

steel is about 70,000 lb. per sq. in. This illustrates clearly the need for adequate continuous reinforcement if transverse cracks are to be kept tightly closed.

It is much too early for observations and

measurements to be too significant, but it is gratifying that they indicate no unexpected or undesirable developments and that the instruments and installations are working satisfactorily.

PROGRESS REPORT ON LOAD DEFLECTION TESTS DEALING WITH LENGTH AND SIZE OF DOWELS

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SYNOPSIS

In 1934 the Michigan State Highway Department started a comprehensive investigation for the evaluation of load transfer devices. The primary object of the investigation was to develop a test procedure for determining the relative efficiency of various types of load transfer devices on the market to the end that definite specifications for their selection and use could be developed. Two progress reports on the results of this work have appeared in the proceedings of the Highway Research Board.

The purpose of this paper is to present the results of another phase of this investigation dealing specifically with the development of a load deflection test procedure and its use in studying the mechanical characteristics and efficiency of dowels of varying length and diameter.

The paper describes the testing machine and test procedure followed in conducting the tests. It presents graphs showing the load deflection characteristics of dowels of three sizes: $\frac{3}{4}$ in., 1 in., and $1\frac{1}{4}$ in. and for lengths in each size of 10, 15, 20, 24, and 30 in. Data bearing on residual deflections and joint rigidity are also presented.

The work suggests the need of a recognized test procedure for evaluating load transfer devices. Further, the data indicate that the length of dowel beyond 10 in. has very little influence on deflection. However, there appears to be an optimum length of dowel for maximum performance irrespective of diameter. That length is between 15 and 20 in. A physical quantity for the measurement of rigidity is suggested and designated "joint modulus." It is evaluated by dividing the shear force in pounds by deflection in inches. For shear values within normal highway load ranges this value is approximately constant and may be assigned a definite average value for each type of load transfer device.

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)¹.

¹ Italicized figures in parentheses refer to list of references at the end of the paper.

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.

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 the measurement of the relative vertical deflection of the block faces. The opening between the blocks was held constant at 1 in. and $\frac{1}{2}$ in. Three diameters of dowels used were $\frac{3}{4}$, 1 and $1\frac{1}{4}$ in. Lengths of 10, 15, 20, 24 and 30 in. 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 in. 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 $\frac{3}{4}$ -in. dowel has approximately one half the efficiency whereas the $1\frac{1}{4}$ in. dowel has only about one and one quarter the efficiency of the 1 in. dowel. Under 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-in. dowel length appears to develop the lowest residual deflection 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 marked difference in joint modulus values for each diameter of dowel. It is believed that 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 a combination of concrete and a load transfer device when used as a structural unit. The results obtained will be used to determine the required rigidity of such load transfer device used in a joint of a concrete pavement. The purpose is to establish the proper spacing of the units in order that they will 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. No doubt other arrangements of these features could 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 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.

The system was designed in such a manner that the moment on the load transfer device

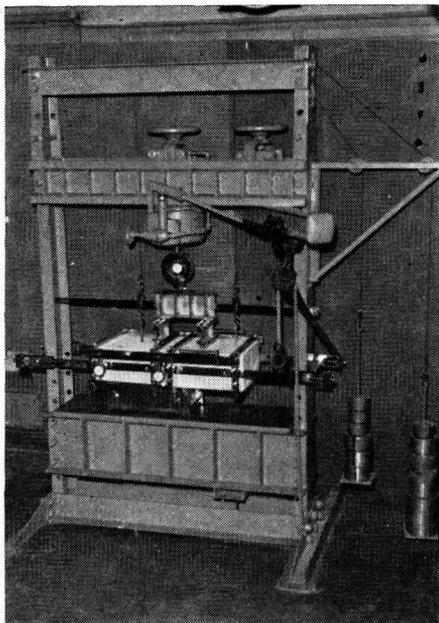


Figure 1. Apparatus for Testing Load Transfer Devices Completely Assembled

could be kept constant and that the shear force was one-half of the load.

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 "B₁" and "B₂". 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 "B₁" 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 "B₂" exerts full bearing across block No. 2 by means of a roller bearing arrangement.

Special supports "D₁" and "D₂" 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.

