

The foundation of a brick chimney erected in 1872 for the McCormack reaper works, 160 feet high, 14 feet square at the base, with a flue 6 feet 8 inches in diameter, is as follows: The base is 25 feet square; area, 625 square feet; the weight of the chimney and the base is approximately 1,100 tons; the pressure on the soil is 24.33 pounds per square inch, 1.75 tons per square foot. Soil was dry, hard clay. This loading is very light.

Foundations for self-sustaining steel chimneys are of necessity of greater bearing surface than for brick chimneys, and will be treated under steel chimneys.

CHAPTER VI

STEEL CHIMNEYS—THEORY PERTAINING TO SAME, AND EXAMPLES FROM EXISTING STRUCTURES

STEEL CHIMNEYS.

THE cheapest chimney that can be erected if ground-space is plenty, is a straight steel tube, held up by one or two sets of guy-rods or wires, four or six in a set. These guys should be fastened to an angle-iron or band at two-thirds the height, and if two sets are used, also at one-third the height. They should be anchored at a distance from the base equal to the height of the band above the ground. Boiler blank flue-heads, 16 to 24 inches larger in diameter than the chimney, and $\frac{3}{4}$ to $\frac{3}{8}$ -inch in thickness, make good bed-plates. If cast-iron bed-plates are used, they should be at least one inch thick. The foundation should extend at least 12 inches above the ground level, and should be sunk 4 feet below ground level, and spread out on the bottom to about twice the diameter of the chimney. An iron or steel casing is superior to a brick one, in that it does not leak and draw in cold air, thus impairing the draft. Moreover, when the ordinary chimney is working at its full capacity the velocity of the ascending column of gases is so great that very little heat is lost by radiation through the shell, even though the latter be without any lining, which is quite common.

It is scarcely necessary to say that steel chimneys are always round. For guy-rods, $\frac{1}{2}$ -inch or $\frac{3}{4}$ -inch iron is a common size. For guy-wires, not over 1 inch in diameter should be used. The following table will give some useful data. Whether rods or wires are used, a turnbuckle is necessary for adjusting the tautness of the connection.

TABLE No. 18.

STANDARD HOISTING ROPE—CRUCIBLE STEEL, NINETEEN WIRES TO THE STRAND.

Circumference. Inches.	Diameter. Inches.	Weight per foot of rope with hemp centre Lbs.	Breaking strain in tons of 2,000 lbs.	Safe working load in tons of 2,000 lbs.
3½	1½	2.00	40	6
3¼	1	1.58	32	5
2½	¾	1.20	24	4
2¼	¾	0.88	18	3
2	¾	0.60	14	2
1¾	¾	0.44	9½	1½
1½	¾	0.35	7½	1
1¼	¾	0.28	6	¾
1½	¾	0.26	5	¾

GUYED STEEL CHIMNEYS.

"Rule of Thumb" for Finding Diameter of Guy Wires for Steel Chimneys. (*Engineering Mechanics*, October, 1893.)

Multiply the height of chimney in feet by its diameter in inches, and take the square root of the product. Divide this by 100, and the quotient is the least allowable diameter in inches for each of four guys.

TABLE OF THICKNESS BY GAUGE OF STEEL FOR GUYED CHIMNEYS.

Diameter—inches...	18	20	24	26	28	30	32	32	34	36
Height—feet.....	40	45	50	50	55	60	65	70	70	75
Thickness—gauge..	16	16	14 & 16	14	14	12 & 14	12 & 14	12 & 14	10 & 12	10 & 12

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WEIGHT PER FOOT OF STEEL-RIVETED TUBES FOR GUYED CHIMNEYS.

Diameter—inches.....	10	12	14	16	20	22	24	26	28	30
No. 16 W. G., Wt. per foot.	7.20	8.66	9.58	11.68	13.75	15.00	16.25	17.5	18.75	20.00
No. 14 W. G., Wt. per foot.	9.40	11.11	13.69	15.00	18.33	20.00	21.66	23.33	25.00	26.66

Circular boiler heads make good bases for guyed steel chimneys. The table on pages 48 and 49 applies to such cases.

SELF-SUSTAINING STEEL CHIMNEYS.

The self-sustaining steel chimney is a feature of a great many modern power plants, because of its many advantages over a brick chimney.

