An Analysis of Hybla Valley Rigid Plate Bearing Data

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This paper presents an analysis of some 89 rigid plate bearing tests, on 26 different flexible pavement sections at the experimental test track at Hybla Valley, Va. The test data are those reported by Benkelman and Williams (1, Tables 4 and 7). The linear equation developed by W.S. Housel (2) is used in the analysis. Statistical results indicating the accuracy with which this linear equation reproduces the results of bearing capacity tests on different sizes of plates are presented. The analysis is carried to the point of determining the stress reactions developed by the flexible surfaces and the supporting subgrade; these results are presented graphically. Bearing capacity and resistance factors for different thicknesses of base and surface are compared. Use of a high-speed digital computer in this analysis is described. Also presented are methods of programming and a cost analysis.

●HRB Special Report 46 (1) contains data from rigid plate bearing tests carried out a the experimental test track at Hybla Valley, Va. Four different test procedures were employed; namely, the incremental, the incremental repetitional, the accelerated, and the repetitional.

The following analysis has been limited to the accelerated tests only. The data fro this test procedure were chosen because they provide a larger variety of pavement se tions, subjected to a wider range of loadings, than do the other test data. Furthermo this test series is the only one in which a uniform rate of loading was maintained thro out the series, permitting a valid comparison between load and settlement of different plate sizes and pavement thickness.

The symbols and abbreviations used in this paper are as follows:

- A = area of plates in square inches;
- B = thickness of stabilized aggregate base in inches;
- D = diameter of plates in inches;
- K_1 = settlement coefficient ($\frac{\Delta}{n}$);
- K_2 = stress reaction coefficient ($\frac{m}{n}$);
- m = perimeter shear in pounds per inch (pi);
- n = developed pressure in pounds per square inch (psi);
- P = perimeter in inches;
- p = unit load or bearing capacity in pounds per square inch (psi);
- t = total pavement thickness in inches;
- W = total load in pounds;
- Δ = deflection or settlement in inches;
- A.C. = thickness of asphaltic concrete in inches; and
- Rem. = removed.

The accelerated test procedure consists of two parts, designated as the increment portion and the accelerated portion. The first part provides for application and rele of three individual loads of increasing magnitude, the period of application or releas being maintained until the rate of movement slows down to 0.001 in. in 15 sec. Foll

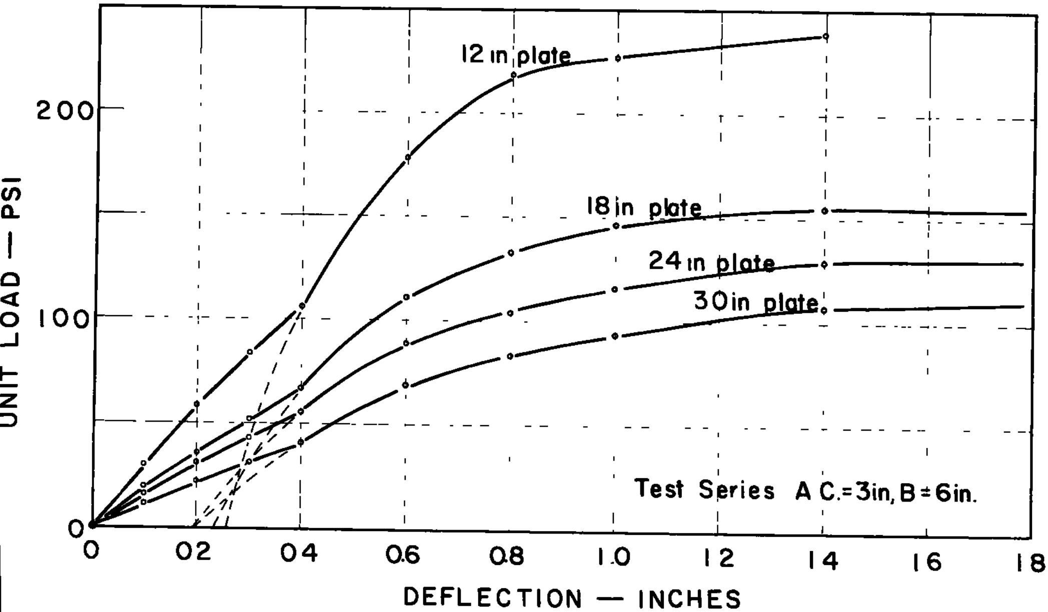

Figure 1. Load-deflection graph.

ng the release of the third load, the accelerated portion is carried out, providing for rate of vertical movement of the surface under a load applied at a settlement rate of .5 in. per min.

Figure 1 shows a typical load-deflection graph from the accelerated tests. As ex-ected, there is a definite discontinuity in the graph at 0.4-in. deflection, due to the hange in rate of loading.

THE LINEAR EQUATION

In Housel's perimeter-shear theory (3), the bearing capacity or intensity of load is xpressed by the following straight line equation for a given amount of deflection:

$$p = m \frac{P}{A} + n$$

which

p = unit load or bearing capacity;
m = perimeter shear, load per unit length;
n = developed pressure, load per unit area;
P = perimeter; and
A = area.

Figure 2 shows how a soil mass devels resistance to applied load in terms of rimeter shear, m, and developed presre, $n_1 + n_2$. It will be noted that all the d applied to the surface of the soil oinates within the plate area. Below the rface some of the load is then distribu- laterally as perimeter shear and the mainder transmitted directly down the tral column as developed pressure.

Previous investigations of plate loading

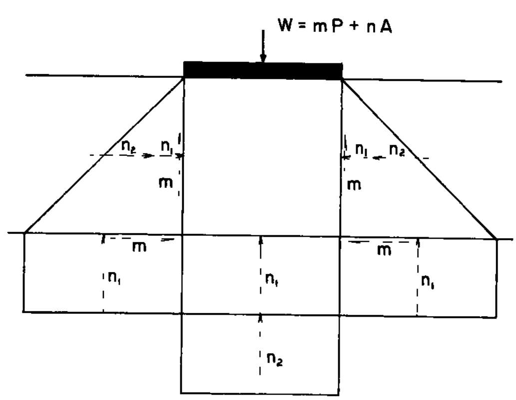

Figure 2. Stress reactions in cohesive soil.

tests have shown that the magnitude and sequence in which these stress reactions are developed varies widely, depending on the relative rigidity of the bearing plate and supporting elements of the soil mass. In the normal case the perimeter shear and developed pressure are mobilized simultaneously, with both having positive magnitudes throughout the entire range of load and settlement. In relatively compressible materials the perimeter shear reaches limiting values first and developed pressure, indicated by concentration of pressure in the central column, follows as the final limit of supporting capacity.

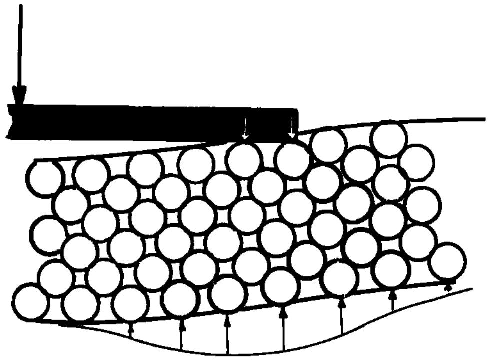

Figure 3. Pressure transmission through pavement.

In layered systems, such as a flexible pavement, it has been found that the sequence in which the two basic stress reactions are developed is the same, but that the rates at which they are mobilized are controlled by the relative rigidity of the bearing plates and supporting elements of the pavement structure and subgrade (4). As the load is applied, an elastic depression forms under the bearing area; rigid plates tend to bridge this depression (Fig. 3) where the transmission of pressure concentration at the edge of the plate through granular paving mixtures has been visualized in terms of arching action. Similar pressure distribution takes place through cohesive mixtures where shearing resistance is the basic reaction.

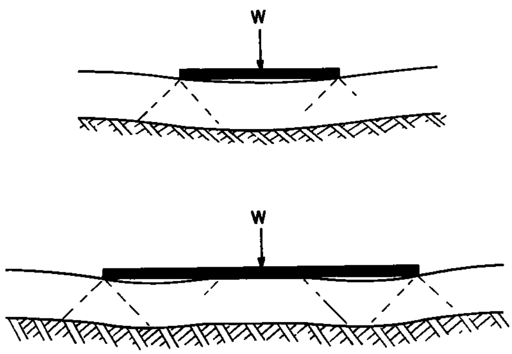

Figure 4. Deflection of pavement under various sizes of plates.

Pressure transmission through a flexible pavement structure is also influenced by the size and rigidity of the bearing plate (Fig. 4). In larger plates where pressure transmission from the perimete is limited in magnitude or angle of pressure transmission from affecting the central zone, direct transmission of pressur down the central column becomes a facto These variations in pressure transmissio must be included in the dimensional effec in plate loading tests and in their analysis in terms of the linear equation for bearin capacity.

The first question is whether or not it is possible to express the bearing capacity of flexible pavements by this linear equation. The second question is whether or not the stress reactions in this type of an alysis will reveal the significant structural behavior of flexible pavements, in spite o the variations which may occur in the sequence and magnitude of these reactions.

ANALYSIS OF DATA

As a first step in the analysis of the test data, it was decided to investigate how well the linear equation represented the relationship between the bearing pressures on the various plate sizes at a constant settlement.

