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FINAL REPORT  
COMPARATIVE STRENGTH OF BOLTED  
ASSEMBLIES

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## FINAL REPORT

## COMPARATIVE STRENGTH OF BOLTED ASSEMBLIES

The object of this study was to determine the comparative strength of bolted assemblies constructed of 5/8-inch bolts passing through steel members of 3/8-inch and 3/16-inch thickness. The three types of bolts used varied essentially in their kind of threading. In all phases of the test program, particular emphasis was placed on the comparative strength of the bolts. The study was made on the request of Commonwealth Associates, Inc., of Jackson, Michigan, as specified in their purchase order No. J5092, dated February 22, 1954, and in accordance with their drawings TS-A72326 sheet 1 and TS-A72326 sheet 2, which specified the kind of test to be made.

DESCRIPTION OF BOLTS

Three kinds of bolts were used for these comparative tests. One type was taken from existing power transmission towers erected more than 20 years ago. These bolts were 5/8 inch in diameter and were threaded over most of their length. They had been installed so that there was bearing on the threads; thus, some minor deformations of the thread had occurred during the service of the bolt. Hereafter in this report these bolts will be identified as "Old Tower Bolts".

The second type of bolt studied was the Commonwealth Associates, Inc. standard bolt, which is also 5/8 inch in diameter. These bolts are installed in such a manner that bearing takes place on the unthreaded portion of the shank. The principal use for these bolts is in the construction of transmission towers; consequently they will be referred to as "New Tower Bolts" throughout this report.

The third type of bolt was a new 5/8-inch-diameter bolt threaded for the full length of the shank and therefore designated in this report as "Full-Threaded Bolts". These were new bolts, and of course, had bearing on the threads when installed.

All three kinds of bolts were galvanized and had square heads with hexagonal nuts. All had rolled threads.

#### STEEL MEMBERS

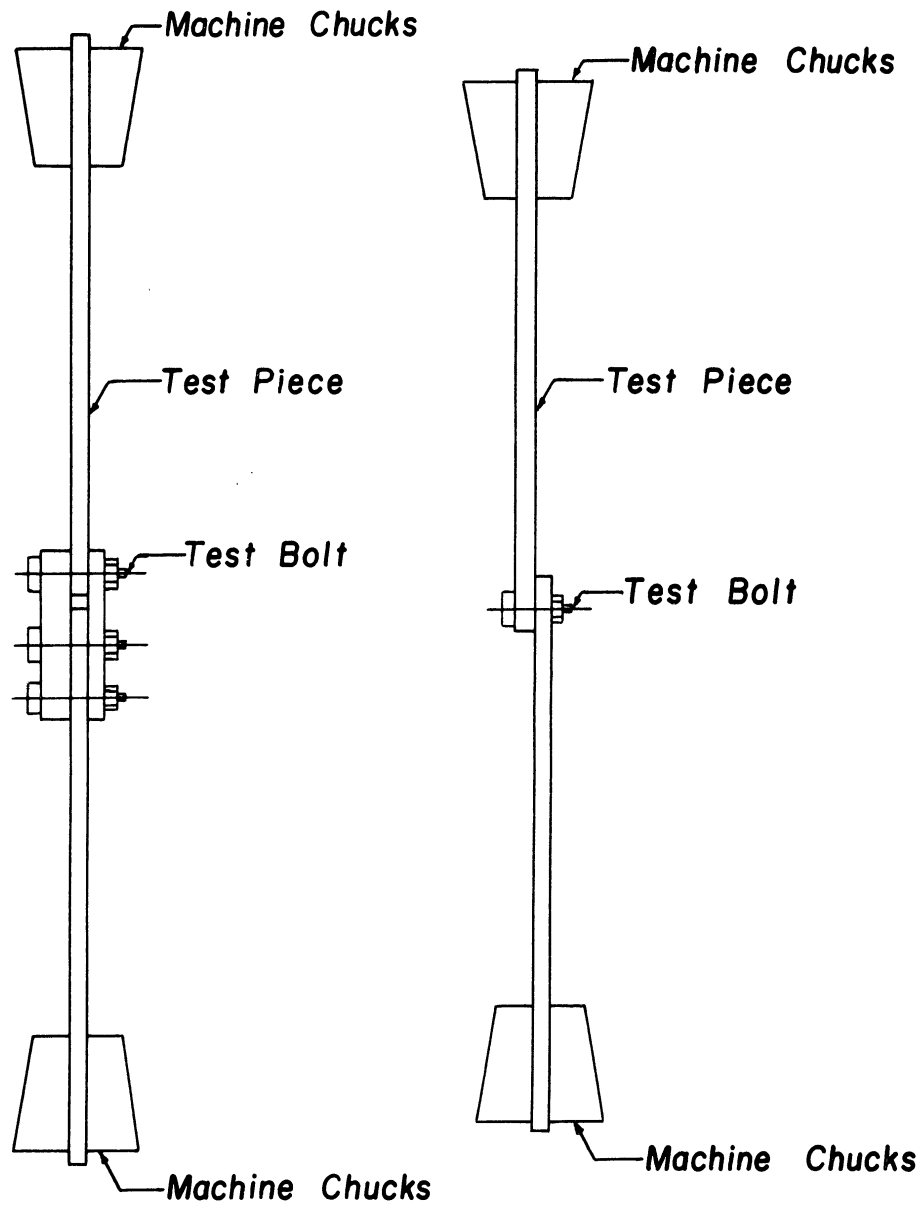
The steel for the members used to load the bolts was cold-rolled bar stock, 1-3/4 inch wide and 3/8 or 3/16 inch thick. This material was used for the tests numbered 1 to 12 inclusive. Three random samples were taken for standard ASTM tension tests (ASTM designation E8-53T, for plate specimens). The results of these tests showed an average ultimate tensile strength of about 97,200 lbs per sq in. and an average elongation of 5.16 percent. Details of these tests are given in Table V of the appendix.

For tests 13, 14, and 15 a 2 x 2 x 3/16 structural steel angle was used as the test member. Specimens were cut from each of these angles for standard ASTM tension tests, which showed an average ultimate tensile strength of 59,800 lbs per sq in. and an average yield strength of about 41,700 lbs per sq in. The average elongation was about 27.8 percent. Details of these tests are also given in Table V of the appendix.

#### TESTING PROCEDURE

Each type of bolt tested was subjected to two sets of conditions, namely single shear and double shear. Each set was further divided by using both 3/8-inch and 3/16-inch-thick test pieces bearing on the bolt. Figure 1 shows these test assemblies. It will be noted that in the double shear test setup two bolts were used on the gripping side of the splice to insure failure either in the test piece or in the test bolt. In addition, when the test piece was 3/16-inch thick the matching bar was increased in width to 2-1/2 inches. For the same purpose in the single shear test setup, the edge distance on the gripping side was increased at the test bolt from 1 inch to 1-1/2 inches. In both types of test the test piece and its matching bar were 2 feet long and were gripped for about 10 inches from the end by the testing machine.

The machine used in these tests is a 400,000-pound universal Tinius-Olsen testing machine with electronic controls, located in the Structural Engineering Laboratory of the Civil Engineering Department of the University of Michigan. All tests were made on this machine with the exception of the ASTM standard tension tests used to determine the tensile strength of the steel bars, for which a 120,000-pound mechanically loaded universal Riehle testing machine located in the Engineering Mechanics Laboratory



Double Shear  
Test Set-up

Single Shear  
Test Set-up

FIGURE 1.

of the Department of Engineering Mechanics of the University of Michigan was used. The speed used in testing on each machine was 0.05 inch per minute.

Figures 2 to 7, inclusive, give detailed dimensions of the test bolts and adjacent pieces. The double shear setups are shown in Figures 2, 4, and 6, while the single shear setups are shown in Figures 3, 5, and 7. The tests have been numbered according to the numbers on these figures and where more than one test has been made under the same conditions a letter has been added after the test number, e.g., 1a, 1b, etc. Tests numbered 13a, 14a, and 15a are not included in these diagrams; however, they are similar to tests 3a, 7a, and 12a, respectively. Different numbers were assigned because an angle was substituted for the test piece in these instances.

Copies of the data taken in the laboratory appear in the appendix.

#### DISCUSSION OF TEST RESULTS

##### Double Shear Bearing Tests

Table I compares the strengths of the bolts tested in double-shear with a  $3/16$ -inch test piece bearing on the bolt. All failures were bearing failures of the  $3/16$ -inch test piece. Breaking loads were higher for the New Tower Bolts than for the Old Tower Bolts; those for the Full-Threaded Bolts were still higher. This increase was only 4.8 percent, however. In bearing unit stress this apparent increase in strength is not so pronounced, being a maximum of 3.61 percent for the Full-Threaded Bolt over the Old Tower Bolt. Such variations are not considered abnormal for tests of this type, and it should be kept in mind that these ultimate values far exceed the usually permitted working loads for  $5/8$ -inch bolts.

Load-strain curves of these tests and photographs of these failures appear in the appendix.

