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DETERMINATION OF DESIRABLE LENGTHS OF Z- AND CHANNEL-SECTION COLUMNS FOR LOCAL-INSTABILITY TESTS

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NACA

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DETERMINATION OF DESIRABLE LENGTHS OF Z- AND CHANNEL-SECTION COLUMNS FOR LOCAL-INSTABILITY TESTS

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SUMMARY

Local-instability tests of 24S-T aluminum-alloy formed Z- and channel-section columns were made in order to determine a length of test specimen that would avoid the increased strength associated with short lengths and also permit the occurrence of a convenient buckling pattern. The effect of column length on the critical compressive stress, on the average stress at maximum load, and on the number of half-waves of the buckling pattern is shown. A buckling pattern of three half-waves is indicated as desirable for test purposes. A curve is presented from which may be determined the lengths of Z- or channel-section columns that give a buckling pattern of three half-waves. When the strength for local instability is very high, a reduction in the length indicated by the curve may be necessary to prevent column failure. In order to avoid the increased strength associated with short lengths, a ratio of length to web width above 3.5 should be used.

INTRODUCTION

In local-instability tests of Z- and channel-section columns, suitable specimen lengths should be determined. As the flanges and webs of such columns may be considered plates with various kinds of edge supports, the local instability of these columns becomes a plate-buckling problem. When a plate is long, the critical compressive stress tends to be independent of length; whereas, if the plate is very short, the stress increases appreciably. (See fig. 6 of reference 1.)

For an investigation of columns that develop local instability, therefore, the specimens should be made long enough to avoid an appreciable increase in stress and yet not long enough to result in column failure. In order to determine lengths of columns that meet these requirements, tests were made of formed Z- and channel-section columns of various lengths. This report presents the test results and a curve for determining desirable column lengths for test purposes.

SYMBOLS

b_F	width of flange, inches
b_W	width of web, inches
L	length, inches
t	thickness of web or flange, inches
E	modulus of elasticity, ksi
σ_{cr}	critical compressive stress, ksi
σ_{max}	average stress at maximum load, ksi
σ_{cy}	compressive yield stress, ksi

SPECIMENS

Formed Z- and channel-section columns were made from 24S-T aluminum alloy with the grain of the material parallel to the length of the column; one sheet of material was used for each type of column, and 73 columns of each type were tested. The ends of the specimens were ground flat, parallel, and at right angles to the length of the column. Figure 1 shows the nominal dimensions of the three cross sections used for the Z- and channel-section columns. The measured dimensions of the columns and the test results are given in table 1. For each cross section, the ratio of length to web width was varied from about 1 to about 10.

Stress-strain tests of the material were made with single-thickness specimens in a roller-type compression fixture similar to that shown in figure 2 of reference 2. Compressive stress-strain curves are shown in figure 2. The values of the compressive yield stress, determined by the 0.2-percent-offset method, and of the modulus of elasticity are given in table 2.

METHOD OF TESTING

The column tests were made in a 300,000-pound-capacity compression testing machine that is accurate within three-quarters of 1 percent for the range of load used in the tests.

A Z-section column under test is shown in figure 3. The displacement of pointers, supported by extension arms attached to the flanges of the columns, was measured by the optical micrometers that can be seen in figure 3. The critical compressive stress was obtained from stress-distortion curves in the manner described and illustrated in reference 3. In this method, the critical stress is determined as the point near the top of the knee of the stress-distortion curve where a marked increase in distortion first occurs with small increase in stress.

RESULTS AND DISCUSSION

The variation of σ_{cr} and σ_{max} with L/b_W for each of the different types of column tested is presented in figure 4. Columns having $\frac{b_W}{t} = 24$ and $\frac{b_F}{b_W} = 0.5$ developed bending failure for $\frac{L}{b_W} > 7$. A definite rise in critical and maximum stresses when the columns become very short is shown by these curves. For all except the very short columns, however, the curves are relatively level. The number of half-waves of the buckling pattern that occurred in each case is also indicated in figure 4.

It has been found desirable for test purposes to make the column length such that an odd number of half-waves develops, because of the convenience in measuring cross-sectional distortion at the center of the column. Economy of material and the possibility of bending failure if the column is long lead to a choice of lengths such that the columns will develop the least number of half-waves and still avoid an appreciable increase in stress due to the effect of short lengths. These considerations, together with the test results shown in figure 4, indicate that a buckling pattern of three half-waves is the one most desirable for investigations of local instability of columns.

The length of the half-wave developed when local instability occurs varies, for a given web width, with the cross-sectional ratio b_F/b_W. The number of half-waves then depends on the ratio of length to web width L/b_W. By showing the number of half-waves that occur for given values of b_F/b_W and L/b_W as illustrated in figure 5, curves may be drawn that show the relationship between b_F/b_W and L/b_W required to obtain any desired number of half-waves. In order to give proper weight to the test results shown in figure 5, the number of tests for which each number of half-waves occurred is indicated.

A recommended curve is drawn in figure 5 to indicate the proportions of either a Z- or a channel-section column required to develop a buckling pattern of three half-waves, which is desirable for test purposes. This curve can be used directly for selecting specimen lengths in many cases. In cases in which the strength for local instability is high (low values of b_W/t), however, specimen lengths selected according to the recommended curve may not be short enough to prevent bending failure. It is therefore necessary to check the column strength of the specimens selected and, in some cases, to shorten the specimens. In any case, figure 4 shows that, in order to avoid an increase in strength due to the effect of very short lengths, the value of L/b_W used should be above 3.5.

