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Design of reinforced concrete water tower and tank

Harvey Oden Garst

Pearl Frederick Michael

Department: Civil, Architectural and Environmental Engineering

DESIGN OF REINFORCED CONCRETE
WATER TOWER AND TANK.

HARVEY ODEN GARST. PEARL FREDERICK MICHAEL.

Approved,

Elmo G Harris

DATA.

CAPACITY 100,000 gal.

HEIGHT OF BOTTOM ABOVE GROUND 80 ft.

DESIGN OF TANK

Theoretically the most economical dimension for a flat bottomed cylindrical tank would be such that the height of the tank is equal to the diameter, but such a tank does not look as well as one which has the height a little greater than the diameter and as the cost will be affected but little by making the height a few feet greater than the diameter, the most economical design will not be strictly carried out in this particular.

APPROXIMATE DIMENSIONS OF THE TANK.

If d = diameter of tank and

h = height of tank

then the capacity of a flat bottomed cylindrical tank is given by the formula

$$\pi \frac{d^2 h}{4} = Q$$

If $\underline{d}$ and $\underline{h}$ be given in feet then

$$\pi \frac{d^2 h}{4} = \frac{100000}{7\frac{1}{2}} \text{ cu ft}$$

Assuming $d = 25$ feet, gives $h = 27.23$ feet. These will be given as the approximate dimensions and will be changed somewhat farther on in the design

DESIGN OF PIPE FOR FILLING AND EMPTYING TANK.

The tank will be filled and emptied by a pipe coming up through the center of the bottom. This pipe will be of 3/16 inch rivited steel and will be large enough to meet all the requirements of a city of 10,000 inhabitants without causing an excessive velocity. It will be assumed that the maximum velocity is to be between 3 and 4 feet per second.

The average daily consumption will be taken as 150 gallons per capita, which would require 1040 gallons per minute. Taking the maximum daily rate as 150% of the ordinary daily rate and the maximum hourly rate as 150% of the maximum daily rate gives the maximum hourly rate as 225% of the ordinary daily rate, or 2340 gallons per minute. Also assuming four fire streams of 250 gallons per minute each, raises the total maximum consumption to 3340 gallons per minute. Then from the formula $Q = \frac{\pi d^2 v}{4}$ where Q is quantity in cubic feet per second, d is diameter of pipe in feet and v is velocity of water through the pipe in feet per second, we have,-

$$d^2 v = \frac{3340 \times 4}{7\frac{1}{2} \times 60 \times \pi} = 9.4 \text{ feet}$$

If v be taken as 4 feet, $d^2 = 2.325$ feet ; $d = 1.5$ feet
But we want the velocity to be less than 4 feet per second so we will take d = 20 inches.

DESIGN OF HOLLOW CENTRAL COLUMN

The pipe just designed will be surrounded by concrete, which will serve to act as a protection to the steel pipe and as a central column for the floor system. For approximate design we can regard the load brought to this central column by each of the eight floor beams shown by the heavy lines, as ab in Fig.1, as one third of the weight of the water over the area acoda.

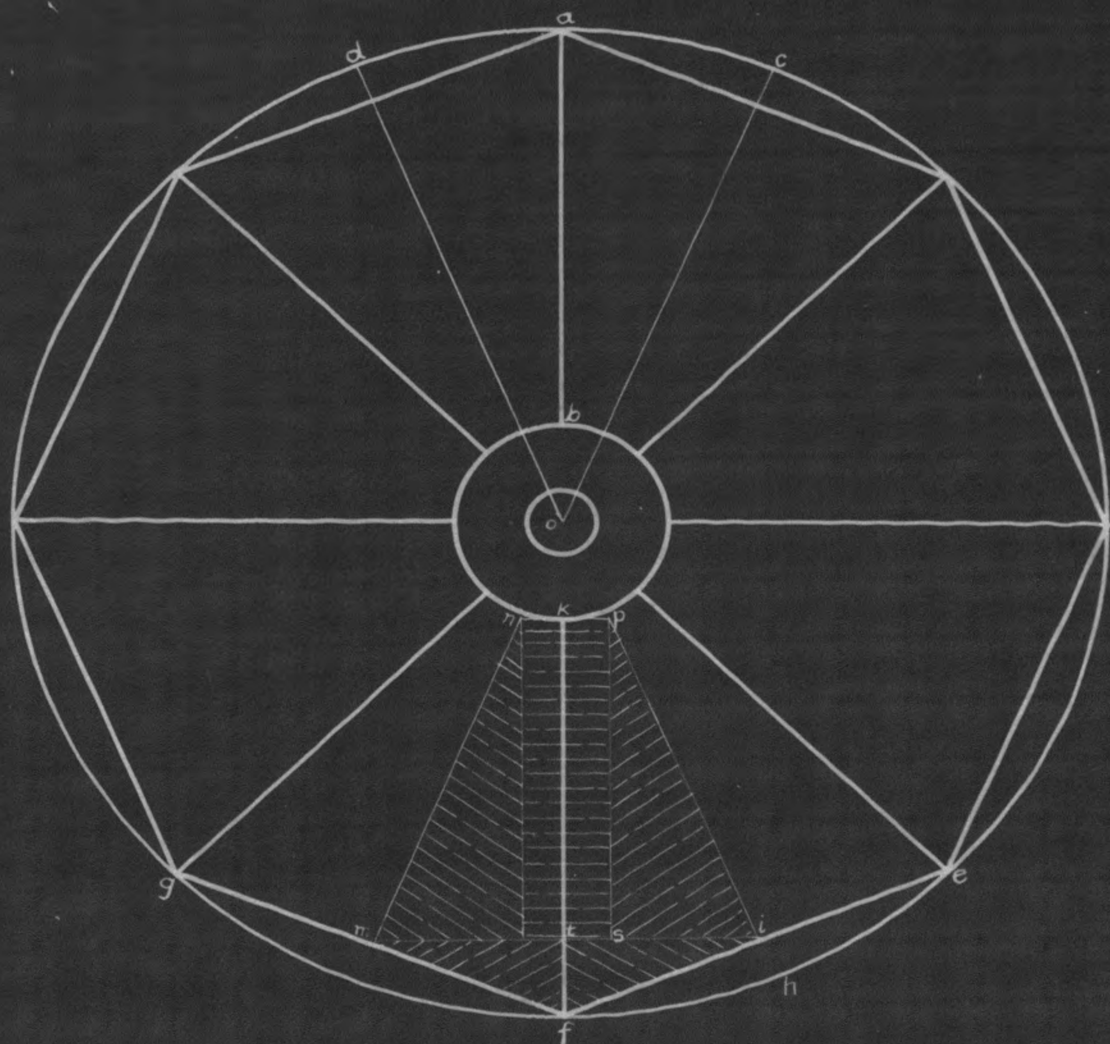


Fig. I

Then,-

$R_{center} = 1/3 \times 27.25$ ft. $\times 62.5$ lbs/ft.$^3 \times 1/8$ the area of a circle 25 ft. Diam.

