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Experimental Determination of Eccentricity of Floor Loads Applied to a Bearing Wall

D. Watstein and P. V. Johnson

Building Research Division
Institute for Applied Technology
National Bureau of Standards
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CONTENTS

Experimental Determination of Eccentricity of Floor Loads Applied to a Bearing Wall

D. Watstein* and P. V. Johnson*

The eccentricity of the loads applied to a specially calibrated compressive strut simulating a brick bearing wall was experimentally determined for a variety of bearing materials and conditions of contact. In one series of tests, an I-beam was bedded in high strength gypsum plaster, bonded and unbonded. For the unbonded plaster bed the eccentricity ratio [1] increased with the applied load to a maximum value of about 0.42, while for the bonded plaster bearing this ratio decreased to an average value of about 0.24 at the maximum load.

In the second series of tests the eccentricity was observed for an I-beam supported on neoprene rubber pads, capped and uncapped, of different thicknesses, and of different bearing length. In general the eccentricity ratio increased slightly with the applied load. Lack of intimate contact between the I-beam and the rubber pad ⅛ in thick resulted in an eccentricity ratio of about 0.40, or nearly the same as for unbonded plaster bearing. Intimacy of contact produced by plaster capping resulted in a marked reduction in the eccentricity ratio to about 0.29; the confinement of the bearing length of the rubber pad to one-half of that used in previous tests and placing it at the extreme end of the beam, further reduced the eccentricity ratio to about 0.18, and to 0.13 for a rubber pad 0.25 in thick.

Key words: Bearing pads, bearing walls, brick masonry, design of bearing walls, eccentricity of applied loads.

1. Introduction

Since exterior bearing walls are designed as eccentrically loaded compression members, it is important to know what the eccentricities of the applied floor loads are for different bearing materials and different conditions of contact between the supporting structure and the floor beams. Some recently completed exploratory studies by the Structural Clay Products Institute Research Fellowship at NBS indicated that it is feasible to measure the eccentricities of applied loads using a specially designed stress-sensitive compressive strut calibrated under loads of known eccentricities. The strut was assumed to simulate a load bearing wall of brick masonry even though the boundary conditions and the elastic properties of the strut were different from those encountered in an actual masonry structure.

The exploratory study included an investigation of such parameters as thickness and rigidity of bearing materials, the intimacy of contact between the supporting structure and the flexural members, and the effect of bond with the bedding material on the eccentricity of the floor loads.

The feasibility of measuring the eccentricity of the force supporting a masonry wall subjected to an eccentrically applied load was also explored.

2. Description of the Compressive Steel Reaction Strut for Measurement of Eccentricities, and Its Calibration

The compressive steel reaction strut was a rectangular steel tube 4 by 8 inches in cross section having a wall 0.187 in thick. The strut was 18 in high and had a ⅜-in welded steel plate insert at the top providing a closed end. The strut was capped with a 1- by 4- by 8-in cold-rolled steel plate bonded to the top welded plate insert with epoxy cement. The whole assembly was then capped with a solid extruded clay brick which served to receive the load, simulating the bearing conditions at the top of a brick masonry wall. The open bottom end was machined normal to the axis of the strut and was supported on a machined steel plate 4 in thick.

The dimensions of the capping brick were 2¼ by 3⁹⁄₁₆ by 7⅞ in and hence the brick did not cover the 1-in steel cap completely. The brick was set flush with one side of the strut (designated as side H) and was centered with respect to the 4-in dimension of the strut as shown in figure 1.

The strut was instrumented with bonded wire strain gages at two different levels. The location of the gages is indicated in figure 1.

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[1] The eccentricity ratio is defined as the ratio of eccentricity to the overall thickness of the strut.

