The Load Transmission Test for Flexible Paving and Base Courses

Part V
Summary of Tire Tests on Various Pavements Overlying a Weak Subgrade

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TABLE OF CONTENTS

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PART V

SUMMARY OF TIRE TESTS ON VARIOUS PAVEMENTS OVERLYING A WEAK SUBGRADE*

SUMMARY

This report, the fifth in a series, presents additional test data from the load-transmission project and summarizes all tests with single airplane tires as the loading medium and with the test pavement supported by a weak subgrade Charts are developed by which the maximum subgrade reaction can be predicted accurately for a wide variety of design conditions for which specific load-test data are not available By correlation between triaxial tests and load-transmission tests it is possible to extend use of these charts to paving materials and combinations of materials which differ greatly in physical characteristics and performance The accuracy of the procedure, as shown by comparison of computed values to observed values, is very good

INTRODUCTION

This is the fifth in a series of reports describing operations of the load-transmission project at the Technical Development Center of the Civil Aeronautics Administration, Indianapolis, Indiana The broad purpose of the project is to study the transmission and redistribution of vertical loads through flexible pavements and base-course materials The project is currently sponsored by the Department of the Navy, Bureau of Yards and Docks, under a research contract

The first report[1] of this series described the mechanical construction of the testing apparatus and the method of operation The second report[2] contained tabulations and discussions of preliminary triaxial-test data obtained in connection with the main testing program Some of the earlier results from the load-transmission tests themselves appeared in the third report[3] of the series These data included tests on gravel bases only, using both rigid plates and airplane tires as loading mediums A weak mechanical subgrade (k = 82) was used The fourth report[4] presented representative data from tire tests on various base-course materials Its primary purpose was to illustrate the effect of base-course quality It showed that the comparative performance of various pavement sections in protecting the subgrade

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*Manuscript submitted for publication January 1956

[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," 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," 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," Technical Development Report No 203, June 1953

[4] Raymond C Herner, "The Load-Transmission Test for Flexible Paving and Base Courses, Part IV, The Effect of Base Course Quality on Load Transmission through Flexible Pavements," Technical Development Report No 269, August 1955

from overstress is influenced by the physical qualities of the paving materials as used It showed also that the comparative performance of sections of a given thickness could be predicted qualitatively by reference to triaxial tests of the paving materials

The purpose of the present report is to record load-transmission test data not previously published and to present a generalized summary of the relationships derived from test results available to date The data and discussion will be restricted to tests using single airplane tires as a loading medium and using a weak subgrade (k = 82) Future reports will extend the coverage to stronger subgrades and to multiple-wheel loadings

TEST RESULTS

As explained in previous reports, the segmented mechanical subgrade permits measurements of vertical deflection and stress over the entire area of the subgrade at intervals of about two inches For single loads the maximum stress occurs under the center of loading The relationship of this stress to the load imposed on the pavement can be used as a simple criterion of pavement effectiveness in comparing one section with another

The load-transmission test data applicable to this study and not included in previous reports are given in Table I. This table gives pavement type and thickness, strength index, applied load, tire inflation pressure, and corresponding maximum subgrade reaction The strength index is a numerical measure of strength determined from triaxial-test data in a manner described later in this report

A small amount of material was taken from each load-transmission test section to prepare the triaxial samples In some instances, however, there were substantial differences in density, moisture content, and other important physical characteristics of supposedly parallel test specimens Also, many of the earlier triaxial tests were run at lateral pressures which later proved to be unrealistic

For these reasons, the determination of strength indices for individual load-transmission test sections has required an element of judgment in the interpretation and modification of results from individual triaxial tests Fortunately, there was a sufficient background of experience with each material that the necessary adjustments for variations in density, moisture content, and lateral pressure could be made with relative assurance in most instances Data from only a few sections were rejected because the basis for adjustment was considered very questionable

DISCUSSION

The design engineer is interested in loading tests as a basis for predicting the subgrade stress or settlement which may be produced by a given applied load. From both theory and experience it can be assumed that the maximum vertical STRESS transmitted to the subgrade will tend to be increased by any of the following changes in design conditions

