# The Load-Transmission Test for Flexible Paving and Base Courses

## Part IV

## The Effect of Base-Course Quality on Load Transmission Through Flexible Pavements

by

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# THE EFFECT OF BASE-COURSE QUALITY ON LOAD TRANSMISSION THROUGH FLEXIBLE PAVEMENTS*


## SUMMARY

Representative test data from the load-transmission project illustrate the relative effectiveness of typical base and subbase materials in protecting the subgrade from overstress Angular materials such as crushed stone or crushed slag are particularly effective in the lower layers of the pavement, where their shearing resistance is greatly augmented by the confining effect of the upper layers

The relative effectiveness of a wide variety of materials can be predicted qualitatively by reference to triaxial tests, and there is hope that such correlation can be established on a quantitative basis It is important that the triaxial loading rate and the condition of the specimens at the time of test be consistent with service conditions expected in the pavement

Knowledge of the comparative values of available paving materials will enable the designer to establish alternate designs of flexible pavements which are truly equivalent Natural competitive forces then will determine the best design for a given construction area Significant savings may be possible by intelligent selection of the most economical materials


## INTRODUCTION

Most organizations engaged in the design and construction of flexible pavements have developed empirical or semiempirical methods for determining the total thickness of pavement considered necessary to protect the subgrade from high stresses imposed on the pavement surface They also have prepared specifications for the surface, base, and subbase materials in order to be sure that the various layers of the pavement will have the minimum strength necessary to resist internal failure Surprisingly little thought appears to have been given to the possibility of decreasing the total pavement thickness by using materials of a quality somewhat higher than these minimum requirements

In fairness, it should be noted that a few individuals have consistently championed the cause of pavement quality versus thickness and that at least one organization has made an effort to incorporate this factor into its design method The CAA Airport Paving Manual (1948) states, "In instances where it might prove economical from a construction standpoint, the depth of bituminous surface may be increased and substituted for base course on the ratio of 1 1/2 inches of base for 1 inch of surface Also, the thickness of base course may be increased and substituted for subbase on the ratio of 1 1/2 inches of subbase for 1 inch of base "

When designs are based on load-bearing tests of trial pavement sections, the effect of pavement quality is included automatically, provided the trial section uses the same materials contemplated for possible use in construction Despite these encouraging exceptions, however, the effect of pavement quality has been generally ignored in the consideration of pavement thickness

Through the operation of the load-transmission project by the Civil Aeronautics Administration and by the Navy Bureau of Yards and Docks, quantitative data on the effectiveness of typical base and subbase materials are now becoming available A study of triaxial tests of the same materials also indicates the encouraging possibility of direct correlation between the two test procedures This would mean that the value of a material in protecting the subgrade from overstress could be determined by use of the comparatively simple triaxial test Such information, combined with cost data on available materials, would enable the design engineer to select the most economical design for any given condition

Although the testing and analysis of data are far from complete, sufficient progress has been made to warrant a progress report at this time The purposes of this report are (1) to focus attention on the need for considering pavement quality as well as thickness, (2) to indicate quantitatively the comparative effectiveness of some common paving materials when used as