Among these advantages are: less floor or ground-space occupied, that is above the ground; ease and rapidity of construction and erection; because it weighs less than a brick

chimney of like capacity, it is better adapted to soils of low load-sustaining power; the steel shaft presents a smaller area to the wind than a brick chimney of equal flue area does.

Self-sustaining chimneys are frequently lined with fire-brick, but more often with ordinary hard-burned red brick, which can receive the chimney gases at 600° to 700° without injury.

Some, however, simply line the chimney at the bottom where the flue enters it, and in such cases second-quality fire-brick answers the purpose very well.

The thickness of brick lining should nowhere be less than 4½ inches, and that in the upper portion of the chimney, and the thickness should be increased toward the bottom, adding 4½ inches every 30 or 40 feet.

The size of flue and thickness of lining being known (usually adding from 18 to 36 inches to the diameter of the chimney shell or tube), we may start with the design of the chimney.

For an example we will assume the case of a chimney with an outside diameter of 66 inches and 150 feet high.

Let the diameter of the chimney be called D .

Let the diameter of the bottom of bell-shaped base be called D_B .

The writer usually makes the height of the bell-base, or $h_B = 2D$, and the diameter of bottom of bell $D_B = 2D$, though 1½ times the diameter D is often used for both the height h_B and diameter D_B .

The outlines of the bell-shaped base in vertical projection should be bounded by straight lines, as of a cone, to give the greatest strength, but the outlines are often made curved as in a pealing bell, making use of thicker sheets of steel to counteract the loss of strength due to the straight outline.

The base-plate, usually made of cast-iron, should be kept from 12 to 24 inches above the level of the ground, but in no case should a high brick pedestal be used, it being much more expensive, less pleasing architecturally than the low foundation, without possessing any advantage with regard to strength, and it occupies much more space on the ground.

The base-plate is usually made of cast iron from 1 inch

TABLE No. 19.
WEIGHTS OF CIRCULAR BOILER HEADS.

Diameter in inches.	THICKNESS IN INCHES.									
	1/2	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16
16	7	11	14	18	22	25	29	33	37	41
17	8	12	16	20	24	28	32	36	40	44
18	9	13	17	21	25	29	33	37	41	45
19	10	14	18	22	26	30	34	38	42	46
20	11	15	19	23	27	31	35	39	43	47
21	12	16	20	24	28	32	36	40	44	48
22	13	17	21	25	29	33	37	41	45	49
23	14	18	22	26	30	34	38	42	46	50
24	15	19	23	27	31	35	39	43	47	51
25	16	20	24	28	32	36	40	44	48	52
26	17	21	25	29	33	37	41	45	49	53
27	18	22	26	30	34	38	42	46	50	54
28	19	23	27	31	35	39	43	47	51	55
29	20	24	28	32	36	40	44	48	52	56
30	21	25	29	33	37	41	45	49	53	57
31	22	26	30	34	38	42	46	50	54	58
32	23	27	31	35	39	43	47	51	55	59
33	24	28	32	36	40	44	48	52	56	60
34	25	29	33	37	41	45	49	53	57	61
35	26	30	34	38	42	46	50	54	58	62
36	27	31	35	39	43	47	51	55	59	63
37	28	32	36	40	44	48	52	56	60	64
38	29	33	37	41	45	49	53	57	61	65
39	30	34	38	42	46	50	54	58	62	66
40	31	35	39	43	47	51	55	59	63	67
41	32	36	40	44	48	52	56	60	64	68
42	33	37	41	45	49	53	57	61	65	69
43	34	38	42	46	50	54	58	62	66	70
44	35	39	43	47	51	55	59	63	67	71
45	36	40	44	48	52	56	60	64	68	72
46	37	41	45	49	53	57	61	65	69	73
47	38	42	46	50	54	58	62	66	70	74
48	39	43	47	51	55	59	63	67	71	75
49	40	44	48	52	56	60	64	68	72	76
50	41	45	49	53	57	61	65	69	73	77
51	42	46	50	54	58	62	66	70	74	78
52	43	47	51	55	59	63	67	71	75	79
53	44	48	52	56	60	64	68	72	76	80
54	45	49	53	57	61	65	69	73	77	81
55	46	50	54	58	62	66	70	74	78	82
56	47	51	55	59	63	67	71	75	79	83
57	48	52	56	60	64	68	72	76	80	84
58	49	53	57	61	65	69	73	77	81	85
59	50	54	58	62	66	70	74	78	82	86
60	51	55	59	63	67	71	75	79	83	87
61	52	56	60	64	68	72	76	80	84	88
62	53	57	61	65	69	73	77	81	85	89
63	54	58	62	66	70	74	78	82	86	90
64	55	59	63	67	71	75	79	83	87	91
65	56	60	64	68	72	76	80	84	88	92

