HELICAL SPRINGS

WHEN DETAILING HELICAL SPRINGS SUFFICIENT INFORMATION MUST APPEAR ON THE DRAWING TO ENABLE THE SPRING MANUFACTURERS TO PRODUCE A SPRING GIVING THE DESIRED CHARACTERISTICS. THIS INFORMATION CAN BE TAKEN FROM THE FOLLOWING LIST AND AS MANY AS POSSIBLE SHOULD BE QUOTED.

1. NUMBER OF COILS. TOTAL NUMBER AND NUMBER OF WORKING COILS.
2. SOLID LENGTH.
3. LENGTH IN POSITION WITH CORRESPONDING LOAD.
4. LENGTH AT MAXIMUM WORKING LOAD AND LOAD.
5. RATE.
6. WIRE DIAMETER OR IF RECTANGULAR, DIMENSION OF SIDES.
7. MEAN DIAMETER, INSIDE DIAMETER AND OUTSIDE DIAMETER.
8. FREE LENGTH.
9. MAXIMUM CORRECTED STRESS.
10. STRESS RANGE (CORRECTED).
11. A NOTE THAT THE CORRECTION IS IN ACCORDANCE WITH THE WAHL FACTOR.
12. TO BE INSPECTED FOR CRACKS BEFORE PLACING IN STORES.
13. FINISH.
14. MATERIAL.

ALL SPRINGS WILL BE ASSUMED TO BE WOUND RIGHT HANDED UNLESS OTHERWISE STATED.

SPECIAL ATTENTION MUST BE PAID TO SPRINGS WHICH WORK IN A CONFINED HOUSING TO MAKE SURE THAT THE SPRING DOES NOT EXPAND INTO THE HOUSING.

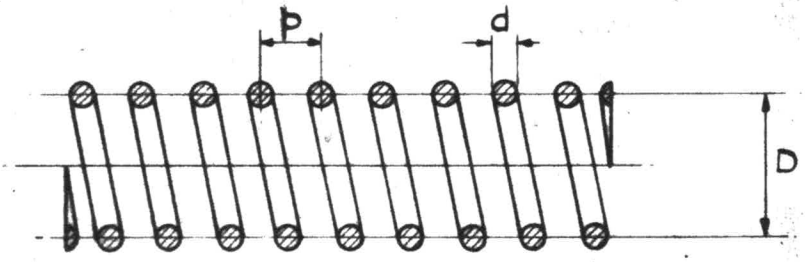
BUCKLING OF SPRINGS.

BUCKLING OF THE SPRING WILL TAKE PLACE IF THE FREE LENGTH IS MORE THAN FOUR TIMES THE MEAN DIAMETER.

SPRINGS SHOULD BE KEPT WITHIN THESE LIMITS,

HELICAL SPRINGS CONT'D.

COMPRESSION TYPE - ROUND WIRE.



SYMBOLS USED IN FORMULAE.

R = RATE OR STIFFNESS IN POUNDS PER INCH.

S = MAXIMUM SHEAR STRESS IN POUNDS PER SQ. INCH (WITHOUT CURVATURE CORRECTION)

S_1 = MAXIMUM SHEAR STRESS IN POUNDS PER SQ. INCH (WITH CURVATURE CORRECTION)

P = AXIAL LOAD IN POUNDS

F = AXIAL DEFLECTION IN INCHES

W = WEIGHT IN POUNDS

d = WIRE DIAMETER, FOR CIRCULAR SECTION SPRINGS IN INCHES.

D = MEAN DIAMETER OF COILS IN INCHES.

N = NUMBER OF WORKING COILS, OMITTING END COILS

TN = TOTAL NUMBER OF COILS.

