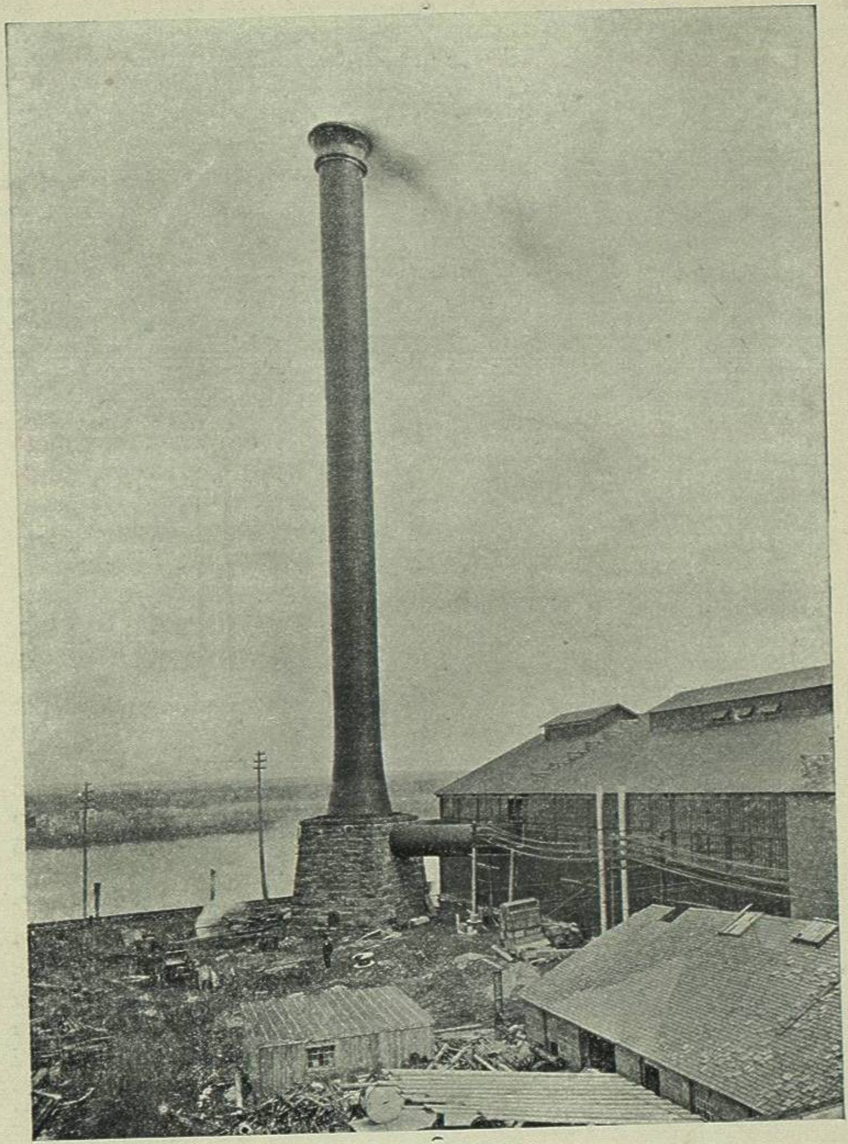


ILLUS. No. 3.

Hartford Street Railway Company's Chimney.

The Hartford Street Railway Co.'s (Hartford, Conn.) chimney is 166 feet high, diameter of bell at base 190 inches, tapering to 129 inches diameter at a height of 21 feet. Twenty-one feet of ½-inch steel at bottom, 30 feet $\frac{7}{16}$-inch steel, 30 feet ⅜-inch steel, 30 feet $\frac{5}{16}$-inch steel, and 55 feet ¼-inch steel at top. Ladder from top to within 2 feet of the base; a 5 by ½-inch flat iron band around the top, on inside; copper cornice 190 inches diameter by 114 inches high, of 24-ounce copper; base plate 18 feet 6 inches square. This stack has 4½ inches lining, thus making a 10 feet diameter flue.

A close approximation between the breaking weights obtained by his experiments and those derived from Mr. Edwin Clarke's and Mr. D. K. Clark's rules will be observed. It may be assumed, therefore, that this system of calculation is practically correct, and that it is eminently safe when a large factor of safety is provided, and from the fact that a chimney may be standing for many years without receiving anything like the strain taken as the basis of the calculation—fifty pounds per square foot. Wind pressure at fifty pounds per square foot may be assumed to be travelling in a horizontal direction and be of the same velocity at all points between the top and the bottom of the stack. This is the extreme assumption. If, however, the chimney is round, its effective area will be only half of its diametral plane, that is, the entire force on round chimneys if concentrated in the centre of the height of the section of the chimney to be considered.

