts for the use of paving materials are to be developed in an orderly, economical manner. Too much emphasis cannot be placed on following the sequence proposed. The results of each step must be carefully and completely analyzed before going to the next if maximum benefit is to be derived from a research and development program.

The need for a sound theory of pavement behavior and performance has long been recognized. This need becomes even greater as new materials are introduced. A rational theory is necessary for the orderly development of a testing program for paving materials. Without some theoretical basis it will be impossible to vary test parameters so as to obtain the maximum significance from the test results.

The test track results can be used as the first step for verifying or modifying the theory as applied to the paving materials. The test track has a number of advantages over both static tests and test roads. With the test track, loads that simulate traffic loads can be applied at a high frequency. As a result of the rapid build-up of load applications, the performance and behavior of the pavement under moving loads can be determined in a relatively short period of time. This reduces the time between initial testing of a material and its final incorporation into a highway pavement. The short period of time required for the load repetition build-up also reduces the cost of the test procedures. The total cost for testing a pavement in the test track is but a small fraction of the cost to test this same paving material in a test road.

It is possible to control many variables in a test track that cannot be controlled in a test road. In a test track the subgrade conditions can be either held constant or varied as desired by the investigator. Climatic conditions can be held constant at the test track to eliminate the effects of exposure. It is possible to vary the magnitude, frequency, and distribution of the loads on the test pavements in the test track.

The test track can be used to determine the relative performance of several highway pavements simultaneously. If the capabilities of one type of pavement are known from experience, the performance of another pavement can be compared with it. In this manner, results from the test track can be used to complement the experience and judgment of the highway engineer.

As with any testing facility, the test track has certain limitations. The results obtained from it are valid only for the conditions under which they were obtained. This holds true for all types of test results, including those from the test roads. The results from the test tack can be extrapolated to other conditions, but only on basis of sound engineering judgment, experience, and theoretical considerations.

The rapid accumulation of load applications listed as an advantage in testing a pavement can also be considered a limitation. It is not practical to consider the effects of time on pavement performance in the test track. This effect can best be studied in actual pavements.

At the present time it is not practical to study the effect of climate on the pavement performance in the test track. Facilities have been provided in the test track to install refrigeration equipment when desired. This, along with the heating and humidity control equipment, already present with the facilities, would make it possible to simulate certain climatic conditions on the test pavements. However, it is felt that for the present time the test track can be used to greater advantage in testing the behavior of pavements under load, leaving the evaluation of the effects of climatic conditions for a later phase of development.

It is the belief of all those who have had a close and knowledgeable association with test track that it, along with appropriate laboratory and theoretical studies, can provide useful information for the orderly evaluation of pavement materials.

TEST PROGRAM AND TYPICAL RESULTS

This section includes partial results from a research program currently in progress at the University of Illinois. The pavement test track is being employed as one of the tools for this study. The results included illustrate the type of data that may be obtained through the use of the test track. The authors have not presented a discussion or interpretation of the data as the sole purpose of including the data is to demonstrate the capabilities of the facility.

Included in this section of the paper is a description of the construction techniques employed in handling and placing the materials, a description of the materials used and data on the behavior and performance of several types of pavements. Performance and serviceability data are presented from typical sections of each type of pavement tested in the test track.

Materials and Construction Operations

The materials selected for use in the test program were selected by the project staff with the approval of an advisory committee. The materials selected were considered to be representative of materials in widespread use throughout the country.

Subgrade.—A total of 150 tons of selected subgrade material were taken from borrow pit No. 1 for the AASHO Road Test near Ottawa, Ill. Routine classification tests were made in the laboratory on samples of the subgrade material, which is a yellow-brown soil with an AASHO classification of A-6. The physical characteristics of the subgrade soil are summarized in Table 1. Additional information on soil from the same source is available in Highway Research Board publications (6, 7) relating to the AASHO Road Test.

Before placing the subgrade soil, a granular filter was placed on the bottom of the test track pit. The filter material was a graded aggregate with a range from ¾-in. through minus No. 200 sieve. The granular filter was compacted with a pneumatic tamper.

After the granular filter had been placed and compacted, the subgrade was placed over the filter material. Before placing the soil in the test track pit, vertical sheet metal separators were placed along both the interior and exterior walls of the test track pit so that the subgrade soil and the material for the vertical granular filter could be kept separated. The soil and the filter material were maintained at approximately the same level during placing. The filter material and the subgrade soil were first compacted around the vertical separators by hand. The vertical separators were removed before final compaction.

