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BEHAVIOR OF MASONRY BEARING PLATES IN HIGHWAY BRIDGES:
AN EXPERIMENTAL INVESTIGATION

BY
VIMAL K. AGRAWAL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE
IN
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UNIVERSITY OF RHODE ISLAND

-1989-

MASTER OF SCIENCE THESIS
OF
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ABSTRACT

An experimental investigation is conducted on the bridge bearing system and the behavior of the masonry bearing plate on the distribution of stresses is studied.

Four specimens of the concrete substructure are cast in two different sizes and strain gages embedded in the concrete at several locations. The effects of the thickness of the bearing plate, size of the concrete substructure, ratio of the plate area to block area, overhang of the bearing plate beyond the loaded area, and the ratio of the loaded area to plate area have also been studied.

The experimental study comprises of 72 tests in the working stress range and four ultimate load tests. Stresses beneath the bearing plate in the concrete substructure and on the bearing plates are measured and presented. For the ultimate load tests, relative slip between the bearing plate and the concrete, and the relative lift of the plate edge in relation to concrete is measured and presented.

Experimental-analytical comparisons of stress distribution are made for some cases. Recommendations are made for designing the bearing plates.

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CONTENTS

List of Figures	v
List of Tables	x
List of Symbols	xi
Chapter 1 Introduction	1
Chapter 2 Experimental Program	
2.1 Concrete Blocks	4
2.2 Bearing Plates	17
2.3 Instrumentation	20
2.4 Testing Program	28
Chapter 3 Test Results	
3.1 Working Stress Range Tests	37
3.2 Ultimate Load Tests	89
Chapter 4 Discussion of Results	
4.1 Working Stress Range Tests	104
4.2 Ultimate Load Tests	127
4.3 Recommendations	132
Chapter 5 Finite Element Analysis	
5.1 Finite Element Model	137
5.2 Comparison of Experimental and Finite Element Results	139
Chapter 6 Summary and Conclusions	145
References	148
Appendix A	149
Appendix B	153
Bibliography	162

LIST OF FIGURES

1(a)	Forms for concrete blocks	6
1(b)	Form for 15 in. block	7
2	Details of gage location	8
3	Location of gages in Block 1 and 2 (12 in. x 12 in.)	9
4	Location of gages in Block 3 and 4 (15 in. x 15 in.)	10
5	Reinforcement details for blocks (top view)	12
6	Reinforcement case for 15 in. block	13
7	Form for 15 in. block after gages were installed	14
8	Stress strain relationship for concrete	18
9	Locations of gages on Bearing Plate	22
10	Recording Schematic	24
11	Wheatstone bridge circuit	27
12	Loading arrangement	31
13	Device for Slip measurement	34
14	Device for Lift measurement	36
15	Distribution of Stresses; Test 1, Block 1	38
16	Distribution of Stresses; Test 2, Block 1	38
17	Distribution of Stresses; Test 3, Block 1	39
18	Distribution of Stresses; Test 4, Block 1	39
19	Distribution of Stresses; Test 5, Block 1	40
20	Distribution of Stresses; Test 6, Block 1	40
21	Distribution of Stresses; Test 7, Block 1	41
22	Distribution of Stresses; Test 8, Block 1	41
23	Distribution of Stresses; Test 9, Block 1	42
24	Distribution of Stresses; Test 10, Block 1	42
25	Distribution of Stresses; Test 11, Block 1	43
26	Distribution of Stresses; Test 12, Block 1	43
27	Distribution of Stresses; Test 13, Block 1	44
28	Distribution of Stresses; Test 14, Block 1	44
29	Distribution of Stresses; Test 15, Block 2	45
30	Distribution of Stresses; Test 16, Block 2	45
31	Distribution of Stresses; Test 17, Block 2	46
32	Distribution of Stresses; Test 18, Block 2	46
33	Distribution of Stresses; Test 19, Block 2	47
34	Distribution of Stresses; Test 20, Block 2	47
35	Distribution of Stresses; Test 21, Block 2	48
36	Distribution of Stresses; Test 22, Block 2	48

LIST OF FIGURES (cont.)

37	Distribution of Stresses; Test 23, Block 2	49
38	Distribution of Stresses; Test 24, Block 2	49
39	Distribution of Stresses; Test 25, Block 2	50
40	Distribution of Stresses; Test 26, Block 2	50
41	Distribution of Stresses; Test 27, Block 2	51
42	Distribution of Stresses; Test 28, Block 2	51
43	Distribution of Stresses; Test 29, Block 2	52
44	Distribution of Stresses; Test 30, Block 2	52
45	Distribution of Stresses; Test 31, Block 3	53
46	Distribution of Stresses; Test 32, Block 3	53
47	Distribution of Stresses; Test 33, Block 3	54
48	Distribution of Stresses; Test 34, Block 3	54
49	Distribution of Stresses; Test 35, Block 3	55
50	Distribution of Stresses; Test 36, Block 3	55
51	Distribution of Stresses; Test 37, Block 3	56
52	Distribution of Stresses; Test 38, Block 3	56
53	Distribution of Stresses; Test 39, Block 3	57
54	Distribution of Stresses; Test 40, Block 3	57
55	Distribution of Stresses; Test 41, Block 3	58
56	Distribution of Stresses; Test 42, Block 3	58
57	Distribution of Stresses; Test 43, Block 3	59
58	Distribution of Stresses; Test 44, Block 3	59
59	Distribution of Stresses; Test 45, Block 3	60
60	Distribution of Stresses; Test 46, Block 3	60
61	Distribution of Stresses; Test 47, Block 3	61
62	Distribution of Stresses; Test 48, Block 3	61
63	Distribution of Stresses; Test 49, Block 3	62
64	Distribution of Stresses; Test 50, Block 3	62
65	Distribution of Stresses; Test 51, Block 3	63
66	Distribution of Stresses; Test 52, Block 4	63
67	Distribution of Stresses; Test 53, Block 4	64
68	Distribution of Stresses; Test 54, Block 4	64
69	Distribution of Stresses; Test 55, Block 4	65
70	Distribution of Stresses; Test 56, Block 4	65
71	Distribution of Stresses; Test 57, Block 4	66
72	Distribution of Stresses; Test 58, Block 4	66

LIST OF FIGURES (cont.)

73	Distribution of Stresses; Test 59, Block 4	67
74	Distribution of Stresses; Test 60, Block 4	67
75	Distribution of Stresses; Test 61, Block 4	68
76	Distribution of Stresses; Test 62, Block 4	68
77	Distribution of Stresses; Test 63, Block 4	69
78	Distribution of Stresses; Test 64, Block 4	69
79	Distribution of Stresses; Test 65, Block 4	70
80	Distribution of Stresses; Test 66, Block 4	70
81	Distribution of Stresses; Test 67, Block 4	71
82	Distribution of Stresses; Test 68, Block 4	71
83	Distribution of Stresses; Test 69, Block 4	72
84	Distribution of Stresses; Test 70, Block 4	72
85	Distribution of Stresses; Test 71, Block 4	73
86	Distribution of Stresses; Test 72, Block 4	73
87	Stresses in Bearing Plate; Test 21, gage location bot(c)	80
88	Stresses in Bearing Plate; Test 21, gage location top(c)	81
89	Stresses in Bearing Plate; Test 15, gage location bot(c)	82
90	Stresses in Bearing Plate; Test 15, gage location top(c)	83
91	Stresses in Bearing Plate; Test 12, gage location bot(c)	84
92	Stresses in Bearing Plate; Test 12, gage location top(c)	85
93	Distribution of Stresses; Test 73, Block 4	87
94	Distribution of Stresses; Test 74, Block 4	87
95	Distribution of Stresses; Test 75, Block 3	88
96	Distribution of Stresses; Test 76, Block 2	88
97	Distribution of Stresses; Test 77, Block 1	89
98	Internal Strain Distribution; Test 74, Block 4	91
99	Internal Strain Distribution; Test 75, Block 3	91
100	Internal Strain Distribution; Test 76, Block 2	92
101	Internal Strain Distribution; Test 77, Block 1	92
102	Internal Stress Distribution; Test 74, Block 4	93
103	Internal Stress Distribution; Test 75, Block 3	93
104	Internal Stress Distribution; Test 76, Block 2	94
105	Internal Stress Distribution; Test 77, Block 1	94
106	Slip of plate relative to concrete; Test 74, Block 4	97
107	Slip of plate relative to concrete; Test 75, Block 3	98
108	Slip of plate relative to concrete; Test 76, Block 2	99

LIST OF FIGURES (cont.)

109	Slip of plate relative to concrete; Test 77, Block 1	100
110	Lift of plate corner relative to concrete; Test 75, Block 3	101
111	Lift of plate corner relative to concrete; Test 76, Block 2	102
112	Lift of plate corner relative to concrete; Test 77, Block 1	103
113	Effect of plate thickness, Tests 1,3,4, Block 1	105
114	Effect of plate thickness, Tests 2,5,7, Block 1	105
115	Effect of plate thickness, Tests 6,8,9, Block 1	106
116	Effect of plate thickness, Tests 16,18,19, Block 2	106
117	Effect of plate thickness, Tests 17,20,22, Block 2	107
118	Effect of plate thickness, Tests 21,23,24, Block 2	107
119	Effect of plate thickness, Tests 34,36,37, Block 3	108
120	Effect of plate thickness, Tests 35,38,40, Block 3	108
121	Effect of plate thickness, Tests 39,41,42, Block 3	109
122	Effect of plate thickness, Tests 43,45,46, Block 3	109
123	Effect of plate thickness, Tests 44,47,49, Block 3	110
124	Effect of plate thickness, Tests 48,50,51, Block 3	110
125	Effect of plate thickness, Tests 55,57,58, Block 4	111
126	Effect of plate thickness, Tests 56,59,61, Block 4	111
127	Effect of plate thickness, Tests 60,62,63, Block 4	112
128	Effect of plate thickness, Tests 64,66,67, Block 4	112
129	Effect of plate thickness, Tests 65,68,70, Block 4	113
130	Effect of plate thickness, Tests 69,71,72, Block 4	113
131	Effect of Pl. thick. and Ld. Area/ Pl. Area; Pl./ Bl. Area = 0.77	114
132	Effect of Pl. thick. and Ld. Area/ Pl. Area; Pl./ Bl. Area = 0.50	115
133	Effect of Pl. thick. and Ld. Area/ Pl. Area; Pl./ Bl. Area = 0.25	116
134	Effect of Pl. Area/ Bl. area , Test 1,10,13, Block 1	118
135	Effect of Pl. Area/ Bl. area , Test 2,11,14, Block 1	118
136	Effect of Pl. Area/ Bl. area , Test 6,12,15, Block 1	119
137	Effect of Pl. Area/ Bl. area , Test 16,25,28, Block 2	119
138	Effect of Pl. Area/ Bl. area , Test 17,26,29, Block 2	120
139	Effect of Pl. Area/ Bl. area , Test 21,27,30, Block 2	120
140	Effect of Pl. Area/ Bl. area , Test 31,34,43, Block 3	121
141	Effect of Pl. Area/ Bl. area , Test 32,35,44, Block 3	121
142	Effect of Pl. Area/ Bl. area , Test 33,39,48, Block 3	122
143	Effect of Pl. Area/ Bl. area , Test 52,55,64, Block 4	122
144	Effect of Pl. Area/ Bl. area , Test 53,56,65, Block 4	123

LIST OF FIGURES (cont.)

145	Effect of Pl. Area/ Bl. area , Test 54,60,69, Block 4	123
146	Effect of Ld. Area / Pl. Area; Plate / Block area = .77	124
147	Effect of Ld. Area / Pl. Area; Plate / Block area = .50	125
148	Effect of Ld. Area / Pl. Area; Plate / Block area = .26	126
149	Effect of Ld. Area / Pl. Area; Plate / Block area = .77	128
150	Effect of Ld. Area / Pl. Area; Plate / Block area = .50	129
151	Effect of Ld. Area / Pl. Area; Plate / Block area = .26	130
152(a)	Initial Cracking pattern for Block 1	135
152(b)	Final Cracking pattern for Block 1	135
153(a)	Initial Cracking pattern for Blocks 2,3 and 4	136
153(b)	Final Cracking pattern for Blocks 2,3 and 4	136
154	Finite Element Mesh	138
155	Vertical stresses in concrete at Strain Gages level	140
156	Variation of Concrete Stresses	141
157	Strain Distribution at failure	142
158	Vertical Displacement at Centerline	143
159	Calibration Curve, Pressure Transducer	150
160	Calibration Curve, Displacement Transducer 1	151
161	Calibration Curve, Displacement Transducer 2	152

LIST OF TABLES

1	RIDOT Specifications for Class B(AE) mix	15
2	Concrete Mix Proportions	15
3	Cylinder Compression Test results	15
4(a)	Plate Sizes for 12 in. x 12 in. Blocks (1 and 2)	16
4(b)	Plate Sizes for 15 in. x 15 in. Blocks (3 and 4)	16
5	Working stress range tests conducted	29
6	Ultimate load tests conducted	30
7	Stresses in bearing plates (working stress range tests)	75
8	Stress in top horizontal rebar (working stress tests)	86
9	Stresses in bearing plates (ultimate load tests)	95
10	Stress in top horizontal rebar (ultimate load tests)	96
11	Stress ratios at the end of Loaded area and at Plate edge	134
12	Factor of safety against failure from Ultimate load tests	134

LIST OF SYMBOLS

a	Square bearing plate dimension
A_1	Loaded area
A_2	Area of the concrete substructure
c	Distance of the extreme fiber from the neutral axis
d	Diameter of the loaded area
ϵ	Strain
E	Modulus of Elasticity
f_b	Allowable bearing stress in concrete
f_{ba}	Allowable bending stress in steel
F_v	Allowable shear stress in steel
F_y	Yield stress for steel
f_c	Ultimate compressive strength of concrete in uniaxial compression
I	Moment of Inertia
l	Overhang of the bearing plate
M	Maximum bending moment
σ	Stress
S_{req}	Required section modulus
t	Plate thickness
V	Shear force
V_{in}	Input voltage to the wheatstone bridge circuit
V_{out}	Output voltage from the wheatstone bridge circuit
w	Uniformly distributed Stress
w/c	Water to cement ratio by weight

CHAPTER 1

INTRODUCTION

Masonry bearing plates are used extensively in highway bridges throughout the United States. These bearing plates serve the purpose of uniformly distributing the load from the superstructure to the supporting concrete substructure.

