AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF LIP ON THE COLUMN STRENGTH OF ROLLED SHEET ZEE AND ANGLE SECTIONS

Thesis submitted by

Lt. Jeremiah C. Hege

and

Thomas Goebel

In Partial Fulfillment of the Requirements for the Degree of Master of Science

California Institute of Technology
Pasadena, California
June 1945

ACKNOWLEDGEMENTS

The authors wish to express their thanks to the Consolidated Vultee Aircraft Corporation for supplying the test specimens used in this program. Further thanks are due to Dr. E.E. Sechler of the Guggenhiem Aeronautical Laboratory for the suggestion of the topic, and to both Dr. Sechler and Mr. Roy A. Miller of Consolidated for their guidance throughout the project.

TABLE OF CONTENTS

INTRODUCTION

The hat section used by certain of the aircraft companies has been quite widely accepted as the most efficient compression carrying member when stiffened by a sheet. However, due to the difficulty of inspection and corrosion control, which is particularly important in naval aircraft, the Consolidated Vultee Aircraft Corporation has for some time been using open angle and zee sections formed from dural sheet. For this reason the members of the engineering staff of Consolidated Vultee became interested in the effect of lips on zee and angle sections such as are frequently used to stiffen panels occuring in the compression side of semi-monocoque structures subjected to bending loads.

This paper is an attempt to determine experimentally the optimum amount of lip for the sections under consideration. Sufficient tests are made to locate the column curves for these sections, and from the curves the strengthening effect of the lip noted.

PREPARATION OF TEST SPECIMENS

The test specimens were formed of commercial Alclad 24SO (AN-A-13) sheet on Yoder rolls and treated in the following manner:

1. Heat treated and stretched 4% to 24RT condition. Specimens in this group are given plain numbers for identification.
2. Heat treated and stretched 1% and artificially aged to 24S-T81 condition. Specimens in this group are given numbers followed by the letter "A" for identification.
3. Heat treated and stretched 4% and artificially aged to 24S-T84 condition. These specimens are given numbers followed by the letter "B" for identification.

Various shapes and thicknesses were rolled (see table on page 4) and then cut to approximately the desired length. The ends were then cast in Wood's metal and milled flat to final length.

TEST PROCEEDURE AND EQUIPMENT

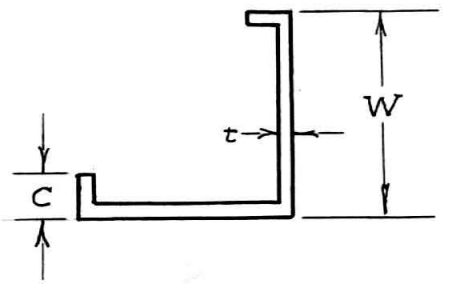
The specimens were tested in compression between flat plates mounted on both the stationary and moving heads of a 300,000 pound Southwark-Emory hydraulic testing machine located in the GALCIT structures laboratory.

TEST SPECIMENS

Since the test specimens were formed in a production shop from commercial sheet, the tolerances were of the same order of magnitude as is customarily encountered in actual aircraft production. The overall dimensions of the specimens were found to be as close to nominal as could be measured, but variations from nominal in sheet thickness of $\pm$0.002 of an inch, and in length of lip of $\pm$0.01 of an inch were not uncommon. The bend radius was one-eighth of an inch for all the test specimens.

The section properties presented in the following tables were calculated from actual measurements of the test specimens.

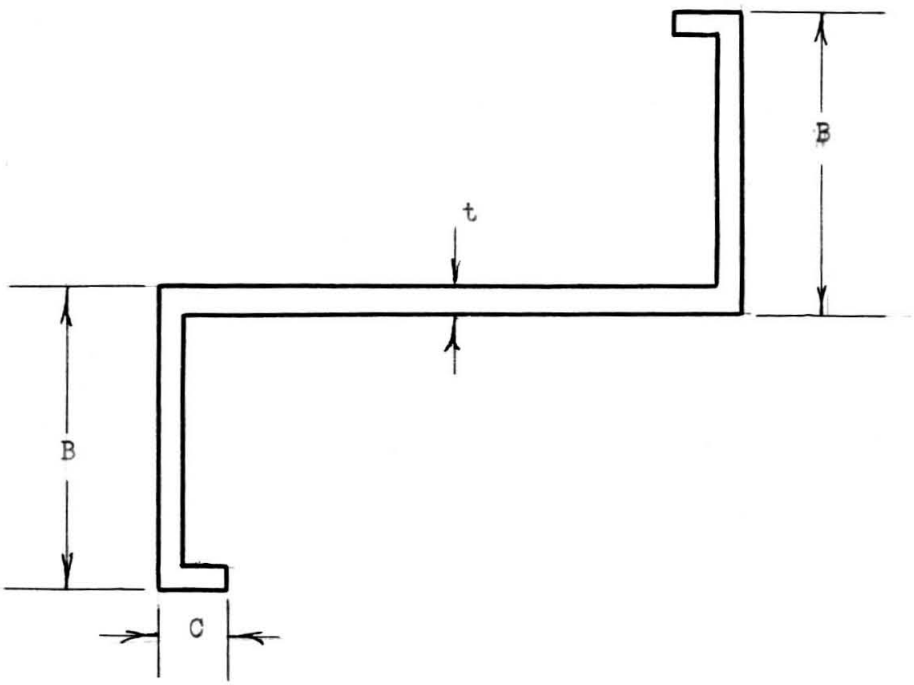
SECTION PROPERTIES OF ANGLE TEST SPECIMENS



Spec	W	t	C	Area	ρ_{Min}
1	2.00	.053	0	.209	.413
2	2.00	.052	.20	.223	.444
3	2.00	.052	.30	.236	.454
4	2.00	.050	.40	.233	.474
5	2.00	.072	0	.283	.401
6	2.00	.072	.18	.299	.423
7	2.00	.072	.25	.309	.438
8	2.00	.072	.40	.330	.469
9	2.00	.087	0	.341	.400
10	2.00	.089	.15	.359	.414
11	2.00	.088	.25	.373	.433
12	2.00	.1213	0	.4706	.399
13	2.00	.1215	.25	.503	.424
14	.75	.031	0	.03403	.182
15	1.00	.038	0	.07976	.204
16	1.00	.063	0	.1257	.239
17	1.00	.030	.150	.0624	.249
18	1.00	.062	.150	.1264	.254
19	.625	.031	.150	.0405	.162

All bend radii are one-eighth of an inch.

ZEE SECTION with LIP



Section properties are tabulated on the following page.

All bend radii are one-eighth of an inch.

SECTION PROPERTIES OF ZEE TEST SPECIMENS

Spec	B	C	t	Area	ρ_{Min}
1	1.25	0	.049	.209	.288
2	1.25	0	.073	.308	.279
3	1.25	0	.085	.356	.284
4	1.25	0	.122	.499	.276
5	1.75	0	.050	.265	.364
6	1.75	0	.071	.370	.356
7	1.75	0	.089	.461	.356
8	1.75	0	.122	.621	.359
9	1.25	.15	.048	.199	.294
10	1.25	.25	.049	.211	.314
11	1.25	.30	.071	.304	.370
12	1.25	.25	.091	.375	.335
13	1.75	.12	.049	.264	.391
14	1.75	.25	.048	.267	.377
15	1.75	.35	.049	.281	.473
16	1.75	.10	.071	.379	.366
17	1.75	.25	.072	.392	.366
18	1.75	.40	.071	.408	.462
19	1.75	.10	.089	.470	.370
20	1.75	.25	.088	.472	.369
21	1.75	.25	.125	.649	.353
22	.75	0	.050	.164	.180
23	.75	.20	.050	.162	.193
24	.75	0	.072	.232	.174
25	.75	0	.088	.280	.173
26	.75	0	.123	.380	.167

ANGLE SECTION TEST DATA

	Length = 16"		Length = 32"		Length = 48"		Length = 64"	
Spec.	P	σ	P	σ	P	σ	P	σ
1	2,360	11,300	1,695	8,110	1,130	5,400	790	3,780
2	2,790	12,500	2,160	9,700	1,390	6,250	1,180	5,300
3	3,340	14,200	2,680	11,400	1,650	7,020	1,080	4,590
4	3,630	15,600	2,320	9,975	1,940	8,350	1,310	5,630
5	4,870	17,220	3,130	11,060	2,120	7,500	1,500	5,300
6	4,930	16,500	4,260	14,260	2,410	8,060	1,910	6,400
7	4,950	16,020	3,590	11,600	2,765	8,960	1,810	5,860
8	5,750	17,400	4,490	13,600	2,930	8,880	2,110	6,385
9	6,570	19,300	5,055	14,850	3,100	9,100	2,520	7,400
10	6,390	17,800	5,000	13,920	3,380	9,430	2,330	6,500
11	.....	.....	5,350	14,340	3,640	9,750	2,790	7,490
12	11,600	24,600	7,870	16,750	6,485	13,700	5,520	11,720
13	11,000	21,900	9,820	19,750	7,360	14,660	5,400	10,750
	Length = 7.5"		Length = 15"		Length = 20"		Length = 30"	
14	660	19,390	400	11,760	310	9,110	150	4,405
15	1,070	13,420	770	9,660	550	6,900	430	5,400
16	2,940	23,800	2,200	17,800	1,140	9,200	1,110	8,950
17	910	14,600	770	12,350	590	9,460	390	6,250
18	3,090	24,450	2,600	20,590	2,160	17,100	1,430	11,300
19	720	17,810	430	10,640	370	9,155	240	5,950

ANGLE SECTION TEST DATA

	Length = 16"		Length = 32"		Length = 48"		Length = 64"	
Spec.	P	σ	P	σ	P	σ	P	σ
1A	2,780	13,800	1,710	8,500	1,280	6,355	870	4,320
2A	3,160	14,860	2,160	10,150	1,290	5,800	930	4,175
3A	3,800	16,150	2,710	11,510	1,640	6,980	1,080	4,595
4A	4,000	17,200	3,190	13,700	2,080	8,950	1,240	5,330
5A	5,070	17,920	3,810	13,470	2,100	7,430	1,520	5,380
6A	6,130	20,500	4,110	13,750	2,380	7,970	2,200	7,375
7A	.....	.....	4,130	13,060	2,890	9,250	1,680	5,370
8A	7,390	22,360	4,904	14,880	3,070	9,300	2,240	6,810
9A	7,530	22,100	5,550	16,300	3,050	8,950	2,640	7,750
10A	8,360	23,300	5,890	16,400	3,620	10,080	2,780	7,750
11A	8,480	22,300	7,260	19,050	3,810	10,000	3,020	7,930
12A	14,000	29,000	16,000	33,000	7,180	14,820	4,920	10,170
13A	14,200	27,750	11,800	23,000	7,650	14,920	6,400	12,500

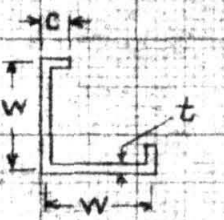
	Length = 7.5"		Length = 15"		Length = 20"		Length = 30"	
14A	710	20,850	410	12,040	280	8,230	150	4,400
15A	1,500	18,800	920	11,530	710	8,900	390	4,900
16A	3,400	27,500	2,620	21,200	1,820	14,600	1,330	10,750
17A	560	8,990	920	14,750	640	10,260	240	3,890
18A	2,850	22,500	2,360	18,690	1,930	15,280	1,650	13,050
19A	870	21,500	470	11,630	380	9,400	160	3,960

ANGLE SECTION TEST DATA

	Length = 16"		Length = 32"		Length = 48"		Length = 64"	
Spec.	P	σ	P	σ	P	σ	P	σ
1-B	2,920	14,000	1,640	7,850	1,120	5,350	900	4,300
2-B	3,160	14,580	2,460	11,350	1,370	6,320	870	4,015
3-B	3,530	15,800	2,220	9,980	1,530	6,500	990	4,450
4-B	3,820	16,400	2,750	11,800	1,710	7,350	910*	3,910
5-B	5,400	19,100	3,480	12,300	2,020	7,140	1,540	5,450
6-B	5,900	17,650	3,740	12,500	2,280	7,650	1,850	6,200
7-B	6,470	21,000	4,010	13,000	2,570	8,325	1,900	6,150
8-B	7,530	22,800	4,970	15,040	3,000	9,080	2,020	6,110
9-B	7,730	22,700	5,100	14,970	3,230	9,480	2,490	7,300
10-B	7,640	21,250	5,480	15,290	3,490	9,730	2,600	7,250
11-B	.....	.....	5,460	14,650	4,190	11,330	3,030	8,130
12-B	13,800	29,100	9,960	21,000	6,090	12,820	5,600	11,800
13-B	14,400	28,400	11,450	22,550	7,460	14,700	5,790	11,400
	Length - 7.5"		Length - 15"		Length - 20"		Length - 30"	
14-B	850	25,000	400	11,760	.....	.....	190	5,585
15-B	1,480	18,570	910	11,400	690	8,650	380	4,760
16-B	3,640	29,400	2,610	20,300	1,340	10,800	1,370	11,100
17-B	1,380	22,100	990	15,880	690	11,060	420	6,740
18-B	3,030	24,000	2,540	20,100	2,160	17,100	1,410	11,250
19-B	906	22,230	550	13,600	370	9,150	220	5,450

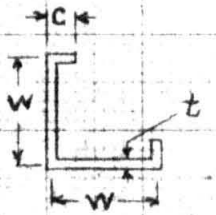
ANGLE SECTIONS

SPEC.	t	w	c
⊙ – 1	.053	2.00	0
□ – 2	.053	2.00	.20
△ – 3	.053	2.00	.30
◇ – 4	.050	2.00	.40



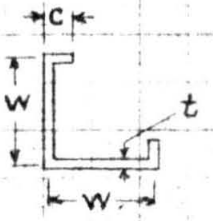
ANGLE SECTIONS

SPEC.	t	w	c
○ – 5	.072	2.00	0
□ – 6	.072	2.00	.18
△ – 7	.072	2.00	.25
◇ – 8	.072	2.00	.40



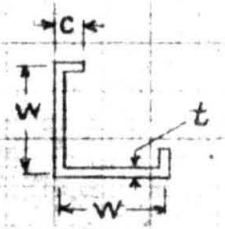
ANGLE SECTIONS

SPEC.	t	w	c
⊙ - 9	.087	2.00	0
□ - 10	.089	2.00	.15
△ - 11	.088	2.00	.25



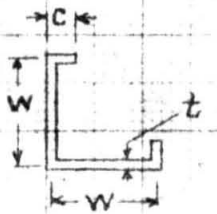
ANGLE SECTIONS

SPEC.	t	w	c
⊙ - 12	.121	2.00	0
⊡ - 13	.121	2.00	.25



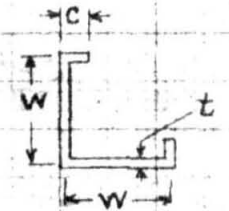
ANGLE SECTIONS

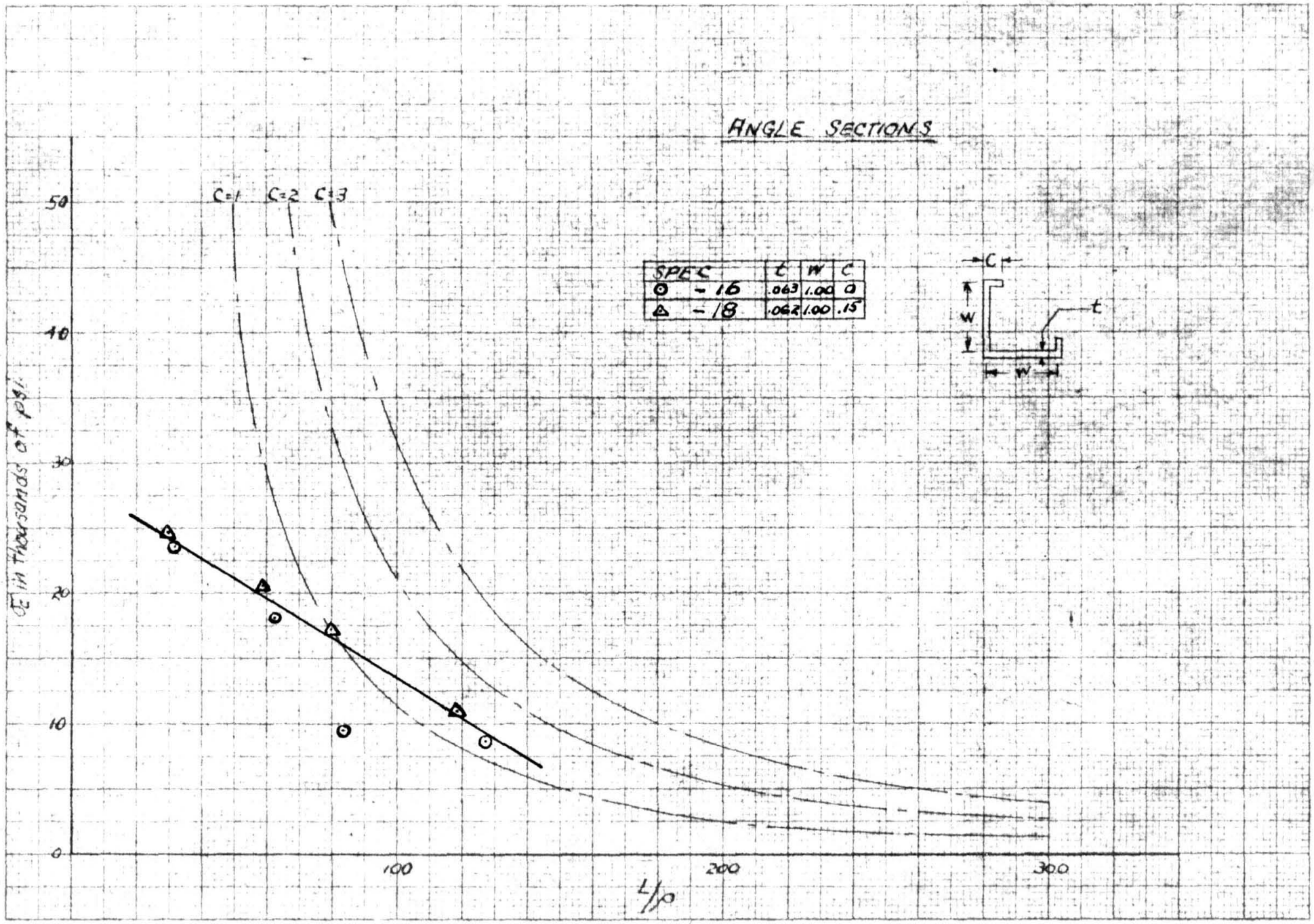
SPEC	t	w	c
⊙ −14	.031	.750	0
⊡ −19	.031	.625	.15



ANGLE SECTIONS

SPEC	t	w	c
⊙ – 15	.038	1.00	0
□ – 17	.030	1.00	.15

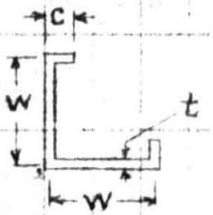



ANGLE SECTIONS
C=1
C=2
C=3
SPEC
t
W
C
⊙ - 16
.063
1.00
0
△ - 18
.062
1.00
.15
C
W
t
W
E in thousands of psi
50
40
30
20
10
0
100
200
300
L/ρ

ANGLE SECTIONS

1A, 2A, 3A, 4A

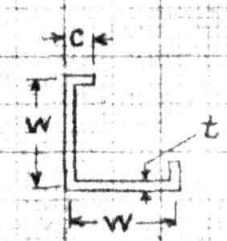
SPEC.	t	w	c
○ — 1A	.053	2.0	0
△ — 2A	.051	2.0	.20
□ — 3A	.050	2.0	.30
◇ — 4A	.050	2.0	.40