The subgrade soil was placed in the track and pulverized with a rotary hoe. Water was added to the soil during the pulverization to bring the material to the desired water content. The material was compacted in layers with 3-in. compacted thickness. Several methods of soil compaction were investigated to determine which would give the most uniform results. After considerable experimentation, it was found that the pneu-

TABLE 1

PHYSICAL CHARACTERISTICS OF SUBGRADE MATERIAL

Characteristic	AASHO Designation	Value
AASHO class.		A-6 (8)
Opt. moist. cont.	T99-57	13.0
Max. dry dens.	T99-57	120
Liquid limit (%)	T89-54	25
Plastic limit (%)	T90-54	14
Plastic index (%)	T91-54	11
Grain-size distr. (% passing sieve):	T88-57	
No. 4		98
No. 10		96
No. 40		92
No. 100		85
No. 200		79
0.02 mm		61
0.05 mm		39
0.002 mm		27

TABLE 2

COMPACTED CHARACTERISTICS OF SUBGRADE[a]

Characteristic	Test Set A	Test Set B	Test Set C
Dry density (pcf):			
At beginning of test	118.0	116.2	116.0
At end of test	122.0	119.8	118.8
Percent dry density[b]:			
At beginning of test	98.3	96.8	96.7
At end of test	101.7	99.8	99.0
Water content (%):			
At beginning of test	13.2	12.8	14.3
At end of test	12.8	12.1	13.4
Modulus of subgrade reaction (k)[c]:			
At beginning of test	164	163	58
At end of test	205	178	81

[a] Each value is average of six or more test values.
[b] Of standard (ASSHO T-99).
[c] At 0.05-in. deflection.

matic tampers gave the most uniform densities. Three to five passes of the tampers were required to bring the soil to the desired density. Alternate passes of the tamper were made in transverse directions to minimize directional densification of the subgrade.

During the process of subgrade placement, continuous testing was performed to control the moisture content and compacted density. After the soil was placed, plate bearing tests were made on the subgrade. The values of these tests are given in Table 2. At the end of each testing program, the base materials were carefully removed so that field density and plate bearing tests could again be made on the subgrade. The profile of the subgrade was carefully measured before and after each testing program.

At the completion of each test set, the subgrade material was removed to a depth of 1 ft or more. The removed soil was pulverized and replaced, as previously described, before placing the base courses for the next test set.

TABLE 3

PHYSICAL CHARACTERISTICS OF CRUSHED STONE BASE MATERIAL

Characteristic	AASHO Designation	Test Set A	Test Set C
Opt. moist. cont.	T99-57	6.8	6.2
Max. dry dens.	T99-57	139.0	144.6
Grain-size distr.			
(% passing sieve):	T88-57		
1-in.		100	100
3/4-in.		96	94
3/8-in.		65	60
No. 4		42	55
No. 10		25	41
No. 40		13	20
No. 200		7	16
Compacted dens.:			
Pcf		143.5	147.7
Percent of standard		103.2	102.1

TABLE 4

GRADATION OF GRAVEL FOR POZZOLANIC BASE

Sieve Size	Grain Size Distr.[a] (%)
3/4-in.[b]	100
3/8-in.	87
No. 4	73
No. 10	52
No. 40	23
No. 200	8
0.02 mm	4
0.05 mm	2
0.002 mm	1

[a] AASHO designation, T88-57.

[b] Material larger than 3/4 in. discarded.

TABLE 5

PROPERTIES OF FLY ASH FOR POZZOLANIC BASE

Property	Value (%)
Major constituent (approx):	
Silicon dioxide	41
Aluminum oxide	25
Ferric oxide	21
Calcium oxide	4
Sulfur trioxide	1
Loss on ignition	7.2
Grain-size distr.	
(passing sieve):	
No. 10	100
No. 40	98
No. 200	87
No. 325	79

During the initial construction phase a special soil planer was developed and was used to bring the various pavement layers to the desired elevation and thickness. The soil planer is capable of trimming the compacted soil to a tolerance of ± 0.03 in., and the compacted base materials to within 0.1 in.

Crushed Stone Bases.—The crushed stone bases used in the test program were designed and constructed to represent those used in typical highway pavements. The crushed stone was a limestone provided by stone producers from materials designated for use in the Illinois Highway Construction Program. The characteristics of the crushed stone are given in Table 3.

Before placing, the crushed stone was mixed on the job site in a concrete mixer, and water was added to bring the moisture content to the desired level. The materials were compacted with vibratory compactors and pneumatic tampers. The desired thickness was obtained by trimming the base with the soil planer.