1 Increase in applied load
2. Decrease in contact area, or increase in tire inflation pressure
3 Decrease in pavement thickness
4 Decrease in strength or stiffness of pavement layers
5 Increase in subgrade stiffness

Subgrade SETTLEMENT should increase under the same circumstances except for the fifth condition where the effect would be reversed

The purpose of this discussion is to provide a quantitative picture of the effect of the first four variables (load, contact area, pavement thickness, and pavement strength), based on a compilation and analysis of load-transmission and triaxial data now available The analysis includes all data given in Table I, in addition to other data previously published It involves consideration of 315 test loads on 55 pavement sections, including single-layer sections of gravel, clay-gravel, sand, crushed slag, crushed limestone, and asphaltic concrete, as well as two-layer combinations of various materials

Pavement thicknesses were varied generally from 8 to 24 inches, with a few gravel sections as thin as 3 inches The general range of tire inflation pressures was from 63 to 200 psi, although a few tests were run at pressures as low as 40 psi Strength indices ranged from a low of 22 per cent for one 8-inch sand section to highs of more than 200 per cent for some of the 16-inch limestone and slag sections. The maximum load was limited

TABLE I

LOAD-TRANSMISSION TEST DATA

Test No	Pavement Type	Pavement Thickness (inches)	Inflation Pressure (psi)	Strength Index	Applied Load (kips)	Maximum Subgrade Reaction (psi)
869	Gravel*	8	63	0 60	2 5	8
870					5 0	16
871					7 5	22
872					10 0	28
873					12 5	33
874					15 0	37
875					17 5	41
876					20 0	45
888	Gravel	8	63	0 49	2 5	12
889					5 0	22
890					7 5	31
891					10 0	38
892					12 5	44
864	Gravel	8	100	0 60	2 5	9
865					5 0	19
866					7 5	27
867					10 0	34
868					12 5	41
893	Gravel	8	100	0 49	2 5	11
894					5 0	23
895					7 5	34
896					10 0	42
897					12 5	50
911	Gravel	8	100	0 72	2 5	11
912					5 0	19
913					7 5	27
914					10 0	33
915					12 5	39
916					15 0	44
917	Gravel	8	100	0 83	2 5	8
918					5 0	16
919					7 5	24
920					10 0	30
921					12 5	36
922					15 0	42
906	Gravel	24	63	0 63	10 0	8
907					15 0	13
908					20 0	17
909					25 0	21
910					30 0	25
899	Gravel	24	100	0 57	10 0	10
900					15 0	13
901					20 0	18
902					25 0	23
903					30 0	28
904					35 0	33
695	Sand	8	63	0 22	5 0	33
696					7 5	44
697					10 0	55
698					15 0	73
706	Sand	16	63	0 34	10 0	22
707					12 5	28
708					15 0	32
700	Sand	24	63	0 46	10 0	9
701					15 0	14
702					17 5	17
514	Sand	24	100	0 53	10 0	10
515					12 5	12
516					15 0	15
517					20 0	19
518					25 0	24
519					30 0	29

*Gravel tests prior to No 592 have been reported previously

TABLE I (continued)

LOAD-TRANSMISSION TEST DATA

Test No	Pavement Type	Pavement Thickness (inches)	Inflation Pressure (psi)	Strength Index	Applied Load (kips)	Maximum Subgrade Reaction (psi)
734	Slag	8	63	1 02	5 0	15
735					7 5	20
736					10 0	25
737					12 5	30
738					15 0	34
739					17 5	38
740					20 0	42
765	Slag	8	63	0 96	5 0	14
766					10 0	25
767					12 5	29
768					15 0	33
769					17 5	37
770					20 0	40
771					22 5	44
772					25 0	47
720	Slag	8	100	1 00	10 0	28
721					15 0	39
722					20 0	48
723					25 0	56
728	Slag	16	100	1 34	10 0	10
729					15 0	14
730					20 0	19
731					25 0	23
732					30 0	27
733					35 0	31
939	Slag	16	200	2 12	12 5	12
940					17 5	18
941					25 0	25
942					35 0	34
943					42 5	41
944					50 0	47
725	Slag	24	100	1 55	30 0	15
726					35 0	17
778	Limestone	8	100	1 33	5 0	16
779					7 5	27
780					10 0	32
781					12 5	37
782					15 0	41
783					17 5	46
824	Limestone	8	100	1 34	2 5	9
825					5 0	15
826					7 5	21
827					10 0	26
828					15 0	34
829					20 0	42
830					25 0	48
795	Limestone	16	63	1 16	5 0	6
796					7 5	9
797					17 5	18
798					25 0	23
799					35 0	30
800					40 0	33
773	Limestone	16	100	2 14	10 0	9
774					20 0	15
775					25 0	19
776					30 0	22
777					35 0	25
838	Limestone	16	200	1 60	5 0	6
839					12 5	13
840					17 5	17
841					25 0	24
842					35 0	32
843					42 5	38
844					50 0	43