Diameter in inches.	THICKNESS IN INCHES.									
	1/2	3/16	1/4	5/16	3/8	7/16	1/2	9/16	5/8	11/16
66	57	61	65	69	73	77	81	85	89	93
67	58	62	66	70	74	78	82	86	90	94
68	59	63	67	71	75	79	83	87	91	95
69	60	64	68	72	76	80	84	88	92	96
70	61	65	69	73	77	81	85	89	93	97
71	62	66	70	74	78	82	86	90	94	98
72	63	67	71	75	79	83	87	91	95	99
73	64	68	72	76	80	84	88	92	96	100
74	65	69	73	77	81	85	89	93	97	101
75	66	70	74	78	82	86	90	94	98	102
76	67	71	75	79	83	87	91	95	99	103
77	68	72	76	80	84	88	92	96	100	104
78	69	73	77	81	85	89	93	97	101	105
79	70	74	78	82	86	90	94	98	102	106
80	71	75	79	83	87	91	95	99	103	107
81	72	76	80	84	88	92	96	100	104	108
82	73	77	81	85	89	93	97	101	105	109
83	74	78	82	86	90	94	98	102	106	110
84	75	79	83	87	91	95	99	103	107	111
85	76	80	84	88	92	96	100	104	108	112
86	77	81	85	89	93	97	101	105	109	113
87	78	82	86	90	94	98	102	106	110	114
88	79	83	87	91	95	99	103	107	111	115
89	80	84	88	92	96	100	104	108	112	116
90	81	85	89	93	97	101	105	109	113	117
91	82	86	90	94	98	102	106	110	114	118
92	83	87	91	95	99	103	107	111	115	119
93	84	88	92	96	100	104	108	112	116	120
94	85	89	93	97	101	105	109	113	117	121
95	86	90	94	98	102	106	110	114	118	122
96	87	91	95	99	103	107	111	115	119	123
97	88	92	96	100	104	108	112	116	120	124
98	89	93	97	101	105	109	113	117	121	125
99	90	94	98	102	106	110	114	118	122	126
100	91	95	99	103	107	111	115	119	123	127
101	92	96	100	104	108	112	116	120	124	128
102	93	97	101	105	109	113	117	121	125	129
103	94	98	102	106	110	114	118	122	126	130
104	95	99	103	107	111	115	119	123	127	131
105	96	100	104	108	112	116	120	124	128	132
106	97	101	105	109	113	117	121	125	129	133
107	98	102	106	110	114	118	122	126	130	134
108	99	103	107	111	115	119	123	127	131	135
109	100	104	108	112	116	120	124	128	132	136
110	101	105	109	113	117	121	125	129	133	137
111	102	106	110	114	118	122	126	130	134	138
112	103	107	111	115	119	123	127	131	135	139
113	104	108	112	116	120	124	128	132	136	140
114	105	109	113	117	121	125	129	133	137	141
115	106	110	114	118	122	126	130	134	138	142

Heads below heavy line will run heavier than the weight given.

thick for 100-foot chimneys to 3 inches thick for 250-foot chimneys, and from 16 inches to 36 inches larger than D_b in diameter for the above heights.

For the convenience of casting base-plates can be made in from two to six sections with flanges, held together by $\frac{3}{4}$ -inch to $1\frac{1}{4}$ -inch bolts, and need be solid only to within 12 inches inside the bell, that is, like a round wrought-iron washer.

Neglecting the flare at the base we will consider the whole height of a chimney with a common diameter D , and proceed to design the shell.

Considering the force of the wind as 50 pounds per square foot—the actual pressure on a cylinder is 50 per cent. of the above, or 25 pounds per square foot on the projected area. Add 5 pounds for compressive strain produced by the wind in one half of the shell and its dead load, and we have 30 pounds as a safe value for wind-pressure.

The height of the chimney under consideration, $H = 150$ feet, which, multiplied by $D = 5\frac{1}{2}$ feet and by 30 pounds, gives 24,750 pounds of wind-pressure distributed over the entire area.

The lever arm about the base being $\frac{H}{2}$, the bending moment is $24750 \times \frac{150}{2} = 1856250$ foot pounds.