Pozzolanic Bases.--The pozzolanic bases were composed of 82 percent gravel, 14 percent fly ash, and 4 percent lime. The gravel used for the pozzolanic bases came from a stockpile of subbase material used in the AASHO Road Test. It was the same material as was used for the cement treated and bituminous treated bases in the special base study at the AASHO Road Test. The grain-size distribution of the gravel is given in Table 4. The fly ash used in the pozzolanic base was obtained from the Public Service Electric and Gas Company, Sewarren, N.J. Properties of the fly ash are given in Table 5. The lime used in the pozzolanic bases was a monohydrated dolomitic lime supplied by the Marblehead Lime Company, Chicago, Ill. Properties of the lime are shown in Table 6.

An extensive laboratory investigation was conducted on pozzolanic base material before the repeated wheel load test in the test track. The general characteristics of the pozzolanic base material are given in Table 7. Figure 6 shows the general relationship between strength and age for the pozzolanic base mixtures used. The relationships shown are for specimens cured under ambient conditions. Specimens cured in moist sand for 28 days had a compressive strength of 710 psi, and those cured for 7 days in a sealed container at 130 F had a compressive strength of 1,360 psi. The pozzolanic base material exhibited no weight loss during the freezing and thawing or wetting and drying durability tests.

The fatigue characteristics of pozzolanic base material were measured and have been reported (16). The coefficient of thermal expansion was measured and found to be approximately 6×10^{-6}. The modulus of elasticity of cured material was found to vary between 1.6×10^{6} and 2.5×10^{6}, depending on the age of the material (Fig. 6).

The pozzolanic base materials were proportioned and mixed at approximately optimum water content in a 1½-cu ft pug mill mixer. The pozzolanic base was compacted with pneumatic tampers in the manner described for the subgrade material and the crushed stone. After compaction, the material was trimmed to the desired level with the soil planer.

Surfacing.—Several types of wearing surfaces were used on the test pavements reported. On test set A (Table 8) the wearing surface for the crushed stone was a sand-asphalt slurry seal, approximately ⅛ in. thick. The wearing surface for the pozzolanic bases in test set B (Table 8) was a troweled fly ash mortar mixture 1/16 to ⅛ in. thick. The wearing surface provided a smooth initial profile and an opportunity to study the crack patterns at an early age in their development. The test pavements in test set C were made up of crushed stone bases covered with 1 to 4 in. of asphaltic concrete (Table 9). The engineering properties of the asphaltic concrete used in test set C are given in Table 9.

Experimental Test Pavements

The test track is divided radially into six test sections for experimental purposes. Each test set was initially composed of six test pavements in which the pavement thickness and/or materials were varied. Table 8 gives the pertinent test data for the test pavements.

Traffic Operations

The wheel loads were applied to the test pavements by the loading frame previously described. A wheel load of 3,200 lb was used for all tests. The load was applied to the pavements through 8.25 x 20 tires inflated to 75 psi.

All tests were conducted with a wheel speed of approximately 13 mph, unless surface roughness dictated that a lesser speed be used. A speed of 13 mph will provide approximately 22,000 load applications for each 8 hr of operation. Loading operations were suspended at regular intervals for routine tests, measurements, and maintenance.

The basic operation plan was to traverse the wheel across the loading path under a

TABLE 6

PROPERTIES OF LIME FOR POZZOLANIC BASE

Property	Value (%)
Major constituents (approx.):	4
Calcium carbonate	59
Calcium hydroxide	2
Magnesium hydroxide	33
Magnesium oxide	
Grain-size distr. (passing sieve):	
No. 30	100
No. 100	97
No. 200	90
No. 325	85

TABLE 7

GENERAL CHARACTERISTICS OF POZZOLANIC BASE MATERIAL

Characteristic	AASHO Designation	Value
Composition (% by wt):		4
Lime		4
Fly ash		14
Gravel		82
Max. dry den.	T99-49	135.4
Opt. moist. cont.	T99-49	7.8
Compacted dens:		
Pcf		132.2
Percent of standard		97.6

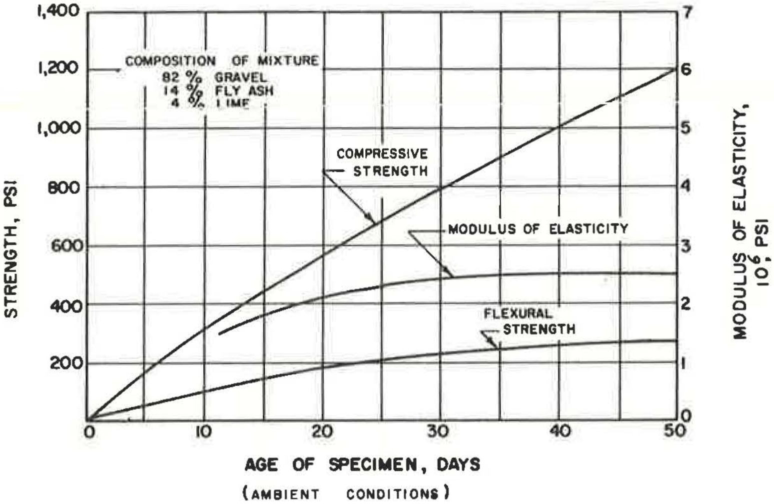

Figure 6. Strength-age relationships for pozzolanic base material.