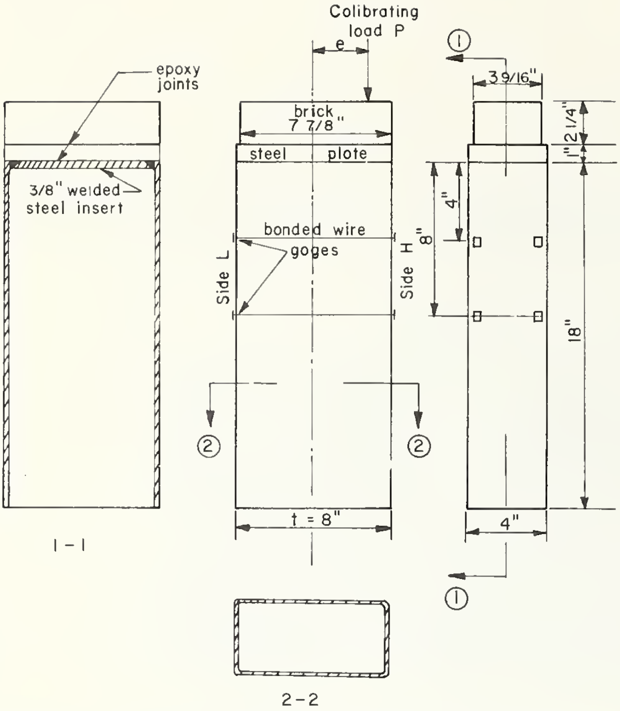

FIGURE 1. *Schematic drawing of instrumented reaction strut for measurement of eccentricity of load.*

During calibration a load, P, was applied to the strut through a hardened steel knife edge seated in a suitable V block. Thus, the eccentricity of the applied load could be measured with a steel scale with an accuracy of about $\frac{1}{32}$ in.

Let $\sigma_{\max}$ and $\sigma_{\min}$ be respectively the stresses on the side of the applied load and the opposite side; then the following expressions can be written:

$$\sigma_{\max}=\frac{P}{A}+\frac{Pec}{Ar^2}=\frac{P}{A}\left[1+\frac{ec}{r^2}\right] \tag{1}$$

and

$$\sigma_{\min}=\frac{P}{A}-\frac{Pec}{Ar^2}=\frac{P}{A}\left[1-\frac{ec}{r^2}\right] \tag{2}$$

where

A=the cross section area of the strut, in.^{2},
c=distance from the neutral axis to the outermost fiber, inches,
r=radius of gyration, inches. (Ar^2=moment of inertia of the section), and
e=eccentricity of applied load, in.

Adding (1) and (2),

$$\sigma_{\max}+\sigma_{\min}=\frac{2P}{A} \tag{3}$$

Subtracting (2) from (1),

$$\sigma_{\max}-\sigma_{\min}=\frac{2\,Pec}{Ar^2} \tag{4}$$

Dividing (4) by (3),

$$\frac{\sigma_{\max}-\sigma_{\min}}{\sigma_{\max}+\sigma_{\min}}=\frac{ec}{r^2} \tag{5}$$

and solving for e,

$$e=\frac{r^2}{c}\left[\frac{\sigma_{\max}-\sigma_{\min}}{\sigma_{\max}+\sigma_{\min}}\right].$$

Assuming that the stresses $\sigma_{\max}$ and $\sigma_{\min}$ are within the elastic limit, the eccentricity e in terms of strains $\epsilon_{\max}$ and $\epsilon_{\min}$ is given by:

$$e=\frac{r^2}{c}\left[\frac{\epsilon_{\max}-\epsilon_{\min}}{\epsilon_{\max}+\epsilon_{\min}}\right]. \tag{6}$$

For the reaction strut used in these tests, $r^2/c=2.06$, and (6) becomes

$$e=2.06\left(\frac{\epsilon_{\max}-\epsilon_{\min}}{\epsilon_{\max}+\epsilon_{\min}}\right). \tag{7}$$

The theoretical relationship given by (7) and the experimental curve determined in two separate laboratory setups are compared in figure 2. The experimental values of eccentricity e were varied over a range of 3 in on each side of the center line of the strut. It should be added that the strain values given in figure 2 were those obtained from the lower set of strain gages, since they yielded a more consistent relationship than the top gages.