CONCLUSIONS

For local-instability tests of Z- and channel-section columns, the specimens should be just long enough to avoid the increased strength associated with short lengths but of such length that a buckling pattern convenient for test purposes occurs. A buckling pattern of three half-waves meets these requirements; the proper length for this condition may be obtained from a curve based on tests. When the strength for local instability is very high, a reduction in this length may be necessary to prevent column failure. In order to avoid the increased strength associated with short lengths, a ratio of length to web width above 3.5 should be used.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., August 10, 1944

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2. Paul, D. A., Howell, F. M., and Grieshaber, H. E.: Comparison of Stress-Strain Curves Obtained by Single-Thickness and Pack Methods. NACA TN No. 819, 1941.

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TABLE 1

MEASURED DIMENSIONS OF FORMED SPECIMENS AND TEST RESULTS

Specimen	t (in.)	b_W (in.)	b_F (in.)	L (in.)	$\frac{L}{b_W}$	$\frac{b_W}{t}$	$\frac{b_F}{b_W}$	σ_{cr} (ksi)	σ_{max} (ksi)	Number of half-waves
Z-section column; section 1										
1a	0.106	2.54	1.30	2.79	1.10	24.00	0.51	47.4	50.2	1
1b	.106	2.54	1.30	2.79	1.10	24.00	.51	46.0	50.2	1
2a	.105	2.53	1.30	5.35	2.12	24.05	.51	44.2	46.7	1
2b	.105	2.53	1.30	5.35	2.12	24.09	.51	43.3	46.3	1
3a	.106	2.54	1.30	7.92	3.11	24.00	.51	41.9	44.3	2
3b	.106	2.54	1.30	7.60	2.99	24.00	.51	42.1	43.5	2
3c	.106	2.54	1.30	7.82	3.07	24.00	.51	41.6	44.1	2
4a	.106	2.53	1.30	10.30	4.07	23.91	.51	40.3	42.7	2
4b	.106	2.54	1.29	10.30	4.05	23.98	.51	40.9	43.7	2
4c	.106	2.54	1.30	10.30	4.05	24.00	.51	40.7	43.5	2
5a	.106	2.55	1.30	12.92	5.07	24.05	.51	39.8	43.0	3
5b	.106	2.54	1.30	12.93	5.08	24.00	.51	41.0	42.9	3
5c	.106	2.55	1.30	12.93	5.07	24.05	.51	39.8	43.5	3
6a	.106	2.54	1.30	15.50	6.09	24.00	.51	39.8	42.7	4
6b	.106	2.51	1.30	15.54	6.19	23.67	.52	39.8	41.9	4
6c	.106	2.54	1.30	15.54	6.11	24.00	.51	40.0	43.2	4
7	.106	2.52	1.30	17.60	6.97	23.81	.51	39.7	41.9	5
Z-section column; section 2										
8a	0.105	2.54	2.58	2.72	1.07	24.14	1.02	34.0	38.7	1
8b	.105	2.55	2.58	2.68	1.05	24.24	1.01	35.8	40.0	1
8c	.105	2.54	2.58	2.68	1.06	24.14	1.02	32.2	41.0	1
9a	.105	2.54	2.58	5.28	2.08	24.14	1.02	21.0	30.9	1
9b	.105	2.54	2.58	5.33	2.10	24.14	1.02	22.8	31.2	1
10a	.106	2.54	2.60	7.70	3.03	24.00	1.02	15.6	31.0	1
10b	.106	2.54	2.60	6.72	2.64	24.02	1.02	15.5	31.1	1
10c	.106	2.54	2.60	7.55	2.97	24.01	1.02	16.3	31.1	1
