AN EVALUATION OF LOAD TRANSFER DEVICES IN CONCRETE PAVEMENT JOINTS

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An Evaluation of Load Transfer Devices In Concrete Pavement Joints

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AN EVALUATION OF LOAD TRANSFER DEVICES IN CONCRETE PAVEMENT JOINTS

FIELD STUDIES

PURPOSE

Field studies have been made by the Michigan State Highway Department Research Laboratory for the purpose of evaluating load transfer units of different types and under different conditions. The evaluation of these load transfer units was made from the standpoint of efficiency, per cent load transferred, and their general desirability when incorporated in the design and construction of concrete pavements. These field studies were conducted on US-12 near Jackson, M-78 near Lansing, and the Michigan Test Road M-115.

This report is intended to compare the data and information gathered on these different types of load transfer units with an ideal load transfer unit, and after comparing the actual units with the ideal unit, to draw some conclusions as to the most desirable units which were investigated.

Due to the many factors which enter into the choosing of the most desirable load transfer unit, it would be impossible to consider them all in the time allotted for this report. Therefore, this report will be limited to the per cent efficiency of the joint as the basis for the evaluation of each joint.

LOAD TRANSFER UNITS

Load transfer units are intended to eliminate cracking of the pavement slab caused by stresses which occur at the free edge of an otherwise continuous concrete slab. These stresses and cracks might be due to several causes or a combination of existing conditions in the slab, subgrade, and different loadings.

The concrete slab expands and contracts due to temperature changes. Therefore, the joints must permit safe expansion and contraction. The difference in temperature between the top and bottom of the concrete slab causes curling which must be permitted without the introduction of undesirable stresses.

The presence of unstable and non-uniform subgrades creates stresses at the joints which must be considered. The temperature of the subgrade will affect the performance of the joint in transferring load.

Vertical loads must be transferred from one slab to the other safely. The pulsating and repeating action of the load must be considered, and the deflections and stresses caused by the vertical loads must be within the allowable limits of good design.

Ideal Load Transfer Unit

The ideal load transfer unit would be one which was economical, easily constructed, and still perform the purposes set forth in the preceding paragraph.

In using efficiency as a basis of comparison we will assume the ideal joint to be 100% efficient when 50% of the load is transferred. A formula which has been developed experimentally is used to determine the per cent load transferred. The formula is based on the deflections of the slab at the joint and is used as follows:

a = deflection on the unloaded side of the joint.

b = deflection on the loaded side of the joint

$m = b - a$

$$\% \text{ Load Transferred} = \frac{100\,a}{2a + m}$$

RESULTS

Tests Made on M-78, Lansing

Field studies were made to determine the ability of the pavement joints, both grooved and premolded strip types, to transfer load. The procedure involved the application of a concentrated load on either side of a joint and measuring the simultaneous effect produced on both sides. In order to subject the joints to a sever test a load of 18,000 pounds was used, and the load was oscillated back and forth over the joint 50 times. The deflection of the slab was measured on either side of the joint and out as far as effect of the load was transmitted. The deflections were measured after the initial load and after the 50 applications of the load. Three positions of loading were used; center loading, quarter point loading, and corner loading. See Figure 1 for the positions of the dials and load. The loads were applied separately to the three positions of the 9 inch uniform 10 foot pavement.

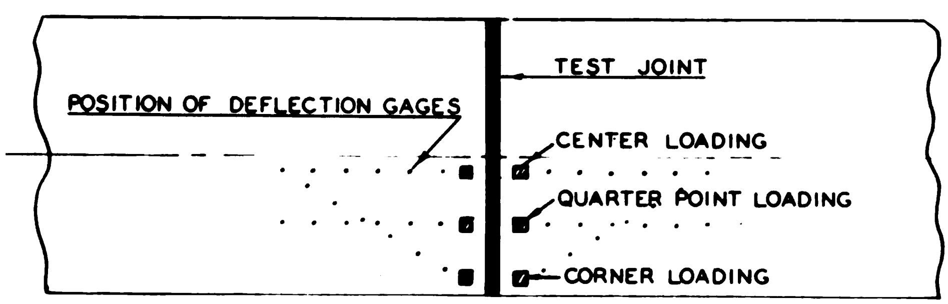

FIGURE 1

Figure 1.

TABLE 1

	Type of Joint	Center Loading	Per Cent Load Transferred Quarter Point Loading	Corner Loading	Average	Average Efficiency Per cent
Grooved Type	A	31.0	38.0	40.0	36.3	73.0
	B	37.0	43.0	36.0	38.7	77.4
	C	37.0	34.0	27.0	32.7	65.4
	D	30.0	34.0	32.0	32.0	64.0
Premolded Strip Type	E	28.0	31.0	36.0	31.7	63.4
	F	20.0	21.0	21.0	20.7	41.4
	G	20.0	26.0	17.0	21.0	42.0
	H	27.0	20.0	11.0	19.3	38.6
	I	23.0	14.0	16.0	17.7	35.4