controlled pattern that approximated the normal distribution of highway traffic. This was accomplished by adjusting the amplitude of oscillation of the loading frame at specified intervals. The resulting histogram of load density approximated the traffic distribution pattern determined by a Bureau of Public Roads study (17).

As testing progressed, it became apparent that the pozzolanic base was distributing load by slab action, and as such, should be considered as a rigid or semi-rigid base. A comparison of the fatigue characteristics of the pozzolanic base material (16) and the theoretical stresses produced during the build-up of a complete histogram of load applications showed that only 40 to 45 percent of the total applications would be effective in producing fatigue failure in the slab. The relatively high cohesive strength of the material also prevented rutting of the base. Therefore, to accelerate the test, tests on pavements with pozzolanic bases were conducted without the use of the traversing mechanism. All test loads applied to pavements with crushed stone bases were performed with the traversing mechanism in operation.

During loading operations, the surfaces of the test pavements were lubricated to reduce tire wear and to minimize horizontal forces created by a wheel moving in a circular path. Effectiveness of the surface lubrication in reducing the horizontal stresses is indicated by the tire wear. The 8.25 x 20 tires which were used in the testing program have traveled more than 5,000 mi with only nominal wear.

Whenever a test pavement failed, the section was declared out of test and pavement maintenance was conducted. The maintenance consisted of rebuilding the section with either asphaltic or portland cement concrete.

TABLE 8

TEST PAVEMENT DATA

Test Set	Test Pavement No.	Base Material	Base Thickness (in.)	Surfacing Material	Surface Thickness (in.)
A[a]	1	Crushed stone	8.0	Slurry seal	Nominal ($\frac{1}{8}$)
	2	Crushed stone	6.0	Slurry seal	Nominal ($\frac{1}{8}$)
	3	Crushed stone	10.0	Slurry seal	Nominal ($\frac{1}{8}$)
	4	Crushed stone	8.0[b]	Slurry seal	Nominal ($\frac{1}{8}$)
	5	Crushed stone	12.0	Slurry seal	Nominal ($\frac{1}{8}$)
	6	Crushed stone	10.0	Slurry seal	Nominal ($\frac{1}{8}$)
B[c]	1	Pozzolanic	4.3	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
	2	Pozzolanic	4.8	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
	3	Pozzolanic	5.3	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
	4	Pozzolanic	5.8	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
	5	Pozzolanic	4.8[b]	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
	6	Pozzolanic	5.3[b]	Mortar	Nominal ($\frac{1}{16}$ to $\frac{1}{8}$)
C	1[d]	Crushed stone	6.0	Asph. conc.	1.0
	2[d]	Crushed stone	3.0	Asph. conc.	1.0
	3[d]	Crushed stone	3.0	Asph. conc.	2.0
	4	Crushed stone	3.0	Asph. conc.	3.0
	5	Crushed stone	6.0	Asph. conc.	3.0
	6	Crushed stone	6.0	Asph. conc.	2.0
	1A[d]	Crushed stone	6.0	Asph. conc.	4.0
	2A[d]	Crushed stone	0.0	Asph. conc.	4.0
	3A[d]	Crushed stone	3.0	Asph. conc.	4.0

[a] Wheel load, 3,200 lb; tire pressure, 75 psi; for all test sets.

[b] Replica test pavement.

[c] Tests on pozzolanic bases began after 5 days during under ambient conditions.

[d] Sections 1, 2, and 3 were replaced after early failure with sections 1A, 2A, and 3A.

Load Distribution Behavior

The principal function of the base course in a highway pavement is to distribute the applied traffic loads to the underlying soil on which the pavement is built.

The manner in which a base course distributed the applied loads was studied by measuring the deflection of the pavement under moving wheel loads. A limited program was conducted on this phase of the research program.

The deflection of the pavement under the moving load was measured by means of linear variable differential transformers (LVDT) mounted in the pavement. The impulses from the LVDT's were transmitted to a Sanborn continuous recording device. With this system, the deflection at a particular point could be measured continuously. As the wheels moved on the pavement surface, a complete pattern of pavement deformation at a point due to the wheel load was measured. The LVDT's were mounted as shown in Figure 7.