$K = \frac{(4C - 1)}{(4C - 4)} + \frac{0.615}{C}$

$C = \frac{D}{d}$

p = PITCH OF COILS

G = MODULUS OF RIGIDITY, TAKEN AS 11,500,000 LB/SQ.IN. FOR STEEL (SEE TABLE 9 FOR OTHER MATERIAL)

STRESS FORMULA

$$S = \frac{P \times D \times 2.55}{d^3}$$

$$S_1 = S \times K$$

AXIAL LOAD

$$P = \frac{G \cdot F \cdot d^4}{8 \cdot N \cdot D^3}$$

HELICAL SPRINGS CONT'D.

DEFLECTION

$$F = \frac{8 \times P \times D^3 \times N}{G \times d^4}$$

RATE

$$R = \frac{P}{F}$$

WEIGHT

$$W = \frac{G \times d^4}{8 \times ND^3}$$

(IN STEEL) $W = 0{\cdot}7d^2 D(N + 1{\cdot}5)$ LBS.

TOTAL NUMBER OF COILS (LIGHT SPRINGS)

$$TN = N + 2$$

NATURAL FREQUENCY OF VIBRATION

$$f \text{ (CYCLES PER MINUTE)} = K_c \frac{d}{ND^2}$$

WHERE $K_c = 132{\cdot}6 \sqrt{\frac{G}{P}}$

$= 846000$ FOR STEEL.

INCREASE IN DIA. OF SPRING DUE TO COMPRESSION OF COILS.

$$D_1 = {\cdot}500 \sqrt[2]{p^2 + 4D_2^2 - d^2}$$

WHERE D_1 = MEAN DIAMETER AT SOLID HEIGHT

D_2 = " " " FREE "

TENSION SPRINGS - ROUND WIRE.

MOST FACTORS GOVERNING THE DESIGN OF TENSION SPRINGS ARE COVERED UNDER COMPRESSION SPRINGS. THE ESSENTIAL DIFFERENCE BETWEEN EXTENSION AND COMPRESSION SPRINGS LIES IN THE FACT THAT THE EXTENSION SPRINGS USUALLY HAVE INITIAL TENSION WOUND INTO THEM. WHERE THERE IS NO INITIAL TENSION, FORMULA FOR COMPRESSION SPRINGS SHOULD BE USED.

FOR CALCULATION PURPOSES THE INITIAL TENSION SHOULD GIVE A STRESS FIGURE OF

HELICAL SPRINGS CONTD.

TENSION SPRINGS.

EXAMPLE

THE MEAN DIAMETER OF A SPRING IS 0·5" AND THE SPRING HAS TEN COILS OF 1/16" DIAMETER ROUND WIRE. THE SPRING IS COILED TO GIVE AN INITIAL STRESS OF 10,000 POUNDS PER INCH. FIND THE INITIAL TENSION.

$$S_2 = \frac{2 \cdot 55\ P\ D}{d^3}$$

$$10{,}000 = \frac{2 \cdot 55 \times P \times 0 \cdot 5}{\cdot 062^3}$$

$$1 \cdot 275\ P_1 = 2 \cdot 38$$

$$P_1 = 1 \cdot 86 \text{ LBS INITIAL TENSION}$$

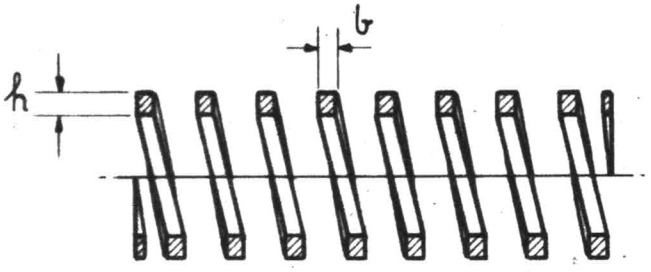
$$= \text{LOAD TO PULL COILS APART}$$

WHERE S_2 = 20% OF S (APPROX)

P_1 = INITIAL TENSION.

IT IS IMPORTANT TO NOTE THAT THE VALUE FOR P_1 MUST BE ADDED WHEN DETERMINING THE RATE OF THE SPRING, USING FORMULA FOR ROUND SECTION WIRE.