The design of the bearing plate currently is based on the assumption that the bearing stresses in concrete are uniform across the entire area of the plate [1],[2]. This thesis project involves investigation of the behavior of the bearing plate in terms of transferring the loads from the superstructure to the concrete substructure.

McEwen et al. [4], and Saxena et al. [8], performed an inelastic finite element analysis of the bearing system in 1985. It was seen that the bearing stress distribution was uniform only under the loaded portion of the bearing plate and contrary to the normal assumption in design, very little lateral distribution of the applied load was observed. The analytical parametric study of the bearing plate and geometry showed that the stresses in concrete are only slightly affected by the plate thickness. Bending stresses in the plate were found to be much lower than the nominal design stresses, and the bearing load seemed to be carried to the concrete almost entirely in direct compression.

The above results were completely analytical in nature and numerous assumptions were made in order to model the system. Assumptions were made for stress strain relations and the failure criteria of concrete. Many constitutive theories have been developed for multidimensional nonlinear behavior of concrete [5]. The model

of Chen & Chen [6] was used, which models the plastic yielding and failure of the concrete by means of a two part yield surface in principal stress space which expands as plastic strain occurs up to a limiting value which defines failure. The failure criteria used have been verified for only a limited number of three dimensional stress states and not for the conditions present in the bearing system.

If the analytical results are correct, the significance of these differences with the acceptable design methods is that not only is the design of the bearing plate overly conservative but that the ultimate capacity of the concrete is considerably greater than normally assumed by the present specifications. A literature search on this project failed however, to locate any experimental studies conducted on the behavior of masonry bearing plates. An experimental investigation was therefore conducted to study the behavior of the masonry bearing plates.

Concrete blocks were cast in two different sizes to study the effect of confining stress. Two blocks of each size were cast for duplication of data. The concrete mix was designed to conform with the Rhode Island Standard Specifications for Road and Bridge Constructions [7] and cylinders were cast and the ultimate strength of the concrete was determined. Stress strain relationship for the concrete was also determined for uniaxial compression. Bearing plates were designed based on the Standard Specifications of Highway Bridges.

For the purpose of the experimental study seventy two tests were conducted within the elastic range and the effect of the following parameters on the stress distribution was studied:

1. Plate thickness: Thicknesses greater than design were chosen.
2. Ratio of loaded plate area to bearing plate area: Ratios of 0.75, 0.50, 0.25 were chosen.
3. Ratio of bearing plate area to the area of the concrete block: Ratios of 0.75,

0.50, 0.25 were chosen.

Four ultimate load tests were also conducted, one on each block to determine the ultimate capacity of each block.

Strain gages were installed inside each form at the desired locations to measure stresses in the concrete substructure. Gages were also installed at various locations on each of the bearing plates and the bending stresses were measured. Acquisition of data was controlled by an automatic data acquisition system. Load readings and strain readings were recorded at desired intervals.

The stress distribution (both in concrete as well as steel) resulting from the experiments has been compared to the stresses resulting from the current design assumption of uniform distribution of the stresses.

For the ultimate load tests, lateral distribution of stresses was also studied. The lateral movement of the plate relative to the concrete was also measured during the ultimate load tests. It was observed during the first ultimate load test that the plate edges lifted up from the concrete surface considerably. The lift of the plate corner relative to the concrete was measured for the remaining three ultimate load tests.

The results obtained are presented and discussed. Conclusions are drawn and recommendations made based on test results.

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The results obtained are presented and discussed. Conclusions are drawn and recommendations made based on test results.

CHAPTER 2

EXPERIMENTAL PROGRAM

The experimental program was designed to study the behavior of masonry bearing plates, and to experimentally measure the stresses occurring in the bearing plates as well as within the concrete substructure. The effect of the following parameters was studied:

- (a) Thickness of the bearing plate,
- (b) Size of the concrete substructure,
- (c) Ratio of plate area to block area,
- (d) Overhang of the bearing plate beyond the loaded area,
- (e) Ratio of loaded area to plate area.

2.1 CONCRETE BLOCKS:

For the purpose of experimental testing four concrete blocks were designed. Two blocks were 12 inches by 12 inches by 12 inches and the other two were 15 inches by 15 inches by 15 inches.

2.1.1 PREPARATION OF FORMWORK:

The main consideration in the preparation of formwork was to keep the adjacent surfaces of the form perpendicular to each other and to stiffen them enough to prevent any kind of warping or shearing in the forms until the concrete was poured and set. Another consideration was to place the strain gages at the desired locations where stresses were to be measured and to take the leads from the gages out without affecting the stress distribution in the the block.

To prevent warping three quarter inch thick plywood was used. To stiffen the forms framing lumber (2" by 3") was used at the top and bottom (*Fig.1(a)*). Half inch holes were drilled on opposite sides of the forms approximately two and half inches from the bottom to receive half inch wide electrical conduits . Holes one eighth inch in diameter were drilled in these conduits to take the leads of the strain gages out of the concrete blocks. For placing the strain gages two steel strips (3/16" wide and 1/64" thick) were run taut directly over the conduits (3" from top surface) and anchored on the plywood. Another strip was run across the diagonal at the same height (*Fig.1(b)*).

Strain gages used inside the blocks were Polyester Mold Gages PMLS-10 (Made by Tokyo Sokki Kenkyujo Co. of Japan and supplied by Texas Measurements Inc.). These gages are especially designed for short and long term measurements of internal strains in concrete. The gage is completely waterproof and is coated with a coarse grit which gives the gage excellent bonding characteristics. The gages were glued to the steel strips using an epoxy adhesive PS (also made and supplied by the above mentioned companies). The gages were glued such that the actual gage length was not attached to the strip (*Fig.2*) . The location of the gages can be seen in *Fig.3* and *Fig.4*. A strain gage was also attached to the reinforcement. The convention used for naming the gages inside the block is as follows:

- (a). The four sides of each block were named North, East, West and South.
- (b). The gages were named based on their locations, and the numbering started from the one closest to the center, *e.g.* E1, E2, NE1, etc.
- (c). The horizontal gages were named as EH1, EH2, SWH1, etc.
- (d). The gage attached to the reinforcement was called RE1.

The reinforcement used was nominal 0.2% for the larger block and 0.24% for the smaller. The spacing between vertical bars was 2.5" and between horizontal

Fig.1(a): Forms for Concrete Blocks.

Fig.1(b): Form for 15" block.

Fig.2: Details of gage location

Fig.3: Location of gages in block 1 and block 2 (12'x12')

Fig.4: Location of gages in block 3 and block 4 (15"x15").

bars was 3.0". The details can be seen in *Fig.5*. A typical reinforcement cage used for the 15" block can be seen in *Fig.6*.

Fig.7 shows a photograph of a typical 15" form after gages were installed.

2.1.2 CONCRETE MIX AND CYLINDERS:

The concrete mix was designed according to the specifications of Rhode Island Department of Transportation [7] to meet classification B with Air Entrainment i.e. B(AE). Section 600 of [7] gives the specifications for different classes of mix. The specifications for class B(AE) are listed in *Table 1*.

The concrete was supplied by a company, Pawtucket Ready Mix, and the proportions are given in *Table 2*. Concrete was used from a freshly mixed two cubic yard batch of standard 3000 psi. design mix with 1/2 inch maximum size aggregate. The cement factor was 516 lbs./cu. yd. and w/c ratio was 0.5.

The forms were oiled and transported to the mixing plant. The concrete was poured carefully in order not to snap any leads from the gages or change the inclination of the gages. Vibratory compaction was used for the blocks. Slump was determined in accordance with ASTM C-143 and was found to be three and half inches.

Six 6 inch by 12 inch cylinders were cast (ASTM C-192 "Laboratory preparation of Molded Concrete cylinders") for testing the compressive strength of the concrete at seven and twentyeight days. In addition twelve 4 inch by 8 inch cylinders were also cast and three were tested at the start of testing of each block to know the compressive strength of concrete at that time.

The concrete blocks and cylinders were cured at about 70 deg. F. and at a relative humidity of 95% for seven days. Curing was stopped after seven days as the strength exceeded 3000 psi. Seven and twenty eight day compressive tests on cylinders were done in accordance with ASTM C-39. The results of these compres-

Fig.5: Reinforcement details for blocks(top view).

Fig.6: Reinforcement case for 15" block.

Fig.7: Form for 15" block after gages were installed.

Minimum cement factor:	
Bags per cu. yd.	5.5
Lbs. per cu. yd.	517
Maximum net water content:	
Per bag of cement; gal.	6.5
Per cubic yard, gal.	35.75
Consistency range in slump:	
Regular placing, in.	2-3
Vibrated, in.	1-2
Minimum compression strength	
7 day, psi.	1600
28 day, psi.	3000

Table 1: RIDOT Specifications for Class B(AE) mix.

Date:	June 14, 1988
Time:	10:21 a.m.
Batch Number:	25
Job Number:	16
Formula Number:	71 (3000 psi. 1/2" Standard)
Batch Volume:	2.0 cu. yds.
Aggregate 1 (sand):	3040 lbs. (moisture content= 3.5%)
Aggregate 2 (1/2"):	3060 lbs. (moisture content= 0.0%)
Cement:	1032 lbs.
Water:	62 gallons
Additives:	Air= 4.0 oz. Water Reducer WRDA15= 32.0 oz.

Table 2: Concrete Mix proportions.

Cylinder No.	Date tested	Strength (psi.)
1	June 21 (7 days)	3978.8
2	June 21 (7 days)	4102.7
3	June 21 (7 days)	3077.0

Table 3: Cylinder compression test results.

<i>Cylinder No.</i>	<i>Date tested</i>	<i>Strength (psi.)</i>
4	July 12 (28 days)	5871.0
5	July 12 (28 days)	5818.0
6	July 12 (28 days)	5835.7
7	Sept. 23	6286.6
8	Sept. 23	5769.4
9	Sept. 23	5809.1
10	Oct. 22	6008.0
11	Oct. 22	5810.0
12	Oct. 22	5848.9
13	Dec. 19	5849.0
14	Dec. 19	5888.7
15	Dec. 19	6167.3

Table 3(continued): Cylinder compression test results.

Plate size:	10.5 × 10.5			8.5 × 8.5			6.0 × 6.0		
Loaded diameter:	10.3	8.3	6.0	8.3	6.8	4.8	6.0	4.8	3.4
Overhang:	0.1	1.1	2.25	0.1	0.85	1.85	0.0	0.6	1.3
Plate thickness:									
based on bending:	.037	.4042	.827	.037	.3123	.68	0.0	0.22	.478
based on shear:	.06	.16	.329	.05	.127	.27	.03	.09	.19
Design:	0.06	.4042	.827	.05	.3123	.68	.03	.22	.478
Selected:	.122	.405	.836	.123	.315	.685	.123	.222	.478
	.476	.837	1.203						
	.837	1.203	1.626						

Table 4(a): Plate Sizes for 12 in. × 12 in. Blocks (1 & 2).

Plate size:	13.0 × 13.0			10.5 × 10.5			7.5 × 7.5		
Loaded diameter:	12.7	10.3	7.3	10.3	8.3	6.0	7.3	6.0	4.25
Overhang:	0.15	1.35	2.85	0.1	1.1	2.25	0.1	0.75	1.625
Plate thickness:									
based on bending:	.055	.496	1.047	.0367	.4042	.827	.036	.276	.597
based on shear:	.08	.20	.42	.063	.163	.33	.05	.112	.24
Design:	0.08	.496	1.047	.063	.4042	.827	.05	.276	.597
Selected:	.124	.50	1.05	.122	.405	.837	.123	.28	.605
				.476	.837	1.203	.368	.605	.856
				.837	1.203	1.626	.605	.856	1.168

Table 4(b): Plate Sizes for 15 in. × 15 in. Blocks (3 & 4).

sive tests are given in *Table 3*. In addition to this, strain gages were mounted on the surface of one of the cylinders to determine the stress strain relation for the concrete. The stress strain relation obtained can be seen in *Fig.8*. The slope of the curve in the linear portion of the curve gives the modulus of elasticity for concrete. The modulus of elasticity from this curve came out to 4.55×10^6 psi.

The value of E for concrete as given by ASTM C 469

$$E = 57000\sqrt{f'_c}$$

comes out to 4.36×10^6 psi., using an average value of 5841.6 psi. for f'_c at 28 days.

2.2 BEARING PLATES:

In all twentyone bearing plates were prepared from A-36 steel to study the effect of various parameters such as edge distance, ratio of plate area to block area and plate thickness. The plates were machined by TAB Enterprises, Pawtucket, R.I. The plate edges were cut by flame and had a rough finish. The plate thicknesses were machined by *blanchard grinding* and had a smooth finish on the top and bottom surfaces.

2.2.1 SELECTION OF PLATE SIZES:

Bearing plate sizes were determined on the basis of the ratio of plate area to block area to study the effect of edge distance of plates. Plate area to block area ratios of 0.75, 0.50 and 0.25 were selected. The plate sizes selected are listed in *Table 4*.