11a	.106	2.54	2.55	10.38	4.08	24.00	1.00	16.1	30.0	2
11b	.105	2.56	2.54	10.37	4.06	24.24	1.00	15.2	29.8	2
11c	.106	2.55	2.53	10.38	4.06	24.09	.99	15.5	30.2	2
12a	.105	2.56	2.54	12.94	5.07	24.38	.99	16.1	29.5	2
12b	.106	2.55	2.53	12.95	5.07	24.09	.99	16.9	29.6	2
12c	.105	2.54	2.54	12.95	5.10	24.19	1.00	16.2	29.3	2
13a	.106	2.54	2.54	15.55	6.11	24.11	1.00	14.9	29.2	3
13b	.106	2.54	2.54	15.55	6.11	24.00	1.00	15.6	29.4	2
13c	.106	2.54	2.54	15.55	6.11	24.00	1.00	15.1	29.2	3
14a	.106	2.54	2.58	18.07	7.10	23.95	1.01	14.7	28.7	3
14b	.106	2.54	2.58	18.07	7.10	24.09	1.01	15.2	28.9	3
14c	.106	2.54	2.58	18.08	7.11	23.98	1.01	14.1	28.9	3
15a	.106	2.54	2.58	20.60	8.10	23.95	1.01	14.4	29.5	3
15b	.106	2.54	2.58	20.60	8.10	23.98	1.01	14.1	28.1	3
15c	.106	2.54	2.58	20.62	8.11	23.95	1.01	13.9	29.4	3
16a	.106	2.54	2.58	23.22	9.13	24.00	1.01	14.2	27.8	4
16b	.106	2.54	2.58	23.22	9.13	23.98	1.01	14.6	27.7	4
16c	.106	2.54	2.58	23.22	9.13	23.98	1.01	14.5	27.6	4
17a	.106	2.54	2.58	25.73	10.10	24.00	1.01	13.3	27.5	4
17b	.106	2.54	2.58	25.65	10.08	24.00	1.01	13.5	27.3	4
17c	.106	2.54	2.58	25.74	10.11	24.00	1.01	14.3	26.9	4
Z-section column; section 3										
18a	0.105	1.40	1.48	1.71	1.23	13.29	1.06	45.8	55.7	1
18b	.105	1.40	1.48	1.74	1.25	13.29	1.06	45.9	55.3	1
19	.105	1.42	1.46	3.07	2.16	13.52	1.03	44.9	51.2	1
20a	.105	1.41	1.48	4.37	3.11	13.38	1.05	43.2	47.1	1
20b	.105	1.40	1.48	4.39	3.15	13.29	1.06	42.0	46.8	1
20c	.106	1.40	1.46	4.40	3.15	13.22	1.04	38.9	46.4	1
21a	.106	1.42	1.45	5.93	4.16	13.50	1.02	42.6	45.7	2
21b	.106	1.42	1.45	5.90	4.14	13.43	1.02	43.1	45.5	2
21c	.106	1.42	1.47	5.90	4.14	13.45	1.03	43.2	45.6	2
22a	.106	1.42	1.45	7.33	5.15	13.43	1.02	38.5	43.8	2
22b	.106	1.42	1.45	7.32	5.14	13.43	1.02	39.6	44.2	3
22c	.106	1.43	1.45	7.33	5.11	13.53	1.01	41.9	44.6	2
23a	.106	1.44	1.44	8.74	6.07	13.58	1.00	41.2	43.9	3
23b	.106	1.44	1.44	8.74	6.07	13.58	1.00	42.2	44.6	3
23c	.106	1.43	1.43	8.74	6.10	13.53	1.00	42.4	44.3	3
24a	.106	1.45	1.42	10.05	6.94	13.67	.98	41.3	43.8	3
24b	.106	1.44	1.42	10.08	6.98	13.62	.98	40.6	43.2	3
24c	.106	1.44	1.41	10.10	6.99	13.62	.98	41.0	44.1	3
25a	.106	1.44	1.41	11.54	7.99	13.62	.98	40.6	42.8	4
25b	.106	1.43	1.42	11.52	8.03	13.52	.99	40.1	43.6	4
25c	.106	1.44	1.41	11.54	7.99	13.62	.98	41.5	43.7	4
26a	.106	1.44	1.42	12.92	8.95	13.62	.98	41.6	43.5	4
26b	.106	1.44	1.42	12.92	8.98	13.58	.99	42.8	44.5	4
26c	.106	1.45	1.41	12.98	8.93	13.72	.97	41.7	43.9	4
27a	.106	1.44	1.42	14.37	9.99	13.55	.99	40.6	43.0	4
27b	.106	1.43	1.42	14.36	10.01	13.50	1.00	39.9	42.3	4
27c	.106	1.44	1.42	14.36	9.95	13.60	.98	40.7	42.4	4