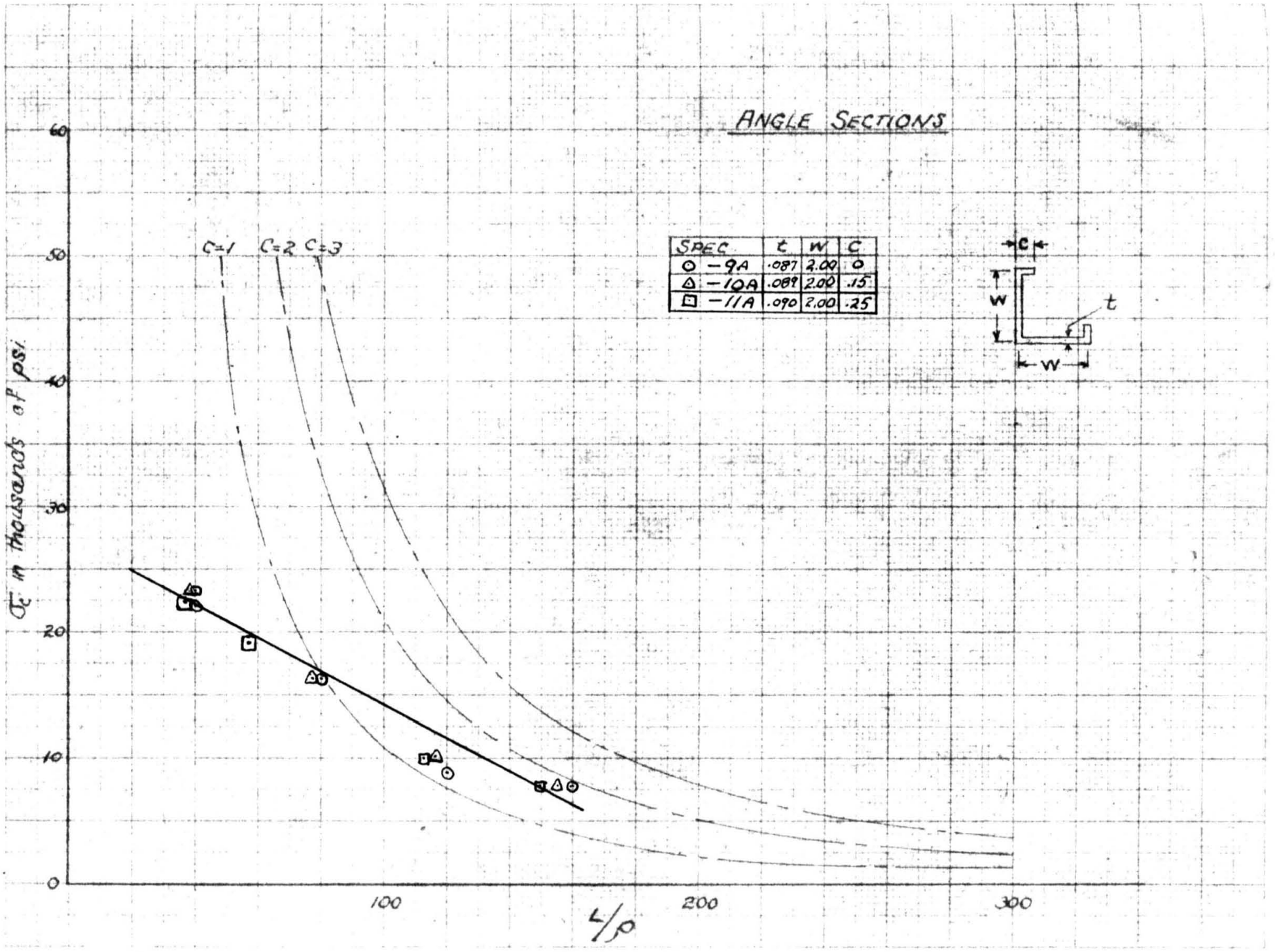
ANGLE SECTIONS

5A, 6A, 7A, 8A

SPEC.	t	W	C
○ – 5A	.072	2.00	0
△ – 6A	.072	2.00	.18
□ – 7A	.073	2.00	.25
◇ – 8A	.072	2.00	.40



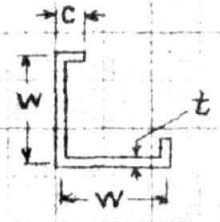
ANGLE SECTIONS

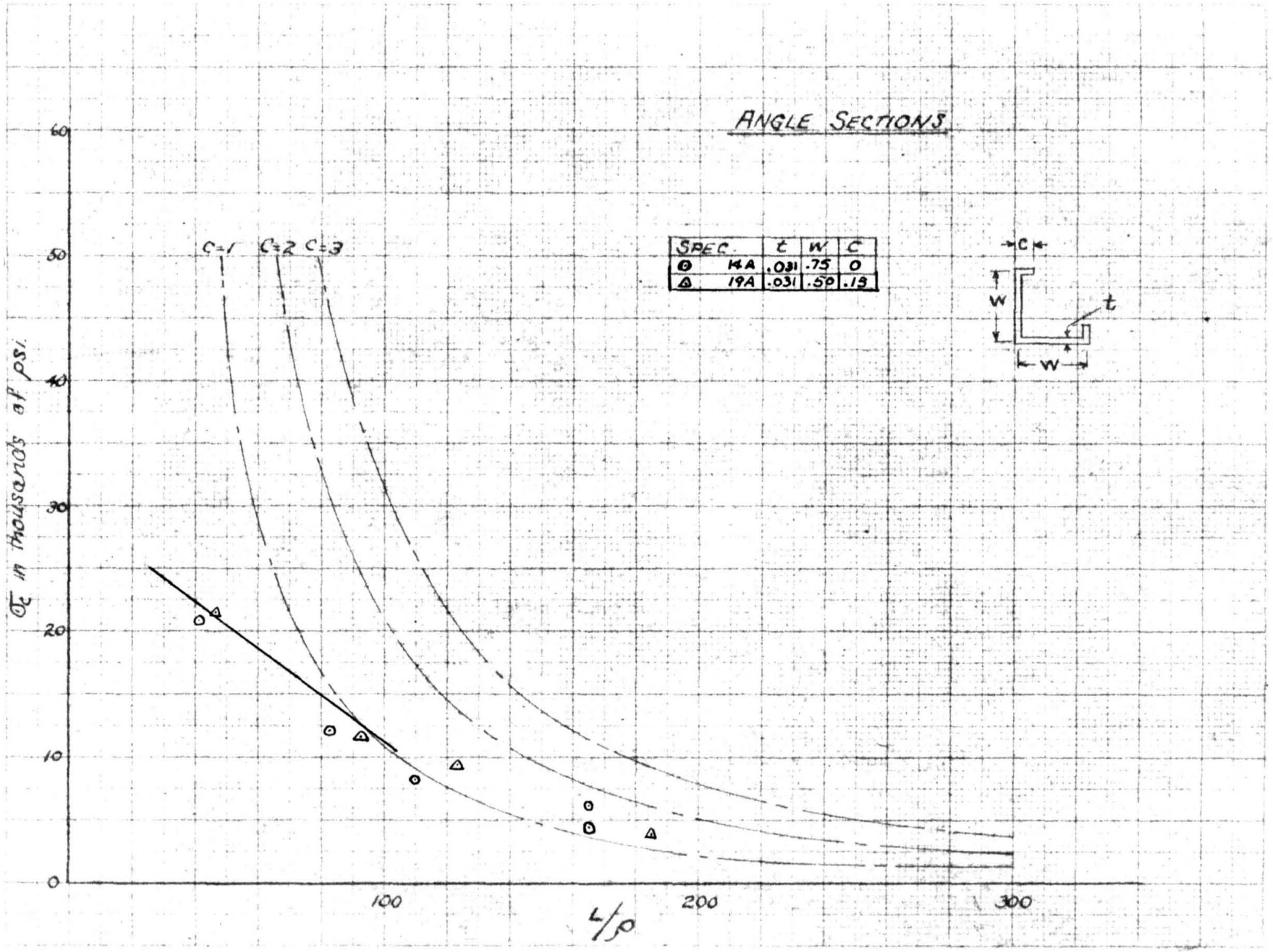


ANGLE SECTIONS

12A, 13A

SPEC.	t	w	c
⊙ — 12A	.125	2.00	0
△ — 13A	.124	2.00	.25

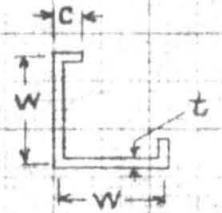



ANGLE SECTIONS
C=1
C=2
C=3
SPEC. t W C
KA .031 .75 0
19A .031 .50 .19
C
W
t
W
60
50
40
30
20
10
0
100
200
300
L/ρ
σc in thousands of psi.

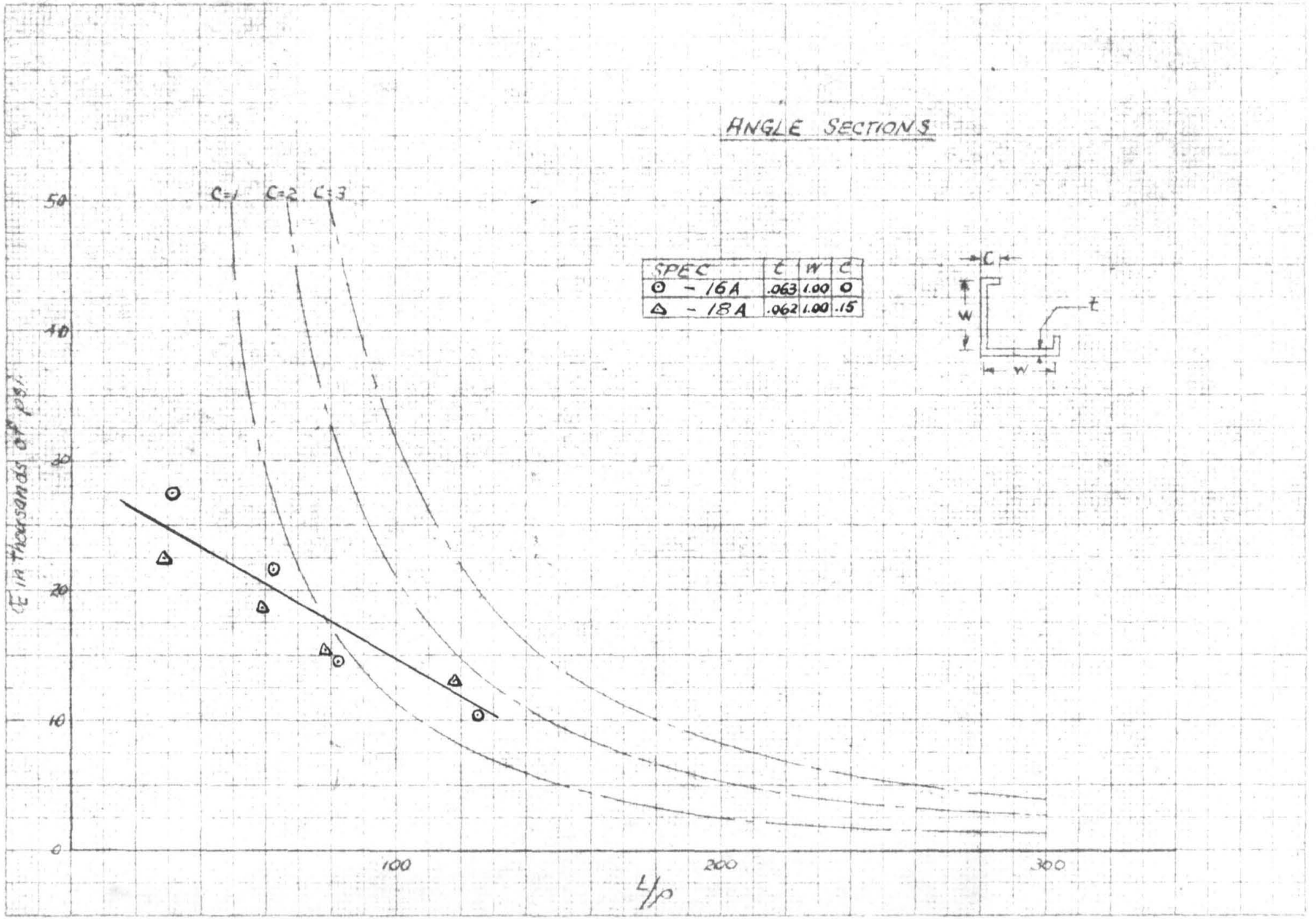
ANGLE SECTIONS

15A, 17A

SPEC	t	w	c
⊙ 15A	.038	1.00	0
△ 17A	.030	1.00	.15



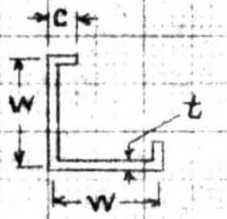
ANGLE SECTIONS



SPEC	t	w	c
⊙ - 16A	.063	1.00	0
△ - 18A	.062	1.00	.15

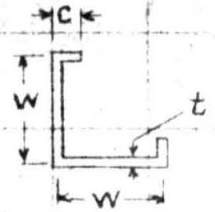
ANGLE SECTIONS

SPEC.	t	W	C
⊙ – 1B	.053	2.00	0
⊡ – 2B	.051	2.00	.20
△ – 3B	.050	2.00	.30
◇ – 4B	.050	2.00	.40



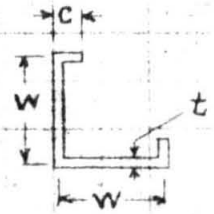
ANGLE SECTIONS

SPEC	t	W	C
⊙ – 5B	.072	2.00	0
□ – 6B	.072	2.00	.18
△ – 7B	.072	2.00	.25
◇ – 8B	.072	2.00	.40



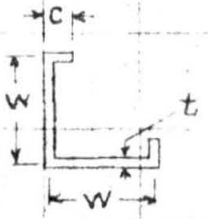
ANGLE SECTIONS

SPEC.	t	w	c
⊙ - 9B	.087	2.00	0
⊡ - 10B	.089	2.00	.15
△ - 11B	.088	2.00	.25



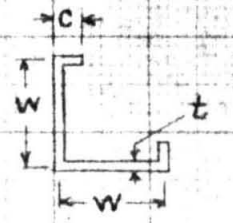
ANGLE SECTIONS

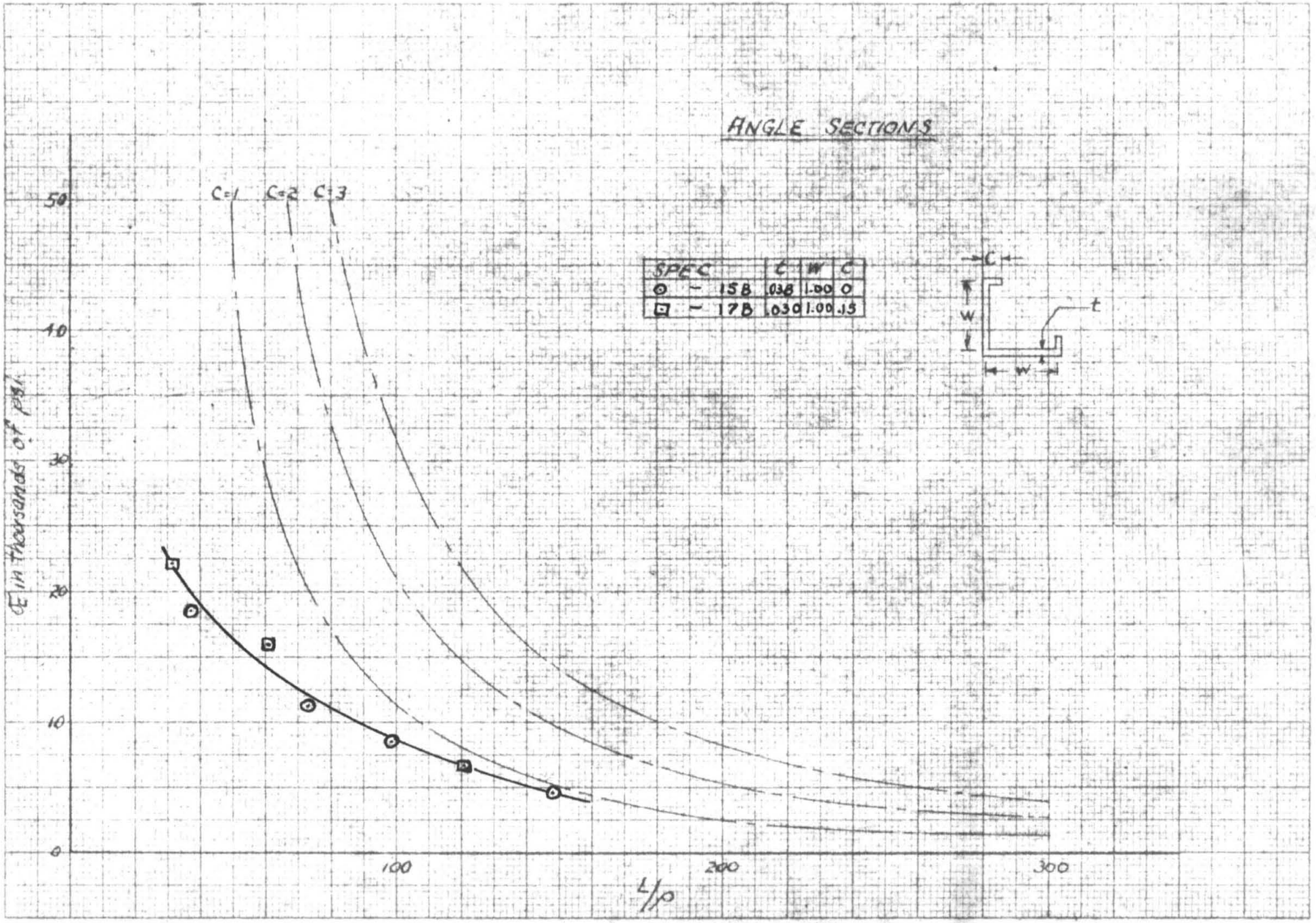
SPEC	t	w	c
⊙ – 12B	.122	2.00	0
□ – 13B	.123	2.00	.25

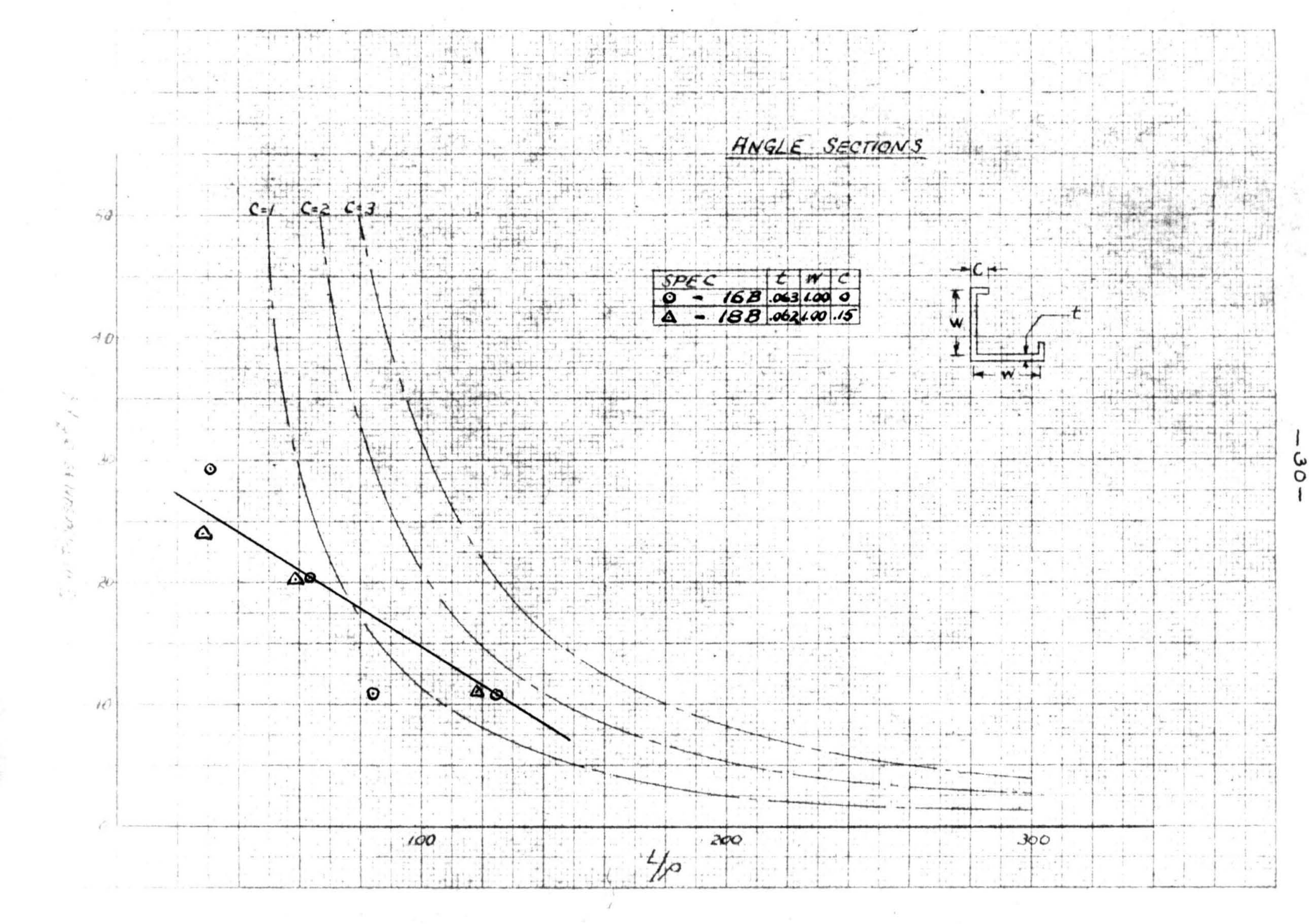


ANGLE SECTIONS

SPEC.	t	w	c
⊙ – 14B	.030	.75	0
⊡ – 19B	.031	.50	.15




ANGLE SECTIONS
C=1
C=2
C=3
SPEC t w c
⊙ – 15B .038 1.00 0
□ – 17B .030 1.00 .15
c
w
t
w
50
40
30
20
10
0
E in thousands of psi
100
200
300
L/ρ