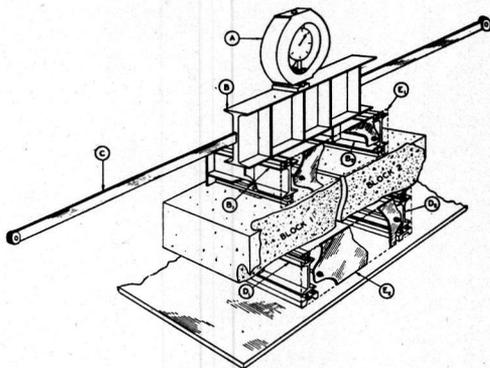


Figure 2. Loading Bridge And Supports

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 set-up the auxiliary deflections will be measured and the true relative deflection for any shear V computed.

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 "D₁," "D₂," "D₃" and "D₄" 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.

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

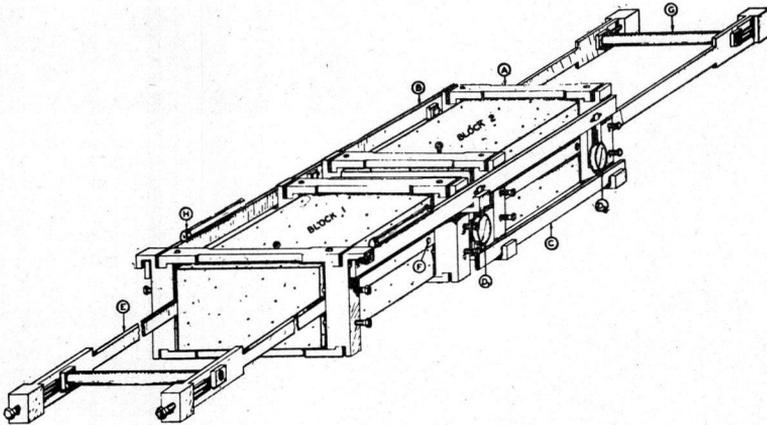


Figure 3. Equipment for Measuring Auxiliary Deflections

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 $\frac{1}{2}(30-W)$ in. long, 12 in. wide, and 7 in. 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 the joint is open.

Figure 4 shows the specimen form with load

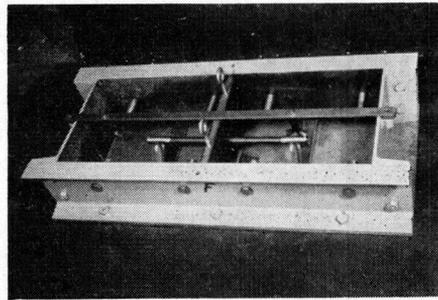


Figure 4. Specimen Form with Load Transfer Device Assembled Ready to Receive Concrete

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 move-

ments of the blocks which take place under this test method. The equations are:

$$\gamma = \alpha + \beta \tag{1}$$

$$d_1 = q\beta - \alpha t \tag{2}$$

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

$$m = q\beta - \alpha\alpha \tag{4}$$

$$\alpha = \frac{pd_1 - qd_2}{fL} \tag{5}$$

$$\beta = \frac{(f - p)d_1 - td_2}{fL} \tag{6}$$

$$\gamma = \frac{d_1 - d_2}{L} \tag{7}$$

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

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

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

True relative deflection $m = m_1d_1 + m_2d_2$ (9)

When w equals 1 in. $m_1 = 1.00135$

$m_2 = 0.0662$

When w equals 0.5 in. $m_1 = 1.00135$

$m_2 = -0.0388$

The computation of relative deflection m is arrived at in the following manner: The dials are designated "D₁" and "D₂" (front side) and "D₁" and "D₂" (back side). The differences in dial readings "D" for both sides in relation to initial readings are averaged to give value d_1 , and in the same manner the differences in dial readings "D₂" 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 1.

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.