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TABLE 1 - Concluded

MEASURED DIMENSIONS - Concluded

Specimen	t (in.)	b_W (in.)	b_F (in.)	L (in.)	$\frac{L}{b_W}$	$\frac{b_W}{t}$	$\frac{b_F}{b_W}$	σ_{cr} (ksi)	σ_{max} (ksi)	Number of half-waves
Channel-section column; section 1										
1a	0.107	2.54	1.26	2.78	1.09	23.79	0.49	44.8	49.3	1
1b	.107	2.54	1.26	2.80	1.10	23.85	.49	44.4	49.1	1
1c	.106	2.55	1.27	2.67	1.05	24.07	.50	45.0	49.8	1
2a	.106	2.55	1.26	5.35	2.10	24.09	.49	42.1	45.7	1
2b	.106	2.54	1.26	5.36	2.11	24.00	.50	41.7	45.6	1
2c	.106	2.53	1.27	5.32	2.10	23.91	.50	43.6	46.8	1
3a	.106	2.56	1.26	7.84	3.06	24.19	.49	40.4	43.8	3
3b	.106	2.55	1.26	7.85	3.08	24.00	.50	41.7	44.1	3
3c	.106	2.54	1.28	7.91	3.11	24.00	.50	41.9	45.1	3
4a	.106	2.53	1.27	10.44	4.13	23.88	.50	40.6	42.6	3
4b	.106	2.54	1.26	10.35	4.07	24.00	.50	39.9	42.4	3
4c	.106	2.55	1.27	10.35	4.06	24.05	.50	39.9	43.0	3
5a	.105	2.55	1.26	13.00	5.11	24.19	.50	40.4	42.7	3
5b	.106	2.54	1.27	13.00	5.11	24.00	.50	40.6	42.8	3
5c	.106	2.54	1.26	12.97	5.10	24.00	.49	40.9	43.1	3
6a	.104	2.56	1.26	15.53	6.08	24.51	.49	40.2	42.2	5
6b	.105	2.55	1.26	15.41	6.04	24.31	.49	40.0	42.4	5
6c	.105	2.53	1.26	15.41	6.10	23.96	.50	39.7	42.5	5
7a	.105	2.55	1.27	18.05	7.09	24.19	.50	39.9	41.9	5
7b	.105	2.55	1.27	18.06	7.10	24.24	.50	39.7	40.9	5
7c	.106	2.54	1.27	18.05	7.11	24.00	.50	39.7	42.3	5
Channel-section column; section 2										
8a	0.105	2.56	2.55	2.90	1.14	24.37	1.00	34.1	37.7	1
8b	.105	2.56	2.54	2.57	1.00	24.47	.99	34.3	37.5	1
8c	.105	2.53	2.54	2.81	1.11	24.14	1.00	37.9	40.5	1
9a	.105	2.55	2.54	5.40	2.12	24.26	1.00	22.9	31.9	1
9b	.105	2.56	2.55	5.38	2.11	24.36	1.00	24.0	32.8	1
10a	.106	2.57	2.54	7.91	3.07	24.26	.99	14.5	31.5	1
10b	.105	2.55	2.56	7.90	3.10	24.31	1.00	15.0	30.3	1
10c	.106	2.54	2.56	7.89	3.10	24.09	1.01	13.5	30.6	1
11a	.106	2.56	2.54	10.40	4.06	24.19	.99	16.3	29.9	2
11b	.106	2.57	2.54	10.42	4.06	24.28	.99	15.8	30.0	2
11c	.106	2.55	2.55	10.38	4.07	24.02	1.00	15.7	30.2	2
12a	.106	2.55	2.55	12.98	5.08	24.09	1.00	15.5	29.7	2
12b	.106	2.56	2.56	12.96	5.06	24.14	1.00	15.7	30.0	2
12c	.106	2.55	2.56	12.97	5.09	24.09	1.00	15.9	29.5	2
13a	.105	2.58	2.54	15.52	6.02	24.67	.99	15.4	29.5	3
13b	.106	2.59	2.53	15.53	6.00	24.45	.98	15.6	29.7	3
13c	.106	2.55	2.55	15.50	6.07	24.20	1.00	16.2	29.1	3
14a	.105	2.57	2.54	18.05	7.04	24.43	.99	13.7	28.9	3
14b	.105	2.56	2.54	18.05	7.06	24.30	1.00	13.6	29.0	3
14c	.106	2.57	2.55	18.05	7.01	24.31	.99	13.0	29.0	3
15a	.105	2.58	2.55	20.66	8.01	24.50	.99	13.5	28.5	3
15b	.106	2.56	2.55	20.63	8.06	24.14	1.00	12.9	27.8	3
15c	.106	2.56	2.57	20.63	8.05	24.17	1.00	14.2	28.1	3
16a	.106	2.58	2.56	23.18	8.97	24.38	.99	14.4	27.6	4
16b	.106	2.55	2.55	23.19	9.08	24.00	1.00	13.7	27.6	4
16c	.106	2.57	2.54	23.22	9.04	24.30	.99	15.0	27.5	4
17a	.106	2.52	2.55	25.70	10.18	23.81	1.01	13.7	26.6	4
17b	.106	2.57	2.55	25.70	9.98	24.35	.99	13.6	28.1	5
17c	.105	2.55	2.55	25.60	10.04	24.29	1.00	12.5	26.0	5
Channel-section column; section 3										
18	0.106	1.41	1.40	1.64	1.16	13.29	1.00	50.4	55.6	1
19a	.105	1.44	1.42	2.83	1.97	13.67	.99	43.8	49.3	1
19b	.105	1.43	1.42	3.02	2.11	13.61	.99	44.1	49.3	1
19c	.105	1.44	1.41	2.98	2.08	13.61	.98	42.1	48.4	1
20a	.105	1.43	1.41	4.43	3.10	13.61	.98	38.1	47.9	1
20b	.105	1.43	1.42	4.39	3.08	13.55	.99	39.2	45.3	1
21a	.106	1.44	1.42	5.79	4.01	13.66	.98	41.5	45.7	2
21b	.106	1.42	1.42	5.81	4.08	13.42	1.00	41.2	45.3	2
21c	.106	1.42	1.47	5.90	4.14	13.45	1.03	38.3	44.2	2
22a	.106	1.44	1.41	7.32	5.09	13.64	.98	40.2	43.6	2
22b	.106	1.45	1.42	7.31	5.05	13.71	.98	39.5	43.7	2
22c	.106	1.42	1.40	7.26	5.10	13.43	.99	38.7	43.6	2
23a	.106	1.42	1.43	8.60	6.04	13.47	1.01	38.7	43.1	3
23b	.106	1.43	1.43	8.52	5.96	13.48	1.00	38.6	43.2	3
23c	.106	1.42	1.43	8.70	6.11	13.43	1.00	39.3	43.8	3
24a	.106	1.44	1.43	10.14	7.05	13.58	1.00	38.5	42.3	3
24b	.106	1.44	1.43	10.06	6.97	13.62	.99	40.3	43.0	3
24c	.106	1.42	1.41	10.07	7.07	13.43	.99	38.4	43.2	3
25a	.106	1.44	1.40	11.65	8.07	13.66	.97	39.9	43.0	4
25b	.106	1.40	1.43	11.40	8.12	13.25	1.02	37.5	41.1	4
25c	.106	1.40	1.42	11.55	8.23	13.20	1.01	38.0	41.3	4
26a	.106	1.43	1.45	12.88	8.98	13.53	1.01	38.6	40.7	4
26b	.106	1.43	1.42	12.92	9.04	13.48	1.00	38.7	42.1	4