The departure of the calibration curve from the straight line predicted by eq (7) may possibly be accounted for by the nonhomogeneous nature of the welded steel tube used in fabricating the strut, and the possible presence of slight irregu-

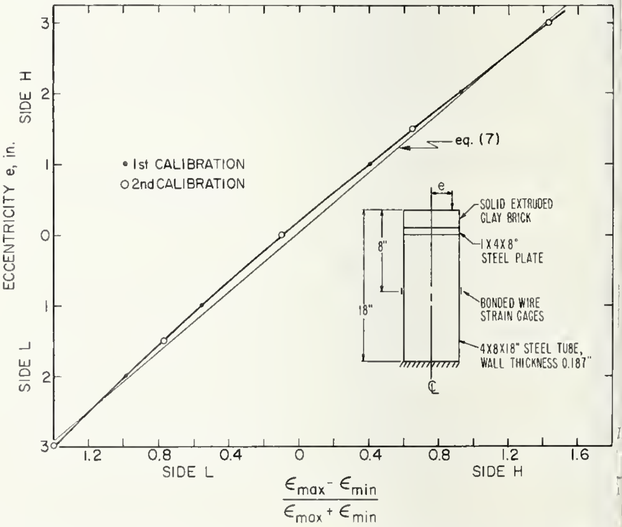

FIGURE 2. *Calibration of reaction strut in terms of eccentricity.*

$$\left(e\ vs.\ \frac{\epsilon_{max}-\epsilon_{min}}{\epsilon_{max}+\epsilon_{min}}\right).$$

larities commonly found in thin walled extruded steel shapes. In future work, it is intended to fabricate a strut of greater strain sensitivity and have it relatively free from the deficiences which might have caused the deviation from theoretical relationship shown in figure 2.

3. Eccentricity of Reaction of an I-Beam Bedded in Gypsum Plaster

One series of five tests was carried out with an **I**-beam 6 in deep and a flange 3½ in wide bedded in high strength gypsum plaster. As in all determinations of eccentricity described in this paper, the end of the **I**-beam extended to the center line of the supporting strut. The arrangement of supports and the load are shown in figure 3, along with the device for measuring the rotation of the beam end at the strut. This measurement was an approximation based on the assumption that the strut did not depart from its initial vertical position, and that the vertical displacement of the point at which the micrometer dial assembly was attached to the **I**-beam was negligible.

In Tests 1 and 2 the **I**-beam was bedded in unbonded plaster. The bond between the plaster and the bearing surfaces was destroyed by confining the plaster putty between two sheets of polyethylene. The variation of the eccentricity ratio with the rotation of the beam end is illustrated in figure 4. It is noted that at small rotations of the beam supported on the strut simulating a wall, the eccentricity ratio e/t[1] was about 0.35, or nearly the value usually assumed in design of masonry walls. The eccentricity ratio increased with the rotation of the beam and tended to reach a constant value at large rotations. For Tests 1 and 2, the maximum values of e/t were 0.43 and 0.40 respectively, with an average of 0.415. The maximum center load applied in these tests was 25 kips and the beam span was 44 inches.

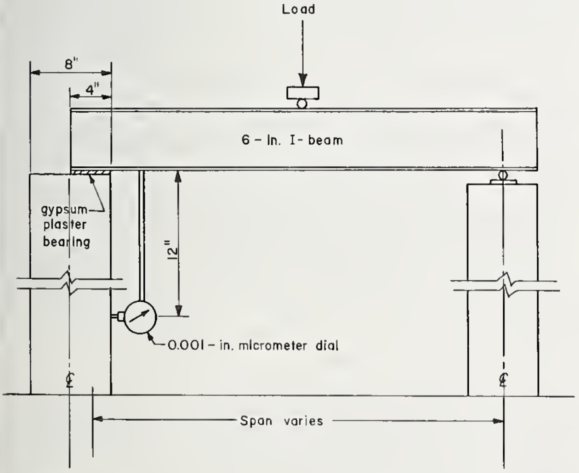

Figure 3. *Schematic diagram of test set-up for an I-beam bedded in gypsum plaster.*