$= 1/3 \times 27.25$ ft. $\times$ 62.5 lbs/ft^3 $\times$ 1/8 490.8739 feet^2

$= 35000$ lbs.

Then the total load brought to the column at the center by all the floor beams is 8×35000 lbs. or 140 tons. Allowing 10 tons per sq.ft. as the permissible load requires a section area of 14 sq.ft. for the central column. This requires the outer diameter of the hollow column to be 4 ft. 8 in. or 4.666ft.

DESIGN OF FLOOR BEAMS.

Large rods will be put in across the outside ends of the beams as shown by ef and fg in Fig.#I . Then we may assume that all the load on the section fiehf is either carried directly out to the circumference fhe or carried out by the rods to the points e and f without ever getting into the floor beams. The load on the small area between the central column and a tangent to its outside circumference at the point k , being small and adjacent to the column, may be assumed to be carried directly to the column without getting into the beam. Therefore in designing the beam as kf in Fig. I. the load which must be considered is that over the shaded area mnkpifm .

REACTION AT ENDS OF BEAM AND CENTER OF GRAVITY OF SUPPORTED LOAD.

To find the center of gravity of the load it is necessary to divide the figure into triangles and rectangles as is shown by the different shading, Fig. I. The length of all the sides are either known or may be computed.

of = 12.5 ft   ok = 2.333ft.

hf=mf=of sin 22° - 30' = 4.784 feet.

ft=ht sin 22°-30'=1.831 ft

it=tm=hf cos 22°-30' 4.4185 feet

kn=kp=ok tan 22° - 30'=0.9665 "

is=rm=it-ts=it-kp = 3.453 feet

kf=of - ok = 10.166 feet

kt=kf - tf = 8.335 feet

The partial areas and distances of center of gravity ($\bar{x}$) with respect to the line np are tabulated below. With respect to the line np, the center of gravity of the whole area mnkpifm is the same as the center of gravity of half the area, viz,- kpifk.

Partial Area	$\bar{x}$ ft	Area sq.ft.	Moment.
kpstk	4.1675	8.0560	33.573
psip	5.5560	14.3910	79.950
ifti	8.9950	4.0555	36.390
Totals		26.4925	149.913

$\bar{x}$ (distance of center of gravity of total area with reference to np) is found by dividing total moment by total area. Therefore $\bar{x} = \frac{149.931}{26.4925} = 5.66$ ft.

If R_1 be the reaction of the beam at k and R_2 be the reaction at f then

$$R_1 = \frac{4.506}{10.166} \text{ load on area nkpifm}$$

$$R_2 = \frac{5.66}{10.166} \quad " \quad " \quad " \quad "$$

The floor area supported by one beam is 2 (area <u>kpstk</u> + area <u>psip</u> + area <u>ifti</u>) = 52.985 sq.ft. The water load on this area is 52.985 $ft^2 \times 62.5$ lbs./ $ft^3 \times 27.25$ ft = 90240 lbs.

$$R_1 = \frac{4.506}{10.166} \times 90240 \text{ lbs.} = 40000 \text{ lbs}$$

$$R_2 = \frac{5.66}{10.166} \times 90240 \text{ lbs.} = 50240 \text{ lbs.}$$

POINT OF MAXIMUM MOMENT IN FLOOR BEAMS.

Let A-B Fig. (a) represent any section of the beam <u>kf</u>, A-B being perpindicular to <u>kf</u>.

x distance from <u>k</u> to this section A-B

$\bar{x}$ distance of center of gravity of <u>bnpeb</u> from A-B

Now taking the forces to the right of the section.

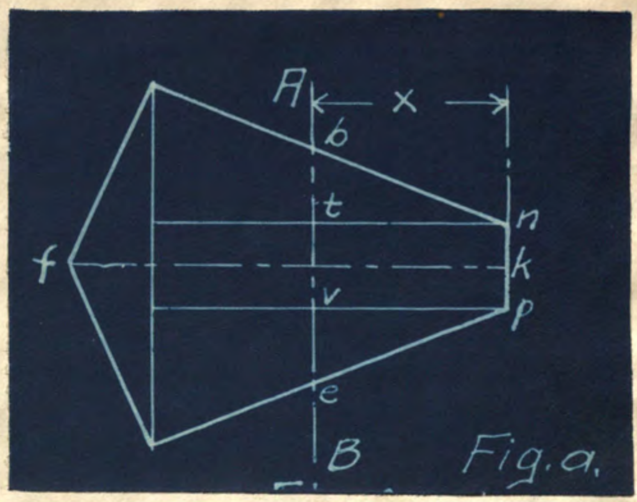


Fig. a.

M_{AB} = M. of R_1 - M of loads to right.

$= 40000\, x$ - (area <u>bnpeb</u>) ($\bar{x}$) (62.5) (27.25) ------------------ I

pn = 2kn = 2 × 0.9665 ft = 1.933 ft.

bt = ev = x tan 22° - 30'

The figure <u>bnpeb</u> will be divided into two triangles, <u>bntb</u> and <u>vepv</u>, and the rectangle <u>tnpvt</u>.

Below is a table of areas, $\bar{x}$'s and <u>M's</u> of the different parts. The moments and $\bar{x}$'s are with respect to <u>np</u>

	Area.	$\bar{X}$	M.
bntb	$\frac{1}{2}(0.4142x^2)$	$\frac{x}{3}$	$\frac{1}{2}(0.1381x^3)$
tnpvt	1.933	$\frac{x}{2}$	$0.9665x^2$
vepv	$\frac{1}{2}(0.4142x^2)$	$\frac{x}{3}$	$\frac{1}{2}(0.1381x^3)$
Total	$(0.4142x^2 \quad 1.933x)$		$(0.1381x^3 \quad 0.9665x^2)$

$\bar{X}$ of whole section on right of A-B. is total M divided by total area or $\bar{X} = \frac{0.1381\ x^3 + 0.9665x^2}{0.4142x^2 + 1.933x} = x\left(\frac{0.1381x + 0.9665}{0.4142x + 1.933}\right)$

Going back to Eq.1 and substituting values of $\bar{X}$ and area of <u>bnpeb</u> we have,-

$M'_{AB} = 40000\ x - x^2\ (0.1381x + 0.9665)\ 62.5 \times 27.25$ -------------II

To find value of <u>x</u> where M is a Max. differentiate, put $\frac{dM}{dx} = 0$ and solve for <u>x</u>. This gives $x = 5.5452$ ft. Substituting this value of <u>x</u> in Eq.II gives $M_{max} = 1,573,000$ inch pounds

say 1600000 " "

DERIVATION AND APPLICATION OF BEAM FORMULAE.

