JOINT TESTING EXPERIMENTS WITH A THEORY OF LOAD TRANSFER DISTRIBUTION ALONG THE LENGTH OF JOINTS

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SYNOPSIS

This paper is a progress report on methods of testing pavement joints and is divided into two parts The first part describes a method of testing concrete pavement joints in shear, and gives results on several types The load deflection diagrams indicate that joints pass through three stages induced by load, and that the boundary between the second and third stages constitutes a critical point that can be used as a criterion in rating joints

The second part describes briefly a theory relative to the load distribution along an elastic joint in an elastic pavement resting upon a uniform-elastic subgrade The theory is developed by considering the elastic joint and two adjoining slabs of pavement as condensed to two elastic bars on two separate elastic foundations in two different levels, one above the other

JOINT TESTING EXPERIMENTS

It is generally accepted that expansion and contraction joints are indispensable in concrete pavements The usual practice is to place expansion joints at about 100 ft and contraction joints at about 30 ft intervals

The expansion joints must·

(1) Transfer vertical forces from one slab to the other safely
(2) Permit safe expansion and contraction of the joints
(3) Keep the deflection or jump over the joint within certain allowable limits.
(4) Be safe in the case where some irregularities occur in the elastic conditions of the subgrade
(5) Be safe under dynamic, repeated and pulsating action of the load
(6) Permit the curling of the slab without the introduction of undesirable stresses

Several ways may be chosen, separately or in conjunction with one another, for determining whether or not these conditions are satisfied by different types of joints

(1) It is possible to go into force and stress analyses of the joints and the adjoining slabs as one composite whole, based on certain assumptions about the elastic characteristics of the slabs and the subgrade.
(2) Verification by tests may be used.
(3) Analyses and tests may be used simultaneously for the same end.

Experiments, the aim of which was to find out to what extent some of the above

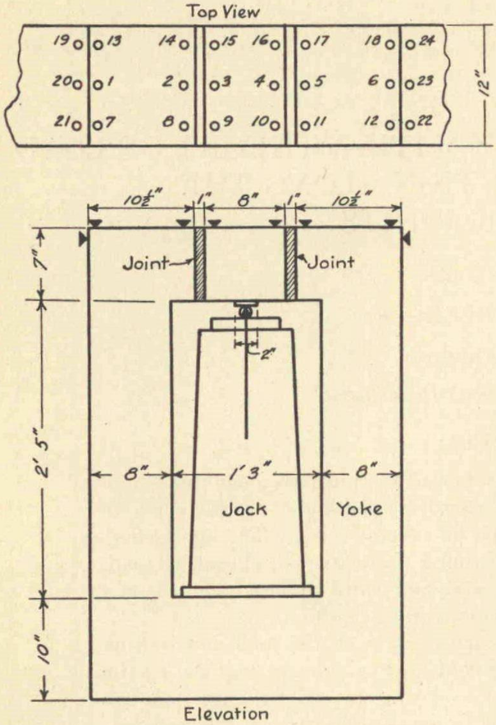

Figure 1. General Arrangement of Joint Tests

conditions are met by some kinds of joints, are described in this report.

As the elastic joints subjected to the tests work predominantly in shear, and the bending moments transferred are comparatively small, the tests were set up as *pure shear tests.*

For the preparation of the concrete "Peninsular" portland cement, having the characteristics presented in Table I was used for all the specimens.

The concrete, which had the characteristics presented in Table II, was of the type used in Michigan pavements, and contained six sacks of cement per cubic yard of concrete.

According to circumstances, these specimens were tested at different ages, but most of them were about 90 days old when tested.

The ultimate compressive strength was found to be around 5000 lb. per sq. in. at 90 days.