2.2.2 DESIGN OF PLATE THICKNESSES:

The design of the bearing plate currently is based on the assumption that the bearing plate distributes the load uniformly from the bearing to the concrete substructure [1], [2]. The thicknesses of the bearing plates were determined based on this assumption. The portion of the plate extending out from the loaded area

Fig.8: STRESS STRAIN RELATION FOR CONCRETE

perpendicular to the edge of the plate was used as the *overhang* for designing the plate as a cantilever.

The overhang of the plate varied based on the ratio of load area to plate area and the ratio of plate area to block area. The loaded area were selected based on the ratio of load area to plate area ratios of 0.75, 0.50 and 0.25.

Allowable bearing stress in concrete

$$f_b = 0.3f'_c \dots\dots\dots (\text{AASHTO sec. 1.5.26.(A).(3)}) \quad [1]$$

Therefore for $f'_c = 3000$ psi., $f_b = 900$ psi.

Designing for bending, assuming a uniformly distributed stress of 900 psi acts on the plate, with an overhang l and assuming a unit width, the maximum bending moment

$$M = 900l^2/2$$

$$S_{req} = M/f_{ba} ; f_{ba} = 0.55F_y \dots\dots\dots (\text{AASHTO table 1.7.1A}) \quad [1]$$

$$\text{Plate thickness } t = \sqrt{6 \times S_{req}}$$

$$\Rightarrow t = 0.3674 \times l ; \text{ where } F_y = 36 \text{ ksi.}$$

Designing for shear, assuming square plate size $a \times a$ and loaded diameter d , the punching shear force $V = (a \times a - \pi d^2/4) \times 900$

$$\text{The allowable shear stress } F_v = .33F_y \dots\dots\dots (\text{AASHTO table 1.7.1A}) \quad [1]$$

$$\Rightarrow F_v = 11880 \text{ psi.}$$

$$\text{Minimum thickness required for shear resistance} = V/(\pi \times d \times 11880)$$

The thicknesses of plates based on design for bending and shear are listed in Table 4. The greater of the two was chosen as design thickness. In cases where the design thickness came out to be less than 0.125 in. , a 0.125 in. design thickness was used.

In addition to this to study the effect of thickness some thicknesses greater than design thickness were chosen for plate sizes 10.5in. $\times$ 10.5in. and for plate sizes

7.5in. $\times$ 7.5in.

2.2.3 MOUNTING OF GAGES ON THE BEARING PLATE:

The strain gages used for measuring stresses in the steel plate were 120 Ω gages supplied by Micro Measurements and designated as EA-13-125BT-120. These were constantan strain gages and were of open faced construction with a tough flexible polyimide film backing.

Gages were mounted on top surface as well as the bottom surface of the bearing plate, close to the loaded area of the overhang to measure the expected maximum stresses resulting from the bending of the plate. Locations of gages on the plate can be seen in *Fig.9*. The convention used for the nomenclature of the gages is as follows:

(a). The gage located along the *diagonal* of the plate was called e.g. top(d), if it was on the top surface of the plate.

(b). The gage located on the line joining the centers of the two opposite edges was called e.g. top(c) if it was on the top surface of the plate, and bot(c) if it was on the bottom surface of the plate.

For achieving perfect bonding between the gage and the plate, the steel plate surface was cleaned with degreasing agent, sanded with a fine paper and cleaned with alcohol. Krazy glue extra strength gel was used for attaching the gages to the surface. After the gages were mounted on the bearing plate they were left for 24 hours for the glue to dry. After the glue had dried, leads were carefully soldered to the gages.

2.3 INSTRUMENTATION:

The loading apparatus and the data acquisition system were about 70 feet apart, therefore twisted and shielded low voltage cables had to be run from the strain gauges on the specimen to the data acquisition system. Since there were over thirty

strain gages it was decided to have a separate wheatstone bridge circuit for each gage rather than having a single bridge and switching gages. This helped to keep the gages energized at all times and minimised the dynamic heating and cooling effects. For measuring strains in the gages simultaneously and avoiding the process of balancing the wheatstone bridge each time, the method of unbalanced wheatstone bridge strain measurement was used [9].

2.3.1 DESCRIPTION OF EQUIPMENT USED:

The instruments and equipment used during the experiments are described as follows:

1. Tinius Olsen 300,000 lbs. capacity Super-L Universal Testing Machine, located in the Civil Engineering laboratory.

2. Hydraulic pressure transducer, Dynisco; PT 310J 1M. This transducer was used for measuring load applied to the specimen. It was inserted in the middle range hydraulic lines of the testing machine, which pressurize the piston applying the load to the specimen. The transducer was calibrated against the load dial of the machine. The calibration curve is given in *Appendix A*.

3. Linear displacement transducer, HP 24DCDT-250. for measuring slip between the bearing plate and the concrete. The transducer was calibrated and the calibration curve is given in *Appendix A*.

4. Linear displacement transducer, HP 24DCDT-500. for measuring lift at the corner of the bearing plate. The calibration curve is given in *Appendix A*.

5. Thirty four wheatstone bridge circuits with $120\ \Omega$ resistor in each arm and one strain gage as the active arm.

6. A 24 volt regulated power supply for displacement transducers, a 10 volt power supply for pressure transducer, and a 5 volt regulated power supply for the wheatstone bridge circuits.

Fig.9: Locations of gages on Bearing Plate.

7. Hewlett Packard Data Acquisition System, HP 3052A. This includes the following:

- a. Scanner - HP 3495A. Scans analog signals from preselected or programmed channels at preselected time intervals.
- b. Voltmeter - HP 3455A. Measures analog signal from scanner and converts into digital signal precisely upto 1 microvolt.
- c. Computer - HP 9816. Helps control the data acquisition and performs the computations.
- d. Plotter - HP 9872A. Plots desired data and is controlled by the computer.
- e. Printer - HP 2671G. Prints desired output or listing of programs.
- f. Disk drive - HP 9121, used for accessing programs and data files.

2.3.2 RECORDING SCHEMATIC:

The recording schematic can be seen in *Fig.10* . The leads from the strain gages were connected to the wheatstone bridges with each gage acting as an active arm of the wheatstone bridge. The wheatstone bridges had a power supply of 5 volts and the output from the bridges went to the 20-channel connector assemblies at the back of the scanner. These assemblies acted as interface to the scanner. Each assembly handled 20 differential channels (i.e. 20 high and 20 low inputs). The common from these assemblies was connected to the 2 wire and 4 wire ground connectors at the back. The pressure transducer has a power supply of 10 volts and the output from the pressure transducer went to the scanner. Leads from the linear displacement transducers for measuring the slip and lift of the bearing plate relative to the concrete block were also connected to the scanner. The digital voltmeter was connected to the scanner and read the voltage from the channel scanned. The digital output from the voltmeter went to the computer from which the data was processed and sent to the printer, the plotter and the magnetic disk drive.

Fig.10: Recording Schematic.

2.3.3 COMPUTER PROGRAMS USED FOR TESTING:

The computer programs used for monitoring the testing are given in *Appendix B*. Program 1 was used for the working stress range tests. Program 2 was used for the ultimate load tests. Input to the programs included the following:

- a. Bearing Number, i.e. the number of the concrete block .
- b. Number of strain gages, including both steel and concrete.
- c. Number of types of gages being used.
- d. Type of gage, Start channel, End channel and Gage factor for each type.
- e. Slope and intercept from the calibration curve for pressure transducer to convert pressure transducer readings to load.
- f. Name of Operator, Date and time of Test.
- g. Dimensions of the bearing plate.
- h. Diameter of the loaded area.
- i. Name of data file for storing raw data.
- j. Name of data file for storing processed data.
- k. Number of readings to be taken for each gage.
- l. Delay between two sets of readings in milliseconds.

After all the necessary input had been fed in, the program paused until the "continue" key was pressed and the first set of readings started after 5 seconds.

2.3.4 DATA ACQUISITION AND CONTROL:

Once the "continue" key was pressed the data acquisition started and the preselected channels were scanned for each set of readings and readings were printed on the screen and stored in the previously named data file. Initial readings were taken close to zero load and then the bearing system was loaded slowly. The load was held approximately constant when each set of readings were taken. The following values were read:

a. Channel 1 thru a maximum of channel 33, voltage outputs from the gage wheatstone bridges.

b. Channel 38 read the output from the pressure transducer, which was read twice, once before each set of readings were taken and once after.

c. Channel 39 read the input voltage supplied to the wheatstone bridges at the time each set of readings was taken.

d. Channel 37 read the output from the transducer used to measure slip between the bearing plate and concrete block (only for ultimate load tests).

e. Channel 34 read the output from the transducer used to measure lift at the edge of the plate relative to the concrete block (only for ultimate load tests).

2.3.5 DATA REDUCTION AND PROCESSING:

The strains were calculated as [9]

$$\epsilon = \left[\frac{-4V_r}{GF \times (1+2V_r)} \right]$$

$$\text{where } V_r = \left[\left(\frac{V_{out}}{V_{in}} \right)_{strained} - \left(\frac{V_{out}}{V_{in}} \right)_{unstrained} \right]$$

V_{in} and V_{out} being the input and output voltages to the wheatstone bridge (Fig.11) and GF being the gage factor for the gage.

The first set of readings close to zero load were regarded as unstrained and the remainder were considered to be under strained condition. For each gage the ratio V_{out}/V_{in} was calculated at each set of readings and strain ϵ was computed.

The wheatstone bridge circuits set up in the lab gave satisfactory results. The modulus of elasticity computed for concrete from the stress strain curve came out to be very close to the expected theoretical value. However, it should be noted that no calibration of the wheatstone bridges was done.

Readings from the pressure transducer were converted to load based on the slope and intercept from the calibration curve *Appendix A*.

For the ultimate load tests, the readings from the displacement transducers

Fig.11: Wheatstone bridge circuit with a strain gage as its active arm.

were converted to displacements based on the slopes and intercepts from the calibration curves *Appendix A*.

2.4 TESTING PROGRAM:

The intention of this experimental investigation was to study the effect of various parameters such as plate thickness, ratio of load area to plate area, ratio of plate area to block area, and blocksize on distribution of stresses the concrete substructure. The testing program consisted of 72 tests in the working stress range and 4 tests, one for each concrete block, to ultimate load. *Table 5*. gives the description of the tests conducted.

Before the actual tests were conducted, some preliminary tests were done to verify the accuracy of the equipment, *e.g.* a three point bend test on a plate was conducted and stresses were measured on the surface of the plate by attaching strain gages to the surface of the plate. Another test was done to determine the stress strain relation for steel in uniaxial tension. The results were satisfactory.

2.4.1 TESTING PROCEDURE:

The top surface of the concrete blocks were leveled using a high strength leveling compound (Savogran's level best floor leveler). An eighth inch thick teflon sheet was used beneath the bearing plate to even out any unevenness on the concrete surface. A concrete block was then put on the Tinius Olsen testing machine and all the working stress range tests corresponding to that block were conducted. Once all the tests in the working stress range were complete, the ultimate load tests were done.

The loading arrangement can be seen in *Fig.12*.

The procedure used during testing is elaborated as follows:

1. Strain gages were mounted on the bearing plate at the desired locations and the bearing plate was put on the concrete block.

Block No.	Test No.	Bearing Plate		Loaded Area (circular) (sq.in.)
		Thickness (inches.)	Area (sq.in.)	
One	1	0.122	110.36	87.25
	2	0.405	114.06	58.09
	3	0.476	113.63	87.25
	4	0.837	113.84	87.25
	5	0.837	113.84	58.09
	6	0.837	113.84	30.09
	7	1.203	113.85	58.09
	8	1.203	113.85	30.09
	9	1.626	113.95	30.09
	10	0.123	72.16	58.09
	11	0.315	75.04	39.26
	12	0.685	75.08	19.17
	13	0.123	36.12	30.09
	14	0.222	38.19	19.17
	15	0.478	37.70	10.64
Two	16	0.122	110.36	87.25
	17	0.405	114.06	58.09
	18	0.476	113.63	87.25
	19	0.837	113.84	87.25
	20	0.837	113.84	58.09
	21	0.837	113.84	30.09
	22	1.203	113.85	58.09
	23	1.203	113.85	30.09
	24	1.626	113.95	30.09
	25	0.123	72.16	58.09
	26	0.315	75.04	39.26
	27	0.685	75.08	19.17
	28	0.123	36.12	30.09
	29	0.222	38.19	19.17
	30	0.478	37.70	10.64
Three	31	0.124	168.93	130.9
	32	0.500	173.58	87.25
	33	1.050	172.92	45.25
	34	0.122	110.36	87.25
	35	0.405	114.06	58.09
	36	0.476	113.63	87.25
	37	0.837	113.84	87.25
	38	0.837	113.84	58.09

Table 5: Working stress range tests conducted

Block No.	Test No.	Bearing Plate		Loaded Area (circular) (sq.in.)
		Thickness (inches.)	Area (sq.in.)	
Three	39	0.837	113.84	30.09
	40	1.203	113.85	58.09
	41	1.203	113.85	58.09
	42	1.627	113.96	30.09
	43	0.123	56.33	45.25
	44	0.280	58.36	30.09
	45	0.368	58.06	45.25
	46	0.605	58.91	45.25
	47	0.605	58.91	30.09
	48	0.605	58.91	15.62
	49	0.856	58.60	30.09
	50	0.856	58.60	15.62
	51	1.168	58.91	15.62
Four	52	0.124	168.93	130.9
	53	0.500	173.58	87.25
	54	1.050	172.92	45.25
	55	0.122	110.36	87.25
	56	0.405	114.06	58.09
	57	0.476	113.63	87.25
	58	0.837	113.84	87.25
	59	0.837	113.84	58.09
	60	0.837	113.84	30.09
	61	1.203	113.85	58.09
	62	1.203	113.85	58.09
	63	1.627	113.96	30.09
	64	0.123	56.33	45.25
	65	0.280	58.36	30.09
	66	0.368	58.06	45.25
	67	0.605	58.91	45.25
	68	0.605	58.91	30.09
	69	0.605	58.91	15.62
	70	0.856	58.60	30.09
	71	0.856	58.60	15.62
	72	1.168	58.91	15.62

Table 5(continued): Working stress range tests conducted

Test No.	Block No.	Bearing Plate		Loaded Area (sq.in.)	Ratio	
		Thickness (in.)	Area (sq.in.)		Plate Area to Block Area	Load Area to Plate Area
73*	4	0.837(design)	113.84	30.09	0.50	0.26
74	4	0.605(design)	58.91	15.62	0.26	0.26
75	3	0.856(>design)	58.60	15.62	0.26	0.26
76	2	0.685(design)	75.08	19.17	0.52	0.26
77	1	0.315(<design)	75.04	19.17	0.52	0.26

* Block did not fail at 250 kips. (maximum capacity of pressure transducer).