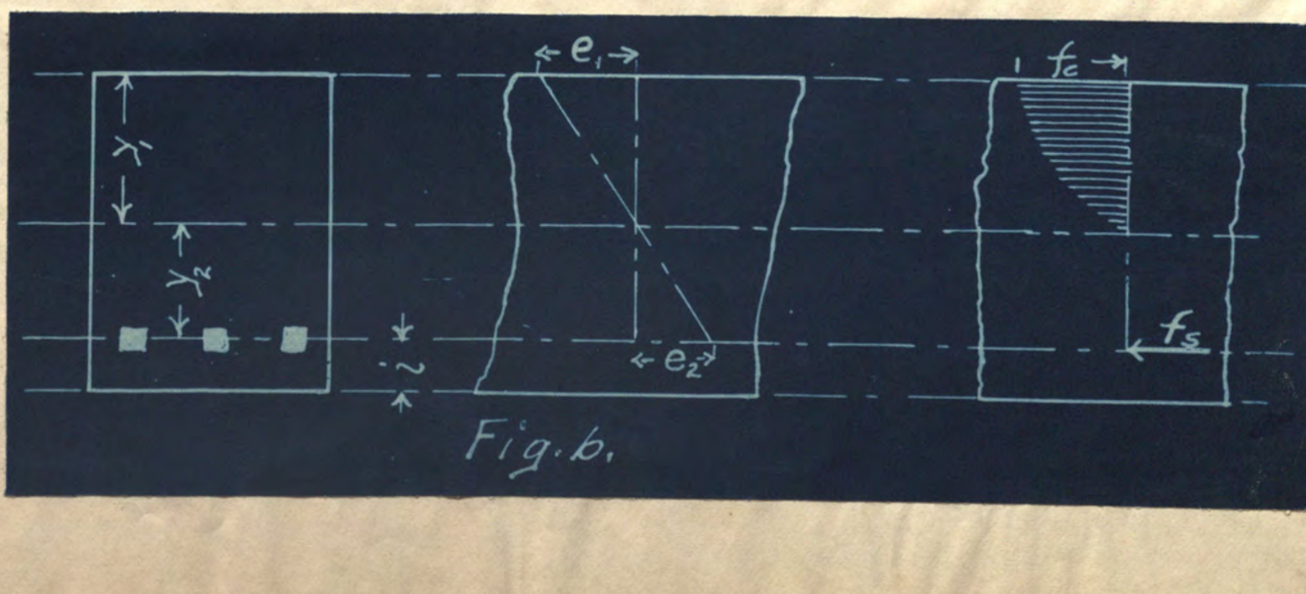


Fig. b.

Let E_s denote Modulus of elasticity of steel

E_c " " " " " concrete

f_s " unit tensile stress in steel.

f_c " " compressive stress in concrete

y_1 " distance of extreme fibre of concrete from neutral axis

y_2 " " " steel from neutral axis

i " depth of concrete below steel

e_1 " unit of deformation in concrete

e_2 " " " " " steel

a " section area of steel per inch of width of beam

z " width of beam in inches

za " total section area of Steel = A

Put

$$\frac{E_s}{E_c} = R \quad \text{and} \quad \frac{f_s}{f_c} = r$$

From Fig. (b) above $\frac{e_1}{e_2} = \frac{y_1}{y_2}$

But $E_s = \frac{f_s}{e_2}$ and $E_c = \frac{f_c}{e_1}$

Whence $e_2 = \frac{f_s}{E_s}$ and $e_1 = \frac{f_c}{E_c}$

Then $$\frac{e_1}{e_2} = \frac{f_c E_s}{f_s E_c} = \frac{y_1}{y_2}$$

$$y_2 = \frac{f_s E_c}{f_c E_s} y_1 = \frac{r}{R} y_1 \quad \text{------------------------------------ III}$$

The total stress per unit width on the concrete is equal to the area of a porabola having vertex on the neutral axis and ordinate f_c and y_1 as abscissa

This stress per unit width is then 2/3 $f_c y_1$ and the total compression on the section is therefore 2/3 $z f_c y_1$.

Tension on steel compression on concrete

T = tension on the steel = 2/3 $z f_c y_1$

$$z a f_s = 2/3\ z f_c y_1$$

$$a = 2/3\ \frac{f_c}{f_s}\ y_1 = 2/3\ \frac{y_1}{r} \quad \text{------------------------------ IV}$$

The point of application of the total compression is at the centroid of the porabola which is 5/8 of the distance from the neutral axis to the top of the beam or 5/8 y_1 from the axis The point of application of $\underline{T}$ is a distance y_2 below the neutral axis hence the moment arm of the couple is (5/8 y_1 y_2) and the moment of the couple being the product of either of them by the arm we may write

$$M = (5/8\ y_1 + y_2)\ 2/3\ z y_1 f_c$$

Substituting, $y_2 = \frac{r}{R}\ y_1$

We have ----- $M = (5/12 + 2/3\ \frac{r}{R}) z f_c y_1^2$ -------------------- V

Now taking,

f_s = 12500 lbs.

f_c = 500 "

r = 25 "

E_s = 28,000,000

E_c = 2,000,000

R = 14

$z = 12$ in

$M_{max.} = 1{,}600{,}000$ in.lbs.and

substituting in Eq.II gives

$y_1 = 12.84$ in.

Then from Eq.III

$y_2 = 22.92$ in.

Make $\underline{i} = 1.74''$ gives total depth of beam, $y_1 + y_2 + i = 37.5$ inches.

From Eq.IV, $a = \dfrac{2 \times 12.84}{3 \times 25}$

$A = za = 4.11$ sq.in.

This area will be approximately given by using three 1 3/16 inch square bars or seven 7/8 inch square bars.

DESIGN OF FLOOR AND INTERMEDIATE REINFORCEMENT BETWEEN THE BEAMS.

Let <u>od</u> (Fig.II) be a line bisecting the angle between two main floor beams.

