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DETERMINATION OF THE MODULUS OF CONCRETE SUPPORT, G, FOR THE DESIGN OF DOWELS IN TRANSVERSE PAVEMENT JOINTS

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DETERMINATION OF THE MODULUS OF CONCRETE SUPPORT, G, FOR THE DESIGN OF DOWELS IN TRANSVERSE PAVEMENT JOINTS

In the analytical determination of the stresses in and around a dowel through a transverse joint in a pavement, the theory of beams on elastic foundations is utilized. This theory was applied to dowel designs by Friberg[1] and is based on an exact mathematical solution of the problem of a dowel of infinite length supported by an elastic mass by Timoshenko and Lessels[2]. Here, the dowel is taken to be the beam, and the concrete is assumed to be the elastic foundation. Its elasticity is characterized by the force per unit area which will cause a deflection equal to unity. This constant is called the modulus of concrete support, and designated herein by the capital letter G. A knowledge of the magnitude of the modulus of support of concrete is necessary for the accurate determination of the dowel stresses and the concrete bearing pressure.

This study was concerned with the determination of the modulus of support of concrete. This was accomplished by making use of the load deflection relationship of dowels embedded in concrete blocks.

SPECIMENS:

Each test specimen consisted of a steel dowel 3/4, 1, 1-1/4, or 1-1/2 inches in diameter and 13-1/2 inches long, embedded in a concrete block 12 inches square and 9 inches deep, see Figure 1. The specimens were poured in pairs. The first pair containing dowels 3/4 and 1 inch in diameter, and the second pair containing 1-1/4 and 1-1/2 inch diameter dowels. This group of four specimens was called a series. In all, six series of specimens were poured. Three test cylinders, and three test beams used for determining the ultimate compressive stress, and modulus of elasticity were made from each

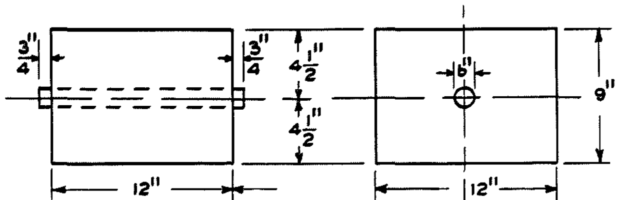


FIGURE 1 TEST SPECIMEN SHOWING EMBEDMENT OF DOWEL IN CONCRETE BLOCK.

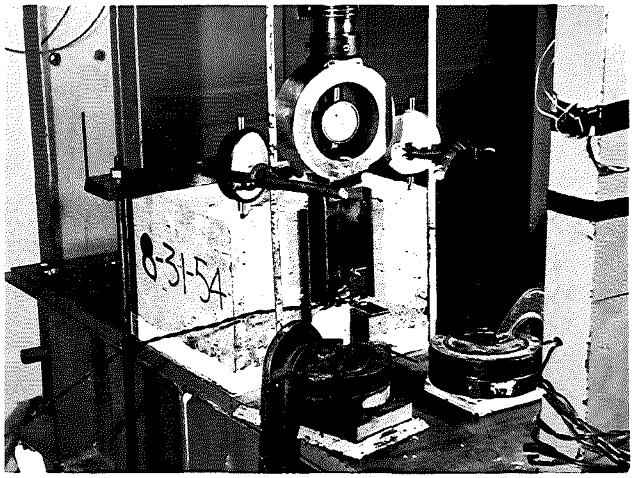


FIGURE 2. TYPICAL TEST SET UP SHOWING SPECIMEN IN MACHINE READY FOR TESTING.