Table 6: Ultimate load tests conducted on Blocks

Fig.12: Loading arrangement

2. Leads from all the gages were connected to the wheatstone bridges making note of each particular gage and its corresponding channel number.

3. The power supply for the wheatstone bridges and transducers were turned on for 15 minutes to stabilize the circuits.

4. A circular plate of desired size for the required loaded area was put on the bearing plate. (The loading head of the testing machine was of 8.5" diameter therefore the thickness of circular plates for loaded diameter close to 8.5" or less than 8.5" were not important and were chosen as 0.5". For the loaded diameter greater than 8.5" the thickness of circular plates was chosen as 1.5").

5. In case of the ultimate load tests, the transducers were mounted for measuring slip at the edge of the bearing plate and for measuring lift at the corner of the bearing plate relative to the concrete.

6. The computer program was loaded, run and the necessary information was input. An interval of about 60 seconds was specified between each set of readings.

7. The Tinius Olsen machine was started and a negligible load of about 0.1 kips was put on the bearing.

8. The data acquisition was started by pressing the "continue" key on the keyboard.

9. The load was then applied to the bearing at the rate of approximately 15 kips. per minute. The load was held approximately constant when the data was being acquired.

10. The last reading was taken at a predetermined maximum applied load.

2.4.1.1 TESTS WITHIN WORKING STRESS RANGE:

For the tests under the working stress range the data was acquired only while loading the bearing. Tests 1 through 72 were conducted under the working stress range. The maximum load applied to the bearing was determined by assuming that

the load was being distributed uniformly to, just under the loaded area and not under the entire bearing plate. So to get the maximum load applied, the allowable bearing stress was multiplied by the loaded area. This was done to make sure that the stresses in concrete did not exceed the allowable stresses.

2.4.1.2 ULTIMATE LOAD TESTS:

Load was applied to each block till the block failed or to the maximum capacity of the machine. *Table 6* lists the ultimate load tests conducted on the four blocks.

Test 73 was done on block 4, but the block did not fail so another test 74 had to be conducted on block 4.

The criteria for selection of the plate sizes and the loaded area were:

(a). Wanted the block to fail within the capacity of the testing machine so that the ultimate load could be determined.

(b). Study the effect of plate thickness.

For one of the 15" blocks, design thickness was used and for the other 15" block bearing plate thickness greater than design thickness was used. Rest parameters were kept the same for both.

For one of the 12" blocks, design thickness was used and for the other 12" block plate thickness less than design thickness was used. Rest parameters were kept the same for both.

Strain gage and slip data was acquired while loading as well as unloading the bearing. The measurement of slip is described in the next subsection.

While performing the ultimate test on block 4 (test 74) it was observed that the edges of the bearing plate lifted away up from the concrete block by a considerable amount, so it was decided to measure the lift at the corner of the bearing plate with the help of another transducer. This is described in subsection 2.5.1.2.(b).

Fig.13: Device for slip measurement

2.4.1.2.(a) SLIP MEASUREMENT:

Horizontal slip at the edge of the bearing plate relative to the concrete block was successfully measured with the help of a linear displacement transducer for tests 74, 75, 76 and 77. The device used for slip measurement can be seen in *Fig.13*.

2.4.1.2.(b) LIFT MEASUREMENT:

Lift of the bearing plate relative to the concrete at the corner of the plate was successfully measured for tests 75, 76 & 77. The device used for lift measurement can be seen in *Fig.14*.

Fig.14: Device used for Lift measurement.

CHAPTER 3

TEST RESULTS

3.1 WORKING STRESS RANGE TESTS:

3.1.1 STRESSES IN CONCRETE:

The vertical stress distribution inside the concrete substructure (at a load level of $\sim 0.4f'_c$ based on loaded area) at a distance of 2.5 inches below the bearing plate is shown in *Figs. 15 thru 86*. A ratio of actual stress measured to the uniformly distributed stress beneath the total plate area (as expected based on the current assumption), called the *stress ratio* from hereon is plotted as a function of distance from the center of the block.

The plots show the actual data points as well as a least squares fit cubic polynomial. The scatter in the data could be attributed to the following:

(a). The gage readings were highly sensitive to the evenness of the concrete surface, which could not be made perfectly even and horizontal. The thin teflon layer used between the bearing plate and the concrete minimised the unevenness but did not eliminate it completely.

(b). The inclination of the gage might have changed while pouring or compacting the concrete.

As it can be noted from the plots that the stress distribution in the concrete beneath the bearing plate is not at all uniform, but on the contrary to the assumption varies nonlinearly with very high stresses resulting in the center and low stresses near the edges of the bearing plate. In a few cases the stress ratio at the center was

Fig.15: DISTRIBUTION OF STRESSES

Fig.16: DISTRIBUTION OF STRESSES

Fig.17: DISTRIBUTION OF STRESSES

Fig.18: DISTRIBUTION OF STRESSES

Stress Ratio(actual/uniform)

Fig.19: DISTRIBUTION OF STRESSES

Stress Ratio(actual/uniform)

Fig.20: DISTRIBUTION OF STRESSES

Stress Ratio(actual/uniform)

Stress Ratio(actual/uniform)

Fig.21: DISTRIBUTION OF STRESSES

Fig.22: DISTRIBUTION OF STRESSES

Fig.23: DISTRIBUTION OF STRESSES

Fig.24: DISTRIBUTION OF STRESSES

Fig.25: DISTRIBUTION OF STRESSES

Fig.26: DISTRIBUTION OF STRESSES

Fig.27: DISTRIBUTION OF STRESSES

Fig.28: DISTRIBUTION OF STRESSES

Fig.29: DISTRIBUTION OF STRESSES

Fig.30: DISTRIBUTION OF STRESSES

Fig.31: DISTRIBUTION OF STRESSES

Fig.32: DISTRIBUTION OF STRESSES

Fig.33: DISTRIBUTION OF STRESSES

Fig.34: DISTRIBUTION OF STRESSES

Fig.35: DISTRIBUTION OF STRESSES

Fig.36: DISTRIBUTION OF STRESSES

Fig.37: DISTRIBUTION OF STRESSES

Fig.38: DISTRIBUTION OF STRESSES

Fig.39: DISTRIBUTION OF STRESSES

Fig.40: DISTRIBUTION OF STRESSES

Fig.41: DISTRIBUTION OF STRESSES

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Fig.48: DISTRIBUTION OF STRESSES

Fig.49: DISTRIBUTION OF STRESSES

Fig.50: DISTRIBUTION OF STRESSES

Fig.51: DISTRIBUTION OF STRESSES

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Fig.60: DISTRIBUTION OF STRESSES

Fig.61: DISTRIBUTION OF STRESSES

Fig.62: DISTRIBUTION OF STRESSES

Fig.63: DISTRIBUTION OF STRESSES

Fig.64: DISTRIBUTION OF STRESSES

Fig.65: DISTRIBUTION OF STRESSES

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Fig.70: DISTRIBUTION OF STRESSES

Fig.71: DISTRIBUTION OF STRESSES

Fig.72: DISTRIBUTION OF STRESSES

Fig.73: DISTRIBUTION OF STRESSES

Fig.74: DISTRIBUTION OF STRESSES

Fig.75: DISTRIBUTION OF STRESSES

Fig.76: DISTRIBUTION OF STRESSES

Fig.77: DISTRIBUTION OF STRESSES

Fig.78: DISTRIBUTION OF STRESSES

Fig.79: DISTRIBUTION OF STRESSES

Fig.80: DISTRIBUTION OF STRESSES

Fig.81: DISTRIBUTION OF STRESSES

Fig.82: DISTRIBUTION OF STRESSES

Fig.83: DISTRIBUTION OF STRESSES

Fig.84: DISTRIBUTION OF STRESSES

Fig.85: DISTRIBUTION OF STRESSES

Fig.86: DISTRIBUTION OF STRESSES

close to 3.5, and in most cases was between 1.0 and 3.5 at the center of the block. The load seems to be carried almost entirely under the loaded area.

3.1.2 STRESSES IN BEARING PLATES:

The measured stresses in bearing plates are given in *Table 7*. The expected stresses due to bending of the plate were calculated based on bending of the plate as a cantilever beam. It should be noted that the three dimensional effect has been neglected for computing the expected stresses.

$$\sigma = -M \times c/I$$

$$\text{where } M = w \times l^2/2$$

c being the distance from the neutral axis to the surface where the gage was attached (positive for top surface).

and $I = t^3/12$ assuming unit width of the plate.

The stresses measured in the bearing plates were very low and little correlation with the theoretical could be found. In some cases tensile stresses were observed where compressive stresses were expected and vice versa, but in most cases stresses were closer to expected at very low loads and as the load increased the stresses either stabilized or reduced. *Figs. 87 thru 92* show some representative plots for stresses in gages on the bearing plate. Perhaps this was due to the behavior of the bearing plate which was observed to lift at the edges during the ultimate load tests.

3.1.3 STRESSES IN REINFORCING BAR:

Stresses measured in the top horizontal reinforcing bar are given in *Table 8*. Several of the measured stresses are quite high indicating the possibility of localized cracking in concrete.

Test No.	Uniformly distributed stress(psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected* (psi.)
1	992.0	0.122	top(d)	1.75	-2001.0	-
2	846.1	0.405	top(c)	0.8	638.0	-9904.0
			bot(c)	0.8	-1392.0	9904.0
3	907.3	0.476	top(d)	2.0	290.0	-
4	887.3	0.837	top(d)	2.0	broken	-
5	907.3	0.837	top(d)	3.0	1624.0	-
			top(d)	2.0	1044.0	-
			top(c)	0.8	2378.0	-2486.6
6	690.2	0.837	top(d)	4.0	broken	-
			top(d)	3.0	1798.0	-
			top(d)	2.0	1247.0	-11822.4
			top(c)	2.0	3770.0	-11822.4
			top(c)	0.8	2639.0	-1891.6
			bot(c)	2.0	-3886.0	11822.4
7	862.8	1.203	top(d)	3.0	2697.0	-
			top(c)	0.8	3248.0	-1144.7
			bot(c)	0.8	-1769.0	1144.7
8	673.4	1.203	top(d)	4.0	2610.0	-
			top(c)	2.0	3248.0	-5583.7
			top(c)	0.8	2552.0	-893.4
			bot(c)	0.8	-1479.0	893.4
9	674.3	1.626	top(d)	4.0	1769.0	-12242.0
			top(c)	2.0	2320.0	-3060.0
			bot(c)	2.0	-116.0	3060.0
10	1369.4	0.123	top(d)	1.8	0.0	-
11	1186.2	0.315	top(d)	2.25	493.0	-
			top(c)	0.6	1073.0	-12911.0
			bot(c)	0.6	-493.0	12911.0
12	656.8	0.685	top(d)	3.5	1740.0	-
			top(c)	1.75	1624.0	-12860.2
			bot(c)	1.75	0.0	12860.2
13	2020.4	0.123	top(d)	1.0	609.0	-
14	1352.0	0.222	top(d)	1.7	1566.0	-
			top(c)	0.45	1247.0	-16665.5
			bot(c)	0.45	-1508.0	16665.5
15	693.2	0.478	top(d)	2.2	435.0	-
			top(c)	1.0	-1972.0	-9101.7
			bot(c)	1.0	2059.0	9101.1

* Expected based on bending of plate as a beam

Table 7: Stresses in bearing plates (working stress range tests)

Test No.	Uniformly distributed stress(psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected* (psi.)
16	1004.3	0.122	top(d)	1.75	-1827.0	-
17	925.5	0.405	top(c)	0.8	841.0	-10833.5
			bot(c)	0.8	broken	10833.5
18	882.6	0.476	top(d)	2.0	493.0	-
19	924.4	0.837	top(d)	2.0	1044.0	-
20	913.7	0.837	top(d)	3.0	1740.0	-
			top(d)	2.0	1943.0	-
			top(c)	0.8	1218.0	-2504.1
21	672.0	0.837	top(d)	4.0	broken	-
			top(d)	3.0	1885.0	-
			top(d)	2.0	1798.0	-11510.6
			top(c)	2.0	290.0	-11510.6
			top(c)	0.8	1421.0	-1841.7
			bot(c)	2.0	-261.0	11510.6
22	870.1	1.203	top(c)	0.8	1015.0	-1154.4
			bot(c)	0.8	174.0	1154.4
23	654.8	1.203	top(d)	4.0	2088.0	-
			top(c)	2.0	-464.0	-5429.5
			top(c)	0.8	841.0	-868.7
			bot(c)	0.8	-174.0	868.7
24	699.6	1.626	top(d)	4.0	2204.0	-12701.3
			top(c)	2.0	-899.0	-3175.3
			bot(c)	2.0	1218.0	3175.3
25	1436.9	0.123	top(d)	1.8	522.0	-
26	1185.9	0.315	top(d)	2.25	-232.0	-
27	687.7	0.685	top(d)	3.5	-1653.0	-
			top(c)	1.75	-1015.0	-13465.3
28	2019.1	0.123	top(d)	1.0	-1885.0	-
29	1341.0	0.222	top(d)	1.7	-4060.0	-
			top(c)	0.45	-4118.0	-16529.8
			bot(c)	0.45	4350.0	16529.8
30	666.7	0.478	top(d)	2.2	-116.0	-
			top(c)	1.0	-4466.0	-8753.8
			bot(c)	1.0	-3915.0	8753.8
31	1188.0	0.124	top(d)	2.25	-14210.0	-
32	789.3	0.500	top(d)	3.5	-19459.0	-
			top(c)	1.1	broken	-11460.6
			bot(c)	1.1	1102.0	11460.6