As it was desired to simulate service

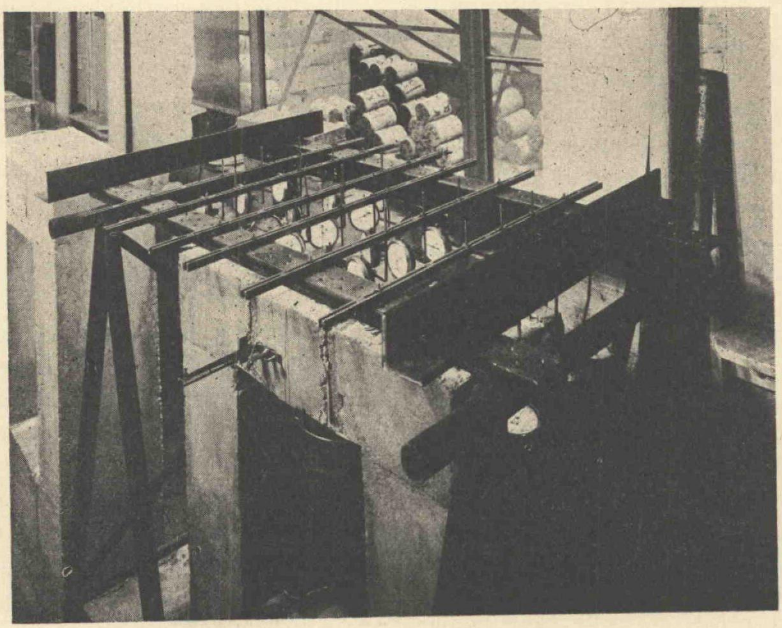

Figure 2

conditions as closely as possible the joints were put between concrete blocks, which were poured on both sides of the joints in the same way as in pavements.

GENERAL ARRANGEMENT

The general arrangement consists of a reinforced concrete yoke with a centre

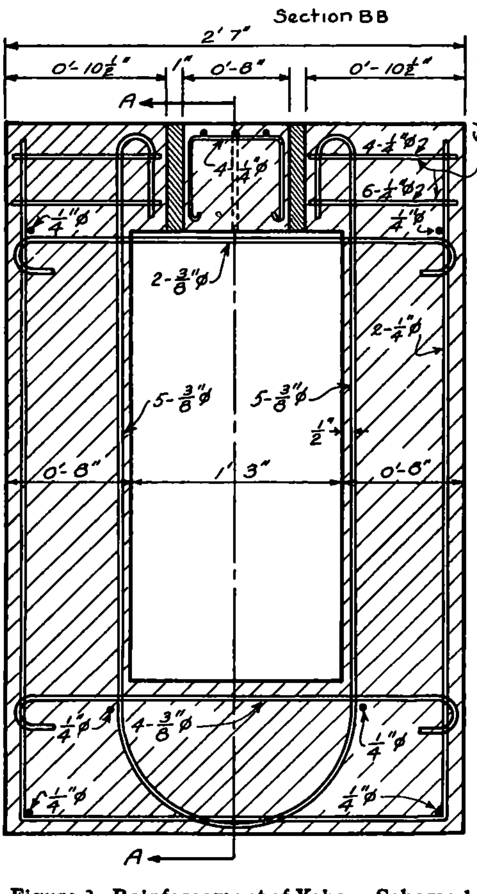

Figure 3 Reinforcement of Yoke. Scheme 1

piece connected with the yoke by two 12 in joints (Figure 1) Figure 2 is a picture of the set up

Two types of reinforcement of the yoke and the centre piece were used Scheme I is shown in Figure 3 and Scheme II is shown in Figure 4 The reinforcement according to Scheme I was intended to make the joint break before failure of the supports The reinforcement according to Scheme II was of lighter type and simulated the ordinary reinforcement of concrete slabs

MEASUREMENT OF DEFLECTIONS

The deflections were measured at 24 points by means of 24 Federal Dial Indicators, Model 5, graduated to 0 001 of an inch and permitting estimation of deflections to 0 0001 of an inch The positions