TABLE I (continued)

LOAD-TRANSMISSION TEST DATA

Test No	Pavement Type	Pavement Thickness (inches)	Inflation Pressure (psi)	Strength Index	Applied Load (kips)	Maximum Subgrade Reaction (psi)
789	Limestone	24	100	1 33	10 0	5
790					20 0	11
791					30 0	16
792					35 0	18
793					40 0	20
794					45 0	22
845	Asphaltic	8	100	0 90	2 5	8
846	Concrete				5 0	16
847					7 5	23
848					10 0	31
849					15 0	41
850					20 0	52
851					25 0	61
877	Asphaltic	8	200	1 02	2 5	11
878	Concrete				5 0	21
879					10 0	42
880					12 5	51
392	Composite	10	42	1 10	3 0	5
393	8 Inches				6 0	11
394	Clay-Gravel,				7 0	12
395	2 Inches				4 0	7
396	Asphaltic				8 2	14
397	Concrete				9 0	16
398					5 0	9
399					10 5	19
400					12 0	22
475	Composite	10	63	1 00	5 0	11
476	8 Inches				7 5	16
477	Gravel,				15 0	27
478	2 Inches				19 0	33
479	Asphaltic				25 0	40
	Concrete					
480	Composite	12	63	0 82	5 0	9
481	8 Inches				7 5	15
482	Gravel				15 0	28
483	4 Inches				19 0	34
484	Asphaltic				24 0	43
	Concrete					
812	Composite	16	100	0 90	5 0	6
813	8 Inches				10 0	12
814	Limestone				15 0	17
815	8 Inches				20 0	22
816	Sand				25 0	28
817					30 0	32
818					35 0	37
507	Composite	24	100	0 68	10 0	8
508	16 Inches				12 5	10
509	Sand,				15 0	12
510	8 Inches				20 0	16
511	Gravel				25 0	20
512					30 0	25
946	Composite	24	100	0 99	10 0	6
947	16 Inches				15 0	9
948	Sand				20 0	12
949	8 Inches				25 0	14
950	Limestone				30 0	17
951					35 0	20
958	Composite	24	100	1 80	20 0	8
959	10 Inches				25 0	10
960	Slag				30 0	12
961	14 Inches				40 0	15
962	Limestone				50 0	19
963					60 0	22

to 60,000 pounds, even on the heaviest and strongest sections, in order to avoid overstrain of some of the loading equipment. Maximum subgrade deflections were generally limited to 0 7 inch, which is well above normal design practice even for thin pavements

All load-transmission tests included in the analysis were run on pavements supported by the weak mechanical subgrade (k = 82) Enough tests have been run on a stronger subgrade (k = 150) to prove the importance of this item in determining stress distribution, but the tests are not sufficient in number to warrant their inclusion at the present time The stress relationships developed in this report, therefore, are applicable only to design problems involving weak subgrades They should be usable without serious error for a range of subgrade moduli from 65 to 100 pounds per inch cubed.

From analysis of some of the earlier data it appeared that the relationship between load and reaction could be expressed with reasonable accuracy by a simple parabolic equation in the form

$$r = aV^b \tag{1}$$

Where

r = maximum vertical stress (or reaction) imposed on the subgrade.

a = a coefficient, varying with pavement thickness, contact area, pavement strength, and subgrade modulus.