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TABLE 2

COMPRESSIVE PROPERTIES OF MATERIAL

Coupon	With grain		Cross grain	
	E (ksi)	σ_{cy} (ksi)	E (ksi)	σ_{cy} (ksi)
Z-section	10,700	44.8	10,600	49.7
Channel section	10,600	44.2	10,600	49.2

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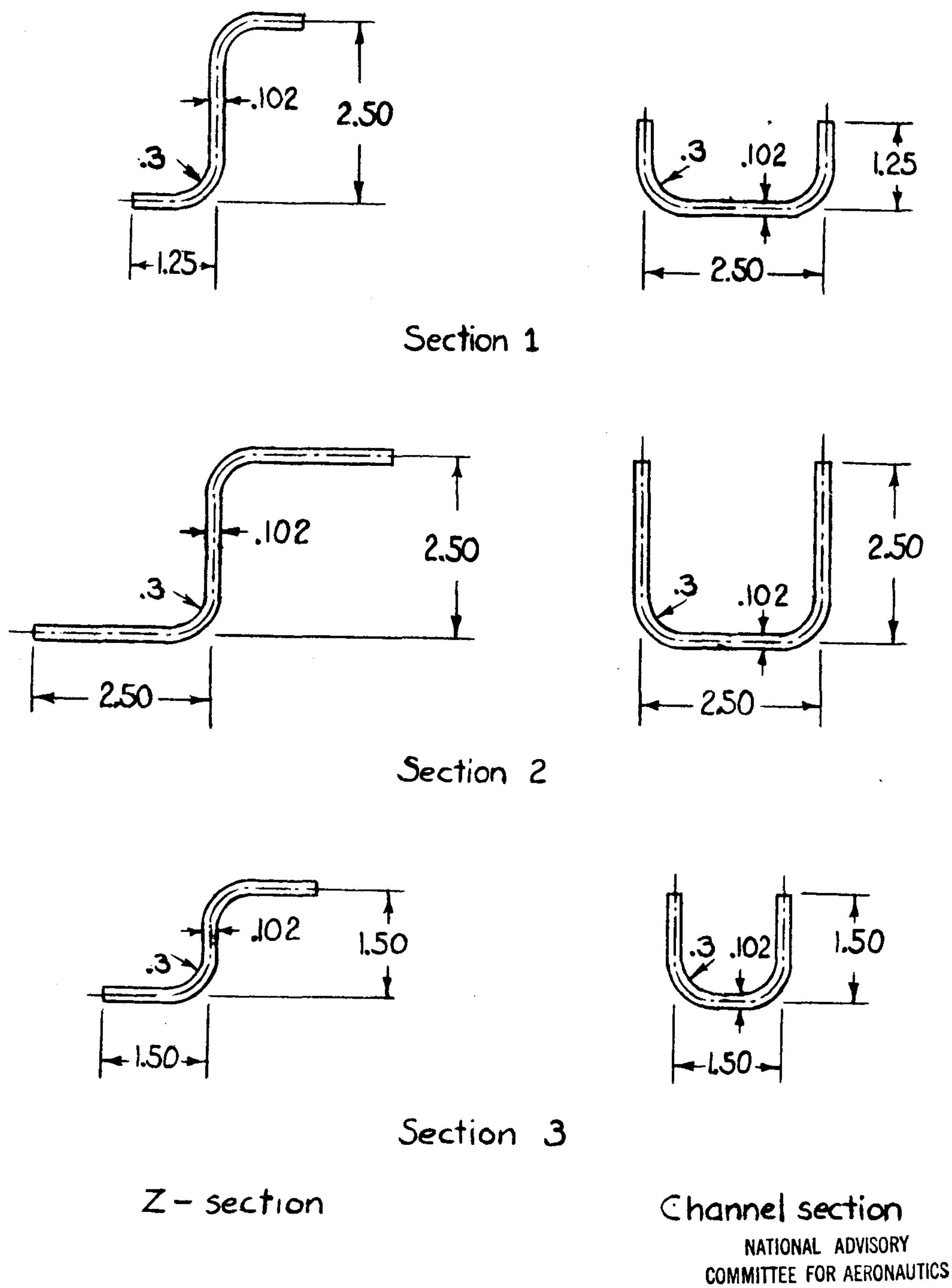

Figure 1.- Column cross sections.