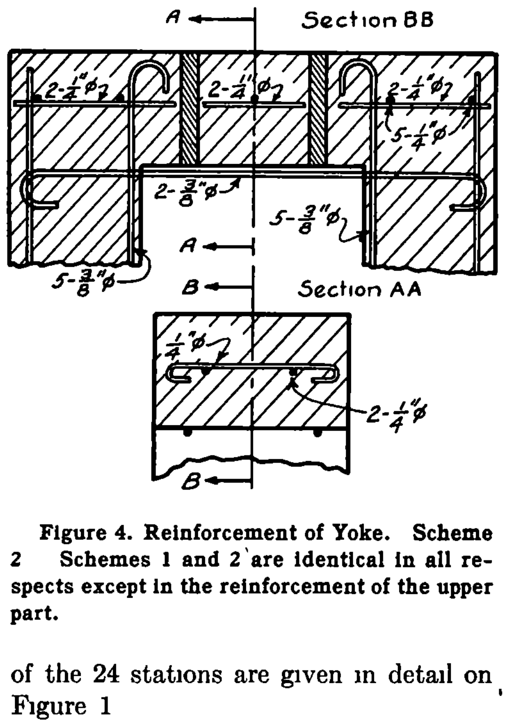

Figure 4. Reinforcement of Yoke. Scheme 2 Schemes 1 and 2 are identical in all respects except in the reinforcement of the upper part.

of the 24 stations are given in detail on Figure 1

The deflections were read after each application of a load, under the load, and without load after each removal of the load

The vertical deflections were measured at points 1 to 18 and the horizontal deflections at points 19 to 24

LOADING

The first application of load on most of the specimens was 2500 lb.; then this load was removed, after this a load of 5000 pounds was applied and removed, in a similar way loads of 7500, 10,000, 12,500, 15,000, 17,500 lb and so on were applied and removed, until the specimen failed