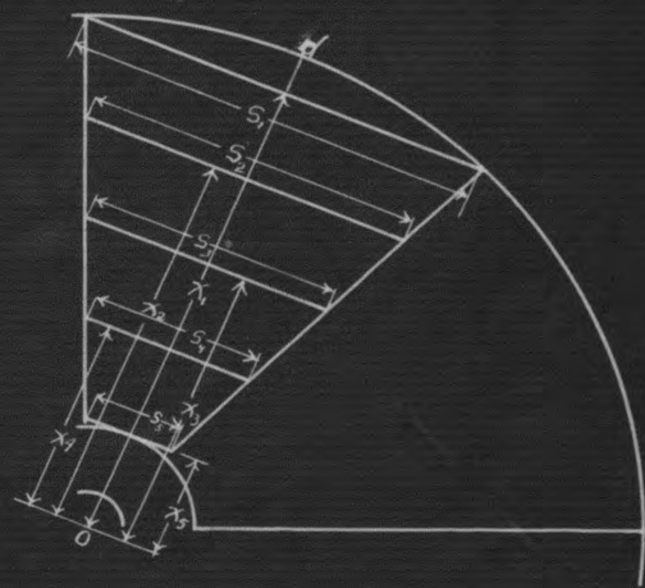
Let $\underline{x}_1$=distance from <u>o</u> out on this line to chord <u>ab</u>=12.5 cos $22^\circ - 30' = 11.55$ ft.

x_5 =distance from <u>o</u> out on <u>od</u> to tangent to outer circumfrence of column $= 2.333$ ft.

Let $\underline{x}_2, \underline{x}_3$, and $\underline{x}_4$ be taken at such points that the distance $\underline{x}_1$ and $\underline{x}_5$ is divided into four equal parts. Let $\underline{s}_1, \underline{s}_2, \underline{s}_3, \underline{s}_4$ and s_5 be the distance perpendicular to <u>od</u> between main floor beams at the points $\underline{x}_1, \underline{x}_2, \underline{x}_3, \underline{x}_4$ and $\underline{x}_5$ respectively.

$$s = 2x \tan 22^\circ - 30'$$

By substituting values of $\underline{x}_1, \underline{x}_2, \underline{x}_3, \underline{x}_4$ and $\underline{x}_5$ find $\underline{s}_1, \underline{s}_2, \underline{s}_3$, $\underline{s}_4$, etc. which with other data is tabulated below Fig.II.



	Span	M_o	y_1''	y_2''	$y_1''+y_2''$	$y_1'+y_2'$	$A\square''$
$X_1 = 11.55$	$S_1 = 9.75$	235450	4.94	8.82	13.72	1.15	1.58
$X_2 = 9.25$	$S_2 = 7.67$	149900	3.94	7.04	10.98	0.92	1.26
$X_3 = 6.94$	$S_3 = 5.75$	84466	2.96	5.29	8.25	0.69	0.95
$X_4 = 4.64$	$S_4 = 3.84$	37670	1.98	3.53	5.51	0.46	0.63
$X_5 = 2.33$	$S_5 = 1.93$	9516	.98	1.78	2.76	0.23	0.32

Fig. II.

Since we have calculated the span between beams at different points we can take strips 12 inches wide at these places and figure a section of the floor as a beam at each of the points $\underline{x}_1$, $\underline{x}_2$, $\underline{x}_3$, etc.

Figuring a strip of floor 12 inches wide between a and b as a beam, we have s_1=9.57 ft. with water load of 62.5 lbs X 27.25 per lineal ft.

The moment is Max. at the center and equal to 235450 inch pounds.

From formula V y_1=4.94 ft

" " 111 y_2=8.82 "

" " IV $a = 2/3 \frac{y_1}{r}$

$A = za = 1.58$ sq.in.

By the same means we can get the section of the floor perpendicular to $\underline{s}_2$, $\underline{s}_3$, $\underline{s}_4$, and $\underline{s}_5$, at the points $\underline{x}_2$, $\underline{x}_3$, $\underline{x}_4$, and $\underline{x}_5$. By plotting values of $\underline{x}$ as abscissa and values of (y_1+y_2) as ordinates it is shown that as the distance from o increases the value of $\underline{y}$ and $\underline{y}_2$ vary as the ordinates of a straight line. The thickness of the floor at the outer circumference of the central column, including i is 0.4 ft. and at distance 11.55 ft. from o it is 1.32 ft.

TO GET EXACT DIMENSION OF TANK.

The volume of water which can be held in the depressed bottom abcda (Fig.F) on detail sheet is the volume of a cone having r = 2.333 ft., R = 12.5 ft. and h = 0.92 ft. and is given by the formula.

$$\text{Vol.} = \frac{\pi h}{3}(R^2 + Rr + r^2)$$

$= 183.8$ cu.ft.

Since the total capacity of the tank is 100000 gallons or $\frac{100000}{7\frac{1}{2}}$ cu.ft. the volume of water which must be held above the level dc is $\frac{100000}{7\frac{1}{2}}$ cu ft.-183.8 cu.ft.= 13149.5 cu.ft.

Since the diameter is to be 25 ft. the Height H_1 is given by the formula,-- $H_1 = \frac{\text{Vol.above level dc}}{\text{Area Cir.25ft.Diam.}} = 26.9$ ft.

$$H_2 = H_1 + 1.32 \text{ ft.} = 28.22 \text{ ft.}$$

THICKNESS OF SIDES OF TANK.

A section of the shell of the tank is shown by qpzvwstkehq in Fig.E on the detail sheet.p and e are points on the line sw,qp being 5 inches and he being 8 inches. pzvwp is a coping, pz being 6 inches and the vertical side zv being 18 inches. At the bottom of the tank a band stkes will be put on for the sake of appearance. ek is 6 inches;kt is vertical and is also 6 inches;se is not vertical but the vertical height of s above hk is 1 ft.

VOLUME AND WEIGHT OF MASONRY IN SHELL.

Not counting the coping pzvwp and the band stkes at the bottom,the volume of the shell,that is the portion qpehq , is given by the following:

$$V = 28.22 \text{ ft.} \times 1/2 \Big[(\text{Area Cir.}25'\text{-}10''\text{ Diam.} - \text{Area Cir.}25\text{-}00''\text{ Diam.}) + (\text{Area Cir.}26'\text{-}4''\text{ Diam.} - \text{Area Cir.}25'\text{-}00''\text{ Diam.})\Big]$$

$= 1228$ cu.ft.

By the same general method the volume of the coping pzvwp is found to be 62 cu.ft. and volume of the bands stkes at the bottom is 31.6 cu.ft. The total volume of the shell represented in section by qpzvwstkehq in Fig.E. is 1321.6 cu. ft. At 150 lbs/ft^3. the weight of shell is 198240 lbs.

VOLUME AND WEIGHT OF MASONRY IN FLOOR.

