MICHIGAN
STATE HIGHWAY DEPARTMENT
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PROGRESS REPORT ON LOAD DEFLECTION TESTS DEALING WITH LENGTH AND SIZE OF DOWELS

By

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TABLE OF CONTENTS

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In 1934 the Michigan State Highway Department became vitally interested in the problem of evaluating load transfer devices and established a comprehensive investigation on this subject. The primary object of the investigation was to develop a test method for evaluating load transfer devices to the end that a definite specification for the selection and use of load transfer devices could be developed. Progress reports on the results of this work so far have been published previously in the proceedings of the Highway Research Board (1) (2)*.

There is unquestionably a great need at the present time for such a test procedure because of the continual appearance on the market of new mechanical load transfer devices to replace the common dowel bar and also because it is imperative that we know the mechanical and physical characteristics of all types of load transfer devices and can predict with reasonable accuracy the performance of such devices under continual service, in order that they can be intelligently designed and properly spaced in a pavement joint.

The purpose of this paper is to present the results of a phase of this investigation on the evaluation of load transfer devices dealing specifically with the development of a load deflection test procedure and its use in studying the mechanical characteristics and efficiency of different types of load transfer devices, especially in respect to the length and diameter of dowel bars.

(*) See bibliography

The study involved the subjection of common dowel bars of different lengths and diameters embedded in concrete blocks to shear forces of varying magnitudes and measuring the relative vertical deflection of the block faces. The opening between the blocks being held constant at 1 inch and 1/2 inch. Three diameters of dowels used were 3/4, 1 and 1-1/4 inches. Lengths of 10, 15, 20, 24 and 30 inches were included for each dowel diameter. Residual deflections under repeated loads were observed and a measure of load transfer unit stiffness, designated joint modulus (shear force "V" divided by true relative deflection "m") was introduced.

The results of this work indicate that the length of the dowel for 10 inches and greater length apparently has very little influence upon the deflections of the dowel-concrete system. The diameter of the dowel, however, is definitely a controlling factor, in this respect. The 3/4 inch dowel is approximately 1/2 as effective whereas the 1-1/4 inch dowel has only about 1/4 greater efficiency than the 1 inch dowel. Under the loadings of different magnitudes the dowel-concrete system assumes a residual deflection which varies in amount for the different conditions imposed. The residual deflection varies with the dowel diameter but for the dowel diameters investigated, the 20 inch dowel length appears to develop the lowest residual deflection value for different load values. The work further indicates that the stiffness of the joint, (joint modulus), is fairly constant for shear values within the normal working range and that there is a markable different in joint modulus values for each diameter of dowel. It is believed that such a value as joint modulus may be successfully employed as one criterion in setting up performance specifications for load transfer devices.

Further work in this investigation is in progress dealing in general with the performance of dowels and commercial load transfer devices under the continual action of repeated loads of magnitudes experienced on the highways.

The report includes a description of the load transfer device testing machine and test procedure and a discussion of the load deflection characteristics of the dowel units included in the study.

LOAD-DEFLECTION TEST METHOD

This test method is intended to determine certain mechanical characteristics of concrete and a load transfer device when used in combination as a structural unit. The results obtained will be used to determine the required rigidity of such load transfer devices when used in a joint of a concrete pavement for the purpose of establishing definite spacing for the units to accomplish, within specified limits, adequate stress relief in the concrete and prevent faulting of the slabs at the joint.

The test procedure is unique from the standpoint of other known methods, published (3) (4) and unpublished (5) (6) (7) (8), in that it permits the testing of load transfer devices under known conditions of shear and bending movement. In this particular case the type of loading apparatus, size of specimen, and specimen loading arrangement have been arbitrarily chosen for convenience in conducting the tests. Other arrangements of these features could no doubt be employed with equal success.

Testing Apparatus

The testing apparatus is comprised of four distinct units: (1) the machine, (2) loading mechanism and specimen supports, (3) the auxiliary equipment for measuring the relative auxiliary deflections of the two sections of the test specimen in which the load transfer device is embedded and (4) the test specimen. A view of the complete test assembly may be seen in Figure 1.

Machine: The frame of the machine was specially constructed for this particular work. All parts were carefully designed and fabricated to insure maximum stability with minimum deflection and accommodate the test specimen with all necessary measuring devices. As shown in Figure 1, the load is obtained by means of a manually operated 50 ton hydraulic ram mounted in such a manner that it may be moved to one side during the installation of the specimen. There is also provided a short adjustable cantilever beam to which a hoist is attached to facilitate lifting and placing of the specimen on the supports.

By means of suspended weights "S_1" and "S_2" the dead weight of the system is counterbalanced and, if desired, the load transfer device may be subjected to the action of a definite bending movement in addition to shear by simply applying the proper weights at "S_1" and "S_2."

The system was also designed in such a manner that the moment on the load transfer device could be kept constant and that the shear force was one-half of the load.