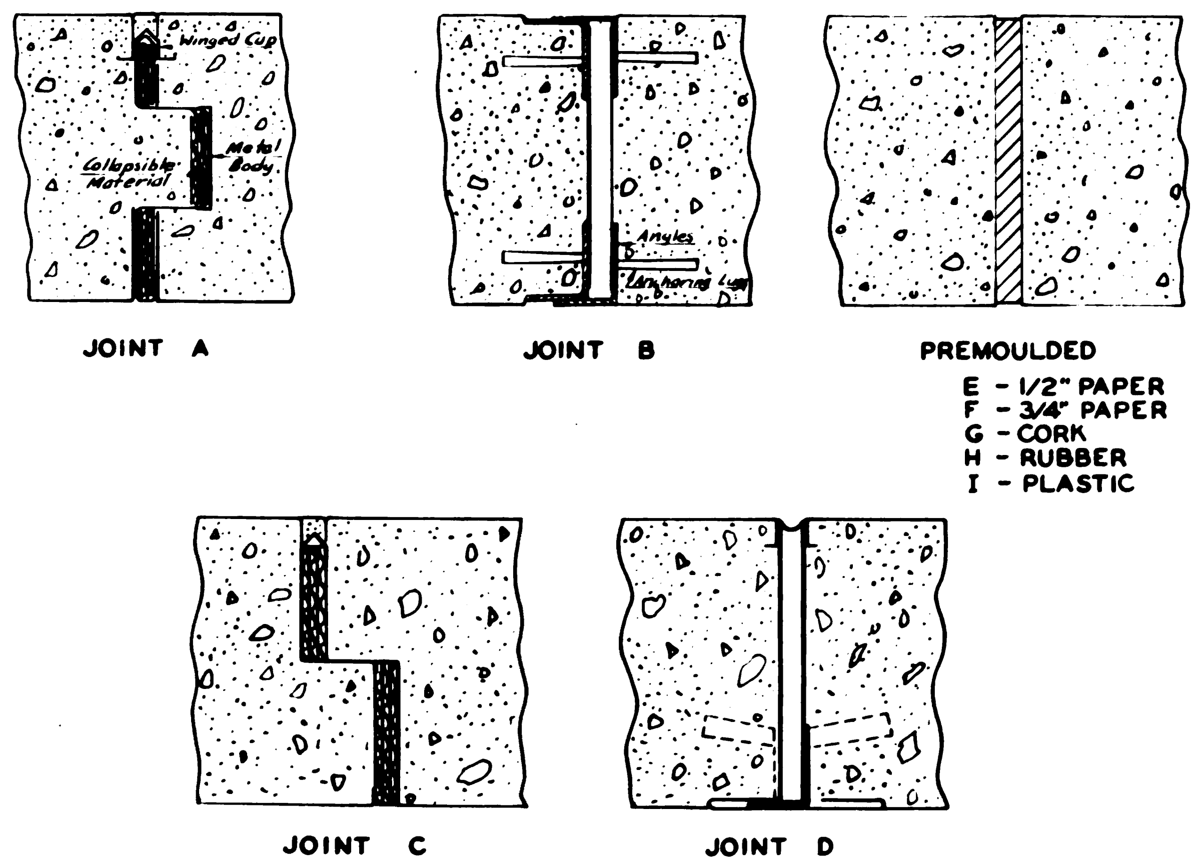
Winged Cup
Metal Body
Collapsible Material
JOINT A
Angles
Anchoring Lugs
JOINT B
PREMOULDED
E - 1/2" PAPER
F - 3/4" PAPER
G - CORK
H - RUBBER
I - PLASTIC
JOINT C
JOINT D

FIGURE 2

From the three sets of deflections the per cent load transferred for each loading was computed and averaged together to obtain the average per cent load transferred by the joint. The average efficiency was then determined from the average per cent load transferred. Table 1 lists the results obtained for each type of joint. The joints are designated by the letters A, B, C, D, E, F, G, H, and I. Figure 2 shows the type of joint corresponding to the above letter designation.

Tests Made on US-12, Jackson

The tests were made on the expansion joints in the northern lane, 11 feet in width, 8 inches thick, of a new three lane concrete pavement between Ann Arbor and Jackson. The purpose of the tests was to determine the efficiency indexes for expansion joints.

Five different types of joint construction were tested and appear in this report under letters J, K, L, M, and N. All of the joint openings were 1 inch and filled with premolded bituminous filler.

A load of 10,000 pounds was applied at the center of the slab as shown in Figure 3. The deflections were located in two rows one each side of the joint, see Figure 3.

Three different methods were used to determine the efficiency index. These methods are based on deflections, average stresses, and maximum stresses. The derivation and computation for these different methods may be obtained from the report "Efficiency Indexes for Pavement Expansion Joints" by W. O. Fremont.

The tabulated results for the different types of joints is recorded in Table 2. The photographs show the construction of the different types of joints under the corresponding letter designation as is used

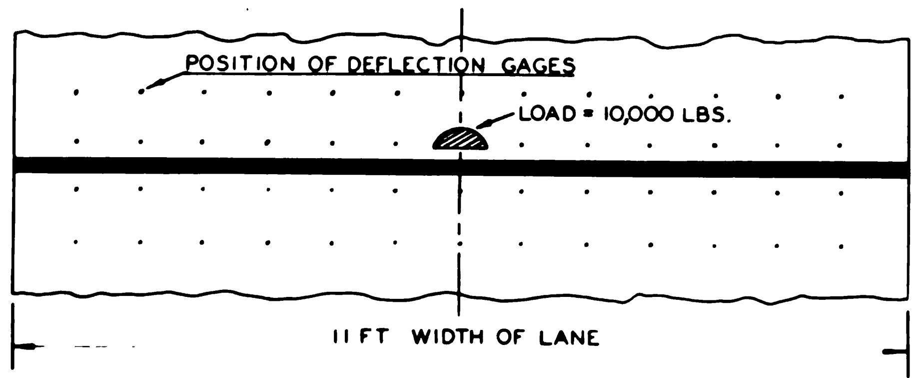

FIGURE 3

Figure 3.

in Table 2. Photographs of Joint M, which is of the plate type, are not available.

Tests Made on Michigan Test Road M-115

Tests were made on expansion and contraction joints of the Michigan Test Road. In all, eight different types of joint construction were investigated. These tests were conducted during the summer, winter, and spring so as to determine the seasonal effect on the performance of the joint.