Taking the average diameter of a 125-feet chimney as 90 inches, the effective surface in square feet upon which the force of the wind may act will, therefore, be $7\frac{1}{2}$ times 125 divided by 2, which multiplied by 50, gives a total wind force of 23,437 pounds. The resistance of the chimney to breaking across the top of the foundation would be 3.14×168^2 (that is, diameter of base), multiplied by $.25 \times 35{,}000 \div (750 \times 4) = 258{,}486$, or 10.6 times the entire force of the wind. We multiply the half height above the joint in inches 750 by 4, because the chimney is considered a fixed beam with a load suspended at one end.

In calculating its strength half-way up, we have a beam of the same character, the beam in this case being fixed at a point half-way up the chimney, where it is 90 inches in diameter and .087 inch thick. Taking the diametral section above this point and the force as concentrated in the centre of it, or half-way up from the point under consideration, its breaking strength is: $3.14 \times 90^2 \times 0.187 \times 35{,}000 \div (381 \times 4) = 109{,}220$. The force of the wind to tear it apart through its cross-section at this line, $7\frac{1}{2} \times 62\frac{1}{2} \times 50 \div 2 = 11{,}725$, or a little more than one-tenth of the strength of the stack.

Riveting.—Not less than $\frac{1}{2}$-inch rivets, and never a less diameter than the thickness of plate should be used.

For vertical or horizontal seams in flaring base the joints should be double-staggered riveting; above the bell a single riveted joint can usually be made use of, though for horizontal joints double-staggered riveted joint may often be most desirable and necessary—having a greater lap for sheet and consequently giving greater stiffness to the shell.

Button-head should invariably be used, with the button-head inside so as to present the least resistance to the gases.

Rivets should be spaced at least $2\frac{1}{2}$ times their diameter centre to centre, by a distance not any further apart than 16 times the thickness of the plate with which they connect; use all possible care to have the joint air tight and of sufficient strength.

In Reuleaux's "Constructor" is the following regarding riveted joints, which may be found of value in this connection.

Let s = thickness of plate.
d = diameter of rivet.
a = pitch of rivets, centre to centre of adjacent rivets.
n = number of rows of rivets.
ϕ = ratio of resistance of joint to full plate.
b' = overlap for shearing.
b'' = overlap for bending.

Overlap is the distance from centre of rivets to edge of plate.

In connection with the above we have the following table, No. 22, regarding lap-joints, which type is most frequently used in steel-chimney construction.

For ease of construction and economy also, the method of making the diameter of the circle between the plates the same for all joints is the best, and the upper end of each section should be placed inside the lower end of the section immediately above it. For brick-lined chimneys the reverse order is preferred.

In recent tests made of the flow of water under the direction of Clemens Herschel, of the East Jersey Water Company, of New York City, it has been found that the friction is appreciably less in pipes constructed as above over the style of one large course than one small one, and large one, etc.*

* Reference—One Hundred and Fifteen Experiments on the Flow of Water Through Riveted Pipes. Herschel. Published by John Wiley & Sons.

TABLE No. 22.

PROPORTIONS OF RIVETED JOINTS (REULEAUX'S "CONSTRUCTOR").

$\frac{d}{t}=$			1.0		1.5		2.0		2.5		3.0		4.0	
n			1	2	1	2	1	2	1	2	1	2	1	2
LAP JOINT.		$\frac{p}{t}$	1.63	2.22	2.92	4.33	4.52	7.04	6.43	10.47	8.67	14.33	14.07	24.14
		$\frac{b'}{t}$	0.39	0.39	0.88	0.88	1.57	1.57	2.54	2.54	3.53	3.53	6.28	6.28
		$\frac{b''}{t}$	1.06	1.06	1.78	1.78	2.58	2.58	3.46	3.46	4.31	4.31	6.48	6.48
		R	0.39	0.55	0.49	0.65	0.56	0.72	0.61	0.76	0.65	0.79	0.72	0.83
	$\frac{\pi d}{5t}=$	$\frac{c}{s}$	0.63	0.63	0.94	0.94	1.26	1.26	1.57	1.57	1.88	1.88	2.51	2.51
BUTT JOINT.		$\frac{p}{t}$	2.26	3.52	4.33	7.15	7.04	12.05	10.37	18.21	14.33	25.61	24.14	44.21
		$\frac{b'}{t}$	0.79	0.79	0.96	0.96	3.14	3.14	4.91	4.91	7.07	7.07	12.56	12.56
		$\frac{b''}{t}$	1.29	1.29	2.20	2.20	3.24	3.24	4.37	4.37	5.60	5.60	8.32	8.32
		R	0.56	0.72	0.65	0.79	0.72	0.83	0.76	0.86	0.79	0.90	0.83	0.94
	$\frac{2\pi d}{5t}=$	$\frac{c}{s}$	1.26	1.26	1.88	1.88	2.51	2.51	3.14	3.14	3.77	3.77	5.03	5.03