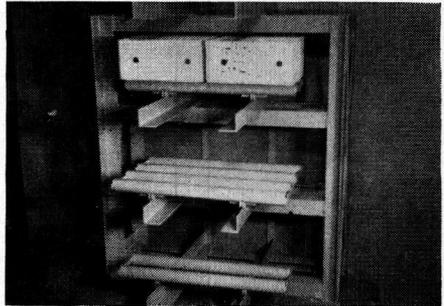


Figure 5. Method of Storing Specimen During Curing Period

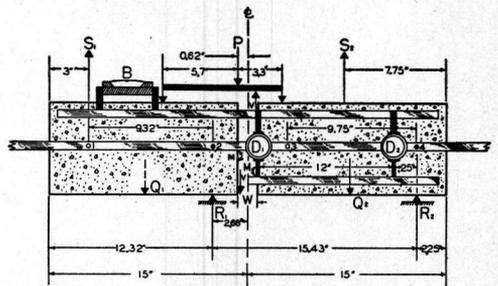


Figure 6. Dimensional Diagram

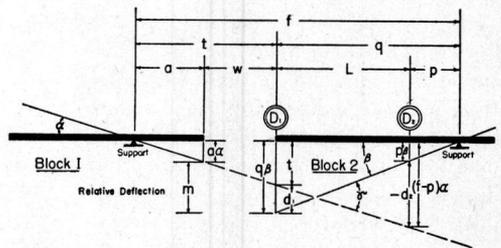


Figure 7. Deflection Diagram

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 in., 1 in. and 1 1/4 in. in diameter and lengths for each diameter of 10, 15, 20, 24, and 30 in. The particular length and diameter of dowels selected for this study were based on those now in common use throughout the several states.

Two complete series of tests were performed for each length and size of dowel, one with a specimen joint opening of 1 in. and the other at ½ in. The 1-in. dimension was selected to simulate the expansion joint opening employed in Michigan. The ½-in. opening was introduced in the study because it was believed that under extreme conditions such an opening would occur at contraction joints creating

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 cu. yd., 5.45 gal. of water per sack of cement, which produced an average compression strength of approximately 3,000 psi. in 7 days. The consistency

TABLE 1
TYPICAL LOAD DEFLECTION TEST RECORD OF A LOAD TRANSFER DEVICE

Load	Shear Force V	Front Side				Back side				Computations in 10 ⁻⁴ in. ²					Joint Modulus J.M.
		Auxiliary Deflections in 10 ⁻³ in.				Auxiliary Deflections in 10 ⁻³ in.				d ₁ ave.	m ₁ d ₁	d ₂ ave.	m ₂ d ₂	Total Def. m	
		Dial D ₁	Diff. d ₁	Dial D ₂	Diff. d ₂	Dial D ₁	Diff. d	Dial D ₂	Diff. d ₂						
lb.	lb.														10 ³ lbs. per 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	4808	+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	3530	+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	+380.5	+361.0	-316.0	+10.7	+371.7	0

^a For joint opening of 1 in.
m₁ = 1.00135
m₂ = -0.0662

For joint opening of ½ in.
m₁ = 1.00135
m₂ = 0.0338

$$m = m_1d_1 + m_2d_2$$

$$J.M. = \frac{V}{m}$$

the 100-ft. 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 hr. 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 ASTM 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

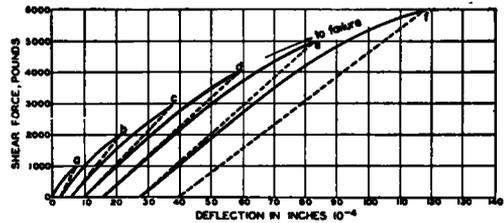


Figure 8. Typical Load Deflection Diagram

of the concrete was held to an average of 1 ½-in. 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, ASTM Designation A-15. The respective ultimate tensile strength characteristics of the steel were 96,755, 84,185, and 86,920 psi. for the ½-in., 1-in. and 1 ½-in. 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

recorded at no load. The 1,000-lb. shear increment was again applied and repeated 20 times as rapidly as the load could be applied and released. At the end of the twentieth