The tests were made at the joint to determine the deflections caused by a load just as it approaches the joint. Figure 8 gives the position of both the load and the deflection gauges. The hind wheels of the truck caused a load of 18,000 pounds on the slab. The front wheels were far enough ahead to avoid causing any effect on the joint

TABLE 2

Type of Joint	Efficiency Indexes Based on Deflections	Average Stress	Maximum Stress	Average Efficiency Index %
J	73	38	47	53
K	70	40	76	62
L	54	36	54	48
M	54	10	21	28
N	58	---	---	19

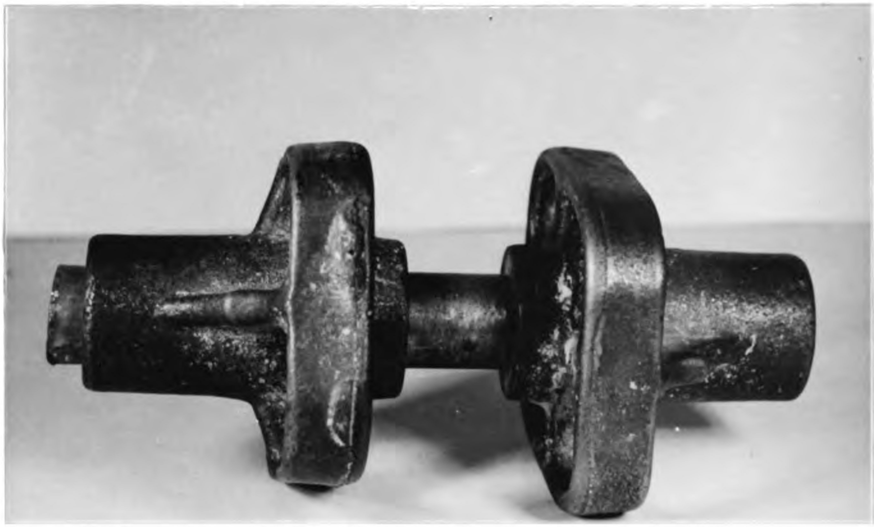

Figure 4. Joint J.

Figure 5. Joint K.

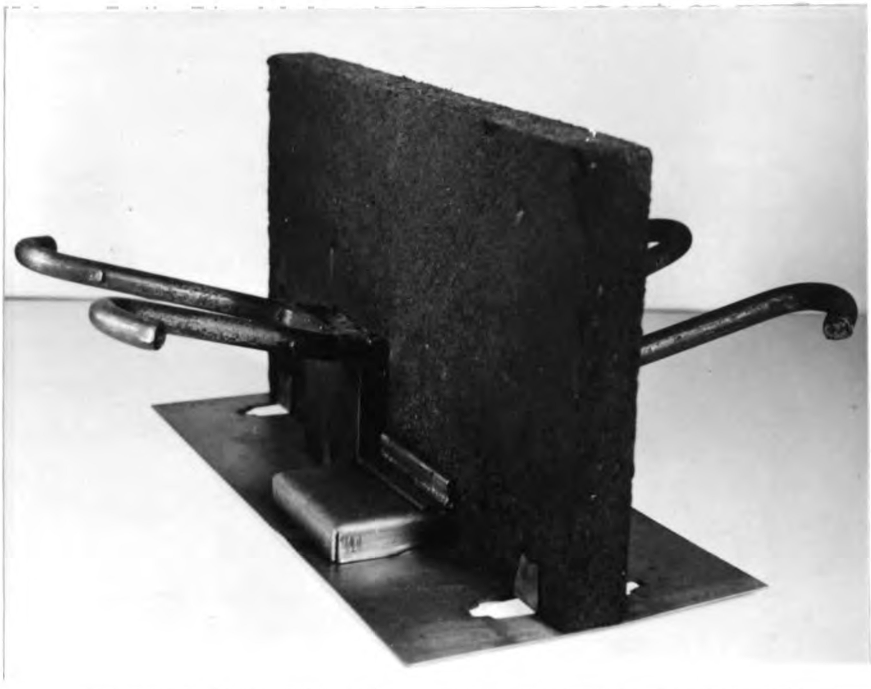

Figure 6. Joint L.

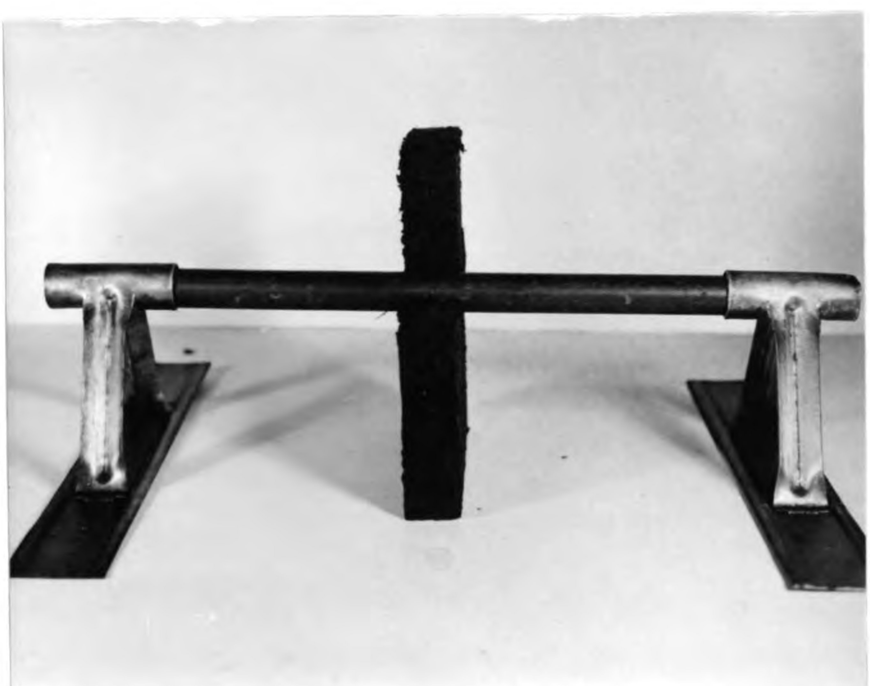

Figure 7. Joint N.

Figure 8.

being investigated. Deflections were measured on both the loaded and unloaded side of the joint.

The computation involved finding the per cent load transferred for each device from the deflections. The same type of joint was installed at several stations along the pavement. Therefore, an average was found for each joint. Then, to obtain the figures listed in Table 3 the average for each season was averaged to obtain an overall average for each load transfer unit. Table 3 shows the efficiency for each unit, and a brief explanation of each joint.

TABLE 3

Type of Joint	Per Cent Load Transferred	Per Cent Efficiency
O	45.5	91.0
P	37.1	74.1
Q	47.6	95.6
R	40.2	80.2
S	40.8	80.8
T	26.5	53.0
U	9.9	19.8
V	34.3	68.5

CONTRACTION JOINTS (Joint Opening 1/2 inch)

O - type DB - 3/4 x 15 inch Dowel Bars, premolded filler.