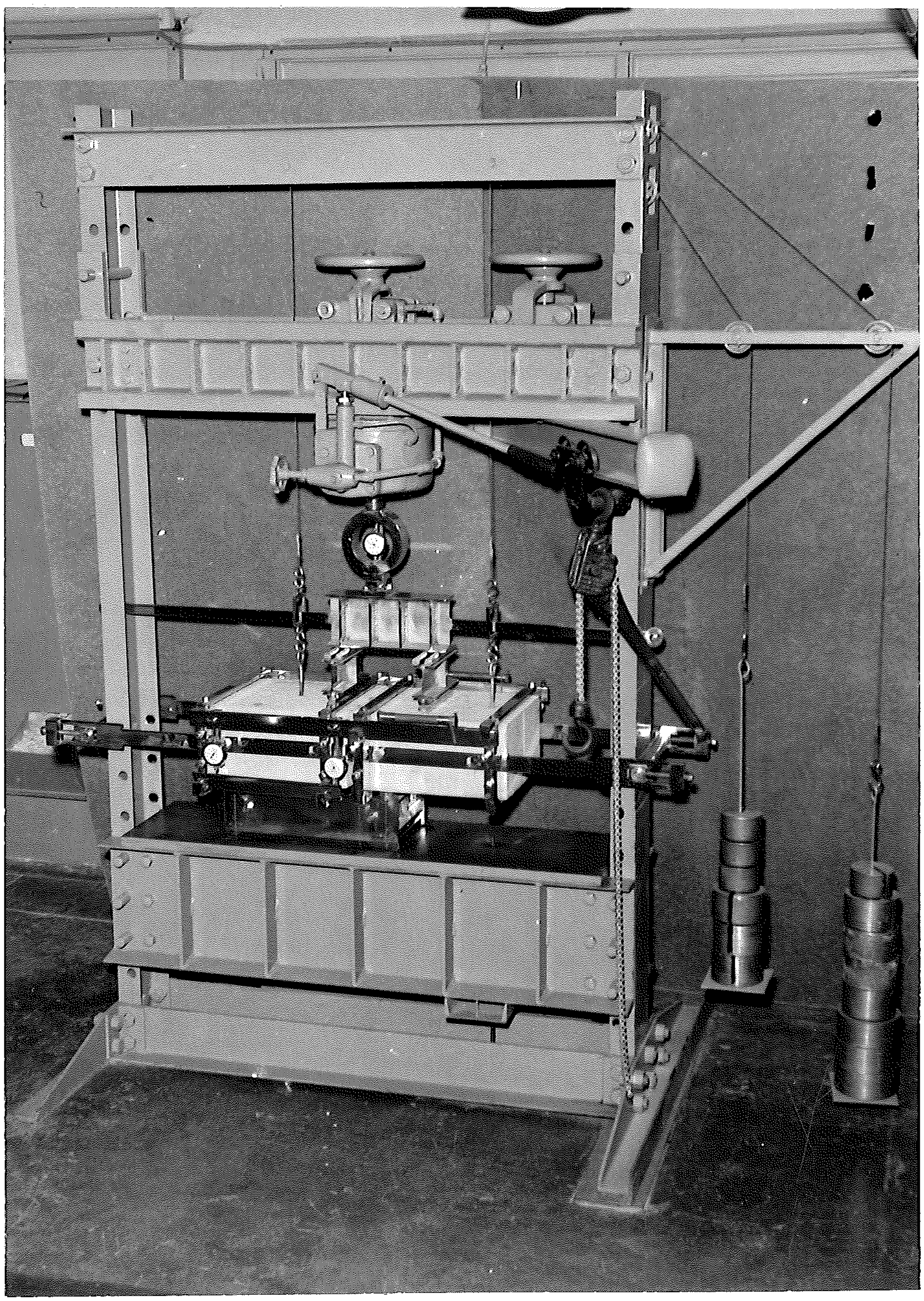


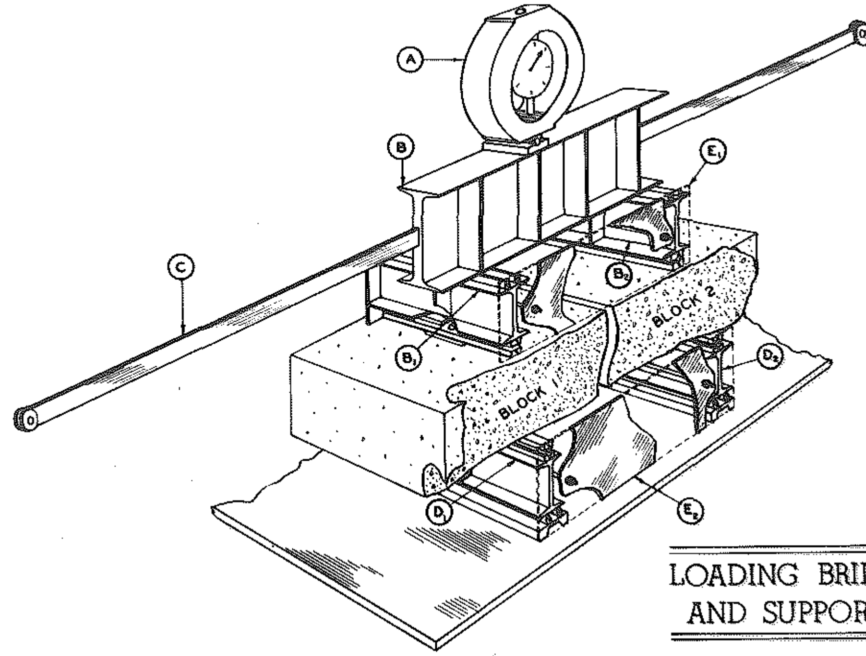
Figure 1. Apparatus for testing load transfer devices completely assembled.

Loading Mechanism: As illustrated in Figure 2, the load is applied to the specimen through a dynamometer ring "A" and special loading head bridge "B" and bearing members "B_1" and "B_2". A ten thousandths dial is mounted on the dynamometer ring "A" to measure its deflection from which the magnitude of loading is determined. Lateral displacement of the loading head bridge "B" is prevented by means of the horizontal bars "C" which bear against the upright supports of the machine. The bearing member "B_1" of the loading head is provided with a ball and socket arrangement to effect point loading on block No. 1 of the specimen. Bearing member "B_2" exerts full bearing across block No. 2 by means of a roller bearing arrangement.

Special supports "D_1" and "D_2" with a single roller on top and double rollers on the bottom are provided to insure freedom of action in a horizontal direction only. The supports are assumed to be rigid in the vertical direction.

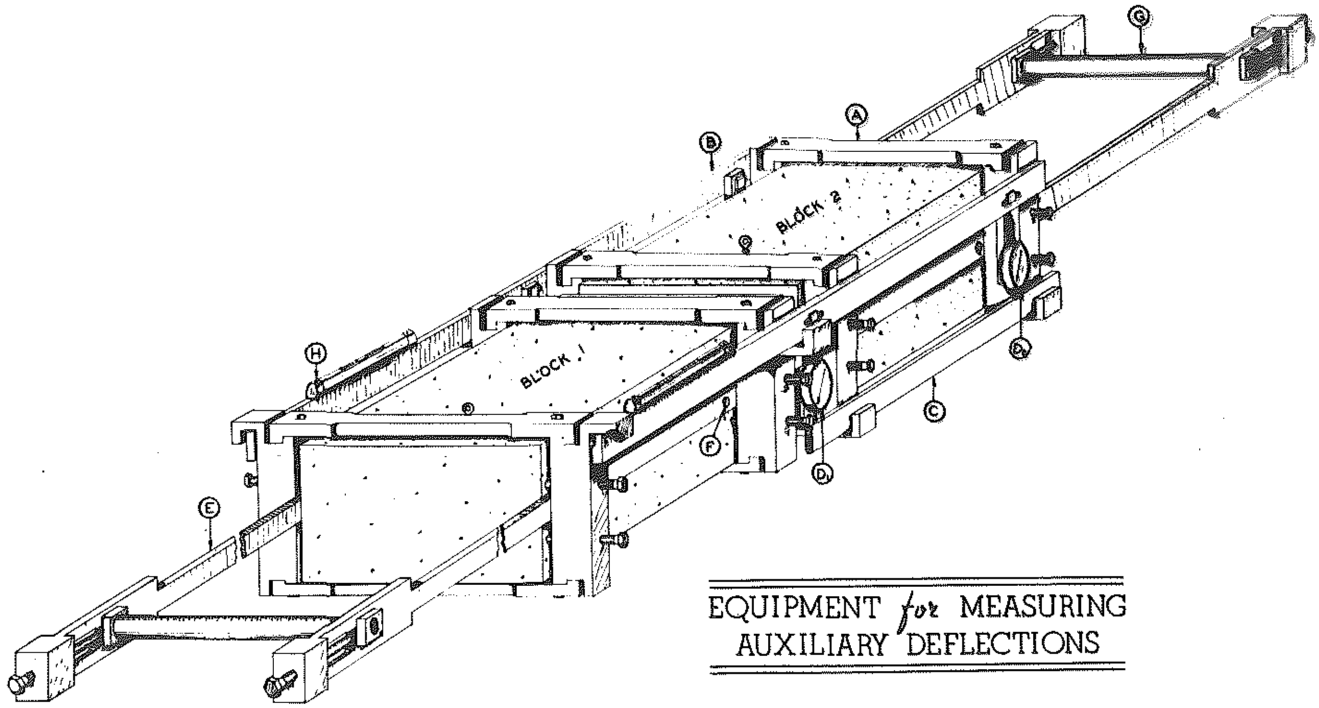
For the measurement of the angular deflection of the blocks, level bubbles "H" were mounted on the top bars "B", as shown in Figure 3.

Auxiliary Equipment: The purpose of the load transfer device test is to measure the relative deflection of the faces of two concrete test blocks in which a particular load transfer device has been embedded and subjected to predetermined loadings. Auxiliary deflections are measured in a direct manner and the desired deflections are calculated from established inter-relations between the auxiliary and desired deflections expressed by an analytical formula. Therefore, in this particular test setup the auxiliary deflections will be measured and the true relative deflection for any shear "V" computed.



LOADING BRIDGE
AND SUPPORTS

Figure 2



EQUIPMENT *for* MEASURING
AUXILIARY DEFLECTIONS

Figure 3

In order to measure the auxiliary deflections in this test procedure, a system of yokes and bars have been provided as shown in Figure 3. Four specially designed demountable yokes "A", two to each block, are attached to the blocks by set screws as shown in sketch. These yokes serve to support the four dial bars, "B" and "C", two on each side of the specimen. Four dials "D_1," "D_2," "D_3" and "D_4" are provided to measure the auxiliary deflection of the blocks. The dials are attached to the long top bars "B" and their stems make contact with the short lower bars "C". Since the top "B" bars follow the movement of Block 1 and the lower "C" bars move with Block 2, the relative movement of the two blocks will be recorded by the dials.

Special lugs "F" are cast into the sides of the specimen blocks to accommodate handling devices and to which the special parallel bars "E" are attached during the test to prevent horizontal displacement of the specimen on the supports. The ends of these bars engage with the vertical members of the machine frame by means of rollers "G" which allowed movement in the vertical but not horizontal direction.

Specimens: The concrete test specimen is composed of two sections or blocks each $\frac{30-W}{2}$ inches long, 12 inches wide and 7 inches deep where "W" is the width of joint opening. The load transfer device is incorporated into the center of the two specimen blocks during pouring operations, perpendicular to the joint opening and parallel to the top and sides of the specimen. The joint opening may be of any desired width. The joint between the specimen blocks may be constructed with prefabricated joint filler material or left open. A removable joint form is necessary when joint is open.