TABLE 9

PROPERTIES OF ASPHALTIC CONCRETE SURFACE MATERIAL

Property	Value
Marshall stability (lb)	2,110
Marshall flow	8
Marshall density (pcf)	144.1
Marshall (% void)	3.5
Gradation[a] (% passing sieve):	
1/2-in.	100
3/8-in.	94
No. 4	71
No. 10	50
No. 40	30
No. 80	9
No. 200	3
Asphalt content (%)	5.3
In-place density (pcf)	137.7
Marshall density (%)	95.6

[a] By extraction.

The LVDT core was attached to a stainless steel (¼-in. diameter) anchor rod which was anchored to a base plate in the bottom of the test track pit. The casing of the LVDT was bonded to the base material. As the wheel load caused the base to deflect, the LVDT casing moved relative to the core and a change in potential was recorded on the Sanborn recorder. Each LVDT was individually calibrated before use.

The Sanborn-LVDT system provided a means of measuring the deflection of the pavement at a specific point, regardless of the position of the load. By observing the location and speed of the wheel, the deflection of the pavement at the LVDT was correlated with the wheel position. By the reciprocal theorem, the deflection at any point

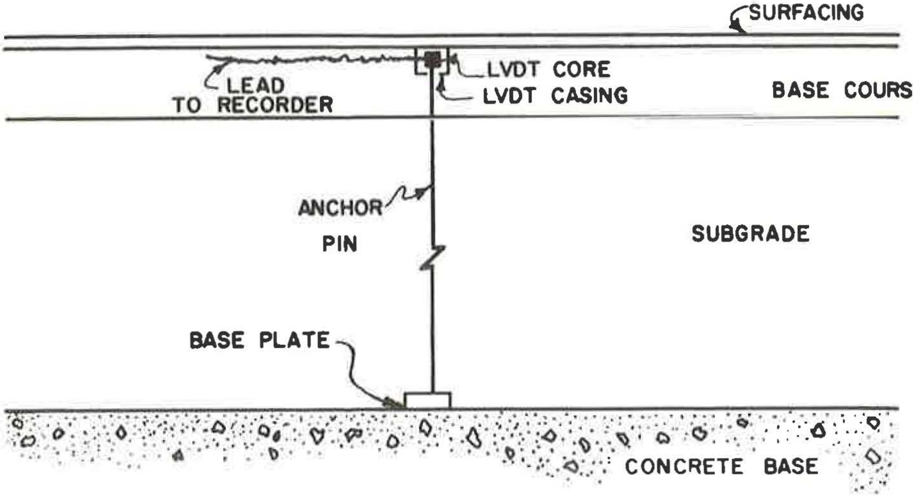

Figure 7. Transient deflection measuring system.

on the pavement as result of the wheel load over the LVDT can be obtained. Thus, the entire deflection pattern of the pavement due to a load at a specific point can be determined.

Figure 8 shows typical deflection patterns obtained with the pozzolanic and crushed stone base materials. Typical cross-sections of the deflection profiles are shown. The pozzolanic bases distributed the load over a larger area than than did the crushed stone bases and had less total deflection. Thus, the pozzolanic bases provide significant bridging action reducing subgrade stresses.

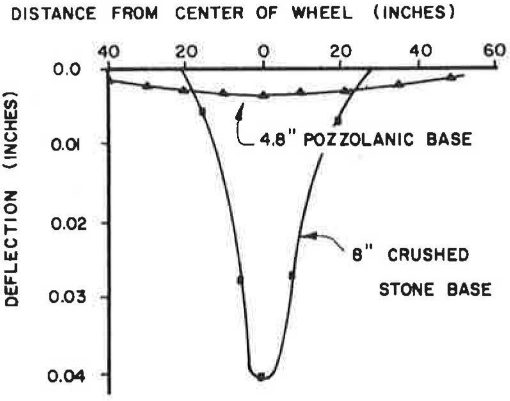

Figure 8. Typical base deflection pattern under moving load.

Pavement Serviceability and Performance

A major portion of the experimental study of pavement behavior involved a study of the relative performance of the test pavements in which the pavement thickness and/or materials were varied. The serviceability-performance concepts developed for the AASHO Road Test were used in this research program.

"The relative performance of various pavements is their relative ability to serve traffic over a period of time" (18). Present serviceability is defined as "the ability of the specific section of pavement to serve high-speed, high-volume, mixed (truck and auto) traffic in its existing condition" (18). The present serviceability index was developed as a mathematical combination of values obtained from certain physical measurements and so formulated as to measure the present serviceability of a pavement. The present serviceability index (PSI) corresponds to the following ratings of a pavement's ability to serve traffic at any given time:

4 - 5	Very good
3 - 4	Good
2 - 3	Fair
1 - 2	Poor
0 - 1	Very poor

The relative performances of various pavements may then be evaluated by a record of the present serviceability against number of load applications. A complete discussion of the serviceability-performance concept is given elsewhere (18).