P - type 4, Contraction plate dowel assembly.

Q - type CB - 1-1/4 x 18 inch Dowel corner bar assembly, premolded filler.

EXPANSION JOINTS (Joint Opening 1 inch)

R - type DB - 1, 3/4 x 15 inch Dowel Bar expansion joint assembly.

S - type TE, Thickened edge 1-1/4 x 18 inch corner dowel bar expansion joint assembly.

T - type CB - 1, 1-1/4 x 18 inch corner dowel bar expansion joint assembly, edge unthickened.

U - type TB, Translode base expansion joint assembly.

DUMMY JOINTS

V - type R - Aggregate interlock, steel mesh reinforcement, continuous through joint.

Pictures showing the type joints in this test are not obtainable. Due to the fact that most of the joints were of the dowel type, the picture below is included to give a general idea of the construction of the dowel type joint.

Figure 9.

SUMMARY OF FIELD STUDIES

The following conclusions, relative to the load transfer properties of joints, may be drawn from the field studies covered in this report.

1. - The grooved type joint is more efficient than the premoulded strip type.
2. - The efficiency of a joint is reduced when the width of the joint is increased.
3. - Aggregate interlock is effective in transferring load.
4. - The subgrade modulus varies from time to time, and has a marked effect on the performance of the joint. Therefore, it follows that in order to get a comparative test, the tests should be run under the same conditions and the same methods used on each type of joint.
5. - The dowel type joint constructed in the Michigan Test Road seemed to produce the best overall results. Table 4 presents all the joints covered in this report tabulated in order with the most desirable joint first.

TABLE 4

Highway	Joint	Per Cent Efficiency
M-115	Q	95.6
M-115	O	91.0
M-115	S	80.8
M-115	R	80.2
M-78	B	77.4
M-115	P	74.1
M-78	A	73.0
M-115	V	68.5
M-78	C	65.4
M-78	D	64.0
M-78	E	63.4
US-12	K	62.0
US-12	J	53.0
US-12	T	53.0
US-12	L	48.0
M-78	G	42.0
M-78	F	41.4
M-78	H	38.6
M-78	I	35.4
US-12	M	28.0
M-115	U	19.8
US-12	N	19.0

AN EVALUATION OF LOAD TRANSFER DEVICES IN CONCRETE PAVEMENT JOINTS

LABORATORY STUDIES

The primary purpose of load transfer across pavement joints is to eliminate cracking of the pavement slab and subsequent deterioration of the concrete. It is also desirable to preserve alignment of the pavement in order to maintain a smooth riding surface.

Because of the continual appearance on the market of new mechanical load transfer devices, it is imperative that engineers know the mechanical and physical characteristics of all types of load transfer devices, and can predict with reasonable accuracy the performance of such devices in order that they can be intelligently designed and properly spaced in a pavement joint.

In 1934, the Michigan State Highway Department started a comprehensive investigation into the evaluation of load transfer devices. The first phase of the investigation was concerned with the development of a test procedure and method for determining the relative efficiency of various types of load transfer devices. This investigation resulted in the design and construction of a testing apparatus and procedure for use in laboratory studies, a complete description of which may be found in the Proceedings of the Twenty-seventh Annual Meeting of the Highway Research Board, December 1947. It is this test apparatus and procedure which was used in evaluating the various devices considered in this study.

PURPOSE

The primary purposes of this study are as follows:

1. To establish a standard type of load transfer device which

would satisfactorily distribute loads across a joint while keeping the slabs in vertical and horizontal alignment to the end that such a standard could be used in the evaluation of other types of devices.

2. To test and evaluate various types of load transfer devices now in use along with proprietary types of devices submitted by various manufacturers with respect to the standard established above.

PROCEDURE

One method of evaluating any type of load transfer device is the comparison of the joint modulus of the device with that of a standard type of device which meets the minimum requirements of load transfer.

"Joint modulus" is the term designated to the value obtained by dividing the shear on the faces of the slab for any particular loading by the relative deflection of the slabs and is a measure of the stiffness of the load transfer unit.

The joint modulus may be found by use of the testing apparatus and procedure referred to in the introduction, an example of which is included in this report. After determining the joint moduli of the various types of devices, the evaluation of any device becomes a simple process. All devices with a joint modulus equal to or greater than the joint modulus of the standard are satisfactory in the performance of load transfer. All devices with a joint modulus less than that of the standard are unsatisfactory.

The load transfer devices selected for evaluation are shown on the following pages.

Devices to be Evaluated

A - 1 x 7/8" square steel bar (SAE 1020)

B - Rigid dowel (welded steel 3/4 x 15" - steel frame)

C - Hollow steel pipe

D - Pipe dowel 1-1/4" diameter

E,F - Aggregate interlock (dummy joint with plane of weakness)

G - Aggregate interlock (with mesh)

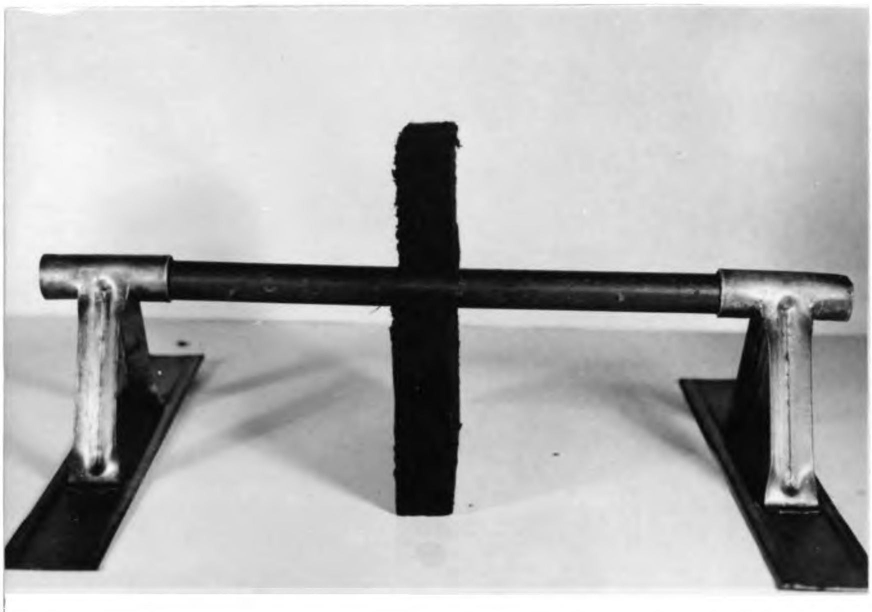

Figure I. Devices H, I, J, K, and L.