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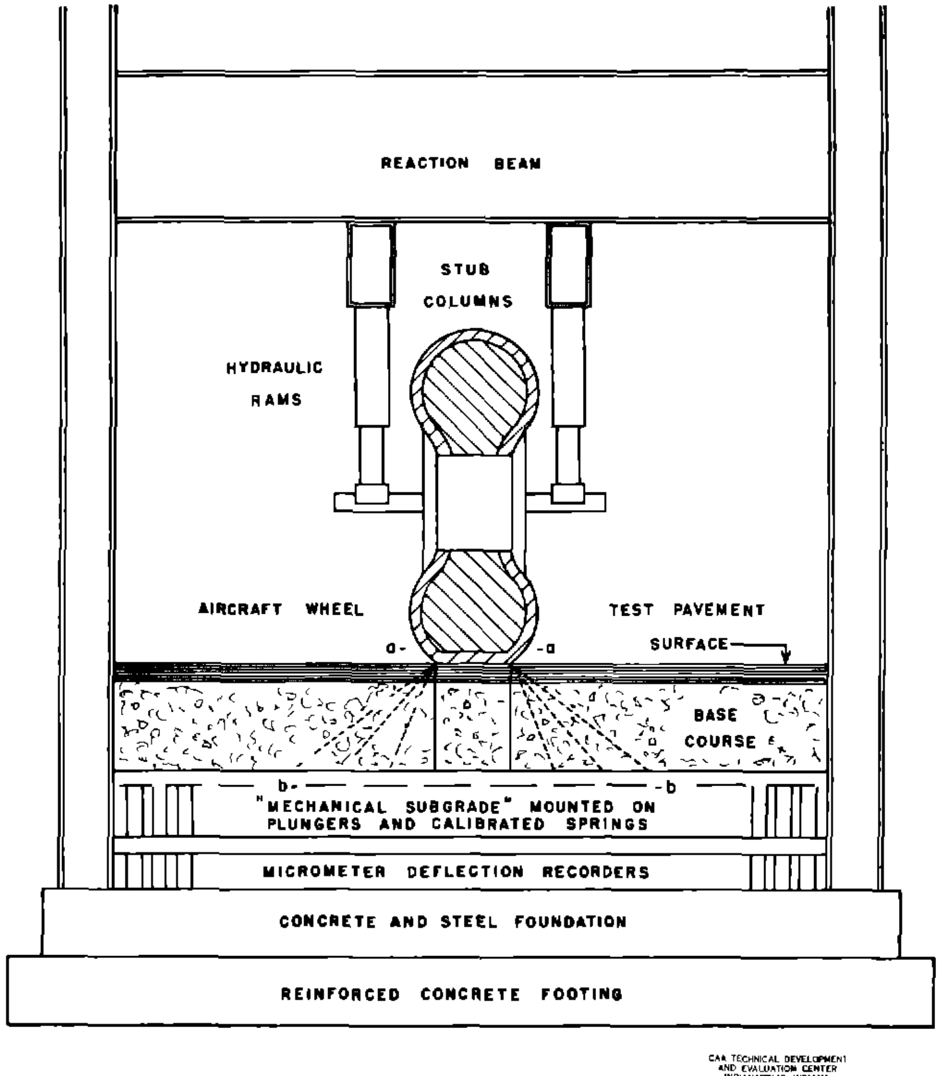


NOTE
A WHEEL LOAD APPLIED TO THE PAVEMENT SURFACE OVER AN AREA a -a IS TRANSMITTED AND DISTRIBUTED THRU THE SURFACE AND BASE COURSE THIS PRODUCES VARYING PRESSURES AND DEFLECTIONS OVER A LARGER AREA b--b ON THE SUBGRADE IN THIS TEST, THE NATURAL SUBGRADE IS REPLACED BY A "MECHANICAL SUBGRADE OR FLOORING COMPOSED OF 3600 SMALL STEEL PLATES THESE ARE MOUNTED ON PLUNGERS AND CALIBRATED SPRINGS IN SUCH A MANNER AS TO SIMULATE A SUBGRADE OF THE DESIRED STRENGTH AND TO PERMIT MEASUREMENT OF THE UNIT PRESSURES TRANSMITTED TO THE SUBGRADE

Fig 1 Load-Transmission Testing Rig

base or subbase, and (3) to indicate the possibilities of correlating triaxial and load-transmission test results from a wide variety of materials More complete data and analyses will appear in subsequent reports