Neglecting the 20 inch hole in the center, the volume of the masonry in the floor is equal to the volume of the cylinder, dcled ,minus the volume of the frustrum of the right-cone, abcda (Fig.F.)

d = diamter of cylinder = 25 ft.

h = height of cylinder = 1.32 "

The volume of cylinder $= \frac{\pi d^2 h}{4} = 647.8$ cu. ft.

The volume of the frustrum of the cone abcda is 183.8 cu. ft. as already determined on Page (11)

The the volume of the masonry in the floor is 464 cu.ft. and the weight of same at 150 lbs./ft^3. is 69600 lbs.

VOLUME AND WEIGHT OF MASONRY IN FLOOR BEAMS.

Assuming the outside columns to be 14 inches square and placed as in Fig.B., the length of the floor beams between center and outside columns is 9.666 ft. The depth of beam below the floor is 2.725 feet at the center column and 1.8 ft. at the outside columns, the average depth below the floor being 2.26 ft. The width of the beam is 1 ft. Then the volume of a beam is 9.666 ft. $\times$ 1 ft. $\times$ 2.26 ft. or 21.84 cu. ft. The weight at 150 lbs./ ft^3. is 3276 lbs.

REINFORCEMENT OF SHELL.

The shell will be reinforced by horizontal bands or hoops of square twisted steel rods placed at proper intervals and by vertical rods spaced 2 ft. apart on the circumference of a circle 25 ft.4in. in diameter. This will make the vertical reinforcement 2 inches from the inside circumference of the shell. The hoops or bands will be spaced as shown in section in Fig.E. Except in the coping and in the band at the bottom these rods will cut the line determined by a point at the top 3 inches from the inside circumference and by a point at the bottom 5 inches from the projection of the inside circumference. All rods composing the hoops act as tension members and must lap not less than 2 feet at joints, it being assumed that the adhesion of the concrete to the steel together with the mechanical bond afforded by the twist in the rods will be sufficient to develop the working stress of the rods. All reinforcement in the shell will be of $\frac{1}{2}$ inch square bars, the bands being twisted and the verticals plain.

SPACING OF HOOPS.

Let $\underline{jrstj}$ be any vertical section in the shell or side of the tank and $\underline{j_1r_1s_1t_1j_1}$ be a similar section directly opposite on the other side. What we want to do is to calculate the number of bands or hoops of a certain size that will be needed in the section $\underline{jrstj}$ to take care of the tension in that section. This tension is due to the pressure of the water on the plane $\underline{rr_1s_1sr}$. This pressure being resisted equally by both the above named sections, the tension in either one of them is therefore one-half the pressure of the water on the plane $\underline{r\,r_1s_1sr}$

Let h_1 = depth of water over top of the plane

h_2 = " " " " bottom of the plane

x = " " " " an element of the plane

dx = width of the element

$25dx$ = area " " " ,since diam. of tank is 25 ft.

$62.5x$ = unit pressure on the element

$dP = 62.5 \times 25dx$ = pressure on element $= 1562.5x\,dx$

$$P = \int_{h_1}^{h_2} 1562.5x\,dx = \text{pressure on plane } \underline{r\,r_1 s_1 sr} \text{ (See Fig. F)}$$

$$= \frac{1562.5}{2}\left(h_2^2 - h_1^2\right)$$

Then since the tension in the section is one half the pressure on the plane we may write,-

$$T = \frac{1562.5}{4}\left(h_2^2 - h_1^2\right)$$

If all the tension is to be carried by the steel and $\underline{\rho}$ is the permissible unit stress in steel and $\underline{a}$ the section area of one rod then the number of rods needed in the section is given by

$$n = \frac{T}{a\rho} = \frac{1562.5}{4a\rho}\left(h_2^2 - h_1^2\right)$$

Since we are using rods $\frac{1}{2}$ inch square, $a = \frac{1}{4}$ sq.in. $\underline{\rho}$ will be taken as 15000 lbs./in^2. Substituting these values in the foregoing equation gives,-

$$n = .10416\left(h_2^2 - h_1^2\right) \text{ ---------------------------- VI}$$

Now beginning at the top and dividing the tank in one foot sections and solving for $\underline{n}$ get the values tabulated below. $\underline{n}$ and $\underline{\Sigma n}$ indicate respectively the theoretical number of rods needed in a given section and the summation of the number in all the sections from the top down through that section, while $\underline{n}^1$ and $/\underline{n}^1$ indicate corresponding numbers actually used.

Section	h_2	h_1	n	Σn	n^1	Σn^1
1	1	0	0.104	0.104	2	2
2	2	1	0.312	0.416	1	3
3	3	2	0.521	0.937	1	4
4	4	3	0.729	1.666	1	5
5	5	4	0.937	2.603	1	6
6	6	5	1.146	3.749	1	7
7	7	6	1.354	5.103	1	8
8	8	7	1.562	6.665	1	9
9	9	8	1.771	8.436	2	11
10	10	9	1.979	10.415	2	13
11	11	10	2.187	12.602	2	15
12	12	11	2.396	14.998	2	17
13	13	12	2.605	17.603	3	20
14	14	13	2.812	20.415	3	23
15	15	14	3.021	23.436	3	26
16	16	15	3.229	26.665	3	29
17	17	16	3.437	30.102	3	32
18	18	17	3.646	33.748	4	36
19	19	18	3.854	37.602	4	40
20	20	19	4.062	41.664	4	44
21	21	20	4.271	45.935	4	48
22	22	21	4.479	50.414	5	53
23	23	22	4.687	55.101	5	58
24	24	23	4.895	59.996	5	63
25	25	24	5.104	65.100	5	68
26	26	25	5.312	70.412	5	73
27	27	26	5.521	75.933	5	78

DETAILS OF REINFORCEMENT OF SHELL AND AMOUNT OF STEEL REQUIRED.

A section of the shell of the tank is shown in Fig.E. on the detail sheet. The hoops or bands cut the section on a line determined by a point 3 inches from the inside circumference at the top of the tank and a point 5 inches from the inside circumference at the bottom. Exceptions to this are made in the coping and in the band at the bottom but in such cases the dimensions given on the drawing will show the exact position. The vertical reinforcement is 2 inches from the inside circumference of tank, being spaced 2 ft. apart on the circumference of a circle 25 ft. 4 in. Diameter. They will run to within one inch of the top and at a distance 27.7 ft. from the top will be bent to a radius of 0.5 ft. and run parallel to the bottom of the floor under the main floor reinforcement as shown in Fig.G. These verticals will be made of 30 ft. lengths and as 40 are required, the total length of vertical reinforcement is 1200 ft.