H - 3/4 x 15" dowel (structural steel)

I - 3/4 x 15" dowel (rail steel)

J - 3/4 x 15" dowel (SAE 1020)

K - 3/4 x 15" dowel (with washer)

L - 1-1/4 x 15" dowel (SAE 1020)

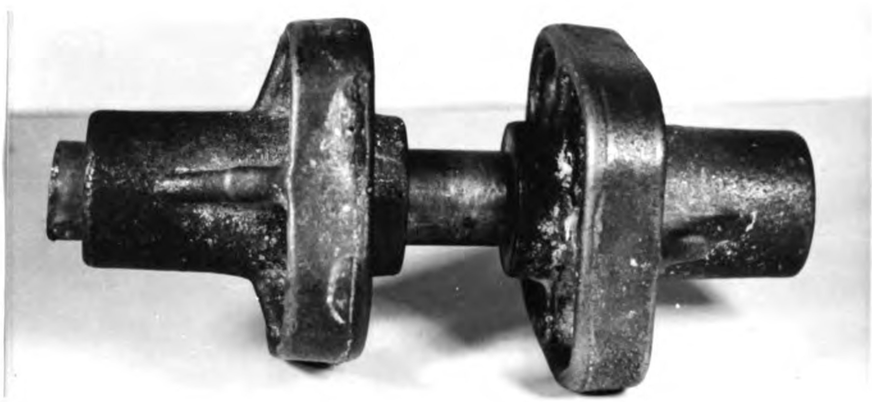

Figure 2. Devices M, N, O, and P.

M - 3/4 x 15" dowel, SAE 1020

N - 1-1/4 x 15" dowel, SAE 1020

O - 3/4 x 15" dowel, cast iron

P - 1-1/4 x 15" dowel, cast iron

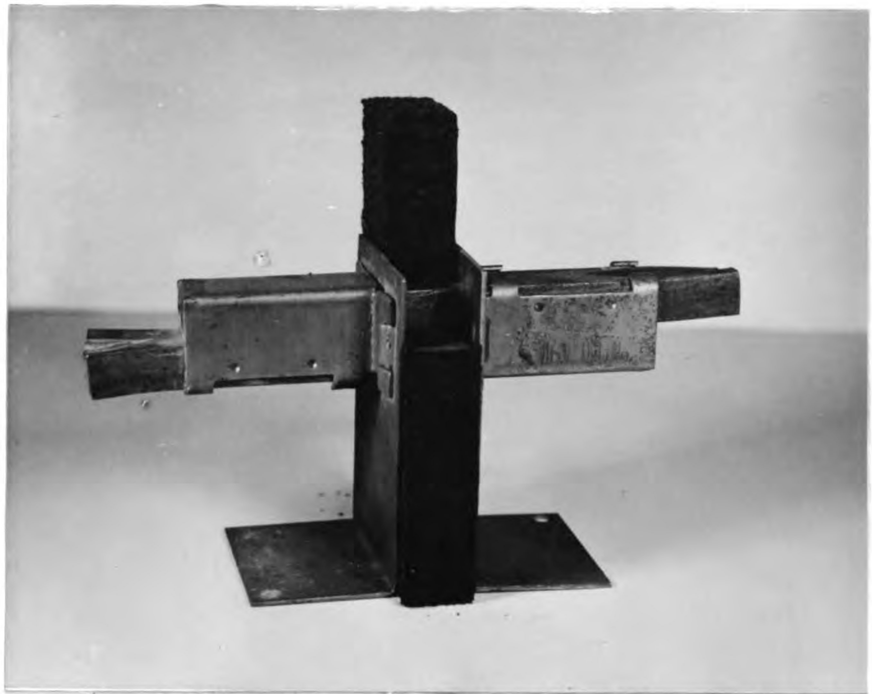

Fig. 3. Device Q

Fig. 4. Devices R and S.

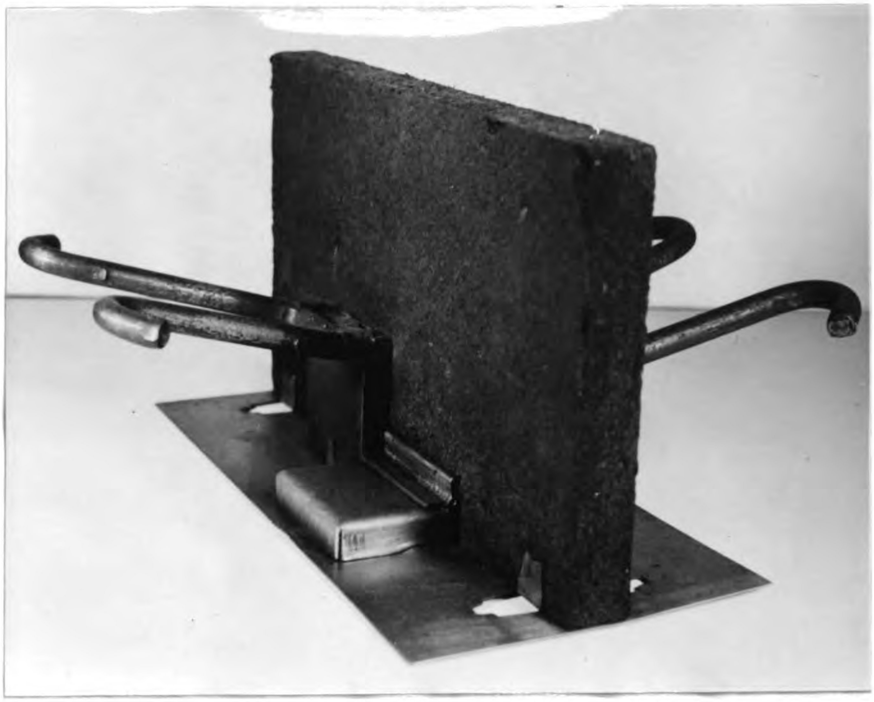

Fig. 5. Device T.