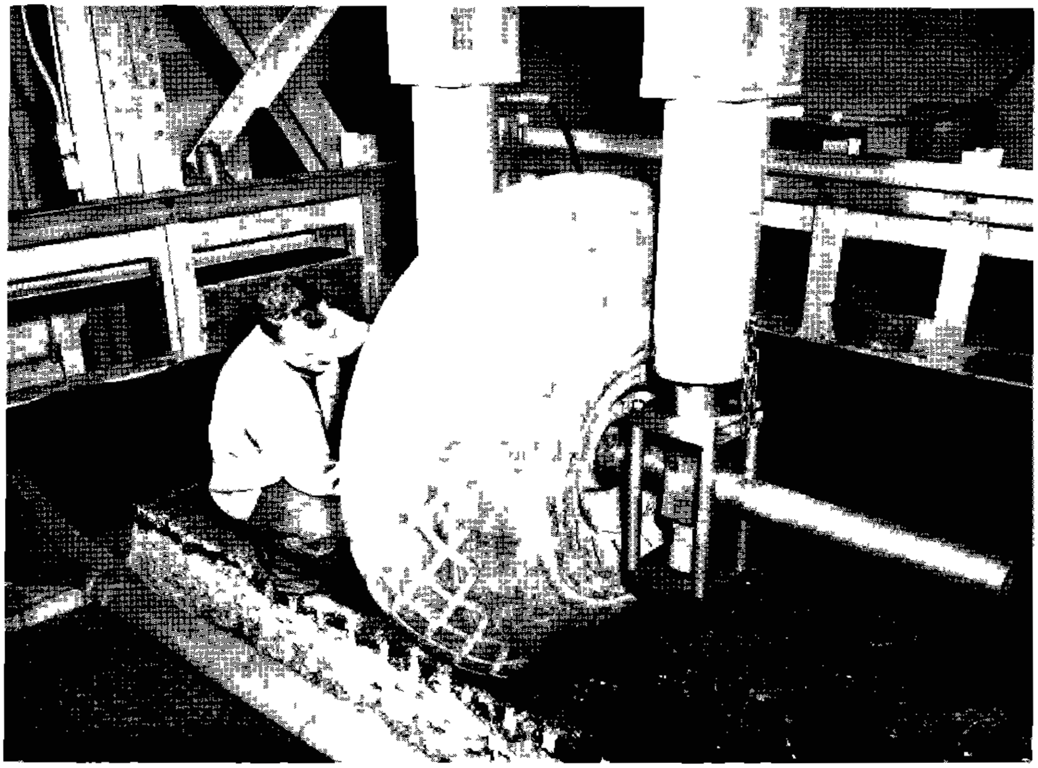

Fig 2 General View — Load-Transmission Apparatus

## TESTING APPARATUS AND METHODS

The load transmission project is being carried out at the Technical Development and Evaluation Center of the Civil Aeronautics Administration at Indianapolis In simplest terms, the project consists of a series of static loading tests conducted under laboratory conditions on full-scale pavement sections The natural subgrade is replaced by a flexible platform ten feet square This is composed of 3600 steel plungers placed in 60 rows of 60 each, each plunger being supported by a calibrated steel spring The sides of the platform are confined by wooden bulkheads Provisions are made for measuring the deflection of each plunger under any loading condition

In operation, a test pavement is constructed on the artificial subgrade, load is applied through an airplane tire or rigid plate, and deflections of the individual subgrade segments are measured Deflections are converted to values of vertical stress by means of calibration curves Figure 1 is a schematic sketch of the apparatus, and Fig 2 is a general photograph of the artificial subgrade with a partial pavement section in place and a tire in loading position

If the contact area of the loading medium is simple and symmetrical in shape, as in the case of a circular plate or the oval imprint of an airplane tire, it is necessary to measure the subgrade pressures only along the major axes of loading in order to get an adequate picture of the pressure distribution Figure 3 is a typical graph showing the longitudinal and transverse distribution of vertical pressure caused on top of the artificial subgrade by a loaded airplane tire on top of the pavement section

Had the pavement been more effective in distributing the applied load, because of greater thickness of the same material or because of use of a better material, the load would have been spread over a larger area of subgrade and the maximum stress under the center of load would have been less This maximum subgrade reaction r then becomes a convenient inverse measure of pavement effectiveness under any given loading condition Conversely, the load required to produce a given value of r will give a direct comparison of pavement effectiveness

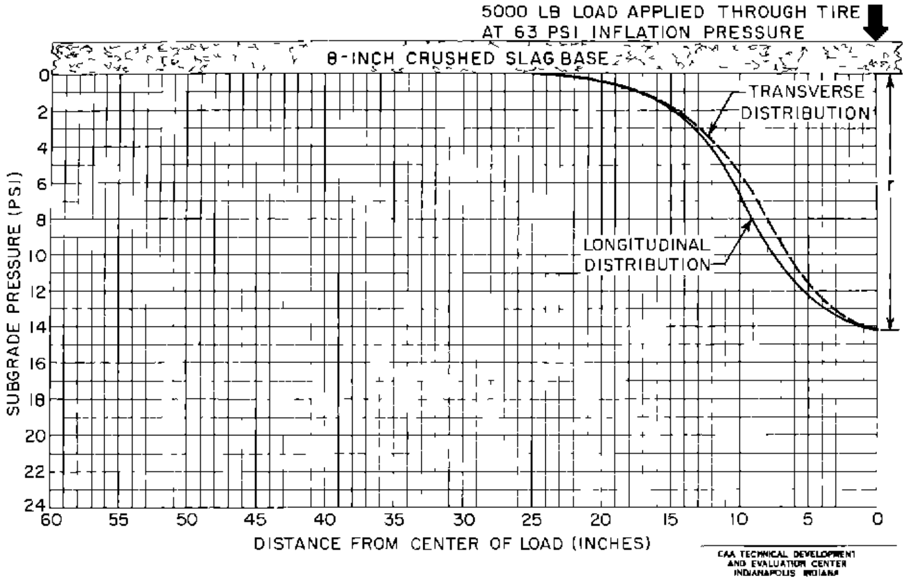


Fig 3 Typical Pressure-Distribution Pattern

Although the value of r for any specific test is a function of many variables, this report will be concerned only with the effect of pavement quality versus pavement thickness