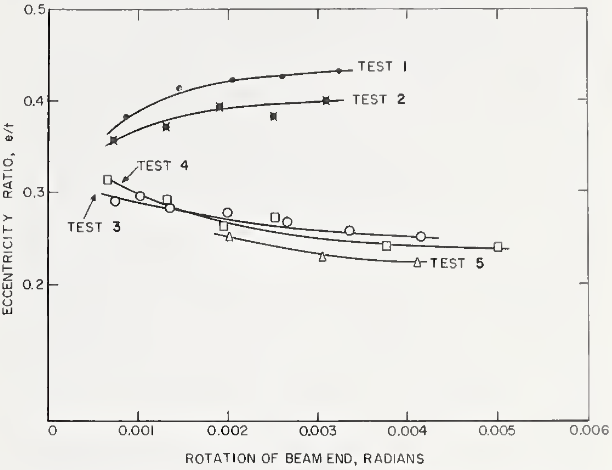

Figure 4. *Eccentricity of reaction for an I-beam bedded in gypsum plaster. Tests 1 and 2—unbonded plaster; Tests 3, 4, and 5—bonded plaster, spans 24, 36, and 48 in, respectively.*

In Tests 3, 4, and 5 the **I**-beam was bedded in bonded plaster and the span lengths were 24, 36 and 48 inches respectively. It is interesting to compare in figure 4 the effect of bonded and unbonded plaster bearings on the behavior of the **I**-beam. The unbonded **I**-beam showed an increase in the eccentricity ratio with load, while that for the bonded I-beam showed the opposite. The value of e/t for the bonded **I**-beam was about 0.32 for low loads and decreased with the rotation of the beam; the eccentricity ratio tended to reach a constant value as the rotation increased. The average e/t for the three tests at the maximum recorded rotation was about 0.24, and represents a reduction of 42% as compared with the eccentricity ratio for unbonded plaster.

Although the use of high strength gypsum plaster is not practical as a permanent bedding material for floor beams, its effect as a bonding bearing material was investigated as one phase of the broad problem of load transfer to masonry walls. It is possible that some other more permanent bedding material can be found which would have the same favorable effect on the eccentricity ratio as the high strength gypsum plaster.

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[1] t is defined as the overall thickness of the strut.

4. Eccentricity of Reaction of an I-Beam Supported on Neoprene Rubber

Five tests were performed to determine the eccentricity ratio for the previously described **I**-beam supported on a neoprene rubber pad. The hardness of the rubber as given by Shore A. Durometer was 65 (instantaneous value). The rubber sheets were $\frac{1}{16}$ in thick and they were stacked to give thicknesses of ⅛ and ¼ in.

The test setup used in the tests with a rubber bearing material was similar to that shown in figure 3, except that the rotation of the beam end was measured with two micrometer dial gages; one of these was clamped to the web of the **I**-beam and measured the movement of the end of the beam with respect to the bearing surface of the strut, while the second one was attached to the side of the strut and its stem was in contact with the underside of the flange of the **I**-beam.

In Tests 6 and 7 the **I**-beam was supported on a neoprene pad ⅛ in thick over its entire 4-in bearing length. The rubber pad was coated with gypsum plaster putty on both bearing surfaces in order to assure intimate contact over its entire area.

The values of e/t obtained in Tests 6 and 7 are shown in figure 5. It is noted that e/t increased with the beam end rotation as would be expected in the case of an unbonded bearing which leaves the beam end free to rotate without any restraint from the supporting wall. The average value of e/t ranged from 0.27 initially to 0.30 at the maximum rotation. The beam span used in these tests was 44 in and the maximum applied load was 30 kips.

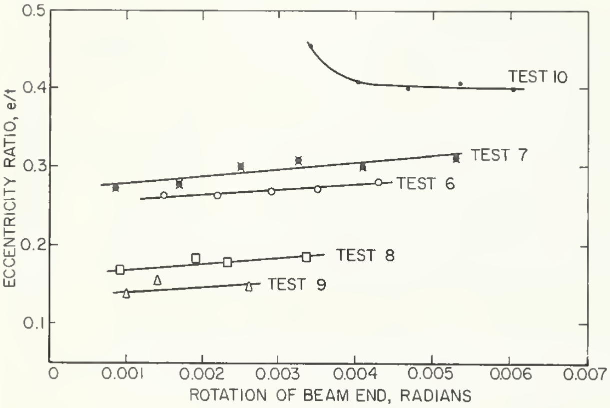

FIGURE 5. *Eccentricity of reaction for an I-beam supported on neoprene rubber pads. Tests 6 and 7—⅛ in rubber pad 4 in long, coated with plaster; Test 8—⅛ in pad, 2 in long, coated with plaster; Test 9—¼ in pad, 2 in long, no plaster; Test 10—same as 6 and 7, but no plaster coating.*