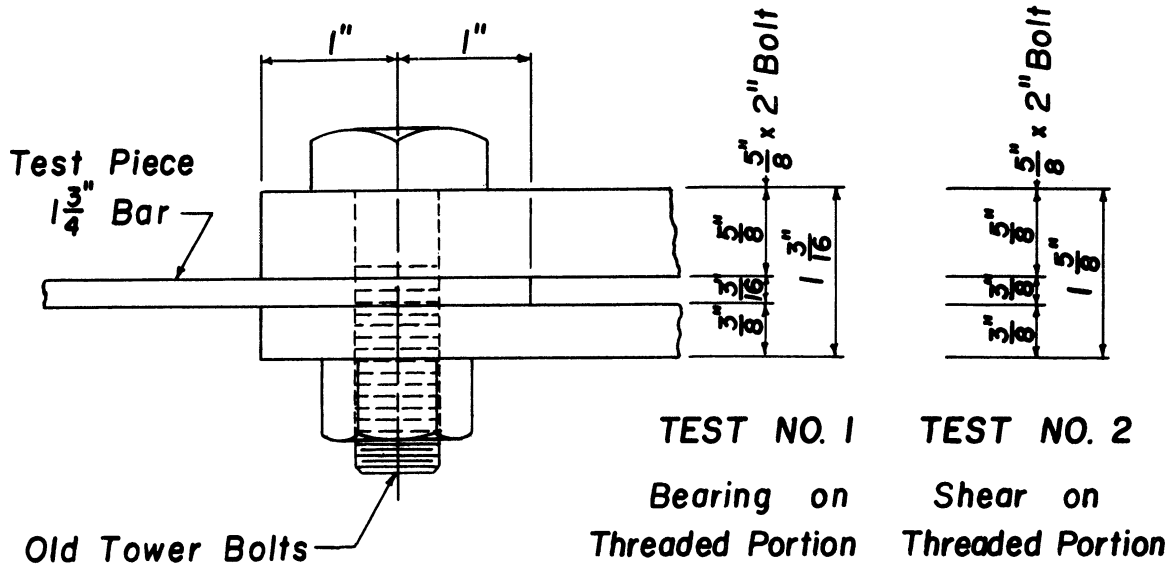


FIGURE 2

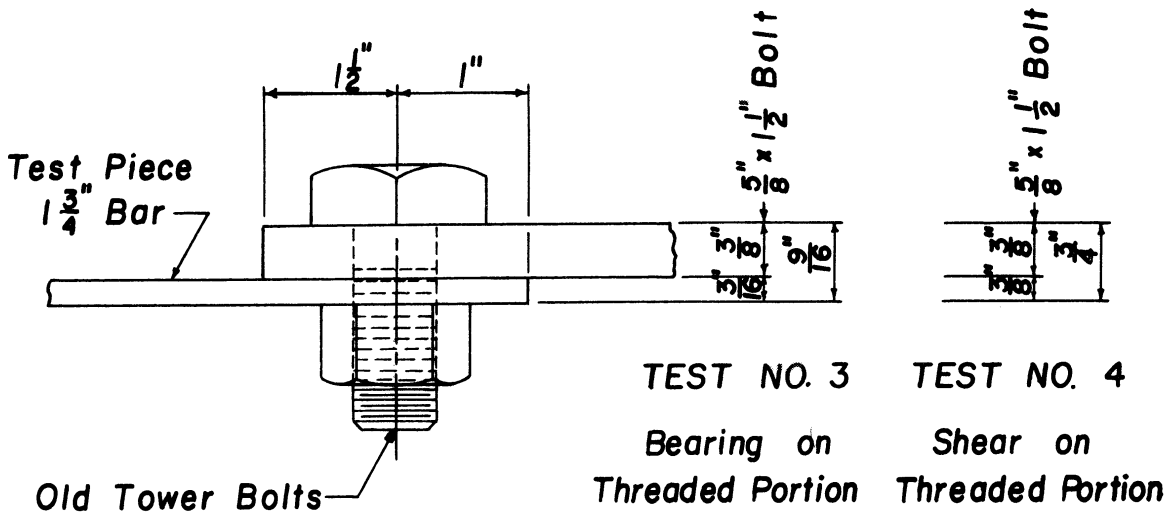


FIGURE 3



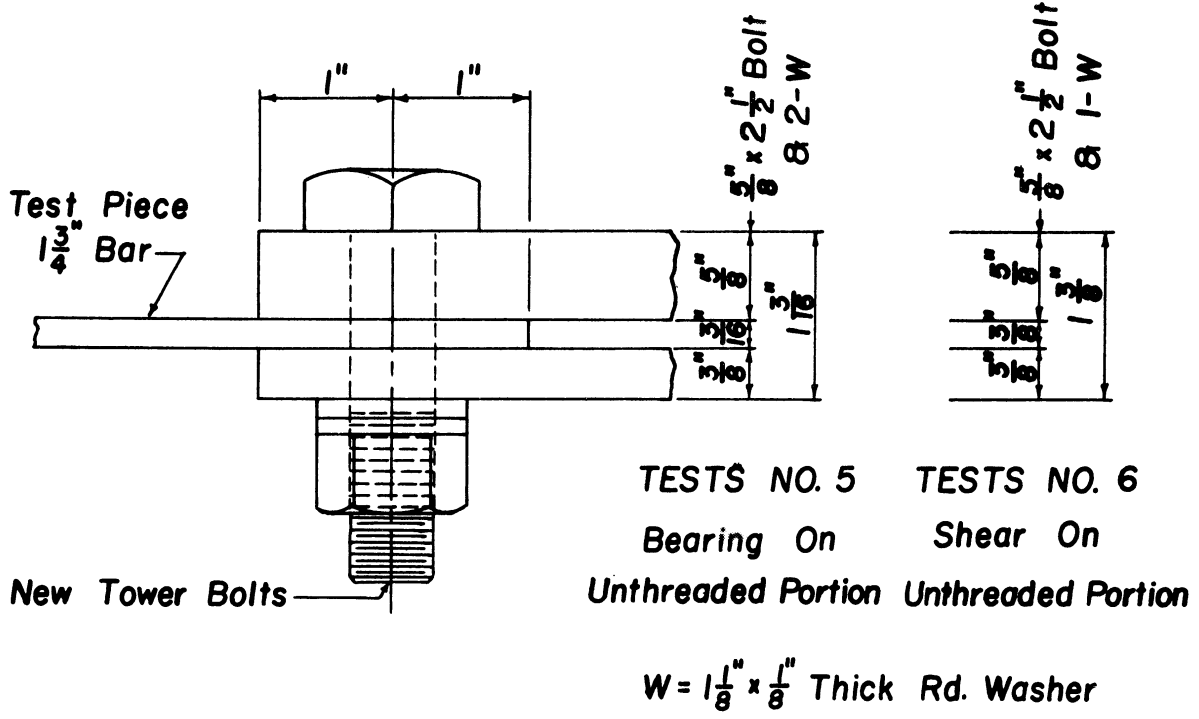


FIGURE 4

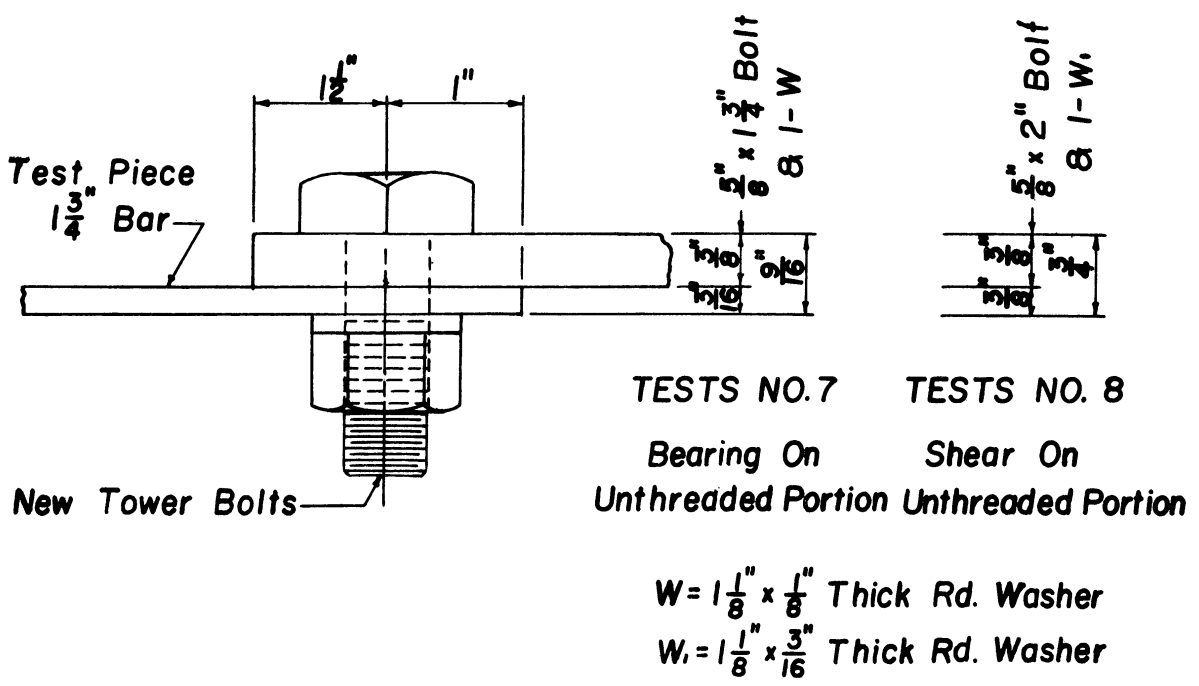


FIGURE 5

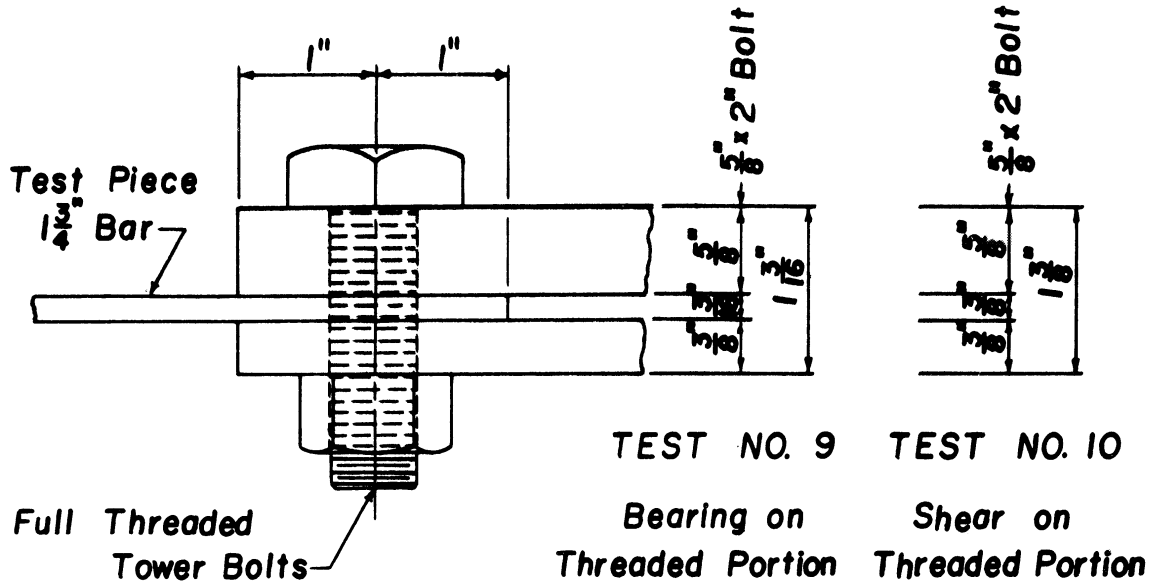


FIGURE 6

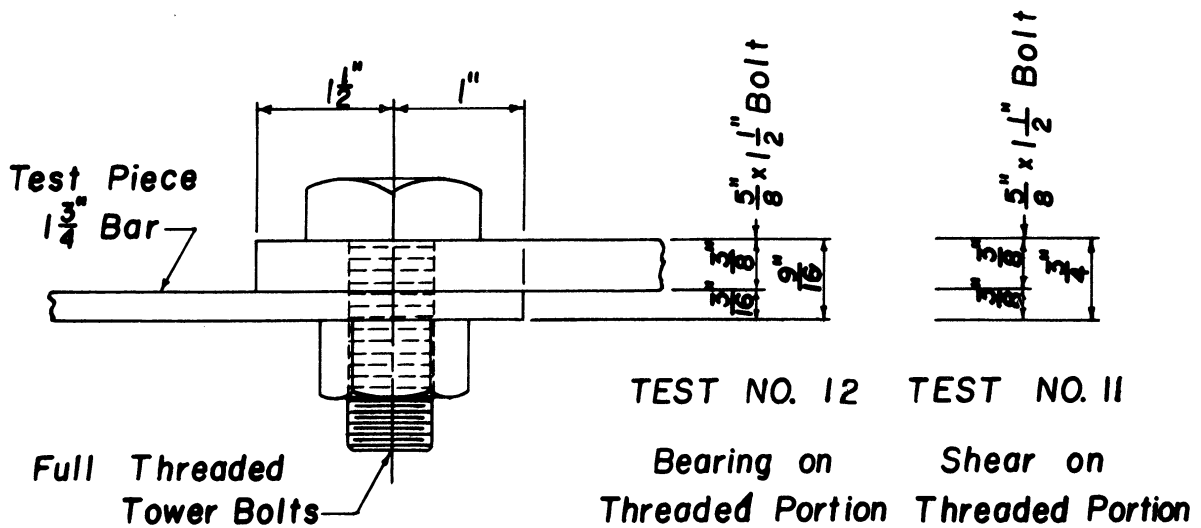
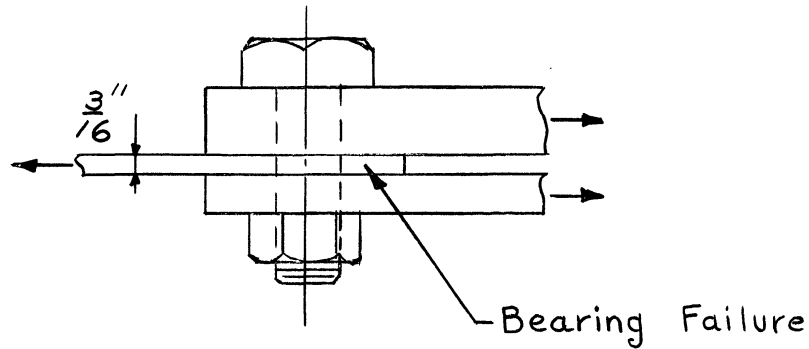


FIGURE 7

TABLE I

DOUBLE SHEAR BEARING TESTS



Thickness of Test Piece = 0.188 in.  
 All Failures Were Bearing Failures.

Test No.	Breaking Load, lbs	Bolt Diameter, in.		Unit Stress at Failure, lbs/in. <sup>2</sup>		Remarks
		Root	Full	Shear	Bearing	
1a	14,450	0.531	0.603	33,600	127,500	Old Tower Bolt
1b	15,100	0.521	0.612	35,400	131,000	" " "
1c	<u>16,350</u>	0.523	0.612	<u>38,000</u>	<u>142,000</u>	" " "
Av.	15,300			35,667	133,500	
5a	15,000		0.625	24,400	128,000	New Tower Bolt
5b	15,350		0.623	25,100	131,000	" " "
5c	<u>16,350</u>		0.625	<u>26,600</u>	<u>139,000</u>	" " "
Av.	15,567			25,367	132,667	
9a	16,100	0.520	0.615	37,900	139,000	Full-Threaded Bolt
9b	15,800	0.510	0.618	38,600	136,000	" " "
9c	<u>16,200</u>	0.527	0.625	<u>37,200</u>	<u>138,000</u>	" " "
Av.	16,033			37,900	137,667	

Double Shear Tests

The comparative strengths of the bolts in double shear with a 3/8-inch test piece bearing on the bolt are shown in Table II. All the bolts tested under these conditions failed in shear, except that of test 6a which failed in bearing. During the tests the edge distance for tests 6b and 6c was increased to 1-1/2 inches to prevent bearing failure as in 6a. Tests 10b and 10c also had the edge distance increased for the same reason. The breaking loads in this series were higher in the tests with the New Tower Bolts than in the tests with either the Old Tower Bolts or the Full-Threaded Bolts. Undoubtedly this greater breaking load was due to the difference in the diameter subjected to the action of shear. On a shearing unit stress basis, however, there was good agreement among the tests, with a 4.56-percent increase for the Full-Threaded Bolt (the maximum value) over the New Tower Bolt (the minimum value).

Load-strain curves of these tests and photographs of these failures appear in the appendix.

Single Shear Bearing Tests

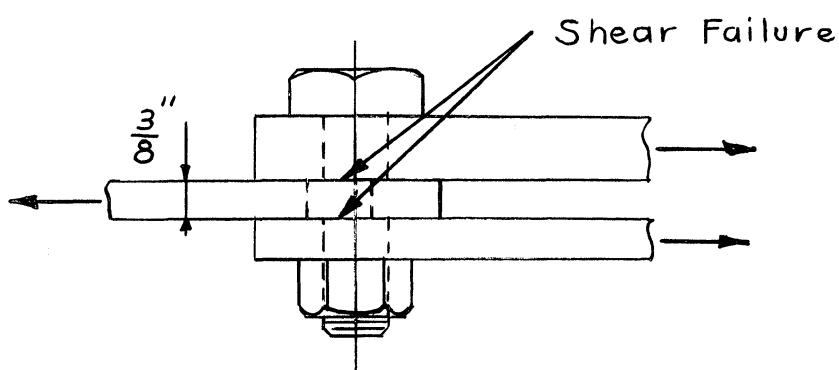
Table III shows the comparative strengths of the three types of bolts as subjected to single shear. The 3/16-inch test piece was arranged to bear on the threads of the Old Tower Bolts and the Full-Threaded Bolts, and to bear on the shank of the New Tower Bolts.

While these tests were made to determine bearing strength, all the bolts of tests 3, 7, and 12 sheared before the test piece failed in bearing. It was believed that this was due to the fact that cold-rolled steel was used for the test specimens. In order to prove this assumption and to verify these results, tests 13a, 14a, and 15a were made using a structural-grade steel angle as the test piece. As noted in the table, test 13a using an Old Tower Bolt failed in shear and test 14a using a New Tower Bolt failed in bearing. Test 15a actually fractured in shear; however, the elongation of the hole was severe. Apparently the strength of one of these bolts through structural-grade steel of the dimensions indicated is the same in shear as it is in bearing within the limits of probability. Therefore, it may be concluded that the values obtained using cold-rolled steel are valid for the bolt strength.

The occurrence of bearing failure with the New Test Bolt in test 14a can be explained by an examination of the results from tests 7, using the New Tower Bolts, as compared to tests 3 and 12. The average breaking load for tests 7 was 12 percent greater than the average of tests 12 which used the Full-Threaded Bolts. Tests 3, using the Old Tower Bolts, had only 0.56 percent higher breaking loads than tests 12, however. A survey of the unit

TABLE II

## DOUBLE SHEAR TESTS



Thickness of Test Piece = 0.373 in.

All Failures Were Shear Failures except Test 6a.

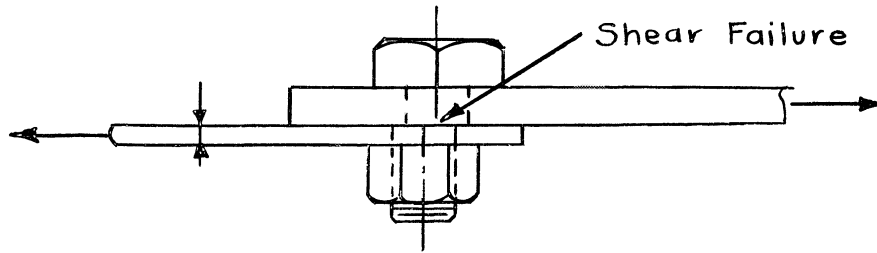
Test No.	Breaking Load, lbs	Bolt Diameter, in.		Unit Stress at Failure, lbs/in. <sup>2</sup>		Remarks
		Root	Full	Shear	Bearing	
2a	20,800	0.550	0.620	43,800	90,000	Old Tower Bolt
2b	20,400	0.539	0.625	44,600	87,600	" " "
2c	<u>20,850</u>	0.527	0.613	<u>47,800</u>	<u>91,100</u>	" " "
Av.	20,683			45,400	89,567	
6a*	28,500		0.626	46,200	122,000	New Tower Bolt
6b	23,900		0.622	39,300	103,000	" " "
6c	<u>29,600</u>		0.626	<u>48,100</u>	<u>127,000</u>	" " "
Av.	27,333			44,533	117,333	
10a	19,950	0.525	0.618	46,000	86,500	Full-Threaded Bolt
10b	19,650	0.518	0.616	46,500	85,500	" " "
10c	<u>19,825</u>	0.517	0.611	<u>47,400</u>	<u>87,100</u>	" " "
Av.	19,808			46,633	86,367	

\* Test Piece for 6a failed in bearing before shear failure of bolt.

Some shearing deformation of the bolt. See photograph in appendix.

TABLE III

SINGLE SHEAR BEARING TESTS



Test Pieces

Tests 3, 7, and 12--Cold-rolled steel with thickness = 0.188 in.

Tests 13a, 14a, and 15a--Structural Grade 2 x 2 x 3/16 angle.

All Failures Were Shear Failures except Test 14a.

Test No.	Breaking Load, lbs	Bolt Diameter, in.		Unit Stress at Failure, lbs/in. <sup>2</sup>		Remarks
		Root	Full	Shear	Bearing	
3a*	13,450	0.534	0.624	44,000	114,800	Old Tower Bolt
3b	11,050	0.527	0.615	50,700	95,700	" " "
3c	10,300	0.535	0.621	45,800	88,400	" " "
3d	9,760	0.536	0.622	43,300	83,500	" " "
Av.	10,370			46,600	89,200	
7a	10,800		0.626	35,000	91,800	New Tower Bolt
7b	11,500		0.625	37,500	98,000	" " "
7c	10,850		0.626	35,200	92,200	" " "
7d	13,050		0.619	43,400	112,000	" " "
Av.	11,550			37,775	98,500	
12a	10,250	0.526	0.619	47,100	88,200	Full-Threaded Bolt
12b	11,000	0.524	0.621	51,000	94,400	" " "
12c	9,800	0.523	0.620	45,500	84,200	" " "
12d	10,200	0.533	0.633	45,700	85,800	" " "
Av.	10,312			47,325	88,150	
13a	9,650	0.527	0.625	44,200	83,500 <sup>1</sup>	Old Tower Bolt
14a**	10,810		0.624	35,400	94,600 <sup>2</sup>	New Tower Bolt
15a	11,800	0.523	0.622	54,800	99,800 <sup>3</sup>	Full-Threaded Bolt

\*Failure took place across shank. Not included in averages.

\*\* Failure was bearing failure of angle. See photograph in appendix.

1. Actual thickness of angle = 0.185
2. Actual thickness of angle = 0.183
3. Actual thickness of angle = 0.190

stress values also bears out the greater strength of the New Tower Bolt. For bearing unit stress, the average for test 7 was 11.7 percent higher than for tests 12, while the average for tests 3 was only 1.19 percent greater. In shearing unit stress the effect is of still greater degree. Tests 7, with the New Tower Bolts, had an average shearing unit stress 25.3 percent greater than that of tests 12, while tests 3, with the Old Tower Bolts, had an average 1.55 percent lower than tests 12. Since the New Tower Bolt has appeared stronger in every respect in tests 7 over tests 3 and 12, it is reasonable that it would appear stronger in test 14a than the other bolts tested in 13a and 15a.

Load-strain curves of these tests and photographs of these failures appear in the appendix.

### Single Shear Tests

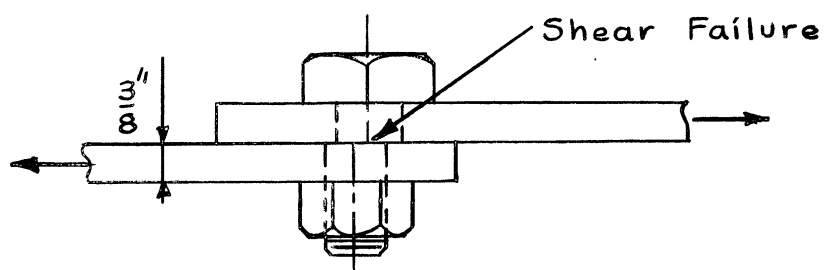
Table IV tabulates the comparative strengths of the three types of bolts in single shear. The thickness of the test piece was  $3/8$  inch and the shearing took place across the threads in tests 4 with the Old Tower Bolts and in tests 11 with the Full-Threaded Bolts. The shear occurred across the shank portion of the New Tower Bolts tested in tests 8.

As would be expected, the average load in tests 8 was greater than that in tests 4 and 11. When the shearing unit stress is examined, however, little significant variation can be noted. The average unit shearing stress for tests 8, which used the New Tower Bolts, was 9.48 percent greater than the average unit shearing stress for tests 4, which used the Old Tower Bolts. At the same time tests 11 with the Full-Threaded Bolts showed only an 8.23 percent greater shearing unit stress than tests 4.

Load-strain curves of these tests and photographs of these failures appear in the appendix.

TABLE IV

SINGLE SHEAR TESTS



Thickness of Test Piece = 0.373 in.  
 All Failures Were Shear Failures.

Test No.	Breaking Load, lbs	Bolt Diameter, in.		Unit Stress at Failure, lbs/in. <sup>2</sup>		Remarks
		Root	Full	Shear	Bearing	
4a	9,050	0.524	0.620	42,000	39,200	Old Tower Bolt
4b	9,000	0.520	0.617	42,400	39,100	" " "
4c	<u>8,950</u>	0.525	0.622	<u>41,300</u>	<u>38,600</u>	" " "
Av.	9,000			<u>41,900</u>	<u>38,966</u>	
8a	14,150		0.625	46,200	60,700	New Tower Bolt
8b	12,900		0.625	42,100	55,400	" " "
8c	<u>15,100</u>		0.625	<u>49,200</u>	<u>64,800</u>	" " "
Av.	14,050			<u>45,833</u>	<u>60,300</u>	
11a	10,000	0.519	0.615	47,200	43,600	Full-Threaded Bolt
11b	9,100	0.525	0.623	42,000	39,100	" " "
11c	<u>10,000</u>	0.523	0.605	<u>46,500</u>	<u>44,300</u>	" " "
Av.	9,700			<u>45,233</u>	<u>42,333</u>	



CONCLUSIONS

In view of the limited number of tests conducted it is difficult to draw definite conclusions about the relative advantage of the three kinds of bolts tested. The New Tower Bolts, now used as Commonwealth Associates, Inc., standard, showed definite advantages in single shear bearing on a 3/16-inch plate and generally ranked high in other respects. Because of its larger effective diameter in bearing and in shear, the load-carrying capacity was generally highest for the New Tower Bolt.