d = diameter of rivet.
t = thickness of plate.
n = number of rows of rivets.
p = centre to centre, or pitch of rivets.
b' = lap for shearing conditions.
b'' = lap for bending conditions.
s = stress in the punched plate.
R = ratio of resistance of joint to that of the full plate.
c = pressure of rivet on thickness of plate.

Wherever possible one section in height should be made of one sheet in circumference, and the author prefers to make the bell one sheet in height by 6, 8, or 12 sheets direction of the circumference; joints in the latter to be double-staggered riveted.

We have the following graphic representation of the rule just given for stability of chimneys:

If the chimney is blown to the position of the angle indicated, or until the line from centre of pressure passes through the third of the foundation, indicated by the arrow, we have, by summation of moments, about $M = O$ or zero.

$$(38)\quad (W_c + W_F)\frac{D_F}{3} = \text{wind-pressure}\left(\frac{h_c}{2} + h_F\right).$$

Collecting the data of a number of existing * self-sustaining steel chimneys and plotting the results given in the last three columns on the right in the accompanying table,† the author finds that a straight line fairly represents each mean, and for any chimney of steel—self-sustaining, the following equation holds good:

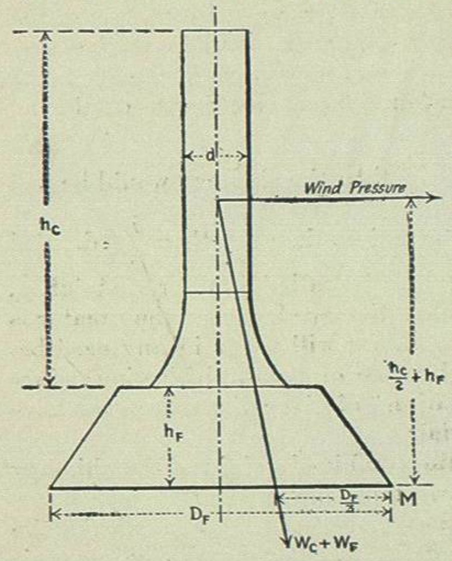
$$(39)\quad D_F = \frac{h_c^2 d}{26000} + 10.$$

Knowing h_c, h_F, which may be taken equal to or assumed a little less than D_F, W_c, D_F and wind-pressure, and substituting in equation, 38, we can obtain W_F for a given case.

By substitution:

$$(40)\quad (W_c + W_F)\frac{D_F}{3} = 30h_c h_F d + 15h_c^2 d.$$

Knowing the least diameter of the base of the foundation we can readily calculate the cubical contents of the necessary frustum of a cone by the following rule:



The contents of the frustum of a cone or pyramid are found by adding together the areas of the ends and the mean proportional between them (the square root of their product), and multiplying the sum by one-third of the perpendicular height.

In the event of the diameter of the base assumed for top and bottom of the foundation not giving enough weight, the size or area of base may be altered from round to hexagon, or square, or built up straight for 2 or 3 feet from bottom, or the weight increased in other ways—at the pleasure of the designer.

* Pp. 60, 61, 62. † Table 23, p. 60.

120 to 150 pounds per cubic foot is about the proper weight for such materials as enter into foundations of this character.

They should be made of any clean stone or brick-bats well grouted in Portland-cement mortar, thoroughly rammed.

The part out of the ground should be laid up with good-sized blocks of local quarry stone, rough dressed, or of brick.

The poorest soil will sustain about one ton load to the square foot of foundation area—quicksand not excepted, if it is properly covered over and confined.

Piling, however, is often resorted to in unstable bottoms, and along river-banks and in marshy lands.

Foundations.—The following is the rule for stability of steel chimneys and the relation to the foundation :

Find the total wind-pressure on the chimney and its moment about an axis in the plane of the base of the foundation.

Find also the total weight of the chimney with its lining, and of the foundation.