*Expected based on bending of plate as a beam

Table 7(continued): Stresses in bearing plates (working stress range tests)

Test No.	Uniformly distributed stress(psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected* (psi.)
33	590.3	1.050	top(d)	5.0	-17255.0	-
			top(c)	2.5	-8381.0	-10039.1
			bot(c)	2.5	broken	10039.1
34	1242.0	0.122	top(d)	1.75	1972.0	-
35	936.8	0.405	top(d)	2.7	-10962.0	-
			top(c)	0.8	-1131.0	-10965.7
			bot(c)	0.8	-29.0	10965.7
36	1205.6	0.476	top(d)	2.0	-11194.0	-
37	1200.9	0.837	top(d)	2.0	-9251.0	-
38	938.6	0.837	top(d)	3.0	-7598.0	-
			top(d)	2.0	1943.0	-16077.0
			top(c)	0.8	2813.0	-2572.4
39	677.0	0.837	top(d)	4.0	-7337.0	-
			top(d)	3.0	-4176.0	-
			top(d)	2.0	-2465.0	-11596.3
			top(c)	2.0	-3074.0	-11596.3
			top(c)	0.8	4089.0	-1855.4
			bot(c)	2.0	3364.0	11596.3
40	939.4	1.203	top(c)	0.8	3219.0	-1246.3
41	670.4	1.203	top(d)	4.0	broken	-
			top(d)	3.0	-5365.0	-12507.4
			top(c)	2.0	broken	-5558.8
			top(c)	0.8	3625.0	-889.4
			bot(c)	0.8	1102.0	889.4
42	672.7	1.626	top(d)	4.0	-7946.0	-
			top(c)	2.0	-1305.0	-3049.5
			bot(c)	2.0	725.0	3049.5
43	1814.1	0.123	top(d)	1.2	broken	-
44	1317.5	0.280	top(d)	1.9	2088.0	-
			top(c)	0.5	29.0	-12603.6
45	1755.1	0.368	top(d)	1.25	-232.0	-
46	1730.4	0.605	top(d)	1.4	-2871.0	-
47	1314.8	0.605	top(d)	2.0	-899.0	-
			top(d)	1.4	145.0	-
			top(c)	1.1	broken	-13039.3
48	712.8	0.605	top(d)	3.0	-7482.0	-
			top(d)	2.0	broken	-
			top(d)	1.4	174.0	-11450.8

* Expected based on bending of plate as a beam

Table 7(continued): Stresses in bearing plates (working stress range tests)

Test No.	Uniformly distributed stress (psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected* (psi.)
48	712.8	0.605	top(c)	1.1	-1276.0	-7069.1
			top(c)	0.6	broken	-2103.2
49	1315.7	0.856	top(d)	2.0	-3741.0	-
			top(c)	0.6	4350.0	-1939.3
50	697.4	0.856	top(d)	2.9	-9077.0	-
			top(d)	2.0	-3248.0	-11421.3
			top(c)	1.5	-1566.0	-6424.5
			top(c)	0.6	3799.0	-1027.9
51	702.4	1.168	top(d)	2.8	-6844.0	-12109.8
			top(c)	1.5	-1247.0	-3475.4
52	1189.5	0.124	top(d)	2.25	-2262.0	-
53	789.0	0.500	top(d)	3.5	-1798.0	-
			top(c)	1.1	-522.0	-11456.3
			bot(c)	1.1	1102.0	11456.3
54	589.0	1.050	top(d)	5.0	928.0	-
			top(c)	2.5	-1450.0	-10017.0
			bot(c)	2.5	1247.0	10017.0
55	1245.0	0.122	top(d)	1.75	-145.0	-
56	939.0	0.405	top(d)	2.7	-841.0	-
			top(c)	0.8	-609.0	-10991.5
			bot(c)	0.8	broken	10991.5
57	1206.6	0.476	top(d)	2.0	-174.0	-
58	1202.4	0.837	top(d)	2.0	-174.0	-
59	937.6	0.837	top(d)	3.0	406.0	-
			top(d)	2.0	725.0	-16060.0
			top(c)	0.8	1450.0	-2569.6
60	672.0	0.837	top(d)	4.0	1102.0	-
			top(d)	3.0	638.0	-
			top(d)	2.0	435.0	-11510.6
			top(c)	2.0	609.0	-11510.6
			top(c)	0.8	1740.0	-1841.7
			bot(c)	2.0	-1160.0	11510.6
61	942.0	1.203	top(d)	2.7	957.0	-14235.4
			top(c)	0.8	1276.0	-1249.7
62	679.2	1.203	top(d)	4.0	348.0	-
			top(d)	3.0	725.0	-12671.6
			top(c)	2.0	-1943.0	-5631.8
			top(c)	0.8	1102.0	-901.1

* Expected based on bending of plate as a beam

Table 7(continued): Stresses in bearing plates (working stress range tests)

Test No.	Uniformly distributed stress(psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected* (psi.)
63	672.0	1.626	top(d)	4.0	464.0	-12185.3
			top(c)	2.0	-435.0	-3046.3
			bot(c)	2.0	522.0	3046.3
64	1810.0	0.123	top(d)	1.2	-348.0	-
65	1312.0	0.280	top(d)	1.9	118.0	-
66	1756.8	0.368	top(d)	1.25	638.0	-
67	1730.0	0.605	top(d)	1.4	1334.0	-
68	1309.0	0.605	top(d)	2.0	1276.0	-
			top(d)	1.4	899.0	-
			top(c)	1.1	broken	-12981.8
69	707.1	0.605	top(d)	3.0	-551.0	-
			top(d)	2.0	1044.0	-
			top(d)	1.4	580.0	-11359.2
			top(c)	1.1	-377.0	-7012.6
			top(c)	0.6	broken	-2086.4
70	1310.0	0.856	top(d)	2.0	870.0	-
			top(c)	0.6	2958.0	-1930.8
71	713.0	0.856	top(d)	2.9	-1769.0	-
			top(d)	2.0	609.0	-11676.8
			top(c)	1.5	-638.0	-6568.2
			top(c)	0.6	2409.0	-1050.9
72	705.0	1.168	top(d)	2.8	-812.0	-12154.6
			top(c)	1.5	-145.0	-3488.2

*Expected based on bending of plate as a beam

Table 7(continued): Stresses in bearing plates (working stress range tests).

Fig.87: STRESSES IN BEARING PLATE

Fig.88: STRESSES IN BEARING PLATE

Fig.89: STRESSES IN BEARING PLATE

Fig.90: STRESSES IN BEARING PLATE

Fig.91: STRESSES IN BEARING PLATE

Fig.92: STRESSES IN BEARING PLATE

<i>Test No.</i>	<i>Load (kips.)</i>	<i>Stress (psi.)</i>	<i>Test No.</i>	<i>Load (kips.)</i>	<i>Stress (psi.)</i>
1	109.5	2001.0	37	136.7	5104.0
2	96.5	1827.0	38	106.9	5742.0
3	103.1	2987.0	39	77.1	4408.0
4	101.0	1827.0	40	106.9	3915.0
5	103.3	1914.0	41	76.3	2871.0
6	78.6	1711.0	42	76.6	1508.0
7	98.2	2320.0	43	102.2	8091.0
8	76.7	1653.0	44	76.9	5829.0
9	76.8	1276.0	45	101.9	7511.0
10	98.8	2291.0	46	101.9	7337.0
11	89.0	1943.0	47	77.4	5626.0
12	49.3	1305.0	48	42.0	3248.0
13	72.9	1566.0	49	77.1	5075.0
14	51.6	1073.0	50	40.9	2639.0
15	26.1	522.0	51	41.4	2262.0
16	110.8	3132.0	52	200.9	5046.0
17	105.6	2871.0	53	136.9	2813.0
18	100.3	3219.0	54	101.9	1914.0
19	105.2	3132.0	55	137.4	2262.0
20	104.0	2697.0	56	107.1	1856.0
21	76.5	1769.0	57	137.1	2320.0
22	99.1	2929.0	58	136.9	2204.0
23	74.5	1914.0	59	106.8	1653.0
24	79.7	1740.0	60	76.5	1102.0
25	103.7	2871.0	61	107.3	1711.0
26	89.0	2610.0	62	77.3	1305.0
27	51.7	2668.0	63	76.5	1508.0
28	72.9	1972.0	64	102.0	1595.0
29	51.2	1189.0	65	76.6	1218.0
30	25.1	464.0	66	102.0	1682.0
31	200.7	6322.0	67	101.9	1624.0
32	137.0	5916.0	68	77.1	1102.0
33	102.1	4089.0	69	41.6	667.0
34	137.1	7743.0	70	76.8	1073.0
35	106.8	7279.0	71	41.8	725.0
36	137.0	6322.0	72	41.5	580.0

Table 8: Stress in top horizontal rebar (working stress tests)

Fig.93: DISTRIBUTION OF STRESSES

Fig.94: DISTRIBUTION OF STRESSES

Fig.95: DISTRIBUTION OF STRESSES

Fig.96: DISTRIBUTION OF STRESSES

Fig.97: DISTRIBUTION OF STRESSES

3.2 ULTIMATE LOAD TESTS:

3.2.1 STRESSES IN CONCRETE:

Stress distribution in the concrete can be seen in *Figs. 93* thru *97*. Similar to the working stress range tests, high stress concentration were seen near the center and less stresses away from the loaded area. The strains measured inside the concrete blocks is shown in *Figs. 98* thru *101*. The stress distribution based on the uniaxial stress strain diagram (*Fig. 8*) after the yielding started at center can be seen in *Figs. 102* thru *105*.

3.2.2 STRESSES IN BEARING PLATES:

The behavior of the bearing plates was similar to the working stress range tests and stresses observed were very low as compared to expected. In many locations where yielding was expected, very low stresses were observed. *Table 9* lists the plate stresses at ultimate loads, which in most cases are quite different than expected theoretical stresses.

3.2.3 STRESSES IN REINFORCING BAR:

Stresses measured in the top horizontal rebar are given in *Table 10*. The stresses are quite high, which indicate local cracking of concrete.

3.2.4 SLIP MEASUREMENT:

The relative horizontal displacement between the concrete block and the edge of the steel bearing plate was measured and is plotted in *Figs. 106* thru *109*. The load at which the slip was measured is evident from the figures while loading as well as unloading. The permanent slip can also be seen in the plots.

3.2.5 LIFT MEASUREMENT:

As mentioned earlier, test 74 (first ultimate load test) resulted in a considerable permanent deformation of the steel plate. For the rest three ultimate load tests, i.e. 75 thru 77, the vertical displacement at the corner of the plate was measured at different load levels and can be seen in *Figs. 110* thru *112*. The permanent deformation can also be seen.

Fig.98: INTERNAL STRAIN DISTRIBUTION

Fig.99: INTERNAL STRAIN DISTRIBUTION

Fig.100: INTERNAL STRAIN DISTRIBUTION

Fig.101: INTERNAL STRAIN DISTRIBUTION

Fig.102:INTERNAL STRESS DISTRIBUTION

Fig.103:INTERNAL STRESS DISTRIBUTION

Fig.104: INTERNAL STRESS DISTRIBUTION

Fig.105: INTERNAL STRESS DISTRIBUTION

Test No.	Uniformly distributed stress (psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress	
			location	overhang (in.)	measured (psi.)	expected ⁺ (psi.)
73*	1433.0	0.837	top(d)	4.0	2552.0	-
			top(d)	3.0	2523.0	-
			top(d)	2.0	1682.0	-24545.5
			top(c)	2.0	broken	-24545.5
			top(c)	0.8	5336.0	-3927.3
			bot(c)	2.0	broken	24545.5
	2180.0		top(d)	4.0	4089.0	-
			top(d)	3.0	6264.0	-
			top(d)	2.0	3973.0	-yield
			top(c)	2.0	broken	-yield
			top(c)	0.8	8091.0	-5974.6
			bot(c)	2.0	broken	yield
74	1669.6	0.605	top(d)	3.0	3422.0	-
			top(d)	2.0	broken	-
			top(d)	1.4	4524.0	-26821.0
			top(c)	1.1	4437.0	-16558.0
			top(c)	0.6	8671.0	-4926.3
			bot(c)	1.1	-3741.0	16558.0
	2430.5		top(d)	3.0	17313.0	-
			top(d)	2.0	broken	-
			top(d)	1.4	7424.0	-yield
			top(c)	1.1	25897.0	-24104.0
			top(c)	0.6	14906.0	-7171.0
			bot(c)	1.1	-15950.0	24104.0
75	1744.5	0.856	top(d)	2.9	-1133.0	-
			top(d)	2.0	-1769.0	-
			top(c)	1.5	-3219.0	-16070.4
			top(c)	0.6	6728.0	-2571.3
			bot(c)	1.5	broken	16070.4
			2582.0	top(d)	2.9	-8468.0
	top(d)			2.0	1160.0	-
	top(c)			1.5	174.0	-23785.5
	top(c)			0.6	8787.0	-3805.7
			bot(c)	1.5	broken	23785.5

* Block did not fail at 250 kips. (maximum capacity of the pressure transducer)

+ Expected based on bending of plate as a beam.