In reviewing the typical load-deflection graph (Fig. 1), involving two different rat of loading, it was obvious that it would be necessary to treat the two portions of each load-deflection curve separately. To do this, it was necessary to estimate the no-lo deflection value for the two portions of each curve. Inasmuch as the primary objecti of loading tests is to determine the ultimate supporting capacity of the flexible pavements, further analysis was concentrated on the higher ranges of load and the initial

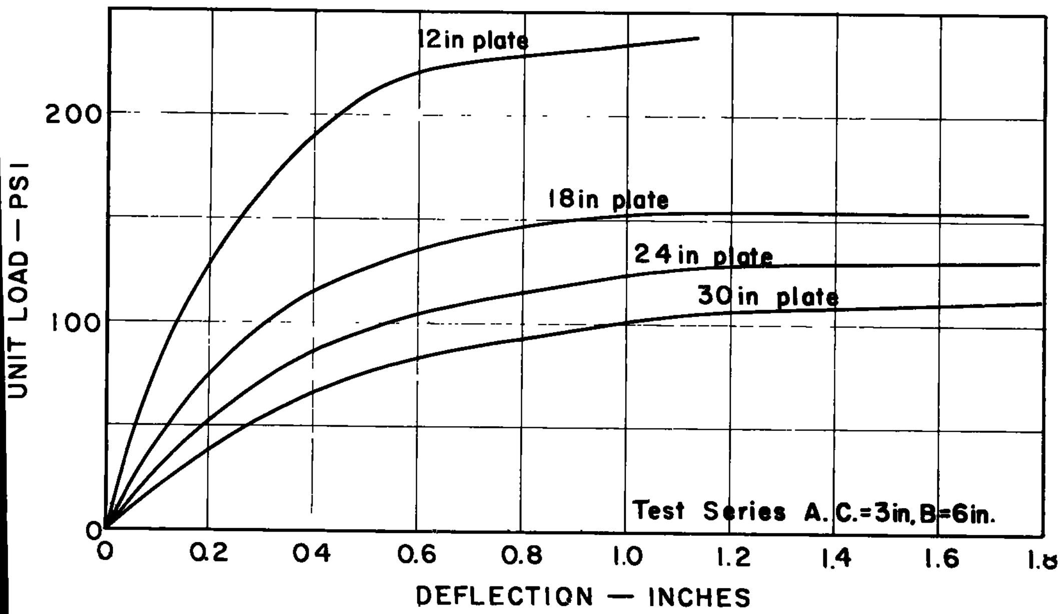

Figure 5. Adjusted load-deflection graph.

TABLE 1

COMBINATIONS OF PLATE SIZES TO WHICH THE LINEAR EQUATION WAS APPLIED

Pavement Sections	Plate Diameters (in.) 12-18-24-30	12-18-24	18-24-30
3-in. A.C. - 0-in. Base	X	X	X
3-in. A.C. - 6-in. Base	X	X	X
3-in. A.C. - 12-in. Base	X	X	X
3-in. A.C. - 18-in. Base	X	X	X
3-in. A.C. - 24-in. Base	X	X	X
6-in. A.C. - 0-in. Base	X	X	X
2-in. A.C. - 0-in. Base	X	X	X
6-in. A.C. - 6-in. Base		X	
6-in. A.C. - 12-in. Base		X	
6-in. A.C. - 18-in. Base			X
6-in. A.C. - 24-in. Base			X
9-in. A.C. - 6-in. Base		X	
9-in. A.C. - 12-in. Base		X	
9-in. A.C. - 18-in. Base			X
3-in. A.C. Rem. - 6-in. Base	X	X	X
3-in. A.C. Rem. - 12-in. Base	X	X	X
3-in. A.C. Rem. - 18-in. Base	X	X	X
3-in. A.C. Rem. - 24-in. Base	X	X	X
6-in. A.C. Rem. - 6-in. Base		X	
6-in. A.C. Rem. - 12-in. Base		X	
6-in. A.C. Rem. - 18-in. Base			X
6-in. A.C. Rem. - 24-in. Base			X
9-in. A.C. Rem. - 6-in. Base		X	
9-in. A.C. Rem. - 12-in. Base		X	
9-in. A.C. Rem. - 18-in. Base			X
9-in. A.C. Rem. - 24-in. Base			X

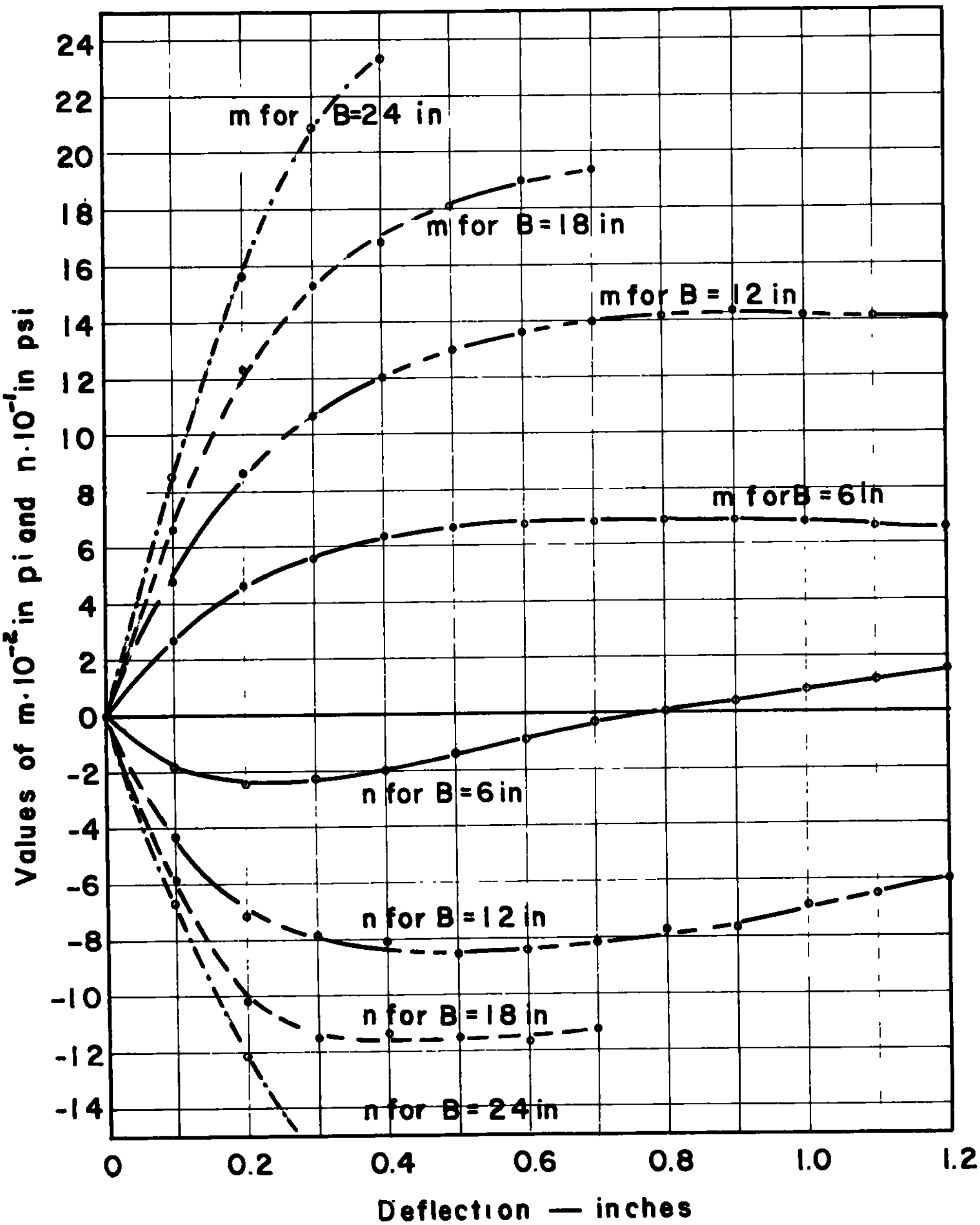

Figure 6. Values of m and n for 3-in. A.C. surface.