The triaxial test is used to measure the physical strength of the materials used in the load-transmission testing program An attempt is made to prepare triaxial samples corresponding to each pavement test section in gradation, density, and moisture content Specimens composed of granular materials are usually constructed 10 inches in diameter and 20 inches high, but most of the asphaltic concrete specimens have been 4 inches in diameter by 8 inches in height

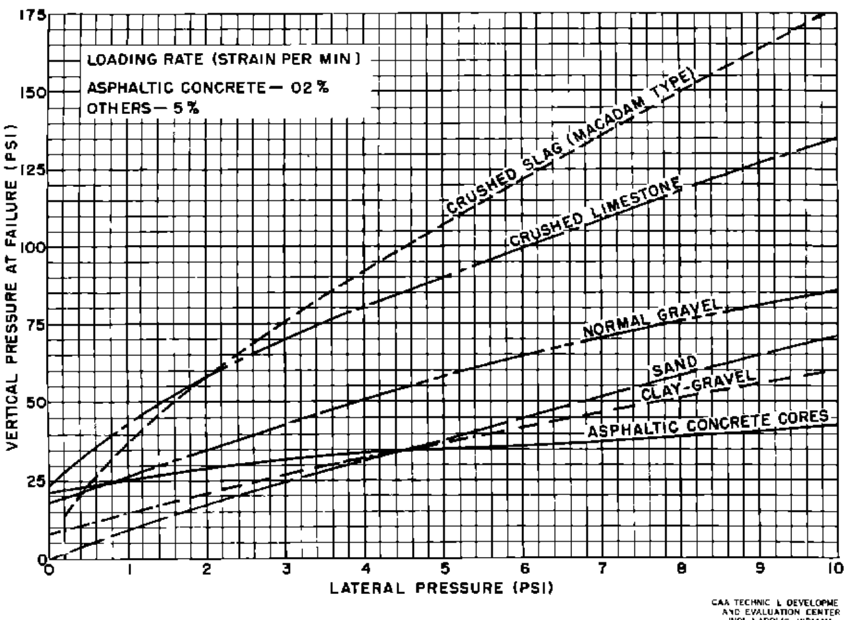


Fig 4 Triaxial Test Data — Relationship of Principal Stresses

In the early part of the program an attempt was made to determine the cohesion and angle of internal friction of the materials by means of the Mohr diagram In most cases, however, these values were indeterminate because the Mohr envelope was curved It was decided, therefore, that the simplest method of describing the strength characteristics of a material was to construct graphs showing the relationship of principal stresses at failure Typical curves are given in Fig 4

The foregoing information has been condensed from material appearing in previous reports[1,2,3,4], to which the reader is referred for more complete information

## DESCRIPTION OF MATERIALS TESTED

Normal Gravel

The material used in a large number of the tests was a partially crushed pit gravel reasonably well graded, with almost 100 per cent passing the 1-inch sieve and an average of about 10 per cent passing the No 200 sieve (by washing) It is typical of base-course material used extensively in the United States For this reason, it was chosen as the standard material against which other materials were rated

This material proved to be a rather unfortunate choice, because there was large variation in gradation of the gravel received in different shipments This, together with variations in density and moisture content which occurred in the mixing and placement of some pavement sections, resulted in wide strength variations in the standard material Such variation makes it necessary to exercise great care in using for direct comparison only those gravel pavements which actually were normal in composition and behavior In this report, the descriptive term "weak" has been added to a few gravel sections which were definitely below average in the triaxial tests

Clay-Gravel

In addition to the gravel sections which were weak from accidental causes, there were a few which were made intentionally weak by the addition of surplus fine material and a higher percentage of water These were intended to represent the poorer clay-gravels often used for subbase and sometimes allowed in base-course construction

Sand

The sand used in these tests was a relatively clean concrete sand, selected to represent fine noncohesive materials It would pass many subbase specifications

Crushed Stone

The crushed limestone was well graded, with a top size of 1 1/2 inches and about 10 per cent passing the No 200 sieve Although the limestone possessed little true cohesion as used, it showed high strength at low lateral pressures in the triaxial test because of good interlocking of particles

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[1]Raymond C Herner and William M Aldous, "The Load Transmission Test for Flexible Paving and Base Courses, Part I, A Description of the Testing Apparatus, Operating Methods, and Anticipated Uses of Test Data," CAA Technical Development Report No 108, April 1950

[2]William M Aldous, Raymond C Herner, and M H Price, "The Load Transmission Test for Flexible Paving and Base Courses, Part II, Triaxial Test Data on Structural Properties of Granular Base Materials," CAA Technical Development Report No 144, June 1951