Table 9: Stresses in bearing plates (Ultimate load tests)

Test No.	Uniformly distributed stress (psi.)	Bearing Pl. thickness (in.)	Strain gage		Stress		
			location	overhang (in.)	measured (psi.)	expected (psi.)	
76	1472.0	0.685	top(d)	3.5	-1914.0	-	
			top(c)	1.75	-319.0	-28822.0	
	2033.2		top(d)	3.5	-2668.0	-	
			top(c)	1.75	899.0	-yield	
77	1009.5	0.315	top(d)	3.5	6554.0	-	
			top(d)	2.25	2523.0	-	
			top(c)	1.75	11107.0	-yield	
			top(c)	0.6	3770.0	-10987.8	
			bot(c)	1.75	-13340.0	yield	
			1356.4		top(d)	3.5	8555.0
	top(d)				2.25	3770.0	-
	top(c)				1.75	15196.0	-yield
	top(c)				0.6	5278.0	-14763.5
			bot(c)	1.75	-18995.0	yield	

+ Expected stress based on bending of plate as a beam.

Table 9(continued): Stresses in bearing plates (Ultimate load tests)

Test No.	Load (kips.)	Stress (psi.)	Load (kips.)	Stress (psi.)
73	163.1	3103.0	248.2	6757.0
74	98.3	1943.0	143.2	2813.0
75	102.2	6467.0	151.3	10904.0
76	110.5	2407.0	152.7	7076.0
77	75.8	986.0	101.8	1421.0

Table 10: Stress in top horizontal rebar (ultimate load tests)

Fig.106: SLIP OF PLATE EDGE RELATIVE TO CONCRETE

Fig.107: SLIP OF PLATE EDGE RELATIVE TO CONCRETE

Fig.108: SLIP OF PLATE EDGE RELATIVE TO CONCRETE

Fig.109: SLIP OF PLATE EDGE RELATIVE TO CONCRETE

Fig.110: *LIFT OF PLATE CORNER RELATIVE TO CONCRETE*

Fig.111: LIFT OF PLATE CORNER RELATIVE TO CONCRETE

Fig.112: LIFT OF PLATE CORNER RELATIVE TO CONCRETE

CHAPTER 4

DISCUSSION OF RESULTS

It is very clear from the test results that the stress distribution beneath the bearing plate is not uniform but rather is parabolic in nature. In most cases, the stresses occurring close to the center, are almost two to three times the expected stresses based on the expected uniform distribution. The stresses occurring in the bearing plate are quite lower than expected. The results indicate that the load is being carried on to the concrete substructure with little bending in the plate. The bearing plate edges lift up from the concrete due to localized high strains in the concrete and steel beneath the loaded area. The effects of the various parameters involved in the study are described below.

4.1 WORKING STRESS RANGE TESTS:

4.1.1 EFFECT OF PLATE THICKNESS:

The effect of plate thickness can be observed in *Figs. 113 thru 130*. The stress ratio is plotted varying with distance from the center for different plate thicknesses, while all other parameters remain the same. The distribution of stresses can be compared and seen that for almost all cases maximum stresses decrease as thickness increases.

It is evident that there is negligible effect of plate thickness on the stress distribution for higher load area to plate area ratios, whereas for lower load area to plate area ratios the stress ratio decreased quite a bit for higher thicknesses. However, this decrease in stress is evident only close to the center and under the loaded area.

Figs. 131, 132, and 133 show the effect of thickness on the maximum stress

Fig.113: EFFECT OF PLATE THICKNESS (Block # 1)

Fig.114: EFFECT OF PLATE THICKNESS (Block # 1)

Fig.115: EFFECT OF PLATE THICKNESS (Block # 1)

Fig.116: EFFECT OF PLATE THICKNESS (Block # 2)

Fig.117: EFFECT OF PLATE THICKNESS (Block # 2)

Fig.118: EFFECT OF PLATE THICKNESS (Block # 2)

Fig.119: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.120: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.121: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.122: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.123: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.124: EFFECT OF PLATE THICKNESS (Block # 3)

Fig.125: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.126: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.127: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.128: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.129: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.130: EFFECT OF PLATE THICKNESS (Block # 4)

Fig.131: *EFFECT OF PLATE THICKNESS AND LD.AREA/PL.AREA*

Fig.132: *EFFECT OF PLATE THICKNESS AND LD.AREA/PL.AREA*

Fig.133: *EFFECT OF PLATE THICKNESS AND LD.AREA/PL.AREA*

ratio for plate area to block area ratios of 0.77, 0.50 and 0.25 respectively. It can be seen that even for the tests in which very thick bearing plates were used, the maximum stress ratio is much higher than 1.0. However, the decrease in the maximum stress ratios with the thickness for a particular load area to plate area ratio is seen to be linear in nature for plate area to block area ratios of 0.77 and 0.50. No trend could be determined for plate area to block area ratio of 0.25.

From these figures we also see that for the same thickness bearing plate, and for plate area to block area ratios of 0.77 and 0.50, we get higher stress ratios as the load area to plate area ratio goes down. For plate area to block area ratio of 0.26 no trend could be observed.

4.1.2 EFFECT OF PLATE AREA TO BLOCK AREA RATIO AND LOADED

AREA TO PLATE AREA RATIOS FOR DESIGN THICKNESSES:

Lower plate area to block area ratios resulted in much lower stress ratios whereas higher plate area to block area ratios resulted in much higher stress ratios not just in the center of the block but away from the center as well. This can be observed in *Figs. 134 thru 145*.

Figs. 146, 147 and 148 show that for load area to plate area ratios of 0.25 and 0.5 as the plate area to block area ratio increases, the maximum stress ratios increase considerably (*i.e.* the stress distribution tends to be more non uniform), but for load area to plate area ratio of 0.75 they do not vary much and are quite low. This indicates that a higher load area to plate area ratio leads to a more uniform distribution as compared to a lower load area to plate area ratio. Also from the same figures it can be observed that as the load area to plate area ratio increases, the maximum stress ratio goes down considerably for plate area to block area ratios of 0.77 and 0.5, but for plate area to block area ratio of 0.25 the maximum stress ratios did not show much variation with increase in load area to plate area ratio.

Fig.134: EFFECT OF PLATE AREA/BLOCK AREA (Block # 1)

Fig.135: EFFECT OF PLATE AREA/BLOCK AREA (Block # 1)

Fig.136: EFFECT OF PLATE AREA/BLOCK AREA (Block # 1)

Fig.137: EFFECT OF PLATE AREA/BLOCK AREA (Block # 2)

Fig.138: EFFECT OF PLATE AREA/BLOCK AREA (Block # 2)

Fig.139: EFFECT OF PLATE AREA/BLOCK AREA (Block # 2)

Fig.140: EFFECT OF PLATE AREA/BLOCK AREA (Block # 3)

Fig.141: EFFECT OF PLATE AREA/BLOCK AREA (Block # 3)

Fig.142: EFFECT OF PLATE AREA/BLOCK AREA (Block # 3)

Fig.143: EFFECT OF PLATE AREA/BLOCK AREA (Block # 4)

Fig.144: EFFECT OF PLATE AREA/BLOCK AREA (Block # 4)

Fig.145: EFFECT OF PLATE AREA/BLOCK AREA (Block # 4)

Fig.146: *EFFECT OF LD.AREA/PL.AREA*

Fig.147: *EFFECT OF LD.AREA/PL.AREA*

Fig.148: EFFECT OF LD.AREA/PL.AREA

4.1.3 EFFECT OF OVERHANG OF BEARING PLATE FOR DESIGN THICKNESS:

The portion of the bearing plate extending beyond the loaded area perpendicular to the edge of the plate has been defined as the overhang of the bearing plate.

Tests with bearing plates having larger overhangs resulted in higher stress ratios. This indicates that the overhang of the plate does not serve its purpose of distribution of the load to the concrete substructure.

Figs. 149, 150 and 151 show the effect of overhang on the maximum stress ratio for plate area to block area ratios of 0.77, 0.50 and 0.26 respectively. It is clear that large overhangs resulted in larger stress ratios, *i.e.* greater non uniformity in the distribution of stresses.

Results indicate that for plate area to block area ratios of 0.77 and 0.50, the maximum stress ratio increased with the increase in overhang for upto about 1 inch and above this increase in the maximum stress ratio was not significant. For plate area to block area ratio of 0.25, no effect of overhang could be observed.

Figs. 87 thru 92 show the stresses in the bearing plates to be much lower than expected, thereby indicating that negligible lateral transfer of stresses by the bearing plate.

4.2 ULTIMATE LOAD TESTS:

4.2.1 STRESSES IN CONCRETE:

Figs. 102 thru 105 show the distribution of stresses which were determined using the stress-strain curve obtained from uniaxial compression test (*Fig.8*). The maximum ultimate stress being 6250 psi. Yielding first starts at the center and then spreads out under the whole loaded area, whereas the stresses away from the loaded area are increased only slightly.

The 12 in. blocks show lateral distribution of stress at lower loads than the 15 in. blocks. Also it should be noted that the loaded area used on 15 in. blocks was

Maximum Stress Ratio(actual/uniform)

Maximum Stress Ratio(actual/uniform)

Fig.149: EFFECT OF OVERHANG OF BEARING PLATE

Maximum Stress Ratio(actual/uniform)

Maximum Stress Ratio(actual/uniform)

Fig.150: EFFECT OF OVERHANG OF BEARING PLATE

Fig.151: *EFFECT OF OVERHANG OF BEARING PLATE*

lower than the loaded area used on the 12 in. blocks.

The ultimate maximum loads carried by the blocks 1, 2, 3 and 4 were 200 kips., 250 kips., greater than 250 kips.(block did not fail completely) and 247 kips. respectively.

The only variable during the ultimate load tests on the 12 in. blocks was the thickness of the bearing plate. The plate thickness used for ultimate load test on block 1 was 0.315 in. ($<$ design) and on block 2 it was 0.605 in. (design). The difference in thickness is significant, it can be seen that even at 75 kips. block 1 had higher stresses than block 2 at 90 kips., and at 150 kips block 1 showed localized yielding whereas block 2 did not.

The initial and final cracking patterns for the 12 in. blocks (blocks 1 and 2) can be seen in *Figs.* 152 and 153. The cracks initiated at the top and as the load was increased, they propagated to the bottom of the block.

The plate thicknesses used for test on block 3 was 0.856 in. ($>$ design) and for block 4 was 0.605 in. (design). Comparing *Figs.* 103 and 102 not much variation in stress distribution can be observed between the two blocks. The stresses occurring in the two blocks are almost the same for the same loads.

The initial and final cracking patterns for the 15 in. blocks (blocks 3 and 4) can be seen in *Fig.* 153. The cracks initiated at the top and as the load was increased, they propagated to the bottom of the block.

4.2.2 STRESSES IN BEARING PLATE:

Similar to the working stress range tests, the stresses were lower than expected. Representative plots of which have been shown in *Figs.* 87 thru 92. The stresses at various loads are shown in *Table* 9. Some gages showed tension where compression was expected and vice versa, which indicates that the bending of the bearing plate is not as a cantilever but is rather more complex in nature. The lifting of the plate

edges confirms this fact.

4.2.3 SLIP OF PLATE EDGE RELATIVE TO CONCRETE:

The relative lateral motion of the plate and concrete has been called the slip. The slip of the plate edge is due to greater lateral strain in concrete than steel. It can be seen in *Figs. 106, 108 and 109* that the slip increases linearly until close to the failure load and then increases rapidly. Some permanent slip is evident after failure and unloading. The permanent slip is due to permanent cracks formed in the concrete.

4.2.4 LIFT OF PLATE CORNER RELATIVE TO CONCRETE:

The lift measurements can be seen in *Figs. 110 thru 112*. It has been observed that the bearing plate does not distribute the load uniformly to the concrete but most of the load is carried by the portion beneath the loaded area. Concrete strains increase beneath the loaded area considerably whereas strains are low in the portion of the concrete away from the loaded area. This forces the bearing plate to have localized high strains at the edge of the loaded area because of the deformed concrete surface, and forces the bearing plate to deform at the end of the loaded area. Therefore the edges of the bearing plates lift up due to this deformation behavior. After unloading, the measurements show some value of lift which indicates permanent deformation in the bearing plate.

4.3 RECOMMENDATIONS:

From the test results it is clear that the actual bending stresses in the bearing plate are lower than expected for most of the cases. *Table 11* summarises the stress ratios occurring beneath the bearing plate (for the tests conducted with design plate thicknesses) at the end of the loaded area (row *A*) and at the edge of the bearing plate (row *B*).

As concluded earlier, for achieving a uniform distribution, an extremely thick bearing plate would be required, but this would not be economical.

The bearing plates can be designed based on the experimental results using the following steps:

1. Assuming the loaded area is known, compute load area to plate area ratio. In case plate area is not known, it would be preferable to choose plate area such that this ratio is close to 0.75.

2. Compute plate area to block area ratio. In case block area is not known, it would be preferable to choose a block area such that this ratio is close to 0.25.

3. Compute the uniformly distributed working stress, using the assumption that the stress is uniformly distributed beneath the plate.