ANGLE SECTIONS
C=1
C=2
C=3
SPEC t w c
○ - 16B .063 1.00 0
△ - 18B .062 1.00 .15
C
w
t
w
50
40
30
20
10
0
100
200
300
L/ρ

ZEE SECTION TEST DATA

Spec.	P	σ	P	σ	P	σ	P	σ
	Length = 10"		Length = 15"		Length = 20"		Length = 30"	
1	4510	21,600	4460	21,350	4350	20,800	3900	18,650
2	9570	31,100	9000	29,200	8520	27,700	7350	23,850
3	.....	.....	11,520	32,400	9300	26,100	9540	26,800
4	20,850	42,500	18,700	37,500	17,100	34,300	13,900	27,900
5	4650	17,530	4720	17,800	4300	16,230	4190	15,800
6	9900	26,800	9560	25,820	8890	24,000	8550	23,100
7	13,550	29,400	12,950	28,100	12,500	27,100	11,070	24,000
8	.....	.....	20,000	32,200	22,650	36,500	18,500	29,800
9	4600	23,100	4470	23,300	4320	21,700	3680	18,500
10	6550	31,000	6410	30,400	5930	28,100	5310	25,200
11	11,100	36,500	11,800	38,900	11,150	36,700	9240	30,400
12	.....	.....	24,450	65,300	14,150	37,750		
13	4900	18,550	4750	18,00	4550	17,240	4170	15,800
14	5000	18,740	5710	21,400	5210	19,500	4820	18,070
15	.....	.....	6390	22,750	6780	24,100	5710	20,340
16	10,300	27,200	9650	25,450	9220	24,300	8260	21,800
17	12,450	31,800	11,590	29,550	10,590	27,000	10,350	26,400
18	.....	.....	13,800	33,900	12,700	31,200	12,200	29,950
19	13,500	28,750	13,250	28,200	12,750	27,100	17,200	36,600
20	16,050	34,000	15,400	32,600	15,000	31,800	14,300	30,350
21	24,700	38,100	.....	.....	.....	.....	19,600	30,200
	Length = 7.5"		Length = 15"		Length = 30"			
22	3990	24,300	3740	22,200	940	5740		
23	4810	29,700	4860	30,000	2910	18,000		
24	7700	33,200	6830	29,400	2970	12,800		
25	12,120	43,800	9200	32,900	3060	12,920		
26								

ZEE SECTION TEST DATA

	Length = 10"		Length = 15"		Length = 20"		Length = 30"	
Spec.	P	σ	P	σ	P	σ	P	σ
1-A	5,550	26,500	5,580	26,700	.....	.....	4,040	19,350
2-A	12,300	40,000	11,320	36,800	11,300	36,700	7,700	25,000
3-A	15,400	43,300	14,500	40,750	.....	.....	11,570	32,500
4-A	27,450	55,100	25,300	50,700	.....	.....	15,000	30,100
5-A	5,700	21,500	5,750	21,700	.....	.....	5,200	19,620
6-A	.....	.....	12,600	34,100	.....	.....	.....	.....
7-A	18,000	39,000	17,300	37.500	.....	.....	14,250	30,950
8-A	27,200	43,800	26,000	41,900	.....	.....	23,000	37,050
9-A	5,850	29,400	5,750	28,900	5,580	28,000	4,530	22,760
10-A	8,200	38,900	7,330	34,800	.....	.....	6,050	28,700
11-A	16,850	55,550	15,300	50,400	14,000	46,000	11,110	36,900
12-A	17,550	46,800	19,300	51,500	.....	.....	15,300	40,800
13-A	5,690	21,550	5,660	21,400	5,750	21,800	4,950	18,750
14-A	7,050	26,400	6,650	24,900	.....	.....	5,680	21,250
15-A	9,100	32,400	8,520	30,300	.....	.....	7,610	27,100
16-A	13,150	34,700	12,800	33,800	11,330	29,900	10,850	28,600
17-A	14,300	36,500	13,200	33,700	12,900	32,900	11,700	29,900
18-A	19,550	48,000	18,350	45,000	.....	.....	14,550	35,700
19-A	16,650	35,500	15,900	33,800	.....	.....	13,500	28,800
20-A	19,800	42,000	19,150	40,550	.....	.....	16,050	34,000
21-A	31,400	48,500	30,350	46,750	22,850	35,300	24,950	38,500
	Length = 7.5"		Length = 15"		Length = 30"			
22-A	4,830	29,500	4,430	26,500	1,910	11,660	.....	.....
23-A	6,000	37,000	5,770	35,700	3,090	19,100	.....	.....
24-A	9,460	40,750	9,200	39,700	2,930	12,600	.....	.....
25-A	16,800	60,000	13,000	46,500	3,530	12,600	.....	.....
26-A	24,900	65,500	18,650	49,100	5170	13,600	.....	.....

ZEE SECTION TEST DATA

	Length = 40"		Length = 70"		Length = 40		Length = 70"	
Spec.	P	σ	P	σ	P	σ	P	σ
1	3300	15,800	780	3740	.....	.....	.....	.....
2	5550	18,000	1760	5720	6410	20,800	1760*	5720
3	6675	18,750	1710*	4800	2330	6550	.....	.....
4	8010	16,050	2630	5270	.....	.....	2560	5130
5	3530	13,300	2850	10,760	.....	.....	1780	6720
6	6200	16,780	2210	5980	3620	9790	.....	.....
7	9830	21,300	3470	7530	.....	.....	3980	8630
8	15,900	25,600	3280*	5290	.....	.....	4960	8000
9	2890	14,500	1010*	5070	3170	15,930	1320	6640
10	4470	21,200	1370	6500	1720	8150	1590	7540
11	6180	20,350	1920	6320	7210	23,750	1970	6490
12	8380	22,350	2200	5880	2880	7690	2770	7390
13	3660	13,880	1760	6670	4100	15,550	1480	5600
14	4810	18,000	2520	9450	2610	9790	.....	.....
15	6100	21,700	2700	9620	.....	.....	3110	11,070
16	8240	21,720	3310	8750	7890	20,800	2770	7310
17	7240	18,470	4320	11,000	9470	24,200	3410*	8700
18	11,440	28,100	5060	12,400	5180	12,700	4790	11,800
19	10,320	22,000	3340	7105	.....	.....	4100	8740
20	11,560	24,500	3180	6745	4760	10,100	4880	10,320
21	14,900	23,000	5670	8890	5430	8370	.....	.....
	← 24RT →				← A-24S-T81 →			

*- 75 inch test lengths

ZEE SECTION TEST DATA

	P	σ	P	σ	P	σ	P	σ
Spec.	Length = 10"		Length = 15"		Length = 20"		Length = 30"	
1-B	5,490	26,250	5,550	26,600	.....	.....	3,450	16,500
2-B	.....	.....	11,450	37.200	11,340	36,820	7,920	25,750
3-B	15,750	44,250	15,200	42,700	.....	.....	10,150	28,500
4-B	.....	.....	27,350	54,800	24,950	50,000	15,100	30,300
5-B	5,850	22,100	6,050	22,800	.....	.....	5,300	20,000
6-B	12,850	34,800	12,250	33,140	.....	.....	10,360	28,000
7-B	18,150	39,400	17,350	37,700	.....	.....	13,900	30,150
8-B	29,250	47,100	28,300	45,550	.....	.....	23,700	38,200
9-B	5,820	29,220	5,750	28,900	.....	.....	4,630	23,220
10-B	8,000	37,900	6,950	33,000	6,930	32,800	6,100	28,900
11-B	.....	.....	13,900	45,700	12,800	42,200	11,060	36,400
12-B	21,100	56,250	20,550	54,800	.....	.....	14,250	38,000
13-B	5,820	22,000	5,790	21,900	.....	.....	5,110	19,370
14-B	6,840	25,600	6,450	24,200	.....	.....	5,800	21,750
15-B	.....	.....	7,320	26,100	7,830	27,900	7,560	26,900
16-B	12,750	33,600	12,150	32,100	.....	.....	9,250	24,400
17-B	.....	.....	14,200	36,200	11,900	30,350	11,970	30,500
18-B	19,100	46,900	16,950	41,500	.....	.....	14,850	36,400
19-B	18,200	38,750	17,350	36,900	.....	.....	12,750	27,100
20-B	20,400	43,200	19,350	41,000	.....	.....	16,200	34,350
21-B	33,200	51,200	31,800	49,000	.....	.....	26,200	40,500
	Length = 7.5"		Length = 15"		Length = 30"			
22-B	4,970	30,300	4,560	27,800	1,880	11,480	.....	.....
23-B	6,200	38,300	6,070	37,500	3,180	19,650	.....	.....
24-B	9,680	41,700	8,730	37,600	3,170	13,700	.....	.....
25-B	16,750	59,800	12,300	44,000	3,340	11,930	.....	.....
26-B	25,650	67,600	18,400	48,500	4950	13,020	.....	.....

ZEE SECTION TEST DATA

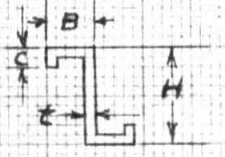
	Length - 40"		Length - 70"	
Spec.	P	σ	P	σ
1-B	1,240	5,950	.....	.....
2-B	6,000	19,500	1,570*	5,100
3-B	2,170	6,100	1,280	3,600
4-B	8,350	16,750	2,230*	4,470
5-B	1,660	6,260	.....	.....
6-B	3,050	8,250	.....	.....
7-B	4,010	8,700	4,300	9,390
8-B	5,330	8,580	5,400	8,700
9-B	.....	.....	920	4,620
10-B	4,810	22,800	1,700	8,050
11-B	6,570	21,600	1,850*	6,090
12-B	.....	.....	2,520	6,725
13-B	1,880	7,130	.....	.....
14-B	.....	.....	2,770	10,390
15-B	6,870	24,450	3,360	11,960
16-B	.....	.....	3,640	9,600
17-B	9,940	25,380	4,630	11,800
18-B	5,150	12,610	4,740	11,620
19-B	4,340	9,230	3,820	8,130
20-B	4,360	9,240	4,390	9,300
21-B	.....	.....	5,740	8,700

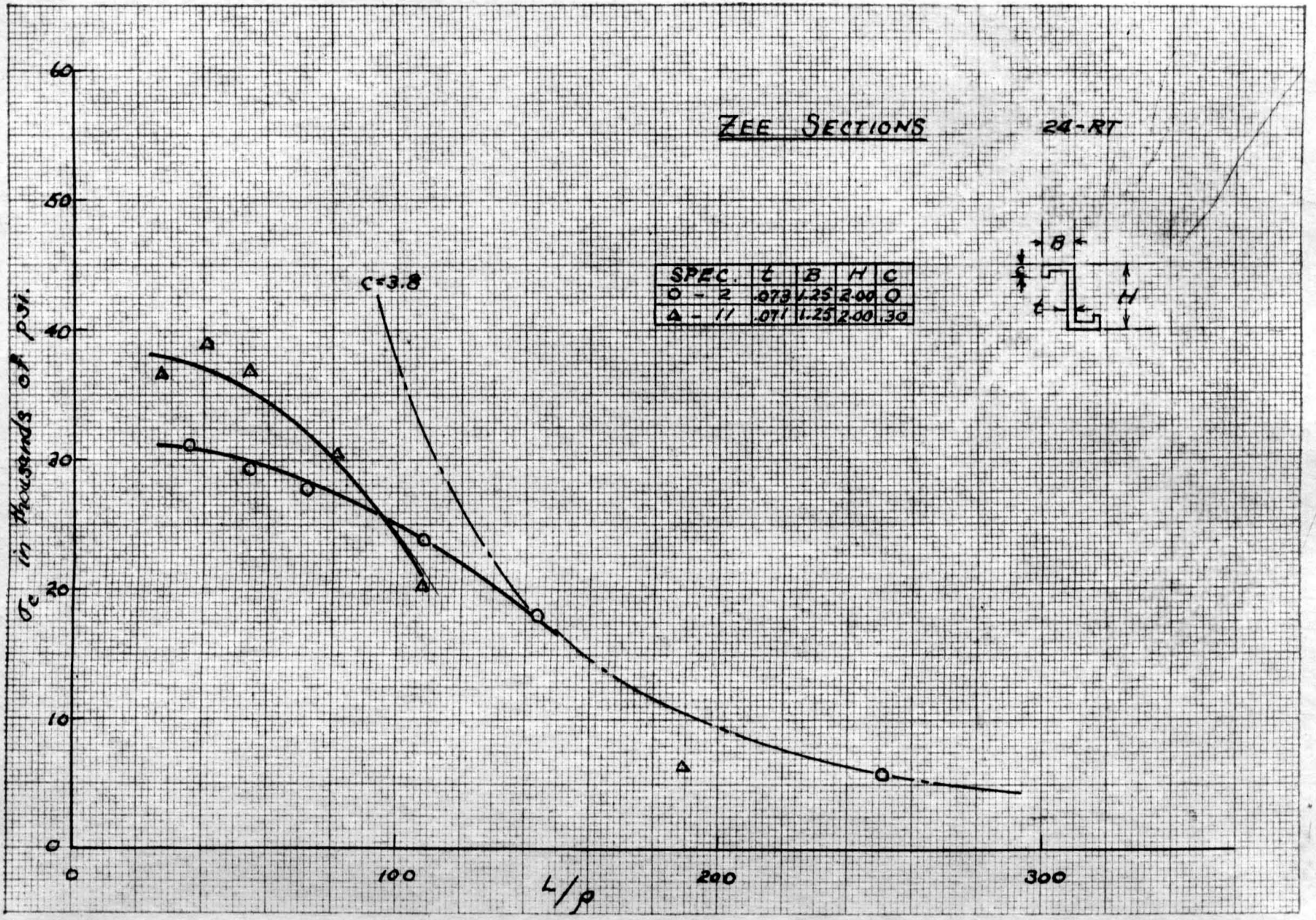
*75" Length Test Specimen

ZEE SECTIONS

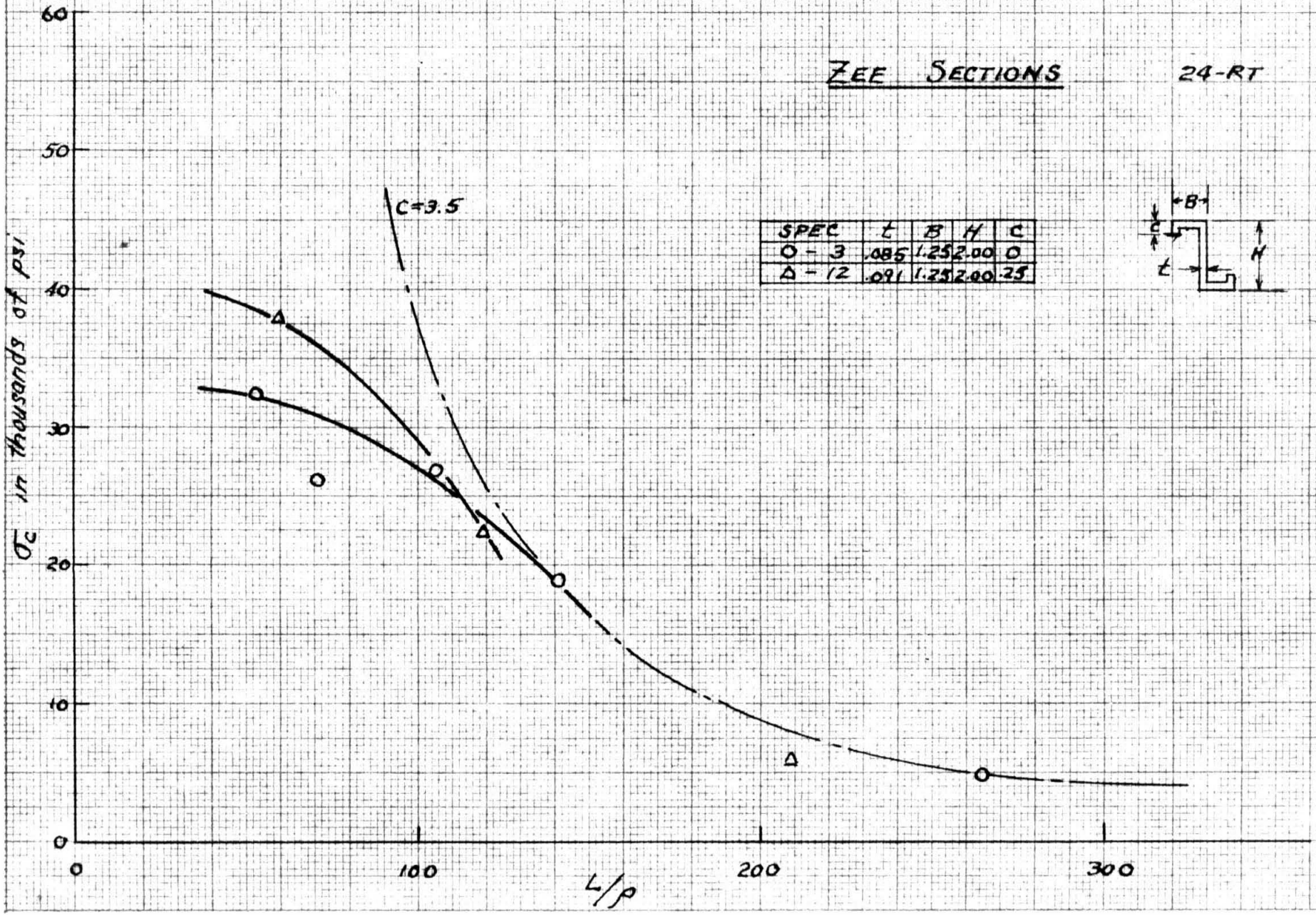
24-RT

SPEC.		t	B	H	C
△	9	.048	1.25	2.00	.15
○	1	.049	1.25	2.00	0
□	10	.049	1.25	2.00	.25




ZEE SECTIONS
24-RT
SPEC. t B H C
O - 2 .073 1.25 2.00 0
Δ - 11 .071 1.25 2.00 30
B
t
H
C=3.8
60
50
40
30
20
10
0
0
100
200
300
σc in thousands of psi.
L/ρ