V = total applied vertical load

b = an exponent, varying primarily with pavement thickness but which also might vary with other test conditions

Further tests, involving wider ranges of loading, showed that this simple relationship was not valid At the higher loads the plot of r versus V, which had approximated a straight line when drawn on logarithmic paper, tended to flatten out, with r approaching a constant value determined by the tire inflation pressure. This appears reasonable because, theoretically, the subgrade reaction should approach the tire contact pressure as a limit when the total load and resulting contact area become very large

Actually, the contact pressure is not uniform over the contact area, the pressure distribution varying somewhat with differences in tire-carcass stiffness and sidewall restraint. For thin pavements, therefore, the maximum subgrade reaction actually may exceed the nominal tire inflation pressure

Within the range of values studied, the relationship of pavement thickness (h) to subgrade reaction (r) can be expressed approximately by a straight-line graph on semilogarithmic paper Typical data from tests are shown in Fig 1 The corresponding equations are of the general form

$$r = ab^h \tag{2}$$

Values of the intercept (a) and slope (log b) vary with applied load and with tire inflation pressure

Efforts to develop simple equations for all of the relationships have been unsuccessful Theoretical analyses such as Burmister's[5] indicate in a qualitative manner the effect of changes in the different variables involved in the tests Quantitatively, however, they do not yield consistent results throughout the entire range of test conditions Pending further study and analysis along these lines, the data have been summarized in a series of charts which show the variation of subgrade reaction with applied load for various combinations of pavement thickness and tire inflation pressure These graphs are shown as Fig 2. They apply to the standard gravel material used as a basis of comparison throughout the testing program, and they represent an averaging and smoothing of all the test data available Values not obtainable directly from the graphs may be interpolated readily

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[5] Donald M Burmister, "The Theory of Stresses and Displacements in Layered Systems and Applications to Design of Airport Runways," Highway Research Board Proceedings, 1943

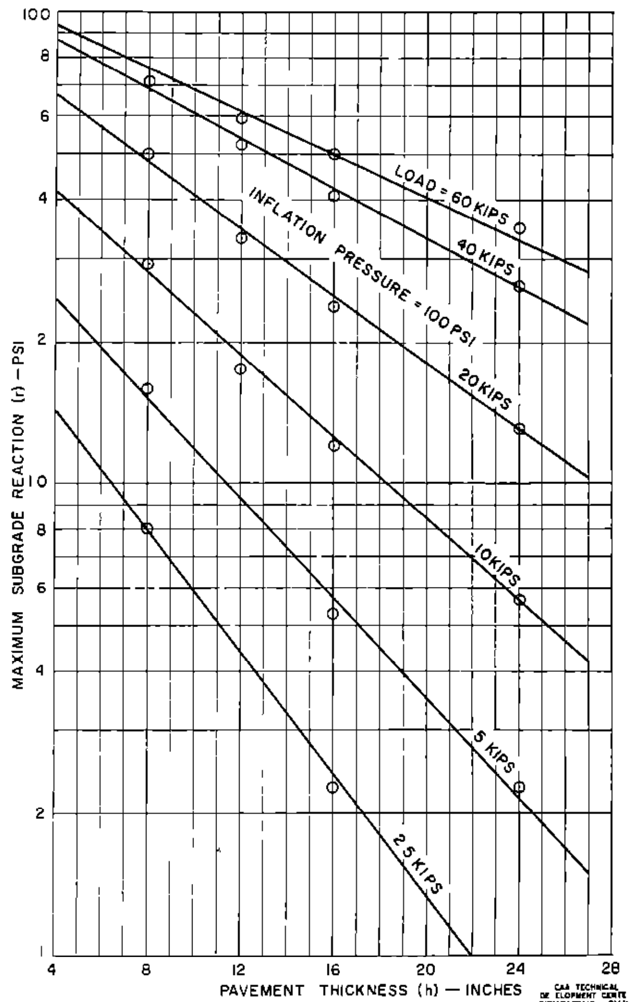

Fig 1 Maximum Subgrade Reaction Versus Pavement Thickness, Typical Test Data

In considering materials other than the standard gravel it is necessary to use triaxial data to obtain a corrected value of subgrade reaction The entire operation involves six steps as follows