[3]William M Aldous, M H Price, and Walker L Shearer, Jr , "The Load Transmission Test for Flexible Paving and Base Courses, Part III, Load Distribution through Gravel Bases to a Weak Subgrade," CAA Technical Development Report No 203, June 1953

[4]Raymond C Herner, "Progress Report on Load-Transmission Characteristics of Flexible Paving and Base Courses," Highway Research Board Proceedings, Vol 31, 1952

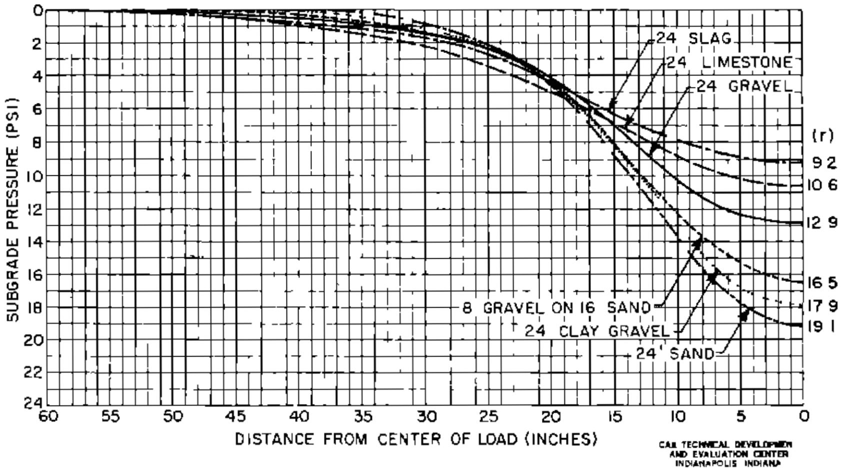


Fig 5 Longitudinal Load-Distribution Pattern for Various Base-Course Materials — 24-inch Thickness, 20-kip Load, 100-psi Inflation Pressure

A blend of three fractional sizes of stone was used in these tests in order to insure uniformity The resultant material was typical of a well-graded, high-grade crushed-stone base course

Crushed Slag

The crushed slag was of the same top size as the crushed limestone, but with practically no minus-200 material and with no cohesion The particles also were more blocky in shape

In order to avoid segregation due to lack of cohesion, the slag was placed in two sizes, using a macadam type of construction The coarse fraction, 1-inch to 1 1/2-inch size, was placed in 4-inch layers, then fine slag, all passing the No 4 sieve, was vibrated into place The resulting mixture had a dry density of about 130 pounds per cubic foot which was adequate for a gap-graded material practically devoid of fines passing the No 200 sieve The triaxial specimens would hardly stand when unconfined but increased rapidly in strength as the lateral pressure was increased

Asphaltic Concrete

A rather open-graded under-course material was used for the asphaltic concrete pavement tests reported herein It was obtained from a commercial hot-mix plant in regular production for street and highway work The aggregate for this mixture was a blend of partially crushed gravel and sand The resulting blend was gap-graded, with very little material in the No 4 to No 8 range and very little passing the No 200 sieve Five per cent of 80-penetration asphalt cement was used A density of 145 pounds per cubic foot was obtained by means of vibratory compaction and pneumatic tamping

The average Marshall stability of the mixture was 1170 with a flow of 28, which is higher than allowed by many specifications Triaxial specimens tested at room temperature showed a wide variation in strength when tested at different rates of loading This will be discussed later

## EFFECT OF PAVEMENT QUALITY ON SUBGRADE PRESSURES

Figure 5 graphically portrays the effect of pavement quality in reducing the vertical pressures transmitted to the subgrade Each curve shows the measured distribution of subgrade pressure along the longitudinal axis of the tire contact area for a different test pavement In each case the applied load is 20 kips, the tire inflation pressure is 100 psi, and the total pavement thickness is 24 inches