The bands or hoops will be made of 30 ft. lengths of steel rods, three lengths being required to make one band. This will give a lap of 3 ft. at each joint at the bottom and a lap of 3 1/3 ft. at the top. The total number of hoops used, including those in the coping and in the band at the bottom is 85. Then the total length of steel for hoops is 3 X 85 X 30 ft. = 7650 ft. All the hoops as well as the verticals are made of ½ inch square steel, the bands being twisted and the verticals plain. The total length of steel in shell is therefore 7650 ft. + 1200 ft., or 8850 ft.

DETAILS OF FLOOR REINFORCEMENT.

A part of the floor is shown in section and in plan in Figs. G and H. The main reinforcement will be of steel rods $\frac{1}{2}$ inch square perpendicular to a line bisecting the angle between two floor beams and placed 0.17 feet from the bottom of the floor. This system of reinforcing rods is numbered from 1 to 42 in Fig.H. It will be seen that the spacing gets less and less as the span increases. The length of span between floor beams at each rod,(s); the number of spans covered by each member, (n); the length of straight rod required to make each member, (M); the number of members required to cover 8 spans,(N); the length of these members,(L); and the summation of the length, (ΣL) are tabulated below,according to the way the rods are numbered in Fig.H. Perpendicular to the reinforcement already described,and 0.1 ft. above it as shown in the section view Fig.G., is another system of reinforcing rods spaced uniformly 4 inches apart. These rods are also $\frac{1}{2}$ inch square. At the edge of the floor next to the circumference of the tank these rods are bent through an angle of 90 degrees to a radius of 0.5 feet, and continued up 3 ft. into the shell of the tank. The purpose of this is to prevent the bottom shearing off from the wall or shell of the tank. The distance of the upturned ends from the inside circumference of the tank is 0.3 ft. The rod on the line bisecting the angle between two floor beams is lettered a, and the rods on either side,b,c,etc. up to n. The length of each member,number of such members needed,total length of such members,and summation of lengths are given in the table with the other data under M,H,L, and ΣL respectively,

	s	n	M	N	L	ΣL
1	2.4	8	22		22	22
2	2.8	8	26	1	26	48
3	3.2	8	28	1	28	76
4	3.5	8	30	1	30	106
5	3.9	8	34	1	34	140
6	4.1	4	22	2	44	184
7	4.4	4	22	2	44	228
8	4.7	4	22	2	44	272
9	5.0	4	24	2	48	320
10	5.2	4	24	2	48	368
11	5.4	4	26	2	52	420
12	5.6	4.	26	2	52	472
13	5.8	4	28	2	56	528
14	6.0	4	28	2	56	584
15	6.2	4	28	2	56	640
16	6.4	4	30	2	60	700
17	6.6	4	30	2	60	760
18	6.8	4	30	2	60	820
19	7.0	4	32	2	64	884
20	7.1	4	32	2	64	948
21	7.3	4	32	2	64	1012
22	7.5	4	34	2	68	1080
23	7.6	4	34	2	68	1148
24	7.8	4	34	2	68	1216
25	7.9	4	36	2	72	1288

	s	n	M	N	L	ΣL
26	8.0	4	36	2	72	1360
27	8.2	4	36	2	72	1432
28	8.4	2	20	4	80	1512
29	8.5	2	20	4	80	1592
30	8.7	2	22	4	88	1680
31	8.8	2	22	4	88	1768
32	8.9	2	22	4	88	1856
33	9.0	2	22	4	88	1944
34	9.1	2	22	4	88	2032
35	9.2	2	22	4	88	2120
36	9.3	2	22	4	88	2208
37	9.4	2	22	4	88	2296
38	9.5	2	22	4	88	2384
39	9.6	2	22	4	88#	
40	10.5	1	10.5	8	84	2468
41	10.0	1	10.0	8	80	2548
42	9.0	1	9.0	8	72	2620
43	7.5	1	7.5	8	60	2680
a			15.	8	120	2800
b			15.	16	240	3040
c			15.	16	240	3280
d			14	16	224	3504
e			13	16	208	3712
f			13	16	208	3920
g			12	16	192	4112
h			11	16	176	4288
i			10	16	160	4448
j			9	16	144	4592

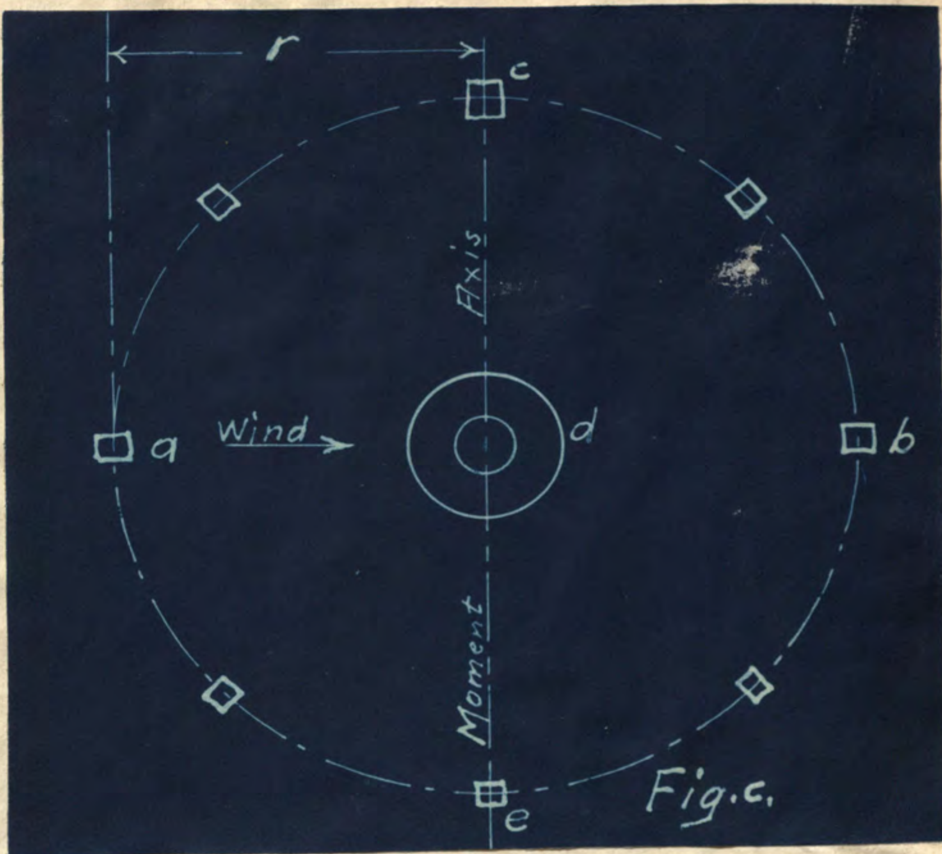
	s	n	M	N	L	ΣL
k			8	16	128	4720
l			7	16	112	4832
m			6	16	96	4928
n			5	16	80	5008

This one is not included in ΣL because it is a $\frac{3}{4}$ inch square bar and the others are all $\frac{1}{2}$ inch square.

