A Comparison of Flat and Conical Bottoms

FOR TANKS ON BRICK TOWERS.

By

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THESIS

For the Degree of Bachelor of Science in the Civil Engineering Course in the College of Engineering.

UNIVERSITY OF ILLINOIS.

1894.
A Comparison of Flat and Conical Bottoms for Tanks on Brick Towers.

The rapid increase in population and the consequent multiplication of small cities in this country the past few years have made necessary the construction of a large number of water works systems. The ultimate economy and the recognized advantages of a stand pipe system over a direct pressure system, especially for the smaller cities, have led to the adoption of that system by a majority of the cities putting in new water works.

In low, prairie country where
High ground is not available for service reservoirs, it has been found necessary to construct large tanks for the storage of water. Most of these tanks have been "stand-pipes," i.e., a continuous tank from the ground up to the height required to give a sufficient quantity of water under the required head. Of late years, however, the tendency has been to supplant these stand-pipes by smaller tanks elevated on towers of either steel or masonry. It has been proved that an elevated tank is both cheaper and more safe than a stand-pipe giving the same pressure.
Of the great number of elevated tanks which have been constructed in this country during the past few years, it is a strange fact that with the exception of two—one at Toacow, Ill., the other at Laredo, Texas—all of any considerable size have been constructed with flat bottoms, and this notwithstanding a great many writers have affirmed positively—though without giving their reasons for so doing—that a tank with a conical or spherical bottom is much cheaper.

The object of this thesis is the comparison of the different
styles of tank bottoms with regard to efficiency, appearance and cost.

There is but little difference between conical and spherical bottoms. The spherical bottom allows thinner plates than the conical, but the plates, being in double curvature, are more difficult to shape and consequently are more expensive. This difference in cost is slight and as the supports and connections for a spherical bottom are the same as for a conical bottom, only the conical and flat bottoms will be compared.

Of course a tank is as efficient
with our style of bottom as with any other if the capacity and average head are the same in both cases. For the same height of tower and tank, the tank with a conical bottom would have a slightly greater capacity, while the tank with a flat bottom would have a little higher average head, but these differences are comparatively small and will be neglected in this discussion. The supports and connections for a conical bottom are somewhat simpler of design and easier of construction than for a flat bottom but this is not
an important consideration.
The bottom and its floor system are hidden from view so the style of bottom has nothing to do with the appearance of the tank.

In order to obtain costs of the two styles of bottoms for comparison, sixteen designs were made of bottoms and of their supports and connections. Eight of these were flat and eight conical bottoms. The diameter chosen were 12, 16, 20, and 25 feet, and with each diameter two heights were used - 30 and 60 feet. The towers in each case were designed
with an 8-inch stone coping. The maximum pressure allowed on the stone was 350 pounds per square inch, or 25.2 tons per square foot. For the tank 12 feet in diameter and 30 feet high, the wall was made 13 inches thick at the top. The wall was made 17 inches thick in all other cases except for the tank 20 feet in diameter and 60 feet high with flat bottom, and the tank 25 feet in diameter and 60 feet high also with flat bottom, when this thickness of wall had to be considerably increased to give a sufficient bearing surface. The increase of masonry was
added as shown in Fig. 1, the shaded portion being the fact added. The maximum pressure allowed on the brick masonry was 139 pounds per square inch or 10 tons per square foot. For the larger size of tuns with flat bottoms, the space on top of the wall and between the I beams was filled with concrete. The purpose of this was to distribute the excess pressure due to wind and to hide the floor beams. The load being practically a static one, a working strength of 16,000 pounds was used in the de-
sign of the steel floor beams for flat bottoms. The maximum distance allowed between floor beams was 24 inches, but this maximum was seldom reached.

The flat bottoms were made the same thickness as the lowest ring of the shell, and were supported by a system of parallel floor beams resting directly on the stone coping as shown in the drawings. The details of the flat bottom and its floor system are shown in Plate IV.

The conical bottoms were given a slope of 30° with the horizontal for the reason that at that angle
the thickness of the bottom equals
the thickness of the lowest plate in
the shell. This thickness was de-
termined from a diagram in Johnson's
"Modern Framed Structures". In the com-
putations for this diagram a tensile
strength of 9,000 pounds per square
inch on the gross section, or 15,000
pounds per square inch on the net
section was used. The conical
bottom was attached to the lowest
ring of the shell at such a height
as to give sufficient clearance of
the wall, and to the lower edge
of this bottom ring were riveted
one or two angles which met
directly on the stone coping. The
 apex of the conical bottom was cut off so as to leave a circle with a diameter of from 18 to 36 inches and the hole thus left was covered by a circular steel plate which was flanged and riveted to the lowest ring of the bottom plate. Through this circular plate the inlet pipe entered. The details of the conical bottom and its connections are shown in Plate V.