Figure 4 shows the specimen form with load transfer device completely assembled ready for receiving concrete. Also note removable joint form special lugs attached to side forms and longitudinal marking member across top. The side forms are securely bolted to a machined base plate to prevent loss of mixing water. The load transfer devices are installed exactly as in a pavement project with expansion shields and bituminous coating to break the bond. Figure 5 shows method of curing specimens.

Method of Determining True Relative Deflection "m"

The various relationships between displacement of the block faces and auxiliary dial movement are derived in the following manner with reference to dimensional diagram given in Figure 6 and deflection diagram illustrated in Figure 7. The following equations may be established for the comparatively small movements of the blocks which take place under this test method. The equations are:

(1) $\gamma = \alpha + \beta$

(2) $d_1 = q\beta - \alpha t$

(3) $d_2 = p\beta - (f-p)\alpha$

(4) $m = q\beta - a\alpha$

(5) $\alpha = \dfrac{pd_1 - qd_2}{f\,L}$

(6) $\beta = \dfrac{(f-p)d_1 - td_2}{f\,L}$

(7) $\gamma = \dfrac{d_1 - d_2}{L}$

(8) $$m = \frac{L + pu}{L} d_1 - \frac{uq}{L} d_2$$

Where $u = \dfrac{w}{f}$

$$m_1 = \frac{L + pu}{L} \text{ and } m_2 = -\frac{uq}{L}$$

(9) True relative deflection $m = m_1 d_1 + m_2 d_2$

When w equals 1 inch $m_1 = 1.00135$

$m_2 = -0.0662$

When w equals 1/2 inch $m_1 = 1.00135$

$m_2 = -0.0388$

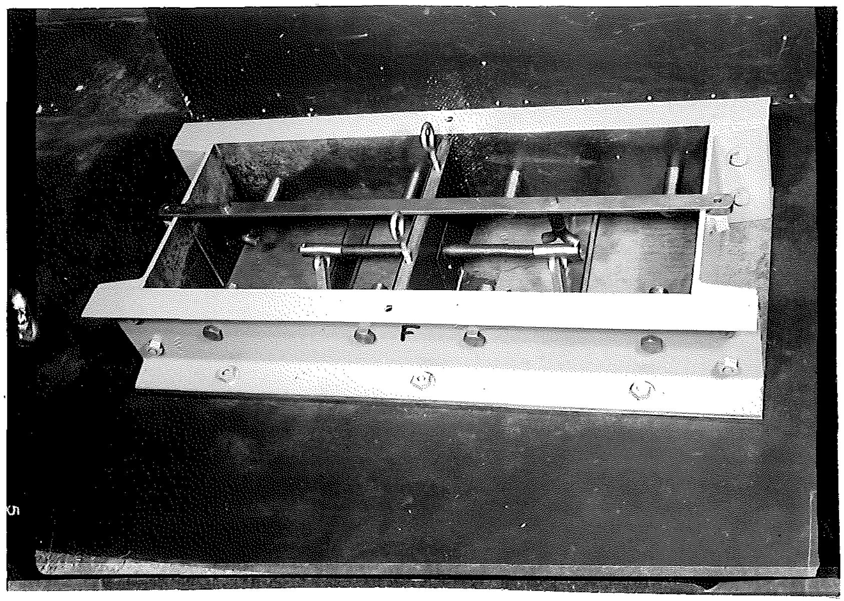
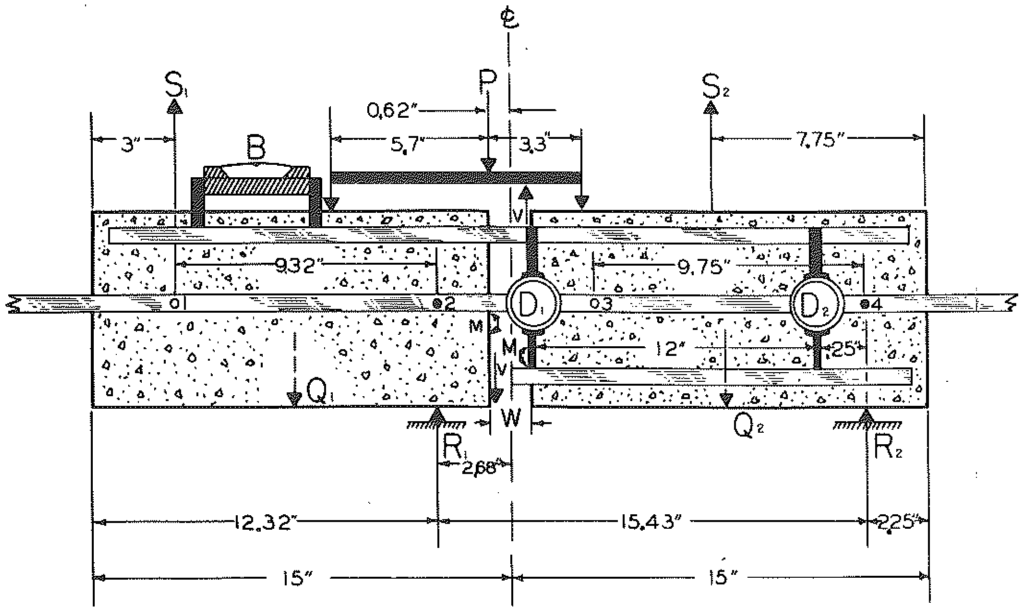


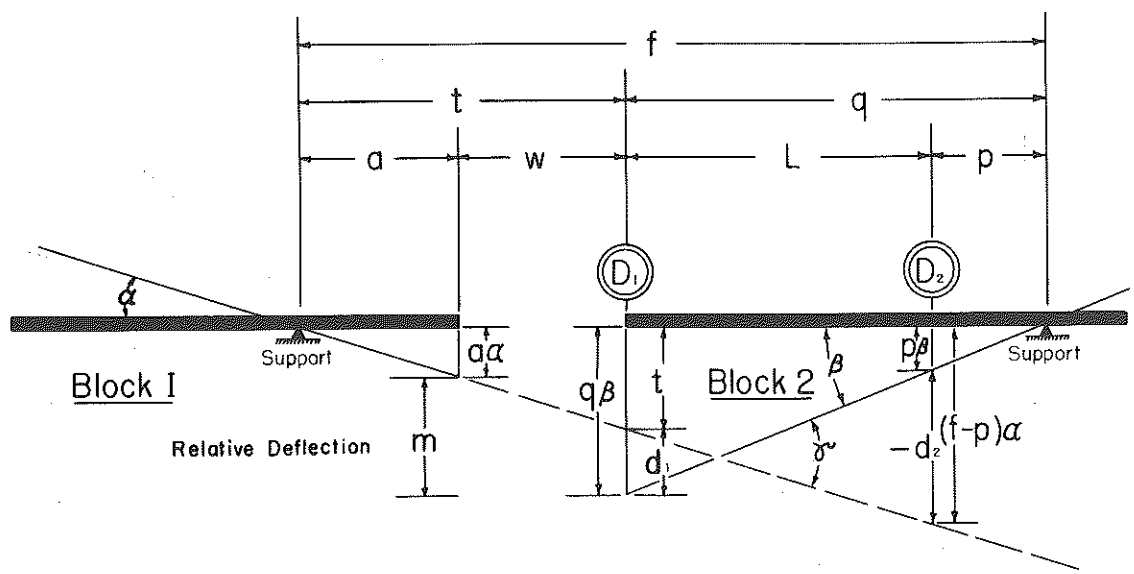
Figure 4. Specimen form with load transfer device assembled ready to receive concrete.

Figure 5. Method of storing specimen during curing period.