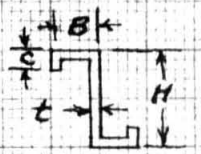
ZEE SECTIONS 24-RT



SPEC	t	B	H	C
O - 3	.085	1.25	2.00	0
Δ - 12	.091	1.25	2.00	.25

ZEE SECTIONS 24-RT

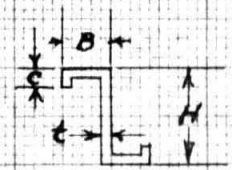
SPEC	t	B	H	C
O – 4	.122	1.25	2.00	0

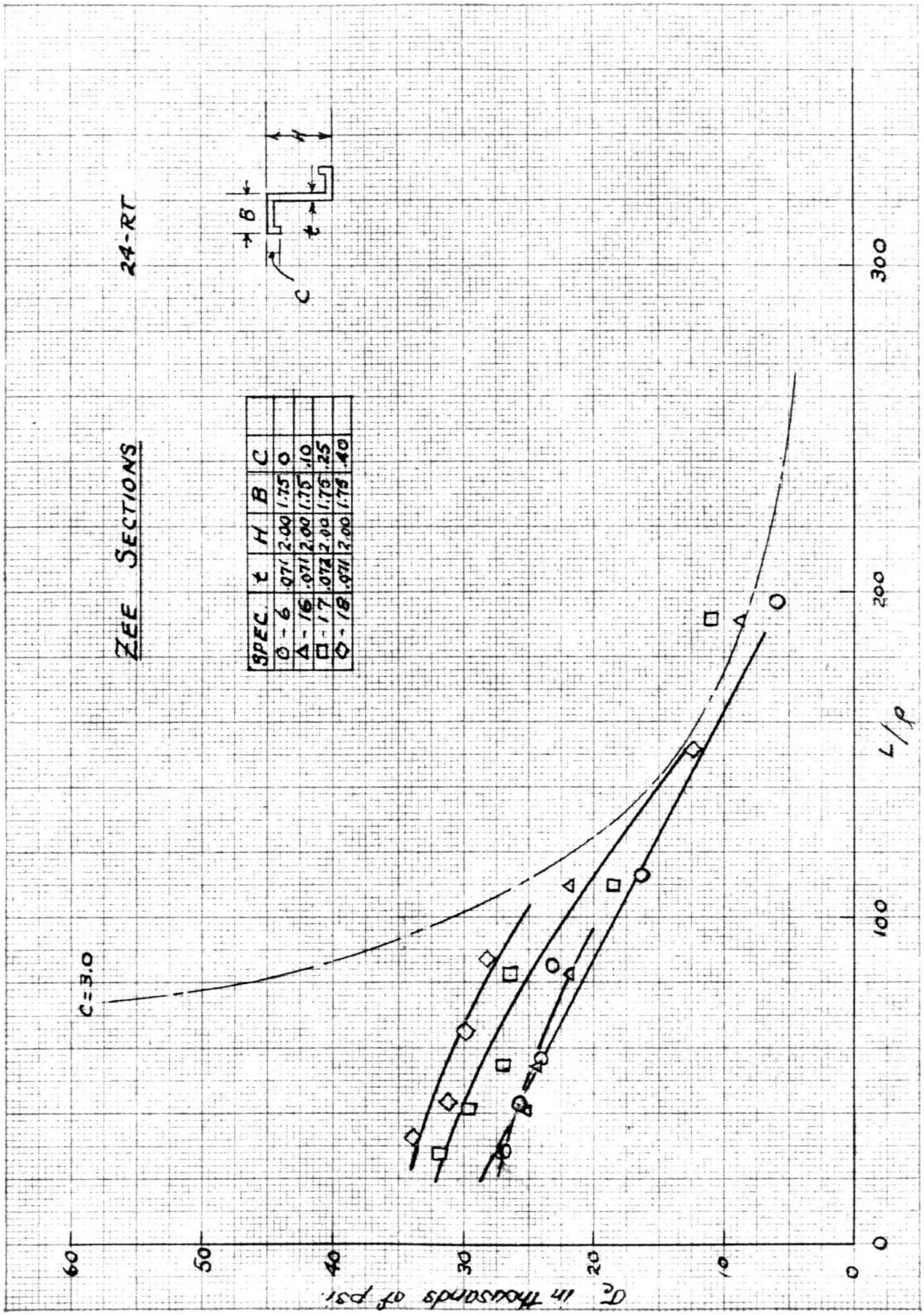


ZEE SECTIONS

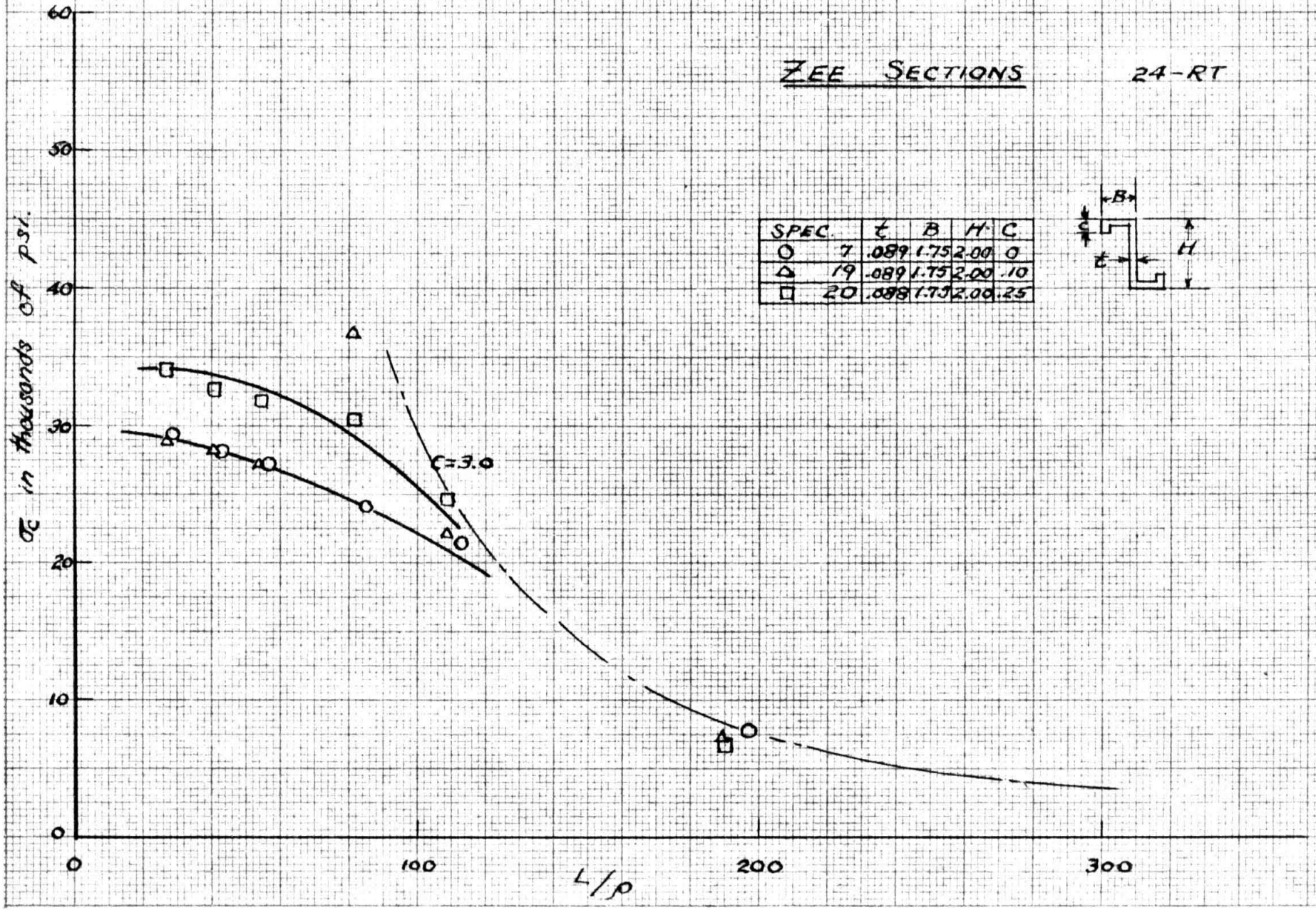
24-RT

SPEC.		t	B	H	C
○	3	.050	1.75	2.00	0
△	13	.049	1.75	2.00	.12
□	14	.048	1.75	2.00	.25
◊	15	.049	1.75	2.00	.35

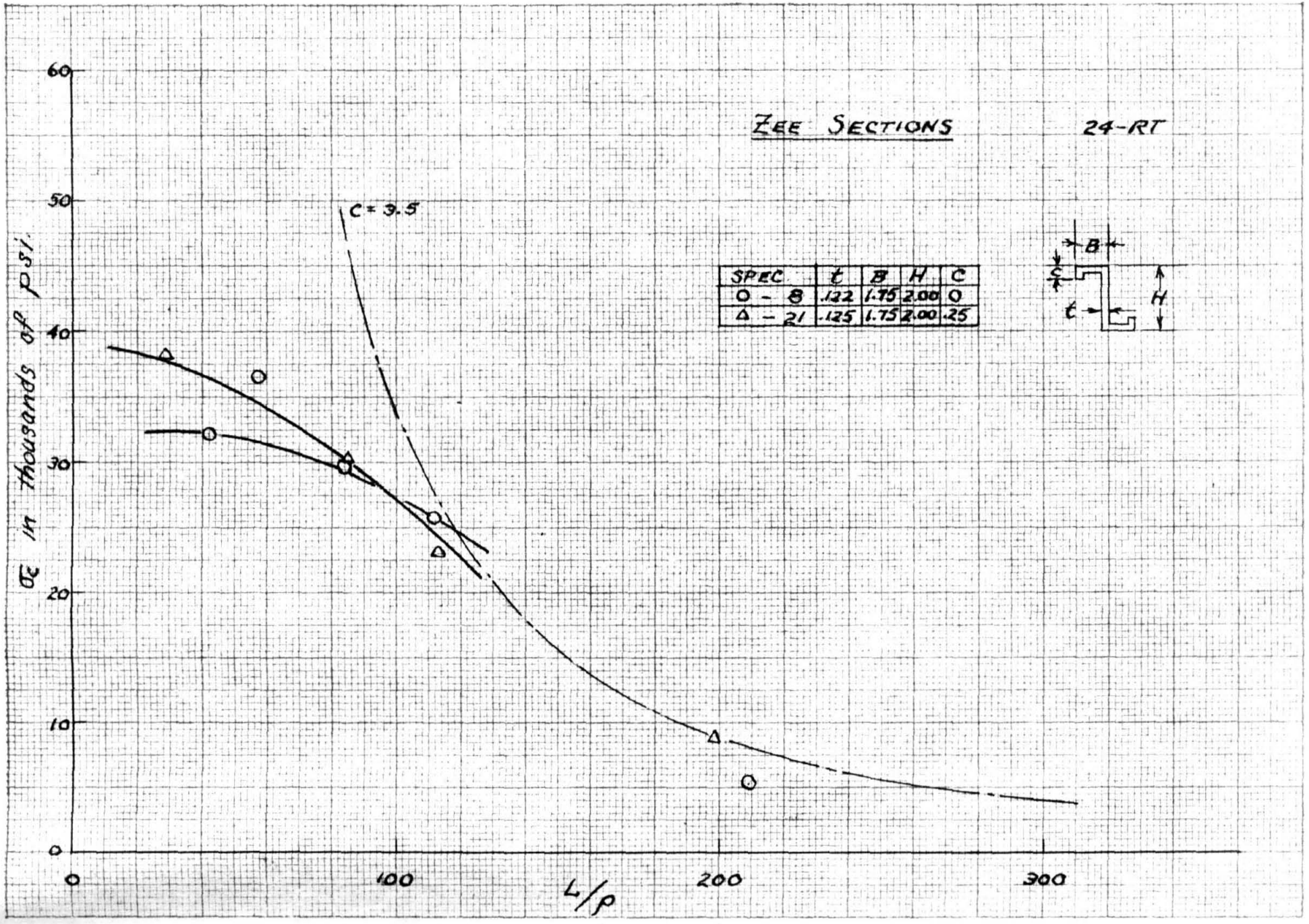



24-RT
ZEE SECTIONS
SPEC t H B C
○ - 6 .071 2.00 1.75 0
△ - 16 .071 2.00 1.75 .10
□ - 17 .072 2.00 1.75 .25
◇ - 18 .071 2.00 1.75 .40
B
H
t
C
C=3.0
σ_c in thousands of psi
L/ρ
0
10
20
30
40
50
60
100
200
300

ZEE SECTIONS 24-RT



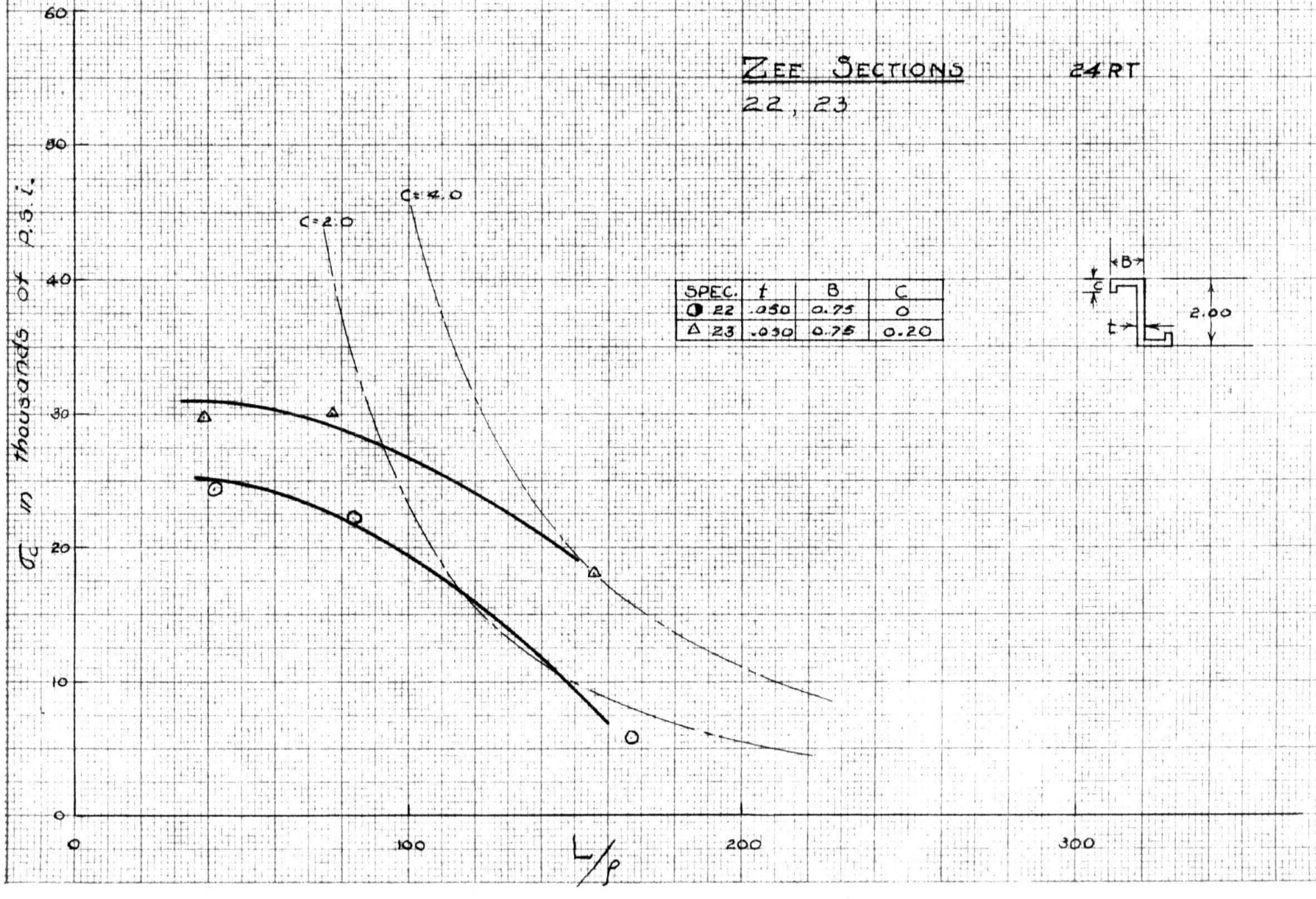
SPEC.		t	B	H	C
○	7	.089	1.75	2.00	0
△	19	.089	1.75	2.00	.10
□	20	.088	1.75	2.00	.25



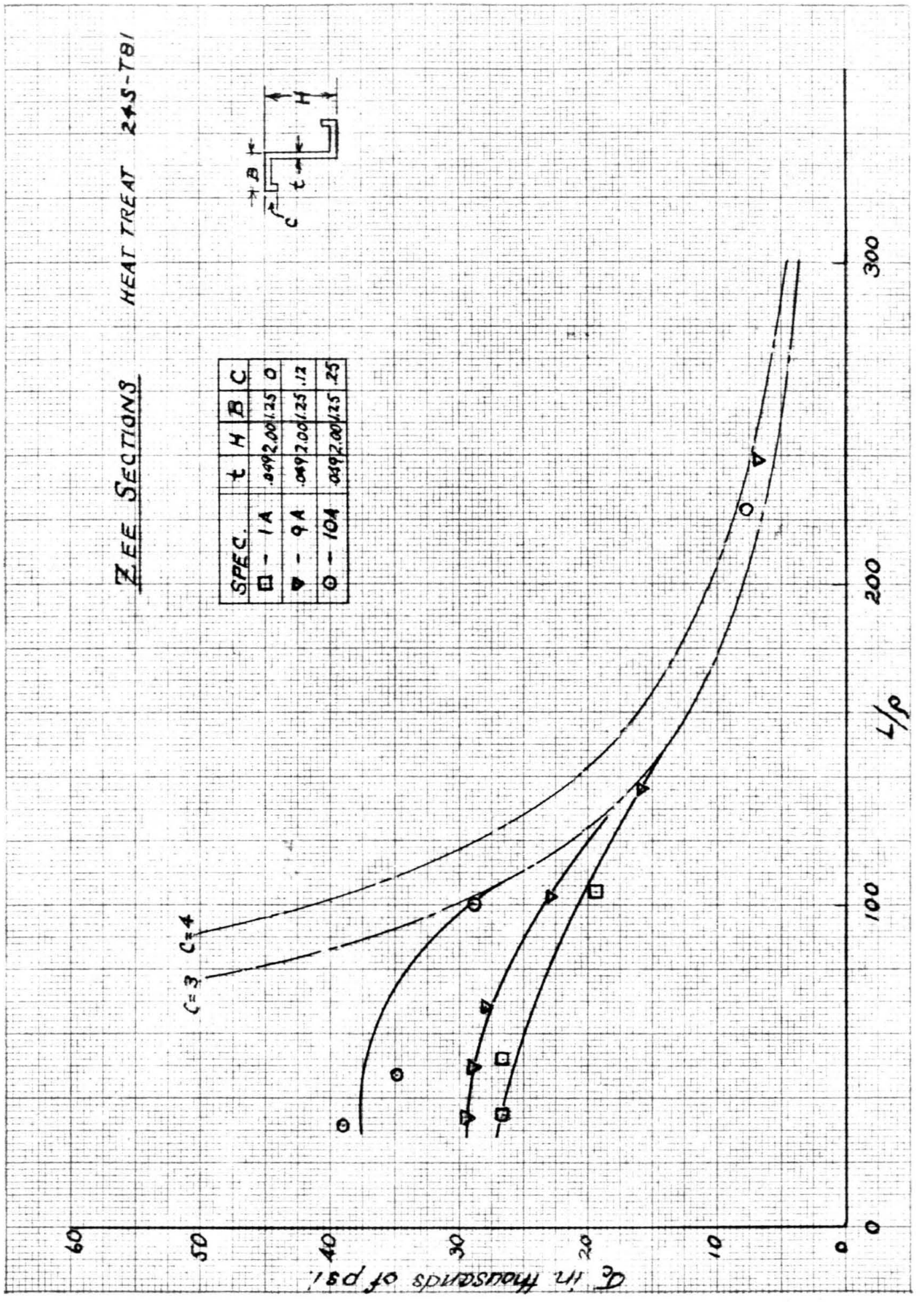
SPEC	t	B	H	C
O - 8	.122	1.75	2.00	0
Δ - 21	.125	1.75	2.00	.25