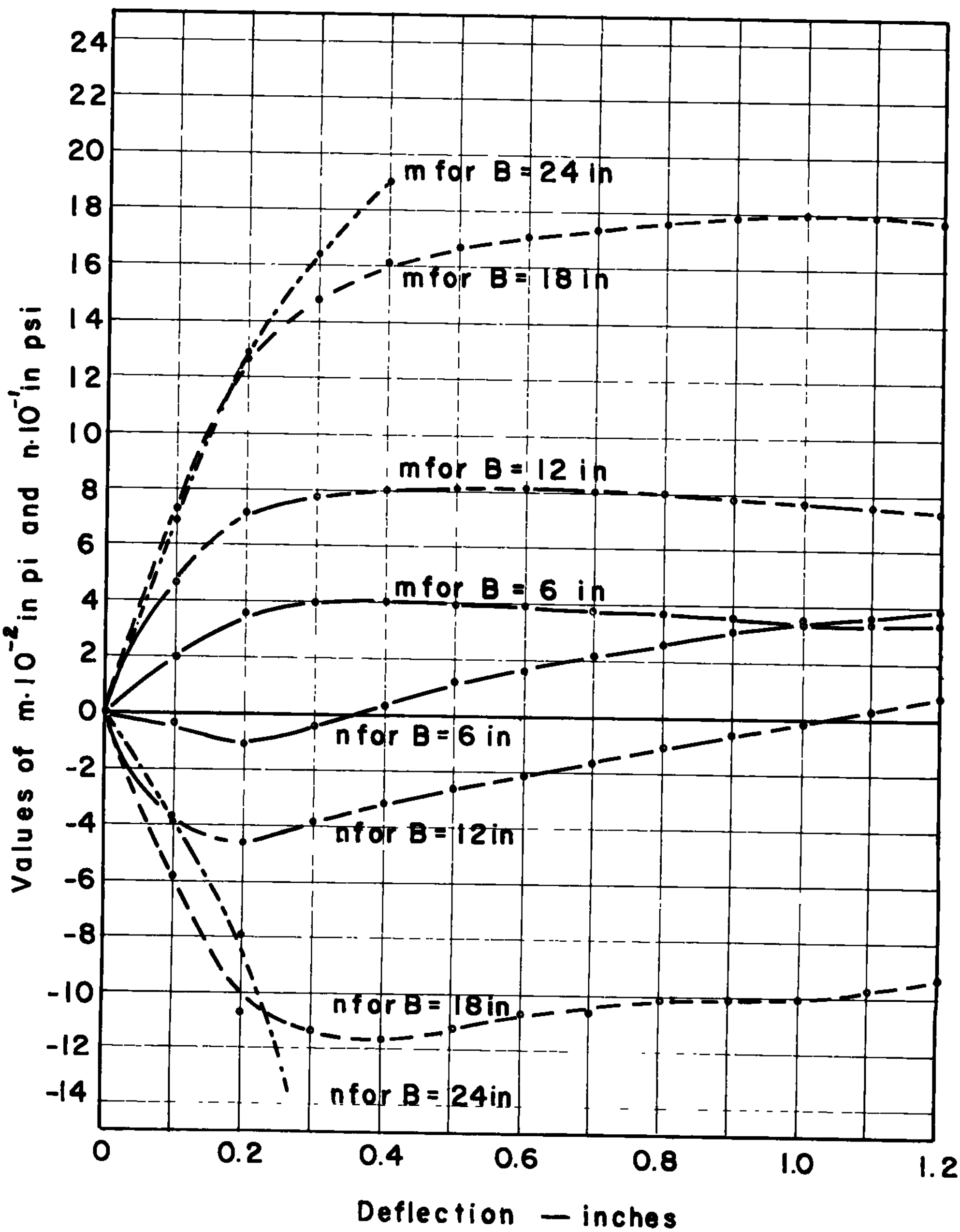

Figure 7. Values of m and n for 3-in. A.C. removed.

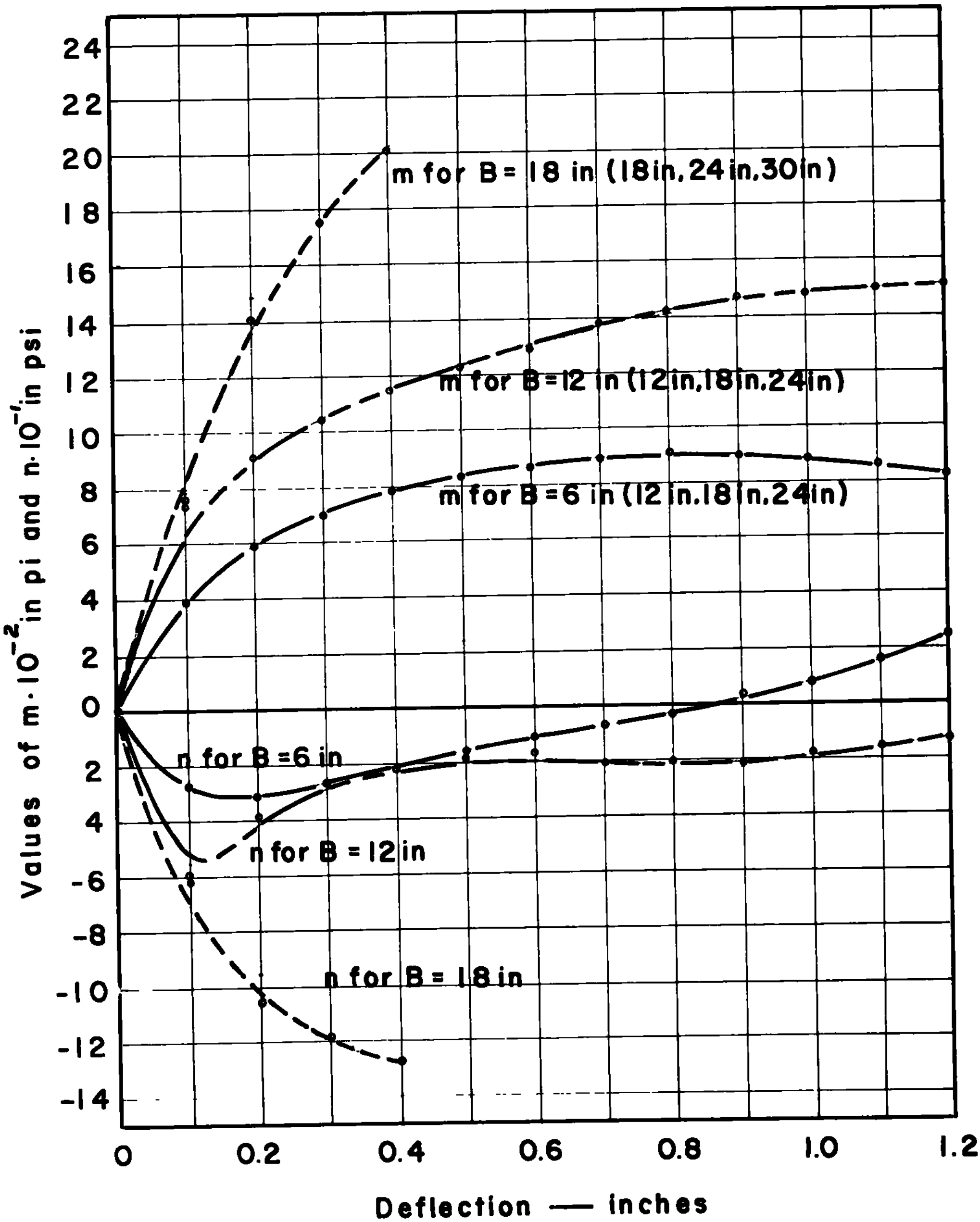

Figure 8. Values of m and n for 6-in. A.C. surface.

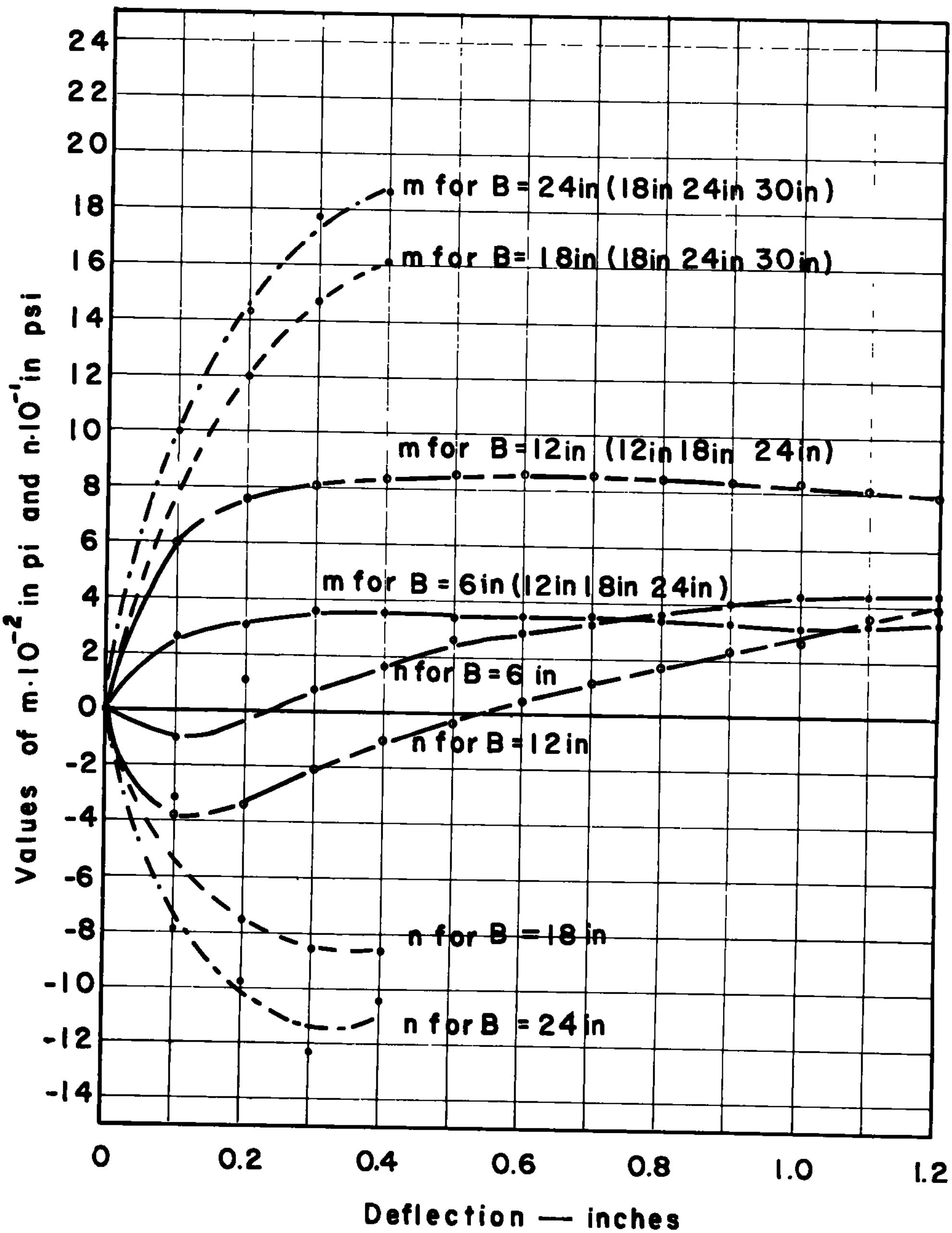

Figure 9. Values of m and n for 6-in. A.C. removed.