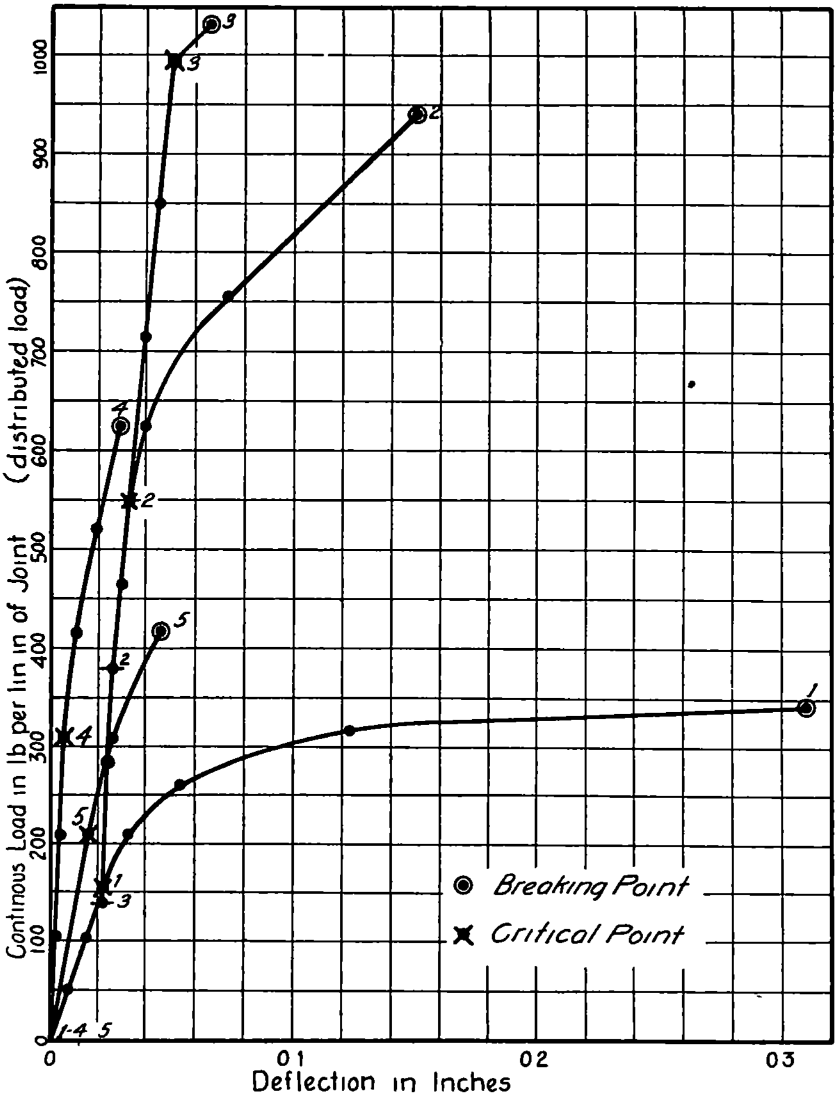

Figure 5. Load Deflection Diagrams

DESTRUCTION

The destruction was brought about either through the failure of the joints and their anchorage in the slabs or the failure of the supports or slabs, whichever occurred first

LOAD-DEFLECTION DIAGRAMS

The load-deflection diagrams given on Figure 5 show that

(1) The ultimate strengths of different kinds of joints in shear vary from 340 to 1025 lb per lin. in. of joint.

(2) Some types of the joints have an

initial adjustment range (stage No 1), in some cases this adjustment can be explained by special conditions of the laboratory set-up with an initial negative deflection For other joints this might be due to their elastic and design characteristics

(3) All of the joints tested have a second stage which follows closely the linear law, for some of the joints this second stage coincides with stage No 1 and then the straight line passes through the origin

(4) All of the joints possess a *critical point*, the boundary between the second and third stages

(5) Beyond the critical point the load deflection diagrams follow the curvilinear law, which is the third stage

(6) Beyond the critical point or very soon after passing the critical load, the residual deflections increase at a higher rate than before passing the critical point

Joints possessing initial adjustment stage evidently do not follow Hooke's Law As the residual deflections start very early, it is possible that the initial adjustment stage is accompanied by overstraining of the material of the joint itself or of the concrete Therefore, the initial behavior of the joint (stage one) deserves to be studied in detail

The second stage or that of rectilinear law is in some specimens very short, in others large

The third stage seems to be conditioned by some *destruction* taking place in the joint construction after the passing of the critical point, similar to the change in steel after the passing of the proportionate limit and the yield point Therefore, unless conclusive evidence to the contrary is obtained, the critical point should be considered, with regard to the safety of the construction, as the proportionate limit and yield point are considered in steel structures The *safety factor* of the joint should be evaluated by comparison of the maximum service load with the critical load

The ultimate load obtained under static conditions could not, therefore, be considered to be a decisive criterion of the serviceability of the joint construction

An attempt has been made to evaluate the maximum service load in joints theoretically under simplified assumptions

TABLE I

CHARACTERISTICS OF CEMENT

Laboratory No 35C–479 Brand Peninsular

	24 Hour Test	
	(4–16–35)	(6–19–35)
Normal Consistency	24 0	24 0
Time of Set		
Initial	3–35	2 40
Final	5–35	4 45
Soundness	OK	OK
Retained 200 mesh sieve		
Grams	4 6	4 1
Per cent	9 2	8 2
Sieve Corr	−1 5	−1 9
Fineness	7 7	6 3

Average Tensile Strength

7 day	368
28 day	453
7 day	383
28 day	462

LOAD TRANSFER DISTRIBUTION

In order to form some idea of the load distribution along an elastic joint in an elastic pavement resting upon a uniform elastic subgrade the following study has been undertaken

It is realized that this study is a first tentative rough approach to the solution of the problem

The elastic joint and the two adjoining slabs of the pavement are condensed to two elastic bars on two separate elastic foundations in two different levels one bar above the other The upper and the lower bars are connected by a continuous row of vertical elastic connecting rods lying in the principal vertical planes of both bars and simulating the elastic joint between the two slabs of the pavement

A concentrated load is applied to the lower bar and the distribution of this load between the two bars and along the joint is studied