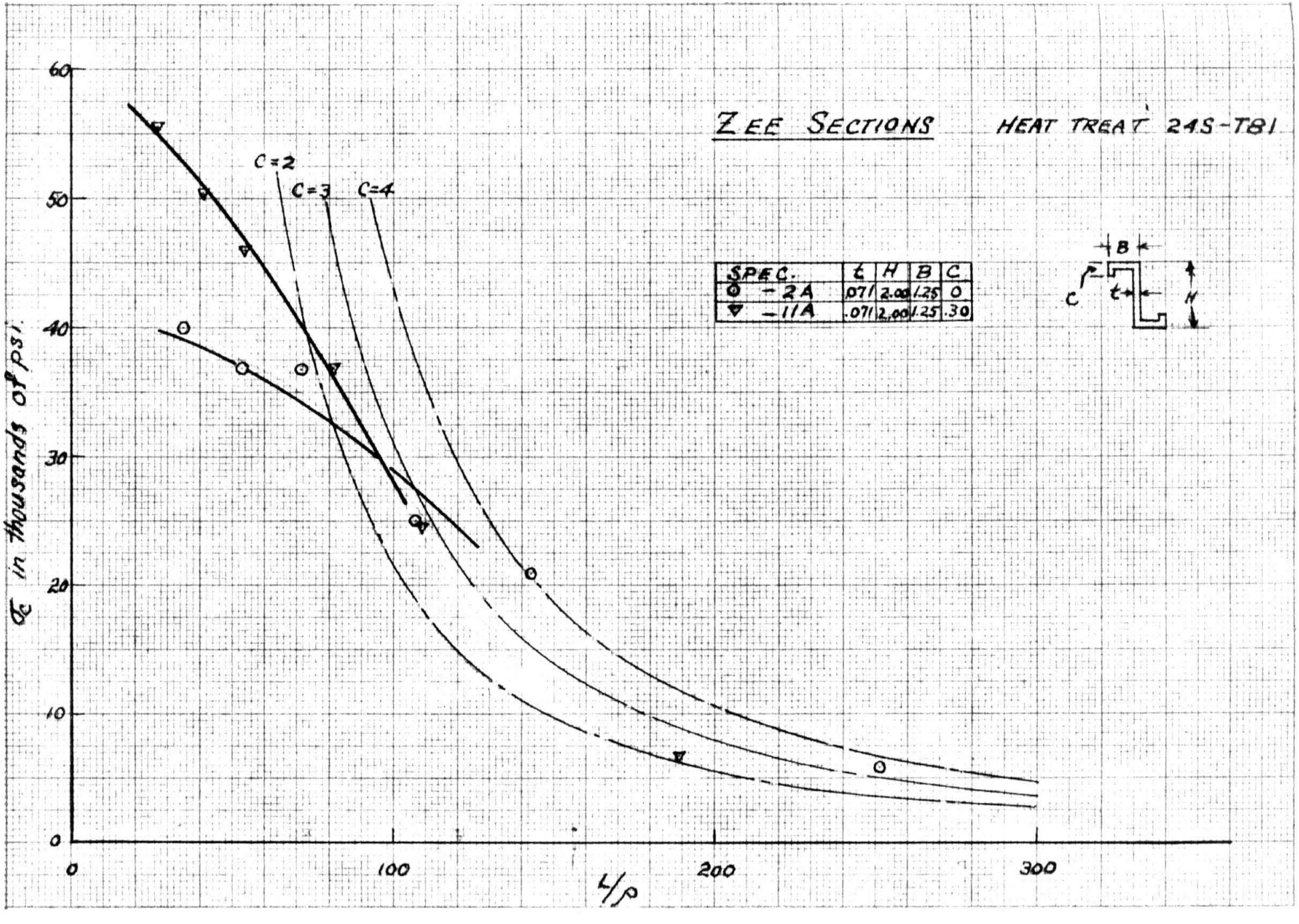
ZEE SECTIONS 24RT

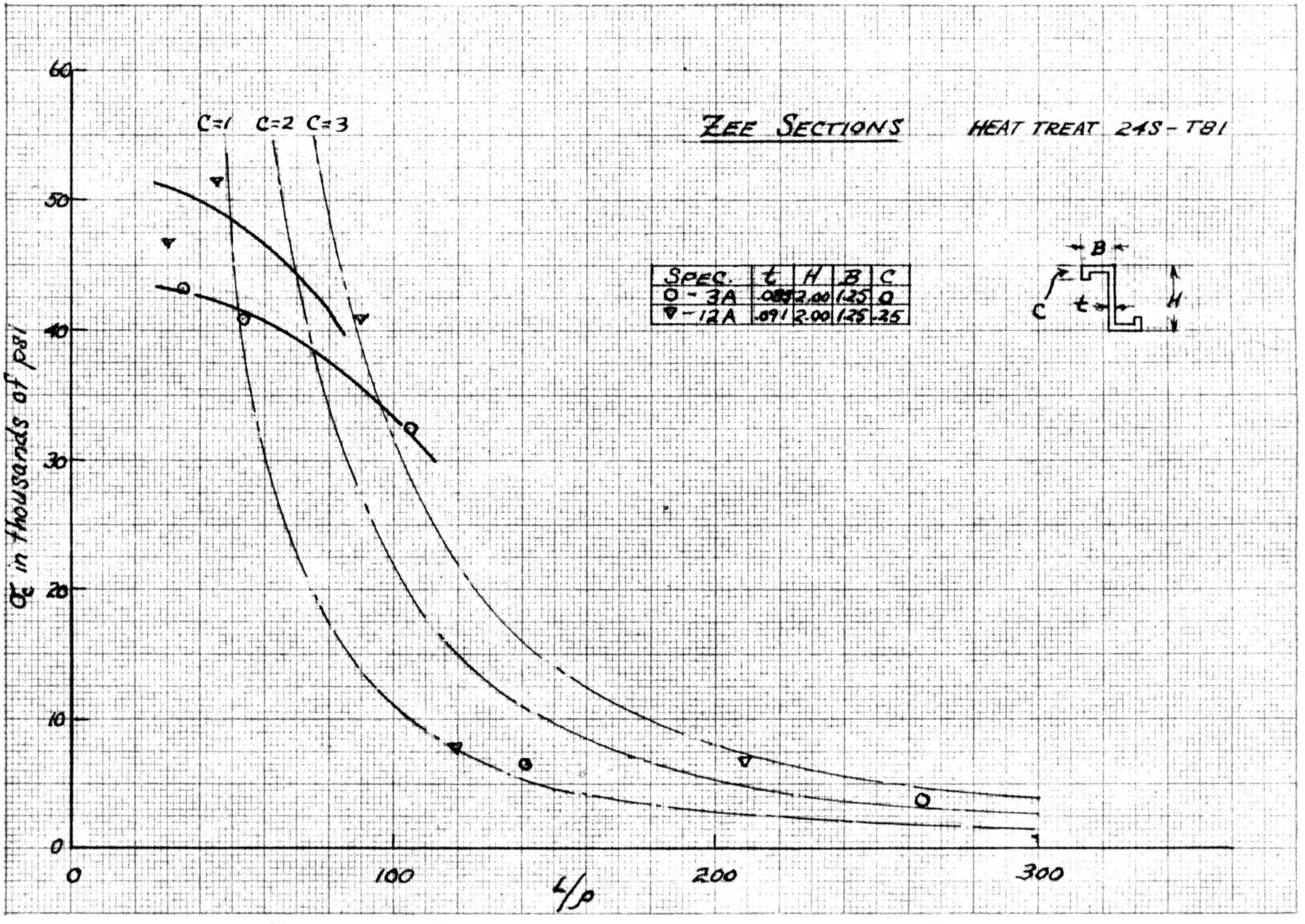
22, 23



SPEC.	t	B	C
◑ 22	.050	0.75	0
△ 23	.030	0.75	0.20

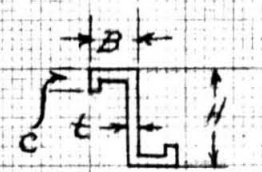

ZEE SECTIONS
HEAT TREAT 24S-T81
SPEC. t H B C
□ - 1A .049 2.00 1.25 0
▼ - 9A .049 2.00 1.25 .12
⊙ - 10A .049 2.00 1.25 .25
B
C
t
H
C=3
C=4
σ in thousands of psi
L/ρ
0
10
20
30
40
50
60
100
200
300

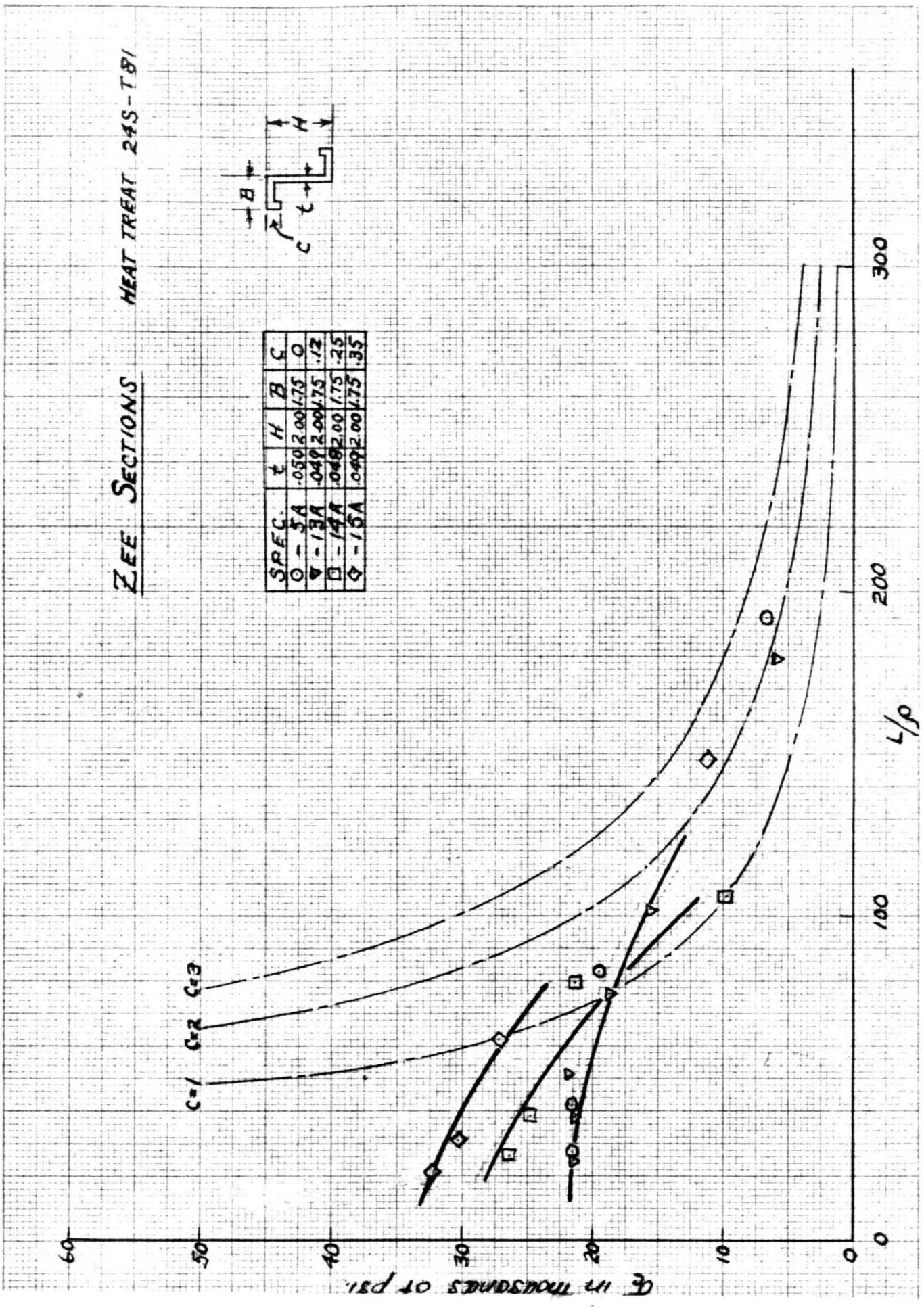

ZEE SECTIONS
HEAT TREAT 24S-T81
C=2
C=3
C=4
SPEC. t H B C
-2A .071 2.00 1.25 0
-11A .071 2.00 1.25 .30
B
C
t
H
60
50
40
30
20
10
0
0
100
200
300
σc in thousands of psi.
L/ρ

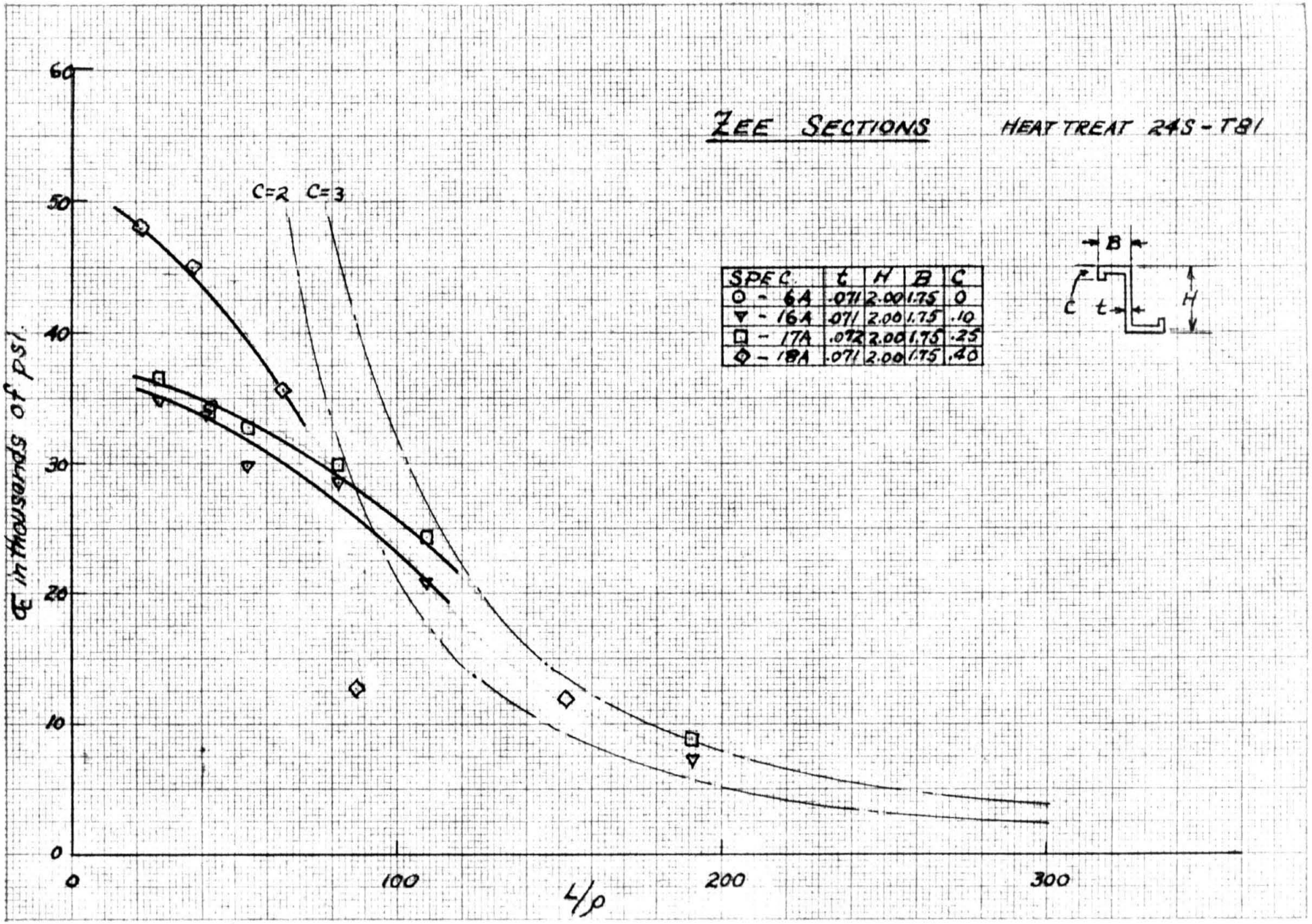

ZEE SECTIONS
HEAT TREAT 24S - T81
C=1 C=2 C=3
SPEC. t H B C
O - 3A .087 2.00 1.25 0
▽ - 12A .091 2.00 1.25 .25
B
C
t
H
σ_c in thousands of psi
0
10
20
30
40
50
60
0
100
200
300
L/ρ

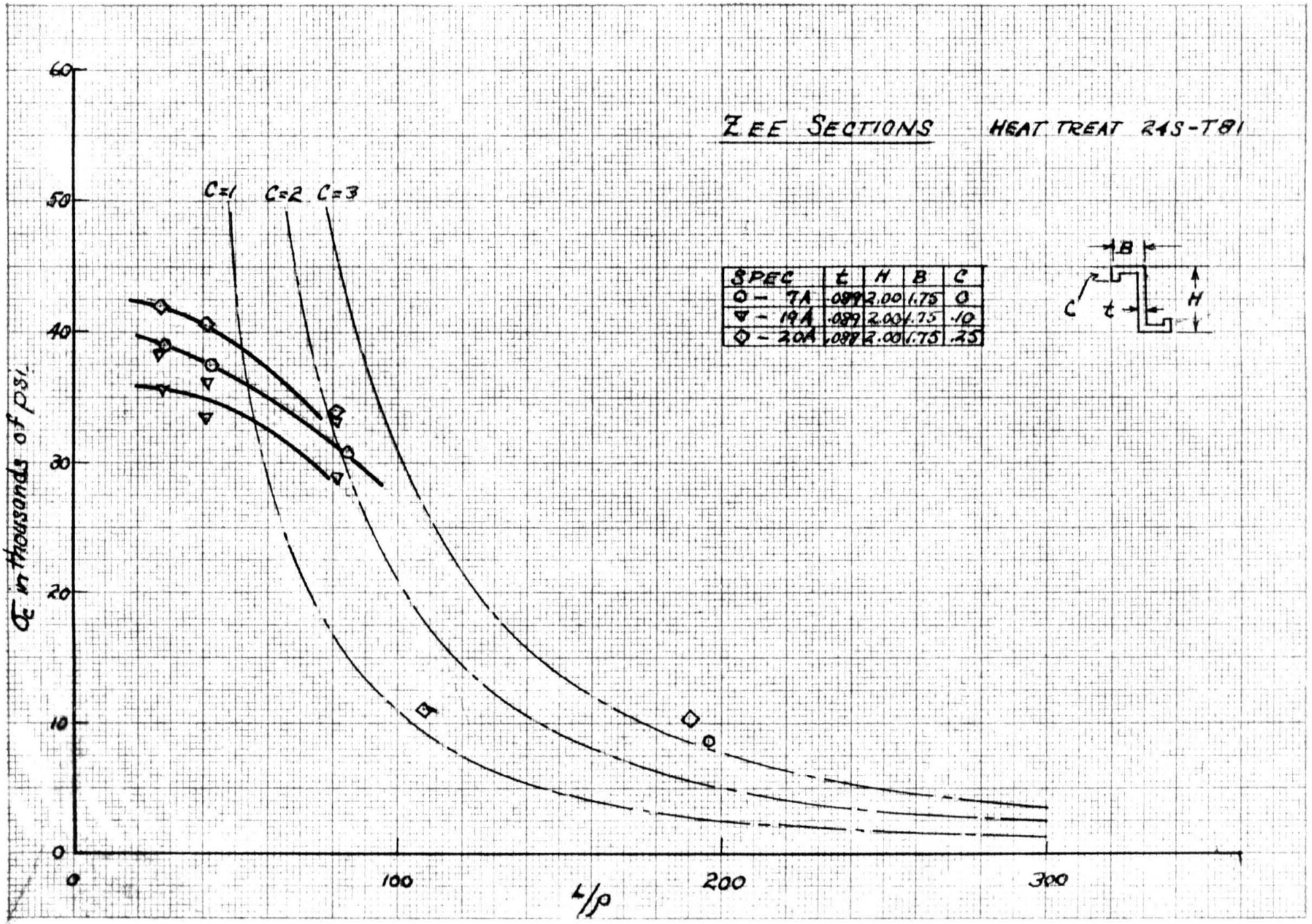
ZEE SECTIONS HEAT TREAT 24S-T81

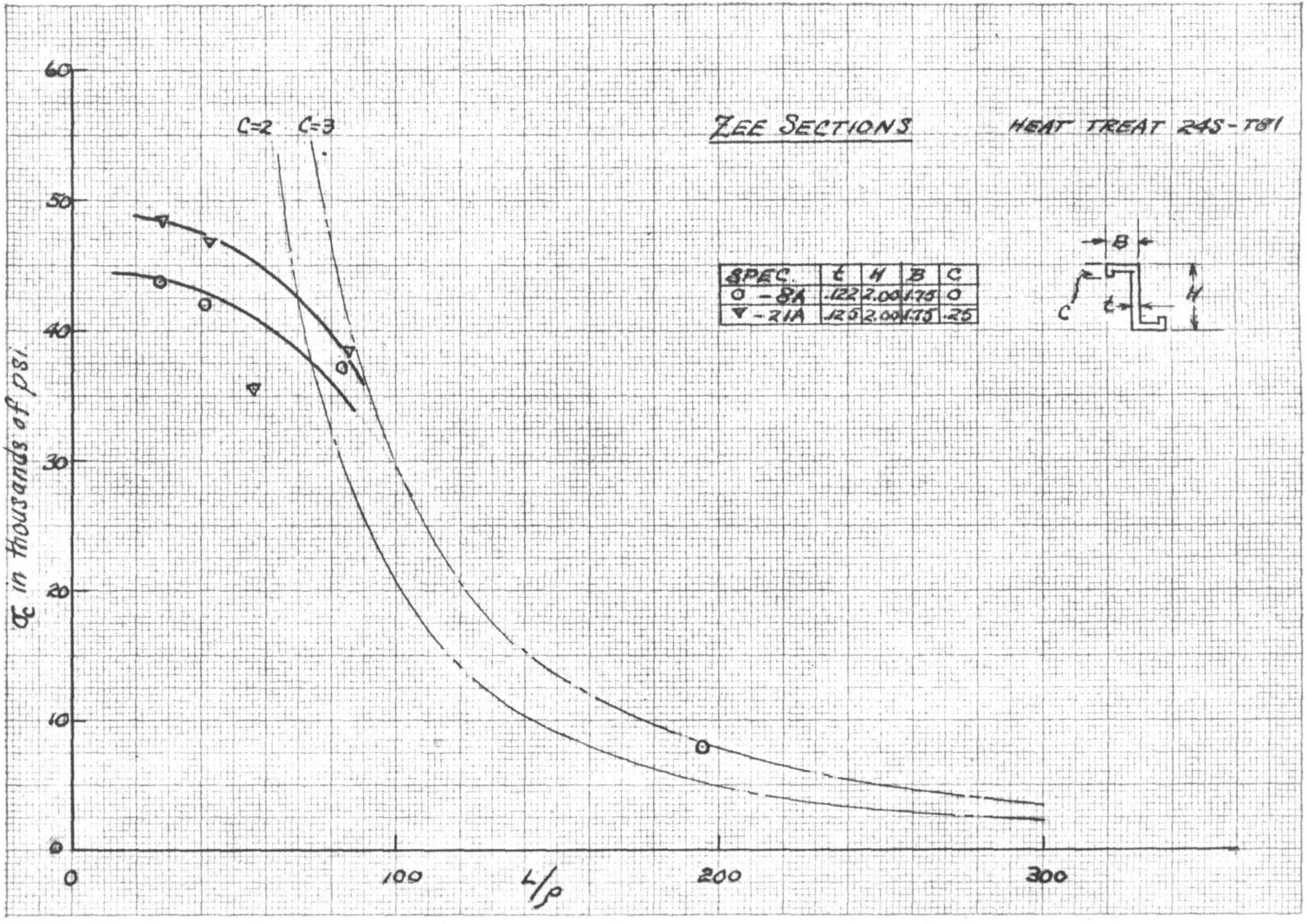
SPEC.	t	H	B	C
O-4A	.125	2.00	1.25	0




ZEE SECTIONS HEAT TREAT 24S-T81
SPEC. t H B C
○ -5A .050 2.00 1.75 0
▽ -13A .049 2.00 1.75 .12
□ -14A .048 2.00 1.75 .25
◇ -15A .049 2.00 1.75 .35
B
H
C
t
C=1
C=2
C=3
σc in thousands of psi
60
50
40
30
20
10
0
0
100
200
300
L/ρ