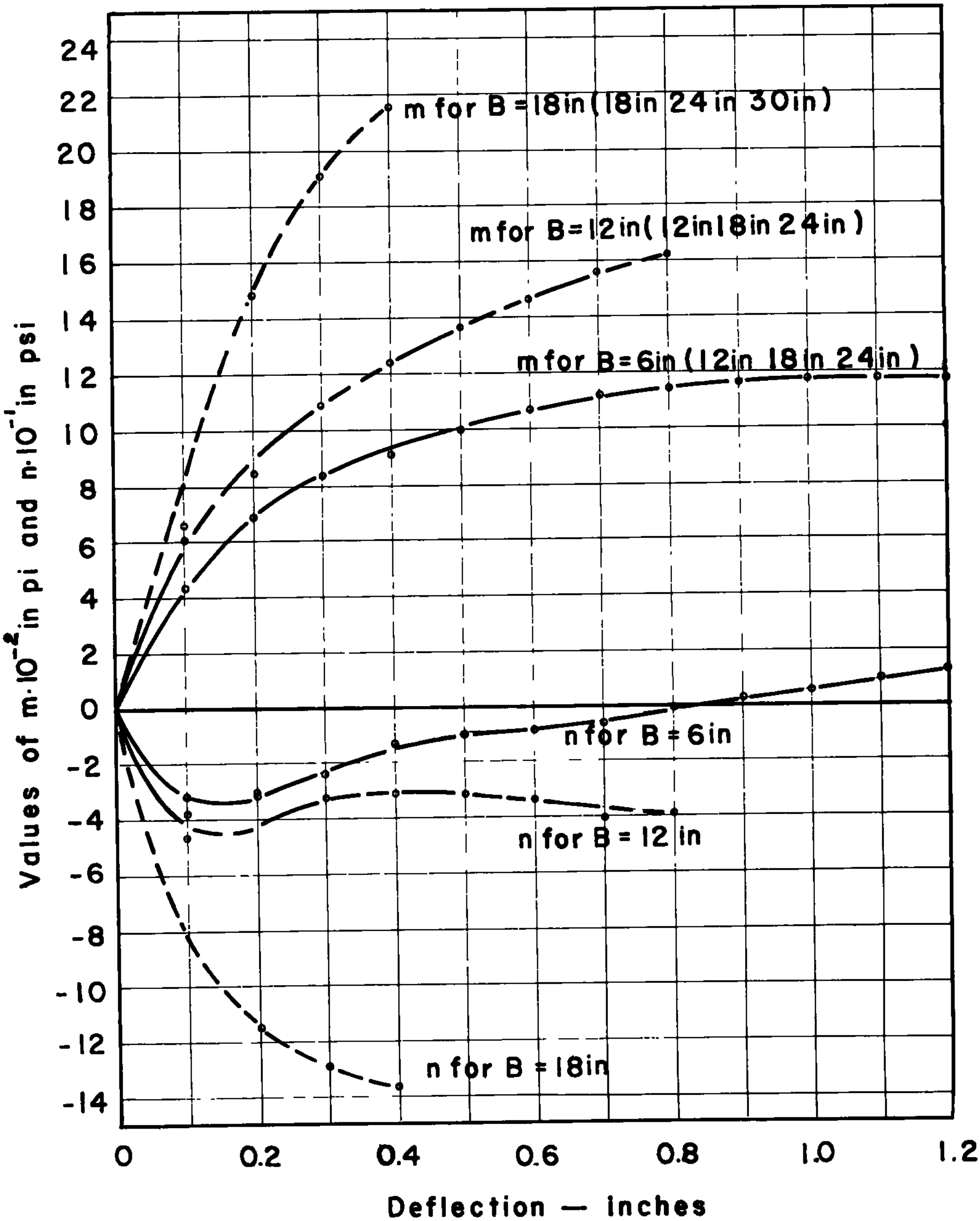

Figure 10. Values of m and n for 9-in. A.C. surface.

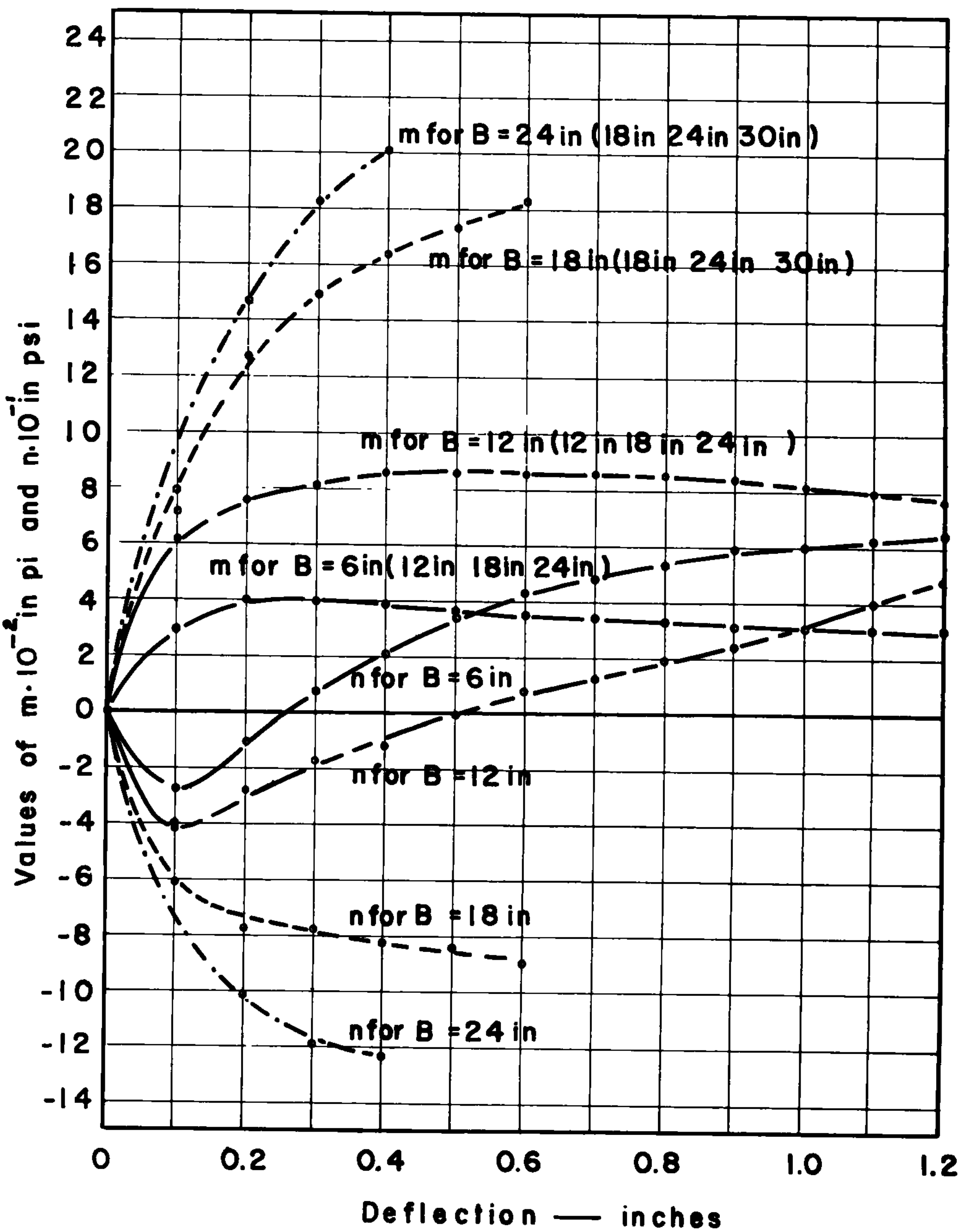

Figure 11. Values of m and n for 9-in. A.C. removed.