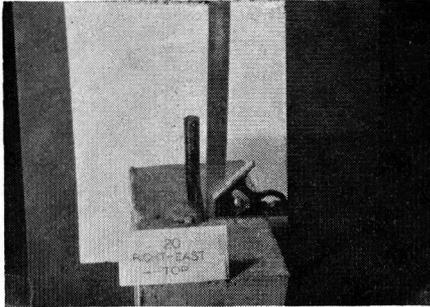


Figure 9. Typical Failure of 3/4-in. Dowel

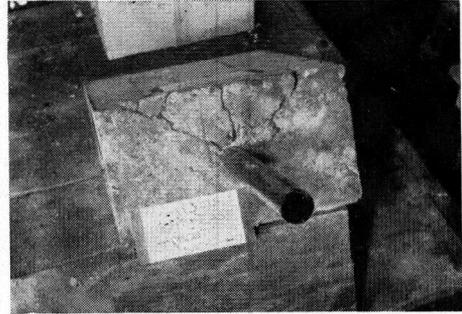


Figure 10. Typical Failure of 1 1/4-in. Dowel.

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 = 10³ pounds per inch

Shear Force Pounds	Diameter = 3/4 inch Length					Diameter = 1 inch Length					Diameter = 1 1/4 inch Length				
	10	15	20	24	30	10	15	20	24	30	10	15	20	24	30
1000	57	52	43	61	47	37	42	28	38	30	26	20	22	28	37
Total Deflection	16	16	-2	10	20	15.1	14	11	19	5	12	5	9	15	26
Residual Deflection	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
Joint Modulus															
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
	161	157.4	162.6	150	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	122	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
					116.7	130	52	36.5	72	13.5	39.5	125	48	44	57
					116.7	116.7	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

readings were taken on all four dials at 100-lb. shear increments. At 1,000-lb. shear increments, the load was released and dial readings

load application, the pressure was released and dial readings taken at no load to determine residual reflection. This loading proce-

cedure 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.

Although special precautions were exercised

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 informa-

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 = 10³ pounds per inch

Shear Force Pounds	Diameter = 3/4 inch Length					Diameter = 1 inch Length					Diameter = 1 1/2 inch 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	16	23	17	5	4.8	8	26
Joint Modulus	149.3	137.0	232.6	144.9	156.3	175.4	204.1	256.4	222.2	192.3	370.4	555.5	434.7	434.7	270.3
2000	149 48 134.2	139 25 143.9	123 8 162.6	152 26 131.6	144 26 138.9	100 41 200.0	66 13.3 303.0	79 6 253.2	88 22 227.3	104 35 192.3	55 26 363.6	41 6 487.8	47 7 425.4	48 13 416.7	68 31 294.1
3000	272 43 110.2	227 25 132.2	207 10 144.9	259 42 115.8	239 32 125.8	162 66 185.2	115 25 260.9	124 12 241.9	134 27 223.9	164 43 182.9	89 39 397.3	62 8 483.9	71 9 422.5	78 19 384.6	97 35 309.3
4000	403 150 99.3	348 35 114.9	292 14 137.0	318 64 125.8	360 47 111.1	237 90 168.8	164 34 243.9	171 15 233.9	183 30 218.6	229 53 174.7	129 64 310.1	90 9 444.4	103 11 388.3	105 19 381.0	129 37 310.1
5000	585 301 85.4	443 57.5 112.9	430 90 116.3	570 128 87.7	578 91 86.5	320 117 156.3	224 51 223.3	226 16 221.2	233 43 214.6	290 62 172.4	185 80 270.3	116 17 431.0	132 12 378.8	135 25 370.4	163 39 306.7
6000	726.8 396 82.6	650 78 92.3	541 90 110.9	913 235 65.7	653 204 91.9	402 201 149.2	304 67 197.4	289 21 207.6	297 48 202.0	361 67 166.2	194.5 85 308.5	141 25 425.5	171 12 350.9	171 25 350.9	211 46 284.4
7000						545 227 128.4	378 79 185.1	360 25 194.4	347 70 201.7	407 73 172.0	223 79 313.9	167 35 419.2	186 15 376.3	203 30 344.8	262 69 267.2
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

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 psi. Subsequently, any marked variation in concrete strengths was readily detected in the deflection values from the specimen loading tests. Specimens with concrete strength and deflection values which were obviously out of line were discarded and new specimens prepared and tested.

tion 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 2 and 3.