ZEE SECTIONS
HEAT TREAT 24S-T81
C=2
C=3
SPEC. t H B C
○ - 16A .071 2.00 1.75 0
▽ - 16A .071 2.00 1.75 .10
□ - 17A .072 2.00 1.75 .25
◇ - 18A .071 2.00 1.75 .40
B
C
t
H
Fc in thousands of psi.
60
50
40
30
20
10
0
0
100
200
300
L/ρ

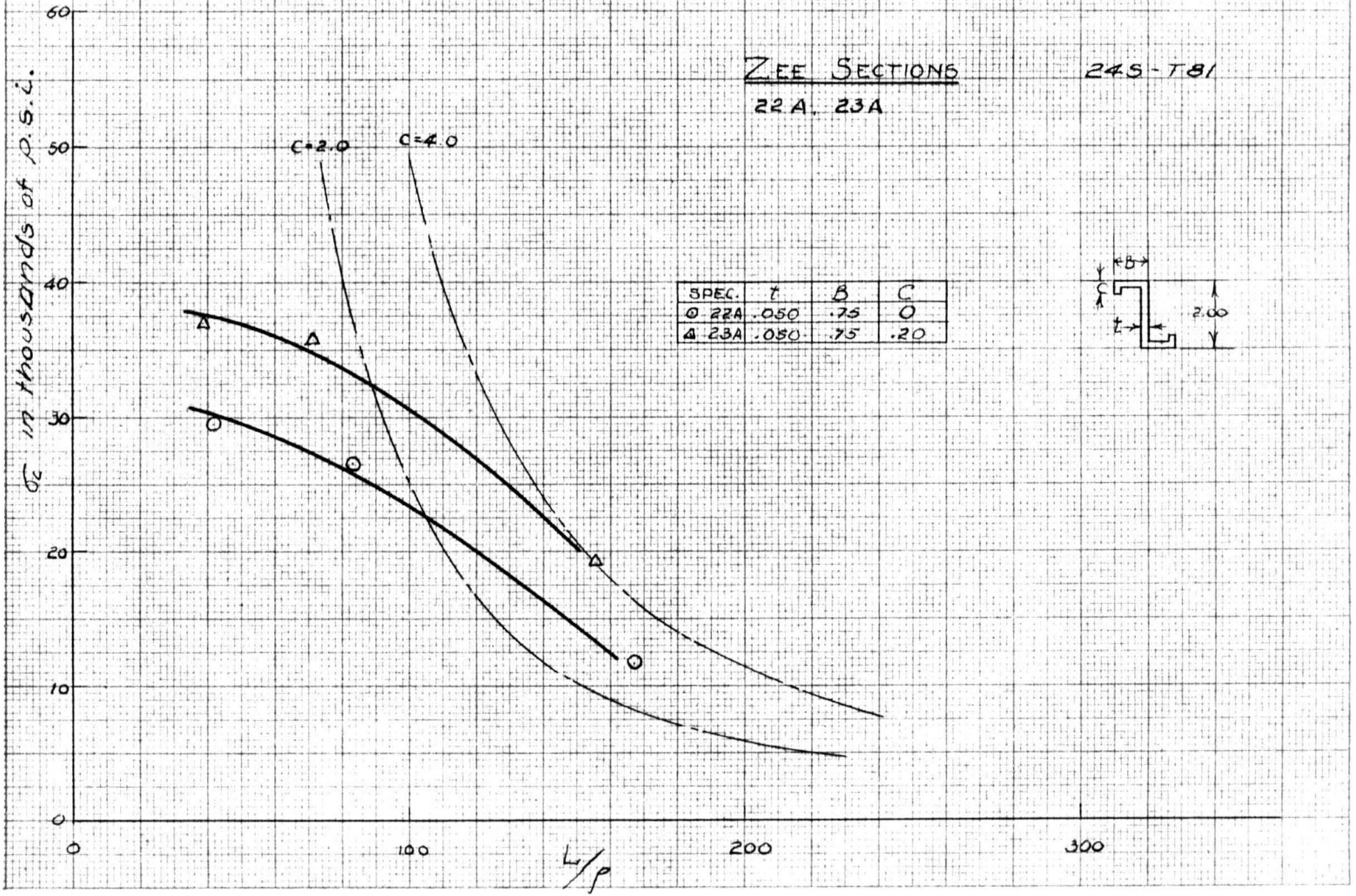

ZEE SECTIONS HEAT TREAT 24S-T81
C=1 C=2 C=3
SPEC t H B C
○ - 7A .089 2.00 1.75 0
▽ - 19A .089 2.00 1.75 .10
◇ - 20A .089 2.00 1.75 .25
B
H
C
t
60
50
40
30
20
10
0
0
100
200
300
L/ρ
σc in thousands of psi.


ZEE SECTIONS
HEAT TREAT 24S-T81
C=2
C=3
SPEC. t H B C
○ -8A .122 2.00 1.75 0
▽ -21A .125 2.00 1.75 .25
B
C
t
H
60
50
40
30
20
10
0
0
100
200
300
L/ρ
σc in thousands of psi.

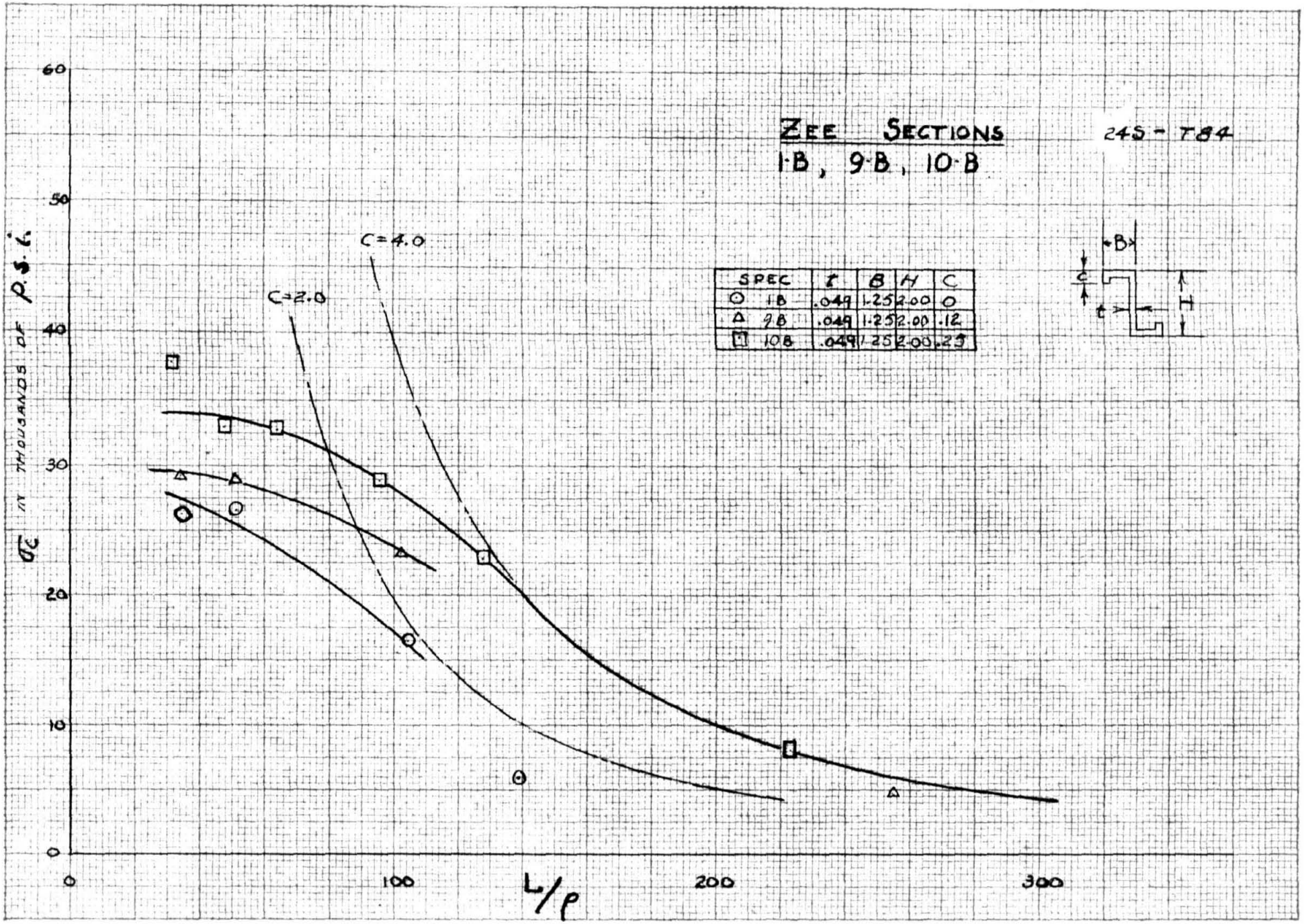
ZEE SECTIONS

22A, 23A

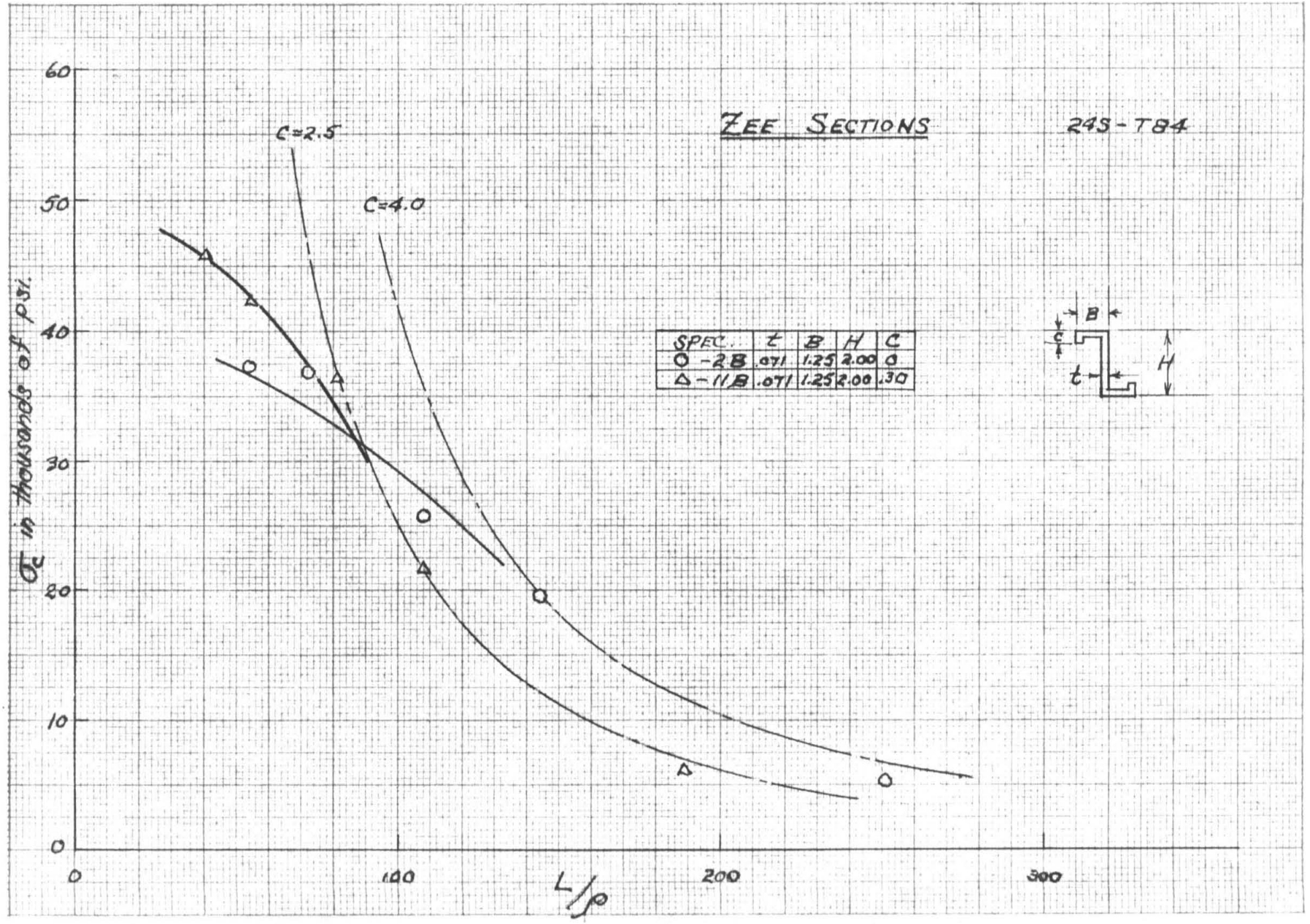
24S-T81



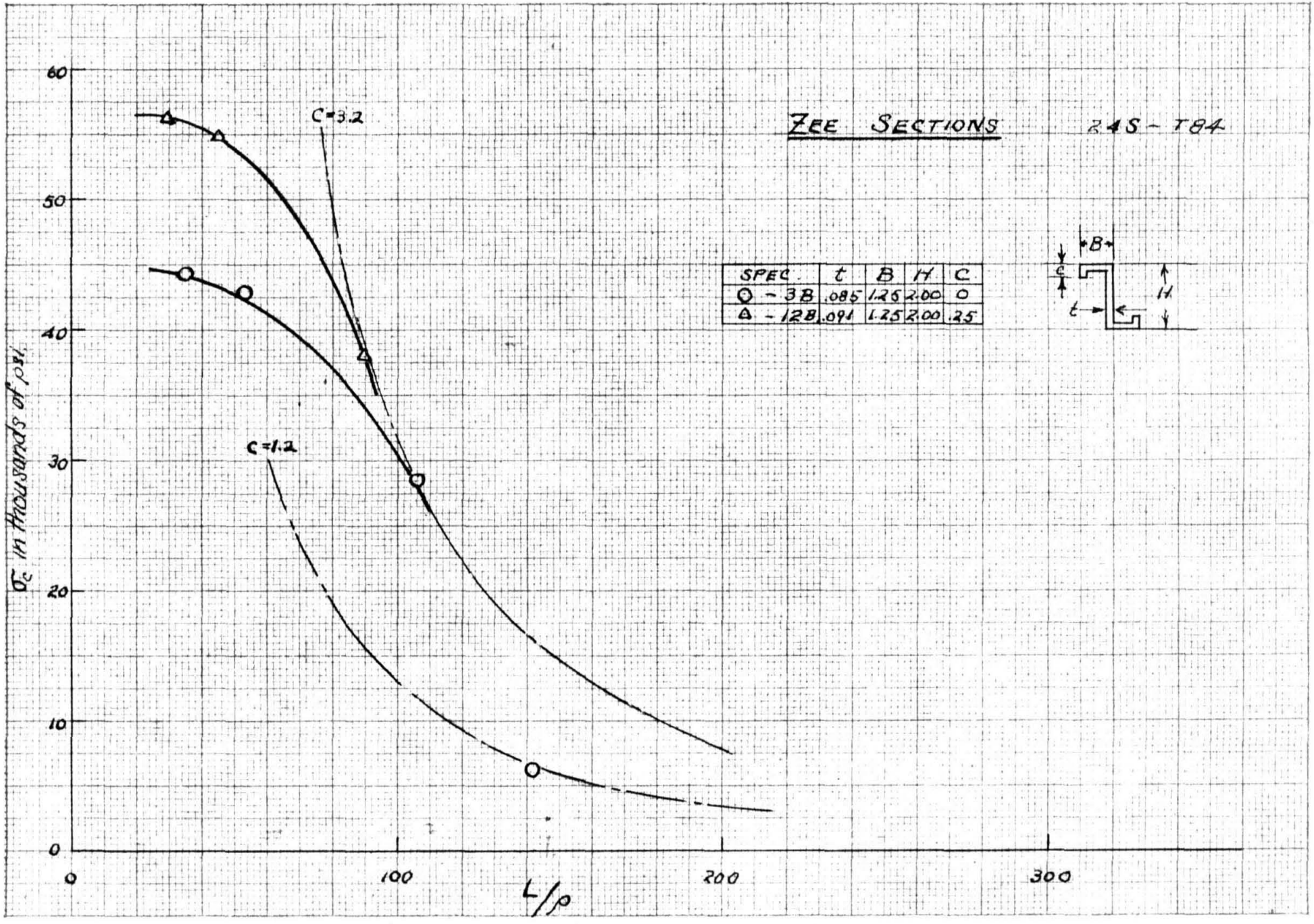
SPEC.	t	B	C
○ 22A	.050	.75	0
△ 23A	.050	.75	.20

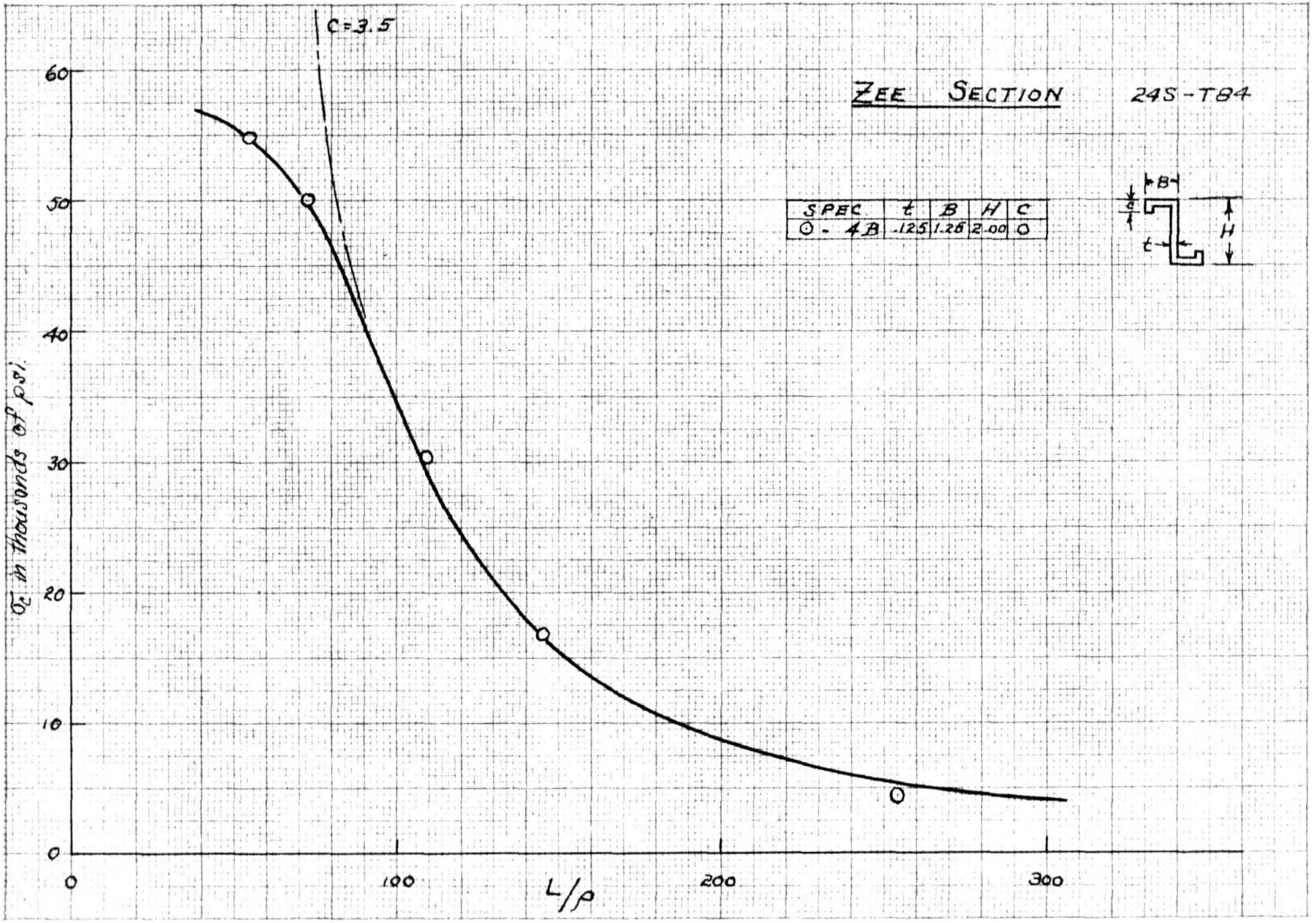

ZEE SECTIONS
1-B, 9-B, 10-B
24S - T84
SPEC t B H C
1B .049 1.25 2.00 0
9B .049 1.25 2.00 .12
10B .049 1.25 2.00 .25
C=4.0
C=2.0
B
C
H
t
60
50
40
30
20
10
0
100
200
300
L/ρ
σc IN THOUSANDS OF P.S.I.