The new Full-Threaded Bolts stood up very well under test and on a unit stress basis were comparable to the New Tower Bolts. The Old Tower Bolts generally had the lowest load-carrying capacity of the three types.

With the exception of the New Tower Bolts tested in a single shear assembly with a 3/16-inch test piece bearing on the bolt (Tests 3, 7, and 12), the ultimate unit stress values in both shear and bearing for all three types of bolt varied less than 9 percent. When only double shear assemblies are considered, the unit stresses in both shear and bearing varied less than 5 percent. Since working unit stresses are well under these ultimate values, it may be concluded that these three types of bolts are equally acceptable for use under conditions similar to those tested. It is to be understood that the above observations have been drawn from static tests only and should not be interpreted as applying to any dynamic or repeated stress conditions.

## APPENDIX

TABLE V

TENSION TESTS  
(ASTM Designation E8-53T)

Standard specimen for plates with 8-inch gage length. Speed of loading 0.05 in. per min.

Cold-Rolled Steel

Specimen No.	Width, in.	Thickness, in.	Area, in. <sup>2</sup>	Ultimate Load, lbs	Ultimate Stress, lbs/in. <sup>2</sup>	Elongation Percent
1	1.503	0.188	0.283	28,920	102,000	4.00
2	1.505	0.186	0.280	24,540	87,700	7.25
3	1.492	0.188	0.281	28,560	101,800	4.25
				Average	97,166	5.16

Structural Steel Angle

Specimen No.	Width, in.	Thickness, in.	Area, in. <sup>2</sup>	Ultimate Load, lbs	Yield Stress, lbs/in. <sup>2</sup>	Ultimate Stress, lbs/in. <sup>2</sup>	Elongation Percent
13	1.500	0.184	0.276	16,500	41,800	59,800	27.70
14	1.500	0.183	0.275	16,600	42,200	60,400	27.80
15	1.499	0.183	0.274	16,200	41,000	59,200	27.80
				Average	41,666	59,800	27.76

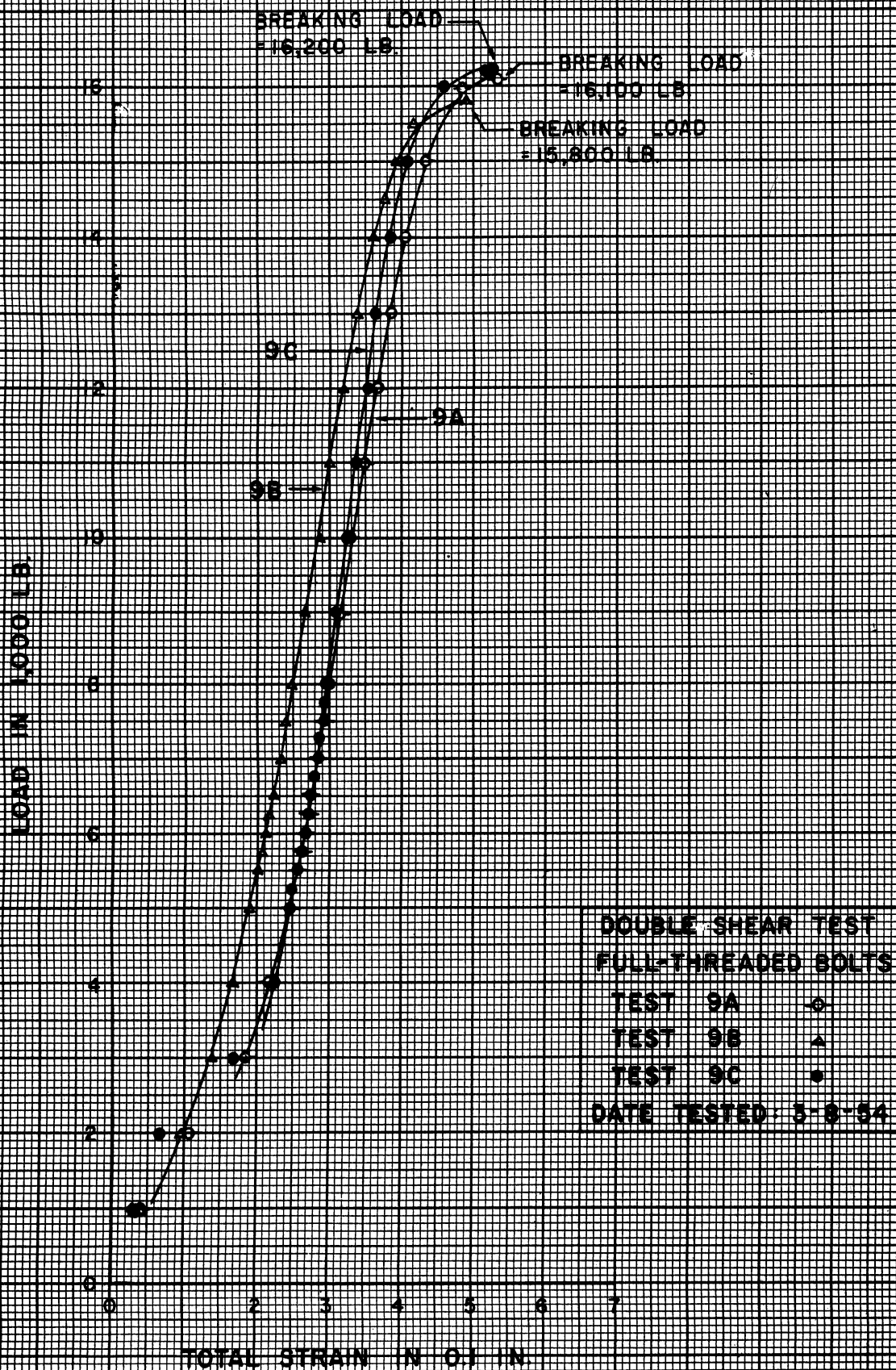
LABORATORY DATA

DOUBLE SHEAR BEARING TEST

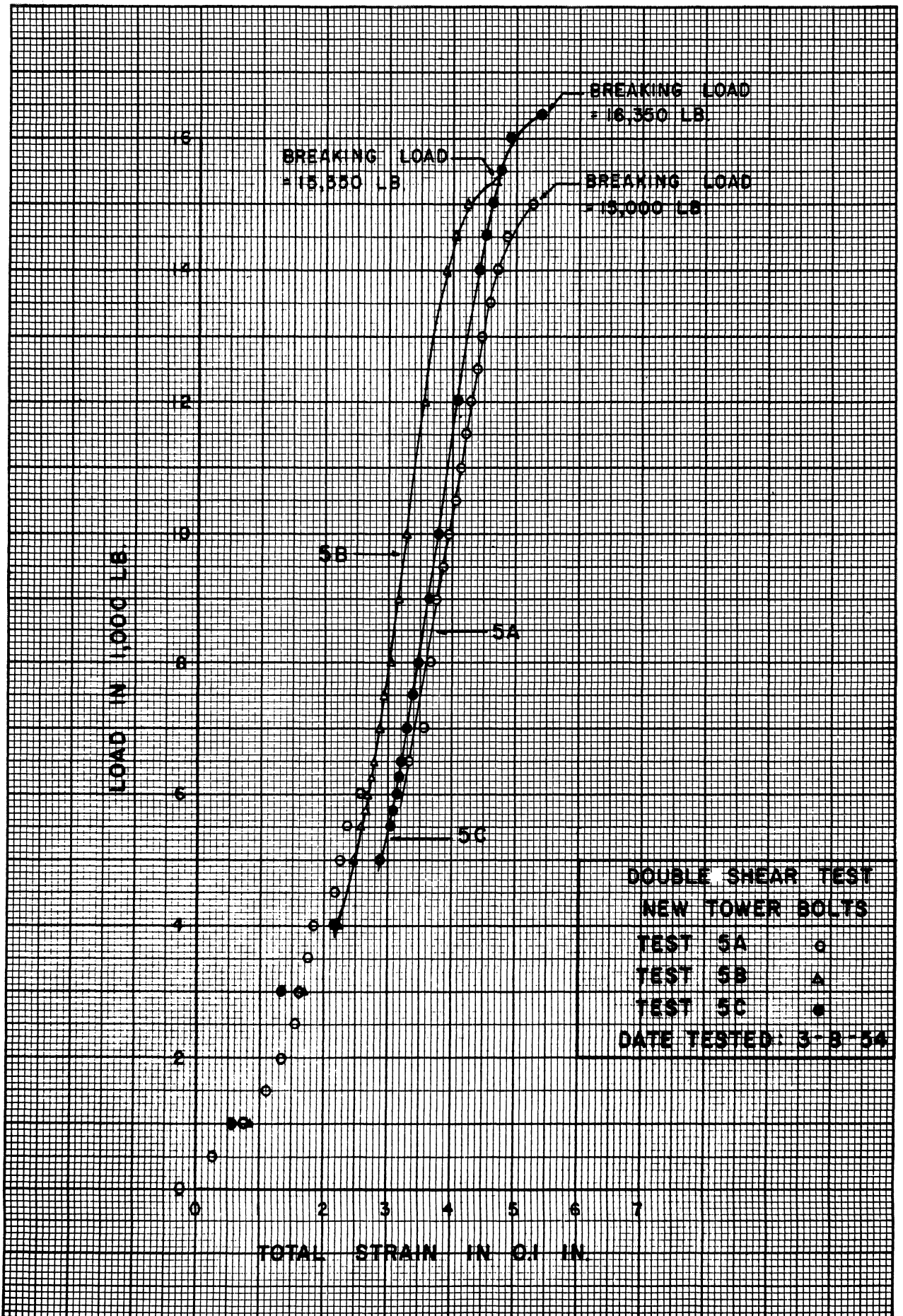
3/16-in. Test Piece - 0.188 in.  
 Old Tower Bolts - 5/8 in. x 2 in.

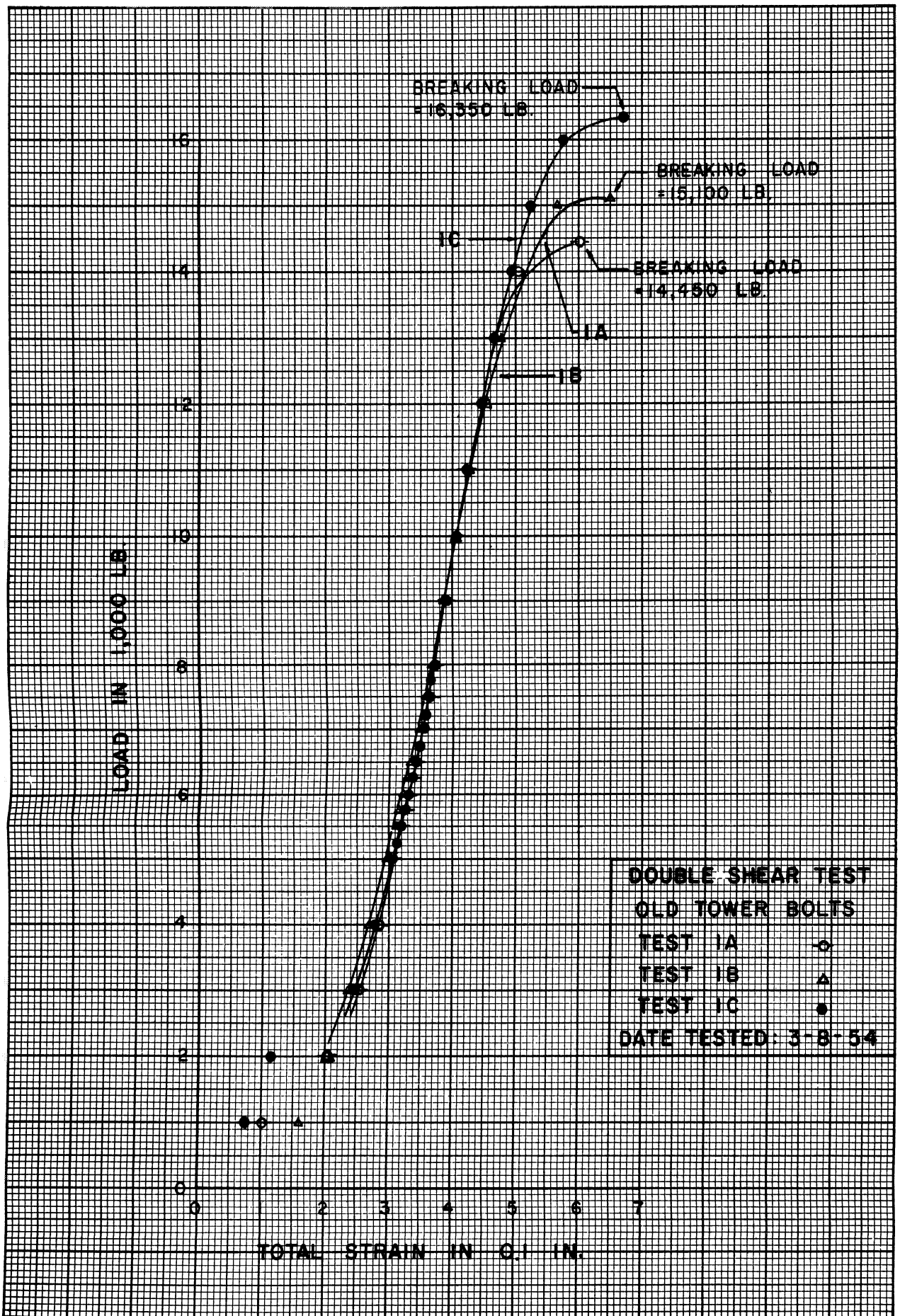
Test No.	1a	1b	1c
Date Tested	3-8-54	3-8-54	3-15-54
Root Dia.	0.531 in.	0.521 in.	0.523 in.
Full Dia.	0.603 in.	0.612 in.	0.612 in.

Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	100 x 0.001	160 x 0.001	74 x 0.001
2000	202	202	114
3000	253	235	249
4000	283	270	276
5000	307	298	307
5250			313
5500	319	311	318
5750	325	317	324
6000	330	323	329
6250	336	329	336
6500	341	335	341
6750			348
7000	352	346	351
7250			357
7500	362	359	363
7750			365
8000	371	369	369
9000	390	388	388
10000	406	408	406
11000	423	429	426
12000	444	452	446
13000	468	477	467
14000	505	508	493
15000		569	524
16000			575
Failure	14,450 lbs Dial 0.600 in. Bearing Failure	15,100 lbs Dial 0.650 in. Bearing Failure	16,350 lbs Dial 0.672 in. Bearing Failure Slight Shear



DOUBLE SHEAR TEST  
 FULL-THREADED BOLTS  
 TEST 9A    ○  
 TEST 9B    ▲  
 TEST 9C    ●  
 DATE TESTED: 3-8-54





LABORATORY DATA

DOUBLE SHEAR BEARING TESTS

3/16-in. Test Piece - 0.188 in.  
New Tower Bolts - 5/8 in. x 2 in.