RECTANGULAR OR SQUARE SECTION COMPRESSION SPRINGS.



SPRINGS MADE FROM SQUARE OR RECTANGULAR SECTION WIRE ARE NOT RECOMMENDED AND SHOULD ONLY BE USED IN EXCEPTIONAL CIRCUMSTANCES.

SPRINGS COILED FROM THIS SECTION CAN BE CALCULATED IN MUCH THE SAME MANNER AS ROUND SECTION WIRE, EXCEPTING THAT A CONSTANT MUST BE USED WHICH VARIES FOR EVERY RATIO

THICKNESS AT THE INSIDE. THE FOLLOWING FORMULAE ARE BASED UPON THIS CONDITION.

AXIAL LOAD.

$$P = \frac{K_2 F G b h^3}{N D^3}$$

WHERE. K_2 = CONSTANT FOR $\frac{b}{h}$ (SEE TABLE, 13)

b = WIDTH OF SECTION

h = HEIGHT OF SECTION PARALLEL TO AXIS OF SPRING

STRESS.

$$S = \frac{P D}{K_3 b h^2}$$

WHERE K_3 = CONSTANT FOR $\frac{b}{h}$ (SEE TABLE, 13.)

RATE.

THE FORMULA FOR ROUND SECTION WIRE CAN BE USED WHICH SHOULD BE MULTIPLIED BY THE APPROPRIATE CONVERSION FACTOR 'Z' GIVEN IN TABLE.

$$R = \frac{G d^4}{8 N D^3} \times Z$$

WHERE Z IS A CONVERSION FACTOR FOR THE RATIO $\frac{b}{h}$.

DEFLECTION.

$$F = \frac{P N D^3}{K_2 G b h^3}$$

TOTAL NUMBER OF COILS.

$$TN = N + 2$$

NATURAL FREQUENCY OF VIBRATION.