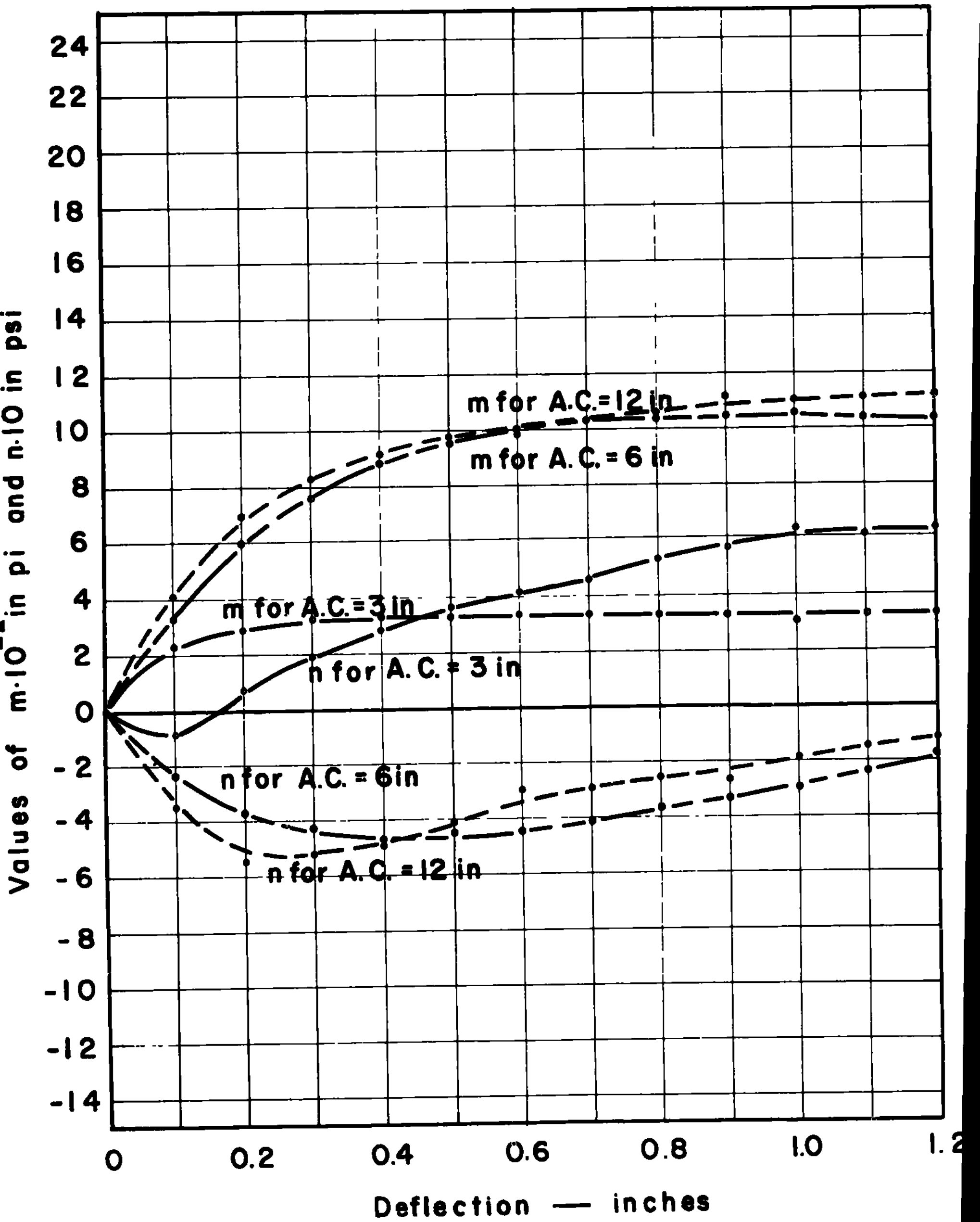

Figure 12. Values of m and n for variable A.C. surface and B = 0 in.

repetitive loading cycle of the accelerated test procedure was considered as a seating process for the accelerated loading which followed.

The no-load deflections for the second portion of the curves could be decided on, either by extending the upper part of the curves graphically down to the abscissa or by considering the permanent settlement of the pavement after release of the last repeti- ive load as the no-load deflection.

Values obtained by the second method were used throughout the analysis; but, in nost cases, both methods gave practically identical values.

In Figure 5 the load-deflection diagrams for the accelerated loading from Figure 1 ave been reproduced with a common origin, hereafter referred to as zero deflection.

When all the test data given in Table 4 and Table 7 of HRB Special Report 46 had een treated as explained previously, the linear equation was tested for its capability o express the bearing capacity for various plate sizes at constant deflection. The ethod of least squares was used to determine the constants, m and n, in the linear quation.

It was realized in the beginning of the analysis that it would be advantageous to use high-speed computer to carry out the numerical work. For this purpose, the author rote a program for the IBM 704 high-speed digital computer. Details of the pro- ram are explained in the Appendix.

The linear equation was applied to three or four plates according to the available ita for each pavement section. Table 1 gives all the pavement sections and plate zes analyzed together as indicated.

The values for the stress reactions, m and n, obtained from the foregoing analyses e plotted in Figures 6 through 12 for base course thicknesses shown on each curve. some cases, the values of m and n were obtained from three plates only, as indi- ted on the graphs. Values of m and n for the same thickness of asphaltic concrete rface but with varying base thickness are grouped together, except in Figure 12 ere results are shown from three pavement sections with varying thickness of as- altic concrete laid on the subgrade with no base course.

When the values of m and n in all test series had been obtained, the bearing capacity expressed by the linear equation was computed and compared to the measured values. viations of the computed bearing capacity were expressed as percentages of the easured values, and are presented in Figure 13 with percent of deviation as the ab- issa and the percentage of almost 2,000 cases as the ordinate.

DISCUSSION OF TEST RESULTS

As summarized in Figure 13, the agreement between the test results and bearing pacity at constant settlement computed by the linear equation is remarkably good. combinations of plate size and pavement thickness are represented in the statisti- analysis; and, without exception, fall within the narrow range of experimental er- shown. Ninety-two percent of all values fall within ± 5 percent, and 99.6 percent within the limits of ± 10 percent. Considering normal variations in construction ctice, such results also demonstrate the excellent quality control exercised in the ing and placement of paving materials and in subgrade preparation.

The data speak for themselves in answer to the first question, the validity of the ear equation as a measure of the variation in bearing capacity with the size of load- areas in the case of flexible pavements. The second question, whether or not the ess reactions in this equation can be broken down into factors which reflect signifi- t variations in the structural behavior of flexible pavements, is much more involved. A review of the data in Figures 6 through 12 brings out several strong trends which consistent throughout the entire test series. Nevertheless, the complete interpre- on of these stress reactions has proved to be peculiarly complex. In all cases, e is a large increase in the perimeter shear, m, as the pavement thickness is in- sed. This is perhaps quite obvious and could be anticipated. However, the mag- de of this increase is surprising and leads to other variations more difficult to ex- n.

TYPICAL LINEAR EQUATIONS

Figure 14 shows a set of linear equations for a typical test series for deflections of 0.2, 0.78, and 1.2 in. The plotted points show the accuracy with which the linear equation for bearing capacity reproduces the test results, illustrative of the data in Figure 13 for the entire series of tests. At the lowest deflection, 0.2 in., the bearing capacity is negative for the larger sizes of plates. This indicates that the larger plates will not develop positive supporting capacity until the pavement deflection or settlement exceeds that amount. Intercepts on the vertical axis give the values of developed pressure, n, at the indicated settlements. Negative values of n in the lower settlement

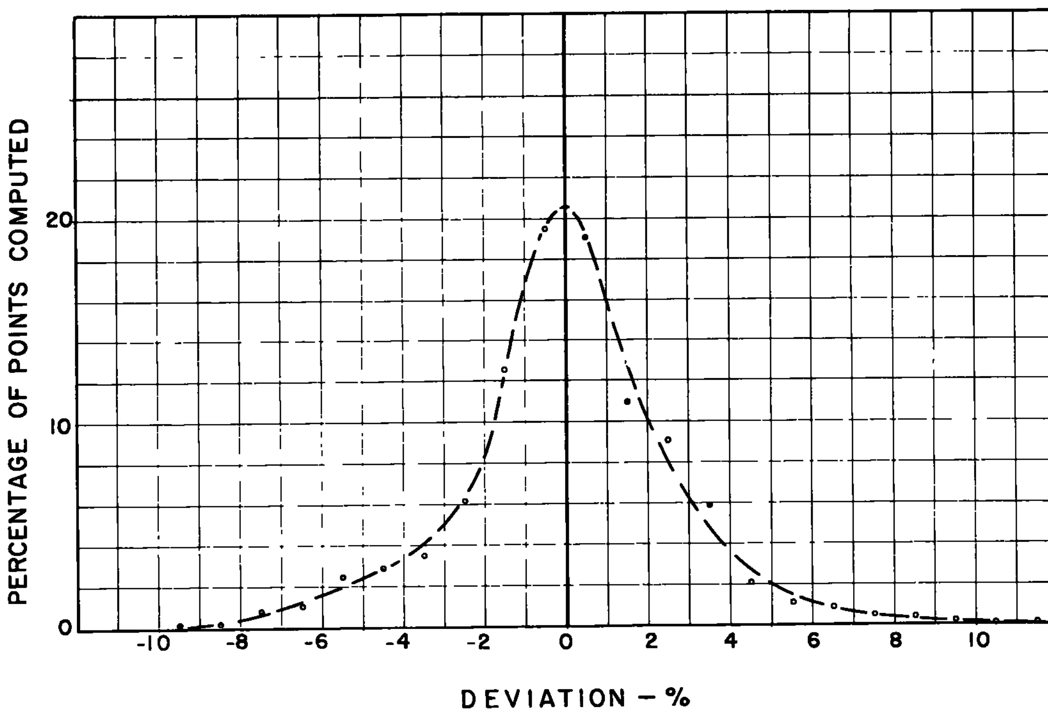

Figure 13. Percentage deviation of computed and observed bearing capacity.

range show that in this range the pressure is not being transmitted directly to the sub grade over the entire bearing plate. Such negative values of n are associated with hi values of perimeter shear, m, represented by the steeper slope of the straight lines Figure 14.

This variation in the stress reactions, m and n, shows that applied loads in the lo er range of settlement are being carried by pressure concentration at the edge of the bearing plates. This pressure concentration is then transmitted through the flexible pavement to the subgrade, where a substantial part of the perimeter shear will have been converted into developed pressure over the central column. Such results are n new, having been reported previously with partial explanations offered (4). Factors believed to produce these results have been shown in Figures 3 and 4 and discussed i a preliminary way. However, it is the quantitative evaluation of these reactions that presents the difficult problem that has yet to be resolved.