The serviceability equations as presented in this reference are

for rigid pavement:

$$\mathrm{PSI} = 5.41 - 1.78 \log (1+\overline{\mathrm{SV}}) - 0.09 \sqrt{\mathrm{C} + \mathrm{P}}$$

for flexible pavement:

$$\mathrm{PSI} = 5.03 - 1.91 \log (1+\overline{\mathrm{SV}}) - 1.38\, \overline{\mathrm{RD}}^2 - 0.01 \sqrt{\mathrm{C} + \mathrm{P}}$$

in which

$\overline{\mathrm{SV}}$ = variance of slope along wheelpath;
$\overline{\mathrm{RD}}$ = depth of rut in wheelpath under a 4-ft straight edge;
C + P = major cracking and patching.

The parameters required for determining the present serviceability index of the test pavements in the test track were measured using procedures similar to those used in developing the equations.

The control reference pins made the measurement of the surface elevations for calculating slope variance a relatively simple task. A special frame was placed over the test pavements and rested on the reference pins. Dial indicators were used to measure

TABLE 10

PAVEMENT PERFORMANCE DATA

Test Set	Test Pavement No.	Base Material	Base Thickness (in.)	Surface Material	Surface Thickness (in.)	Approx. Thousands of Applications Before Serviceability Dropped to 4.0	3.0	2.0	Subgrade Conditions
A	1	Cr. stone	8.0	Slurry seal	Nominal	1	3	6	γ_d = 118.0 pcf;
	2	Cr. stone	6.0	Slurry seal	Nominal	1	2	3	w = 13.2%;
	3	Cr. stone	10.0	Slurry seal	Nominal	1	4	7	k = 164 pci
	4	Cr. stone	8.0	Slurry seal	Nominal	1	2	4	
	5	Cr. stone	12.0	Slurry seal	Nominal	2	7	18	
	6	Cr. stone	10.0	Slurry seal	Nominal	1	4	8	
B	1	Pozzolanic	4.3	Mortar	Nominal	210	320	350	γ_d = 116.2 pcf;
	2	Pozzolanic	4.8	Mortar	Nominal	--[a]	--[a]	--[a]	w = 12.8%;
	3	Pozzolanic	5.3	Mortar	Nominal	--[a]	--[a]	--[a]	k = 163 pci
	4	Pozzolanic	5.8	Mortar	Nominal	--[a]	--[a]	--[a]	
	5[b]	Pozzolanic	4.8	Mortar	Nominal	12	30	48	
	6	Pozzolanic	5.3	Mortar	Nominal	--[a]	--[a]	--[a]	
C	1	Cr. stone	6.0	Asph. conc.	1.0	--[c]	1	1	γ_d = 116.0 pcf;
	2	Cr. stone	3.0	Asph. conc.	1.0	--[c]	--[c]	--[c]	w = 14.3%;
	3	Cr. stone	3.0	Asph. conc.	2.0	--[c]	--[c]	1	k = 58 pci
	4	Cr. stone	3.0	Asph. conc.	3.0	1	3	5	
	5	Cr. stone	6.0	Asph. conc.	3.0	5	10	--[a]	
	6	Cr. stone	6.0	Asph. conc.	2.0	--[c]	2	5	
	1A	Cr. stone	6.0	Asph. conc.	4.0	1	3	23	
	2A	Cr. stone	0.0	Asph. conc.	4.0	2	5	14	
	3A[c]	Cr. stone	3.0	Asph. conc	4.0	--[c, d]	--[c, d]	--[c, d]	

[a] Serviceability of test pavement did not drop to this level.
[b] Removal of base after failure showed material segregation on bottom of base.
[c] Less than 500 applications.
[d] Crushed stone base inadvertently compacted to a density of 137.8 pcf compared with 147.7 pcf for other bases in test set C.

the surface elevation of the test pavements at 9-in. intervals both tangentially and radially. The surface elevation data from the wheelpath were used to compute the slope variance of the test pavements. The rut depth was obtained from the radial measurements of the surface elevations.

Surface irregularities will inevitably occur on any surface finished by normal construction procedures. These irregularities produce non-uniform values for the initial present serviceability indexes of the test pavements. These initial irregularities are not indicative of the performance of a given test pavement. Thus, to eliminate the effects of any initial surface irregularities, the change in slope due to the applied loads was used rather than the actual slope for determining the slope variance. The serviceability equation developed for rigid pavements was used for evaluating the performance of the pozzolanic bases, and the equation for flexible pavements was used in conjunction with the pavements with crushed stone bases. The serviceability record for each test pavement was plotted using a three-point moving average as a smoothing technique.