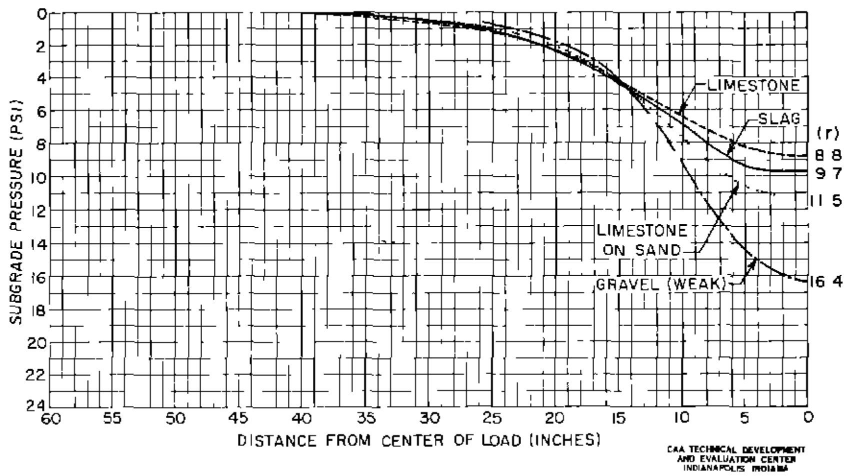


Fig 6 Longitudinal Load-Distribution Pattern for Various Base-Course Materials — 16-inch Thickness, 10-kip Load, 100-psi Inflation Pressure

Each curve represents data from only one test section and may be subject to minor revision as more test data are accumulated and averaged The indicated differences in performance are large enough, however, to overshadow any probable experimental error Moreover, the differences appear very logical when one considers the nature of the materials

The pavement section composed entirely of sand, with consistently low strength at all confining pressures in the triaxial test, is also the weakest in the load-transmission test The clay-gravel, with excess fines and moisture, is little better On the other hand, the crushed slag and limestone, with sharp angular particles, show up well under the high degree of confinement present in the 24-inch depth of pavement The normal gravel is intermediate in effectiveness, and the composite section with an 8-inch gravel base on a 16-inch sand subbase very properly falls between the values for these two materials

Similar information from 16-inch pavement sections is given in Fig 6 A 10-kip load is used for these comparisons Here again, the crushed slag and stone are the most effective

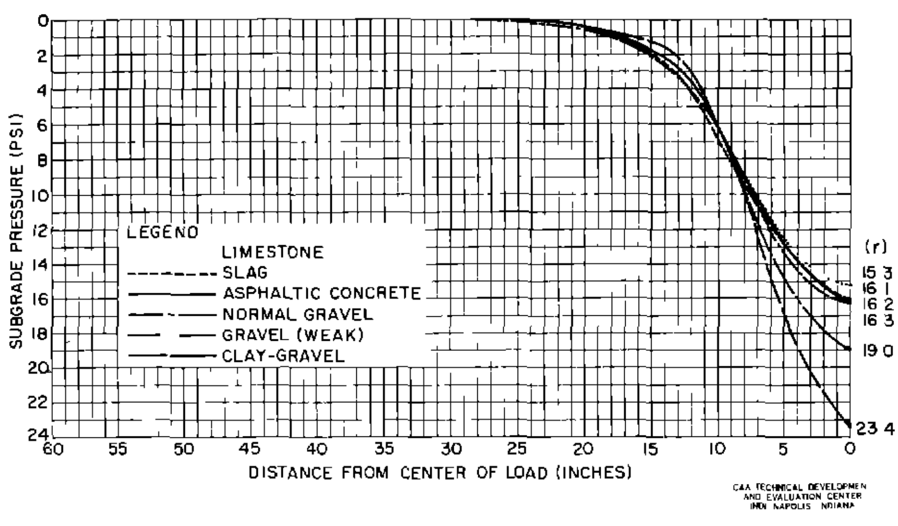


Fig 7 Longitudinal Load-Distribution Pattern for Various Base-Course Materials — 8-inch Thickness, 5-kip Load, 100-psi Inflation Pressure

materials but have changed places in the rating Although this difference is minor and may not be significant, it is logical in view of the lower degree of confinement in the 16-inch pavement and the cohesionless nature of the slag The weak gravel section (density a little low and moisture a little high) gave the poorest performance of the 16-inch group, whereas the composite stone-and-sand section fell into its logical intermediate position

The differences found in comparisons of 8-inch pavements, Fig 7, are not as great as those found in the thicker pavements This is only natural, because the thin pavement does not provide sufficient confinement to bring out the potential effectiveness of the angular crushed-slag and limestone materials The crushed stone is still the best material because of its good interlock, even at low degrees of confinement The slag, however, is now hardly as effective as the normal gravel The weak gravel and the clay-gravel are relatively ineffective Although there is no corresponding section constructed of sand, there are data available from tests at other inflation pressures indicating that such a section would be very ineffective also

The performance of the 8-inch asphaltic-concrete section barely equaled that expected of normal gravel, which confirms limited test results previously reported [5] These results, which may prove surprising to many, may be explained by the differences in properties of the various materials tested The granular materials, which support loads largely through interaction between discrete particles, tend to behave in a semielastic manner when loaded Movement ceases soon after loading, and there is measurable rebound when the load is removed The asphaltic concrete, on the other hand, behaves as a very viscous solid On application of a static load, as in the load-transmission test, plastic flow may continue for several hours before a state of equilibrium is approached In triaxial tests, with the load applied at a constant rate of strain, there is a wide variation in apparent shear strength, depending upon the loading rate selected