1 Divide the proposed pavement sections into layers if necessary, each not more than eight inches thick, and each composed of only one type and quality of material
2 Perform triaxial tests on specimens representing each layer of material, using a lateral pressure which is determined by the average depth of the layer in the pavement section. See Fig 3 for the lateral pressure to be used
3 Divide the vertical pressure at failure, determined in Step 2, by the corresponding value for the standard gravel at the same lateral pressure Values for the standard gravel are given in Fig 4, which also shows average curves for some of the other materials which have been tested.
4 If the pavement consists of more than one layer, take a weighted average of the ratios obtained for the various layers in Step 3 This is the STRENGTH INDEX for the entire pavement section.
5 Use the charts (Fig 2) to obtain the subgrade reaction for a standard gravel pavement of the proposed thickness
6 Divide the subgrade reaction obtained in Step 5 by the square root of the strength index determined in Step 4 This gives the corrected value for the proposed section

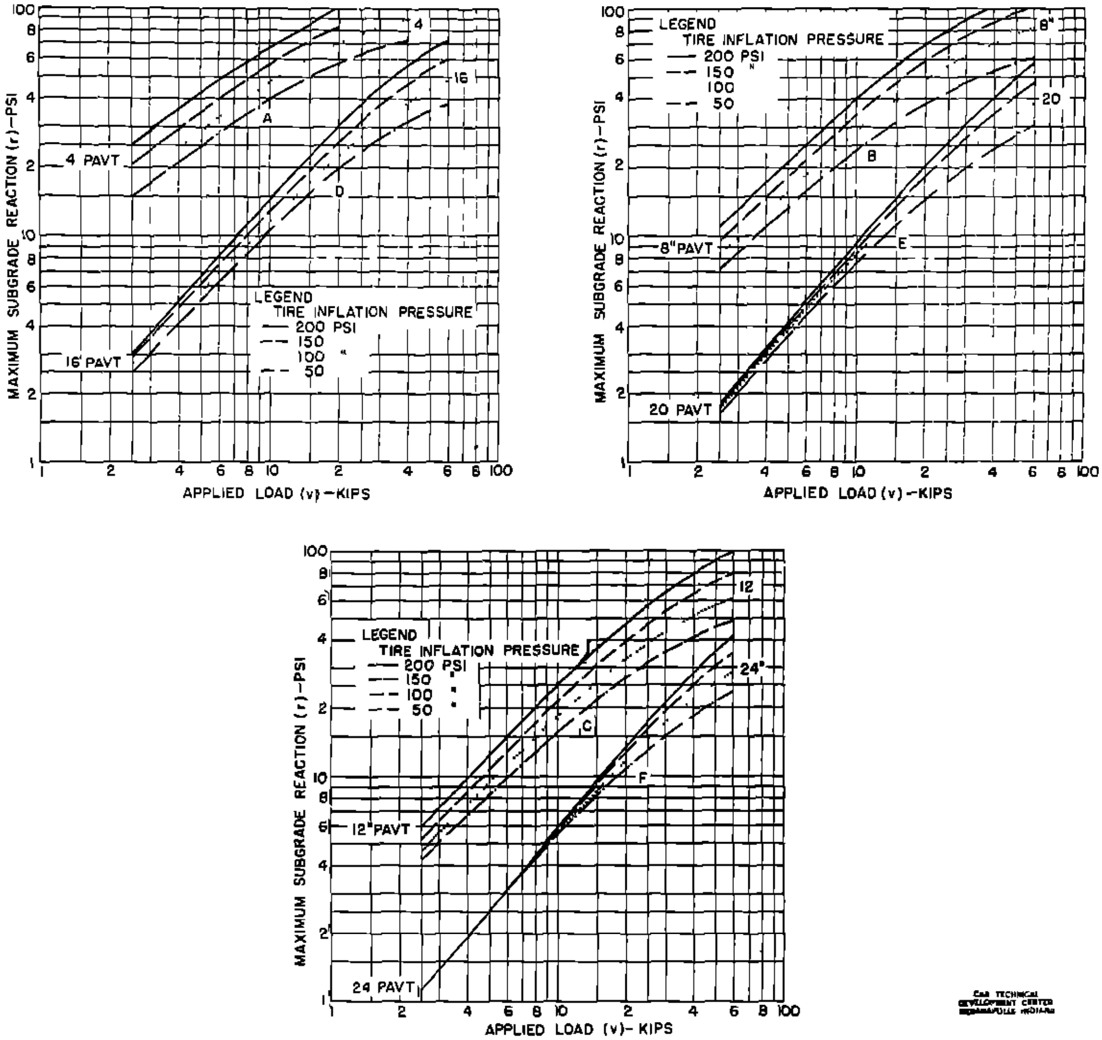

Fig 2 Maximum Subgrade Reaction Versus Applied Load for a Standard Gravel Pavement

If the answer obtained by the above process does not meet the design assumptions within desired limits, the pavement cross-section may be revised and the process repeated With a little practice, the desired value can be approximated closely on the first attempt While the procedures may appear rather complicated, the entire process actually can be completed in a few minutes

The over-all accuracy of the process was checked by comparing computed values with measured values of subgrade reaction for all of the 315 tests included in the analysis The comparison is shown graphically in Fig 5 Of the computed values, 46 per cent are within 5 per cent of those recorded in the tests, 71 per cent are within 10 per cent, and 96 per cent are within 20 per cent The median deviation is only 6 per cent This is remarkably low when one considers the wide variety of materials, the variable nature of the materials themselves, and the wide range of other variables included in the tests

Stress values predicted by this process may be used to check theoretical formulas, to check the shape and spacing of families of design curves, to extend empirical design methods into areas not covered by previous field experience, or to provide usable design data based on a limiting stress or deflection in the subgrade Such use presupposes knowledge of the strength and deflection characteristics of the subgrade, obtained by plate-bearing tests or assumed from other available data