Test No.	5a	5b	5c
Date Tested	3-8-54	3-8-54	3-8-54
Bolt Dia.	0.625 in.	0.623 in.	0.625 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
500	27 x 0.001		
1000	75	81 x 0.001	58 x 0.001
1500	110		
2000	132		
2500	152		
3000	163	168	133
3500	174		
4000	184	222	219
4500	217		
5000	226	247	289
5500	234	257	301
5750		263	307
6000	258	268	312
6250		273	318
6500	331	277	321
7000	355	286	330
7500		294	340
8000	367	302	348
9000	376	315	364
9500	385		
10000	393	329	379
10500	404		
11000	412		
11500	420		
12000	429	357	409
12500	439		
13000	448		
13500	458		
14000	470	390	441
14500	486	403	451
15000	529	423	461
15500			474
16000			491
Failure	15,000 lbs Dial 0.529 in. Shear Failure	15,350 lbs Shear Failure	16,350 lbs Shear Failure

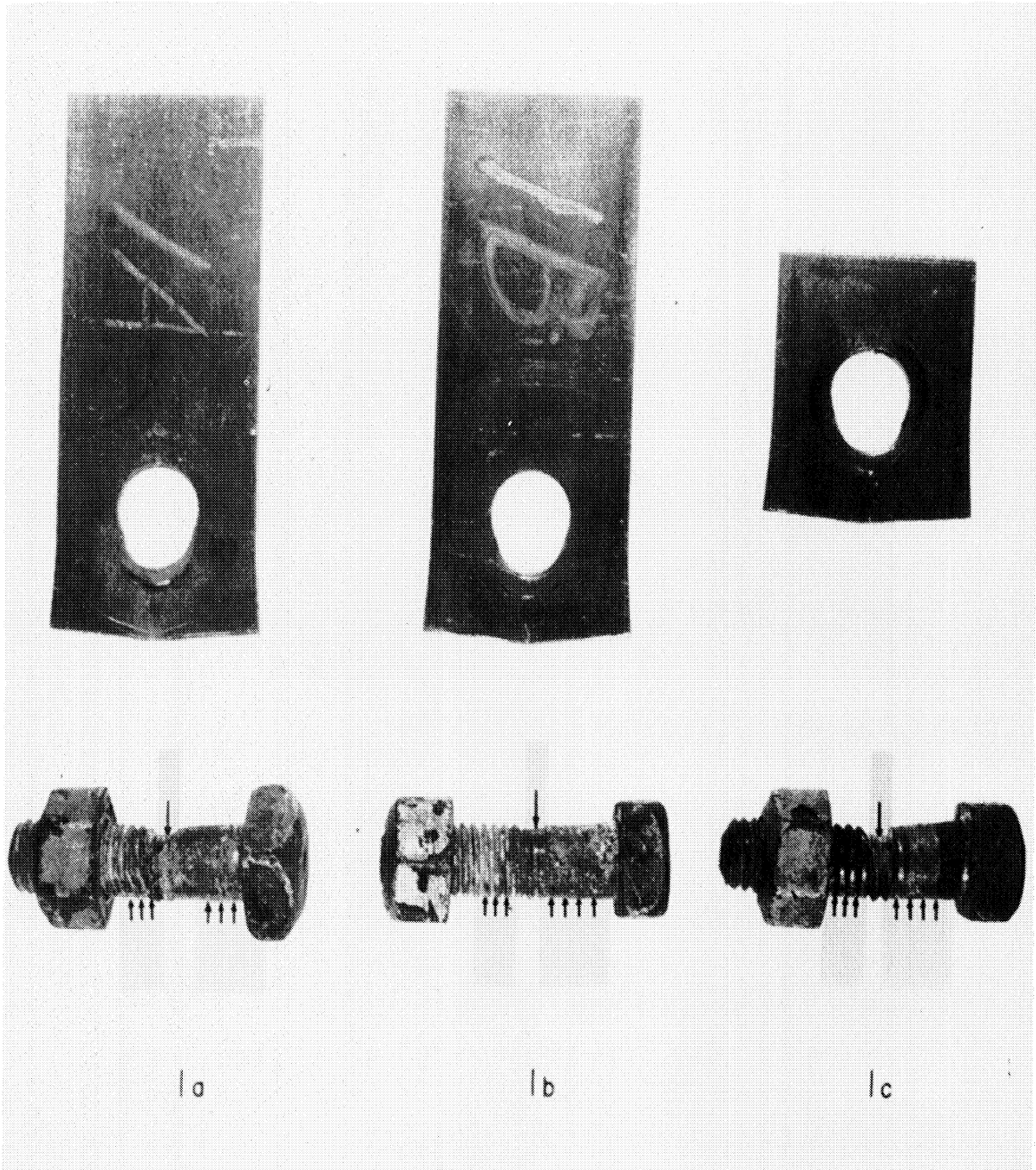


LABORATORY DATA

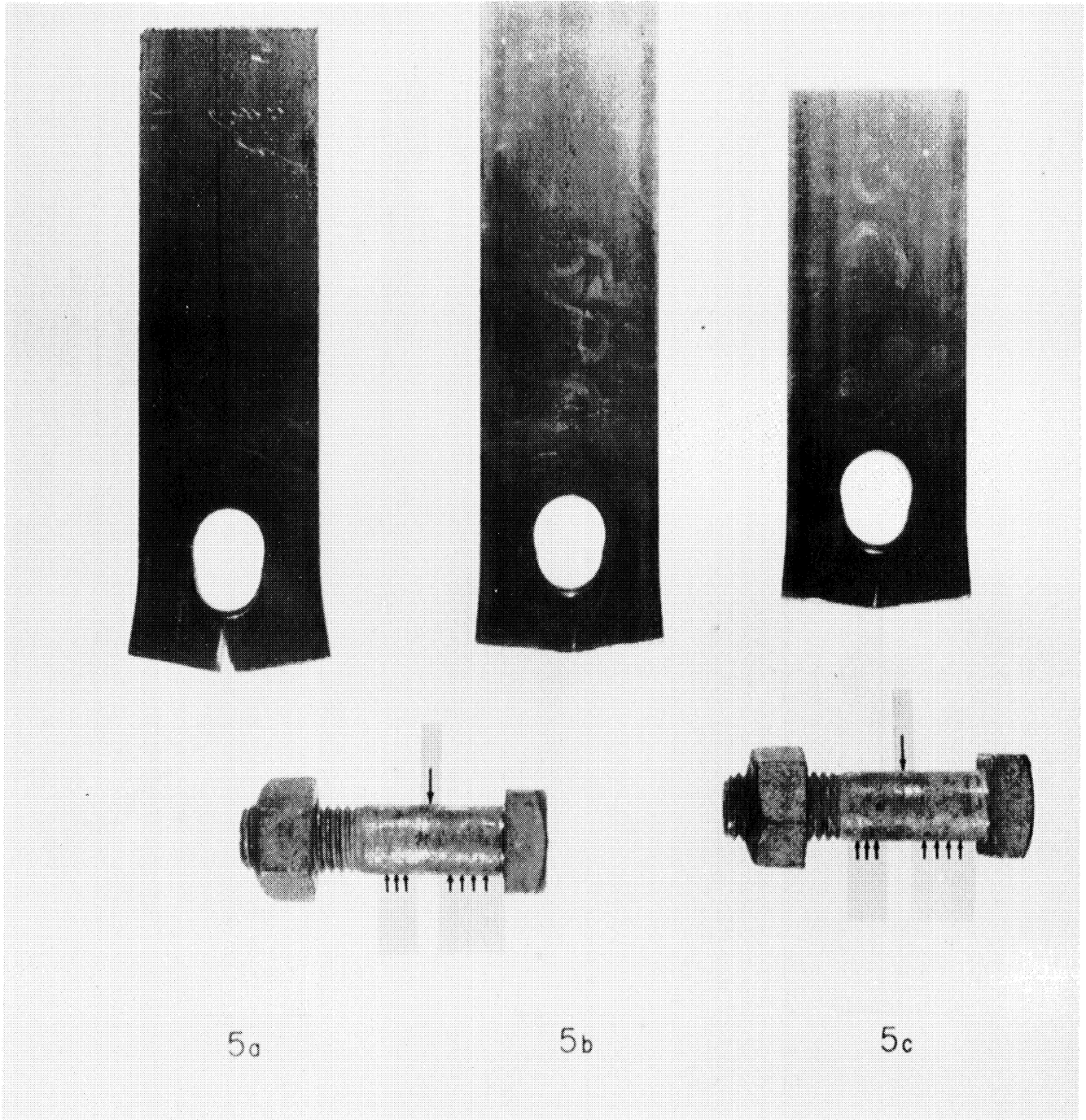
DOUBLE SHEAR BEARING TESTS

3/16-in. Test Piece - 0.188 in.  
Full-Threaded Bolts - 5/8 in. x 2 in.

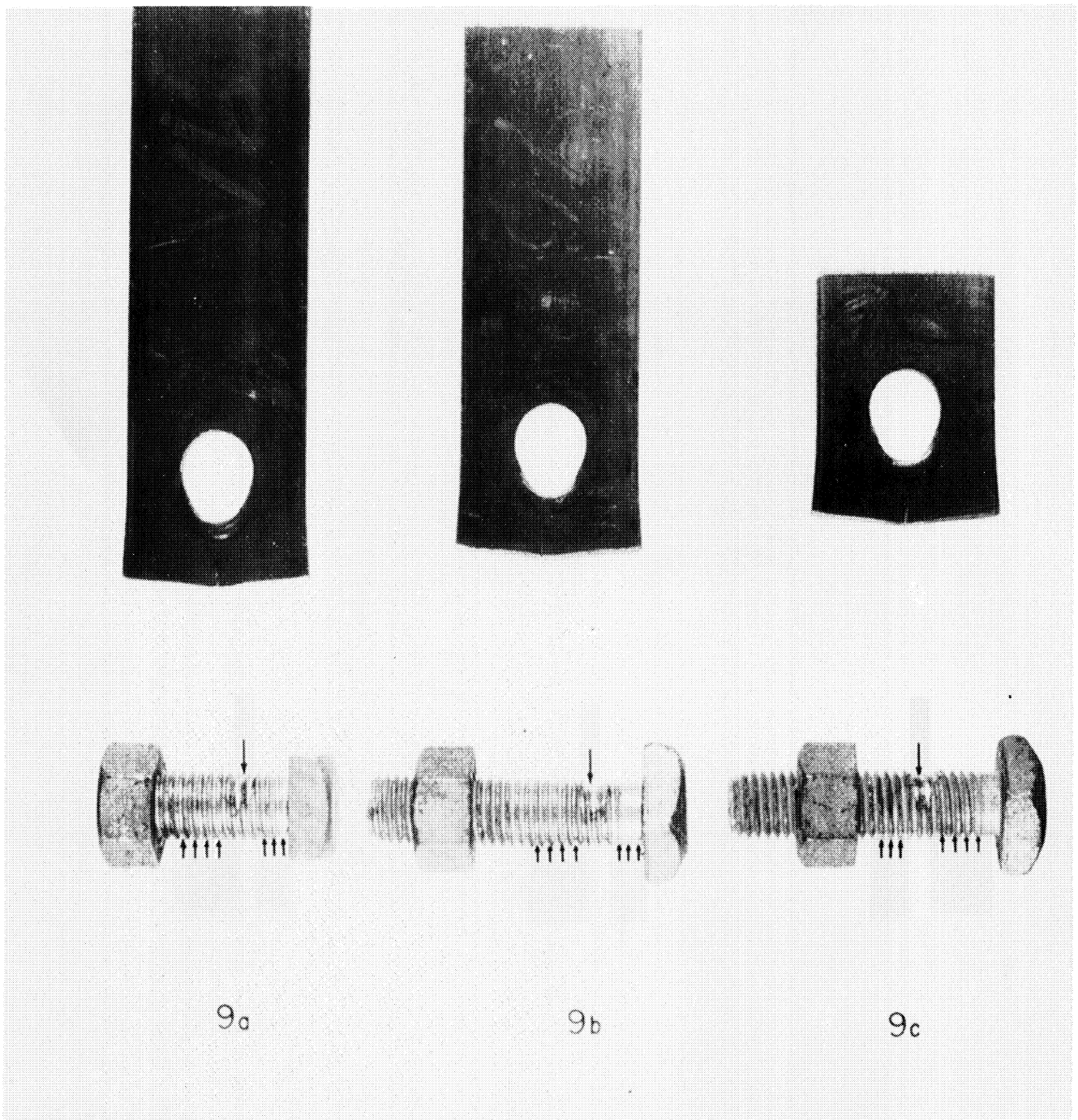
Test No.	9a	9b	9c
Date Tested	3-8-54	3-8-54	3-15-54
Full Dia.	0.615 in.	0.618 in.	0.625 in.
Root Dia.	0.520 in.	0.510 in.	0.527 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	40 x 0.001	40 x 0.001	33 x 0.001
2000	105	95	66
3000	181	139	169
4000	217	165	220
5000	245	190	245
5250			247
5500	255	200	256
5750	261	207	261
6000	267	211	267
6250	271	216	270
6500	276	221	275
6750			279
7000	284	231	283
7250			286
7500	292	240	289
7750			293
8000	300	249	297
9000	315	267	310
10000	332	285	323
11000	349	300	336
12000	368	319	351
13000	386	338	366
14000	406	361	385
14500		375	
15000	433	391	409
15500		417	
16000	485		458
Failure	16,100 lbs Dial 0.535 in. Bearing Failure	15,800 lbs Dial 0.490 in. Bearing Failure	16,200 lbs Dial 0.529 in. Bearing Failure



Double Shear Bearing Test  
Old Tower Bolts  
3/16-in. Test Piece



Double Shear Bearing Test  
New Tower Bolts  
3/16-in. Test Piece



Double Shear Bearing Test  
Full-Threaded Bolts  
3/16-in. Test Piece

LABORATORY DATA

DOUBLE SHEAR TEST

3/8-in. Test Piece - 0.373 in.  
 Old Tower Bolts - 5/8 in. x 2 in.

Test No.	2a	2b	2c
Date Tested	3-8-54	3-8-54	3-8-54
Root Dia.	0.550 in.	0.539 in.	0.527 in.
Full Dia.	0.620 in.	0.625 in.	0.613 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	50 x 0.001	49 x 0.001	72 x 0.001
2000	172	231	123
3000	216	291	193
4000	242	332	221
5000	262	363	242
6000	280	383	262
7000	295	399	279
8000	310	416	294
9000	325	431	307
10000	339	448	322
11000	354	465	336
12000	368	481	351
13000	381	497	365
14000	395	513	379
15000	410	529	394
16000	426	547	408
17000	442	566	426
18000	461	585	445
19000	481	606	468
20000	509	635	493
Failure	20,800 lbs Dial 0.580 in. Shear Failure	20,400 lbs Dial 0.673 in. Shear Failure	20,850 lbs Dial 0.545 in. Shear Failure

LABORATORY DATA

DOUBLE SHEAR TESTS

3/8-in. Test Piece - 0.373 in.  
 New Tower Bolts - 5/8 in. x 2-1/2 in.

Test No.	6a	6b	6c
Date Tested	3-8-54	3-8-54	3-8-54
Bolt Dia.	0.626 in.	0.622 in.	0.626 in.
Edge Dist.	1.0 in.	1.5 in.	1.5 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	50 x 0.001	57 x 0.001	47 x 0.001
2000	153	101	160
3000	225	124	191
3500	239		
4000	259	147	210
4500	278		
5000	290	169	228
5500	299		
5750	305		
6000	308	190	243
6250	312		
6500	316		
7000	323	207	256
7500	330		
8000	336	222	269
8500	343		
9000	349	239	280
9500	355		
10000	360	253	291
10500	367		
11000	371	267	300
11500	377		
12000	382	281	310
12500	387		
13000	392	294	320
13500	397		
14000	402	307	329
14500	406		
15000	411	320	339

(cont.)

LABORATORY DATA

DOUBLE SHEAR TESTS

3/8-in. Test Piece - 0.373 in.

New Tower Bolts - 5/8 in x 2-1/2 in.

Test No.	6a	6b	6c
Date Tested	3-8-54	3-8-54	3-8-54
Bolt Dia.	0.626 in.	0.622 in.	0.626 in.
Edge Dist.	1.0 in.	1.5 in.	1.5 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
15500	416		
16000	420	334	350
16500	426		
17000	430	350	360
17500	435		
18000	441	366	370
18500	445		
19000	450	382	380
19500	455		
20000	460	403	392
20500	467		
21000	472	422	402
21500	478		
22000	483	443	413
22500	489		
23000	496	469	424
23500	501		
24000	507		436
24500	515		
25000	523		450
25500	530		
26000	540		466
26500	550		
27000	560		485
27500	574		
28000	590		508
28500	632		
29000			539
Failure	28,500 lbs	23,900 lbs	29,600 lbs
	Dial 0.632 in.	Dial 0.512 in.	Dial 0.583 in.
	Bearing Failure	Shear Failure	Shear Failure
	Slight Shear		

LABORATORY DATA

DOUBLE SHEAR TESTS

3/8-in. Test Piece - 0.373 in.  
Full-Threaded Bolts - 5/8 in.  $\phi$

Test No.	10a	10b	10c
Date Tested	3-8-54	3-8-54	3-15-54
Full Dia.	0.618 in.	0.616 in.	0.611 in.
Root Dia.	0.525 in.	0.518 in.	0.517 in.
End Dist.	1.0 in.	1.5 in.	1.5 in.
Torque	80 ft-lbs	80 ft-lbs	80 ft-lbs

Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	54 x 0.001	113 x 0.001	208 x 0.001
2000	199	203	300
2500			319
3000	229	235	339
3500			360
4000	255	300	376
4500			390
5000	276	319	402
5500			415
6000	291	337	425
6500			435
7000	307	353	444
7500			451
8000	320	368	459
8500			468
9000	334	381	476
9500			482
10000	347	394	489
10500			495
11000	360	406	501
11500			508
12000	373	419	514
12500			519
13000	387	430	527
13500			533
14000	400	443	539
15000	415	456	553
15500			561
16000	431	470	568
16500			577
17000	447	484	583