Divide the moment of the wind-pressure by the weight of the chimney and foundation ; the quotient will be the distance from the outer edge at M which is the length of the lever-arm of the combined weights of foundation and chimney producing equality of moments.

Should this distance be $\frac{D_F}{2}$ then the chimney would be just stable ; should this distance be less than $\frac{D_F}{2}$ then $\frac{D_F}{2}$ divided by the distance in question may be called a factor of stability, and consequently the less this distance becomes the greater is the factor of stability; this factor will never in any case become infinity (except in the case of no wind blowing), since no " chimney and its foundation " of given dimensions can have an infinite weight of material.

Therefore, the heavier the combined weight of the chimney and its foundation, the more stable the structure.

Should the distance above mentioned come within the outer third of the width of the foundation, the chimney is stable, with a fair factor of safety, provided of course that the chimney proper and its anchorage to the foundation have been properly designed and constructed.

The strength obtained from the ground to support the sides of the foundation, has been left out of our calculation, though the stability is increased by it. See p. 42.

For the chimney we have been considering, p. 50, using formula 38, we have :

$$\text{(41)}\quad 150 \times 30 \times 5\tfrac{1}{2} \times \left(\frac{150}{2} + 16\right) = 2252250 \text{ foot-pounds,}$$

where 16 feet is the depth of the foundation.

Weight of chimney is 38,000 pounds.
Weight of foundation is 400,000 pounds.

Total weight, 438,000 pounds, then

$2252250 \div 438000 = 5.14$, which is less than $16 \div 3$, or 5.33, so the chimney is stable with a factor of stability of $8 \div 5.14 = 1.55$.

For foundations on loose soils it may be found desirable to increase the factor of stability to say $2\frac{1}{2}$ or 3.

If we had substituted the value of the wind moment about an axis in the plane of the base of the chimney, as obtained from equation 42, in place of the value obtained from 41, our result would show a still greater stability ; this method, however, would not be strictly correct, as the depth of foundation, which in many cases is largely above ground, is left out of the consideration in equation 42.

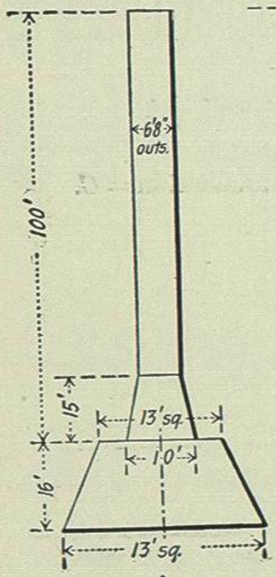
$$\text{(42)}\quad \text{Moment} = h_c \times 30 \times \frac{h_c d}{2} = 30\left(\frac{h_c^2}{2}\right) d.$$

Diameter at base of foundation $= D_F$.
Cubic feet of masonry in foundation $= C$.

TABLE No. 23.

Chimney.	$\frac{h_c^2 d}{2}$	D_F	C	Foundation Depth.
No.		Feet.		Feet.
1.	8,575	13 square	2,704	16
2.	77,890	18 square	8,100	25
3.	188,360	25 square	15,625	25
4.	230,000	30 diameter	18,500	30
5.	430,304	36 square	25,058	22
6.	146 330	20 square	2,666	20
7.	9,600	11¼ square	632	5
8.	22,500	15 diameter	1,340	9
9.	10,666	10½ square	707	9
10.	9,600	13 diameter	676	8
11.	348,046	47 diameter	27,566	22
12.	188,180	30 diameter	6,961	13½
13.	35,156	15 square	2,250	10
14.	17,150	10 square	583	8

Anchorage.—To anchor the chimney to the foundation, bolts or rods are used running from a foot fastened to the bell of the chimney through the base-plate nearly to the bottom of the masonry, terminating in a lock-nut cast-iron washer.



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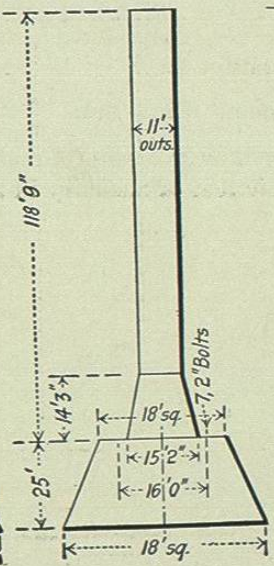