ZEE SECTIONS 24S-T84

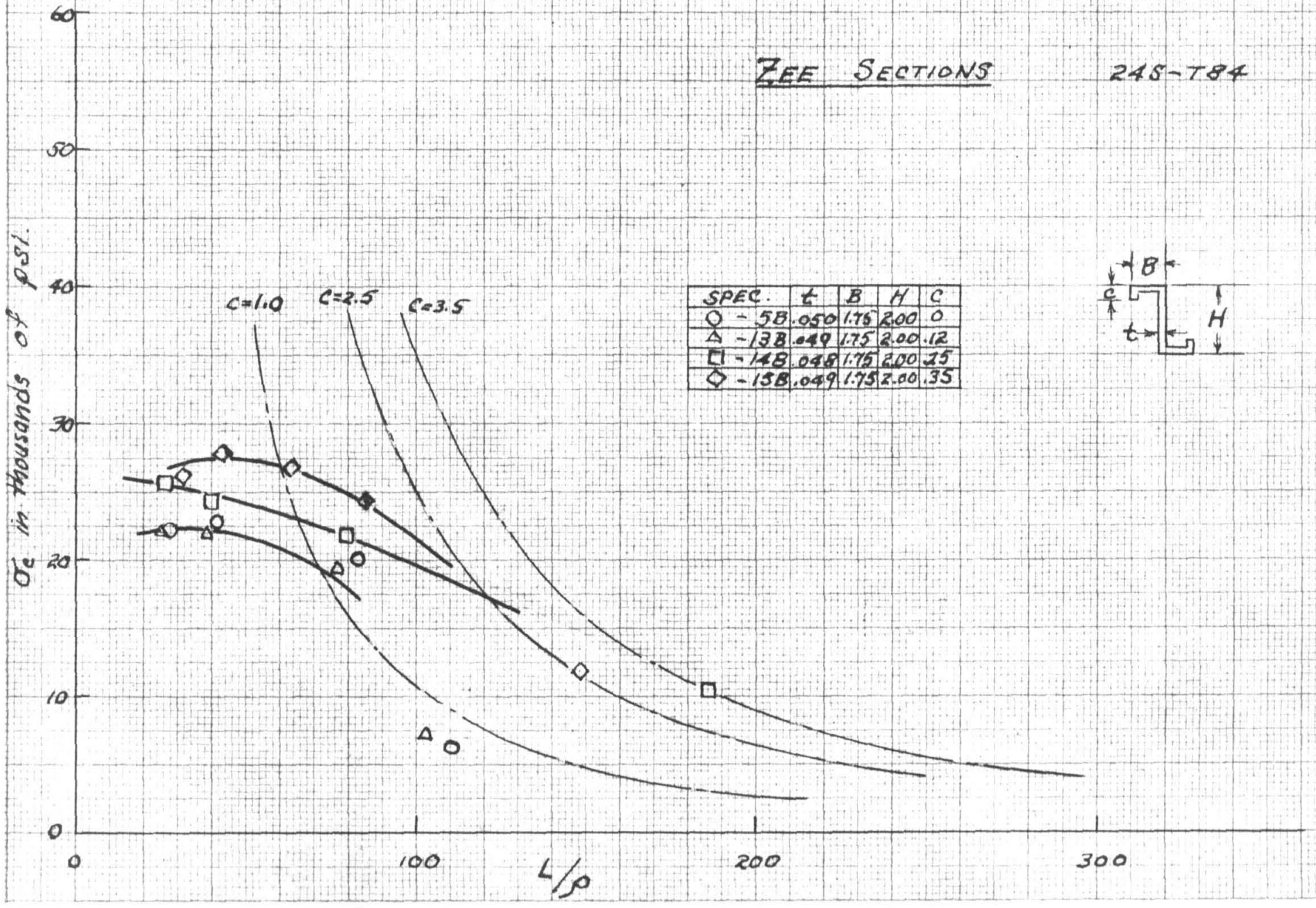


SPEC.	t	B	H	C
O -2B	.071	1.25	2.00	0
Δ -11B	.071	1.25	2.00	.30


ZEE SECTIONS 24S - T84
SPEC t B H C
O - 3B .085 1.25 2.00 0
Δ - 12B .091 1.25 2.00 .25
B
C
H
t
C=3.2
C=1.2
60
50
40
30
20
10
0
0
100
200
300
L/ρ
σc in thousands of psi.

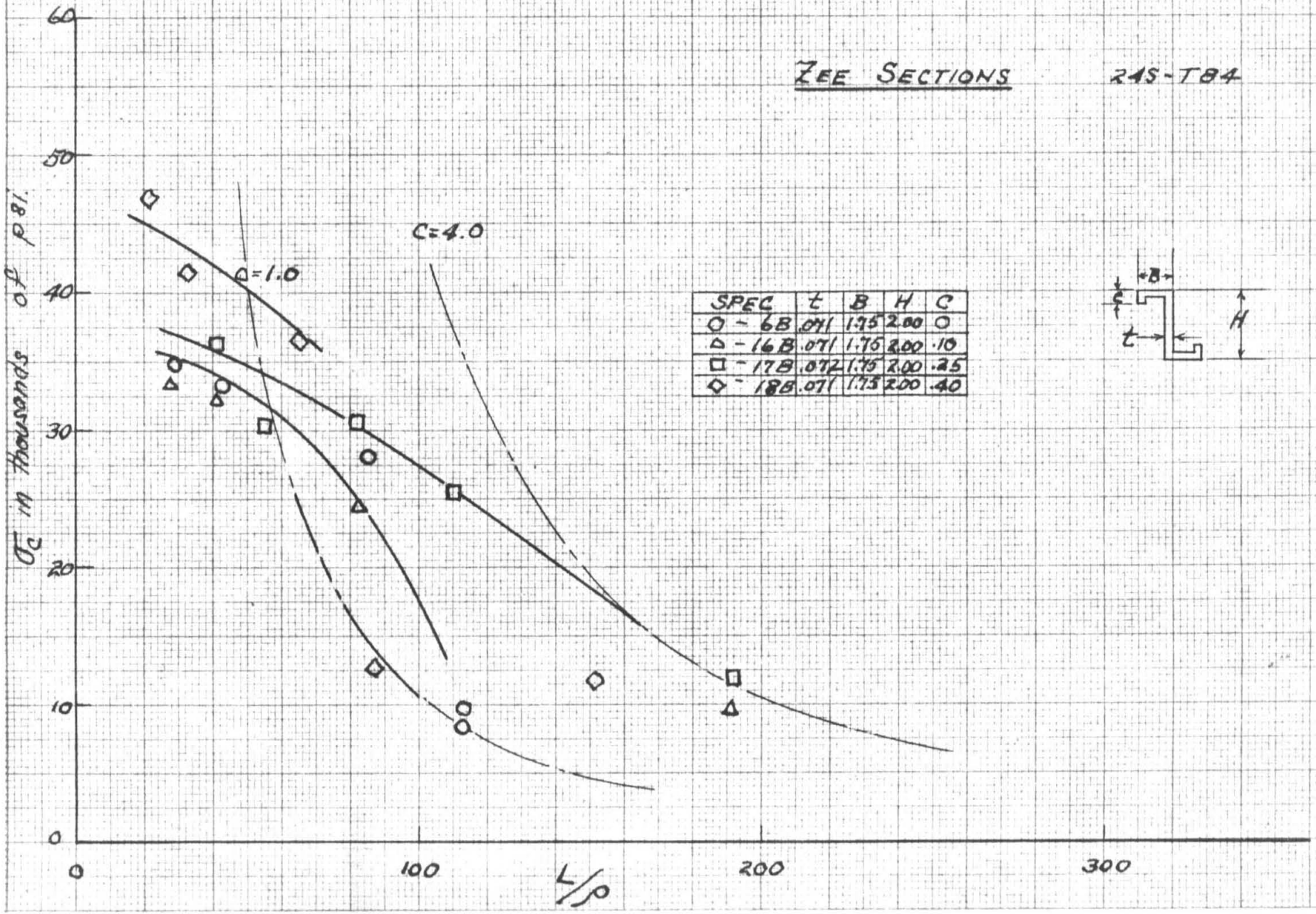

C=3.5
ZEE SECTION 24S-T84
SPEC t B H C
⊙ - 4B .125 1.26 2.00 0
B
t
t
H
60
50
40
30
20
10
0
0
100
200
300
L/ρ
σc in thousands of psi.

ZEE SECTIONS 24S-T84



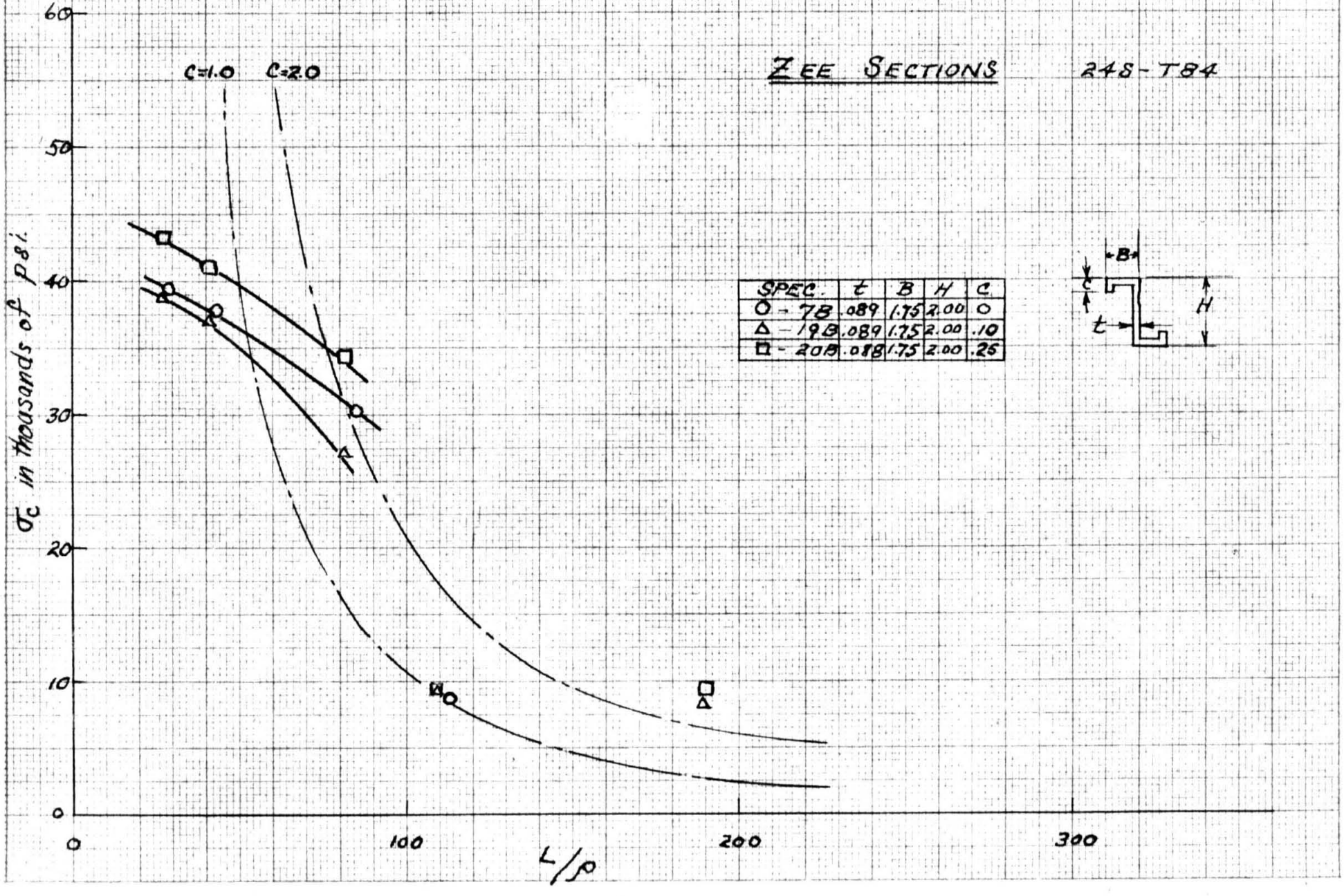
SPEC.	t	B	H	C
○ - 5B	.050	1.75	2.00	0
△ - 13B	.049	1.75	2.00	.12
□ - 14B	.048	1.75	2.00	.25
◇ - 15B	.049	1.75	2.00	.35

Zee Sections 24S-T84



SPEC	t	B	H	C
○ - 6B	.071	1.75	2.00	0
△ - 16B	.071	1.75	2.00	.10
□ - 17B	.072	1.75	2.00	.25
◇ - 18B	.071	1.75	2.00	.40

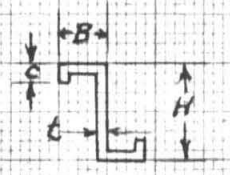
ZEE SECTIONS 24S-T84

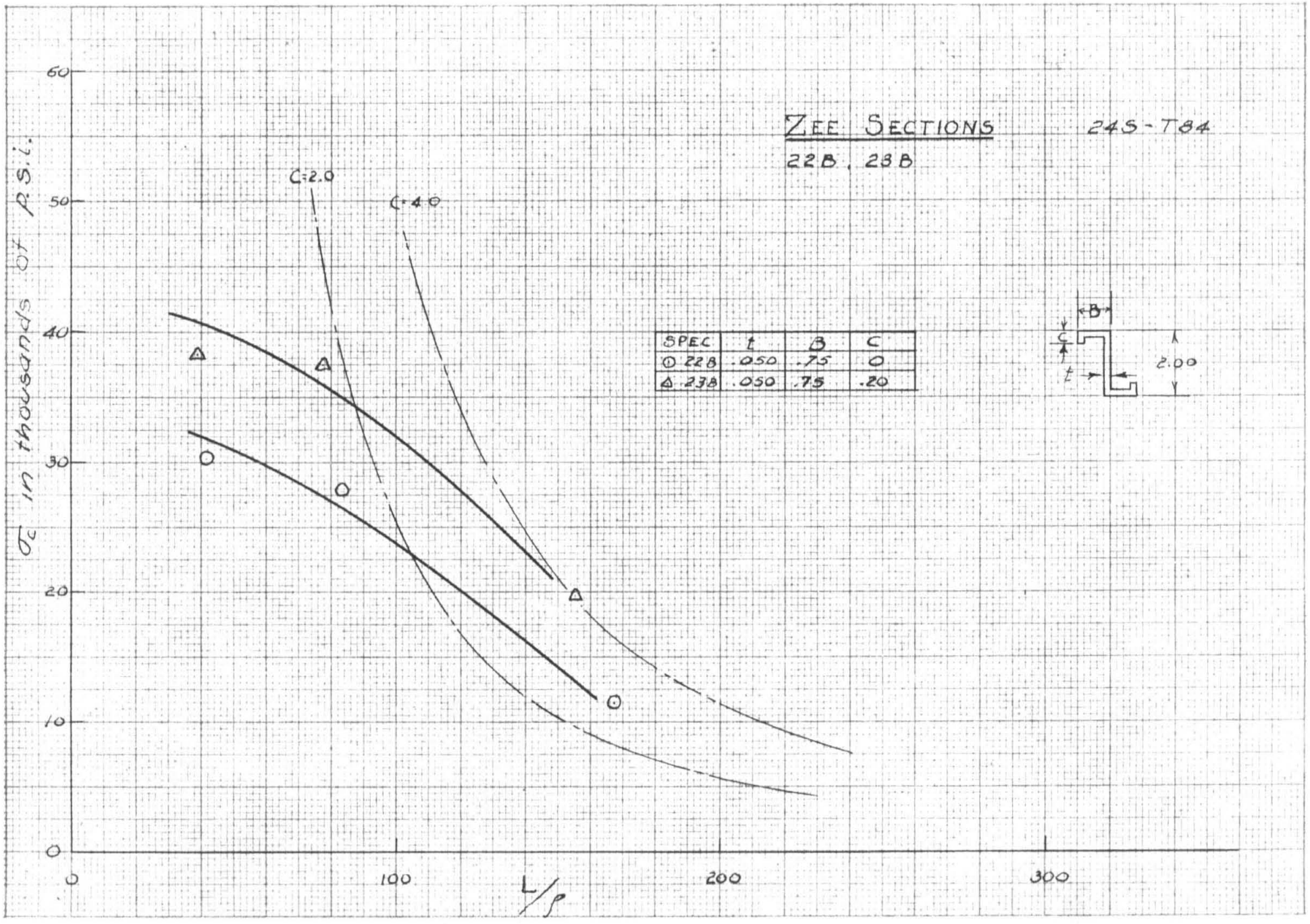


SPEC.	t	B	H	C
○ - 7B	.089	1.75	2.00	0
△ - 19B	.089	1.75	2.00	.10
□ - 20B	.088	1.75	2.00	.25

ZEE SECTIONS 24S-T84

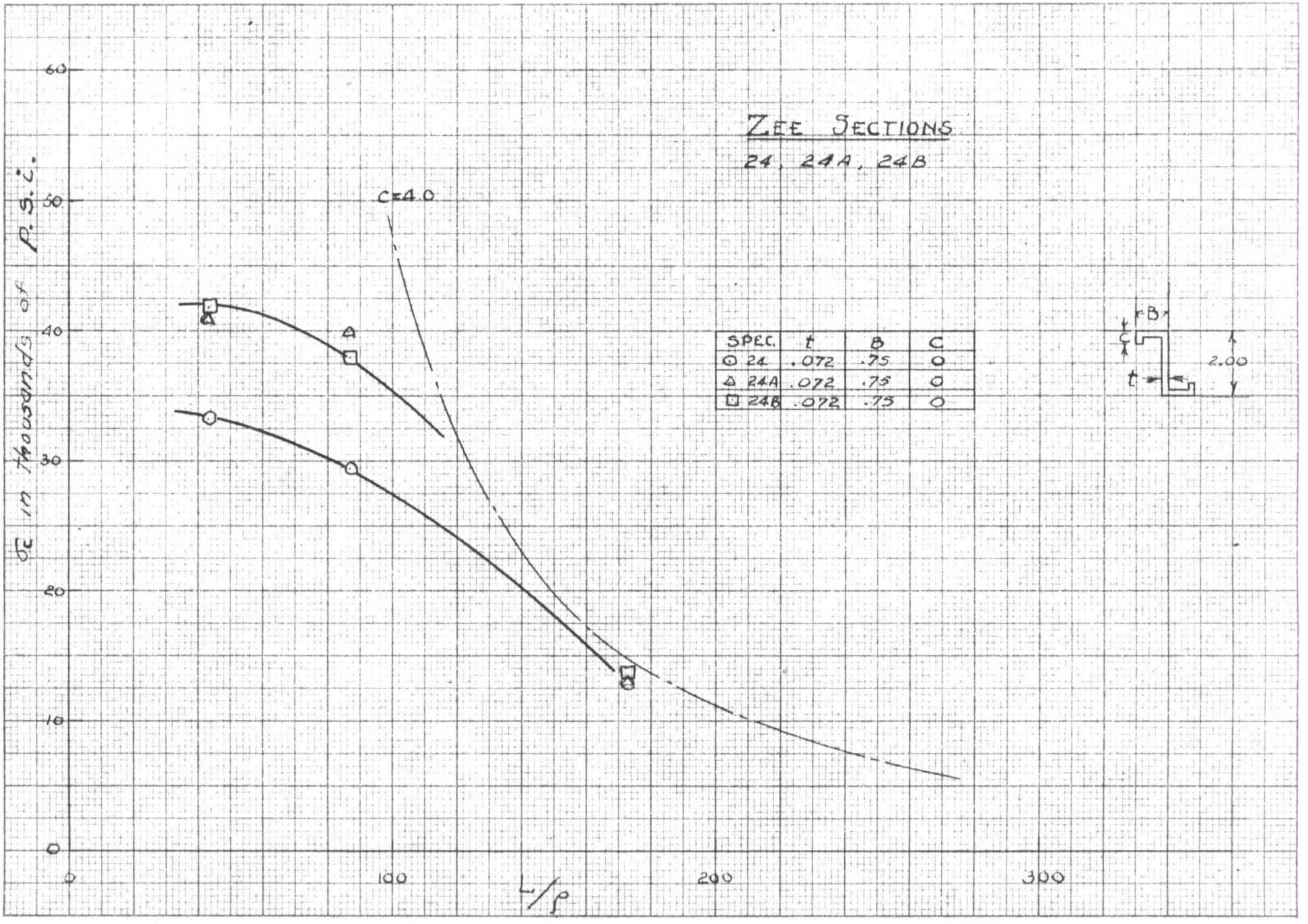
SPEC.	t	B	H	C
⊙ - 8B	.122	1.75	2.00	0
△ - 21B	.125	1.75	2.00	.25