Fig. 6. Device U.

Fig. 7. Device V

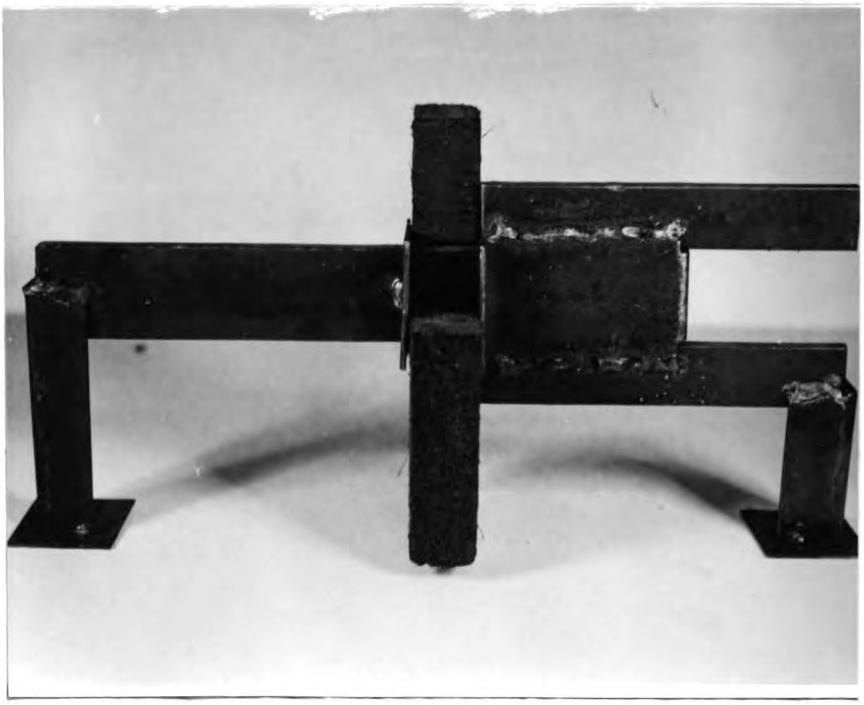

Fig. 8. Device W.

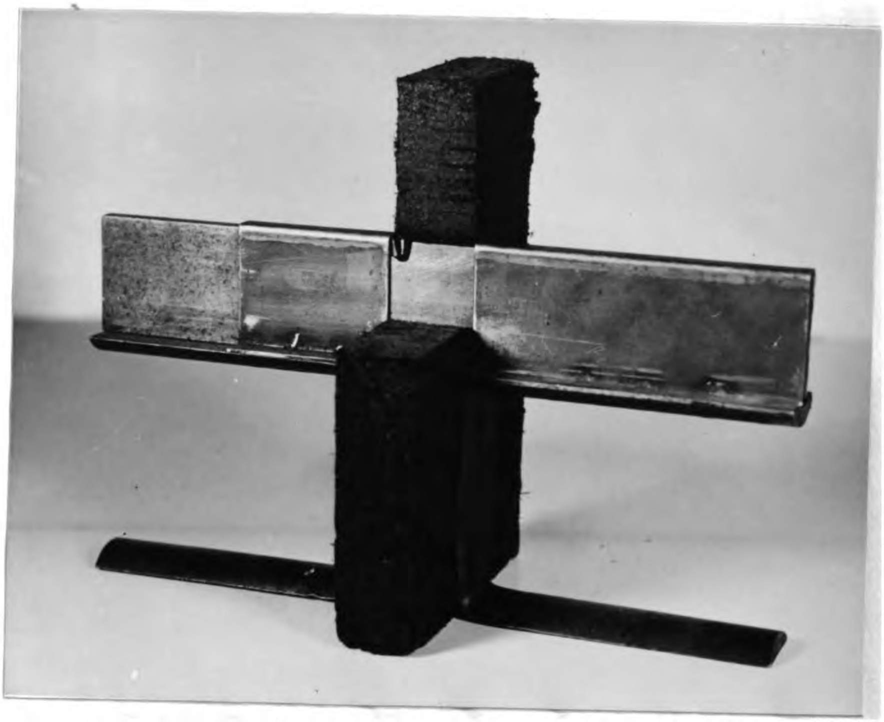

Fig. 9. Device X.

TESTING APPARATUS

The device to be tested is cast in a mold such as is shown in Figure 10, the dimensions of which are 12 inches in width, 7 inches in depth, and 15 inches in length for each half of the mold. The mix is made up of standard portland cement, 2 NS sand, 6 A washed gravel, and water combined in such proportions as will give a compressive strength to the concrete of about 3,000 pounds per square inch when seven days old.

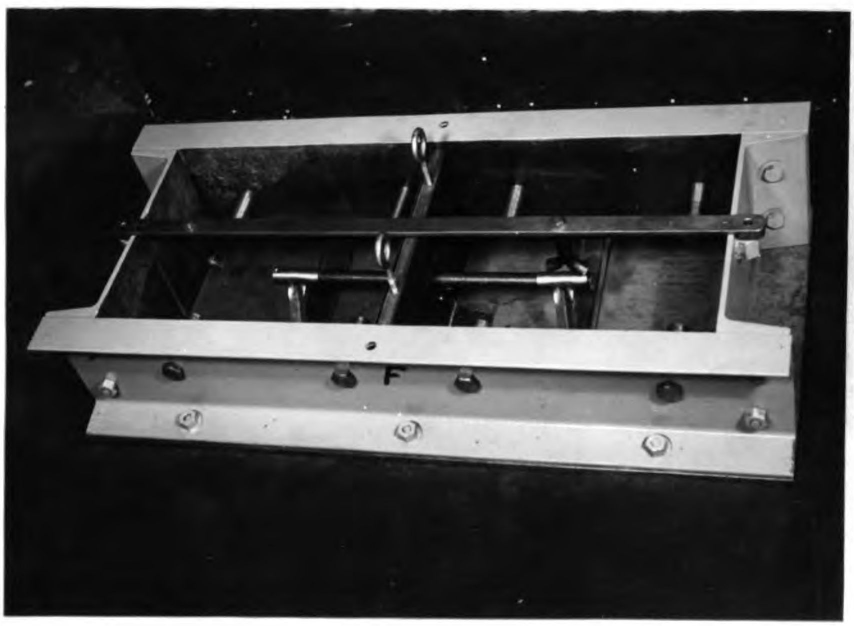

Fig. 10

After final set has taken place, which usually requires one day, the specimen is removed to the moist room and placed upon a rack which is shown in Figure 11, after which the specimen is allowed to cure for six more days.