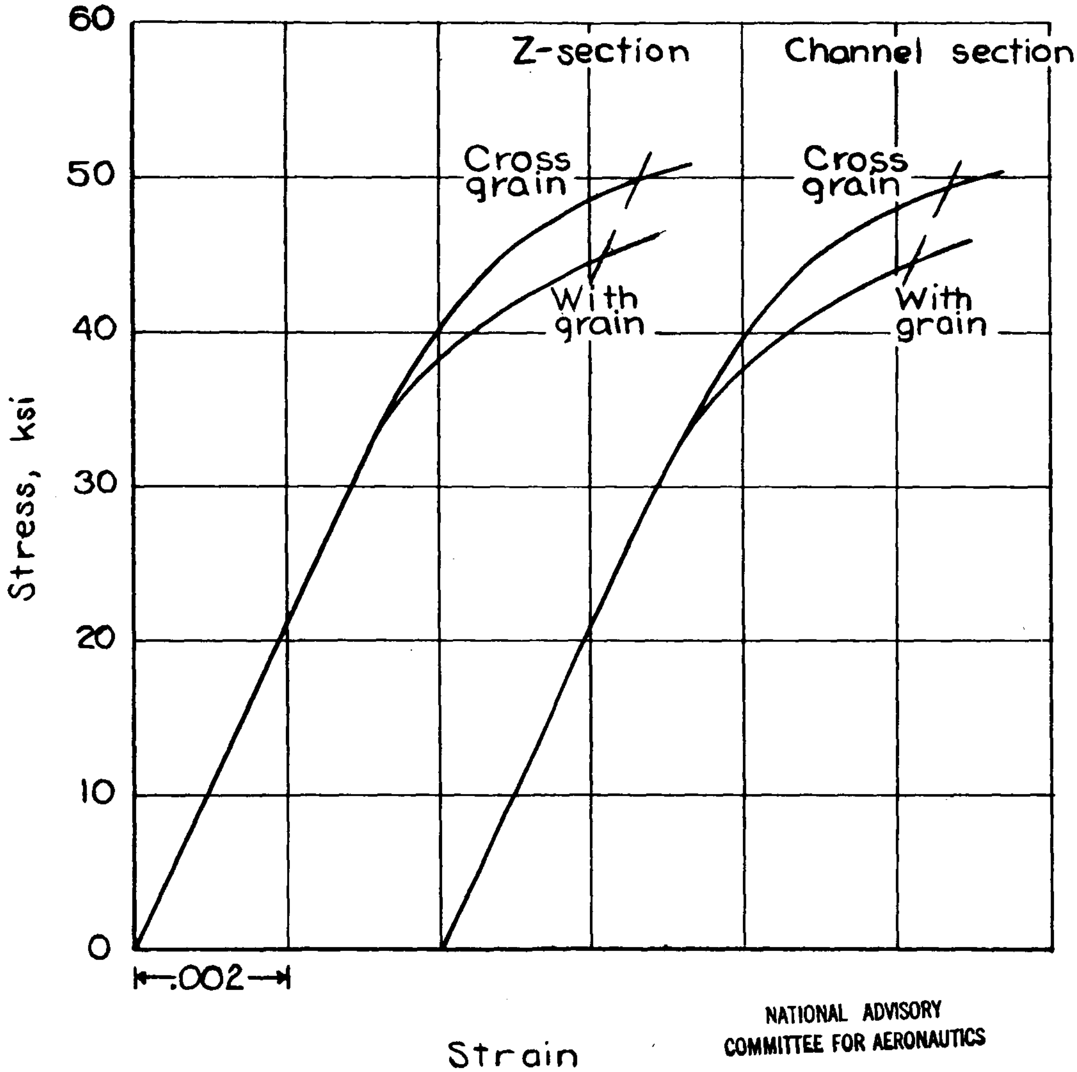

Figure 2.-Compressive stress-strain curves.