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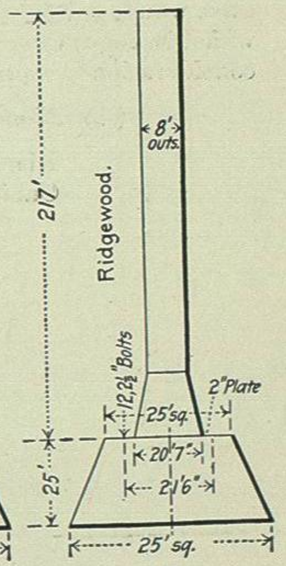

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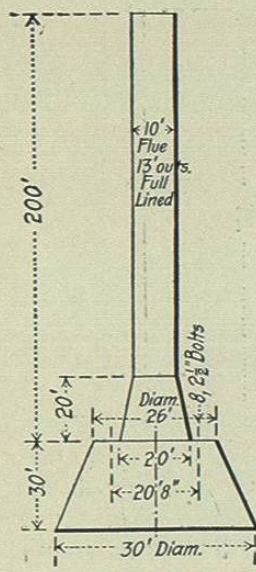

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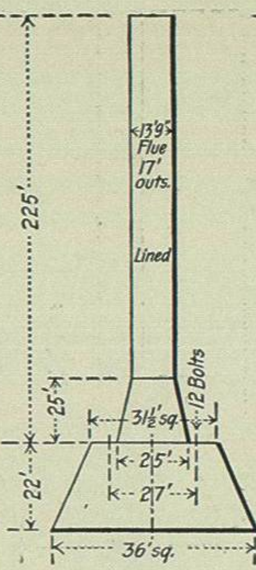

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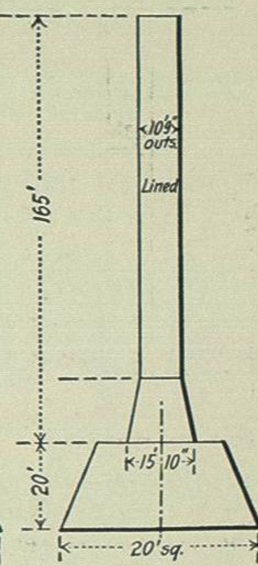

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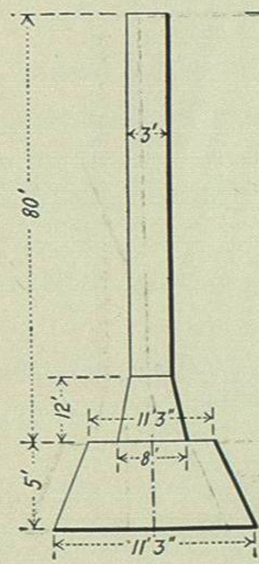

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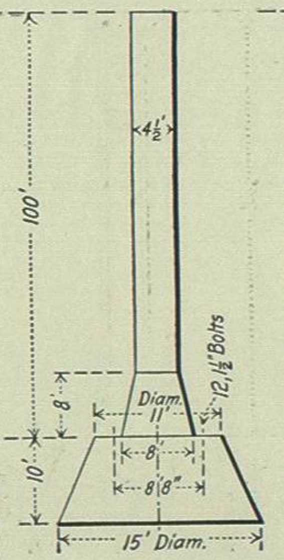

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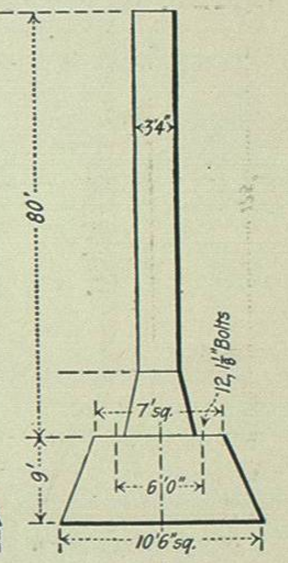

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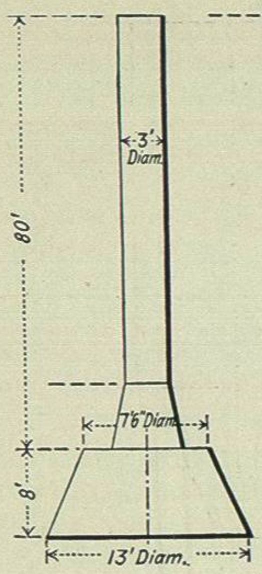