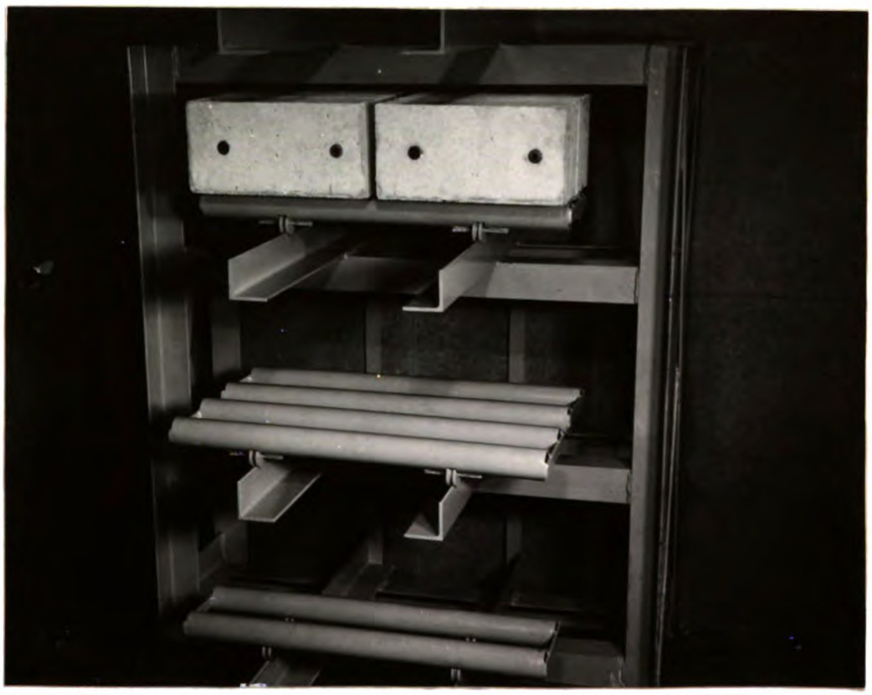

Fig. 11

After curing for a total of seven days, the specimen containing the load transfer device is taken from the moist room and set up in the testing machine shown in Figures 12a and 12b.