This phenomenon of viscous flow in asphaltic concrete has been discussed quite thoroughly in excellent papers by Nijboer[6] and McLeod [7] Nijboer gives values of dynamic shear moduli more than five times as high as those for static loads It is apparent, therefore, that the quantitative data on paving materials presented herein can be applied directly only to those design problems where the critical loads are either static or slow-moving

## CORRELATION OF LOAD-TRANSMISSION AND TRIAXIAL TEST RESULTS

A further study of Fig 4 reveals the excellent manner in which the protection of the subgrade by various pavement sections has been predicted by triaxial tests of the same materials The strength curves for crushed stone, normal gravel, and sand are generally parallel and definitely separated throughout the range of lateral pressures used in the triaxial tests If these tests are indicative of what may be expected in the pavement loading tests, the crushed stone should give the best performance of these three materials, regardless of pavement depth, and the sand should give the worst It has been shown that this was consistently true

The triaxial curve for slag starts low, crosses the gravel curve at about 0 5-psi lateral pressure, and continues upward to cross the crushed stone curve at about 2-psi lateral pressure Upon reference again to the load-transmission data given in Figs 5 to 7, it appears that comparative performances of 8-inch pavements could be predicted qualitatively at least by running triaxial tests of the materials at a lateral pressure of about 0 5 psi Similar comparisons for 16-inch pavement could be made by running tests at about 1 5 psi, whereas comparisons for 24-inch pavements would require triaxial tests at about 2 5 psi

In the preceding paragraph, an attempt has been made to select a single lateral pressure in the triaxial test which reflects the average over-all degree of confinement existing in a

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[5] Ibid

[6] L W Nijboer, "Mechanical Properties of Asphalt Road Materials and the Structural Design of Asphalt Roads," Highway Research Board Proceedings, Vol 33, 1954

[7] Norman W McLeod, "The Rational Design of Bituminous Paving Mixtures," Highway Research Board Proceedings, Vol 29, 1949

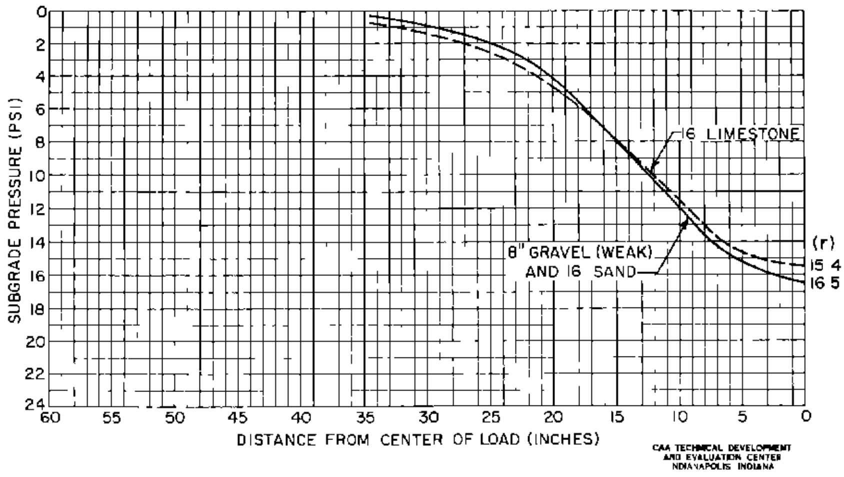


Fig 8 Quality Versus Thickness for Equal Load Distribution — 20-kip Load, 100-psi Tire Pressure

pavement of given depth This would be applicable only to a single-layered pavement using the same material for its entire depth In multiple-layered pavements composed of different surface, base, and subbase materials, it will be necessary to establish the lateral pressure corresponding to the degree of confinement at any depth in the pavement structure After evaluating each layer of material according to its position in the pavement, it then will be necessary to combine these figures into an over-all rating for the entire pavement structure

Enough work has been done to warrant a hope that such a quantitative method of evaluation can be worked out and that it will be simple enough for practical use More testing and analysis remain to be done, however, before this phase of the project can be reported

When asphaltic triaxial specimens were tested at the same rate of strain (0 5 per cent per minute) used for granular materials, the apparent strengths were too high for correlation with load-transmission test data This was due to the viscous effect previously mentioned Through a series of supplementary tests it was found that increasing the rate of strain by a factor of 10 increased the apparent strength of the asphaltic specimens by 50 to 100 per cent, whereas a similar change in rate for granular specimens increased the values by only about 10 to 20 per cent In order to obtain comparable results it was found necessary to reduce the rate of strain to about 0 02 per cent per minute when testing asphaltic samples The asphaltic-concrete curve shown in Fig 4 was obtained by interpolating between tests run at higher and lower rates of strain