The relation between load, settlement, and size of bearing area has been formula in more general terms involving two soil resistance coefficients, K_1 and K_2 (3). The settlement coefficient, K_1, has been defined as the ratio of settlement, Δ, divided b developed pressure, n ($K_1 = \Delta / n$). This coefficient is analogous to the conventional

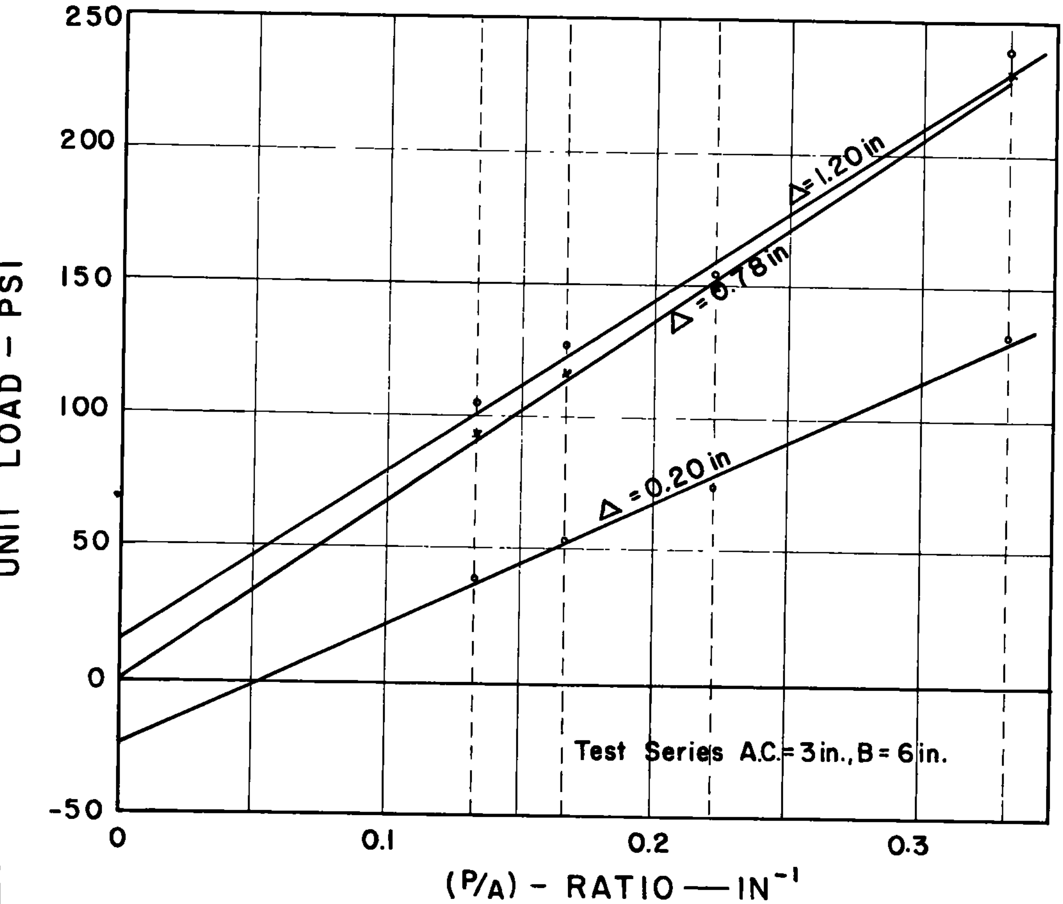

Figure 14. Typical linear equations.

oefficient of compressibility. The stress reaction coefficient, K_2, has been defined s the ratio of perimeter shear, m, divided by developed pressure, n (K_2 = m/n). K_2 ives the relative magnitude of these two types of resistance at any specified settle-ent.

Maximum and minimum values of the soil resistance coefficients, K_1 and K_2, have een identified as measures of the bearing capacity limit of supporting masses in terms static resistance. As shown in Figure 15, such maximum and minimum values oc-ır in tests on flexible surfaces when the developed pressure, n, is equal to zero. hen encountered in previous tests, another method of identifying the static resistance mit was available for confirmation. This confirmation was provided by extrapolating tes of settlement for various loads to obtain the yield value or load at which progres-ve settlement was zero. Incremental loading at constant time intervals was not used the Hybla Valley tests, hence this demonstrated procedure is not available.

In passing, it may be noted that the ultimate capacity of these surfaces is such that e total loads employed in the investigation provided only a limited range of pavement flection which was not sufficient to reach limiting values of the variables involved. ttlement for the 24-in. pavement thickness seldom exceeded 0.4 in., and most of e tests for the 18-in. pavement are also limited in the settlement range. Several sts on the 24-in. base thickness have been omitted as there were only one or two ints on the load-settlement diagrams, not enough to justify plotting.

The present tests produce the largest volume of comprehensive data confirming ese more complex variations that has yet been available for study; the factual na-

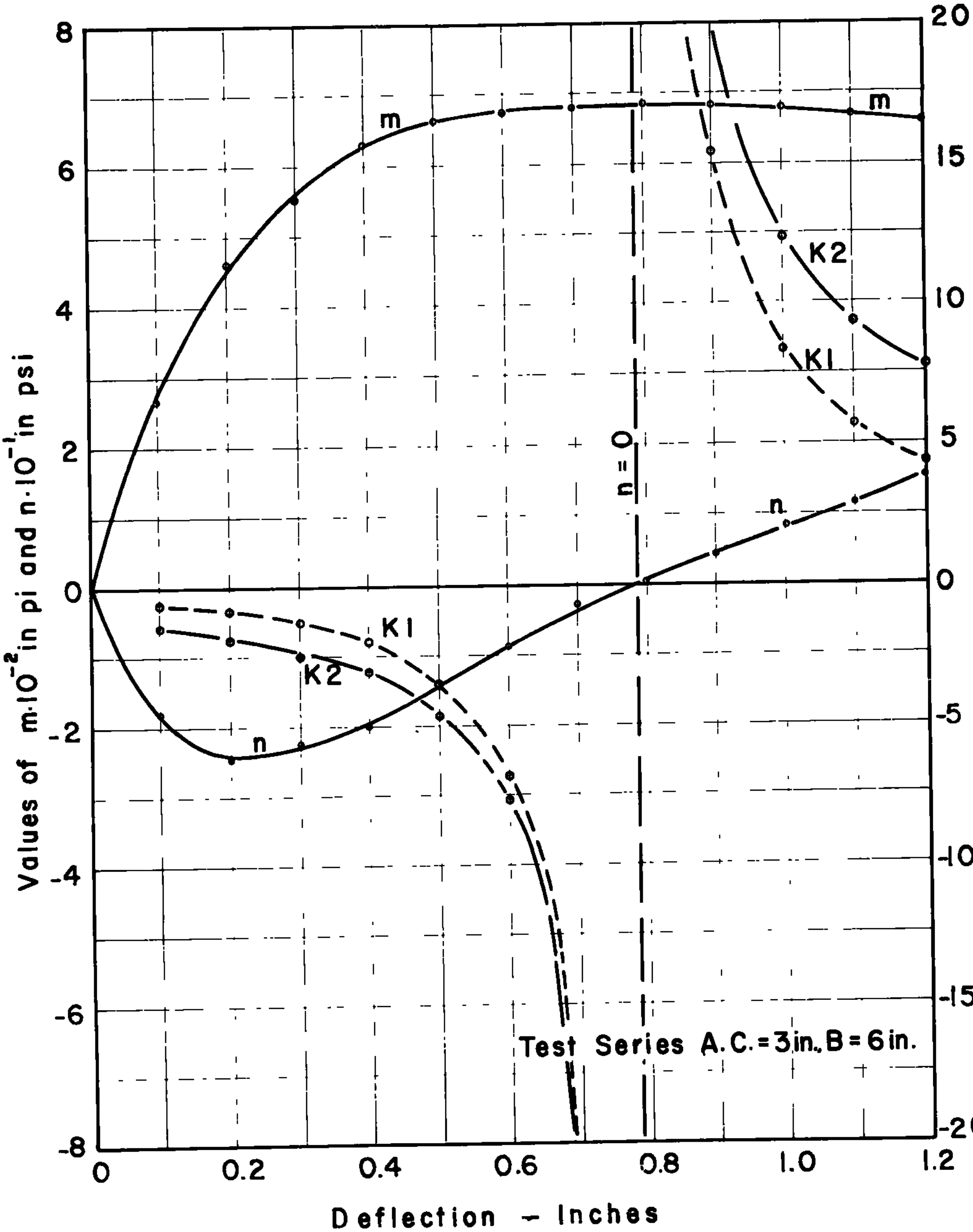

Figure 15. Soil resistance coefficients.

ture of these data cannot be passed over lightly. The extended range over which nega tive values of developed pressure occur is surprising and this, too, is a consistent r sult in all test series. In only a limited number of the tests has the loading been suf- ficient to produce a zero value of n, previously identified as the limit of static resis- tance in the pavement structure. However, there are a sufficient number of tests ca ried to and beyond this critical range to provide a fairly adequate basis for further a alysis.

It is hoped that such further study may throw some light on the source and charac of these secondary effects. One possible approach that might be helpful is the non-dimensional analysis presented by Kondner and Krizek (5). It is hoped that these investigators may follow up this suggestion and see what their analysis might contribute to a solution of the problem. Housel has been following the author's work on the analysis of the loading tests from Hybla Valley, and presents a written discussion hereinafter. Perhaps others may come forward with other methods of analyzing these tests. The volume of data made available and the care with which it has been gathered have not been achieved in any previous investigation. Furthermore, the consistent variation in the stress reactions developed certainly justifies much more study on such an important problem in the design of a flexible pavement, the structural action of which is still quantitatively indeterminate in terms of the mechanics involved.

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Appendix

USE OF HIGH-SPEED DIGITAL COMPUTERS

It may be assumed that in the near future there will be a very substantial increase n the use of high-speed digital computers in practically every field of engineering. roblems involving time-consuming computations, which are repeated over and over gain, are particularly adaptable to the use of high-speed computers.