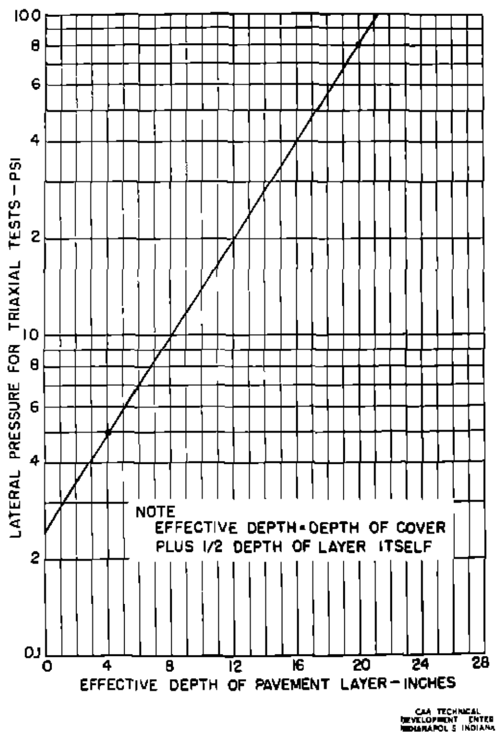

Fig 3 Determination of Lateral Pressure for Testing Triaxial Specimens

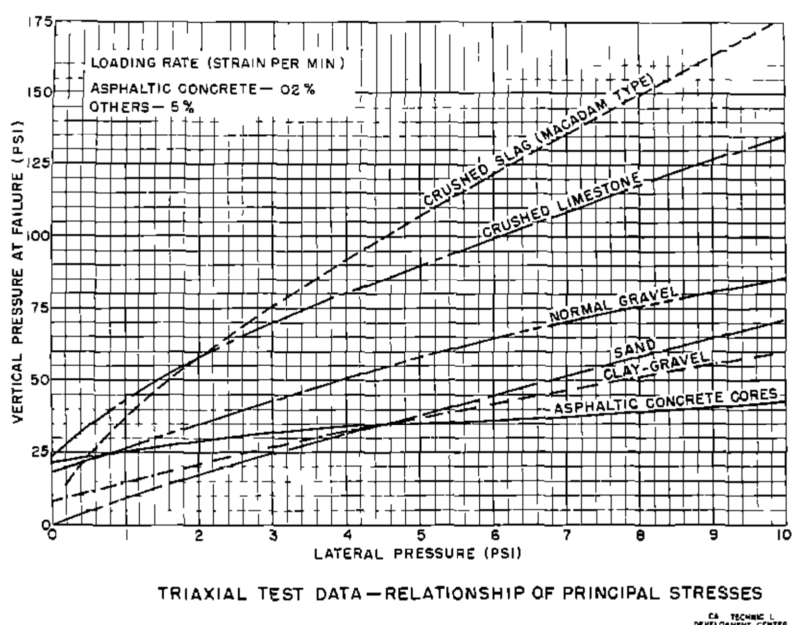

Fig 4 Triaxial Test Data, Relationship of Principal Stresses

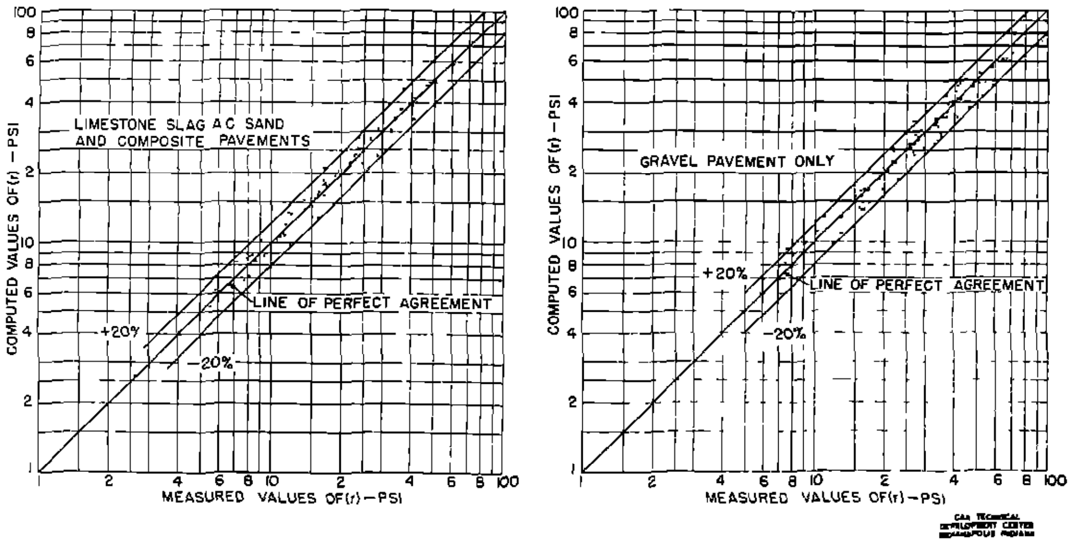

Fig 5 Measured Versus Computed Values of Maximum Subgrade Reaction

The effect of load repetition and the comparative effect of static and dynamic loads on various materials must be considered also. It may be possible to study the latter effect by performing triaxial tests on various materials over a wide range of loading rates. Some preliminary tests have indicated that asphaltic concrete is much more sensitive to rate of strain than are the granular materials This would be a decided advantage under dynamic tests of short duration

CONCLUSIONS

1. An analysis of results from 55 load-transmission test sections has resulted in a series of charts from which the relationship of subgrade reaction to applied load can be predicted accurately for a wide range of design conditions.
2. The effect of pavement quality can be measured quantitatively by triaxial tests
3. The effect of subgrade stiffness is measurable, but the available data are insufficient for complete analysis of this effect Use of the charts should be limited, therefore, to pavements supported by weak subgrades
4 As load-transmission tests involve single applications of static loads only, it is necessary to evaluate the effects of load repetition in selecting stress or deflection criteria for design The comparative effect of static and dynamic loads on various materials must be considered also