$$f = K \sqrt{\frac{b h}{N D^2}}$$

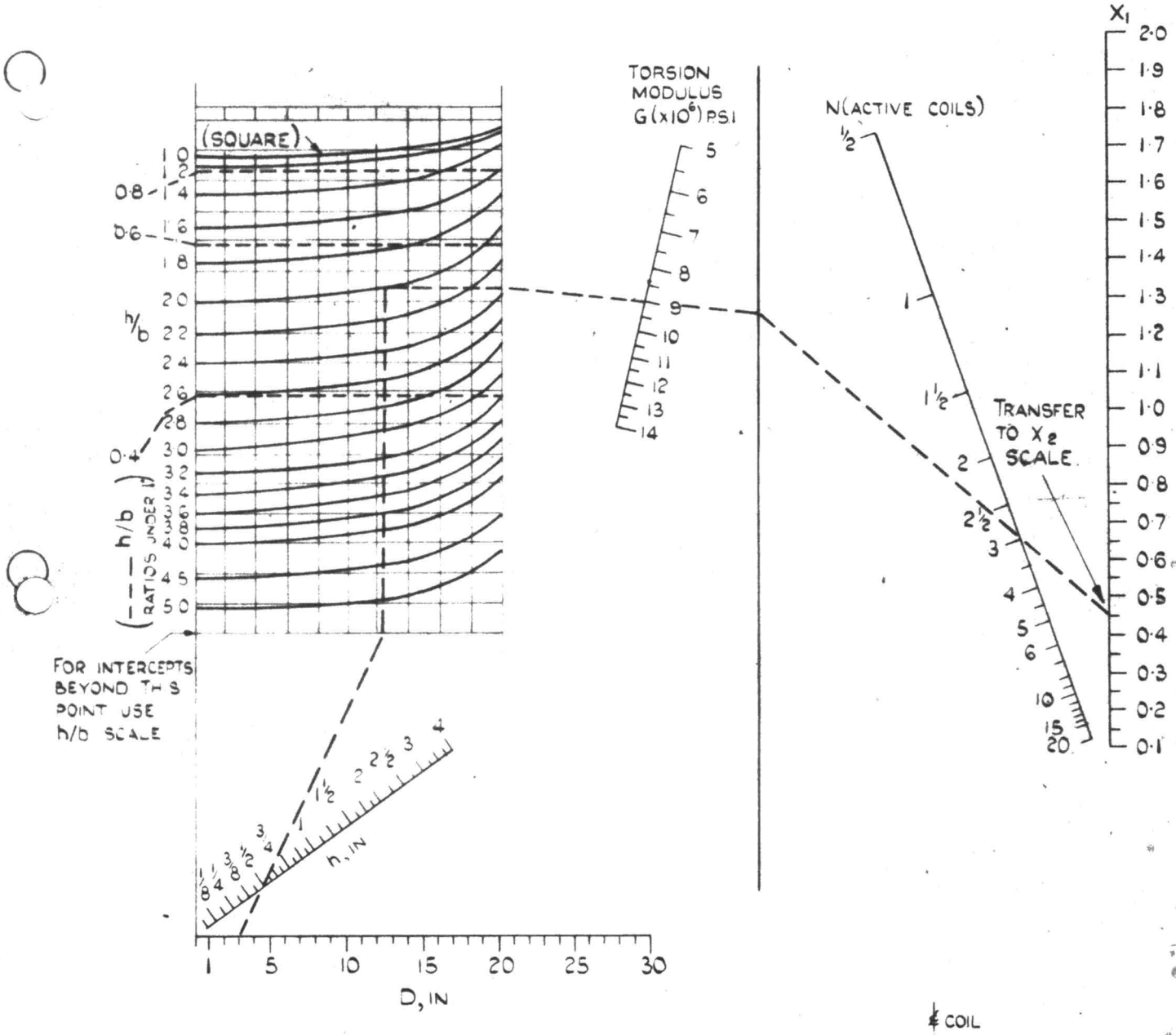
RECTANGULAR SECTION

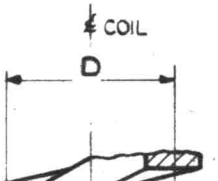
HELICAL SPRING STIFFNESS.

HELICAL SPRINGS OF RECTANGULAR BAR ARE FINDING INCREASING WORK FOR SUCH DUTIES AS SAFETY-VALVE SPRINGS, HEAVY-VEHICLE SUSPENSIONS, COUPLINGS. THE TWO NOMOGRAPHS PRESENTED HERE HELP FIND NEEDED DIMENSIONS.

EXAMPLE :-

A SPRING WITH h = ½ IN., b = ¼ IN. (SEE SKETCH) HAS MEAN DIA D = 3 IN., AND THREE EFFECTIVE COILS. IF TORSION MODULUS $G = 9 \times 10^6$, FIND STIFFNESS AND DEFLECTION UNDER 150 lb LOAD.