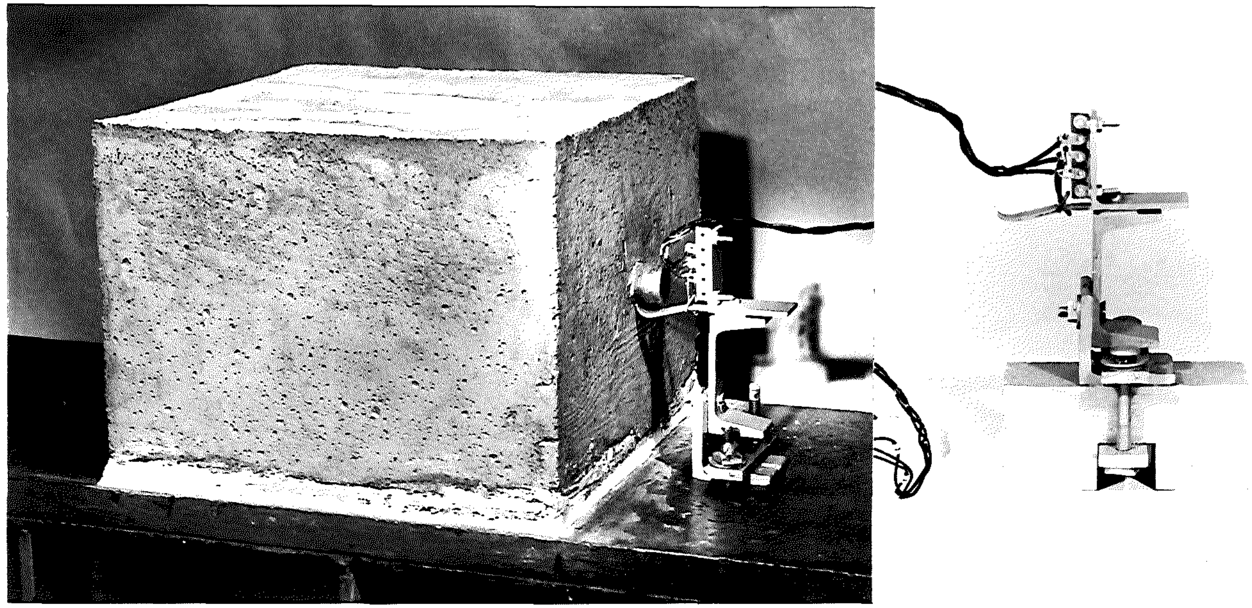
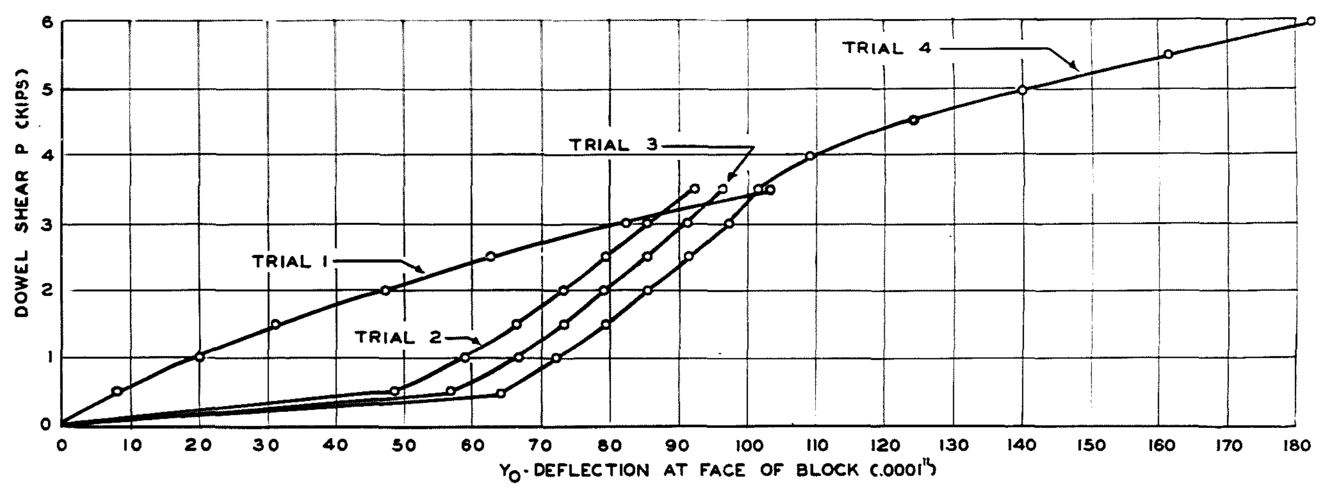