TABLE II

CHARACTERISTICS OF CONCRETE

	4-23-35 A B	5-1 & 2-35 C D	5-7-35 E	5-21-35 F
Weight per cu ft of bone dry loose coarse aggregate, lb	96 16	97 5	97 5	98 0
Weight per sack of cement				
Cement, lb	94 0	94 0	94 0	94 0
Coarse Aggregate bone dry, lb	328 0	333 5	333 5	335 0
Fine Aggregate bone dry, lb	208 0	204 0	204 0	203 0
Water, lb	53 5	50 0	50 0	49 8
Slump, in	1 5	1 5	1 5	1 5
Compressive Strength, lb per sq in	5410			
Sacks of cement per cu yd of concrete	6	6	6	6
Peninsular Cement, specific gravity—3 12	3 12	3 12	3 12	3 12
Coarse Aggregate, Killins Sand & Gravel Co				
Specific Gravity	2 66	2 66	2 66	2 66
Absorption	1 6	1 6	1 6	1 6
Fine Aggregate, Killins Sand & Gravel Co				
Specific Gravity	2 59	2 59	2 59	2 59
Absorption	0 7	0 7	0 7	0 7
Relative Water Content	1 23	1 23	1 23	1 23

TABLE III

Type of Joint	Ult Strength per lin inch of joint—lb	Critical Load per lin inch of joint—lb	Deflection over Joint at Critical Load—in		Factor of safety Critical Load/200 lb
			Total	Residual	
1	340	150	0 022	0 004	0 75
2	940	530	0 033	0 010	2 65
3	1025	993	0 050	0 022	4 97
4	7625	310	0 005	0 001	1 55
5	415	210	0 015	0 002	1 05

The theory is accompanied by a numerical example in which the usual conditions of a joint in the pavement are simulated as closely as possible

The deflection, load distribution, load transfer, moment and shear force curves are presented on Figure 7

Conclusions are reached, that under the assumptions made, the *intensity of load* *transfer* over the joint would not exceed 2 per cent of the concentrated load per linear inch of the joint

Possibilities of adjusting the values of the foundation moduli from experimental data, so as to approach by the theory the actual load distribution in the case of *slabs* are outlined in connection with an extended elastic scheme.

In order to secure the above stated theoretical load distribution, it is necessary that the bars should work as elastic bars, i.e., that no cracks should appear in the regions of tension. In other words, some reinforcement of the slabs must be introduced along the joints

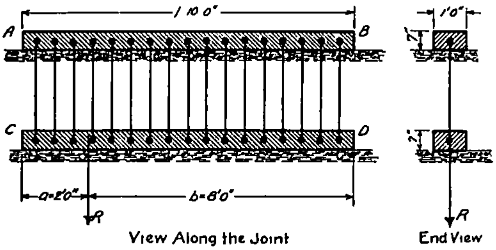

Figure 6

THEORY OF ELASTICALLY CONNECTED BEAMS ON ELASTIC FOUNDATIONS

We consider two parallel beams AB and CD, of constant cross-section, both on separate elastic foundations, one above the other, having their vertical principal planes in one common plane

Both bars are connected by elastic vertical rods distributed in a continuous row in the same vertical plane

For the particular case, presented on Figure 6, the application of the theory gave the following results

We consider in Figure 6, two concrete beams 10 ft long each, of the cross-sections shown, with a force R applied to the lower beam

We assume

The elastic modulus of the connecting rods $k_s = 10^5$ lb per sq in

The elastic modulus of the foundations $k = 1200$ lb per sq in.

$$a = 24 \text{ in}$$
$$b = 96 \text{ in}$$
$$l = 120 \text{ in}$$
$$R = 10{,}000 \text{ lb}$$

A number of points of the deflection curves of beams AB and CD were found,

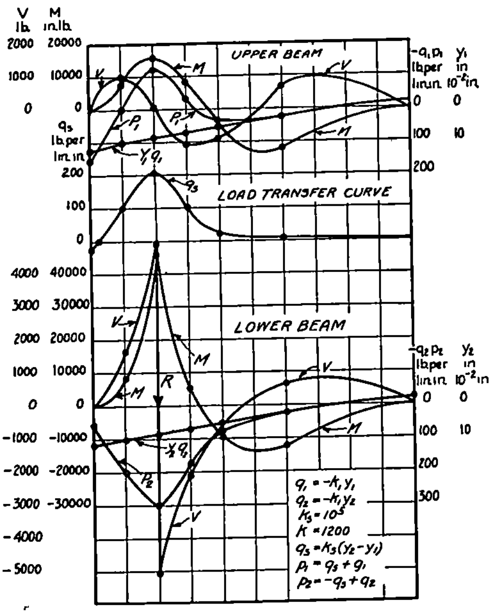

Figure 7. Bending Moments, Transverse Forces, Deflections, Load Distribution, and Load Transfer Curves for Two Elastically Connected Beams on Elastic Foundation.