Because the analysis of plate load bearing tests is at least partly this type of probem, the author took advantage of this opportunity and wrote a program which would ermit the use of a digital computer in carrying out the bulk of the numerical work.

A simplified flow-diagram which could be used for the evaluation of the stress reltions, m and n from a set of data is shown in Figure 16. The flow-diagram is a raphical representation of the sequence of operations required to solve the problem question. It is absolutely independent of the computer or computer language used, it serves as a guide when one wishes to write a detailed program for a computer. or those not acquainted with this representation, it may be helpful if the two symbols " and "=" are defined. The symbol ":" means "Compare the variable on the left to e one on the right and choose between greater than (>) or less than (<), as inditted." The symbol "=" means "Make the value of the variable on the left equal to e current values of the terms on the right."

The IBM 704 computer which was available is a large-scale computer which emoys a special user's language called MAD, the Michigan Algorithm Decoder. The ogram was written in such a manner that it would be required only to feed the comter with the very minimum of information necessary to carry out the computations; d, when completed, the results would be printed or plotted in the most convenient rm.

Figure 17 shows a part of a data-deck which was used in this program. The first rd contains a title to be printed with the results. This may be any phrase the user ooses, containing no more than 80 letters and blanks. The second card contains me information pertaining to the computations themselves. The word "ROUND" inates that the plates used are round, and could be replaced by "SQUARE" or "RECNGLE." "DIMENSIONS" tells that the size of each plate is given in terms of dieter or sides, rather than "AREA." The next three numbers indicate the number

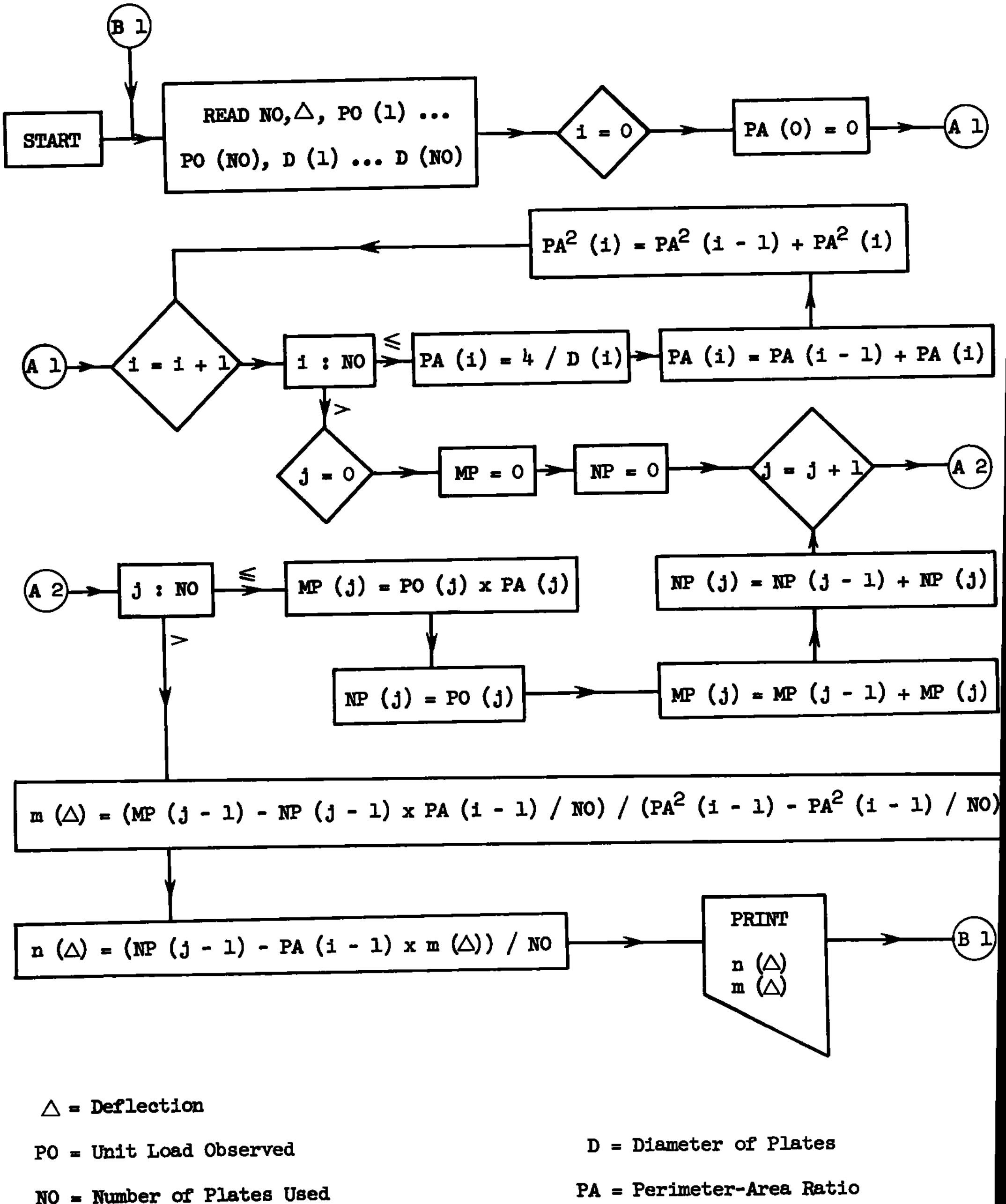

Figure 16. Flow diagram for solution of stress reactions m and n.

of plates used, the number of deflection points to be computed, and the thickness of flexible pavement, respectively. "NO" means that it is not desired to call in the plot routine to produce a graphical representation of the results. The last two words indicate the units used. The third card gives the plate sizes, and the observed data are listed on the following cards. The data are listed as the value of deflection followed by the unit pressure for each plate; for example, at 0.1-in. deflection, 63 psi, 42 psi, and 31 psi, for the 12-, 18-, and 24-in. plates, respectively. If the next test

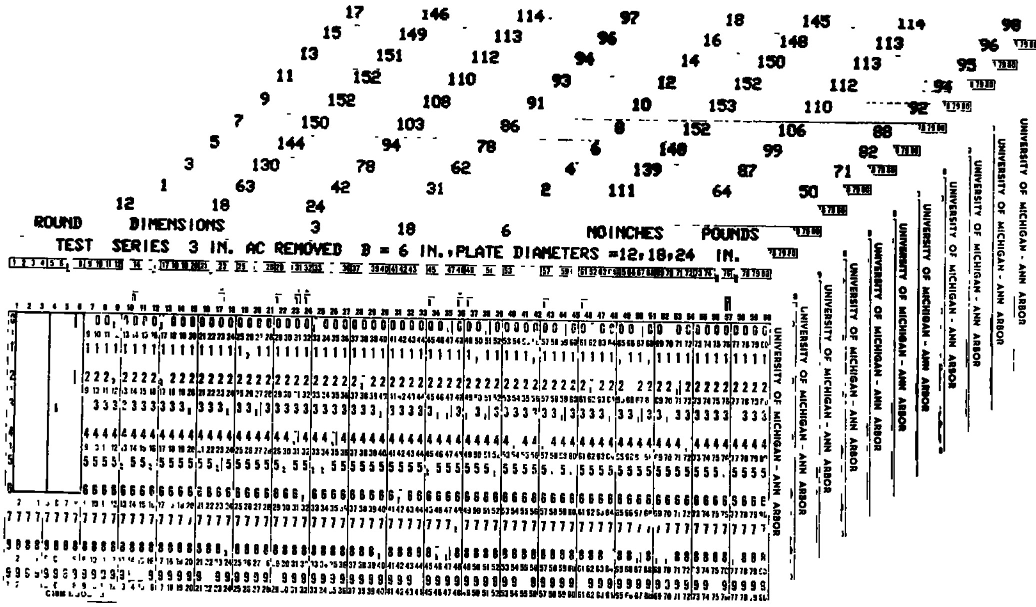

Figure 17. Example of input deck.

eries in the deck were for the same sizes of plates, the word "ROUND" could be re-laced by "SAME" which would prevent unnecessary duplication of computations al-eady carried out for the preceding test series.

Figure 18 shows a typical page of printed output. Although an example of the plot-ed output is not available, this system includes a plot-routine which is capable of reparing graphs and plotting results at the rate of 400 points in a full-page graph in bout 2.5 sec.

It is not intended to list the complete program here. It is felt, however, that some arts of the program should be reproduced to indicate how the MAD language and other imilar languages are being developed to make the use of digital computers more ac-essible to a person who is not in a position to spend the time and energy to study the etails of the internal functions of the computer. It may be said today that learning write programs in the MAD language (that is, learning to use the computer) is an-logous to learning to drive an automobile. One may perfect the former technique ithout acquiring much knowledge of computers themselves.

A very powerful statement in the MAD language is the "WHENEVER-Statement." o demonstrate this, reference is made to the input cards shown in Figure 17. De-nding on the first and second words on Card 2, it is possible to deduce the P/A tio in various ways. For round and square plates, this may be as follows:

```
WHENEVER SHAPE .E. $ SQUARE $. .AND. SIZE .E. $ AREAS $
PERARE (J) = 4. / SQRT. (TEMP (I))
OR WHENEVER SHAPE .E. $ ROUND $. .AND. SIZE .E. $ AREAS $
PERARE (J) = 2. / SQRT. (TEMP (I) / 3.14)
OTHERWISE
PERARE (J) = 4. / TEMP (I)
END OF CONDITIONAL
```

Most of the abbreviations used in the above sequence are self-explanatory. "TEMP

ANALYSIS OF PLATE BEARING TEST DATA

TEST SERIES 3 IN. AC REMOVED B = 6 IN., PLATE DIAMETERS = 12, 18, 24 IN.