Table 10 summarizes the relative performance of the test pavements. The relationship between serviceability and the number of load applications for the 21 test pavements is shown in the Appendix.

CONCLUSIONS

A description of the test track and concepts of its use have been presented along with typical results to illustrate how the facility can be used to evaluate paving materials. Any conclusion regarding the trends in the data would necessarily require a discussion and interpretation of the results. Because the test program is not complete and only a portion of the available data has been presented herein, it would be both premature and unwise to discuss and interpret the data presented. It is anticipated that the entire testing program will be presented, and the results interpreted and discussed at some future date.

With respect to the test track proper, it has been shown that the facility was designed to keep the influence from the boundary conditions to a minimum while holding the volume of materials required to a reasonable amount. It was shown that the loading frame can apply a large number of loads distributed in a manner to simulate traffic loads in a relatively short period of time.

Typical test results were presented in this report. This should not be taken to mean that this is the only type of data that can be collected. On the contrary, data on many different phases of pavement behavior and performance can be gathered. The extent and type of data that can be obtained are limited only by the imagination of the personnel conducting the research.

The cost of evaluating a paving material with this facility will vary with the extensiveness of the program undertaken but will always be but a small fraction of the cost to evaluate the material in a test road.

ACKNOWLEDGMENTS

The authors wish to acknowledge the great number of individuals and organizations who have made the development of the University of Illinois pavement test track possible. The Federal Aviation Authority gratuitously supplied the test track loading frame, the University of Illinois and the National Science Foundation supplied the funds to construct and equip the test track, and several organizations from industry contributed the funds for the test program from which the typical results were taken.

The work covered in this report was carried out under the administrative supervision of W. L. Everitt, Dean of the College of Engineering; R. J. Martin, Director of the Engineering Experiment Station; N. M. Newmark, Head of the Department of Civil Engineering; and E. Danner, Director of the Illinois Cooperative Highway Research Program and Professor of Highway Engineering. The suggestions and advice given by the advisory committee to the project are gratefully acknowledged.

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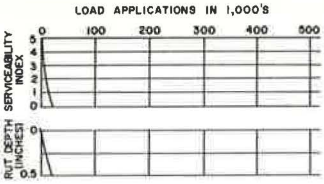
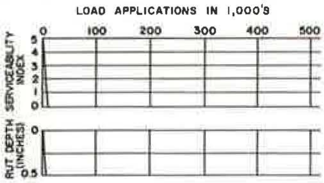
Appendix

SERVICEABILITY/LOAD APPLICATIONS FOR TEST PAVEMENTS

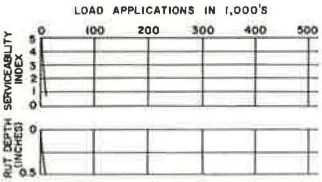
TEST PAVEMENT NO. A-1
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 8.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



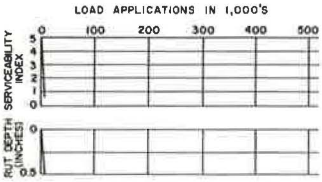
TEST PAVEMENT NO. A-2
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 6.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



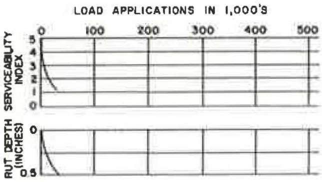
TEST PAVEMENT NO. A-3
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 10.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



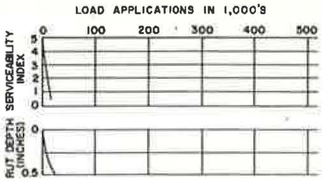
TEST PAVEMENT NO. A-4
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 8.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



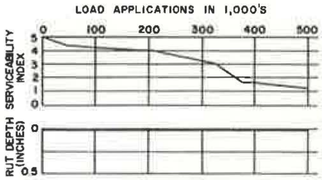
TEST PAVEMENT NO. A-5
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 12.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



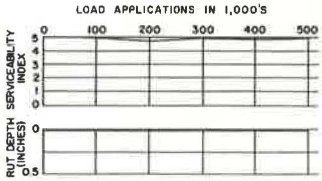
TEST PAVEMENT NO. A-6
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 10.0 IN.
SURFACE MATERIAL SEAL COAT
SURFACE THICKNESS NOMINAL