Load Deflection Characteristics—The load deflection characteristics for the various dowel units at joint openings of 1 in. and 3/4 in. are presented graphically in Figures 11, 12, and 13. The curves in Figures 11, 12, and 13 represent the relationship between shear force, deflec-

tion, length and diameter of dowels for the two joint spacing distances of 1 in. and $\frac{1}{2}$ in. Each point on the curves is an average of three test values.

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

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 2 and 3 and presented graphically by curves in Figure 14. The data bring out the inherent weakness of the $\frac{3}{4}$ -in. dowel in this respect and for low shear values there is very little difference between the 1-in. and $1\frac{1}{4}$ -in. dowels. It is logical to expect, however, that the $1\frac{1}{4}$ -in. dowel should have a lower residual

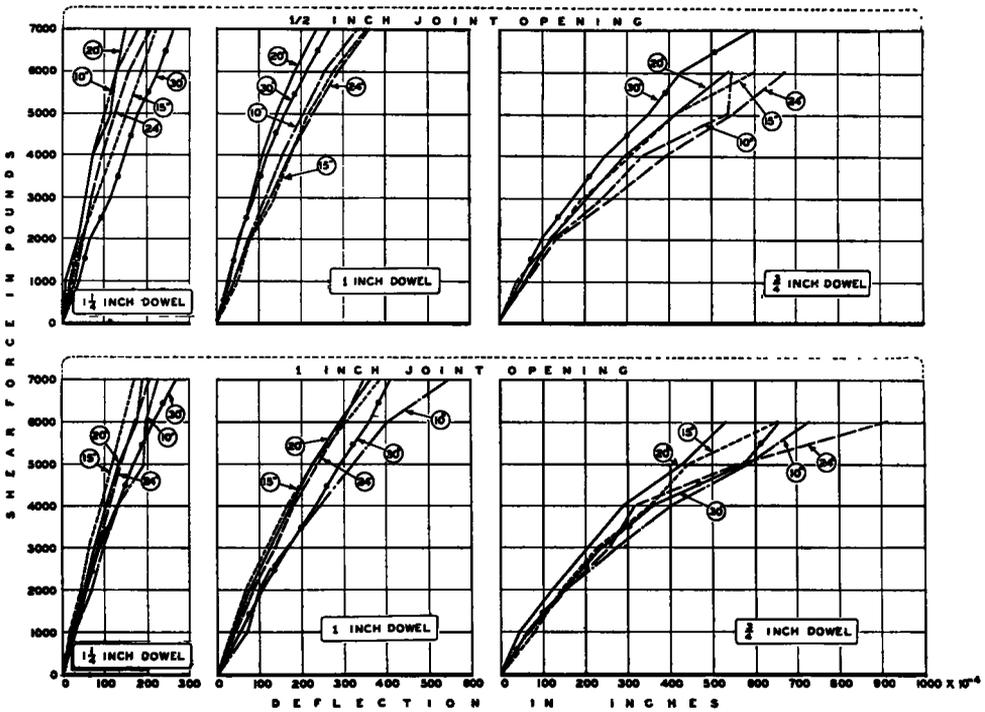


Figure 11. Effect of Dowel Length on Deflections—for Dowels of $\frac{3}{4}$ -in. Diameter

diameter exceeds 1 inch; third, dowels have greater resistance to deflection as the joint opening decreases, but a change from 1 inch to $\frac{1}{2}$ inch was not sufficient to develop marked 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

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.