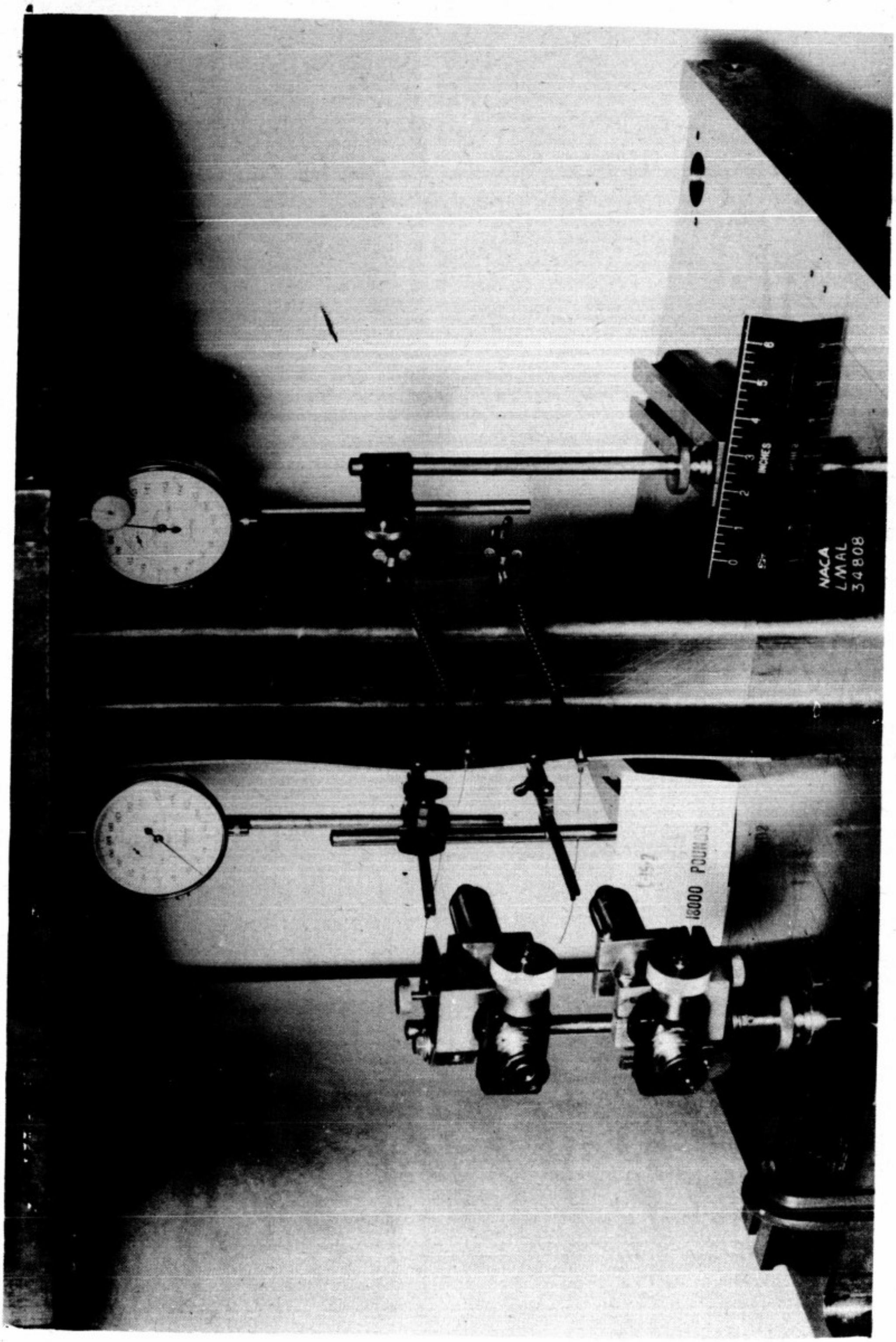

Figure 3.- Local instability of a Z-section column.

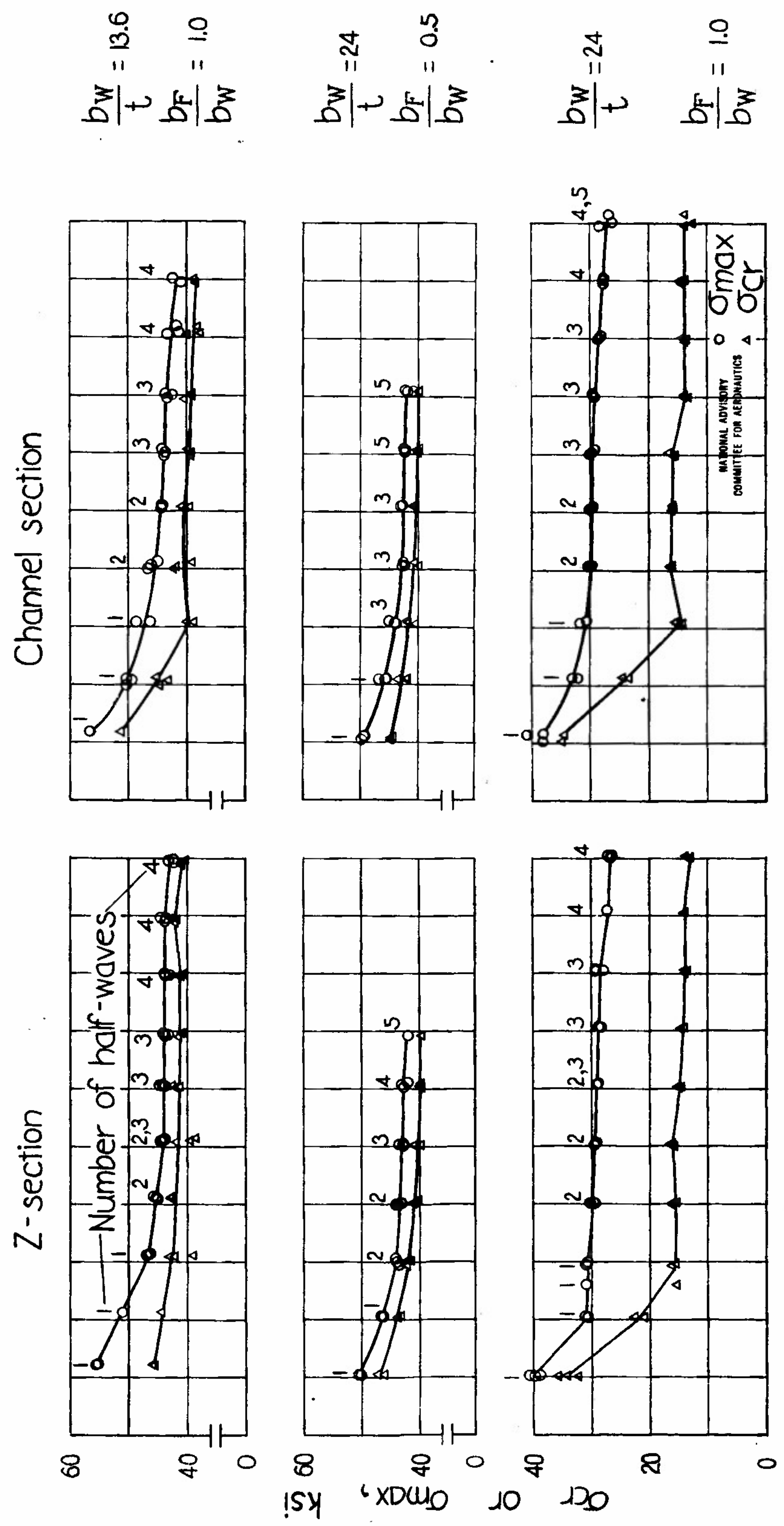

Figure 4.- Variation of σ_{cr} and σ_{max} with L/b_W for Z- and channel-section columns of 24 S-T aluminum alloy.