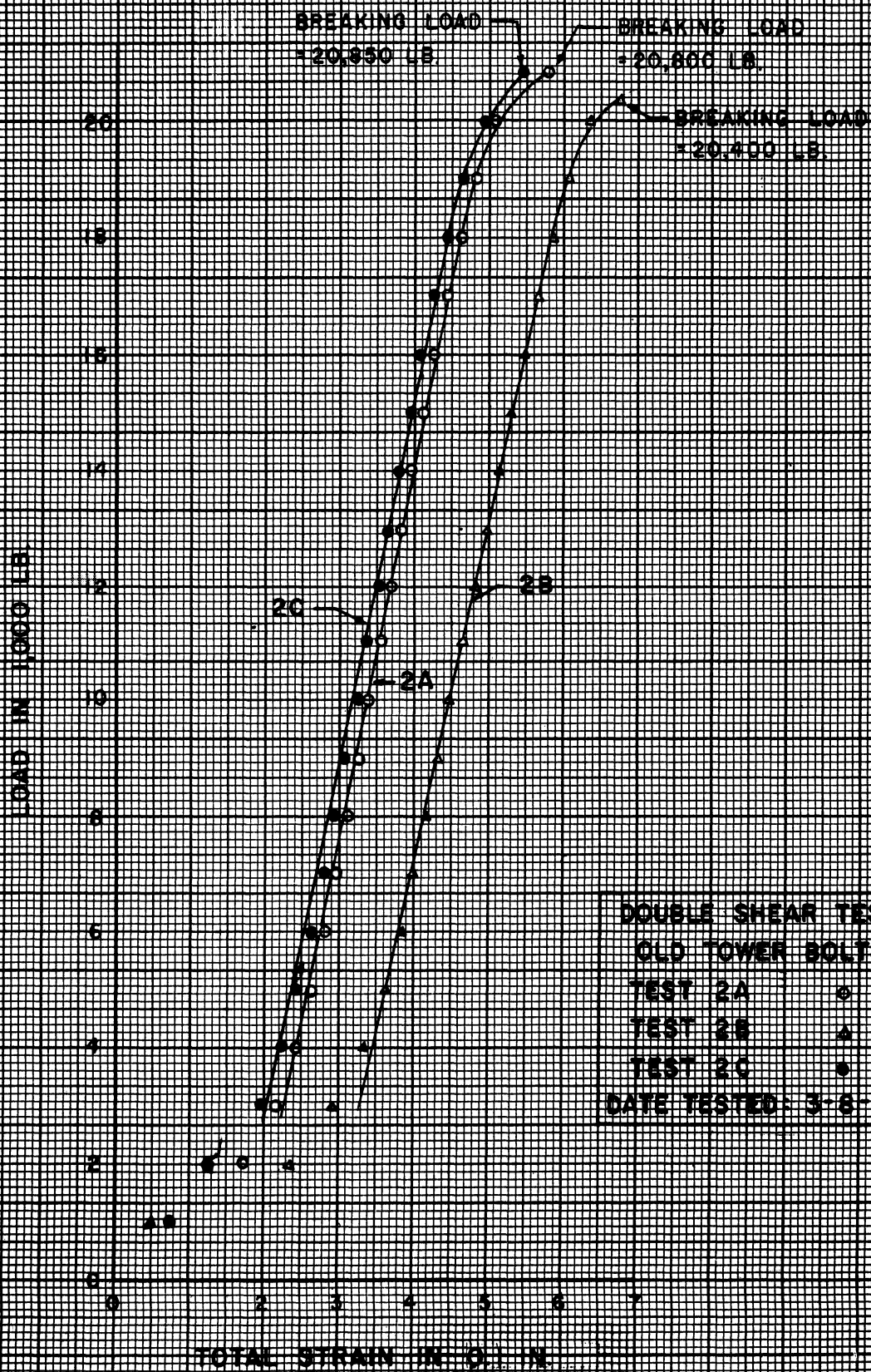


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LABORATORY DATA

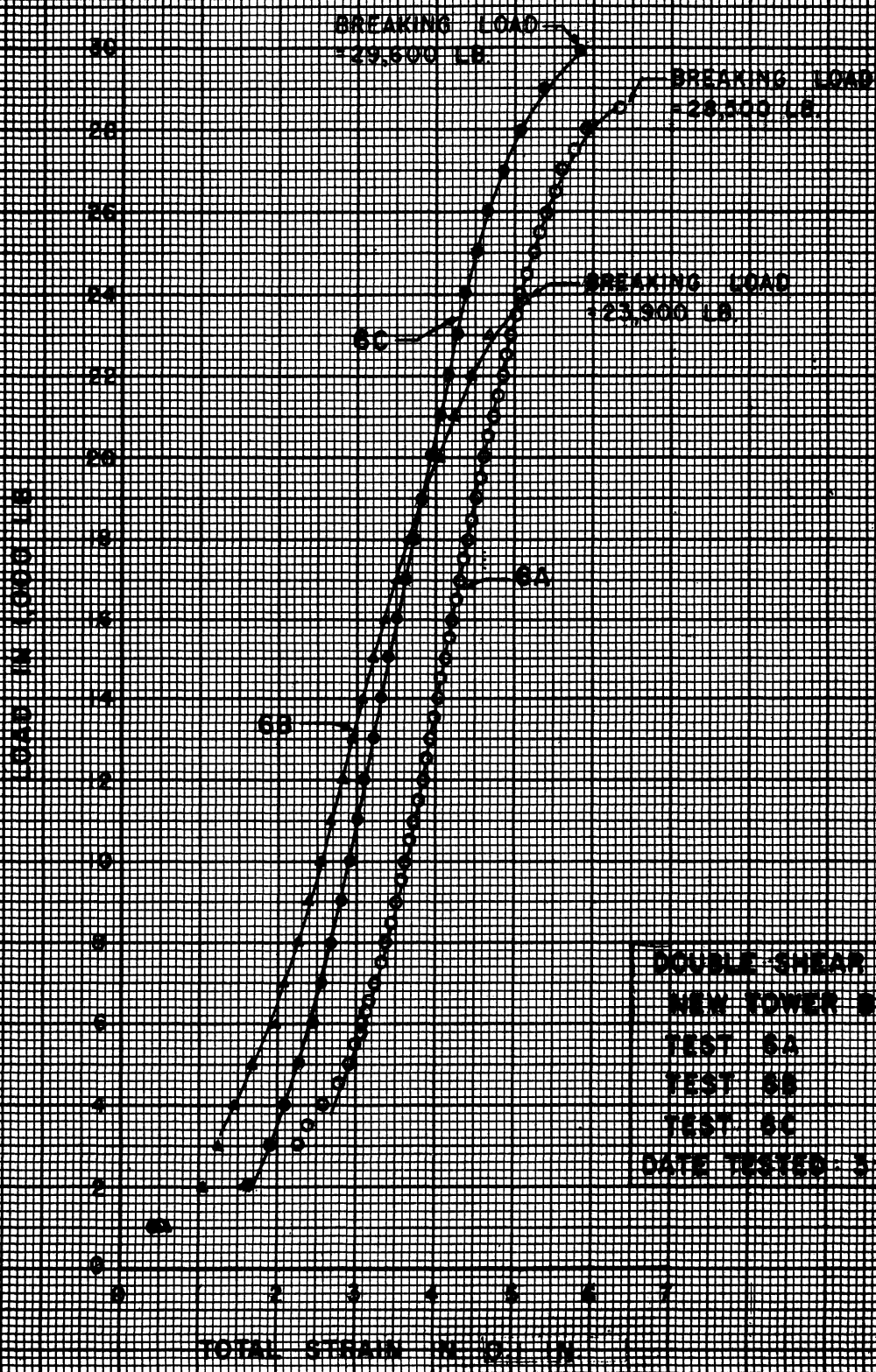
DOUBLE SHEAR TESTS

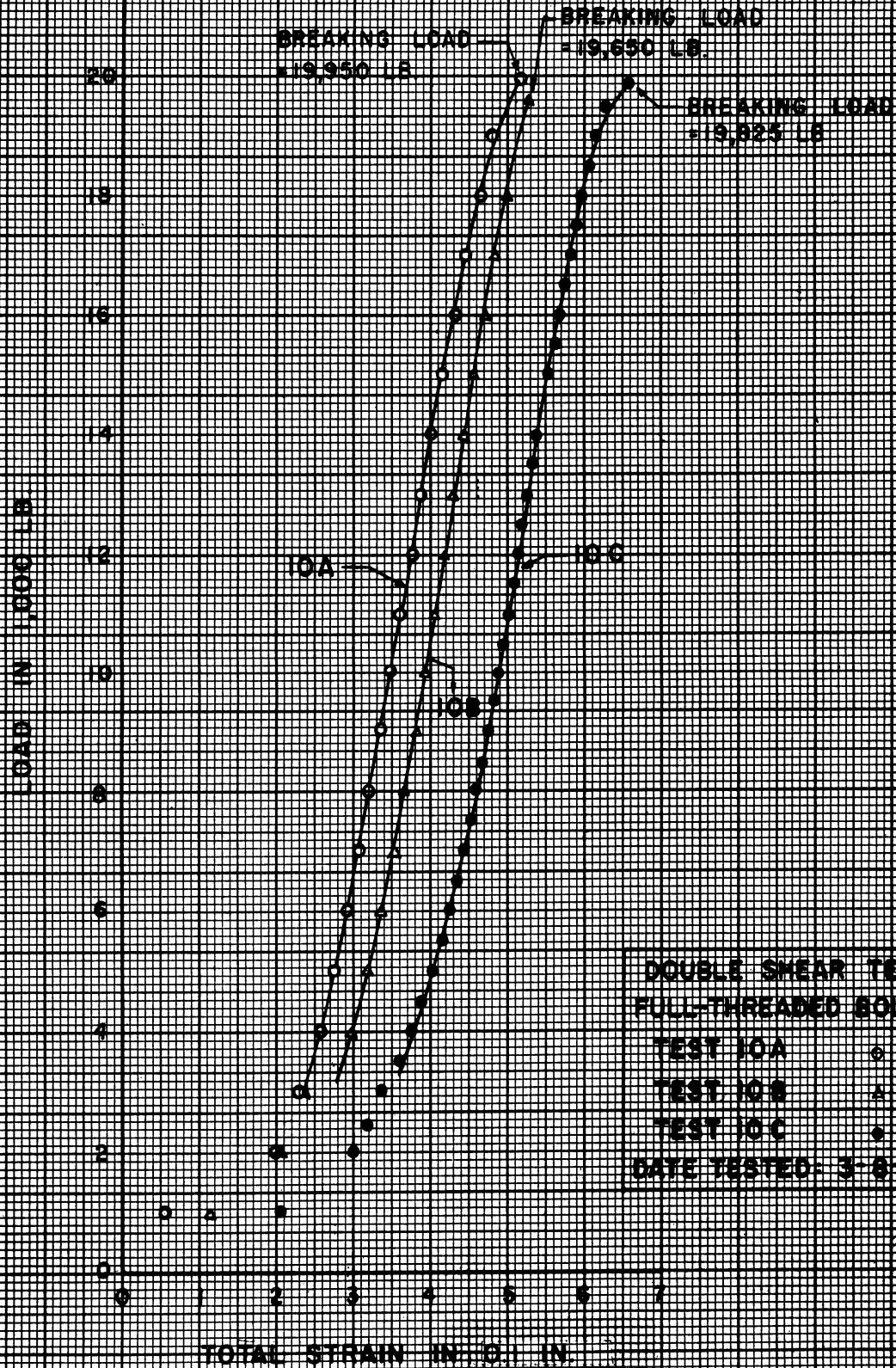
3/8-in. Test Piece - 0.373 in.  
Full-Threaded Bolts - 5/8 in.Ø

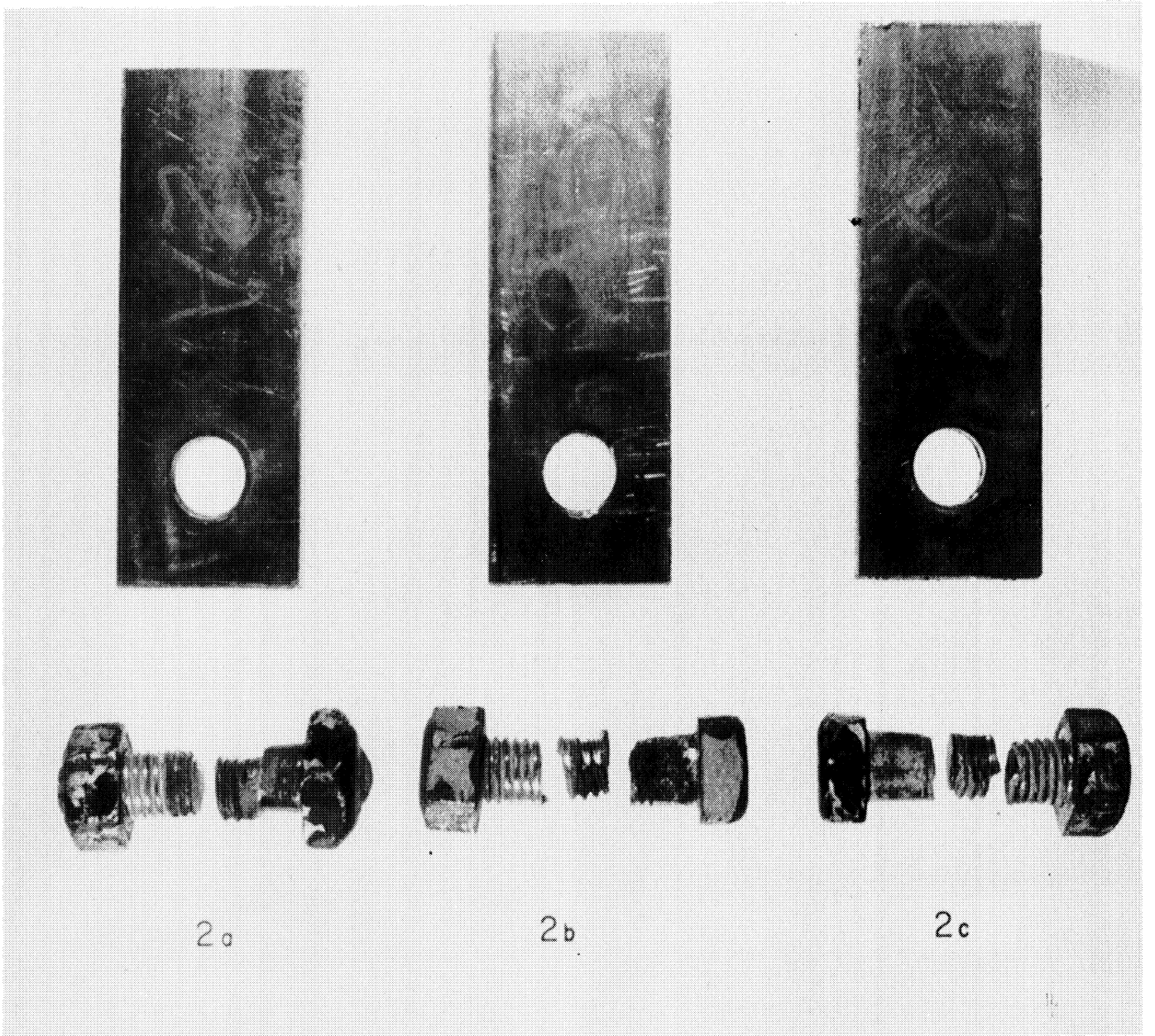
Test No.	10a	10b	10c
Date Tested	3-8-54	3-8-54	3-8-54
Full Dia.	0.618 in.	0.616 in.	0.611 in.
Root Dia.	0.525 in.	0.518 in.	0.517 in.
End Dist.	1.0 in.	1.5 in.	1.5 in.
Torque	80 ft-lbs	80 ft-lbs	80 ft-lbs
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
17500			590
18000	464	500	599
18500			607
19000	480		614
19500			628
Failure	19,950 lbs	19,650 lbs	19,825 lbs
	Dial 0.518 in.	Dial 0.524 in.	Dial 0.658 in.
	Shear Failure	Shear Failure	Shear Failure



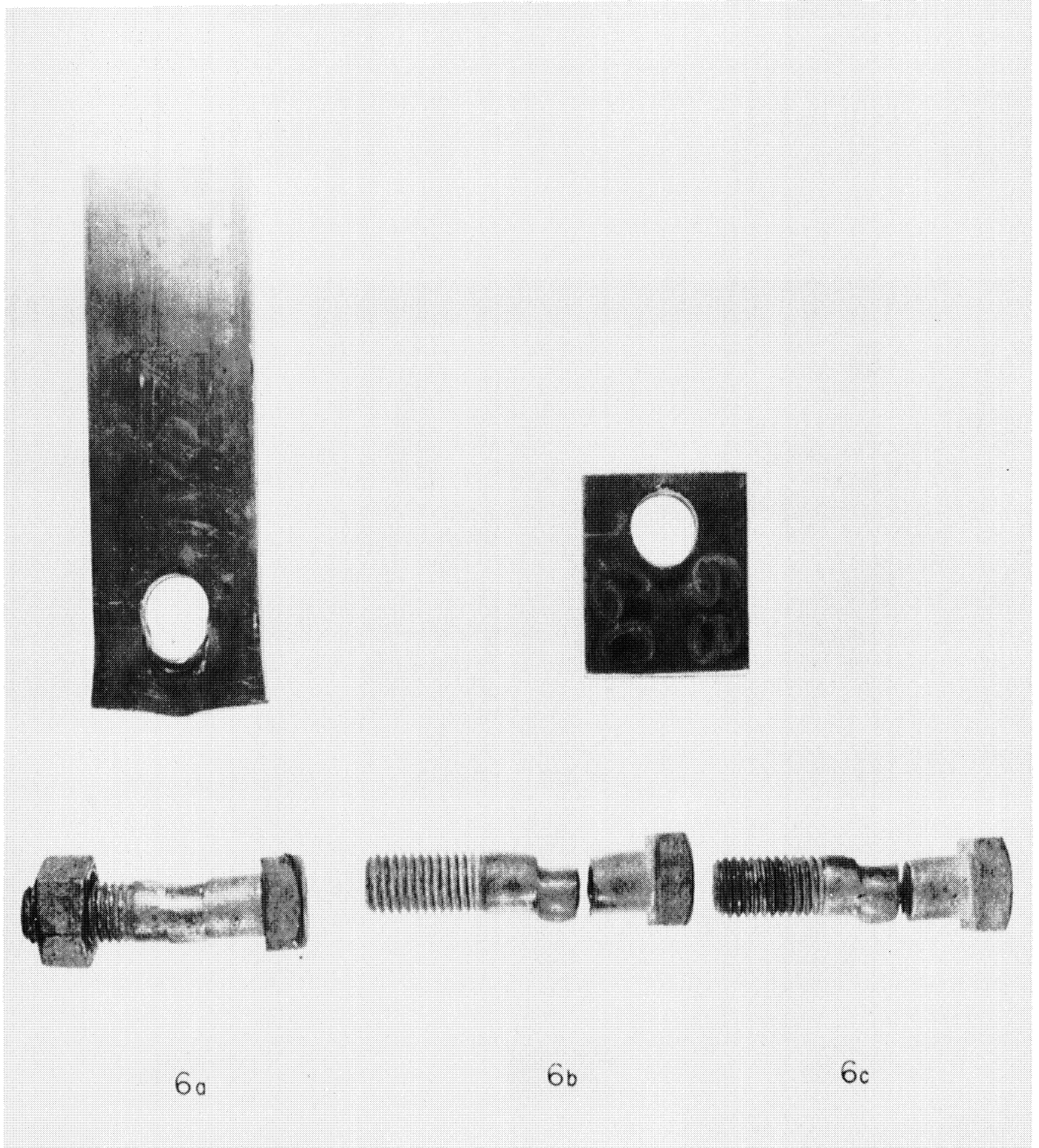
DOUBLE SHEAR TEST  
 OLD TOWER BOLTS  
 TEST 2A    ◯  
 TEST 2B    ▲  
 TEST 2C    ◆  
 DATE TESTED: 3-8-54