The pressure due to wind was computed for a pressure of 40 pounds per square foot on one-half the diametrical area of the tank. The estimate of cost given below are based on current prices.
The cost of the separate items was made up as follows:

<table>
<thead>
<tr>
<th>Items</th>
<th>Rolled Shapes</th>
<th>Steel Plate in Flat Bottom</th>
<th>Steel Plate in Conical Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago price</td>
<td>1.40c</td>
<td>1.80c</td>
<td>1.8</td>
</tr>
<tr>
<td>Shop work</td>
<td>.45</td>
<td>.75</td>
<td>1.0</td>
</tr>
<tr>
<td>Waste</td>
<td>.05</td>
<td>.20</td>
<td>.4</td>
</tr>
<tr>
<td>Freight</td>
<td>.10</td>
<td>.10</td>
<td>.1</td>
</tr>
<tr>
<td>Erection</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>Profit and Contingencies 20%</td>
<td>.50</td>
<td>.65</td>
<td>.7</td>
</tr>
<tr>
<td>Totals</td>
<td>3.00$</td>
<td>4.00$</td>
<td>4.5$</td>
</tr>
</tbody>
</table>

Field mints were taken at 4 cents each, in addition to the cost of erection given above. Brick masonry with cement mortar was taken at $5.00 per cubic yard, and concrete at $4.50 per cubic yard. The
anchor rods and the connections of the inlet pipe were omitted from the estimates of cost as they would be the same for both styles of bottoms.
Floor System.

Plate III.

Diam. of Tank, 12 ft.
Height .. 60 "
Beams, 15 in. 50 lb. I.

Scale 1 in. = 1.5 ft.
Floor System.

Scale 1 in. = 2 ft.

Diam. of Tank, 16 ft.
Height ... 30...
Beams, 15 in. 41 lb. I.
Floor System and Details of Flat Bottom.

Diam. of Tank, 16ft.
Height " 60"
Details of Conical Bottom.

Diam of Tank  16 ft.
Height      60 ft.

Plate V

Scale 1 in = 2 ft.
Floor System.

Diam. of Tank, 20 ft.
Height " 30 "
Beams, 15 in. 75 lb I.

Scale 1 in. = 2.5 ft.
Floor System.

Diam. of Tank, 20 ft.
Height  60
Beams, 24 in. 80 lb. I.

Scale 1 in. = 2.5 ft.
Floor System.

Plate VIII.

Diam. of Tank, 25 ft.
Height, 30 ft.
Beams, 20 in. 80 lb. I.
Floor Plan

Diam. of Tank, 25 ft.
Height 60
Beams, 24 in. 80 lb. I.

Scale 1 in. = 3 ft.
### Flat Bottom

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Quantity</th>
<th>Rate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>81.4 ft. 12&quot; 32&quot; I</td>
<td>2605&quot;</td>
<td>@ 3c</td>
<td>78.15</td>
</tr>
<tr>
<td>113.1 sq. ft. 1/4&quot; plate @ 10&quot;</td>
<td>1131&quot;</td>
<td>@ 4c</td>
<td>47.52</td>
</tr>
<tr>
<td>38 ft. 5&quot; x 5&quot; x 3/8&quot; L @ 12&quot; + 2%</td>
<td>465&quot;</td>
<td>@ 3c</td>
<td>13.95</td>
</tr>
<tr>
<td>1562 1/2&quot; rivets</td>
<td></td>
<td>@ 4c</td>
<td>62.48</td>
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<td></td>
<td></td>
<td></td>
<td>$202.10</td>
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### Conical Bottom

<table>
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<th>Quantity</th>
<th>Rate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>38 ft. 1 3/4&quot; x 1 3/4&quot; L @ 5.5&quot; + 2%</td>
<td>2 13&quot;</td>
<td>@ 3c</td>
<td>6.69</td>
</tr>
<tr>
<td>165.8 sq. ft. 1/4&quot; plate @ 10&quot;</td>
<td>1658&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15% for lap</td>
<td></td>
<td>@ 4c</td>
<td>65.88</td>
</tr>
<tr>
<td>1647 1/2&quot; rivets</td>
<td></td>
<td>@ 4c</td>
<td>65.88</td>
</tr>
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BILL OF MATERIALS.