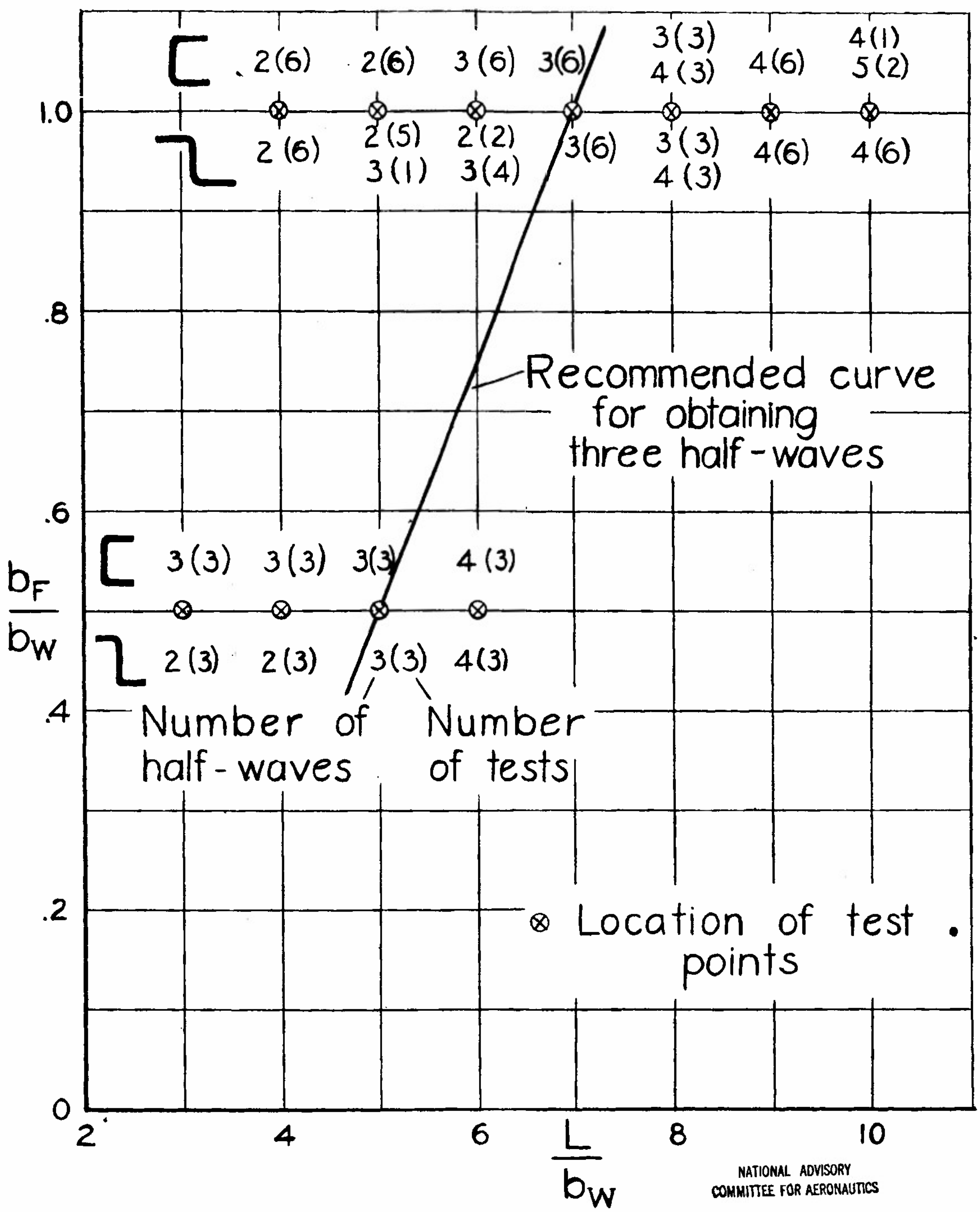

Figure 5.- Number of half-waves in buckle pattern produced by various proportions of Z- and channel-section columns of 24 S-T aluminum alloy.

TITLE: Determination of Desirable Lengths of Z- and Channel-Section Columns for Local-Instability Tests

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ABSTRACT:

For local instability tests of 24 S-T aluminum-alloy formed Z- and channel-section columns the specimens should be just long enough to avoid the increased strength associated with short lengths but of such length that a buckling pattern convenient for test purposes occurs. A buckling pattern of three half-waves meets these requirements. The proper length for this condition may be obtained from a curve based on tests. In order to avoid the increased strength associated with short lengths, a ratio of length to web width above 3.5 should be used.

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