FIGURE 3. LEFT, PICTURE SHOWING CANTILEVER DEVICE ATTACHED TO BASE OF TESTING MACHINE WITH THE FREE END BEARING AGAINST THE UNDERSIDE OF THE DOWEL.

RIGHT, PICTURE SHOWING CLOSE UP VIEW OF CANTILEVER DEVICE USED IN OBTAINING DEFLECTION OF DOWEL AT FACE OF CONCRETE BLOCK.

FIGURE 4. TYPICAL FAILURE OF CONCRETE SPECIMEN WITH A ONE INCH DIAMETER DOWEL.

FIGURE 5. TYPICAL LOAD DEFLECTION CURVE FOR FOUR TRIALS OF LOADING.
SERIES #3 — 3/4" DIA. DOWEL.



batch of concrete used in pouring the blocks. All specimens, test cylinders and test beams were allowed to cure for eight days in a moist room prior to testing.

TEST PROCEDURE:

Each specimen was placed on the base of a compression testing machine. A thin layer of plaster was placed between the block and the base to assure proper seating, and the block was clamped down to prevent tipping. See Figure 2.

A load was exerted downward on the dowel 1/8-inch from the face of the block. All specimens were subjected to four trials of loading as follows:

3/4-inch dia. { no load to 3500# in 500# increments for three trials.
no load to 6000# in 500# increments for one trial. }

1 inch dia. { no load to 5000# in 500# increments for three trials.
no load to 6000# in 500# increments for one trial. }

1-1/4 & 1-1/2 inch dia. { no load to 6000# in 500# increments for three trials.
no load to 8000# in 500# increments for one trial. }

Measurement of the deflection of the dowel at the face of the block was accomplished by means of a steel cantilever made especially for this purpose. See Figure 3. The free end of the cantilever was sharpened and bent so that it could bear against the under side of the dowel very close to the block. The fixed end of the cantilever was fastened indirectly to the base of the loading machine. Two Type SR-4 strain gages were mounted on the top and bottom of the cantilever which was designed in such a manner that a 0.0001 inch deflection at the free end produced 4 micro inches/inch of strain.

The deflection of the concrete block at the face was measured with two 0.0001 inch dials as shown in Figure 2. The average of the deflections obtained from these dials was subtracted from the absolute deflection of the dowel measured by the cantilever and the resulting value was used in the determination of the modulus of Support, G.

The calculation of dowel stresses was based on the equation,

$$y = \frac{e^{-\beta x}}{2 E I \beta^3} \left\{ P \cos \beta x - \beta M_o (\cos \beta x - \sin \beta x) \right\} \quad \text{---(1)}$$

and its derivatives, where,

E = the modulus of elasticity of the dowel

I = the moment of inertia of the dowel

P = the dowel shear

M_o = the bending moment exerted on the dowel at the face of the joint

y = the deflection of the dowel at a point x distance from the joint

b = the diameter of the dowel

G = the modulus of concrete support

$$\beta = \left(\frac{G b}{4 E I} \right)^{\frac{1}{4}} \quad \text{------(1a)}$$

According to the manner in which the load was applied, $M_o = -P/8$. By substituting this into the above equation and setting x equal to zero, we get,

$$\frac{\beta^3}{1 + \beta / 8} = \frac{P}{2 E I y_o} \quad \text{------(2)}$$

where, y_o is the deflection of the dowel at the face of the block.