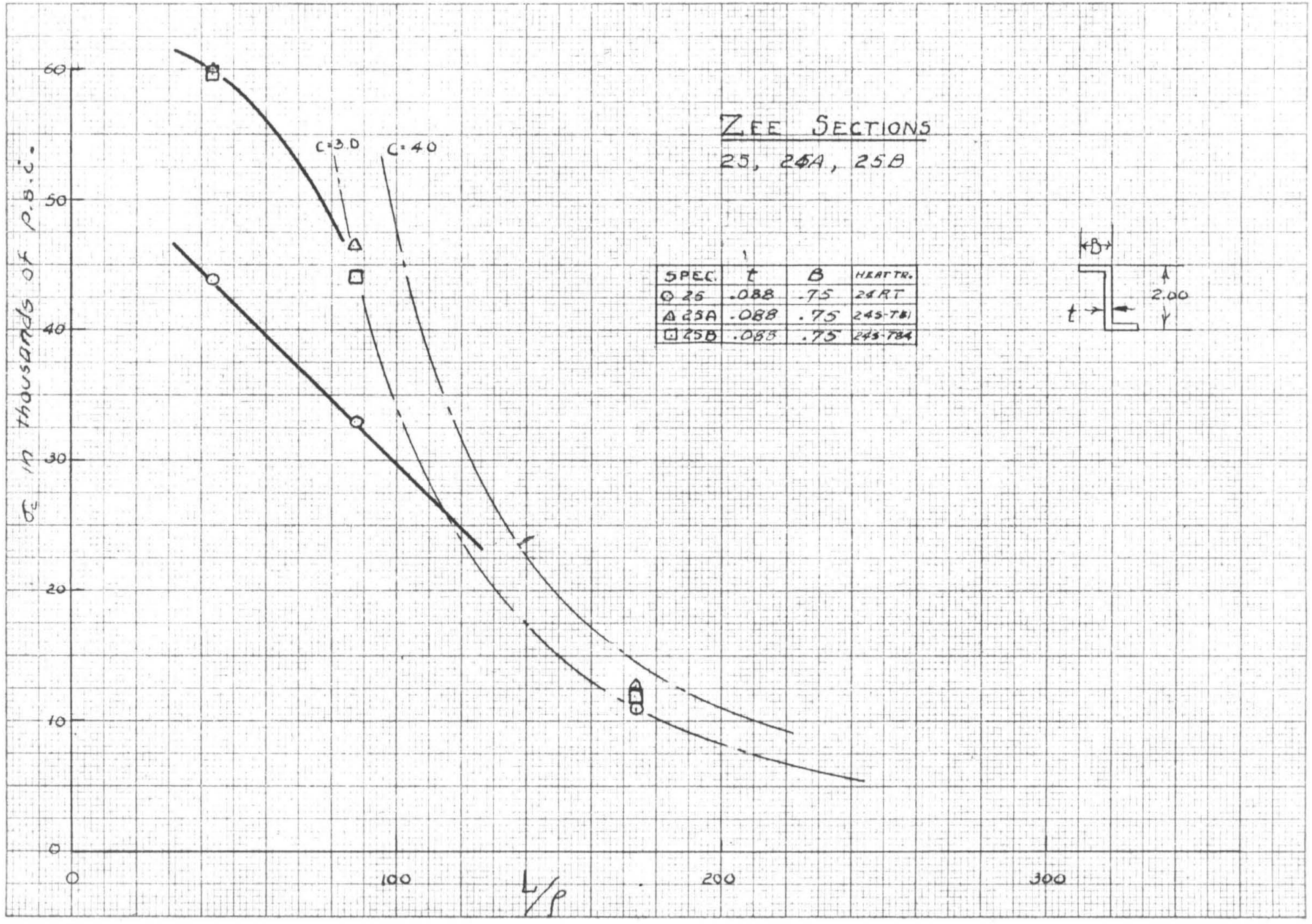

ZEE SECTIONS
24S-T84
22B, 23B
C=2.0
C=4.0
σc in thousands of P.S.I.
L/ρ
0
100
200
300
10
20
30
40
50
60
SPEC | t | B | C
① 22B | .050 | .75 | 0
△ 23B | .050 | .75 | .20
B
C
t
2.00

ZEE SECTIONS

24, 24A, 24B



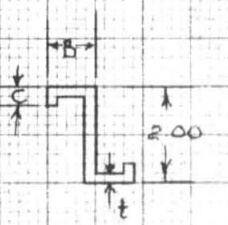
SPEC.	t	B	C
○ 24	.072	.75	0
△ 24A	.072	.75	0
□ 24B	.072	.75	0


ZEE SECTIONS
25, 25A, 25B
C=3.0
C=4.0
SPEC. | t | B | HEAT TR.
25 | .088 | .75 | 24RT
25A | .088 | .75 | 24S-T81
25B | .083 | .75 | 24S-T84
B
t
2.00
σc in thousands of P.S.I.
60
50
40
30
20
10
0
0
100
200
300
L/ρ

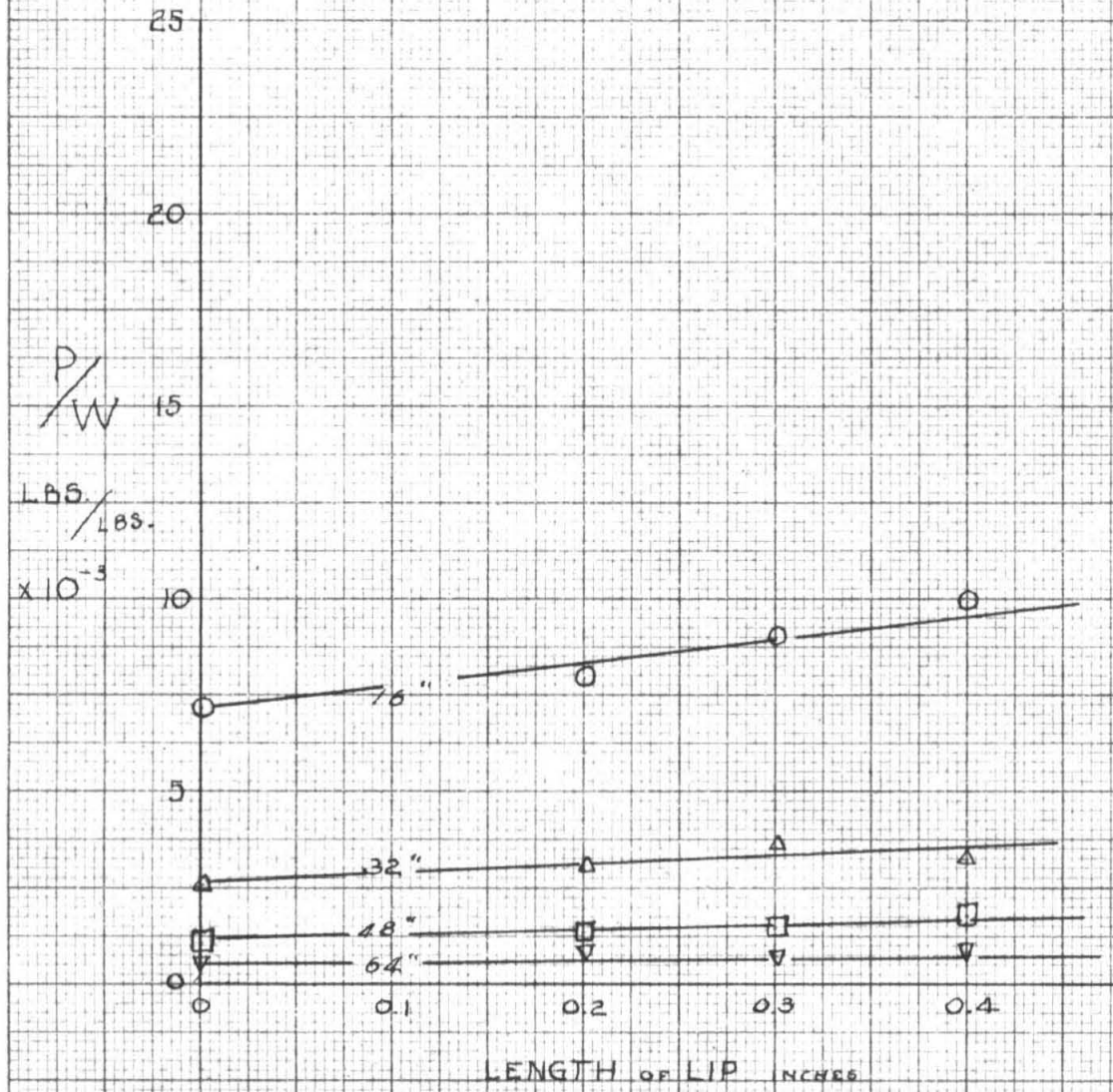
ZEE SECTIONS

26, 26A, 26B

SPEC.	B	C	t
○ 26	0.75	0	.123
△ 26A	0.75	0	.123
□ 26B	0.75	0	.123



ANGLE SECTIONS
1, 2, 3, 4
STRENGTH - WEIGHT RATIO
VS.
LIP



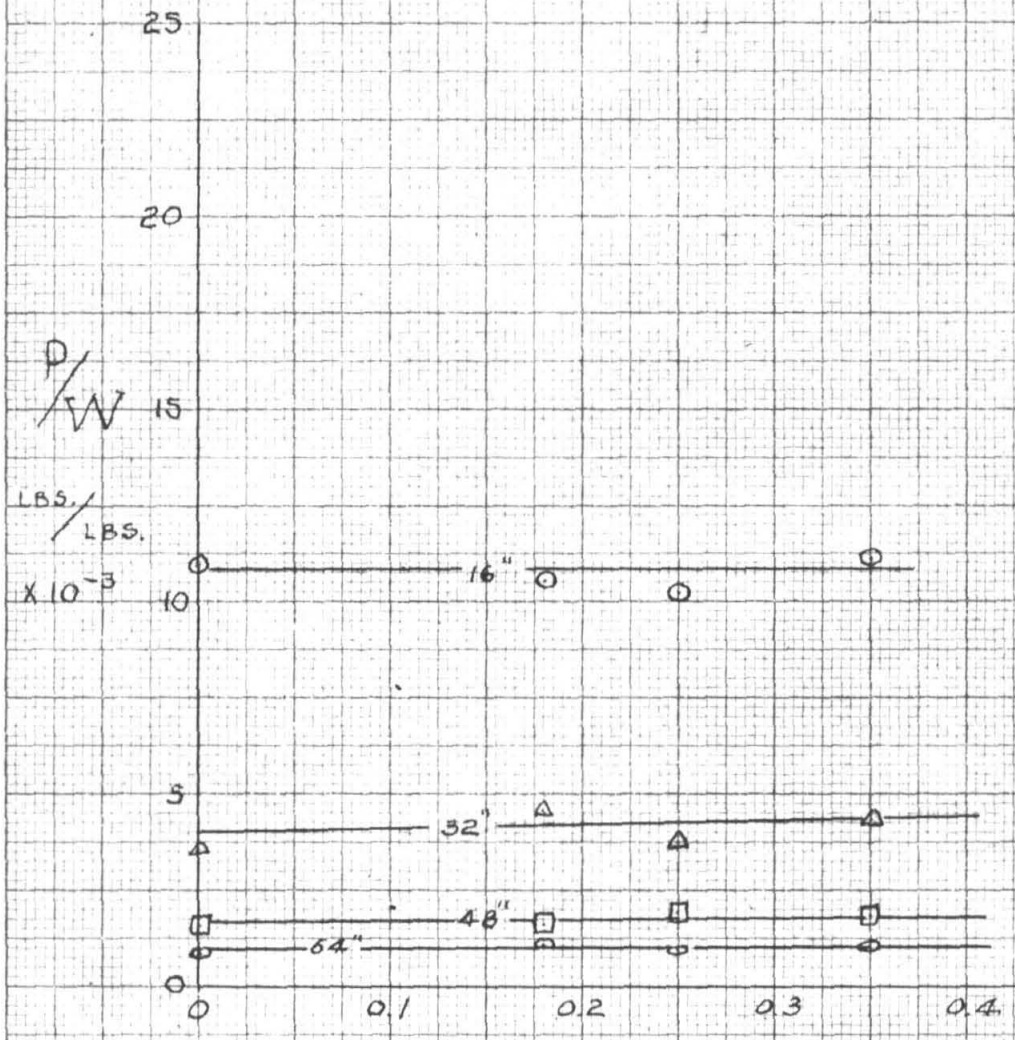
ANGLE SECTIONS

5, 6, 7, 8

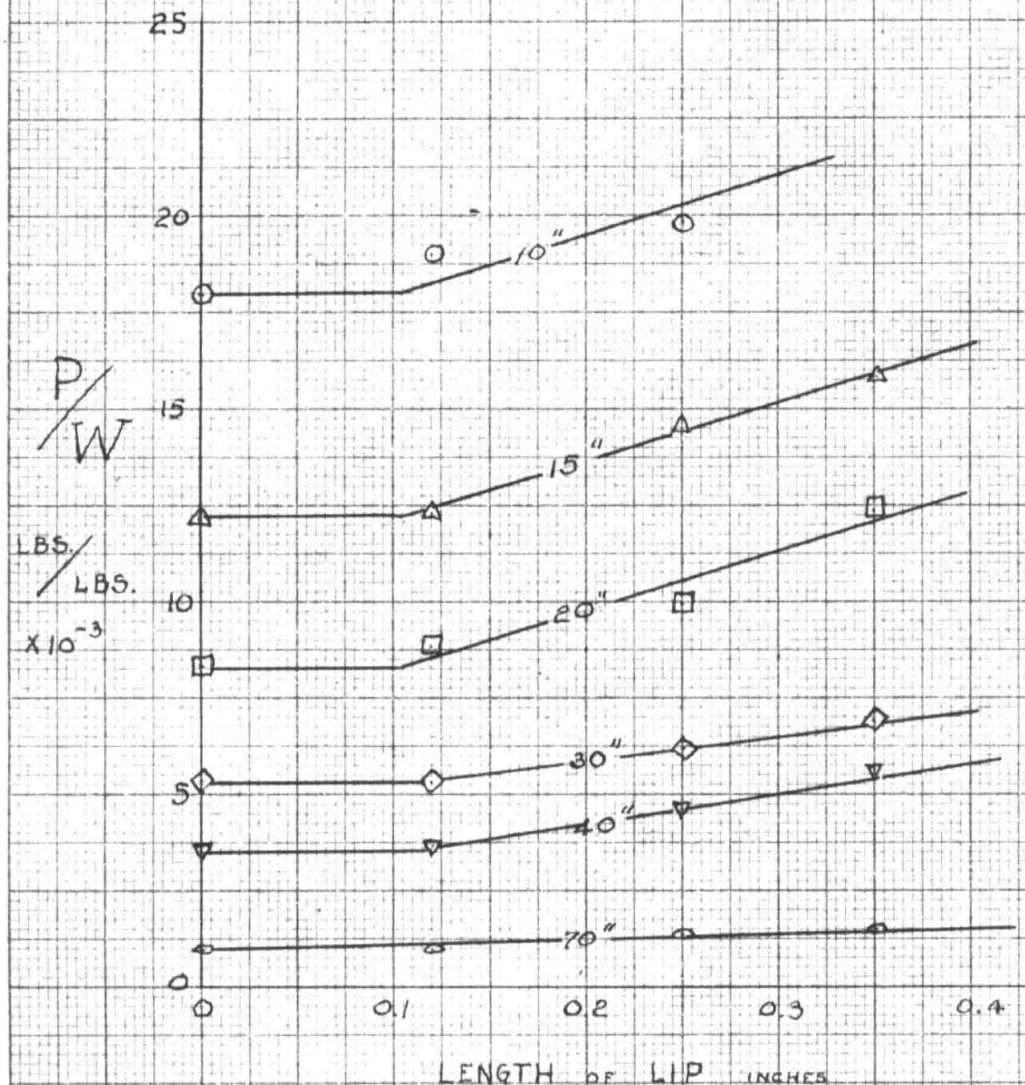
STRENGTH-WEIGHT RATIO

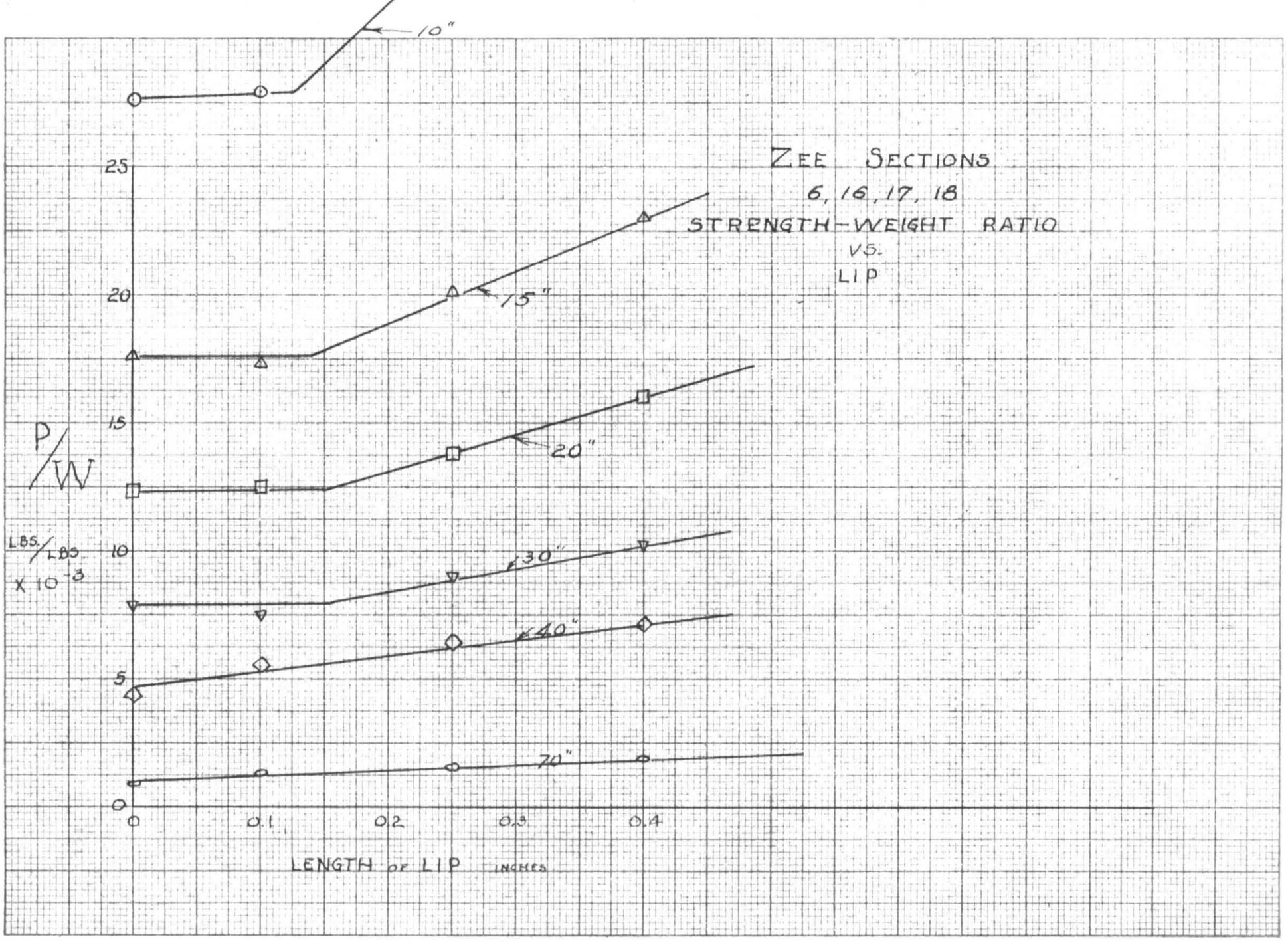
VS.

LIP



ZEE SECTIONS
5, 13, 14, 15
STRENGTH-WEIGHT RATIO
VS
LIP




ZEE SECTIONS
6, 16, 17, 18
STRENGTH-WEIGHT RATIO
VS.
LIP
P/W
LBS./LBS.
X 10⁻³
25
20
15
10
5
0
10"
15"
20"
30"
40"
70"
0
0.1
0.2
0.3
0.4
LENGTH OF LIP INCHES

RESULTS AND CONCLUSIONS

The test results appear in tabular form on pages 7 and 31 and are presented graphically on pages 10 and 36.

The effect of lip on the column strength of angle sections is seen to be negigible. However, in the case of the zee sections, the effect of increasing the lip is to increase the column strength, particularly in the short and intermediate column regimes. The effect of a small amount of lip, 0 to 0.15 of an inch, is negigible, while the effect of lip above 0.25 of an inch is to raise the column strength of the zee sections very definitely, in some cases as much as 15%. The maximum amount of lip on the specimens tested was 0.40 of an inch. At this amount of lip the column strength of the zee sections was still increasing with increasing lip, so it is not possible to say what the ultimate optimum length of lip would be from the results of these tests.

A few typical strength-weight versus length-of-lip curves are presented on pages 66 through 69. These plots indicate the degree of efficiency with which the material is being used, and it can be seen that in the case of the zee sections the efficiency increases with lip while it stays about constant for the angle sections. From a weight saving viewpoint it can be said that for the angle sections the optimum amount of lip is no lip at all. For the zee sections the optimum lip within the range tested (0 to 0.40 of an inch) is the maximum lip, or 0.40 of an inch. Since the effect of small lips is negigible, the best utilization of material can be obtained for the zee sections by using lips longer than 0.25 of an inch.

The column strength of the 24S-T81 and 24S-T84 specimens were almost identical in every case and were 20% to 30% higher than the column strength of the 24RT specimens in the short and intermediate column regime. As would be expected from consideration of Euler's classical formula the condition of the material made no difference in the long column regime.

It would appear that the increase in strength with increase in length of lip is not a function of the thickness.