DIMENSIONAL DIAGRAM

Figure 6



DEFLECTION DIAGRAM

Figure 7

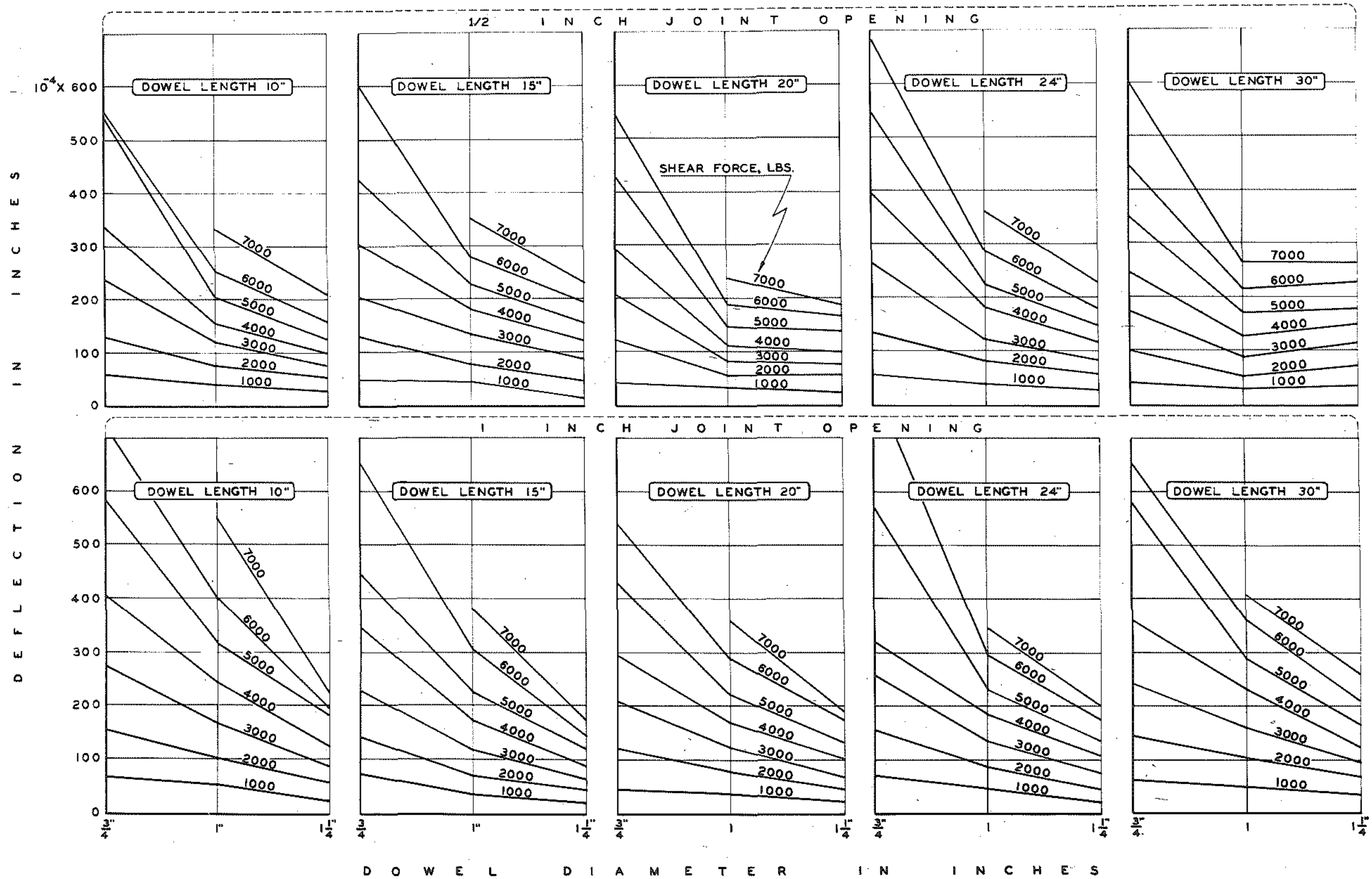
The computation of relative deflection "m" is arrived at in the following manner: The dials are designated "D_1" and "D_2" (front side) and "D_1" and "D_2" (back side). The differences in dial readings "D_1" for both sides in relation to initial readings for each load increment are averaged to give value "d_1", and in the same manner the differences in dial readings "D_2" are averaged to give value "d_2". The values "d_1" and "d_2" are substituted in equation (9) to give the true relative deflection "m" of the block faces for any shear value "V".

In order to expedite the compilation of the test data and calculations of the relative block deflections, a special record sheet was prepared as illustrated in Table I.

A typical shear deflection diagram is presented in Figure 8. The points a, b, c, etc. represent the shear deflection values used in comparing the relative performance of the various dowel bar units. The residual deflection values are represented by the points at which the sloping dash lines intersect the x axis or line of zero shear value.

LOAD DEFLECTION CHARACTERISTICS OF DOWELS

By means of the testing procedure previously described, specimens were cast and load deflection tests conducted on single units involving dowel bars of 3/4 inch, 1 inch and 1-1/4 inch in diameter and lengths for each diameter of 10, 15, 20, 24, and 30 inches. The particular length and diameter of dowels selected for this study were based on those now in common use throughout the several States.



EFFECT *of* DOWEL LENGTH *and* DIAMETER *on* DEFLECTION

Figure 13

TABLE I

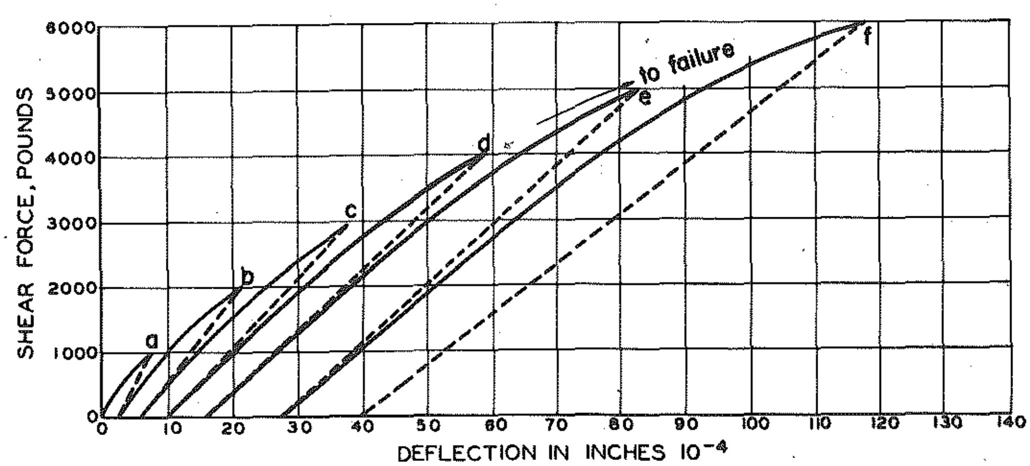
TYPICAL LOAD DEFLECTION TEST RECORD OF A LOAD TRANSFER DEVICE

LOAD	SHEAR FORCE	FRONT SIDE Auxiliary Deflections in 10^{-5}"				BACK SIDE Auxiliary Deflections in 10^{-5}"				*COMPUTATIONS IN 10^{-5} INCHES					Joint Modulus
lbs.	V in lbs.	Dial D_1	Diff. d_1	Dial D_2	Diff. d_2	Dial D_1	Diff. d_1	Dial D_2	Diff. d_2	d_1 ave.	m_1d_1	d_2 ave.	m_2d_2	Total Def. m	J.M. 10^3 lbs/in
0	0	5272		5086		5350		5381							
2000	1000	5697	-425	6042	-956	4284	+1066	4824	+557	+320.5	+320.9	-199.5	+ 6.74	+327.7	+305.1
0	0	5902	-630	6275	-1189	4430	+920	5069	+312	+145.0	+145.2	-438.5	+14.8	+160.0	0
4000	2000	5500	-228	5783	-697	3801	+1549	4432	+949	+660.5	+661.4	+126.0	- 4.3	+657.1	+304.4
0	0	6189	-917	6573	-1487	3982	+1368	4705	+676	+225.5	+225.8	-405.5	+13.7	+239.5	0
6000	3000	5204	+68	5515	-429	3510	+1840	4199	+1182	+954.0	+955.3	+376.5	-12.7	+942.6	+318.3
0	0	6190	-918	6578	-1492	4608	+1742	4608	+773	+412.0	+412.6	-358.5	+12.1	+424.7	0
8000	4000	4932	+340	5275	-189	3372	+1978	3978	+1403	+1159.0	+1160.6	+607.0	-20.5	+1140.0	+350.9
0	0	6274	-1002	6666	-1580	3580	+1770	4450	+931	+384.0	+384.5	-324.5	+11.0	+395.5	0
10000	5000	4662	+610	5032	+54	3081	+2269	3736	+1645	+1439.5	+1441.4	+849.5	-28.7	+1412.7	+353.9
0	0	6359	-1087	6688	-1602	3542	+1808	4411	+970	+360.5	+361.0	-316.0	+10.7	+371.7	0

* For joint opening of 1 inch
$m_1 = 1.00135$
$m_2 = -0.0662$

* For joint opening of 1/2 inch
$m_1 = 1.00135$
$m_2 = -0.0338$

* $m = m_1d_1 + m_2d_2$
$J.M. = \frac{V}{m}$



TYPICAL LOAD DEFLECTION
DIAGRAM

Figure 8

Two complete series of tests were performed for each length and size of dowel, one with a specimen joint opening of 1 inch and the other at 1/2 inch. The 1 inch dimension was selected to simulate the expansion joint opening employed in Michigan. The 1/2 inch opening was introduced in the study because it was believed that under extreme conditions such an opening would occur at contraction joints creating the 100 foot continuous pavement slabs such as now considered in Michigan's concrete pavement design practice.