For each test specimen a load deflection curve was plotted for the four trials of loading. One such curve for a 3/4-inch diameter bar is shown in Figure 5. The value of the slope P/y_0 that was used in the evaluation of G was determined as follows:

The data from trials 2, 3, and 4 was averaged and plotted. Using the 1000# loading as the origin, and disregarding that part of the curve below the 1000# mark, a straight line was drawn through the remaining set of points. This value of P/y_0 was substituted into equation (2) yielding the value of β. This value of β was then substituted into equation (1a) and this equation was solved for the value of G.

RESULTS:

The values of G for each specimen, along with the compressive stress and modulus of elasticity of the concrete are listed in Table 1.

A typical failure of a concrete specimen with a 1-inch diameter dowel is shown in Figure 4.

From the test data the following observations can be made:

1. No apparent relationship exists between the magnitude of G and the ultimate compressive stress of the concrete.
2. No apparent relationship exists between the magnitude of G and the diameter of the dowels.
3. The values of G varied from 1.0×10^6 pci. to 5.7×10^6 pci.

The average value of G obtained from the average of all the specimens was 2.5×10^6 pci.

The value of G as determined here might be suitable for the determination of the concrete bearing stress, but would not be suitable for determining the dowel stresses.

Due to the nature of the load deflection curves, a value of the slope for obtaining a G indicative of the dowel stress could not be justified.

TABLE 1

TABULATION OF TEST DATA

Series	Ultimate Compressive Stress	Modulus of Elasticity	Modulus of Concrete Support (G)	
			3/4-in. Dia.	1-in. Dia.
1	3400 psi	6.5×10^6 psi	5.7×10^6 pci	2.3×10^6 pci
2	3330 psi	7.0×10^6 psi	3.6×10^6 pci	1.7×10^6 pci
3	2600 psi	5.7×10^6 psi	2.5×10^6 pci	2.0×10^6 pci
4	3800 psi	6.6×10^6 psi	2.2×10^6 pci	1.0×10^6 pci
5	3230 psi	6.4×10^6 psi	2.3×10^6 pci	2.1×10^6 pci
6	3820 psi	6.5×10^6 psi	2.5×10^6 pci	1.8×10^6 pci
Ave.	3360 psi	6.5×10^6 psi	3.1×10^6 pci	1.8×10^6 pci

Series	Ultimate Compressive Stress	Modulus of Elasticity	Modulus of Concrete Support (G)	
			1-1/4 in. Dia.	1-1/2 in. Dia.
1	3940 psi	6.8×10^6 psi	- - -	- - -
2	2970 psi	6.4×10^6 psi	2.1×10^6 pci	2.1×10^6 pci
3	3090 psi	6.0×10^6 psi	3.1×10^6 pci	3.3×10^6 pci
4	3380 psi	6.6×10^6 psi	2.9×10^6 pci	4.2×10^6 pci
5	3250 psi	6.8×10^6 psi	1.4×10^6 pci	1.6×10^6 pci
6	2830 psi	5.5×10^6 psi	1.4×10^6 pci	1.2×10^6 pci
Ave.	3240 psi	6.4×10^6 psi	2.4×10^6 pci	2.5×10^6 pci

REMARKS:

The absence of an apparent relationship between values of G and the diameters of the dowels and the compressive strength of the concrete may be due to the large variation in the magnitude of G coupled with the relatively small number of test specimens. Then too, a refinement of the testing apparatus and test procedure might have produced better results, especially for the specimens containing the larger diameter dowels. This data does at least indicate the approximate magnitude of G to be expected.

It will be seen from Figure 4, that the load deflection behavior of the dowel is not the same as that given by the theoretical equations. After the initial loading, a local failure of the concrete at the face of the block takes place, and for the remaining cycles of loading the dowel is not entirely supported by the concrete as it was initially. In order to get the correct dowel stresses from these equations, a much smaller value of G would have to be used.

It was felt that more extensive studies on this problem would have to be made before a solution could be attained that would yield a satisfactory dowel design criteria.

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