4. Using the last column in *Table 11*, pick up the maximum stress ratios at the end of loaded area (row A) and at the edge of the bearing plate (row B) for the respective load area to plate area ratio and plate area to block area ratio.

5. Multiplying these values to the stress computed in 3, get actual stresses beneath the plate at the end of the loaded area and at the edge of the plate.

6. Assume a linear variation of stress in between and design the plate based on this distribution.

It can be seen that without affecting the stress distribution, the thickness of the bearing plates can be reduced for most of the cases.

Ratio of			Stress Ratios				
Plate Area to Block Area	Load Area to Plate Area		Block 1 (12 in.)	Block 2 (12 in.)	Block 3 (15 in.)	Block 4 (15 in.)	Mazimum value
0.75	0.25	A	1.4	1.5	1.0	1.2	1.5
		B	0.5	0.5	0.5	0.4	0.5
	0.50	A	0.9	0.7	1.0	0.8	1.0
		B	0.6	0.5	0.6	0.5	0.6
	0.75	A	0.6	0.5	0.6	0.5	0.6
		B	0.6	0.5	0.6	0.5	0.6
0.50	0.25	A	1.25	1.4	1.1	1.5	1.5
		B	0.6	0.5	0.5	0.5	0.6
	0.50	A	0.9	0.8	0.7	0.7	0.9
		B	0.6	0.5	0.5	0.4	0.6
	0.75	A	0.6	0.5	0.6	0.5	0.6
		B	0.6	0.5	0.6	0.5	0.6
0.25	0.25	A	1.0	1.0	1.0	1.0	1.0
		B	0.6	0.5	0.5	0.5	0.6
	0.50	A	0.75	0.75	0.75	0.75	0.75
		B	0.6	0.6	0.5	0.5	0.6
	0.75	A	0.5	0.6	0.5	0.5	0.6
		B	0.5	0.6	0.5	0.5	0.6

Table 11: Stress ratios at end of Loaded Area and at Plate edge.

Block No.	Bearing Plate		Mazimum Load (kips.)	Working stress Design Load (kips.)	Factor of Safety
	Thickness (in.)	Area (sq.in.)			
1	0.315(<design)	75.04	200.0	140.7	1.42
2	0.685(=design)	75.08	250.0	140.7	1.77
3	0.856(>design)	58.60	>250.0	109.9	>2.27
4	0.605(=design)	58.9	247.0	110.4	2.23

Table 12: Factor of safety against failure from Ultimate load Tests.

Fig.152(a): Initial cracking pattern for block 1

Fig.152(b): Final cracking pattern for block 1

Fig.153(a): Initial cracking pattern for blocks 2,3&4

Fig.153(b): Final cracking pattern for blocks 2,3&4

CHAPTER 5

FINITE ELEMENT ANALYSIS

A finite element model of the bearing system was developed by McEwen et al [10] for the purpose of comparing the analytical results to the experimental results. The model was developed for the 12 inch concrete block and for the purpose of comparison test number 12 and test number 76 were selected as the working stress and ultimate load tests. It should be realized that for the finite element analysis, various assumptions are involved for the material properties and behavior of concrete, therefore the finite element analysis results may not be exactly the same as the results from the experiments.

5.1 FINITE ELEMENT MODEL:

Test numbers 12 and 76 consisted of bearing plate size $8.66'' \times 8.66'' \times 0.685''$. The finite element model is shown in *Fig. 154*. A total of 408 nodes and 72 elements were used for the purpose of analysis. The elements used for the concrete blocks consisted of both eight node linear displacement bricks and variable node bricks.

ABAQUS [3], a non-linear finite element code was used to solve the problem. The loading being symmetric about the vertical axis, only one quarter of the system was analysed using appropriate boundary conditions at the two planes of symmetry.

The concrete stress strain behavior was taken from the cylinder tests at 28 days, shown in *Fig. 8*.

The nominal reinforcement present in the concrete blocks was modelled as a layer of steel of constant thickness based on the area of the rebar divided by its

Fig.154: FINITE ELEMENT MESH

spacing.

5.1.1 APPLIED LOADS:

To compare the working stress test results, the bearing system was analysed for an applied uniform stress of 2220 psi. applied over the circular area of 19.17 sq. in. For the ultimate load test the stress was increased from zero to failure.

5.2 COMPARISON OF EXPERIMENTAL AND FINITE ELEMENT

RESULTS:

The vertical stresses resulting in the concrete block at the level of the strain gages is shown in *Fig. 155*. The stresses observed in concrete were in the elastic range and the stress distribution is close to axisymmetric.

The comparison for the vertical stresses can be seen in *Fig. 156*. The experimental results are the least squares fit of the data as shown in *Fig. 26*, and it can be seen from both the analytical and experimental results that the stress distribution is non uniform.

The stresses measured in the steel plates at the applied stress of 2220 psi. (49.3 kips. load) over the loaded area, at the top surface of the steel plate were 1.62 ksi., and 1.74 ksi. in tension. These are quite low as compared to the design stresses and are opposite in sign. From the finite element analysis we get stresses of approximately 1.18 ksi in compression at the same location.

Fig. 157 shows a comparison of the strains measured near failure (load 220 kips.) with those resulting from the finite element analysis. The strains measured are higher than the analytical results probably due to extensive cracking of the concrete.

Fig. 158 shows the load-displacement curve for the concrete block determined by the finite element analysis. The displacements are vertical displacements at the

load- 2220 PSI

Fig.155: VERTICAL STRESSES(psi) IN CONCRETE
AT STRAIN GAGES LEVEL

Fig.156: VARIATION OF CONCRETE STRESSES

Fig.157: STRAIN DISTRIBUTION AT FAILURE

Fig.158: VERTICAL DISPLACEMENT AT CENTERLINE (INCHES)

center of the block. The ultimate load from the figure can be seen to be 10000 psi. (221 kips.). The actual ultimate load applied for failure was 250 kips. It can be seen from the load displacement curve that it is linear upto 8000 psi. whereas the cylinder stress-strain curve (*Fig. 8*) shows linearity upto 3000 psi. and an ultimate stress of only 6400 psi.

CHAPTER 6

SUMMARY AND CONCLUSIONS

A parametric study on the behavior of the masonry bearing plates has been performed. The results show that the stress distribution beneath the bearing plate is not at all uniform but is parabolic, with stresses almost two to three times the expected stresses occurring close to the center. The analytical solution [11] using a two dimensional model also gives a parabolic distribution for a similar case. The measured stresses in the bearing plates are quite lower than expected. All this is due to the fact that stresses in both steel and concrete are highly localized and lateral transfer of stresses takes place by little bending of the bearing plate.

The finite element analysis results show a good agreement with the experimental results for the stresses measured in concrete for the working stress and also for the ultimate load the system can carry. However, the stresses in the bearing plate differed greatly from the values expected based on the design assumptions, and were quite erratic.

For high load area to plate area ratios, effect of plate thickness was negligible. This is because of the small overhang of the plate, therefore not much bending of the plate is involved. However, for small load area to plate area ratios, some decrease in stresses could be observed. It is important to note that, even for a very thick bearing plate, a uniform distribution could not be achieved, which means that an extremely thick plate would be required for achieving a stress distribution close to uniform.

From the test results it is clear that the actual bending stresses in the bearing plate are lower than expected for most of the cases. *Table 11* summarises the stress ratios occurring beneath the bearing plate (for the tests conducted with design plate thicknesses) at the end of the loaded area (row *A*) and at the edge of the bearing plate (row *B*).

As concluded earlier, for achieving a uniform distribution, an extremely thick bearing plate would be required, but this would not be economical.

The recommendations for the design of the bearing plate have been made and summarized in section 4.3, and it can be seen that without affecting the stress distribution, the thickness of the bearing plates can be reduced for most of the cases.

The load carrying capacities of the concrete blocks based on working stress design (*i.e.* $0.3f'_c \times \text{Bearing Plate Area}$) have been shown in *Table 12*. The factor of safety is computed based on the maximum load carried by each system. Looking at these factor of safety values against failure, it is worth noting that the factor of safety against failure increases considerably with increase in the size of the concrete substructure. However, since there were only two different sized blocks, it is difficult to conclude the exact relationship between the ultimate load carrying capacity and the size of the concrete substructure.

The expected factor of safety from the current design assumptions is 3.33 (*i.e.* $\text{Ultimate Stress } f'_c / \text{Allowable Stress } 0.3f'_c$). The factor of safety obtained from the ultimate load tests conducted in the laboratory are quite low, because of high stresses at the centerline in concrete.

Section 1.5.26.(3) of the Standard specifications for Highway Bridges [1] recommends that the allowable bearing stress on concrete be taken as $0.3f'_c$ and that the allowable bearing stress on the loaded area may be increased by $\sqrt{A_2/A_1}$, but

not more than 2, when the area of the concrete substructure A_2 is wider on all sides of the loaded area A_1 . This is not advisable for small concrete substructures, because the factor of safety would go down further.

A series of ultimate load tests may be required with different sized blocks to determine the effect of the size of the concrete substructure on the ultimate stress carrying capacity of the bearing system.

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APPENDIX A

Fig.159: CALIBRATION CURVE, PRESSURE TRANSDUCER

Fig.160: CALIBRATION CURVE, DISPLACEMENT TRANSDUCER # 1

Fig.161: CALIBRATION CURVE, DISPLACEMENT TRANSDUCER # 2

APPENDIX B

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100: "*****":
101: "*****":
102: "PROGRAM TO COLLECT DATA FROM BEARING TESTS":
103: "*****":
104: "This program would scan upto 40 channels and store the read voltage
105: "into the specified data file. The program asks for some information
106: "that has to be input, and then proceeds with scanning. Items to be
107: "input include
108: "
109: "1) Pot bearing number
110: "2) Number of strain gauges
111: "3) No. of different types of gauges being used
112: "4) Start ch., end ch., gauge factor for each type
113: "5) Operator
114: "6) Date
115: "7) Time
116: "8) Name of data files
117: "9) Number of readings to be taken for each gauge
118: "10) Delay between the readings in milliseconds
119: "11) Conversion factors from pressure transducer
120: "    readings to load
121: "
122: "After all the necessary information is input, the program pauses and
123: "waits for the (Continue) key to be pressed to start scanning, and
124: "reading the voltage. Readings are stored in the specified file,
125: "displayed on the screen, and printed.
126: "Arrays L[M],V[M] and S[M,N] are used to store the readings obtained.
127: "The kind of readings stored are :
128: "    L[M] = Pressure Transducer (Loading). (channel 38)
129: "    V[M] = Voltage input to bridges (channel 39)
130: "    S[M,N] = Voltage output from bridges corresponding
131: "              to different gauges.(channels 1 thru N)
132: "Both disk drives are used in this program. Drive 0 is used for the
133: "diskette containing the programs, while Drive 1 is used for curing
134: "the run of the test to store all readings obtained in the specified
135: "data file. This diskette is only used for data storing.
136: "*****":
137: dim IS(10,40),NS(10),JS(10,20),MS(10)
138: prt "POT BEARING TESTS":spc 2
139: ent "Pot Bearing Number :",IS[1]
140: fnt 1,"Pot Bearing Number          :",b40./
141: prt 701.1,IS[1]
142: ent "Number of Strain Gauges :",N
143: fnt 1,"Number of Strain Gauges:",b9x,f2.0./
144: prt 701.1,N
145: dim CIN(,GIN)
146: ent "How many different types of gauges are being used....?",M
147: for J=1 to M
148: ent "Type of gauge",JS[J]
149: ent "Enter start channel for this type",L
150: ent "Enter end channel for this type",K
151: ent "Gauge factor for this type",F
152: fnt 1,"GAUGE :",b10," Start Ch:",f2.0," End Ch:",f2.0," G.F.",f5.2./
153: prt 701.1,JS[J],L,K,F
154: for I=1 to K
155: F/GC[I]
156: next I
157: next J
158: fnt 2.7,"Gauge Numbers : Gauge Factors:",f7.31"+",

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53: fnt 3,f2.0,"":",f4.2,2>,";
54: for i=1 to 4
55: i=C(i)
56: next i
57: dsp "enter data from pressure transducer calibration curve:"
58: wait 2000
59: ent "Slope for conversion from transducer reading to load :".S
60: ent "Intercept for conversion from transducer reading to load :".C
61: ent "Operator :".IS[2]
62: ent "DATE :".IS[3]
63: ent "TIME :".IS[4]
64: ent "Square plate dimensions:".IS[5]
65: ent "circular plate diameter:".IS[6]
66: fnt 1,2/,"Operator :".c29,/
67: wrt 701,1,IS[2]
68: fnt 1,"Date :".c29,/
69: wrt 701,1,IS[3]
70: fnt 1,"Time :".c29,/
71: wrt 701,1,IS[4]
72: fnt 1,"Rectangular plate :".c29,/
73: wrt 701,1,IS[5]
74: fnt 1,"Circular plate diameter :".c29,/
75: wrt 701,1,IS[6]
76: "*****";
77: ent "NAME OF DATA FILE TO STORE RAW VOLTAGE READINGS".MS
78: ent "NAME OF DATA FILE TO STORE PROCESSED DATA i.e. Load and Strains".MS
79: ent "NUMBER OF READINGS ?".M
80: ent "TIME DELAY IN MILLISECS :".T
81: "BYTES REQUIRED":
82: 8*M*N>B:5.5*B/256>R:R+1>R
83: msi ":M700,1"
84: open NS,R
85: open MS,R
86: asgn NS,1,1
87: asgn MS,2,1
88: rread 1,1
89: rread 2,1
90: "*****";
91: fnt 1,"Slope for Transducer Calibration :".f16x,e11.4,/
92: wrt 701,1,S
93: fnt 1,"Intercept for Transducer Calibration".f17x,e11.4,/
94: wrt 701,1,C
95: fnt 1,"Data File for raw Data".2x,"":".c40,/
96: wrt 701,1,MS
97: fnt 2,"File for processed Load and Strains".":".c29,/
98: wrt 701,2,MS
99: fnt 1,"Number of readings".17x,"":".24x,f5.0,/
100: wrt 701,1,M
101: fnt 1,"Delay between two sets (in seconds)".":".22x,f5.0
102: T/1000>R
103: wrt 701,1,R
104: "*****";
105: T/60>T
106: ren 7:cl: 7
107: fnt 1,f2.0,"F",z
108: "*****";
109: fnt 2,3/,"READINGS :".f7,/"*****",/
110: fnt 5,"Reading No.:".f2.0
111: fnt 9,"Press. Trans.: initial :".f9.6,1x,".f9.6,1x,". Min:".f9.6
112: fnt 6,f9.6,1x,z
113: fnt 7,/
114: fnt 8,"Out from strain gauges:"
115: wrt 15,2

```