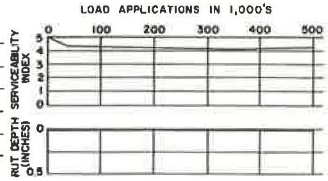
TEST PAVEMENT NO. B-1
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 4.3 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL



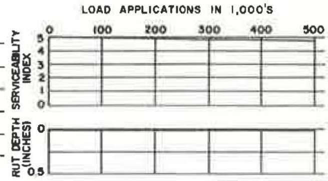
TEST PAVEMENT NO. B-2
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 4.8 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL



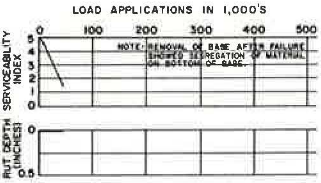
TEST PAVEMENT NO. B-3
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 5.3 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL



TEST PAVEMENT NO. B-4
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 5.8 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL

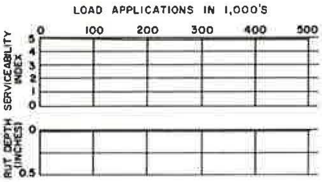


TEST PAVEMENT NO. B-5
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 4.8 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL

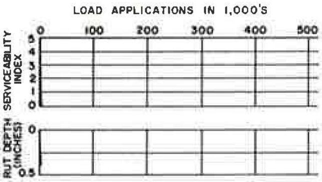


NOTE: REMOVAL OF BASE AFTER FAILURE SHOWED SEGREGATION OF MATERIAL ON BOTTOM OF BASE.

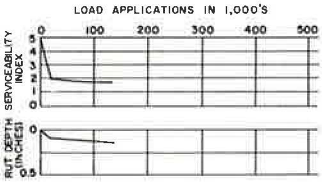
TEST PAVEMENT NO. B-6
WHEEL LOAD 3,200 LB
BASE MATERIAL POZZOLANIC
BASE THICKNESS 5.3 IN.
SURFACE MATERIAL MORTAR
SURFACE THICKNESS NOMINAL



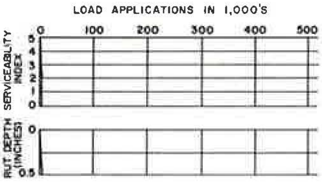
TEST PAVEMENT NO. C-1
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 6.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 1.0 IN.



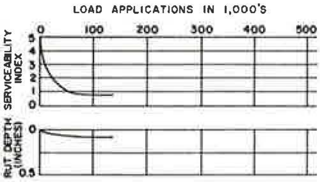
TEST PAVEMENT NO. C-1A
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 6.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 4.0 IN.



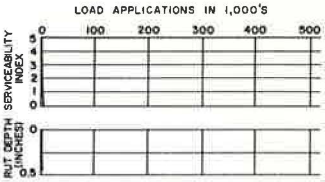
TEST PAVEMENT NO. C-2
WHEEL LOAD 3,200 LB.
BASE MATERIAL CR. STONE
BASE THICKNESS 3.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 1.0 IN.



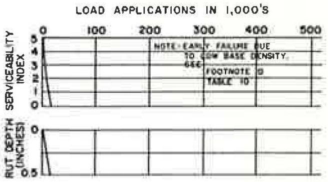
TEST PAVEMENT NO. C-2A
WHEEL LOAD 3,200 LB.
BASE MATERIAL NONE
BASE THICKNESS 0
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 4.0 IN.



TEST PAVEMENT NO. C-3
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 3.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 2.0 IN.

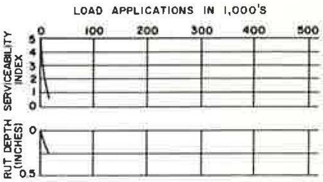


TEST PAVEMENT NO. C-3A
WHEEL LOAD 3,200 LB.
BASE MATERIAL CR. STONE
BASE THICKNESS 3.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 4.0 IN.

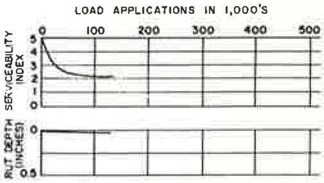


NOTE: EARLY FAILURE DUE TO LOW BASE DENSITY. SEE FOOTNOTE D TABLE 10

TEST PAVEMENT NO. C-4
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 3.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 3.0 IN.



TEST PAVEMENT NO. C-5
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 6.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 3.0 IN.



TEST PAVEMENT NO. C-6
WHEEL LOAD 3,200 LB
BASE MATERIAL CR. STONE
BASE THICKNESS 6.0 IN.
SURFACE MATERIAL ASP. CONC.
SURFACE THICKNESS 2.0 IN.