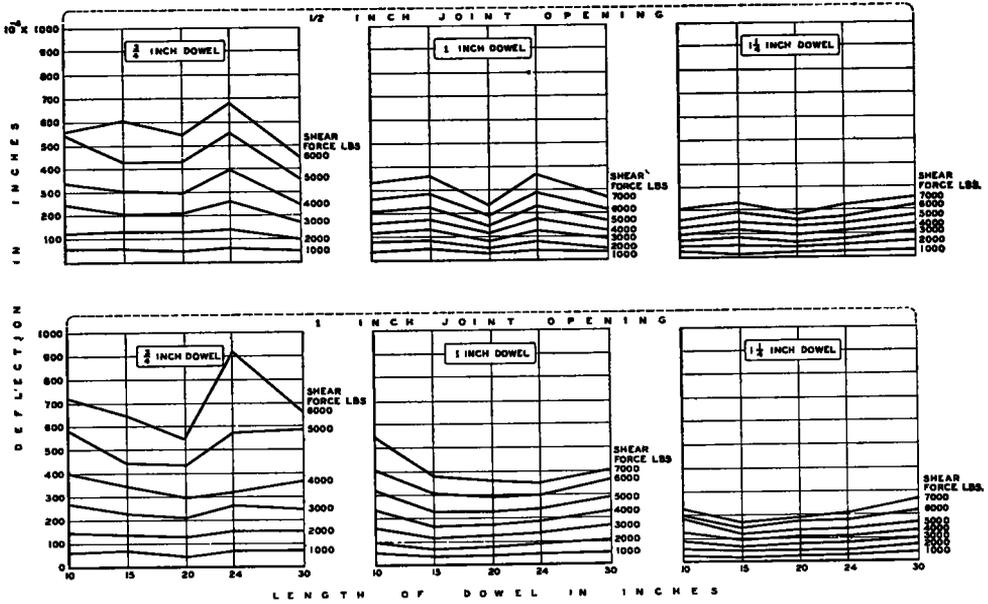


Figure 12. Effect of Dowel Length and Diameter on Deflection for Joint Openings of 1 in. and 1/2 in.