Test Specimens

The specimens were cast in the manner previously described under testing apparatus employing the open joint method. Three specimens constitute a test on each size of dowel. All specimens were cured 24 hours in the mold with wet burlap covering, then 6 days out of the mold in a moist room and tested at 7 days. The strength of the concrete was determined by parallel compression and flexural tests on specimens cast from the same concrete used in casting specimens.

An attempt was made to insure the same quality of concrete in all specimens. The Portland cement used conformed to current specifications A.S.T.M. Designation C-150, Type I. The coarse and fine aggregates met the Department's grading and physical requirements respectively for 6-A material and natural sand 2-NS as specified for pavement concrete. The coarse aggregate consisted of gravel from Green Oak, Michigan. The sand also came from the same source.

The concrete mixture was designed in accordance with the Mortar-Void principle employed by the Department. The mix design was based on 5.5 sacks per cubic yard, 5.45 gallons of water per sack of cement, which produced an average compression strength of approximately 3,000 pounds per square inch in 7 days. The consistency of the moisture was held to an average of 1-1/2 inch slump.

The steel in the dowel bar units met the requirements for intermediate or hard grade steel of the Current Specifications for Billet-Steel Bars for Concrete Reinforcement, A.S.T.M. Designation A-15. The respective ultimate tensile strength characteristics of the steel were 96,755; 84,185 and 86,920 pounds for the 3/4 inch, 1 inch and 1-1/4 inch diameter dowels.

In order to duplicate field conditions, each dowel received a complete coating of asphalt cut-back material (RC-1) before the concrete was poured in the specimen mold.

Observations

The same test procedure was employed on all specimens. Simultaneous readings were taken on all four dials at 100 pound shear increments. At 1,000 pound shear increments, the load was released and dial readings recorded at no load. The same 1,000 pound shear increment was again applied and repeated 20 times as fast as the load could be applied and released. At the end of the twentieth load application, the pressure was released and dial readings taken at no load to determine residual deflection. This loading procedure continued until failure occurred as manifested by bending of the dowel or fracture of the concrete specimen or both. The shear at this point was designated as the ultimate shear strength of the specimen. Typical specimen failures are shown in Figures 9 and 10.

Figure 9. Typical failure of 3/4 inch dowel.

Figure 10. Typical failure of 1-1/4 inch dowel.

Although special precautions were exercised in an attempt to insure concrete of uniform strength in all specimens, there prevailed a noticeable variation in compressive strength as indicated from the test cylinders. Average specimen strength was approximately 3500 pounds per square inch. Subsequently, any marked variation in concrete strengths was readily detected in the deflection values from the specimen loading tests. The results of specimens obviously out of line of concrete strength and deflection values were discarded and new specimens were prepared and tested.

The testing program had a threefold purpose; first, to obtain reliable data in order to establish satisfactory load deflection characteristic curves for dowels of different lengths and diameters; second, to compare the residual deflection characteristics of the individual dowel units; and finally, to develop information on the rigidity characteristics of the dowel-concrete system, all of which would be directed toward the solution of the load transfer problem. A summary of test data is presented in Tables II and III.

Load Deflection Characteristics

The load deflection characteristics for the various dowel units at joint openings of 1 inch and 1/2 inch are presented graphically in Figures 11, 12 and 13. The curves in Figures 11, 12 and 13 represent the relationship between shear force, deflection, length and diameter of dowels for the two joint spacing distances of 1 inch and 1/2 inch. Each point on the curves is an average of three test values.

TABLE 2

SUMMARY OF AVERAGE TOTAL DEFLECTION, RESIDUAL DEFLECTION, AND JOINT MODULUS DATA FOR DIFFERENT LENGTHS AND SIZES OF DOWELS AT JOINT OPENING OF ONE-HALF INCH

Units for Deflections = 10^{-4} inches, Joint Modulus = 10^{3} pounds per inch

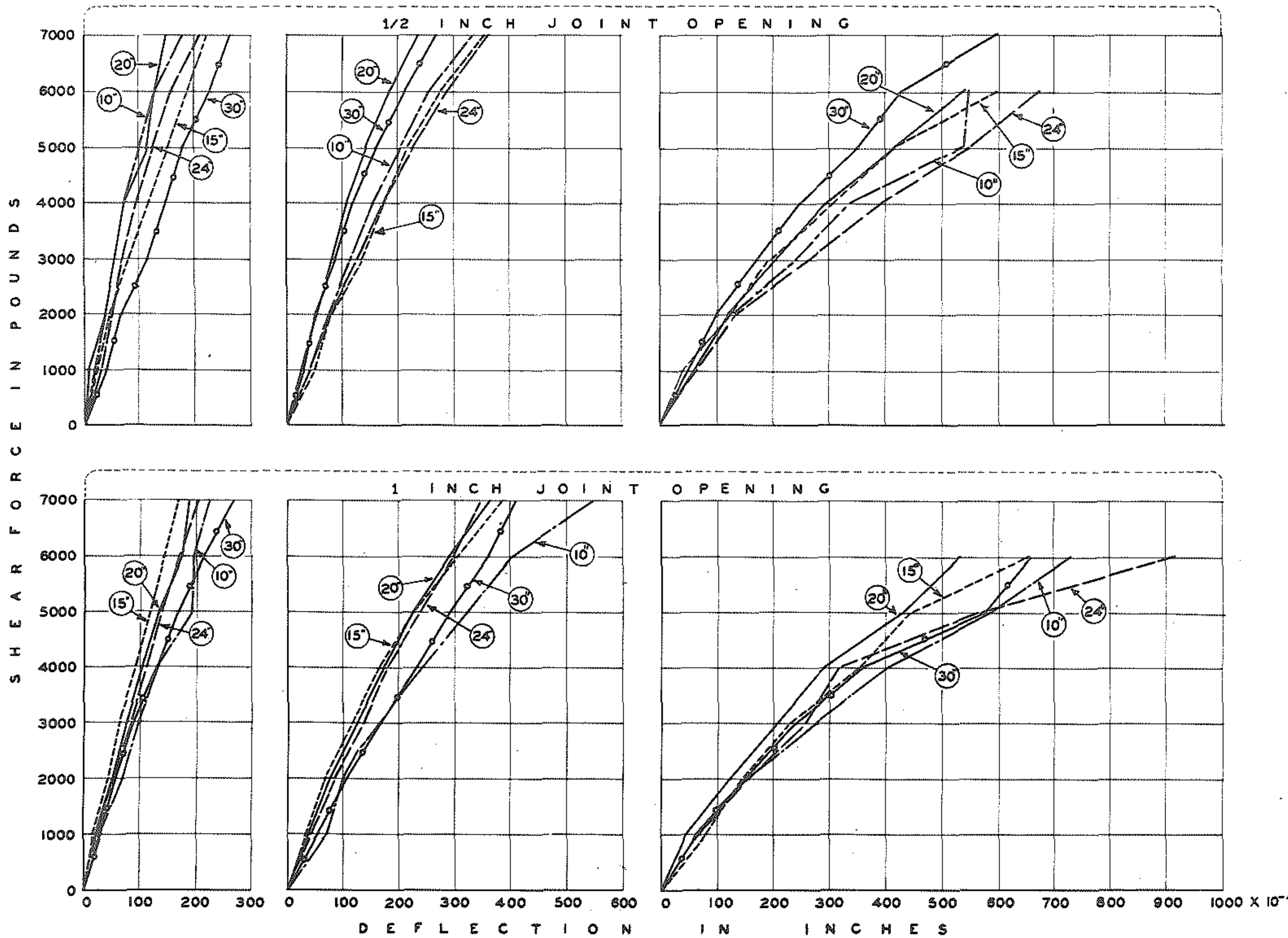
SHEAR FORCE Pounds	DIAMETER = 3/4 INCH					DIAMETER = 1 INCH					DIAMETER = 1-1/4 INCH				
	Length					Length					Length				
	10	15	20	24	30	10	15	20	24	30	10	15	20	24	30
1000															
Total Deflection	57	52	43	61	47	37	42	28	38	30	26	20	22	28	37
Residual Deflection	16	16	-2	10	20	15.1	14	11	19	5	12	5	9	15	26
Joint Modulus	175.4	192.3	232.6	163.9	212.8	270.3	238.1	357.1	263.2	333.3	384.6	500.0	454.5	357.1	270.3
2000															
	124	127	123	133	99	76	80	51	78	50	49	48	44	53	71
	86	21	11	27	41	31	22	16	20	9	21	17	18	21	35
	232.6	157.4	162.6	160.4	202.0	263.2	250.0	392.2	256.4	400.0	408.2	416.7	454.5	377.4	281.7
3000															
	239	202	207	263	167	115	132	80	123	87	70	83	69	81	112
	110	28	14	47	53	49	34	23	33	10	31	30	24	26	44
	125.5	148.5	144.9	114.1	179.6	260.9	227.2	375.0	243.9	344.8	428.6	361.4	434.8	370.4	267.9
4000															
	337	302	292	397	247	154	175	111	175	122	96	117	96	112	149
	154	38	26	85	66	68	40	28	40	12	33	44	32	29	46
	118.6	132.4	137.0	100.8	161.9	259.7	228.6	360.4	228.6	327.9	416.7	341.9	416.7	357.1	268.5
5000															
	541	424	430	551	353	205	225	144	226	165	126	151	135	144	183
	253	28	35	99	95	78	47	35	44	13	39	53	33	35	47
	92.4	117.9	116.3	90.7	141.6	243.9	222.2	347.2	221.2	303.0	396.8	331.1	370.4	347.2	273.2
6000															
	551	605	541	680	441	254	283	188	288	211	160	191	158	175	227
	387	72	17		122	108	49	53	55	14	50	92	40	40	53
	108.9	99.1	110.9	88.2	136.1	236.2	212.0	319.1	208.3	284.4	375.0	314.1	379.7	342.9	264.3
7000															
					600	330	359	236.5	362	265	208	233	184	224	259
						130	52	36.5	72	13.5	39.5	125	48	44	57
					116.7	212.1	195.0	296.0	193.4	264.2	336.5	300.4	380.4	312.5	270.3
Ultimate Shear in lbs.	6000	6500	5667	5917	6417	8750	8833	8083	9750	9250	9833	9167	11,000	9667	8167