DESIGN OF THE OUTER COLUMNS.

The load due to direct stresses which must be supported by each of the outer columns is the weight of the masonry shell, the weight of the floor system,and the weight of the water supported. The weight of the shell is 198240 lbs.(see page 12) and 1/8 of this or 24780 lbs. goes into each of the outer columns. The weight of the masonry in the floor is 69600 lbs. (see Page 12). Now 1/8 of this or 8700 lbs. is divided in some proportion between each of the outer columns and the central column. The greater part of each 8700 lbs. is carried by the outer column,only a small part going to the center column. Therefore,as an approximation,we will assume that each of the outer columns carries a load of 8700 lbs. due to the weight of the floor. This does not include the weight of the floor beams but as that weight is small in comparison and as the load due to the floor is less than we have counted,it will balance up our approximation somewhat if the weight of the floor beams is disregarded. The water load due to the reaction R_2 as at f Fig.I.(see discussion on page 5) is 50240 lbs. There is also the water load on the segment fiehf which is not included in R_2. This is equal to the product of the area by the depth by the weight of a cubic foot of water and is approximately 10000 lbs. The total load due to direct stresses is therefore 93720 lbs.,say 94000 lbs.

There are also large stresses due to the moment of the wind pressure on the tank and the tower which must also be considered. We will consider the wind as blowing in the direction indicated in Fig. c. The posts most affected by the wind moment are a and b. The effect is to produce compression in b and tension in a. Let Fig. c be any section cut through the tower



by a horizontal plane. If M is the moment at this section of the wind pressure on the tower and tank, then the fibre-stress in posts a and b will be,

$f = \frac{Mr}{I}$ where I is moment of inertia of the entire tower about M-N. If the moment of inertia of posts c, d and e about M-N be disregarded then $I = 4Ar^2$ where A = section area of one post.

Hence,- $$f = \frac{M}{4Ar} \quad \text{------------------------------------ VII}$$

Assuming 14 inch posts and three sets of 8 in. × 12 in. cross braces, the wind moment may be divided up as follows,-
Moment due to wind pressure on (a), tank; (b), columns; (c), cross bracing; (d), floor beams. Below is a table giving the area of the projection on a vertical plane parallel to M-N of tank,

columns, bracing, and floor beams; the unit pressure, p; the total pressure, P; the distance of center of pressure above a horizontal plane 80 ft. below bottom of tank, l; and moment of this pressure at the plane, M.

MOMENT TABLE FOR HORIZONTAL SECTION 80 FEET BELOW BOTTOM OF TANK.

	Area sq.ft	p lbs/ft.^{2}	P lbs.	l ft	M ft.lbs.
(a)	740	30	22200	93.7	2,070,000
(b)	832	50	41600	40.0	1,664,000
(c)	75	50	3750	40.0	150,000
(d)	50	50	2500	80.	200,000
				Total M =	4,084,000

In the above tables the area and the data in column l are not given as being exact. They are close approximations, close enough for the design and what error there is, is on the side of safety.

Now changing total M to inch pounds gives 49,000,000. Substituting M, A and r in Eq. VIII. gives

$f = 410$ lbs.

$P_1 = fA = 80360$ lbs. wind stress on columns a and b at a section 80 ft. below bottom. This would tend to produce tension in post a and compression in b. Then total stress in b is 174360 lbs. compression. It will be seen that a 14 inch column, as was assumed, is not nearly large enough. A larger size of columns will expose more surface to the wind, causing still more compression in b than we have calculated. Therefore we will design the columns for a load of 180000 lbs.

Let A = total section area of column

A_c = " " " " concrete

A_s = " " " steel

p = ratio of steel area to total $= \frac{A_s}{A}$

f_c = stress in concrete

n = ratio of moduli of steel and concrete at the given stress $f_c = \frac{E_s}{E_c}$

P = strength of plain column for stress f_c

P_1 = " " reinforced " " " "

Then $P = f_c A$ and $P_1 = f_c A_c + f_s A_s = f_c(A - pA) + f_c npA$

Whence,

$$P_1 = f_c A \left[1 + (n-1)p\right] \qquad \text{-------------------------- VIII.}$$

Now Put,- $P_1 = 180000$ lbs.

$f_c = 500$

$n = \frac{28000000}{2000000} = 14$

$p = 2\%$, gives $A = 285$ sq.in. which requires a column 17 inches square. A_s is then 5.7 sq. in, which requires a 1 3/16 inch square bar in each corner. Instead of using a section 17 inches square we will use a section 18 inches square. Taking a section through the tower 20 ft. above the section just considered, that is at the first system of cross bracing and allowing for wind stresses as well as for direct load, requires a column 16 inches square reinforced with bars 1 1/8 inches square in each corner. However, the column used will be 17 inches square. By the same methods the column at the second system of bracing is 16 inches square and reinforced with a 1-1/16 inch square bar in each corner,and at the third system of braces the section is 15 inches square with 1 inch bar placed as before. From this point on up the section will vary in the same manner as before only that at the top the posts will be arched up to the bottom with a radius of 2 ft. as shown in Fig.A.

The centers of the tops of the posts lie on a circle 25.166 ft. Diam. and the posts have been designed as though they were vertical,but in order that the structure may present a more stable appearance the columns will be spread out at the bottom so that their centers lie on a circle 35 ft. in Diam.

The longitudinal reinforcing in the columns will be so placed that the centers of the rods are 2 inches from either of the adjacent faces of the columns. The ends will also be planed square so as to get a perfect bearing of one rod on another and a six inch sleeve will be put at each joint to keep the rods from slipping one from off the other. The 1-3/16 inch square iron bars used in the first story of the tower will be continued into the second story one of them in each column 2 ft.,one 3 ft., one 4 ft., and one 5 ft. The same will apply to the other stories. The purpose of this is so as not to have all the joints of the reinforcement in the same section of a post.

It will necessitate the use of different lengths of steel in the first story columns but above the first story all the longitudinal reinforcement will be of bars 20 ft. long.

The longitudinal reinforcement will have a spiral wrapping of No.10 soft steel wire. The spacing between spirals to be 3 inches.

PROVISION FOR TENSION IN POSTS WHEN TANK IS EMPTY.