```

127: *****
128: urt 711,"FOR7T1"
129: urt 714,""
130: for I=1 to N
131: sprt 713,I
132: next I
133: *****
134: dsp "To start the test press the (Continue) key "data
135: dep "Test starts in 5 seconds":wait 1000
136: dsp "Test starts in 4 seconds":wait 1000
137: dsp "Test starts in 3 seconds":wait 1000
138: dsp "Test starts in 2 seconds":wait 1000
139: dsp "Test starts in 1 second":wait 1000
140: dep "START"
141: *****
142: dim L[M],V[M],S[M,N],P[M],Q[M]
143: for I=1 to M
144: urt 722,"FOR7T1"
145: urt 709,1.38
146: trg 722:red 722,P[I]
147: ren 7:clr 7
148: for J=1 to N
149: urt 722,"FOR7T1"
150: urt 709,1.38
151: trg 722:red 722,S[I,J]
152: ren 7:clr 7
153: next J
154: urt 722,"FOR7T1"
155: urt 709,1.39
156: trg 722:red 722,V[I]
157: ren 7:clr 7
158: urt 709,1.37
159: trg 722:red 722,Q[I]
160: ren 7:clr 7
161: deep
162: deep
163: urt 16.5,I
164: urt 16.9,P[I],L[I],V[I]
165: urt 16.8
166: sprt 1,I
167: sprt 1,P[I],L[I],V[I]
168: for J=1 to N
169: urt 16.6,S[I,J]
170: sprt 1,S[I,J]
171: next J
172: urt 16.7
173: for K=1 to 60
174: wait T
175: next K
176: next I
177: dep "DATA COLLECTED":wait 1000
178: *****
179: -25.595:r1
180: 1.9572:r2
181: dsp "PROCESSING DATA"
182: dim H[N],E[M,N],T[M]
183: for J=1 to N
184: sprt 1,J>A[J]

```

```

185: next I
186: for I=1 to M
187:   Q[I]=F2)/r1/Q[I]
188:   Q[I]=Q[I]/L[I]
189:   L[I]=S+Q/L[I]
190:   P[I]=S+Q/P[I]
191:   if L[I]<0:Q[I]
192:   if P[I]<0:P[I]
193:   for J=1 to N
194:     S[I,J]/V[I]=A[J]/V[I]*A
195:     -4*V/(S[I]+(1+2*V))/E[I,J]
196:   next J
197: next I
198: int 2,2/,"PROCESSED DATA:"/,,"*****"/
199: int 3,"Read No.",f2,0,". Load: in.",f10,2,".f1.",f10,2,".Slip",f9,5
200: int 4,"Strains from Gauges:"
201: wrt 16,2:wrt 701,2
202: sprt 2,M,N
203: for I=1 to M
204:   wrt 16,3,I,P[I],L[I],T[I]
205:   wrt 16,4
206:   wrt 701,3,I,P[I],L[I],T[I]
207:   wrt 701,4
208:   sprt 2,P[I],L[I]
209:   for J=1 to N
210:     wrt 16,6,E[I,J]
211:     wrt 701,6,E[I,J]
212:   sprt 2,E[I,J]
213: next J
214: wrt 16,7:wrt 701,7
215: next I
216: dsp "PROPROCESSING COMPLETE":end
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3: " BEARING TESTING ( ULTIMATE LOAD TESTS )"
4: "*****";
5: "PROGRAM TO COLLECT DATA FROM BEARING TESTING";
6: "*****";
7: "This program would scan upto 40 channels and store the read voltage
8: "into the specified data file. The program asks for some information
9: "that has to be input, and then proceeds with scanning. Items to be
10: "input include :
11: "
12: "          1) Pot bearing number,
13: "          2) Number of strain gauges
14: "          3) No. of different types of gauges being used
15: "          4) Start ch., End ch., gauge factor for each type
16: "          5) Operator
17: "          6) Date
18: "          7) Time
19: "          8) Name of data files
20: "          9) Number of readings to be taken for each gauge
21: "         10) Delay between the readings in milliseconds
22: "         11) Conversion factors from pressure transducer
23: "            readings to load
24: "
25: "This program is a modified form of previous program to incorporate
26: "slip and lift for the plate edge, relative to the concrete. The
27: "coefficients from the calibration curves from the transducers have
28: "been included in the program.
29: "
30: "After all the necessary information is input, the program pauses and
31: "waits for the (Continue) key to be pressed to start scanning, and
32: "reading the voltage. Readings are stored in the specified file,
33: "displayed on the screen, and printed.
34: "Arrays L[M],V[M] and S[M,N] are used to store the readings obtained.
35: "The kind of readings stored are :
36: "          L[M] = Pressure Transducer (Loading), (channel 38)
37: "          V[M] = Voltage input to bridges, (channel 39)
38: "          S[M,N] = Voltage output from bridges corresponding
39: "                   to different gauges, (channels 1 thru 40)
40: "Both disk drives are used in this program. Drive 0 is used for the
41: "diskette containing the programs, while Drive 1 is used for during
42: "the run of the test to store all readings obtained in the specified
43: "data file. This diskette is only used for data storing.
44: "*****";
45: dim IS[10,40],NS[10],JS[10,20],MS[10]
46: prt "POT BEARING TESTS":spc 2
47: ent "Pot Bearing Number :",IS[1]
48: fnt 1,"Pot Bearing Number          :",c40,/,
49: wrt 701.1,IS[1]
50: ent "Number of Strain Gauges :",N
51: fnt 1,"Number of Strain Gauges:",39x,f2.0,/,
52: wrt 701.1,N
53: dim C[N],G[N]
54: ent "How many different types of gauges are being used...?",M
55: for J=1 to M
56: ent "Type of gauge",JS[J]
57: ent "Enter start channel for this type",L
58: ent "Enter end channel for this type",E
59: ent "Gauge factor for this type",F
60: fnt 1,"GAUGE :",c10,," Start Ch:",f2.0,," End Ch:",f2.0,," G.F.:",f5.2,/,
61: wrt 701.1,JS[J],L,F

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59:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
60:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
61:  text :
62:  next :
63:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
64:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
65:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
66:  fnt 2,1,"Gauge Numbers : Gauge Factors : /,1" + "/,1"
67:  text :
68:  dsp "Enter data from pressure transducer calibration curve:"
69:  wait 2000
70:  ent "Slope for conversion from transducer reading to load :".S
71:  ent "Intercept for conversion from transducer reading to load :".C
72:  ent "Operator :".IS[2]
73:  ent "DATE :".IS[3]
74:  ent "TIME :".IS[4]
75:  ent "Square plate dimensions :".IS[5]
76:  ent "Circular plate diameter :".IS[5]
77:  fnt 1,2/,"Operator :".c29./
78:  wrt 701,1,IS[2]
79:  fnt 1,"Date :".c29./
80:  wrt 701,1,IS[3]
81:  fnt 1,"Time :".c29./
82:  wrt 701,1,IS[4]
83:  fnt 1,"Rectangular plate :".c29./
84:  wrt 701,1,IS[5]
85:  fnt 1,"Circular plate diameter :".c29./
86:  wrt 701,1,IS[5]
87:  "*****";
88:  ent "NAME OF DATA FILE TO STORE RAW VOLTAGE READINGS".NS
89:  ent "NAME OF DATA FILE TO STORE PROCESSED DATA i.e. Load and Strains".MS
90:  ent "NUMBER OF READINGS ?".M
91:  ent "TIME DELAY IN MILLISECS :".T
92:  "BYTES REQUIRED":
93:  3*M+N*B/5.5*B/256/R/R+1/R
94:  ms1 "M700.1"
95:  open NS.R
96:  open MS.R
97:  asgn NS,1,1
98:  asgn MS,2,1
99:  rread 1,1
100:  rread 2,1
101:  "*****";
102:  fnt 1,"Slope for Transducer Calibration :".f2x,e11,4./
103:  wrt 701,1,S
104:  fnt 1,"Intercept for Transducer Calibration :".f2x,e11,4./
105:  wrt 701,1,C
106:  fnt 1,"Data File for raw Data".2x,"":c40./
107:  wrt 701,1,NS
108:  fnt 2,"File for processed Load and Strains".":c29./
109:  wrt 701,2,MS
110:  fnt 1,"Number of readings".f2x,"":c24x,f5,0./
111:  wrt 701,1,M
112:  fnt 1,"Delay between two sets (in seconds)".":c32x,f5,0
113:  T=60/1000/RB
114:  wrt 701,1,TB
115:  "*****";
116:  rem 7:clr 7
117:  fnt 1,fz2,0,"E":
118:  "*****";
119:  fnt 2,3/,"READINGS :".f2./ + "*****";
120:  fnt 5,"Reading No.:".f2,0
121:  fnt 3,"Press. Trans.: initial :".f9,5,1x,"final :".f9,5,3x," /in :".f9,5,6

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121: int 5.15.5. > 1
122: int 1
123: int 3, "Your form strain gauges!"
124: wrt 15.3
125: "*****";
126: wrt 722, "F0R7T1"
127: sprt 1, M, 1
128: for J=1 to N
129: sprt 1, G, J
130: next J
131: "*****";
132: dsp "To start the test press the (Continue) key "test
133: dsp "Test starts in 5 seconds":wait 1000
134: dsp "Test starts in 4 seconds":wait 1000
135: dsp "Test starts in 3 seconds":wait 1000
136: dsp "Test starts in 2 seconds":wait 1000
137: dsp "Test starts in 1 second":wait 1000
138: dsp "START"
139: "*****";
140: dim L[M], V[M], S[M,N], P[M], Q[M], R[M]
141: for I=1 to M
142: wrt 722, "F0R7T1"
143: wrt 709, 1, 38
144: trg 722:red 722, P[I]
145: rem 7:clr 7
146: for J=1 to N
147: wrt 722, "F0R7T1"
148: wrt 709, 1, C[I,J]
149: trg 722:red 722, S[I,J]
150: rem 7:clr 7
151: next J
152: wrt 722, "F0R7T1"
153: wrt 709, 1, 38
154: trg 722:red 722, L[I]
155: rem 7:clr 7
156: wrt 722, "F0R7T1"
157: wrt 709, 1, 39
158: trg 722:red 722, V[I]
159: rem 7:clr 7
160: wrt 709, 1, 37
161: trg 722:red 722, Q[I]
162: rem 7:clr 7
163: wrt 709, 1, 34
164: trg 722:red 722, R[I]
165: rem 7:clr 7
166: beep
167: beep
168: wrt 16.5, I
169: wrt 16.9, P[I], L[I], V[I]
170: wrt 16.8
171: sprt 1, I
172: sprt 1, P[I], L[I], V[I]
173: for J=1 to N
174: wrt 16.6, S[I,J]
175: sprt 1, S[I,J]
176: next J
177: wrt 16.7
178: for K=1 to 60
179: wait 1
180: next K
181: next I
182: next I
183: dsp "DATA COLLECTED":wait 1000
184: "*****";

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185: -25.595/r1
186: -1.522/r2
187: -20.626/r3
188: 4.3973/r4
189: dsp "PROCESSING DATA"
190: do P[1],E[1],N[1],M[1],U[1]
191: do 1
192: do 1
193: for J=1 to N
194: S[I,J]=A[J]
195: next J
196: for I=1 to M
197: (Q[I]-r2)/r1/Q[I]
198: (R[I]-r4)/r3/R[I]
199: Q[I]-Q[I]*T[I]
200: R[I]-R[I]*U[I]
201: L[I]=S+C/L[I]
202: P[I]=S+C/P[I]
203: if L[I]<0:0/L[I]
204: if P[I]<0:0/P[I]
205: for J=1 to N
206: S[I,J]/V[I]-A[J]/V[I]:V
207: -4*V/(G[J]*(1+2*V))*E[I,J]
208: next J
209: next I
210: fnt 2.2/,"PROCESSED DATA:"./,"*****"../
211: fnt 3,"No.",f2.0,". Ld:in.",f10.2,".f1.",f10.2,".S11o",f9.5,".Lift",f9.5
212: fnt 4,"Strains from Gauges:"
213: wrt 16.2;wrt 701.2
214: spnt 2,M,N
215: for I=1 to M
216: wrt 16.3,I,P[I],L[I],T[I],U[I]
217: wrt 16.4
218: wrt 701.3,I,P[I],L[I],T[I],U[I]
219: wrt 701.4
220: spnt 2,P[I],L[I]
221: for J=1 to N
222: wrt 16.6,E[I,J]
223: wrt 701.6,E[I,J]
224: spnt 2,E[I,J]
225: next J
226: wrt 16.7;wrt 701.7
227: next I
228: dsp "PROCESSING COMPLETE":end
*2750

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