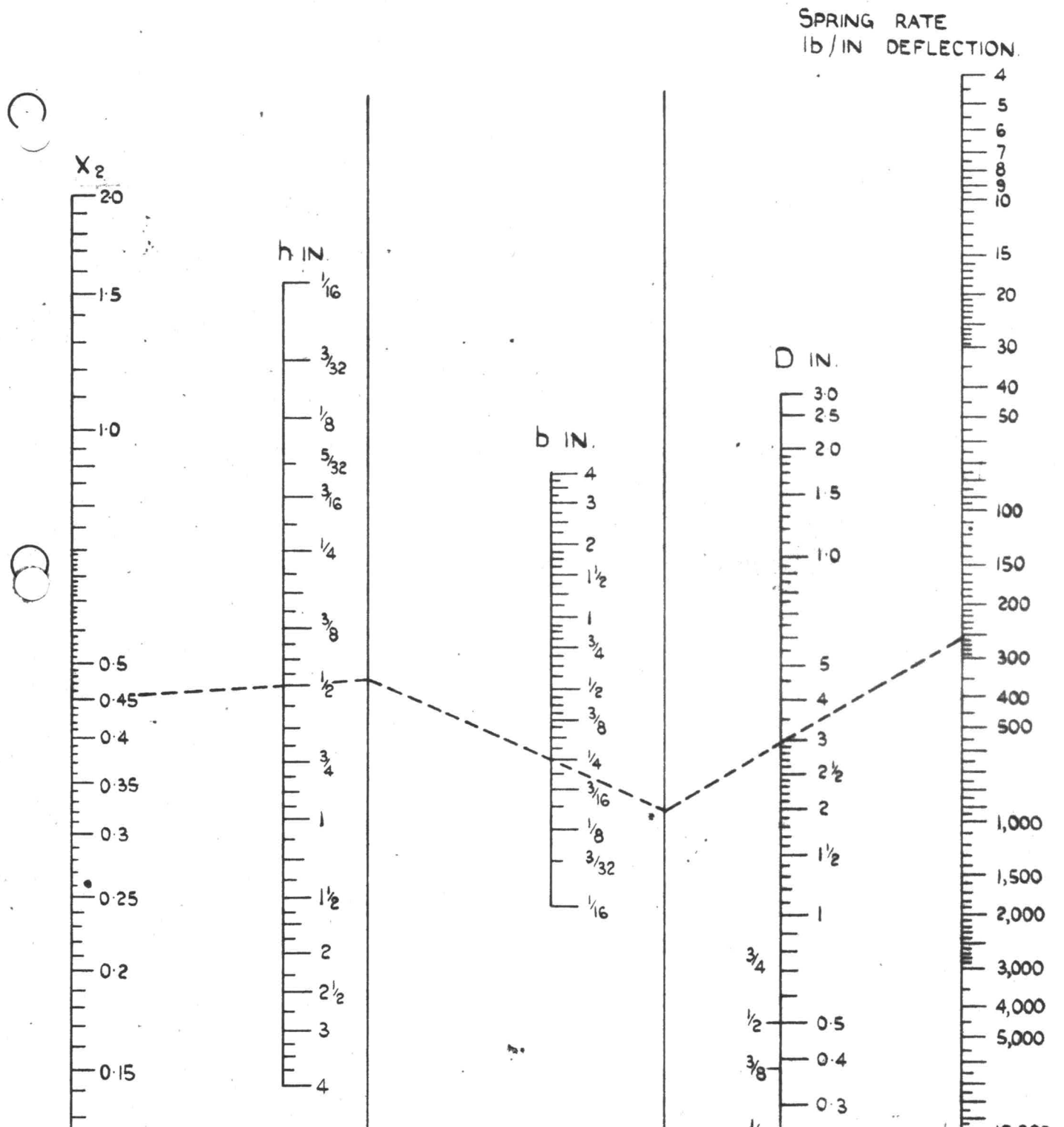


HELICAL SPRING STIFFNESS CONT'D.

PROCEDURE JOIN KNOWN QUANTITIES BY SECANTS TO FIND SPRING RATE (STIFFNESS) = 258 lb PER IN. DEFLECTION. FOR 150 lb LOAD, DEFLECTION WILL BE 150 / 258 = 0·58 IN. THE NOMOGRAPHS ARE BASED ON THE FORMULA :-

$$\text{RATE} = \frac{G u b^2 h^2}{N D^3}$$

WHERE u IS A FACTOR DEPENDENT UPON VALUES OF h/b AND D/h. THE SMALL CHART COMBINED WITH FIRST NOMOGRAPH INCORPORATES THIS FACTOR, WHICH IS BASED ON INFORMATION IN BRITISH STANDARD 1726 : 1951, AVAILABLE HERE THROUGH THE AMERICAN STANDARDS ASSOCIATION.



HELICAL SPRING FORMULAE.

MODULUS TABLE.