The direct load on each post when the tank is empty is due to the weight of the tank and as given in the first part of the discussion on columns is 8700 + 24780 or 33480 lbs. The weight of the column is about 20000 lbs. then the load on each column with tank empty is 53480 lbs. at the bottom of the column. The wind stress at the bottom of the columns is 80360 lbs. Then the resultant of direct load and wind stress is 27000 lbs. tension on post a on the windward side. This will be cared for if the pedestals are set into a hole blasted into the rock a depth of about 3 ft. and four reinforcing rods one inch square are set into diverging holes drilled 4 feet deep at an angle of 30 degrees to the vertical, well surrounded with good cement grout and continued up through the pedestals into the posts four feet.

The resultant tension at the first system of cross bracing is about 10000 lbs. Therefore if a 5 ft. length of $\frac{3}{4}$ inch square bar is put in at each joint of the longitudinal reinforcement the tension will be well taken care of. At the second system of bracing the wind pressure we have assumed will cause less stress than the total direct load so that there will be no tension. However, 5 ft. lengths of $\frac{1}{2}$ inch square rods will be put in at the joints of the longitudinal reinforcement so as to help out in case of unusual wind stress. Above this section it is unnecessary to consider tension, as the direct load exceeds the wind stress by a safe margin.

CROSS BRACING.

The first system of cross bracing will be put in 20 ft. above the pedestals. It will consist of 8 inch 12 inch beams as shown in Fig.C. These will be reinforced by putting a ½ inch square rod in each corner. The rods near the upper face of the beam will be bent up at the ends and continued up 2 ft.into the columns at each end. Likewise those near the lower face of the beams will be bent down and continued 2 ft. in the columns at each end. Two other sets of cross bracing will be put in,one 40 ft and one 60 ft. above the pedestals. They will be the same size as the first system already described and will be reinforced and built into the columns in the same way.

PEDESTALS.

The pedestals will be made 20 inches square on top and spread out so as to give a base of at least 9 sq.ft. This need not be square but will be so assumed. The longitudinal reinforcement of the columns must be continued down into the pedestals at least four feet.

DESIGN OF CENTRAL COLUMN.

The actual load which is to be supported by the central column is not materially different from that assumed on page (2) for approximate design,and as 10 tons/ft^2 is a very conservative loading the size will not be changed from that adopted in the approximate design. The column will be reinforced with 12 vertical rods ½ inch square placed 2 inches from the outside circumference of the column,as shown in Fig.C.

The pedestal will be made 5 ft. Diam. at the top and spread out to 8 ft.Diam on the stone foundation. No wind stress will be assumed in this column and hence it will not be necessary to extend the reinforcing rods into the stone for a better bond in case of tension as was done in the other columns.

SPECIFICATIONS FOR REINFORCED CONCRETE WATER TOWER AND TANK.

CRUSHED STONE. The stone must be a tough,hard,clean limestone,screened through a two inch mesh.All stone will be rejected that contains more than one percent of earth or clay matter.

SAND. The sand must be clean,sharp and free from clay and foreign material.

CEMENT. The cement shall be a portland brand,sound and free from sulphur. All cements will be tested and if found to be of inferior quality shall be immediately removed from the work. The cement shall have a tensile strength of 500 pounds per square inch after seven days set,according to the standard tests of the American Society of Civil Engineers. The cement shall be stored in a dry place convenient to the work. All cement must be placed in the store house and the Engineer notified at least seven days before using.

CONCRETE. The concrete shall be a mixture of one part cement, two parts sand and four parts crushed stone by volume;one sack of cement will be considered as one cubic foot. All concrete must be mixed on substantial platforms of plank or boards securely fastened together,so that the various materials of the concrete can be kept entirely free from an admixture of foreign material. The proper amount of the several kinds of material shall be measured in some way which is entirely satisfactory to the Engineer or Inspector in charge of the work.

Hand mixed concrete shall not be made in batches of more than one yard in each batch. The details of mixing concrete by hand shall be generally as follows: The proper amount of sand shall be measured out and spread upon the concrete platform, and the proper amount of cement shall be delivered and spread upon the same; the sand and cement shall be turned over dry, by means of shovels, until they are evenly mixed. They shall then be wet and made into a rather thin mortar, and shall then again be spread into a uniform and thin layer upon the platform. The proper amount of concrete stone, having been previously drenched with water, shall be spread upon the mortar, and the whole mass shall be turned over at least twice by shovels, before it is removed from the concrete platform. The concrete shall be of such a consistency that, when thoroughly rammed, it will quake slightly.

FORMS. The face of the form next to the concrete shall be planed, matched lumber. Material for the forms shall be of sufficient thickness, and the frame holding them shall be of sufficient strength, so that they shall be practically unyielding during the process of filling and tamping.

PLACING. The concrete is to be laid immediately after mixing and shall be laid in layers not exceeding six inches in depth. All concrete shall be thoroughly compacted by ramming into the water flushes to the surface. The ramming is to be done wihh an edged tool and shall be worked around the mass next to the mold in such a manner that all large rocks are worked towards the center.

REINFORCEMENT. All reinforcement rods and wire must be securely fastened in their proper places before placing any concrete in the mold.

STEEL. All rods must be of medium steel, free from injurious seams, flaws or cracks, and have a clean smooth finish. The tensile strength, limit of elasticity and ductility, shall be determined from a standard test piece, cut from the finished material, of one half square inch section. The limit of elasticity shall not be less than 36000 pounds nor more than 42000 pounds.

INSIDE LINING OF TANK. After the inside of the tank has been thoroughly wet, a layer of portland cement mortar, mixed in the proportion of one part cement to one part sand, one fourth inch thick is applied uniformly with trowels and left rough. Allowing this to set, it is moistened and a one fourth inch layer of neat portland cement is put on with trowels and finished smooth.

FOUNDATION. Holes must be dug for the columns a depth of 3 ft. into the rock. If blasted, care should be taken to prevent loosening or disturbing the walls of the hole. All loose material must be removed and the bottom and walls of the hole sprayed with water before depositing the concrete.

CENTER COLUMN. The center column is to be lined with riveted steel three-sixteenths of an inch thick. The steel shall be soft open hearth steel, having an elastic limit not less than 36000 pounds nor more than 42000 pounds, to be tested same as reinforced rods. Metal must be free from laminations and surface defects, and shall be rolled truly to the specified thickness.

PUNCHING. The rivet holes shall be punched with a center punch, sharp and in perfect order, from the surface to be in contact. The diameter of the punch shall not exceed that of the rivet by more than one sixteenth of an inch.

<u>RIVETS</u>. The best grade of soft charcoal rivets shall be used. Sufficient stock must be provided in the rivets to completely fill the holes and make a full head.