TABLE 3

SUMMARY OF AVERAGE TOTAL DEFLECTION, RESIDUAL DEFLECTION, AND JOINT MODULUS DATA FOR DIFFERENT LENGTHS AND SIZES OF DOWELS AT JOINT OPENING OF ONE INCH

Units for Deflections = 10^{-4} inches, Joint Modulus = 10^{3} pounds per inch

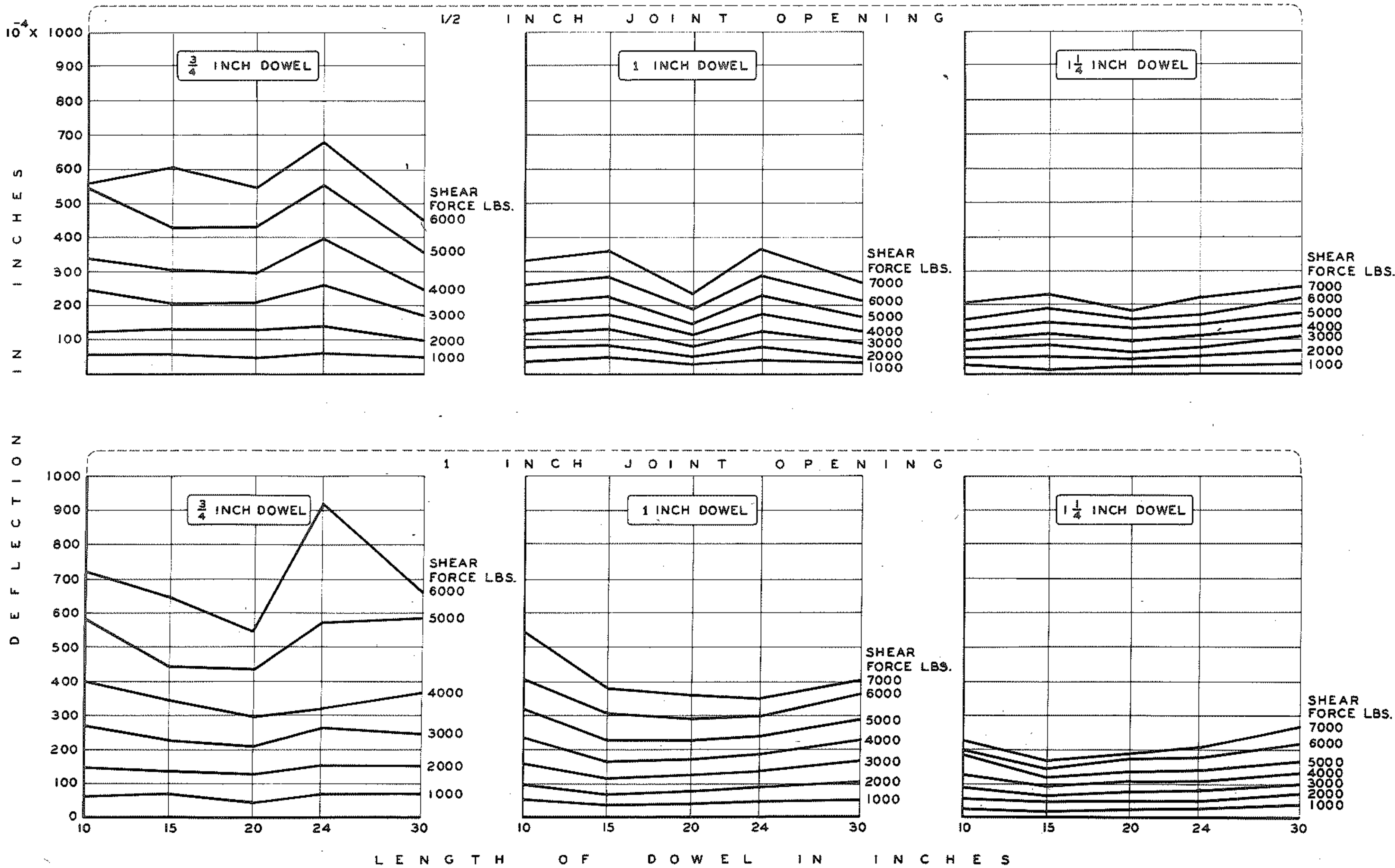
SHEAR FORCE Pounds	DIAMETER = 3/4 INCH					DIAMETER = 1 INCH					DIAMETER = 1-1/4 INCH				
	Length					Length					Length				
	10	15	20	24	30	10	15	20	24	30	10	15	20	24	30
1000															
Total Deflection	67	73	43	69	64	57	34	39	45	52	27	18	23	23	37
Residual Deflection	27	20	7	14	18	23	4.4	4	16	23	17	5	4.8	8	26
Joint Modulus	149.3	137.0	232.6	144.9	156.3	175.4	294.1	256.4	222.2	192.3	370.4	555.5	434.7	434.7	270.3
2000															
	149	139	123	152	144	100	66	79	88	104	55	41	47	48	68
	48	25	8	26	26	41	13.3	6	22	35	26	6	7	13	31
	134.2	143.9	162.6	131.6	138.9	200.0	303.0	253.2	227.3	192.3	363.6	487.8	425.5	416.7	294.1
3000															
	272	227	207	259	239	162	115	124	134	164	89	62	71	78	97
	43	25	10	42	32	66	25	12	27	43	39	8	9	19	35
	110.2	132.2	144.9	115.8	125.8	185.2	260.9	241.9	223.9	182.9	333.3	483.9	422.5	384.6	309.3
4000															
	403	348	292	318	360	237	164	171	183	229	129	90	103	105	129
	150	35	14	64	47	90	34	15	30	53	64	9	11	19	37
	99.3	114.9	137.0	125.8	111.1	168.8	243.9	233,9	218.6	184.7	310.1	444.4	388.3	381.0	310.1
5000															
	585	443	430	570	578	320	224	226	233	290	185	116	132	135	163
	301	57.5	90	128	91	117	51	16	43	62	80	17	12	25	39
	85.4	112.9	116.3	87.7	86.5	156.3	233.3	221.2	214.6	172.4	270.3	431.0	378.8	370.4	306.7
6000	726.8	650	541	913	653	402	304	289	297	361	194.5	141	171	171	211
	396	78		235	204	201	67	21	48	67	85	25	12	25	46
	82.6	92.3	110.9	65.7	91.9	149.2	197.4	207.6	202.0	166.2	308.5	425.5	350.9	350.9	284.4
7000															
						545	378	360	347	407	223	167	186	203	262
						227	79	25	70	73	79	35	15	30	69
						128.4	185.1	194.4	201.7	172.0	313.9	419.2	376.3	344.8	267.2
Ultimate Shear in lbs.	5833	6000	5333	6333	5833	8000	10,250	10,917	9333	10,583	7000	13,000	11,667	9167	12,833