with the corresponding bending moments, shear forces and the intensities of the continuous loadings of the beams from the elastic foundations (reaction), from the elastic connecting rods and the combined intensity of both just mentioned continuous loadings

Then curves were drawn through these points, which are represented on Figure 7

Most important is the load transfer curve, which shows, that:

(1) About 90 per cent of the total load transferred from one beam to the other is effected over a length of the joint of 3 ft in the immediate vicinity of the load

(2) The load distribution is almost symmetrical with respect to the force

(3) Roughly, the highest intensity of load transfer takes place as if one quarter of the load is transferred uniformly over a length of 1 ft

These results were obtained for definite geometric and elastic characteristics of the beams, their connecting rods and the elastic foundations

It would be interesting to have the load transfer distribution for other elastic characteristics of the subgrade and the connecting rods, simulating different types of joints

However, the authors are of the opinion, that the length of distribution and the shape of the load transfer curve will not be affected very much by *small changes* in the elastic characteristics of the joints or connecting rods and the subgrade

For absolutely stiff or rigid connecting rods the whole load will be transferred by one rod at the point of application of the load, whereas for very elastic (say rubber rods) the load transfer curve will approach the elastic curve of the lower beam In this case no load transfer will take place and almost the whole load will be taken up by the lower beam alone

In the case of an absolutely rigid foundation no load transfer will take place through the connecting rods

The load transfer curves for these extreme conditions would be: (1) a straight horizontal zero line having an infinity peak at the *point* of application of the load, (2) the elastic deflection line of the lower beam

For intermediate elastic conditions the load transfer curve will have the character presented on Figure 7 As the elastic characteristics of an actual joint could not be stiffer, than in our numerical example ($k_s = \frac{p}{\delta} = 10^5$ or $\delta = p \times 10^{-5}$ where p is the load transfer in lbs per lineal inch of joint and δ is the deflection over the joint), the load transfer curve is expected to be lower and wider, than as presented on Figure 6 for most of the joints in use That means that less than one quarter of the load will be transferred over 12 in of the joint.

The total load transferred by the connecting rods from the lower to the upper beam amounts to 4530 lb or 45 3 per cent of the concentrated load R = 10,000 lb

This load distribution and transfer will take place only on the condition that our elastic bars remain elastic As soon as cracks appear on the underside of the slab in the tension zone, the maximum intensity of transfer may increase considerably and destroy the joint

Therefore, some reinforcement is recommended along the joint to prevent tension cracks near the joint

CONCLUDING REMARKS

In our problem we were dealing with comparatively long bars or beams extending along the joint, whereas in highway practice we have slabs extending also considerably in the direction perpendicular to the joint Most of the joints in use can not transfer considerable moments or are very flexible in bending, therefore these moments could be neglected in the first approach to the solution

On the other hand, the slabs extending

both sides of the joint might be regarded in their action as component parts of the elastic foundation In the latter case the problem might be reduced to finding the moduli of such type of composite elastic foundations as well as the dimensions of the beams which would have to enter into the equations of our beam theory, by experiments on actual slabs and joints in the field

It is not necessary to say that the whole theory has been developed for ideal uniform conditions of the subgrade, though different moduli can be used for the upper and lower beam subgrades in the formulas