## ECONOMIC SIGNIFICANCE OF DIFFERENCES IN BASE-COURSE QUALITY

The comparative effectiveness of different materials is illustrated very forcibly in Fig 8 Here are two pavements supporting the same load (20 kips), with the same tire inflation pressure (100 psi), and yielding very nearly the same pressure pattern on the subgrade One pavement, of conventional construction, is 24 inches thick, the other, using superior material, is only 16 inches thick but is doing a slightly better job of protecting the subgrade

By interpolating between test values given in this paper and with some reference to other test data not included herein, it is possible to arrive at thicknesses of different materials and combinations of materials which might be considered equivalent in value under a given design condition Figure 9 shows such equivalent designs for a 15-kip load on a soft subgrade, the subgrade pressure to be limited to a maximum of 12 psi Estimated costs per square yard for each type of construction are also given These costs are based on prices in the Indianapolis area and are intended only for purposes of illustration

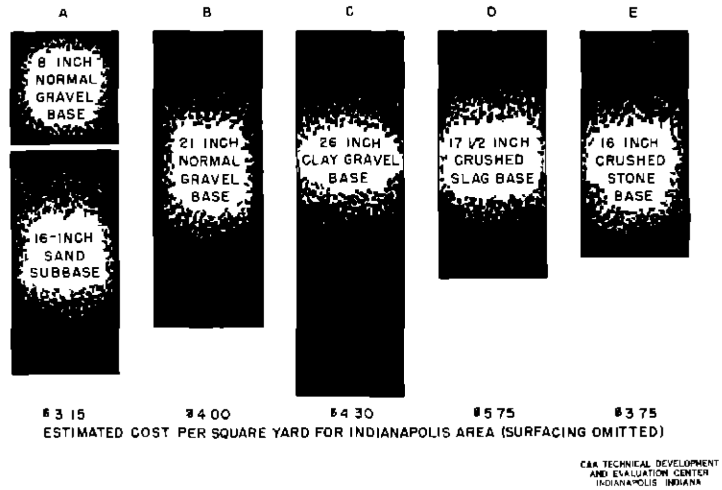


Fig 9 Economic Comparison of Equivalent Pavement Sections

Because sand is very cheap in this area, being a plentiful by-product of gravel production, the composite section using sand as a subbase is estimated as the cheapest construction shown Crushed stone should be competitive with gravel, even at a higher price per unit of volume There would be no advantage in specifying clay-gravel in this area, as the natural product is relatively clean and the price differential is small The crushed slag would be out of the question because of high shipping costs

The reader can readily visualize how the picture might change for other areas, particularly those where the better materials are locally available and do not have to overcome a large differential in freight costs In any event, we are now obtaining data which will allow the paving engineer to prepare designs which are really equivalent from the standpoint of subgrade protection The normal forces of competition may then be depended on for selection of the most economical design for any given locality

## CONCLUSIONS

The principal points of this report may be summarized as follows

1 Subgrade pressure distribution caused by application of static loads to a pavement structure is affected to an important degree by the physical characteristics of the base and subbase materials

2 Angular coarse-graded materials are particularly effective in the lower layers of the pavement structure because of the confining action of the upper layers

3 The comparative performances of various materials in protecting the subgrade can be predicted qualitatively by study of triaxial data With sufficient test information, there is hope that the comparison may be made quantitative

4 The performance of viscous materials such as asphaltic concrete varies widely with the rate of loading The ratings of such materials under short-duration dynamic loads should be much higher therefore, than their ratings under static loads

5 These findings are of economic significance in any construction area where high-quality materials are available at prices approaching those of inferior materials

In applying the data and conclusions to his own specific problems, the pavement designer is urged to keep in mind that the load-transmission data reported herein were obtained from static loads with the pavement sections supported by a weak mechanical subgrade He should remember also that there may be wide differences in physical characteristics of materials of the same general type Any material contemplated for use should be tested triaxially, therefore, under conditions approaching those expected in actual service If these limitations are observed, the data have great potential value in pavement design

ACKNOWLEDGEMENT

This report would not have been possible without the efforts of many engineers who have been active in the operation of the load-transmission project  While it is impractical to list all of them, special recognition is due William M  Aldous, whose foresight and perseverance made the project possible

Personnel of the Navy Bureau of Yards and Docks also deserve credit and thanks, both for their close technical co-operation and for provision of financial support of the project