MATERIAL	VALUE OF G
PIANO WIRE (EN 44)	11, 500, 000
OIL TEMPERED WIRE (EN 45/48)	11, 500, 000
HARD DRAWN WIRE (EN 49)	11, 500, 000
STAINLESS (EN. 50)	10, 500, 000
MONEL METAL.	9, 200, 000
PHOSPHOR BRONZE	6, 250, 000
BRASS	5, 000, 000.

TABLE 9.

RATIOS 'C' OF SPRING MEAN DIAMETERS TO WIRE DIAMETERS.

C	K	C	K	C	K	C	K
2·0	2·06	3·6	1·46	5·4	1·28	9·5	1·15
2·1	1·98	3·7	1·44	5·6	1·27	10·0	1·14
2·2	1·90	3·8	1·43	5·8	1·26	10·5	1·14
2·3	1·84	3·9	1·42	6·0	1·25	11·0	1·13
2·4	1·79	4·0	1·40	6·2	1·24	11·5	1·12
2·5	1·75	4·1	1·39	6·4	1·24	12·0	1·12
2·6	1·71	4·2	1·38	6·6	1·23	12·5	1·11
2·7	1·68	4·3	1·37	6·8	1·22	13·0	1·11
2·8	1·64	4·4	1·36	7·0	1·21	13·5	1·11
2·9	1·60	4·5	1·35	7·2	1·21	14·0	1·10
3·0	1·58	4·6	1·34	7·4	1·20	14·5	1·10
3·1	1·56	4·7	1·34	7·6	1·19	15·0	1·10
3·2	1·53	4·8	1·32	7·8	1·19	16·0	1·09
3·3	1·51	4·9	1·32	8·0	1·18	17·0	1·08
3·4	1·49	5·0	1·31	8·5	1·17	18·0	1·08
3·5	1·48	5·2	1·30	9·0	1·16	19·0	1·07

HELICAL SPRINGS CONT'D.

SQUARES CUBES AND FOURTH POWERS OF WIRE DIAMETERS.

S.W.G.	DIAMETER INS	SQUARE d^2	CUBE d^3	FOURTH POWER d^4
7/0	·500	·25000	·12500	·062500
6/0	·464	·21530	·099997	·046353
5/0	·432	·18662	·080622	·034828
4/0	·400	·16000	·064000	·025600
3/0	·372	·13838	·051479	·019150
2/0	·348	·12110	·042144	·014666
0	·324	·10499	·034012	·011020
1	·300	·090000	·027000	·0081000
2	·276	·076176	·021024	·0058028
3	·252	·063504	·016003	·0040327
4	·232	·053824	·012487	·0028970
5	·212	·044944	·0095281	·0020200
6	·192	·036964	·0070779	·0013590
7	·176	·030976	·0054518	·00095951
8	·160	·025600	·0040960	·00065536
9	·144	·020736	·0029860	·00042999
10	·128	·016384	·0020971	·00026843
11	·116	·013456	·0015609	·00018106
12	·104	·010816	·0011249	·00011698
13	·092	·0084640	·00077869	·000071639
14	·080	·0064000	·00051200	·000040960
15	·072	·0051840	·00037325	·000026974
16	·064	·0040960	·00026214	·000016777
17	·056	·0031360	·00017562	·0000098345
18	·048	·0023040	·00011059	·0000053084
19	·040	·0016000	·000064000	·0000025600
20	·036	·0012960	·000046656	·0000016796
21	·032	·0010240	·000032768	·0000010486
22	·028	·00078400	·000021952	·0000061465
23	·024	·00057600	·000013824	·0000033177
24	·022	·00048400	·000010648	·00000023425
25	·020	·00040000	·0000080000	·0000016000
26	·018	·00032400	·0000058320	·0000010497
27	·0164	·00026896	·0000044109	·00000072340
28	·0148	·00021904	·0000032418	·00000047978
29	·0136	·00018496	·0000025154	·00000034210
30	·0124	·00015376	·0000018066	·00000022402

SQUARES AND CUBES OF FRACTIONAL NUMBERS.