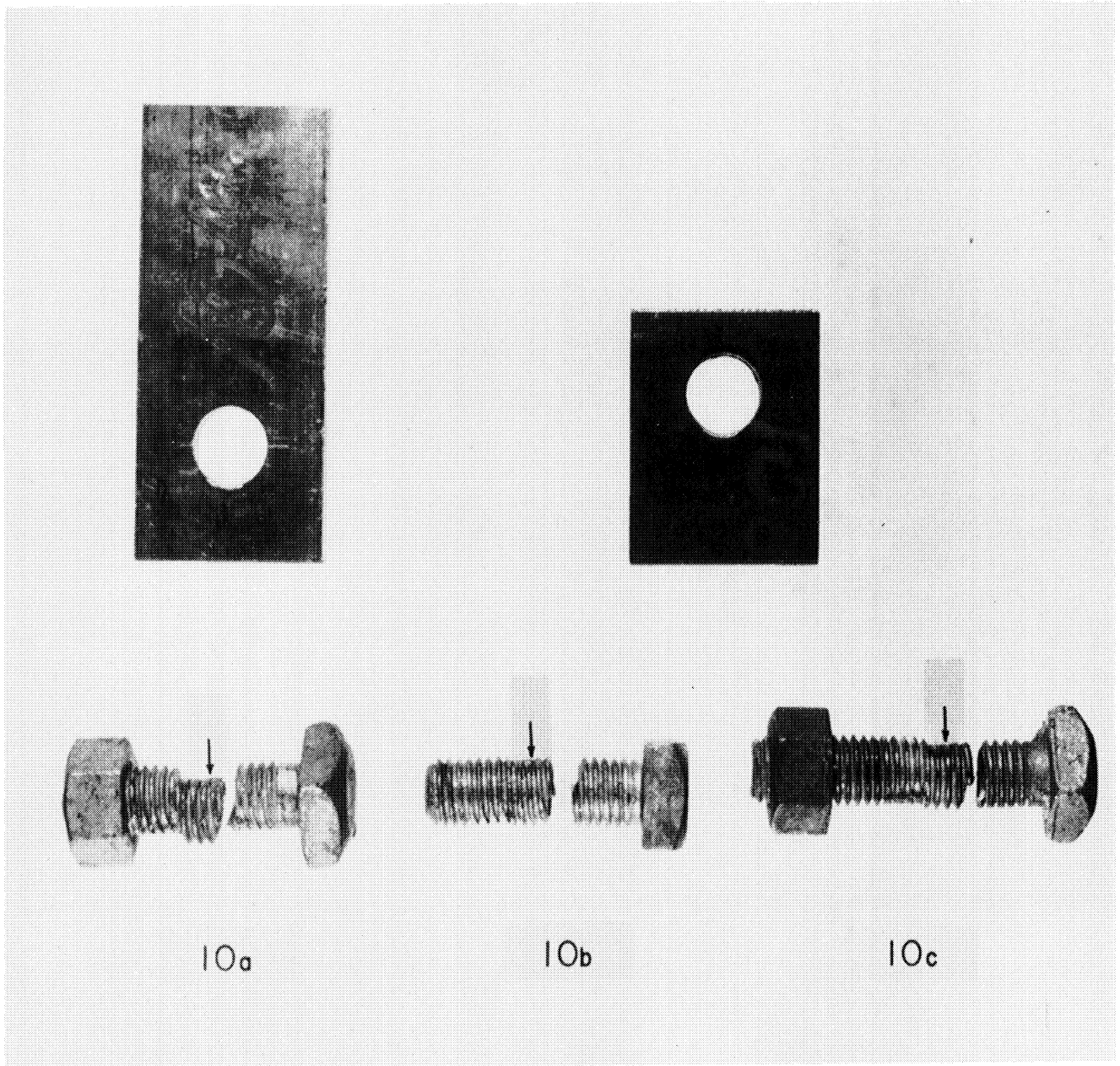




Double Shear Test  
Old Tower Bolts  
3/8-in. Test Piece



Double Shear Test  
New Tower Bolts  
3/8-in. Test Piece



Double Shear Test  
Full-Threaded Bolts  
3/8-in. Test Piece  
36

LABORATORY DATA

SINGLE SHEAR BEARING TEST

3/16-in. Test Piece - 0.188 in.  
 Old Tower Bolts - 5/8 in. x 1-1/2 in.

Test No.	3a	3b	3c	3d
Date Tested	3-8-54	3-8-54	3-8-54	3-15-54
Root Dia.	0.534 in.	0.527 in.	0.535 in.	0.536 in.
Full Dia.	0.624 in.	0.615 in.	0.621 in.	0.622 in.
Torque	100 ft-lbs	100 ft-lbs	40 ft-lbs	100 ft-lbs
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	90 x 0.001	97 x 0.001	69 x 0.001	98 x 0.001
2000	129	232	83	141
2500	144	251	87	157
3000	156	264	91	170
3500	166	276	95	182
4000	179	288	100	196
4500	189	299	104	209
5000	197	310	109	222
5500	207	322	114	236
6000	216	334	119	249
6500	227	347	128	261
7000	238	359	135	276
7500	249	372	143	289
8000	259	382	153	304
8500	269	395	161	320
9000	279	409	174	338
9500	290	421	186	360
10000	301	439	205	
10500	313	458		
11000	325	485		
11500	339			
12000	358			
12500	377			
13000	405			
Failure	13,450 lbs Dial 0.455 in. Shear Failure Across Shank	11,050 lbs Dial 0.500 in. Shear Failure	10,300 lbs Dial 0.240 in. Shear Failure	9,760 lbs Dial 0.420 in. Shear Failure



LABORATORY DATA

SINGLE SHEAR BEARING TEST

3/16-in. Test Piece - 0.188 in.  
 New Tower Bolts - 5/8 in. x 1-3/4 in.

Test No.	7a	7b	7c	7d
Date Tested	3-8-54	3-8-54	3-8-54	3-15-54
Bolt Dia.	0.626 in.	0.625 in.	0.626 in.	0.619 in.
End Dist.	1.0 in.	1.0 in.	1.0 in.	1.0 in.
Torque	100 ft-lbs	100 ft-lbs	100 ft-lbs	100 ft-lbs
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	37 x 0.001	87 x 0.001	18 x 0.001	25 x 0.001
2000	73	126	48	37
2500	92	140	104	101
3000	106	152	110	110
3500	117	162	117	119
4000	129	175	127	127
4500	139	186	135	136
5000	149	195	143	142
5500	159	207	150	149
6000	169	216	159	155
6500	180	227	168	162
7000	191	237	177	169
7500	203	248	188	177
8000	216	259	198	185
8500	231	272	210	192
9000	248	286	224	200
9500	268	300	240	209
10000	293	318	262	218
10500	325	340	293	230
11000		366		242
11500		407		254
12000				273
12500				287
13000				318
Failure	10,800 lbs Dial 0.372 in. Shear Failure	11,500 lbs Dial 0.425 in. Shear Failure	10,850 lbs Dial 0.340 in. Shear Failure	13,050 lbs Dial 0.335 in. Shear Failure

LABORATORY DATA

SINGLE SHEAR BEARING TESTS

3/16-in. Test Piece - 0.188 in.  
Full-Threaded Bolts - 5/8 in. x 1-3/4 in.

Test No.	12a	12b	12c	12d
Date Tested	3-8-54	3-8-54	3-8-54	3-15-54
Full Dia.	0.619 in.	0.621 in.	0.620 in.	0.633 in.
Root Dia.	0.526 in.	0.524 in.	0.523 in.	0.533 in.
End Dist.	1.0 in	1.0 in	1.0 in.	1.0 in.
Torque	100 ft-lbs	100 ft-lbs	100 ft-lbs	100 ft-lbs

Load, lbs    Dial Reading, in.    Dial Reading, in.    Dial Reading, in.    Dial Reading, in.

1000	64 x 0.001	23 x 0.001	75 x 0.001	8 x 0.001
2000	102	52	111	70
2500	116	60	126	82
3000	129	67	139	92
3500	141	75	151	102
4000	153	82	163	116
4500	163	90	173	123
5000	174	96	183	133
5500	184	103	193	142
6000	194	110	202	150
6500	205	118	214	158
7000	213	125	224	168
7500	223	134	235	178
8000	233	143	245	188
8500	243	153	256	199
9000	255	164	269	210
9500	268	173	285	222
10000	285	184		237
10500		198		
11000		219		

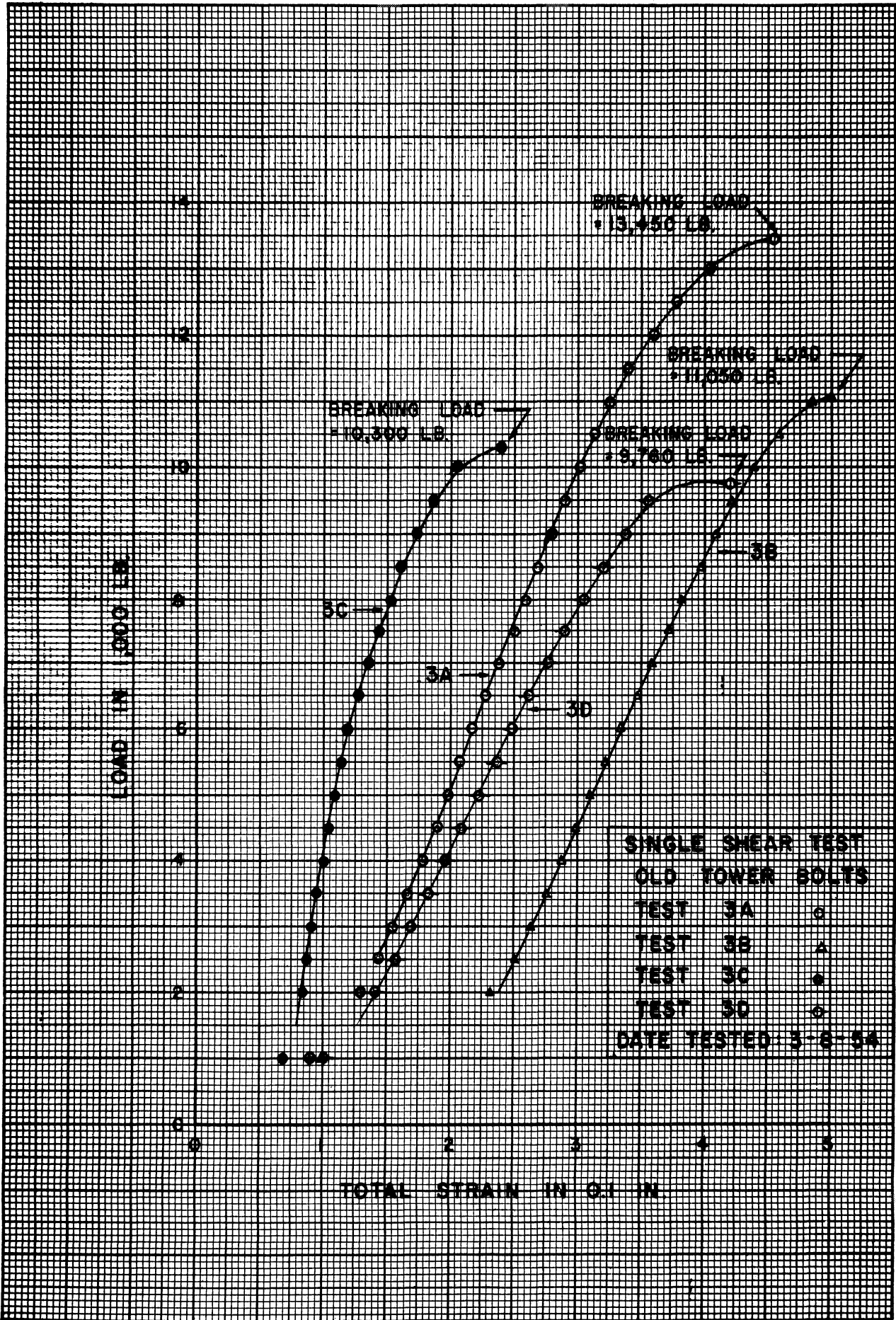
Failure	10,250 lbs	11,000 lbs	9,800	10,200 lbs
	Dial 0.307 in.	Dial 0.227 in.	Dial 0.314 in.	Dial 0.258 in.
	Shear Failure	Shear Failure	Shear Failure	Shear Failure