The section modulus, Z , for hollow cylinders is $\frac{\pi}{32} \left(\frac{D^4 - d^4}{D} \right)$, where d = the inside diameter of the shell, and simplified the value of $Z = .0982 \left(\frac{D^4 - d^4}{D} \right)$; having used feet before, feet should be used in this formulæ, or divide the results obtained from using inches by 12.

Dividing the bending moment obtained as above, by the section modulus Z , we obtain the strain per square inch on any section considered.

By calculating the bending moments at different heights of the chimney by multiplying the diameter by H by one-half of the height above the section under consideration by 30 pounds, we may then make use of the following table.

TABLE No. 20.

MOMENTS OF RESISTANCE OF THIN HOLLOW CYLINDRICAL BEAMS (IN FEET).

 D = outside diameter. R in inches = $\frac{.0982 (D^4 - d^4)}{D}$ d = inside diameter.

Inside Diameter, Inches.	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
44	23.9	31.9	39.9	47.9	56.1	64.1	72.2	80.4
48	28.3	37.9	47.4	56.9	66.5	76.1	85.8	95.4
52	33.4	44.5	56.7	66.8	78.1	89.4	101.0	112.0
56	38.6	51.6	64.5	77.5	90.5	104.0	117.0	130.0
60	44.4	59.3	74.0	89.0	104.0	119.0	134.0	149.0
64	50.4	67.3	84.1	101.0	118.0	135.0	152.0	169.0
68	56.8	75.9	94.9	114.0	133.0	152.0	172.0	191.0
72	63.8	85.0	107.0	128.0	149.0	171.0	192.0	214.0
76	71.8	94.0	125.0	150.0	175.0	200.0	226.0	251.0
80	80.8	104.0	145.0	174.0	203.0	232.0	261.0	291.0
84	86.8	116.0	166.0	200.0	233.0	267.0	300.0	334.0
88	93.0	129.0	189.0	227.0	265.0	303.0	341.0	380.0
92	100.0	143.0	213.0	256.0	299.0	342.0	385.0	428.0
96	107.0	158.0	239.0	287.0	335.0	383.0	432.0	480.0
100	114.0	173.0	267.0	320.0	373.0	427.0	481.0	535.0
104	122.0	189.0	295.0	354.0	414.0	473.0	533.0	592.0
108	130.0	206.0	327.0	390.0	451.0	512.0	576.0	640.0
112	138.0	224.0	360.0	428.0	490.0	553.0	621.0	690.0
116	147.0	243.0	395.0	468.0	530.0	596.0	668.0	740.0
120	156.0	263.0	432.0	510.0	572.0	641.0	716.0	796.0
124	165.0	284.0	471.0	554.0	616.0	688.0	766.0	852.0
128	175.0	306.0	512.0	600.0	663.0	738.0	819.0	909.0
132	185.0	329.0	555.0	648.0	712.0	792.0	876.0	968.0
136	196.0	353.0	600.0	698.0	763.0	848.0	936.0	1030.0
140	207.0	378.0	647.0	750.0	816.0	906.0	999.0	1094.0
144	219.0	404.0	696.0	804.0	871.0	966.0	1064.0	1160.0
148	231.0	431.0	747.0	860.0	928.0	1028.0	1127.0	1228.0
152	244.0	459.0	800.0	918.0	987.0	1092.0	1193.0	1298.0
156	257.0	488.0	855.0	978.0	1048.0	1158.0	1262.0	1370.0
160	271.0	518.0	912.0	1040.0	1111.0	1226.0	1334.0	1444.0
164	285.0	549.0	971.0	1104.0	1176.0	1296.0	1408.0	1520.0
168	299.0	581.0	1032.0	1170.0	1243.0	1368.0	1484.0	1598.0
172	314.0	614.0	1095.0	1238.0	1312.0	1442.0	1562.0	1678.0
176	329.0	648.0	1160.0	1308.0	1383.0	1518.0	1642.0	1760.0
180	344.0	683.0	1227.0	1380.0	1456.0	1596.0	1724.0	1844.0
184	359.0	719.0	1296.0	1454.0	1531.0	1676.0	1808.0	1930.0
188	375.0	756.0	1367.0	1530.0	1608.0	1758.0	1894.0	2018.0
192	390.0	794.0	1440.0	1608.0	1687.0	1842.0	1982.0	2108.0
196	406.0	833.0	1515.0	1688.0	1768.0	1928.0	2072.0	2200.0
200	422.0	873.0	1592.0	1770.0	1851.0	2016.0	2164.0	2294.0
204	438.0	914.0	1671.0	1854.0	1936.0	2106.0	2258.0	2390.0
208	455.0	956.0	1752.0	1940.0	2023.0	2198.0	2354.0	2488.0
212	471.0	1000.0	1835.0	2028.0	2112.0	2292.0	2452.0	2588.0
216	488.0	1045.0	1920.0	2118.0	2203.0	2388.0	2552.0	2690.0
220	505.0	1091.0	2007.0	2210.0	2296.0	2486.0	2654.0	2794.0
224	522.0	1138.0	2096.0	2304.0	2391.0	2586.0	2758.0	2900.0
228	539.0	1186.0	2187.0	2400.0	2488.0	2688.0	2864.0	3008.0
232	556.0	1235.0	2280.0	2498.0	2587.0	2792.0	2972.0	3118.0
236	573.0	1285.0	2375.0	2598.0	2688.0	2898.0	3082.0	3230.0
240	590.0	1336.0	2472.0	2699.0	2791.0	2996.0	3194.0	3344.0