Tests 6 and 7 were two independent determinations representing as nearly as possible identical support conditions. It is important to note that in spite of all efforts to secure uniform and intimate contact with the rubber bearing pad, the two determinations of e/t varied from 0.28 to 0.31 at the maximum rotation. Perhaps this variability even between two supposedly identical tests will account for the very large difference in e/t values between Test 10 and Tests 6 and 7. In Test 10 the carefully leveled **I**-beam was set directly on a rubber pad ⅛ in thick; however, it was noted that the contact with the rubber pad was not intimate, and that daylight could be seen under the outer corners of the **I**-beam flange. In this instance a large rotation was observed at extremely small load. In this test the value of e/t was initially 0.45 and it tended to become nearly constant at 0.40 for the maximum rotation of the beam end. The span length in this test was 44 in and the maximum applied load was 30 kips. This comparison of otherwise identical tests (Tests 6, 7, and 10) points up the importance of attaining intimate contact with rubber pads of limited thickness and large bearing area. It can be seen that the e/t ratio of 0.40 for Test 10 was about the same as for unbonded plaster bearing pads in figure 4.

In Tests 8 and 9 the length of the bearing pad was reduced to 2 in at the extreme end of the beam. As would be expected, the confinement of the bearing reduced the e/t ratio considerably. For Test 8, with a capped bearing pad ⅛ in thick, e/t ranged from an initial value of 0.17 to 0.185 at the maximum end rotation. For Test 9 in which the rubber pad thickness was increased to ¼ in and no plaster capping, the e/t ratio was further reduced to yield a maximum of about 0.15. It is noted that in this test the minimum value of e/t was 0.135, as compared with a theoretical value of 0.125. This theoretical value would be expected from the assumption that the centroid of the bearing stresses lies at the midpoint of a uniformly compressed pad.

5. Eccentricity of Supporting Force at the Base of a Bearing Wall Subjected to an Eccentrically Applied Load

Two exploratory tests were performed to investigate the feasibility of measuring the eccentricity of the supporting force at the base of a wall subjected to an eccentrically applied load. An overall view and a closeup of the loading fixture are shown in figures 6 and 7.

The wall used in these tests was essentially a pier $3\frac{9}{16}$ by $7\frac{7}{8}$ inches in cross section built of solid extruded clay brick laid in stacked bond with extremely thin joints of high strength gypsum plaster. The strut was used as a base for this assembly, as shown in figure 6. The wall was built in two stages—the first was 24 in high and the second was 48 in high; both dimensions are nominal. The wall was subjected to two loads at each height, a centrally applied load, and an