DISCUSSION ON CONCRETE PAVEMENT JOINTS

MR CLIFFORD OLDER, *Consulting Engineer*· I would like to ask a question It appears that, in the theoretical development of the distribution of load transfer along the joint, it was assumed that subgrade reaction is in proportion to slab deflection Now as I said a few minutes ago, I cannot believe that this is true either at a corner or elsewhere along a transverse joint, because the subgrade may be permanently depressed where the deflection is greatest Such depression was noted by Mr Spangler and was also noted in connection with the Bates Road tests I would like to ask, therefore, if it is not entirely possible that the distribution along the joint, in the case of a pavement in service, might not be such as to require less load transfer than the equivalent of one-fourth of the load spread evenly along three feet of the joint The maximum load transfer capacity required under service conditions is extremely important Until we know this with certainty we can neither design with safety nor economy

MR FREMONT. I shall answer first the question whether the load might distribute itself in the joint over a longer distance than 3 ft It is pointed out in the report that the curve was obtained for certain definite elastic characteristics If these elastic characteristics change, the curve will also take a different shape It is also pointed out in the report that for absolutely rigid connection rods the whole load will be transferred by one rod at the point of application of the load with a load transfer curve in the form of a horizontal line having an infinity peak at the point of application of the load In such a case there would not be any distribution of load at all, but there would be perfect load transfer On the other hand, for very elastic rods (say rubber rods), the shape of the load transfer curve will approach the deflection curve of the lower beam, which is almost a straight line, and we would get a good distribution of load, but a very poor transfer of the load

For intermediate elastic characteristics of the joint construction, we shall get load transfer curves of the character presented Our assumptions as to the rigidity characteristics of the connection rods corresponded very nearly to the upper limit of the same of all the joint constructions that have come to our attention. This means that the joints in actual pavements are more elastic and would have flatter load transfer curves than those presented with a load distribution over a length greater than 3 ft

Now with regard to the other remark, that the subgrade reaction would not be proportionate to the deflections, I should like to say that the joint construction has to be satisfactory for any type of subgrade, if there is evidence that in some or many cases the reaction is not proportionate to the deflection, I think there is not enough evidence or assurance that it is *never* proportionate to the deflection In this situation lies one of the justifications of the proportionality assumption as perfectly meeting the actual conditions of one phase of service of the joint construction With regard to the other phase, when there is no such proportionality, the following might be said in favor of the proportionality assumption of our theory

According to our assumption we condensed the two slabs, abutting at the joint, into two beams, placed one above the other and connected by a continuous row of elastic rods lying in the common principal plane of both beams It is easy to see that in the circumstances of actual service the slabs extending on both sides of these imaginary beams and forming one solid whole with the corresponding beams affect the behavior of our imaginary beams in a way very similar to an elastic foundation with reactions proportionate to the deflections, as farther away from the joint the subgrade will better approach the assumption of elasticity and proportionality And it is a question which of the two foundations, either the actual subgrade directly under the imaginary beams or the elastic slabs extending beyond them, exert a greater influence upon the beams Maybe it might be possible to operate, with fairly good approximation, with an elastic foundation having reactions proportionate to deflections, even in the case of no actual subgrade reaction under the imaginary beams of the theory by a proper selection of the composite foundation moduli The proper values of these moduli to be used in connection with this theory might be determined experimentally for each kind of joint and subgrade

As our theory is developed now it is adaptable to conditions when

1 The subgrade moduli are different on both sides of the joint
2 The subgrade moduli are different under the imaginary beam and the corresponding slab

Of course, a better answer might be given by a theory of two slabs extending sufficiently far on both sides of the joint, on elastic foundations, simulating *satisfactorily* the *varying* actual conditions of the subgrade in the vicinity of the joint and at points at other various distances from the joint

Our theory, as described above, based on *rough simplifying assumptions*, has nevertheless worked out into quite a complicated one, requiring a considerable amount of arithmetical precision work for each particular case to which the theory might be applied

As there are no experimental data at hand about the distribution of load in the transfer through joints and such data are very hard to obtain, depending on *very small* differences in the deflections of the abutting slabs, this work had been undertaken and finds its justification Without the knowledge of the distribution of load the relative merits of the existing joint constructions depending on the maximum service intensity of load transfer could not be determined