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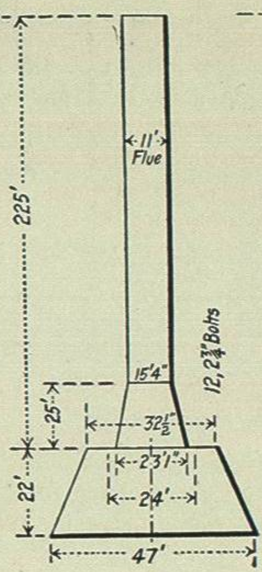

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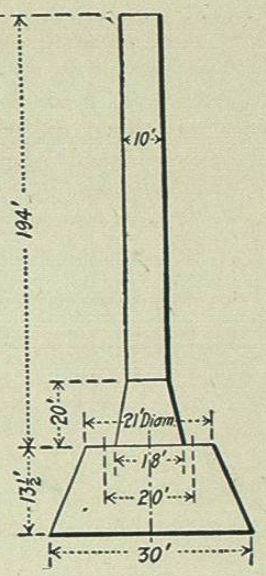

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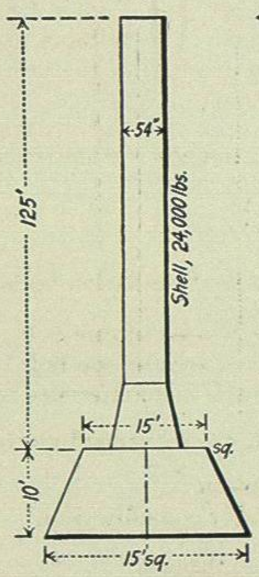

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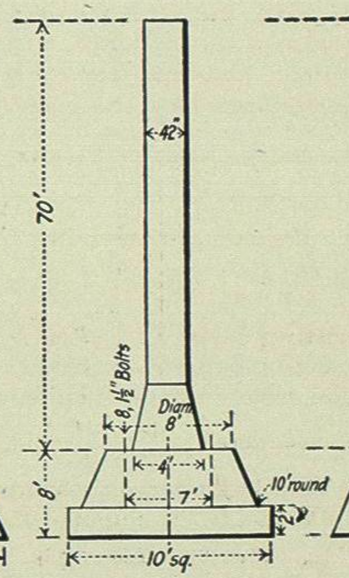

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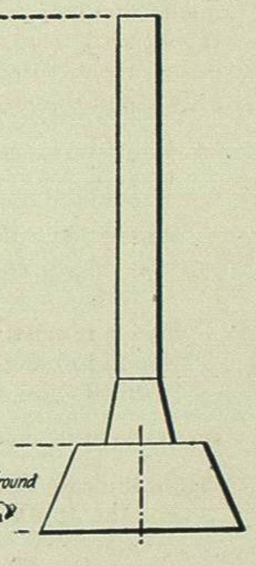

15.

These anchor-bolts are both subjected to tension and shearing, but the chimney being not very likely to slide on its foundation, we neglect the shearing strain in our calculations.

As the lining of chimneys is not always in place or in good repair, we will neglect its weight, as it cannot be counted upon for assistance in keeping the chimney stable.

The overturning moment, M, is about the circumference of the largest diameter of the bell-base, or on a circle whose diameter is D_B and equals, $M = 25 D_B \frac{H^2}{2}$. The weight of the steel shell being W, the moment of contrary effect to above, m is $m = W \times \frac{D_B}{2}$; which enables us to find the overturning moment $T = M - m$.

This is the moment on the foundation bolts, which are equally spaced in a circle, and are from 6 to 12 or even more in number, and the calculations for the bolts are made as follows:

Considering any point in the bolt circle, the approximate mean distance from the circumference of same on a line through the centre of the bolt circle to all of the bolts is the radius of that circle; and considering that one-half of the bolts only stand the strain, we have this equation:

$T_c = \frac{D_c}{2} \times$ tension on bolts $= \frac{D_c}{2} \times 9000$ pounds $\times$ number of bolts $\times$ area of one bolt.

Where D_c = diameter of bolt circle,

(43) $T_c = \left(T \times \frac{D_c}{2}\right) \div \frac{D_B}{2}$ or the moment on the foundation bolts.

For 6 foundation bolts, $T_c = 27000\ D_c \times$ area of one bolt.
For 12 foundation bolts, $T_c = 54000\ D_c \times$ area of one bolt.

In reality the mean distance of bolts from circumference in the half circle considered is $\frac{D_c}{2} + \frac{D_c}{6}$, and we are considerably inside the safe limit in the former assumption.

For the application to the chimney under consideration

$$(44) \quad M = \frac{25 \times 5\frac{1}{2} \times 150 \times 150}{2} = 1546875.$$