Diam. of Tank, 12 ft. Height, 60 ft.

**Flat Bottom.**

82.3 ft. 15" 50# I 4,115# @ 3c 123.45

123 sq. ft. 5/16" plate @ 12 1/2# 1538# 7 7 1/16# @ 4c 64.60

57# for cap

38 ft. 5" x 5" x 3/8" L @ 12# + 2% 465# @ 3c 13.95

38 ft. 5" x 3" x 3/8" L @ 9.5# + 2% 368# @ 3c 11.04

1744 5/8" rivets @ 4c 69.76

$282.80

**Conical Bottom.**

38 ft. 4" x 3" x 5 1/16" L @ 6.5# + 2% 252# @ 3c 7.56

165.8 sq. ft. 5/16" plate @ 12 1/2# 2073#

157# for cap 311# 2384# @ 4 1/2c 107.28

38 ft. 5" x 3" x 3/8" L @ 9.5# + 2% 368# @ 3c 11.04

1592 5/8" rivets @ 4c 63.68

$189.56
**Bill of Materials.**  Diam. of Tank, 16 ft. Height, 30 ft.

### Flat Bottom.

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Units</th>
<th>Rate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>138.5 ft. 15&quot; 41/2&quot; I</td>
<td>1</td>
<td>5,679&quot;</td>
<td>@ 3c</td>
<td>170.37</td>
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<tr>
<td>201.1 sq. ft. 1/4&quot; plate @ 10&quot;</td>
<td>1</td>
<td>2011&quot;</td>
<td>5% for laps</td>
<td>101&quot; 21/2&quot; @ 4c</td>
</tr>
<tr>
<td>51 ft. 5&quot; x 5&quot; x 3/8&quot; L @ 12&quot; + 2%</td>
<td>1</td>
<td>624&quot;</td>
<td>@ 3c</td>
<td>18.72</td>
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<tr>
<td>2128 1/2&quot; rivets</td>
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<td></td>
<td>@ 4c</td>
<td>85.12</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
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<td></td>
<td><strong>$358.69</strong></td>
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### Conical Bottom.

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<th>Rate</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>51 ft. 2 1/2&quot; x 2&quot; x 5/16&quot; L @ 5&quot; + 2%</td>
<td>1</td>
<td>260&quot;</td>
<td>@ 3c</td>
<td>7.80</td>
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<tr>
<td>278 sq. ft. 1/4&quot; plate @ 10&quot;</td>
<td>1</td>
<td>2780&quot;</td>
<td>15% for laps</td>
<td>417&quot; 3197&quot; @ 4c</td>
</tr>
<tr>
<td>3123 1/2&quot; rivets</td>
<td></td>
<td></td>
<td>@ 4c</td>
<td>124.92</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>3</strong></td>
<td></td>
<td></td>
<td><strong>$276.59</strong></td>
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Bill of Materials.  Diam. of Tank, 16 ft. Height, 60 ft.

Flat Bottom.

139.2 ft. 20" 64" I 39.09" @ 3c 267.27

214 sq. ft. 3/8" plate @ 15" 3,210" 57 for 161" 3371" @ 4c 134.84

51 ft. 5" X 5" X 3/8" L @ 12" + 2% 624" @ 3c 18.72

51 " 5" X 3" X 3/8" L @ 9.5" + 2% 495" @ 3c 14.85

1962 9/16" rivets @ 4c 78.48

20 9/16" bolts @ 4c .80

4.5 cu. yds. concrete @ 4.50 20.25

Total $535.21

Conical Bottom.

51 ft. 5" X 5" X 3/8" L @ 12" + 2% 624" @ 3c 18.72

218 sq. ft. 3/8" plate @ 15" 4170" 157 for 626" 4796" @ 4c 215.82

51 ft. 5" X 3" X 3/8" L @ 9.5" + 2% 495" @ 3c 14.85

2376 9/16" rivets @ 4c 95.04

Total $344.43
**BILL OF MATERIALS.**  Diam. of Tank, 20 ft. Height, 30 ft.