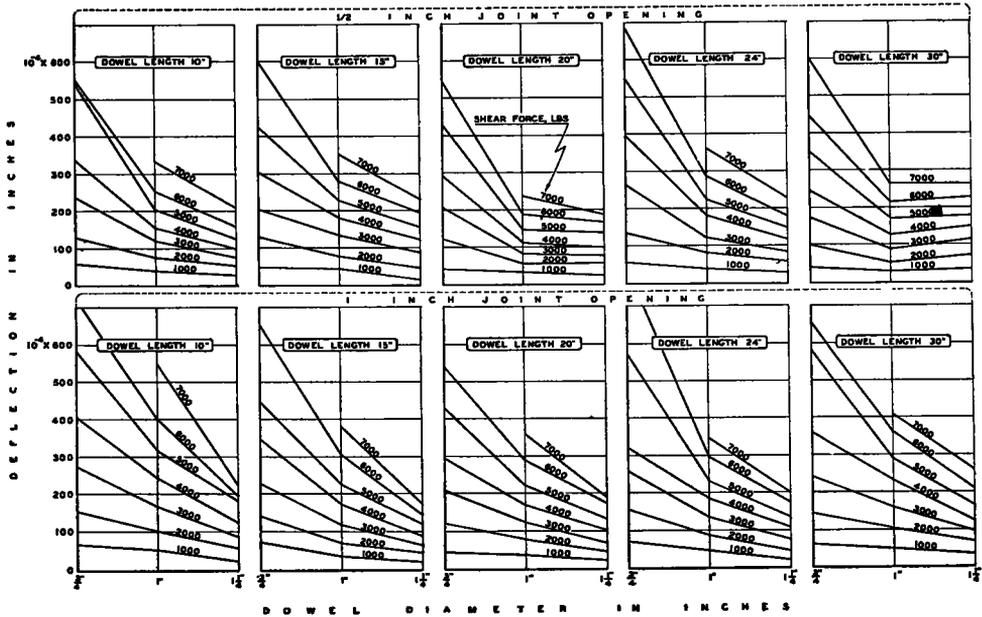


Figure 13. Effect of Dowel Length and Diameter on Deflection

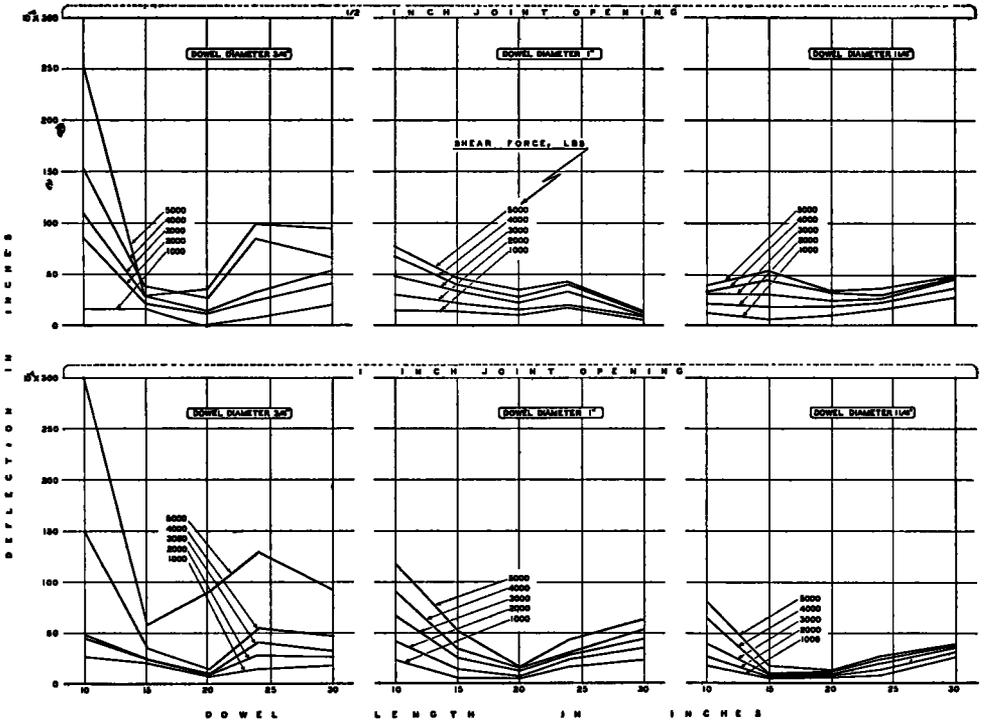


Figure 14. Effect of Dowel Length on Residual Deflection

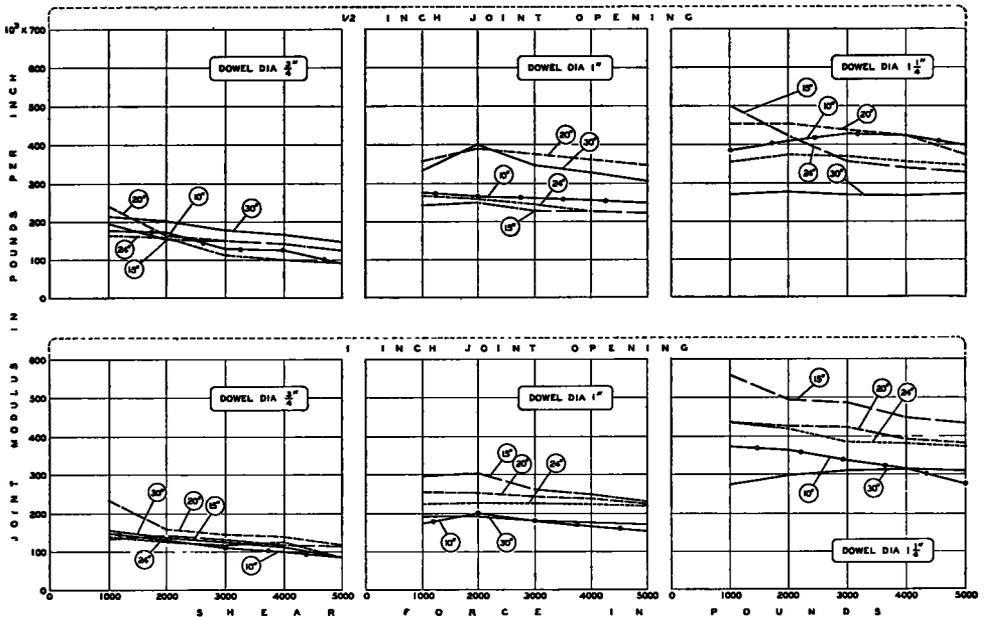


Figure 15. Effect of Dowel Length on Joint Modulus

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 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.

SUMMARY

We do not regard the results of this study as conclusive, but we feel that sufficient evidence has been adduced 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 in. are relatively ineffective in controlling deflections under normal shear loads. On the other hand, dowels with diameters greater than 1 in. 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 in. 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.

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