VALUES OF 'D'

No. D	SQUARE D^2	CUBE D^3	No D	SQUARE D^2	CUBE D^3
1/32	0·000976	0·000031	1 1/2	2·250000	3·375000
1/16	0·003906	0·000244	17/32	2·344727	3·590363
3/32	0·008789	0·000824	9/16	2·441406	3·814697
1/8	0·015625	0·001953	19/32	2·540039	4·048187
5/32	0·024414	0·003815	5/8	2·640625	4·291016
3/16	0·035156	0·006502	21/32	2·743164	4·543365
7/32	0·047852	0·010468	11/16	2·847656	4·805419
1/4	0·062500	0·015625	23/32	2·954102	5·077362
9/32	0·079102	0·022247	3/4	3·062500	5·359375
5/16	0·097656	0·030518	25/32	3·172852	5·651642
11/32	0·118164	0·040619	13/16	3·285156	5·954346
3/8	0·140625	0·052734	27/32	3·399414	6·267660
13/32	0·165039	0·067047	7/8	3·515625	6·591797
17/16	0·191406	0·083740	29/32	3·633789	6·926910
15/32	0·219727	0·102997	15/16	3·753906	7·273193
1/2	0·250000	0·125000	31/32	3·875977	7·630828
17/32	0·282227	0·149933	2	4·00000	8·00000
9/16	0·316406	0·177979	1/32	4·12598	8·38089
19/32	0·352539	0·209320	1/16	4·25391	8·77368
5/8	0·390625	0·244141	1/8	4·51563	9·59570
21/32	0·430664	0·282623	3/16	4·78516	10·46754
11/16	0·472656	0·324951	1/4	5·06250	11·39063
23/32	0·516602	0·371307	5/16	5·34766	12·36646
3/4	0·562500	0·421875	3/8	5·64063	13·39648
25/32	0·610352	0·476837	7/16	5·94141	14·48218
13/16	0·660156	0·536377	1/2	6·25000	15·62500
27/32	0·711914	0·600678	9/16	6·56641	16·82642
7/8	0·765625	0·669922	5/8	6·87063	18·08789
29/32	0·821289	0·744293	11/16	7·22266	19·41089
15/16	0·878906	0·823975	3/4	7·56250	20·79688
31/32	0·938477	0·909149	13/16	7·91016	22·24731
1	1·000000	1·000000	7/8	8·26563	23·76367
1/32	1·063477	1·096800	15/16	8·62891	25·34741
1/16	1·128906	1·199463	3	9·00000	27·00000
3/32	1·196289	1·308441	1/16	9·37891	28·72290
1/8	1·265625	1·423828	1/8	9·76563	30·51758
5/32	1·336914	1·545807	3/16	10·16016	32·38550
3/16	1·410156	1·674561	1/4	10·56250	34·32813
7/32	1·485352	1·810272	5/16	10·97266	36·34692
1/4	1·562500	1·953125	3/8	11·39063	38·44336
9/32	1·641602	2·103302	7/16	11·81641	40·61889
5/16	1·722656	2·260986			
11/32	1·805664	2·426361			
3/8	1·890625	2·599609			
13/32	1·977539	2·780914			
7/16	2·066406	2·970459			

HELICAL SPRINGS CONT'D.

VALUES OF CONSTANT 'K' AND CONVERSION FACTOR 'Z'