(Power, 1897.)

Dividing above result by the strength in tension of steel-plate—45,000 to 50,000 pounds, divided by a factor of safety of 4, obtain the factor which in the horizontal line of chimney diameter will be found in the column of proper thickness of steel to be used for the shell at the section considered.

Thus for the chimney under consideration, 40 feet down from the top, we have $(5\frac{1}{2} \times 40) 30 \times \frac{40}{2} = 132000$, which, divided by 12,000 pounds, gives 11 as the section modulus; so the shell may be made of less than $\frac{3}{16}$ " thickness at that elevation. It is not advisable to use less than $\frac{1}{8}$ " to $\frac{3}{16}$ " thickness of metal in any tall chimney, or short one, if long life is to be desired.

The Philadelphia Engineering Works, Ltd., gives the following for the shells of steel chimneys:

TABLE No. 21.
SIR WILLIAM FAIRBAIRN'S EXPERIMENTS.

	Clear span.	Thickness iron.	Outside diameter.	Sectional area.	Breaking weight.	Breaking weight by Clark's formula. Constant 1.2 lbs.
	Feet. Inches.	Inch.	Inches.	Square inches.	Lbs.	
I....	17 0	.037	12.0	1.3901	2,704	2,627
II....	15 7½	.113	12.4	4.3669	11,440	9,184
III....	23 5	.0631	17.68	3.487	6,400	7,302
IV....	23 5	.119	18.18	6.74	14,240	13,910

Mr. Edwin Clarke has formulated a rule, from experiments conducted by him, in the use of iron and steel for hollow tube bridges, which is as follows:

$$(36) \text{ Centre breaking load in tons} = \frac{\left\{ \begin{array}{l} \text{Area of material} \\ \text{in inches.} \end{array} \times \begin{array}{l} \text{Mean depth} \\ \text{in inches.} \end{array} \times \begin{array}{l} \text{Con-} \\ \text{stant.} \end{array} \right\}}{\text{Clear span in feet.}}$$

When the constant used is 1.2, the calculation for the tubes experimented upon by Mr. Fairbairn are given in the last column of the above table.

D. K. Clark's "Rules, Tables, and Data for Mechanical Engineers," page 513, gives the following rule for hollow tubes:

$$(37) \quad W = \frac{3.14 D^2 T S}{L}$$

W = Breaking weight in pounds in centre.

D = Extreme diameter in inches.

T = Thickness in inches.

L = Length between supports in inches.

S = Ultimate tensile strength in pounds per square inch.

Taking S , the strength of a square inch of a riveted joint at 35,000 pounds, this rule figures as follows for the different examples experimented upon by Mr. Fairbairn:

$$\begin{aligned} \text{I. } & 3.14 \times 144 \times 0.037 \times 35,000 \div 204 = 2,870 \\ \text{II. } & 3.14 \times 153.76 \times 0.113 \times 35,000 \div 187.5 = 10,190 \\ \text{III. } & 3.14 \times 312.5 \times 0.0631 \times 35,000 \div 282 = 7,700 \\ \text{IV. } & 3.14 \times 330.5 \times 0.119 \times 35,000 \div 282 = 15,320 \end{aligned}$$