LABORATORY DATA

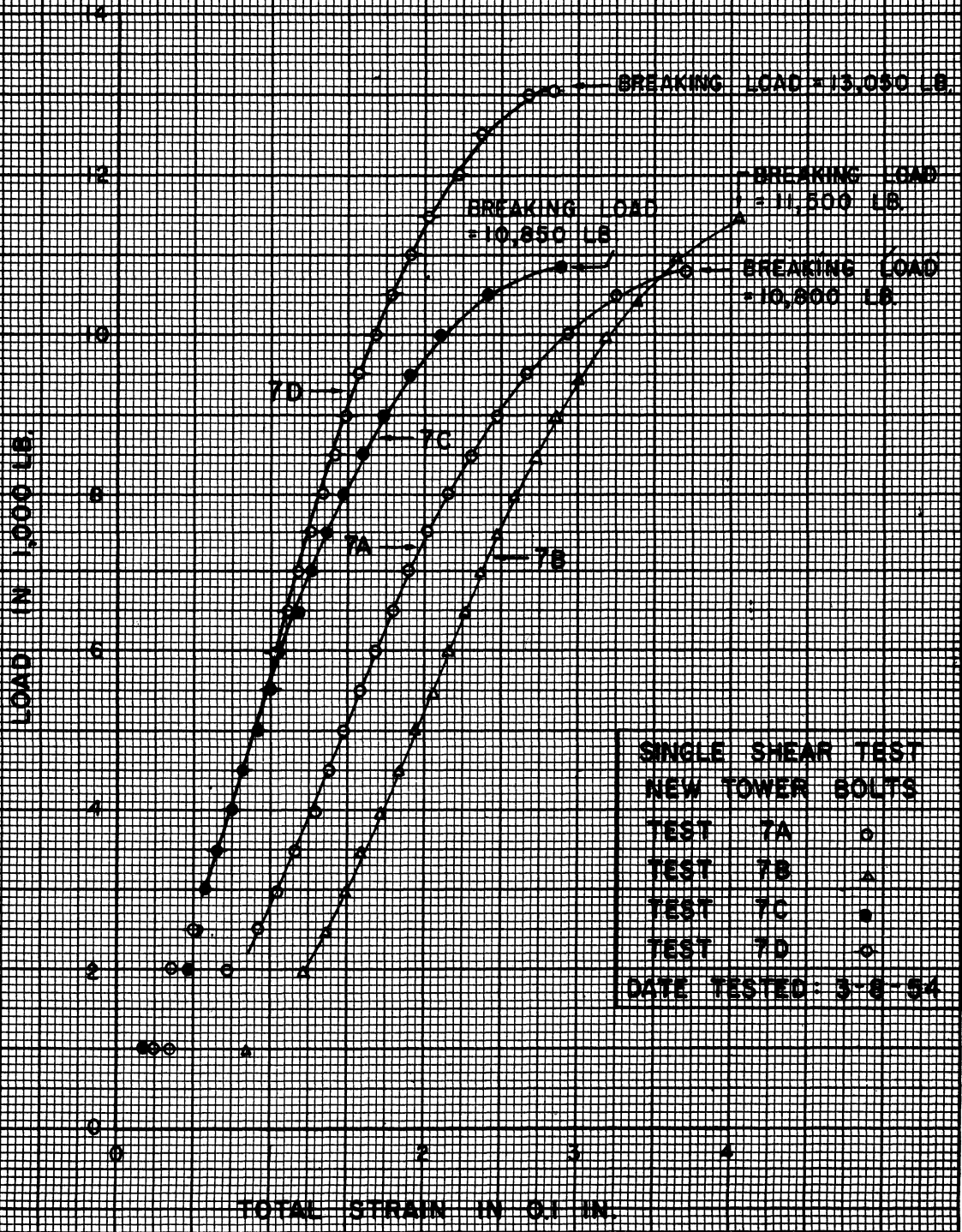
SINGLE SHEAR BEARING TESTS

2 in. x 2 in. x 3/16 in. Structural Steel Angle Test Piece

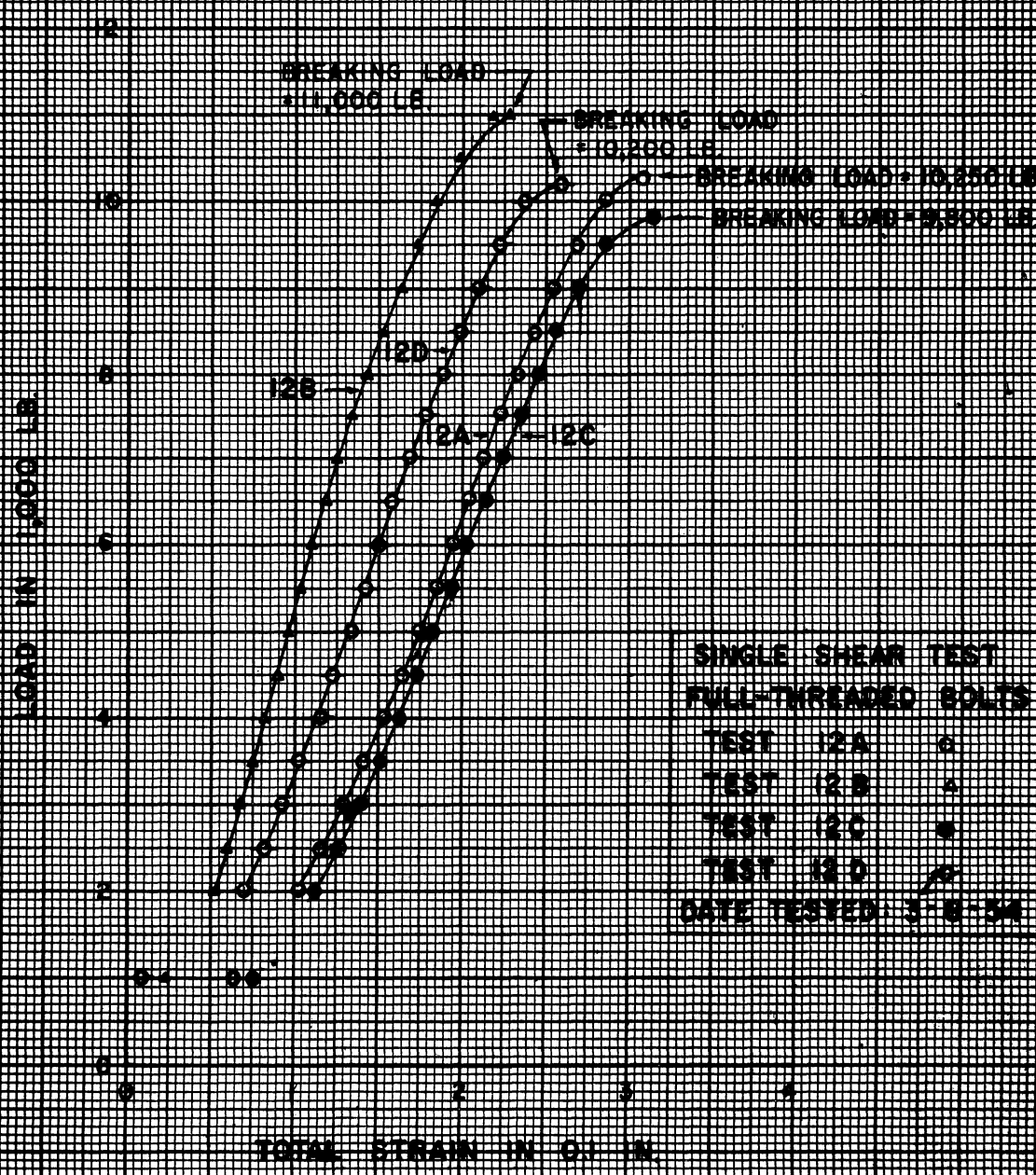
Test No.	13a	14a	15a
Date Tested	4-5-54	4-5-54	4-5-54
Bolt	OTB-5/8"x2"	NTB-5/8"x1-1/2"	FTB-5/8"x1-3/4"
Full Dia.	0.625 in.	0.624 in.	0.622 in.
Root Dia.	0.527 in.	0.526 in.	0.523 in.
Angle Thick.	0.185 in.	0.183 in.	0.190 in.
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	129 x 0.001	250 x 0.001	122 x 0.001
2000	178	300	175
2500	196	317	192
3000	210	331	207
3500	223	345	219
4000	239	359	234
4500	252	372	245
5000	277	383	256
5500	296	396	267
6000	314	409	279
6500	334	423	290
7000	356	440	304
7500	383	459	319
8000	415	479	338
8500	450	503	359
9000	493	530	387
9500	557	567	416
10000		621	452
10500		700	491
11000			547
11500			620
Failure	9,650 lbs Dial 0.622 in. Shear Failure	10,810 lbs Dial 0.850 in. Bearing Failure	11,800 lbs Dial 0.714 in. Shear Failure Plus Bearing Failure



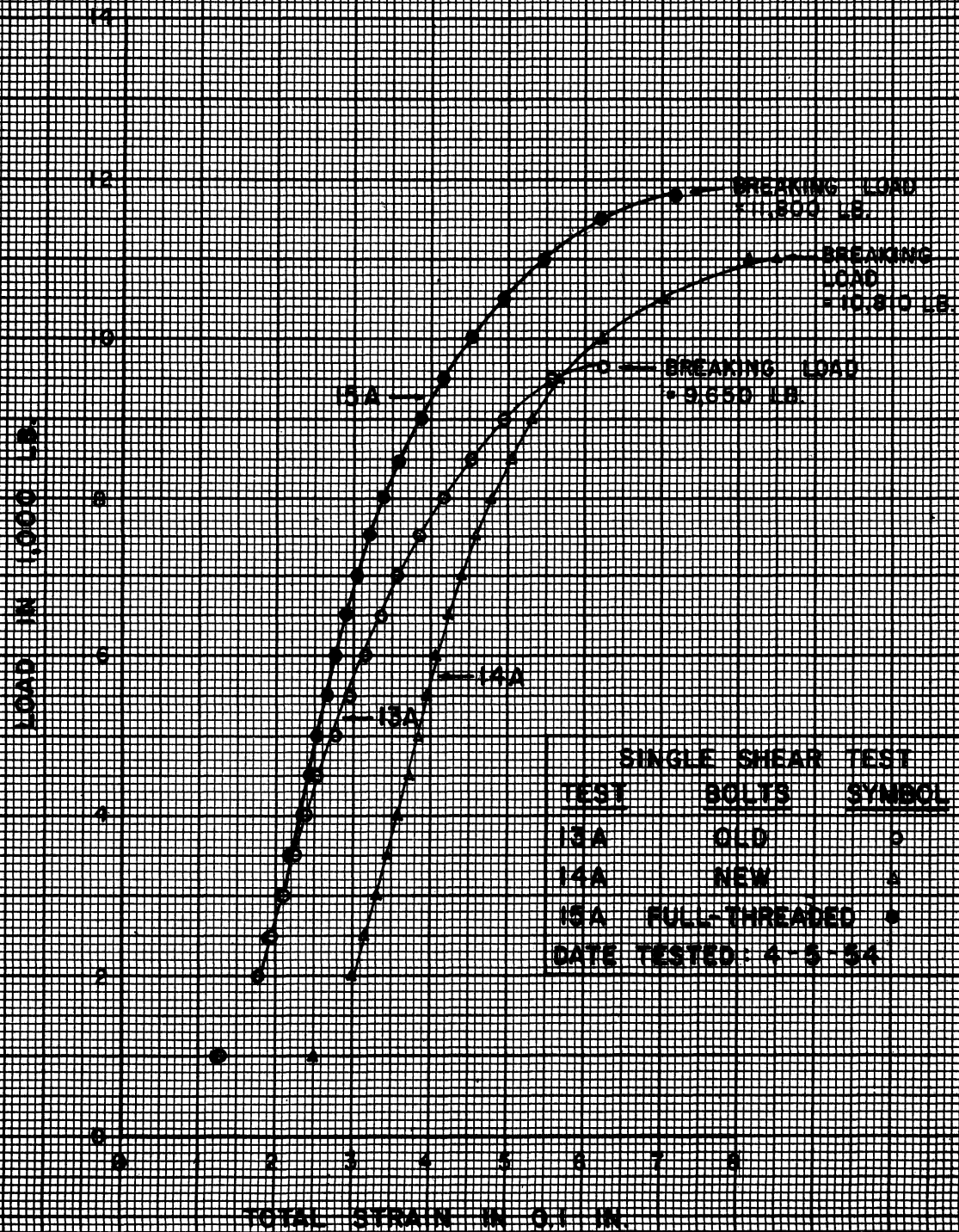
SINGLE SHEAR TEST  
 OLD TOWER BOLTS  
 TEST 3A ○  
 TEST 3B ▲  
 TEST 3C ●  
 TEST 3D ◊  
 DATE TESTED 3-8-54



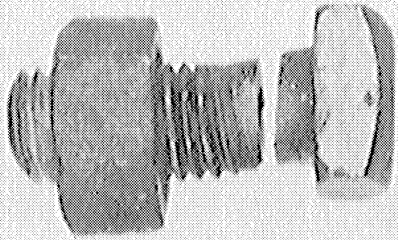
SINGLE SHEAR TEST  
 NEW TOWER BOLTS  
 TEST 7A ○  
 TEST 7B ▲  
 TEST 7C ●  
 TEST 7D ◊  
 DATE TESTED: 3-8-54



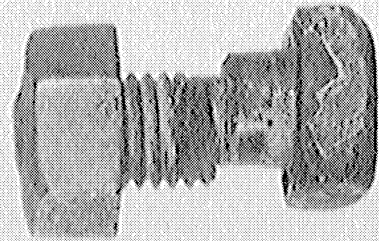
SINGLE SHEAR TEST  
 FULL-THREADED BOLTS  
 TEST 12A ○  
 TEST 12B ▲  
 TEST 12C ■  
 TEST 12D ◆  
 DATE TESTED 3-8-34



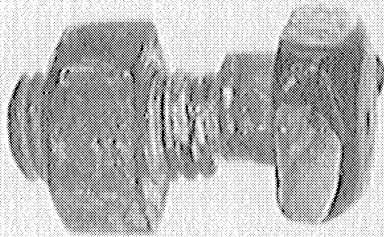
SINGLE SHEAR TEST		
TEST	BOLTS	SYMBOL
13A	OLD	○
14A	NEW	▲
15A	FULL-THREADED	●
DATE TESTED: 4-5-34		



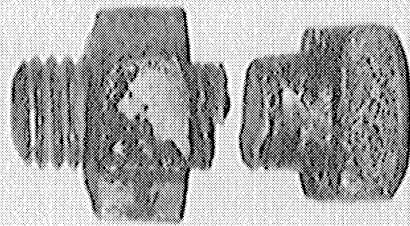
3a



3b



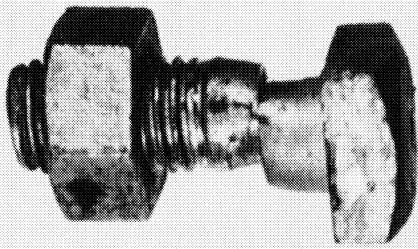
3c



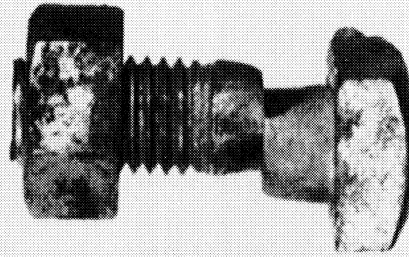
3d

Single Shear Bearing Test  
Old Tower Bolts  
3/16-in. Test Piece

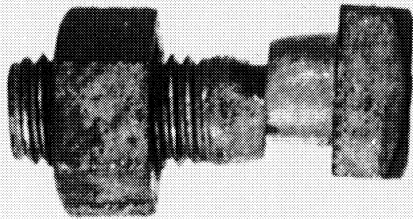




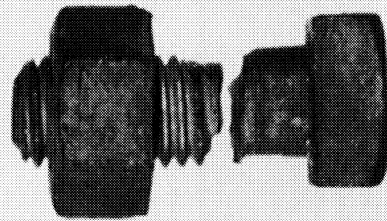
7a



7b

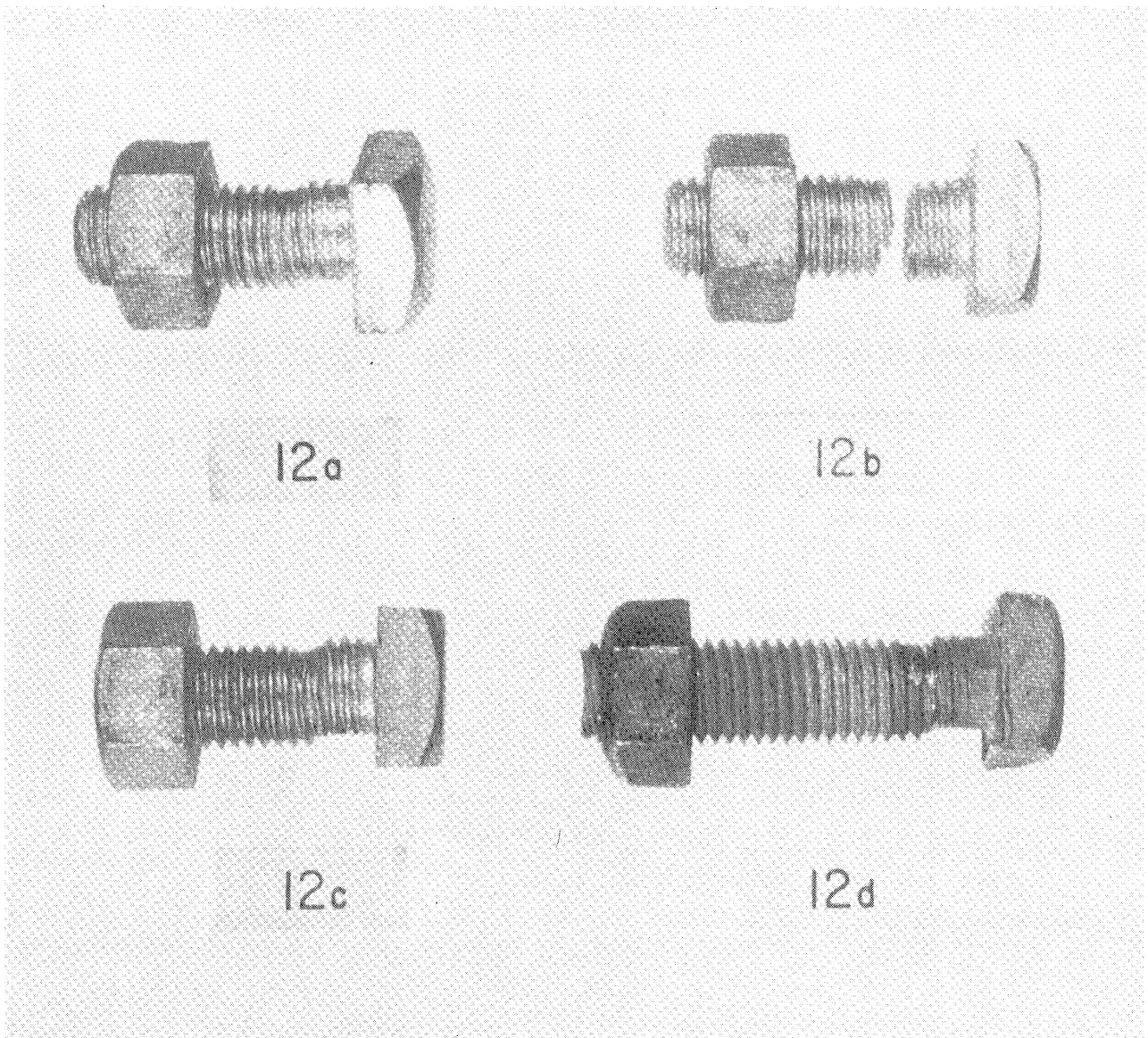


7c

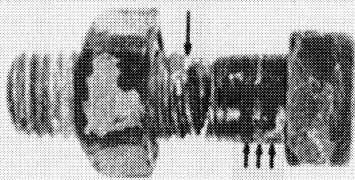
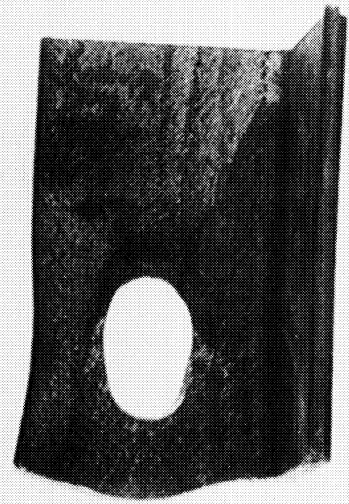
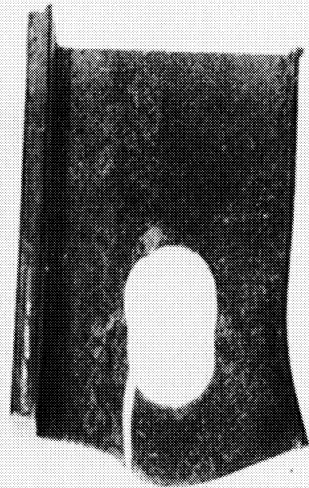
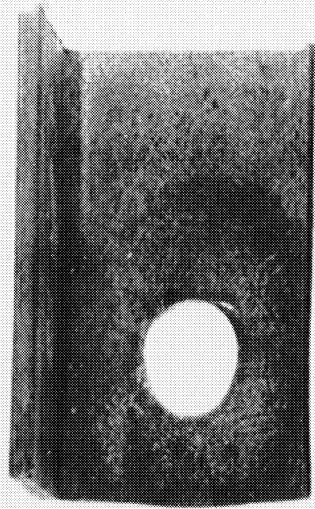


7d

Single Shear Bearing Tests  
New Tower Bolts  
3/16-in. Test Piece

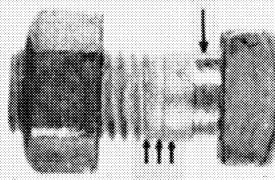


Single Shear Bearing Test  
Full-Threaded Bolts  
3/16-in. Test Piece



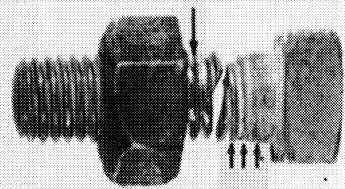
13a

Old Tower Bolts



14a

New Tower Bolts



15a

Full Threaded Bolts

Single Shear Bearing Test  
3/16-in. Test Piece

LABORATORY DATA

SINGLE SHEAR TEST

3/8-in. Test Piece - 0.373 in.  
 Old Tower Bolts - 5/8 in. x 1-1/2 in.

Test No.	4a	4b	4c
Date Tested	3-8-54	3-8-54	3-8-54
Root Dia.	0.524 in.	0.520 in.	0.525 in.
Full Dia.	0.620 in.	0.617 in.	0.622 in.
Torque	100 ft-lbs	100 ft-lbs	100 ft-lbs
Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	165 x 0.001	55 x 0.001	8 x 0.001
2000	218	236	77
2500	233	250	88
3000	247	263	97
3500	259	274	105
4000	269	286	115
4500	281	300	129
5000	291	313	138
5500	301	326	148
6000	313	339	159
6500	326	355	170
7000	340	371	184
7500	355	389	198
8000	373	406	213
8500	390	424	233
9000	414	449	
Failure	9,050 lbs Dial 0.432 in. Shear Failure	9,000 lbs Dial 0.461 in. Shear Failure	8,950 lbs Dial 0.275 in. Shear Failure

LABORATORY DATA

SINGLE SHEAR TEST

3/8-in. Test Piece - 0.373 in.  
 New Tower Bolts - 5/8 in. x 2 in.