$\frac{b}{h}$	K_2	K_3	Z	$\frac{b}{h}$	K_2	K_3	Z
1·0	·1795	·416	1·436	3·4	—	—	9·580
1·1	·2018	·427	1·771	3·5	·3544	·550	9·920
1·2	·2203	·437	2·111	4·0	·3632	·564	11·616
1·3	·2360	·446	2·450	4·5	·3700	·575	13·313
1·4	·2495	·455	2·790	5·0	·3754	·583	15·012
1·5	·2611	·462	3·130	5·5	·3799	·590	16·711
1·6	·2707	·469	3·469	6·0	·3836	·596	18·408
1·7	·2804	·475	3·808	6·5	—	—	20·103
1·8	·2884	·482	4·166	7·0	·3894	·606	21·806
1·9	·2955	·487	4·488	7·5	—	—	23·508
2·0	·3020	·492	4·827	8·0	·3938	·612	25·197
2·1	·3078	·498	5·168	9·0	·3972	·619	28·598
2·2	·3131	·503	5·491	10·0	·3999	·626	31·984
2·3	·3179	·508	5·846	11·0	·4022	·631	35·384
2·4	·3220	·512	6·186	12·0	·4040	·634	38·794
2·5	·3265	·516	6·524	13·0	·4056	·636	42·172
2·6	·3302	·520	6·864	14·0	·4068	·638	45·667
2·7	·3337	·523	7·204	15·0	·4081	·641	48·960
2·8	·3369	·527	7·542	16·0	—	—	52·365
2·9	·3400	·530	7·883	17·0	—	—	55·760
3·0	·3431	·534	8·222	18·0	—	—	59·155
3·1	—	—	8·561	19·0	—	—	62·548
3·2	—	—	8·901	20·0	—	—	65·953
3·3	—	—	9·240		—	—	

TABLE 13.

Helical Spring Design Nomograph.
For Circular Section Wire.

The Nomograph on Sheet 49B is a quick design aid to enable the approximate dimensions of a required Spring to be obtained prior to the final calculation. The Wahl curvature correction factor is not included andthe Nomograph is based on the following formulae.

$$S = \frac{8PD}{\pi d^3} \qquad i$$

$$F = \frac{\pi N D^2 S}{Gd} \qquad ii$$

where
- S = Maximum Allowable Shear Stress due to torsion under load P
- P = Maximum Load. LBS
- D = Mean Diameter of Coil. inches
- d = Diameter of Wire. inches
- F = Deflection under maximum load. inches
- N = Number of Coils
- Nd = Length of Spring fully compressed
- G = Modulus of Torsional Rigidity

For the Nomograph the following valves are taken:-

S = 70,000 LB/in.^{2}
G = 11,200,000 LB/in^2 (for Steel)

To Use the Nomograph:-

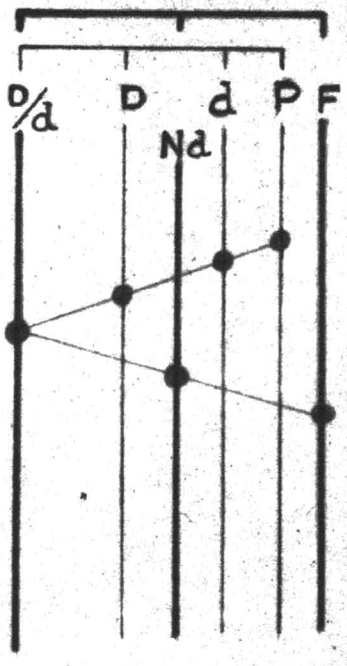
Quantities usually known are: the spring deflection F under Load P, the maximum allowable Stress S and the modulus of Rigidity G.

A solution is obtained by taking arbitrarily a value of the index on the D/d scale and tracing two lines from this point.

The first line goes to the point on the F scale representing the known deflection. This gives the value of Nd.

The second line goes to the point on the P scale corresponding to the known load. Thus the values of D & d are obtained

Well proportioned springs have an index D/d of 7 to 9 but ratios of 5 to 7 and 9 to 12 are common.



Design Example

To design a spring with P = 90lbs at a deflection F equal to 6" and a maximum stress S of 70,000 lbs/in^2 with G = 11,200,000 lbs/in^2

A line between P = 90 and D/d = 9 gives a value of d between 7 and 8 SWG. Taking wire of 7 SWG (.176 in) the index D/d becomes 9·5. This gives a mean diameter D of 1.11/16 in. The second line joining D/d = 9.5 and F = 6 gives the value of Nd, the fully compressed length of spring, which is equal to 3.42 in. The number of coils are therefore $\frac{3.42}{.176} = 19.4$.