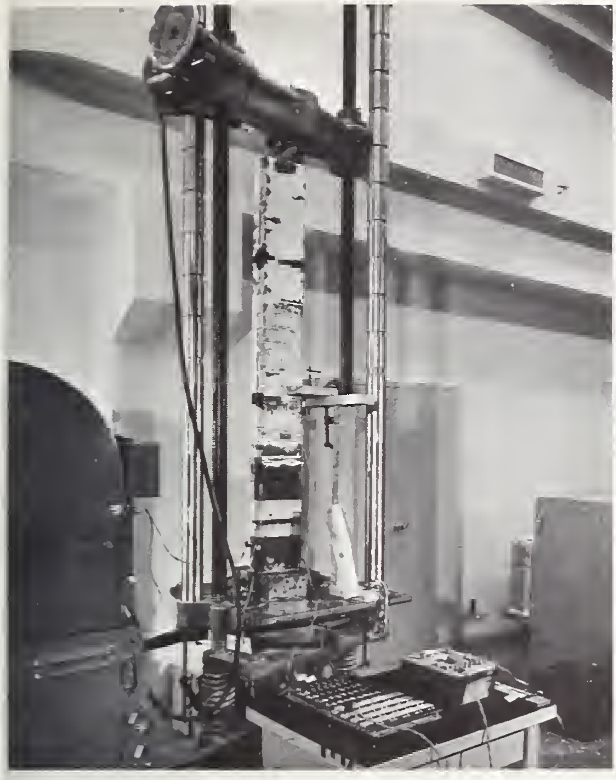

Figure 6. *Overall view of test setup to determine the eccentricity of supporting force at the base of an eccentrically loaded bearing wall.*

Figure 7. *Closeup of eccentrically loaded wall showing the loading knife edge.*

eccentric load applied on side H (see fig. 1) 2.5 in from the center line of the pier.[2] The values of eccentricity of applied loads and the measured values of eccentricity of reactions at the base of the wall are given in table 1 for both the 24- and 48-in heights of wall.

It can be seen from the data in table 1 that the calibrated reaction strut can be used to measure the eccentricity of the reaction at the base of a bearing wall. The effect of the height of the wall on the possible decrease of eccentricity at the base will be further explored in future tests using a calibrated reaction strut of sufficient capacity to accommodate a larger wall specimen.

Table 1. *Measured eccentricities of reaction at the base of wall subjected to a load of known eccentricity*

Wall height	Eccentricity of applied load	Applied load	Measured strains on strut		$\frac{\epsilon_{max}-\epsilon_{min}}{\epsilon_{max}+\epsilon_{min}}$	Measured eccentricity at base of wall (from fig. 2)
			ϵ_{max}	ϵ_{min}		
in	in	kips	10^{-6}	10^{-6}		in
24	0	15	112	112	0	0.15
24	0	20	151	149	.007	.16
24	2.5	10	155	[1] −10	1.14	2.45
48	0	10	69	77	−.05	0.06
48	0	20	148	159	−.04	.06
48	2.5	5	83	0	1.00	2.20
48	2.5	10	157	2	0.97	2.14

[1] Tensile strain.

6. Summary

The following comments appear appropriate to summarize the work reported herein:

1. A test procedure was developed by means of which the eccentricity of loads applied to a strut assumed to simulate a bearing wall could be measured. The device also was suitable for measuring the eccentricity of the supporting force at the base of a bearing wall subjected to an eccentric load.
2. Both rigid and resilient bearing materials such as gypsum plaster and neoprene rubber were used to support an I-beam as a floor member.
3. For an unbonded plaster bearing, the observed eccentricity ratio increased with rotation of the beam end to a maximum value of about 0.42. For the bonded plaster bearing this ratio decreased with rotation to an average value of 0.24 at the maximum load.
4. Intimacy of contact was essential for achieving a favorable distribution of bearing stresses

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[2] The center line of the pier was taken as the center line of the compressive strut.

with a neoprene rubber pad. Lack of intimate and complete contact between the I-beam and the rubber pad resulted in an eccentricity ratio of about 0.40; this value was reduced to 0.29 by bedding the rubber pad in plaster. A 50 percent reduction of the bearing length of the pad and its confinement to the extreme end of the beam further reduced the eccentricity ratio to a minimum value of 0.135.

5. The eccentricity ratio was not found to be sensitive to substantial increases in the rotation of the beam end in the loading range producing rotations on the order of 0.004–0.005 rad.

6. Because of the limited sensitivity of the eccentricity measuring device, the values of eccentricity ratio observed for low loads and extremely small rotations were not considered sufficiently accurate for presentation.

7. Because of the limitation of the span lengths and flexural rigidities of the floor beam and the reaction strut used in these tests, the eccentricity ratios reported herein may not be applicable to spans and rigidities of widely different values. It is considered that additional experimental work with greater range of parameters is needed.

8. In order to achieve a greater degree of similitude between the eccentricity measuring device and an actual masonry wall, the boundary conditions with respect to sidesway at the top and restraint at the base of the strut will need to be observed both during calibration and the measurement of eccentricities.

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