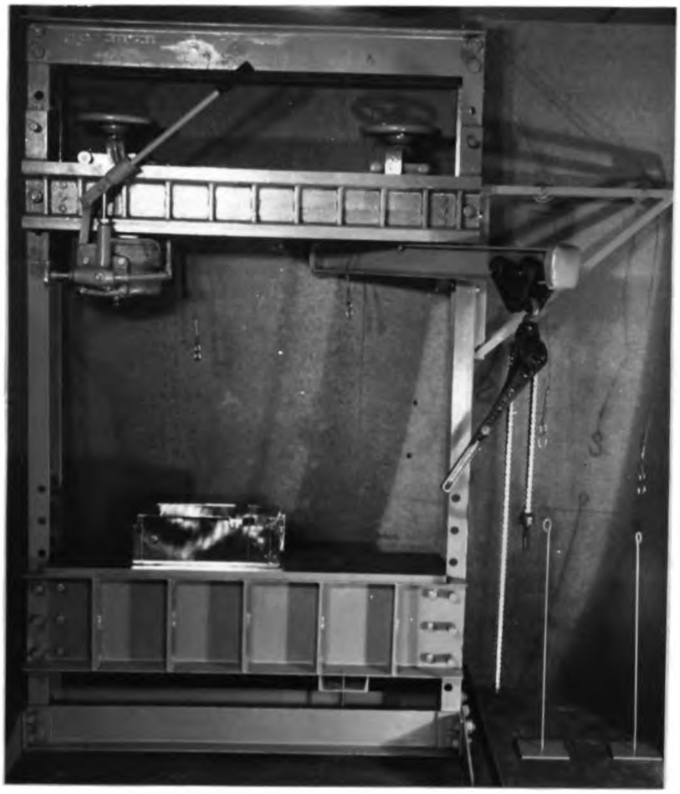

Figure 12a

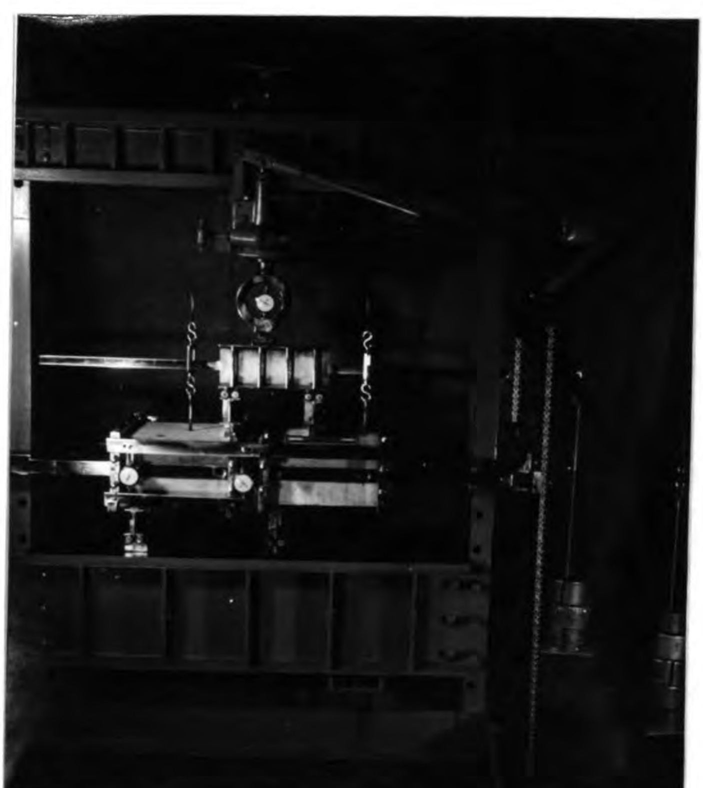

Figure 12b

The testing machine is so rigged that when a load is applied to the specimen by the hydraulic joint through the proving ring, the shear on the load transfer unit is equal to half of the applied load. Thus, the shear for any particular deflection is known. The relative deflection between the two slabs containing the load transfer unit is determined through use of a system of dial indicators. Readings are taken from the dials each time the load on the specimen is increased. The load is increased in increments of 400 pounds until the unit fails. Failure may occur through cracking of the concrete, or, what is more important, through permanent or excessive deflection of the unit itself.

Knowing the shear and the deflection for any particular loading, the joint modulus may then be determined as shown in Table I.

Many of the load transfer units will not withstand shears of 6,000 pounds. This, however, is more than adequate and it was decided to base comparisons of the joint moduli on values obtained under 4,000 pounds of shear.

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

Load	Shear Force V	Front Side: Auxiliary Deflections in 10^{-6} in.				Back side: Auxiliary Deflections in 10^{-6} in.				Computations in 10^{-6} in.[a]					Joint Modulus J.M.
		Dial D_1	Diff. d_1	Dial D_2	Diff. d_2	Dial D_1	Diff. d	Dial D_2	Diff. d_2	d_1 ave.	m_1d_1	d_2 ave.	m_2d_2	Total Def. m	
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	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

[a] For joint opening of 1 in. $m_1 = 1.00135$, $m_2 = -0.0662$. For joint opening of ¼ in. $m_1 = 1.00135$, $m_2 = -0.0338$.

$m = m_1d_1 + m_2d_2$

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

DATA

Since a dowel is one of the most common and simple types of load transfer devices, it was decided to select some form of it as a standard. It would then be necessary to determine only the diameter, length, and spacing of the dowel.

The Public Roads Administration, during the past several years, has tested a limited number of dowels in which the spacing of the dowels across the joint was varied. Four dowel spacings of 12, 18, 27, and 36 inches were investigated. It was found that joints with dowel spacings of 18, 27, and 36 inches were rather ineffective in controlling stresses while the joint with 12-inch spacing of dowels was quite high in this respect. This leads to the conclusion that dowel spacing, as might be expected, is an important consideration.

However, according to previous field and laboratory studies of the Michigan State Highway Department, dowel diameter is the most important factor in controlling deflection. Dowels with diameters less than 1 inch are relatively ineffective in controlling deflection under normal shear loads. The inherent weakness of the 3/4-inch dowel in regard to residual deflection was brought out in these studies. This particular dowel has proven to be one of the most inefficient joint units in use. It is pointed out, however, that a 1-1/4-inch dowel presents little decrease in residual deflection over the 1-inch dowel, with the larger dowel tending to rupture the concrete before failing in flexure.

These same studies by the Michigan State Highway Department show that a dowel length of 15 inches is the most desirable, since there is very little increase in efficiency for dowels of greater length, while a considerable decrease in efficiency is encountered in dowels of lengths less than 15 inches.

The foregoing observations led to the selection of a 1-inch diameter structural steel dowel, 15 inches long and spaced 12 inches apart across the joint, as the standard type load transfer device by which other devices may be evaluated. The joint modulus of such a standard is 230 x 10^3 pounds per inch for a joint width of 1 inch. Generally, joint modulus for any particular unit decreases with an increase in joint width, with a joint width of 1 inch being the maximum considered in this report.

The joint moduli of the devices being evaluated are shown below.

Device	Joint Modulus	Joint Width (Inches)
A	560 x 10^3 #/inch	1
B	0	1
C	211	1/4
D	338	1/4
E	255	1/16
F	524	0
G	241	0
H	200	1
I	180	1
J	260	1
K	265	1
L	485	1
M	355	1
N	570	1
O	290	1
P	1040	1
Q	350	1
R	354	1
S	988	1/16
T	240	1
U	205	1
V	250	1
W	220	1
X	134	1/16

RESULTS

The following designated devices were found to be satisfactory in the performance of load transfer since they produced joint moduli which were equal to or greater than the joint modulus of 230 x 10^3 pounds per inch for the device selected as a standard.

1-inch	joint	width	-	C, D, E, F, G, H, J, L, M, N, O, P
1/4 "	"	"	-	S
1/16"	"	"	-	T, V
0 "	"	"	-	Y, Z

The following devices were found to be unsatisfactory by comparison with the standard.

1-inch	joint	width	-	A, B, I, K, Q
1/4 "	"	"	-	R
1/16"	"	"	-	U, W, X

CONCLUSION

The method used in this study in evaluating load transfer devices is a relatively simple process, once the joint modulus has been determined. However, finding the joint modulus involves considerable time and effort. There are a few other methods of evaluating devices. One is by the comparison of the efficiency developed by each device which necessitates the acquiring of more data than is needed when using joint modulus as a basis of evaluation. Another method involves the internal stresses built up in the slabs under loading which is by far the most complicated of the three methods herein mentioned.

The method of comparing joint moduli while not conclusive and probably no more accurate than any of the other methods, does offer an opportunity for evaluating an unlimited number of devices with what is probably a minimum of effort compared to other methods.

This study is only a phase of the evaluation of load transfer devices. The Michigan State Highway Department is now carrying on further studies involving different types of devices along with various joint widths.

REMARKS

Since these studies were made in cooperation with Testing and Research Laboratory of the Michigan State Highway Department, it was attempted, in each case, to evaluate as many types of devices as possible. This resulted in the evaluation of devices in the field and laboratory which do not necessarily correspond. The lack of time made it impossible to correlate the two reports and draw final conclusions.

It is suggested that the correlation of the two studies, along with evaluation of other types of devices, might be subject matter for a future thesis.

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