Test No.	8a	8b	8c
Date Tested	3-8-54	3-8-54	3-8-54
Bolt Dia.	0.625 in.	0.625 in.	0.625 in.
End Dist.	1.0 in.	1.0 in.	1.0 in.
Torque	100 ft-lbs	100 ft-lbs	100 ft-lbs

Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	45 x 0.001	21 x 0.001	50 x 0.001
2000	75	39	96
2500	90	44	110
3000	102	50	120
3500	110	57	132
4000	119	65	144
4500	128	72	151
5000	136	78	158
5500	143	85	165
6000	150	91	172
6500	158	97	178
7000	167	103	184
7500	175	109	190
8000	184	115	195
8500	192	122	202
9000	199	129	209
9500	207	137	215
10000	216	146	222
10500	225	156	230
11000	234	168	238
11500	244	180	245
12000	257	200	253
12500	269	219	261
13000	285		272
13500	302		283
14000	327		297
14500			316
15000			342
Failure	14,150 lbs Dial 0.352 in. Shear Failure	12,900 lbs Dial 0.257 in. Shear Failure	15,100 lbs Dial 0.360 in. Shear Failure

LABORATORY DATA

SINGLE SHEAR TESTS

3/8-in. Test Piece - 0.373 in.  
Full-Threaded Bolts - 5/8 in. x 2 in.

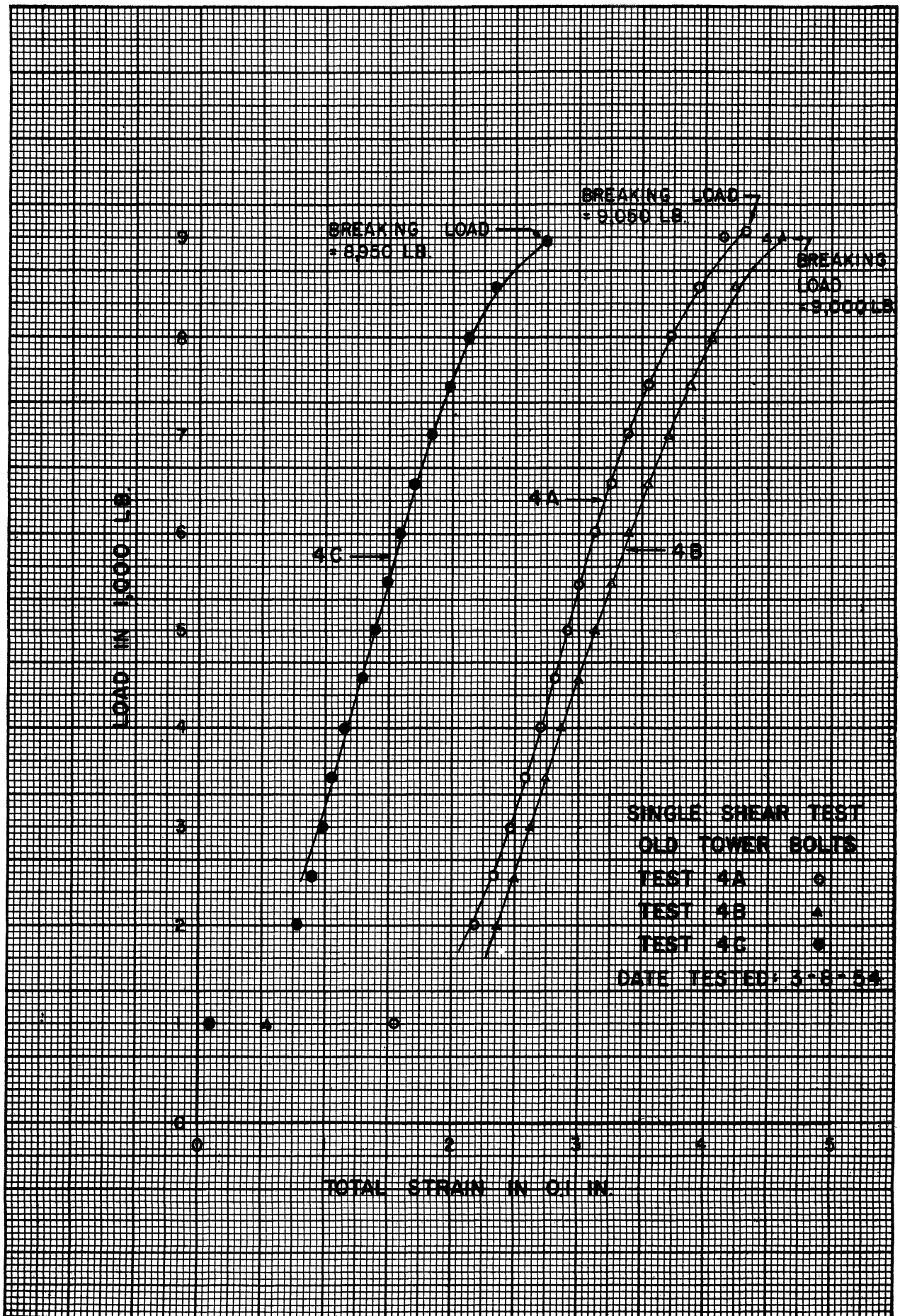
Test No.	11a	11b	11c
Date Tested	3-8-54	3-8-54	3-8-54
Full Dia.	0.615 in.	0.623 in.	0.605 in.
Root Dia.	0.519 in.	0.525 in.	0.523 in.
End Dist.	1.0 in.	1.0 in.	1.0 in.
Torque	100 ft-lbs	100 ft-lbs	100 ft-lbs

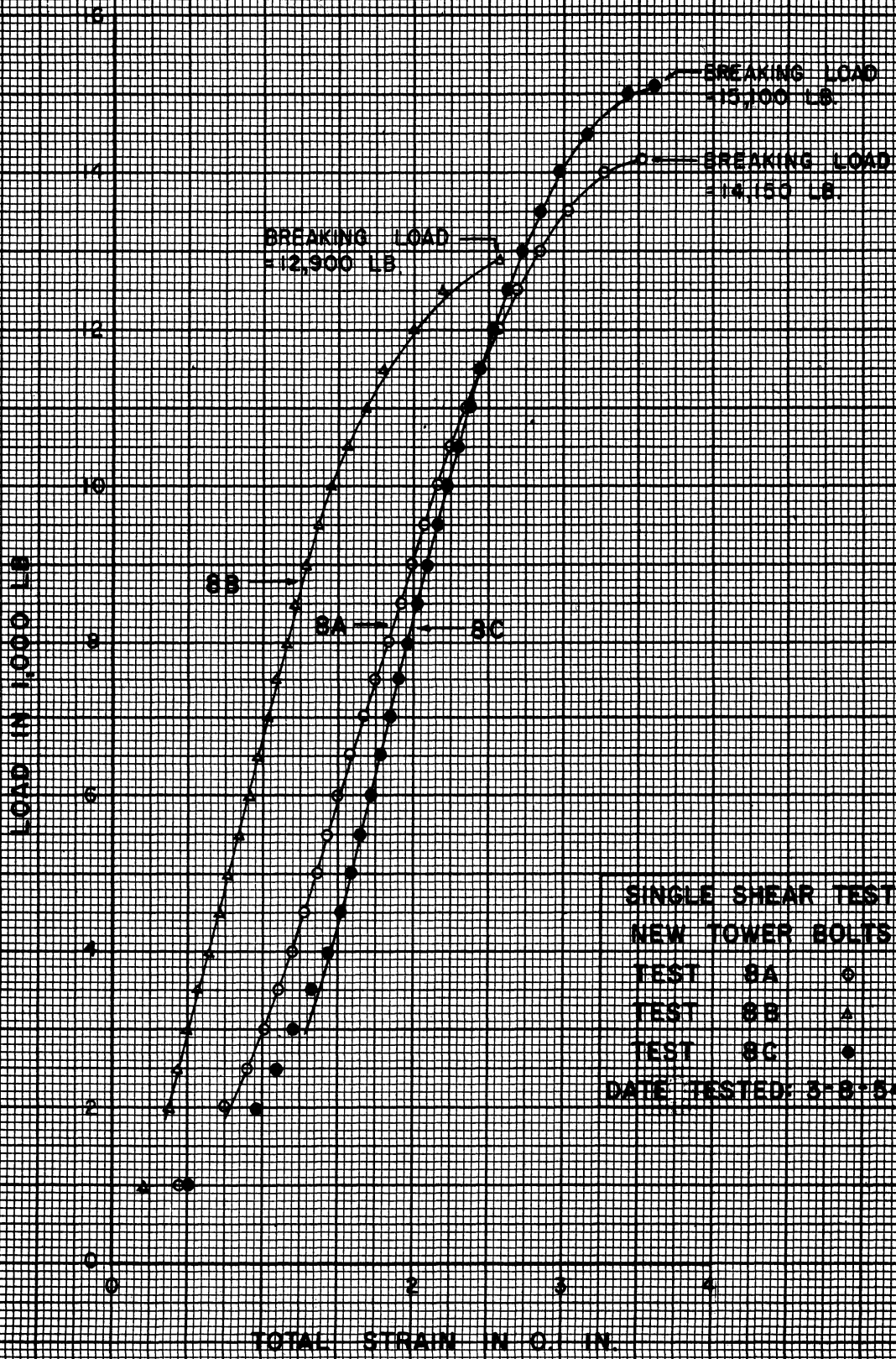
  

Load, lbs	Dial Reading, in.	Dial Reading, in.	Dial Reading, in.
1000	47 x 0.001	45 x 0.001	58 x 0.001
2000	82	91	190
2500	99	104	199
3000	111	115	206
3500	121	128	212
4000	134	140	219
4500	145	151	227
5000	154	164	232
5500	164	176	239
6000	174	188	247
6500	185	200	255
7000	195	211	263
7500	206	224	272
8000	216	237	280
8500	227	254	291
9000	238	278	301
9500	251		312
10000	272		330

Failure	10,000 lbs	9,100 lbs	10,000 lbs
	Dial 0.280 in.	Dial 0.311 in.	Dial 0.340 in.
	Shear Failure	Shear Failure	Shear Failure





SINGLE SHEAR TEST  
 NEW TOWER BOLTS  
 TEST 8A ○  
 TEST 8B ▲  
 TEST 8C ●  
 DATE TESTED: 3-8-54

BREAKING LOAD  
 = 12,900 LB

BREAKING LOAD  
 = 15,100 LB

BREAKING LOAD  
 = 14,150 LB

8B

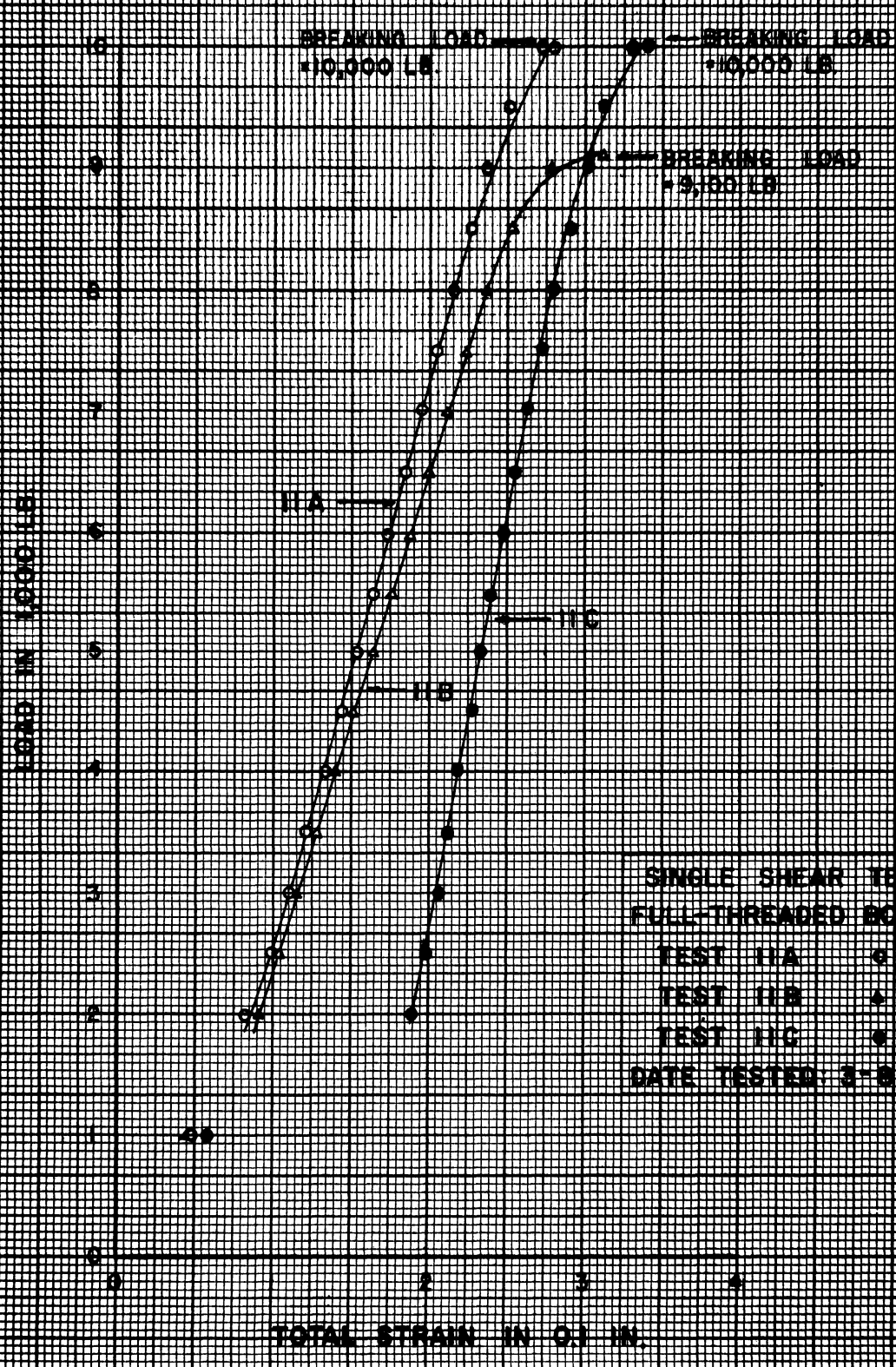
8A

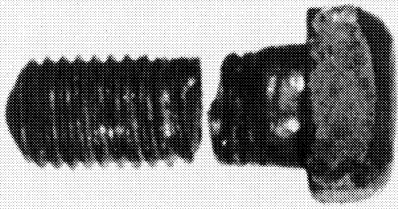
8C

LOAD IN 1000 LB

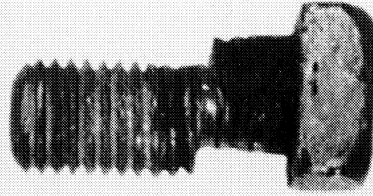
TOTAL STRAIN IN 0.1 IN



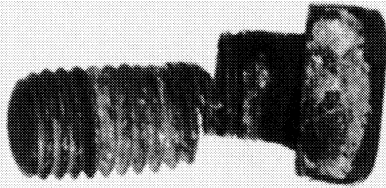




4a

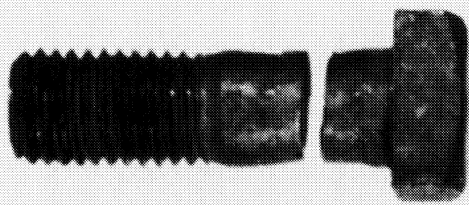


4b

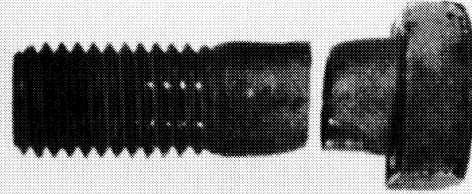


4c

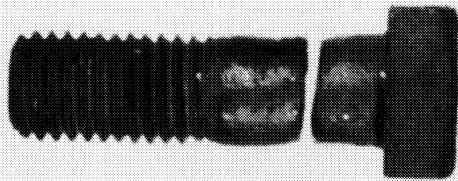
Single Shear Test  
Old Tower Bolts  
3/8-in. Test Piece



8a

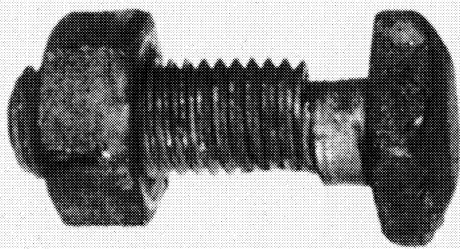


8b

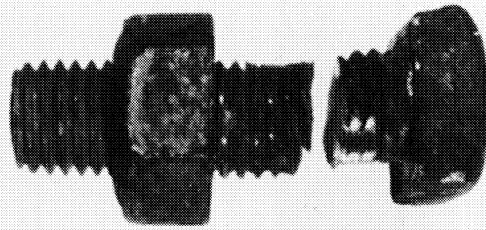


8c

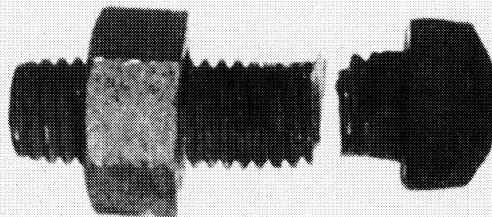
Single Shear Test  
New Tower Bolts  
3/8-in. Test Piece



11a



11b



11c

Single Shear Test  
Full-Threaded Bolts  
3/8-in. Test Piece