SETTLEMENT DELTA	OBSERVED PRESSURE	COMPUTED PRESSURE	PERCENTAGE DIFFERENCE	PERIMETER SHEAR M	DEVELOPED PRESSURE N	M * P/A	K 1 DELTA/N	K 2 M/N
INCHES	P./SQ.I.	P./SQ.I.		P./I.	P./SQ.I.	P./SQ.I.	CU.I./P.	I.
0.1	63.00	63.07	-0.11	191.57	-0.79	63.86	-0.12727	-243.819
	42.00	41.79	0.51			42.57		
	31.00	31.14	-0.46			31.93		
0.2	111.00	109.64	1.22	374.14	-15.07	124.71	-0.01327	-24.825
	64.00	68.07	-6.36			83.14		
	50.00	47.29	5.43			62 36		
0.3	130.00	128.57	1.10	416.57	-10.29	138.86	-0.02917	-40.500
	78.00	82.29	-5.49			92.57		
	62.00	59.14	4.61			69.43		
0.4	139.00	137.57	1.03	416.57	-1.29	138.86	-0.31111	-324.002
	87.00	91.29	-4.93			92.57		
	71.00	68.14	4.02			69.43		
0.5	144.00	142.71	0.89	403.71	8.14	134.57	0.06140	49.579
	94.00	97.86	-4.10			89.71		
	78.00	75.43	3.30			67.29		
0.6	148.00	146.93	0.72	402.43	12.79	134.14	0.04693	31.475
	99.00	102.21	-3.25			89.43		
	82.00	79.86	2.6[illegible]			67.07		
0.7	150.00	149.07	0.62	389.57	19.21	129.86	0.03643	20.275
	103.00	105.79	-2.70			86.57		
	86.00	84.14	2.16			64.93		

Figure 18. Example of printed output.

(I)" is a location in the memory of the computer where "AREAS" or "DIMENS" are stored. ".E." means "same as."

Another very interesting statement is the "THROUGH-Statement." An example of this follows:

```
   THROUGH D, FOR PLATE = 1,1, PLATE .G. PLNUMB
   SHEAR (SET, PLATE) = M (SET) PERARE (PLATE)
   COMPPR (SET, PLATE) = SHEAR (SET, PLATE) + N (SET)
   DIFFER (SET, PLATE) = (DEPRES (SET, PLATE + 1) - COMPPR
                              (SET, PLATE))
D  PERCT (SET, PLATE) = DIFFER (SET, PLATE) 100. / (DEPRES
                              (SET, PLATE + 1))
```

The first instruction would sound like this in plain English: "Go through all computations up to and including those in Line D; first, by putting the parameter "PLAT = 1," then, next time, by putting "PLATE = 1 + 1," and so on until "PLATE" is grea er than "PLNUMB"."

The parameter "SET" stands for the deflection point being computed; that is, first, second, and so on. "M (SET)" and "N (SET)" are the constants m and n in Housel's linear equation. "COMPPR (SET, PLATE)" stands for computed pressure or bearing capacity, and "DEPRES (SET, PLATE + 1)" for observed bearing capacity. "(DEPRES (SET, 1))" stands for the amount of deflection, and "PLNUMB" is the number of plates used.

Any equality can be written in practically the same way one would when carrying out computations by hand. For example, if the stress coefficient K_1 referred to in this paper is to be computed, it is required only to add one instruction to the program.

$$K_1 \text{ (SET)} = \text{DEPRES (SET, 1)} / \text{N (SET)}$$

It should be clear from this that programming in MAD is not a very difficult task. Input and output instructions can, however, be tedious; but, by no means hard to understand.

The reader may be interested in getting an idea of the cost of carrying out the computations in this program.

Once the program has been written, the only requirement for processing data is to punch the data on cards, as shown in Figure 17. The punching is comparable to typewriting; hence, it would be difficult to give any definite figures as to how many cards one could expect to finish in a given time. This, however, would never be a very costly operation.

As an example of the cost of using the computer, it was found that the completion of 20 pages of output, as shown in Figure 18, took 1.6 min. The computer charges are $5,00 per min, and the foregoing would thus be about $8.00.

The time consumed in writing and testing the program itself was, in this case, the major factor. However, if it were found desirable to use it for substantial computations, the cost of programming would eventually be negligible.

One great advantage of the computer program is that it becomes easy and inexpensive to test out new theories and formulas which might be applicable to the program in question. Changes in the program itself are easy to make because instructions can be added or removed as required without changing the output and input to any great extent.

This example of the use of a high-speed digital computer has been included here for the reader who is not well acquainted with this powerful tool and who might be able to benefit from its use. It may be emphasized that it is not necessary to know the mechanical details of the computer itself to be able to use it, but merely to learn a relatively straightforward set of instructions such as those illustrated.

Discussion

.S. HOUSEL, Professor of Civil Engineering, University of Michigan, and Research onsultant, Michigan State Highway Department—The writer has spent some time in an tempt to interpret the stress reactions developed in the Hybla Valley tests in the antitative terms of the linear equation for bearing capacity used by the author, witht coming to a final conclusion. This discussion will consequently be devoted to raisg several questions yet to be answered and commenting on certain aspects of the ructural behavior of flexible pavements.

Statistically, the linear equation reproduces the measured results of all the tests volved within a very narrow range of experimental error. Satisfying this test of lidity does not reveal, in terms of structural behavior of the pavement structures, l of the factors which contribute to the surprisingly high values of perimeter shear, e inability of rigid plates to transmit direct pressure over the contact area, and the normally high deflections at which the full supporting capacity of the pavement structe is developed.

The fact that the maximum and minimum values of soil resistance coefficients deved from the linear equation for bearing capacity do determine the upper limit of tic resistance or bearing capacity of the entire system has been demonstrated a mber of times in the design of building foundations (1, 2). This relation has been confirmed in previous rigid plate bearing tests on flexible pavements (3, 4). If this principle is applied to the Hybla Valley tests, the limit of supporting capacity is not reached until the deflection is much higher than the range of thousandths of an inch normally considered in current practice. For example, in Figure 15 the critical deflection at a developed pressure of n = 0 is reached at approximately 0.8 in. for a total pavement thickness of 9 in. As shown in Figure 6, the same limits are not even reached in the Hybla Valley tests and would be at deflections considerably greater than 1 in.

Determining the source of these abnormally high deflections and correspondingly high values of perimeter shear is peculiarly perplexing. One may surmise that one possible source is in the permanent deformation due to yielding at the edges of the plate under the high pressure concentration along these edges. The increase in the critical deflection with increased thickness of base course suggests that consolidation or stress conditioning of the base courses is another potential source. Similar permanent deformation in the subgrade is another possible source that cannot be neglected If the high deflections originate from these sources rather than in shearing displacement, it is important to recognize that the pavement structures will improve with time and load applications in service and that this greater range of available supporting capacity may eventually be mobilized. Either that or the sources of permanent deformation must be eliminated by greater initial compaction or the pavement must be designed with greater flexibility in order to develop this supporting capacity more effectively

In this respect, current pavement design in this country may be penalizing itself by continued use of design criteria based on the elastic properties of rigid solids in which the assumed proportionality between total load and deflection takes precedence over th relationship between applied pressure and subgrade bearing capacity in plastic support ing media to which the linear equation for bearing capacity applies.

Rigidity and strength under the conditions of pavement performance are not synonymous. Rigidity carries with it susceptibility to fracture and the weakness of brittle failures. The objective of pavement design should be to build flexible strength or controlled flexibility into pavement structures. For most efficient performance, relative rigidity of the pavement components should be reduced to a minimum. Rigid pavemen surfaces should be made more flexible or the supporting elements of base and subgrad made more rigid. Flexible pavements have the advantage of mobilizing available subgrade support more effectively. There should be no prejudice against larger deflections as long as the yield value of the supporting subgrade or other pavement components is not exceeded and the structural continuity and riding quality of the pavement itself is not impaired.

This design philosophy calls for a rather definite reorientation of the current design practice which relies on proportionality between total load and deflection and relationships developed from the concept of a rigid pavement. It might be remarked tha one seldom sees steel wheels on a tea wagon; if there were, it might be as damaging to polished floors of hardwood and tile as the pinpoint heels of current ladies' shoes are to bituminous surfaces.

In this same connection, much of the difficulty with the analysis of rigid plate bear ing tests may be in their relative rigidity and the secondary dimensional effects whicl they induce. These effects appear to mask the basic supporting capacity which the tests attempt to measure.

One method of eliminating this difficulty would be to make such tests with flexible bearing areas more nearly comparable to pneumatic tires. This procedure has been given some previous attention but has not yet supplanted the more common use of rig id plates adapted from foundation practice (5). Insofar as the writer is concerned, the attempt to unscramble the dimensional factors involved in perimeter shear and negative values of developed pressure has not been abandoned. There are some pron ising possibilities not completely explored, but any further progress in this directio must await further study.

In conclusion, it seems pertinent to make note of some European practices in pav ment design. By taking advantage of more liberal use of highly compacted granular subbases and structural continuity supplied by prestressing and hydraulic compressi units installed in the pavement base, surprising results are being obtained. In this connection, it has been reported that concrete pavements 3.5 to 7 in. thick are being generally built. One such pavement in Switzerland was reported to have been in service for several years under heavy traffic without having developed any cracks in some miles of pavement. These are practical accomplishments to which pavement designers in this country should be alert if they wish to keep abreast of the continued developments in pavement design.

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