EFFECT of DOWEL LENGTH on DEFLECTIONS

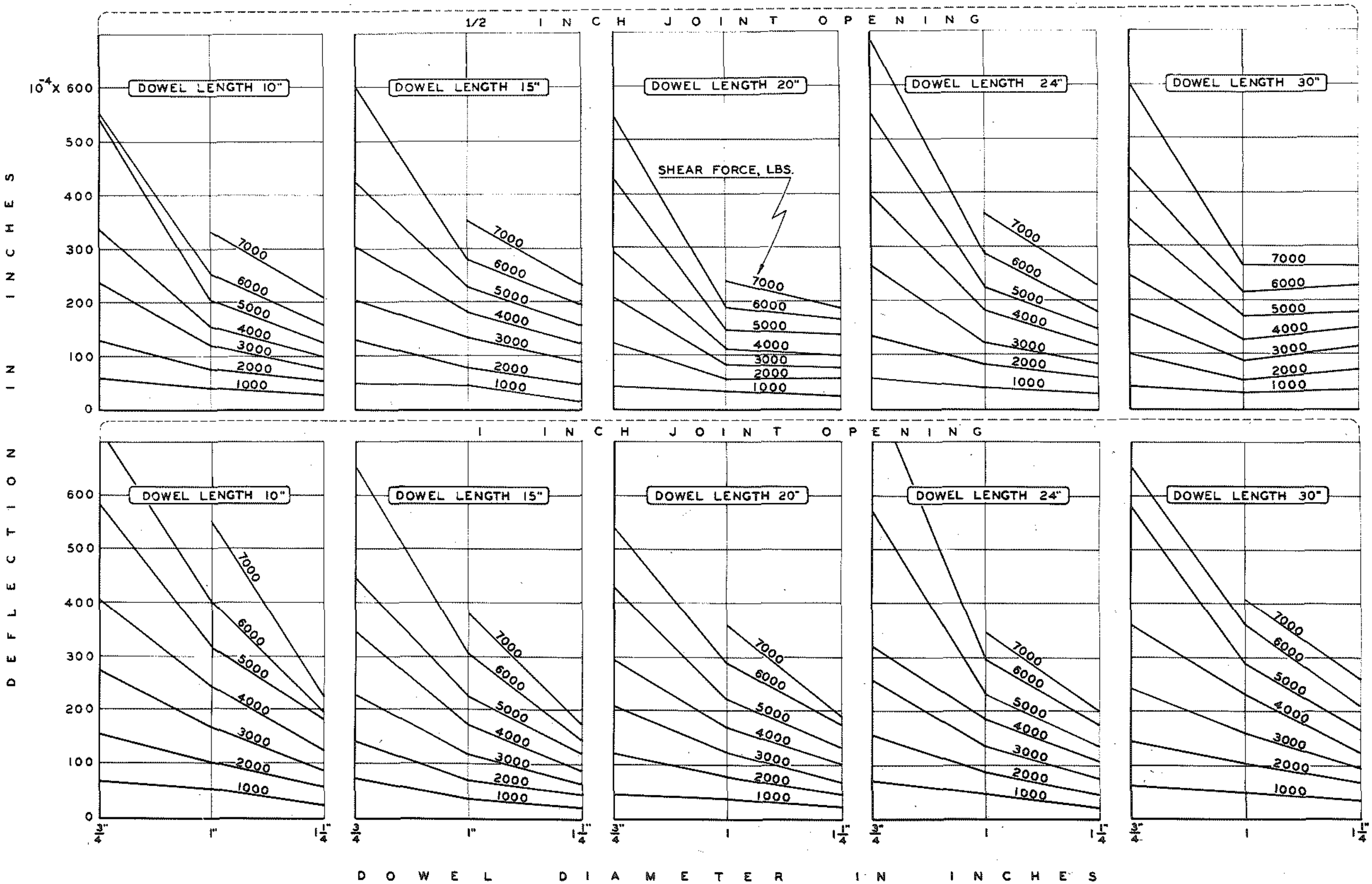
FOR DOWELS OF 3/4" DIAMETER

Figure 11



EFFECT *of* DOWEL LENGTH *and* DIAMETER *on* DEFLECTION
for JOINT OPENINGS *of* 1" *and* 1/2"

Figure 12



EFFECT *of* DOWEL LENGTH *and* DIAMETER *on* DEFLECTION

Figure 13

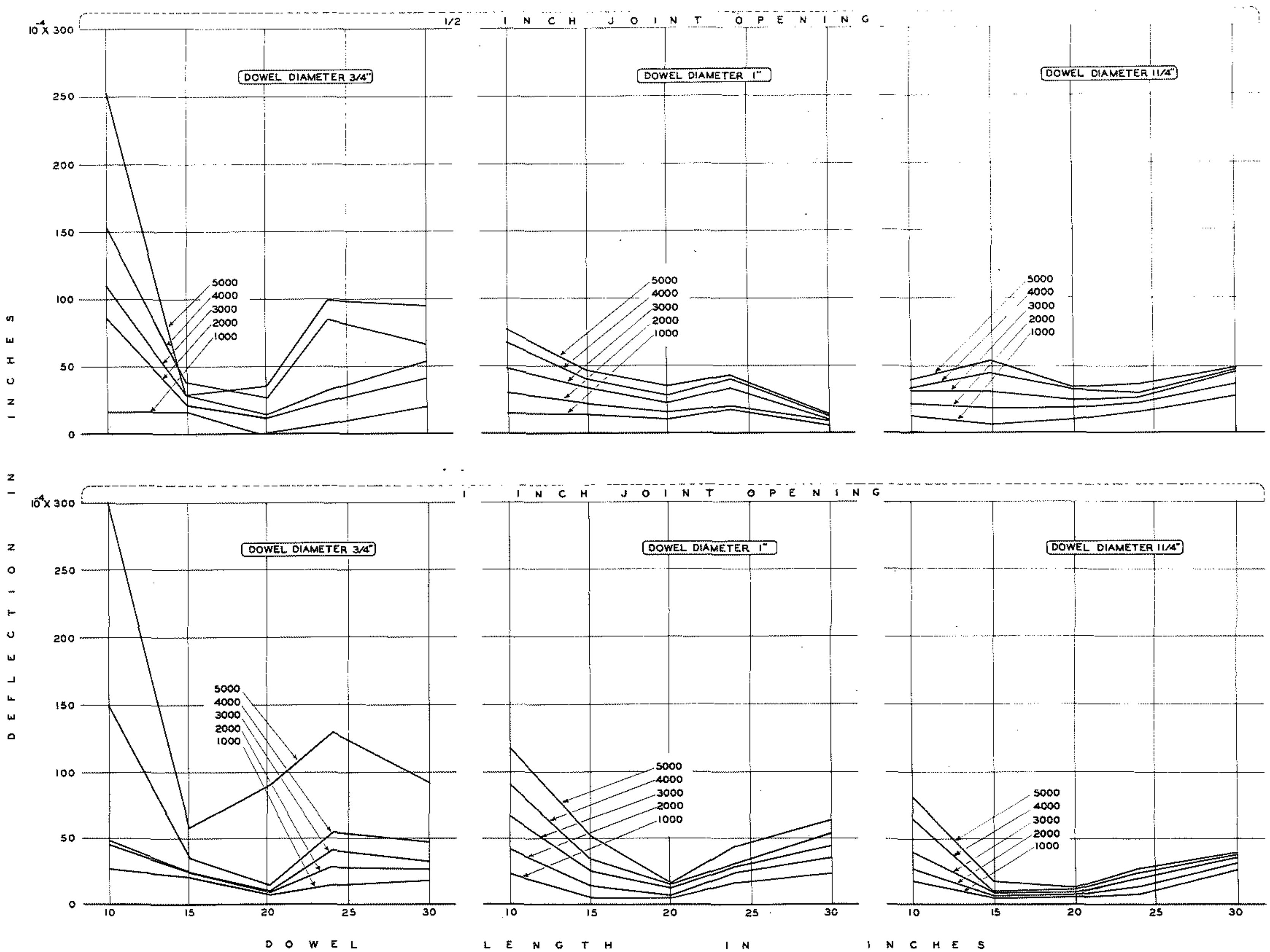
Considering the limitations of the test procedure, the results obtained indicate that; first, within the normal load range expected on the pavement, the length of the dowel has very little influence on deflections; second, the diameter of the dowel greatly influences the deflection, but to a much lesser degree as the diameter exceeds 1 inch; third, dowels have greater resistance to deflection as the joint opening decreases, but a change from 1 inch to 1/2 inch was not sufficient to develop markable differences in deflection values.

Influence of Dowel Diameter on Residual Deflection

As mentioned previously under test procedure, 20 repetitions of loadings were made at each 1,000 pound shear increment, and at cessation of repeated loading the deflection at no load was recorded. It was thought that such a loading procedure might give some indication as to the relative efficiency of the various dowel units under repeated loads. The residual deflections resulting from these tests are summarized in Tables II and III and presented graphically by curves in Figure 14. The data bring out the inherent weakness of the 3/4 inch dowel in this respect and for low shear values there is very little difference between the 1 inch and 1-1/4 inch dowels. It is logical to expect, however, that the 1-1/4 inch dowel should have a lower residual deflection due to its greater bearing area and stiffness as compared to dowels of lesser diameter.

Rigidity of Load Transfer Units

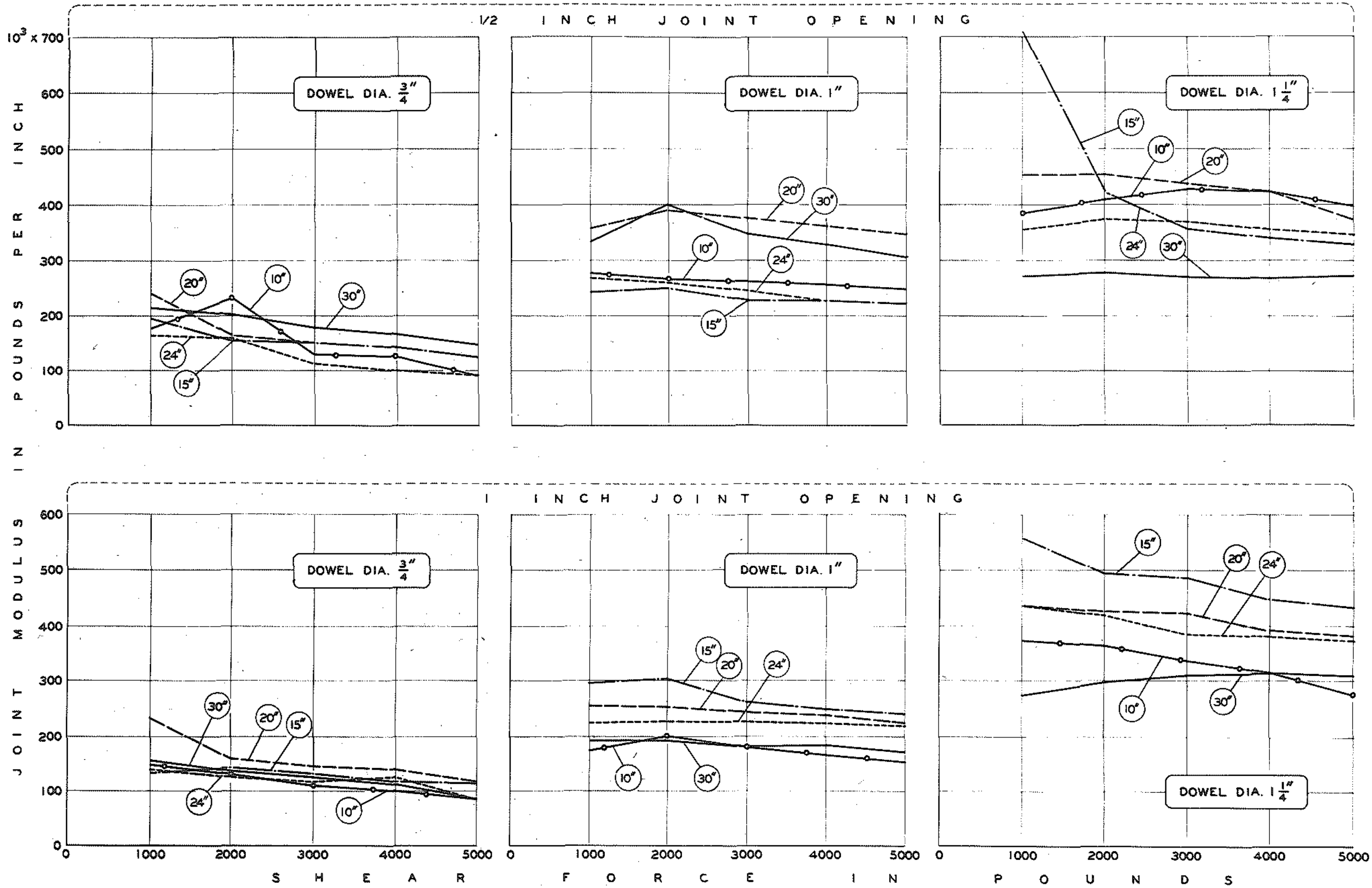
The stiffness or rigidity of load transfer devices may be expressed by a physical quantity proportionate to the shear force and inversely proportionate to the deflection which is expressed by $\frac{V}{m}$ where "V" is the shear force in pounds and m the deflection of the unit in inches. This expression has been termed the Joint Modulus.



EFFECT of DOWEL LENGTH on RESIDUAL DEFLECTION

Figure 14

When joint moduli are plotted against shear force, the relative rigidity of the dowel units for different conditions are clearly defined. This is graphically illustrated in Figure 15. The data show that within reasonable load limits the joint modulus for the different dowel units remains fairly constant. This being true, it would appear then that such a physical value as joint modulus could be successfully employed as one of several criteria necessary for setting up performance specifications and for creating comparative standards for use in evaluating commercial load transfer devices versus dowel bars



EFFECT *of* DOWEL LENGTH *on* JOINT MODULUS

Figure 15

SUMMARY

We do not regard the results of this study as conclusive, but we feel that sufficient evidence has been adducted to warrant recognition of a load deflection test procedure for the purpose of evaluating load transfer devices in order to prepare specifications for their performance and use, and to determine basic information necessary to advance the design and construction of transverse joints in concrete pavements. Significant findings of this study are:

1. No significant relationship exists between length and relative deflection of the dowel-concrete system.
2. Dowel diameter is the most important factor in controlling deflection. Diameters less than 1 inch are relatively ineffective in controlling deflections under normal shear loads. On the other hand, dowels with diameters greater than 1 inch tend to rupture the concrete before failing in flexure. This would indicate the need for considering slab thickness in relation to dowel diameter.
3. For similar load conditions the residual deflection of dowels diminishes with increase in dowel diameter, but appears to be at a minimum amount for dowels of 20 inches in length irrespective of diameter.

4. The stiffness or rigidity of load transfer devices may be expressed by a physical quality proportional to the shear force and inversely proportional to the deflection termed the Joint Modulus and expressed by $\frac{V}{m}$. The joint modulus for all practical purposes and within reasonable load values may be considered a constant value. Data indicates the possibility of using such a value for comparing the relative efficiency of load transfer units.

ACKNOWLEDGMENT

Since the background of experience associated with this study dates back to 1934, and the investigation has been periodically worked upon and developed during the interim, it is difficult for the authors to specifically acknowledge indebtedness to all persons concerned. Acknowledgmént is made to J. W. Kushing, former Research and Testing Engineer for the Department, who organized the investigation in 1934 and did much to develop the test procedure; to L. D. Childs, Physical Research Engineer, for assistance in preparing the report; to Paul Keiffer, Physical Research Engineer, for supervising the testing and laboratory work; and to the many other mémbers of the organization for their assistance in actual performance of the work.

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