**Flat Bottom.**

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
<th>Unit</th>
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<th>Total</th>
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<tr>
<td>203 ft. 15&quot; 75# I</td>
<td>1</td>
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<td>3c</td>
<td>456.75</td>
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<tr>
<td>314 sq. ft. 5/16&quot; plate @12½&quot;</td>
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<td></td>
<td>4c</td>
<td>164.84</td>
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<tr>
<td>5% for lap</td>
<td></td>
<td></td>
<td>4c</td>
<td></td>
</tr>
<tr>
<td>63 ft. 5&quot; x 5&quot; x 3/8&quot; L</td>
<td>1</td>
<td></td>
<td>3c</td>
<td>23.15</td>
</tr>
<tr>
<td>2308 5/8&quot; rivets</td>
<td></td>
<td></td>
<td>4c</td>
<td>92.32</td>
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<tr>
<td></td>
<td></td>
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<td>737.04</td>
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**Conical Bottom.**

<table>
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<th>Quantity</th>
<th>Unit</th>
<th>Rate</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>63 ft. 2½&quot; x 2½&quot; x 3/8&quot; L</td>
<td>1</td>
<td></td>
<td>3c</td>
<td>15.24</td>
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<tr>
<td>319 sq. ft. 5/16&quot; plate @12½&quot;</td>
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<td></td>
<td>4½c</td>
<td>206.37</td>
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<tr>
<td>15% for lap</td>
<td></td>
<td></td>
<td>4½c</td>
<td></td>
</tr>
<tr>
<td>3098 5/8&quot; rivets</td>
<td></td>
<td></td>
<td>4c</td>
<td>123.92</td>
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<td></td>
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<td>345.53</td>
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**Flat Bottom:**

- **200 ft. 24" 80# I 16,000#** @ 3c = 480.00
- **347 sq ft. 1/16" plate @ 17½" 6072#** 5% for lap 304 6376# @ 4c = 255.04
- **2396 1/16" rivets** @ 4c = 96.84
- **126 ft. 5" x 5" x 1/2" L @ 15.8# + 2%, 20 30# @ 3c = 60.90**
- **22 5/8" bolts** @ 4c = .88
- **28 1/4 cu. yds. brick masonry** @ 8.00 = 226.00
- **7 " " concrete** @ 4.50 = 31.50

**Total for Flat Bottom = $1150.16**

**Conical Bottom:**

- **189 ft. 5" x 3" x 1/2" L @ 12.5# + 2%, 2410# @ 3c = 72.30**
- **319 sq ft. 1/16" plate @ 17½" 5583#** 15% for lap 837 6420# @ 4½c = 288.90
- **2,932 1/16" rivets** @ 4c = 117.28

**Total for Conical Bottom = $478.48**
Bill of Materials  
Diam of Tank, 25 ft. Height, 30 ft.

Flat Bottom:
338 ft. 20 in. 80 sq ft I. 27,040\* @ 3c 811.20
491 sq ft. 5/16" plate @ 12 1/2" 6138\* 5% for lap 307\* 6445 @ 4c 257.80
79 ft. 5"x5"x3/8" L @ 12\* +2\% 967\* @ 3c 29.01
3174 5/8" rivets @ 4c 126.96
** 1,224.97

Conical Bottom:
79 ft. 3" x 2 1/2" x 3/8" L @ 8.7\* + 2\%, 701\* @ 3c 21.03
637 sq ft. 5/16" plate @ 12 1/2" 7963\* 15% for lap 1194\* 9157\* @ 4c 412.07
4750 5/8" rivets @ 4c 190.00
** 623.10

Flat Bottom.

<table>
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<tr>
<th>Item</th>
<th>Quantity</th>
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<th>Total</th>
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<tr>
<td>464 ft.</td>
<td>24 in.</td>
<td>80* I</td>
<td>@ 3c</td>
<td>1,113.60</td>
</tr>
<tr>
<td>531 sq. ft.</td>
<td>1/2 in. plate</td>
<td>@ 20# 10,620#</td>
<td>5% for lap</td>
<td>531# 11,151# @ 4c</td>
</tr>
<tr>
<td>3,118</td>
<td>3/4 in. rivets</td>
<td></td>
<td>@ 4c</td>
<td>124.72</td>
</tr>
<tr>
<td>42</td>
<td>3/4 in. bolts</td>
<td></td>
<td>@ 4c</td>
<td>168</td>
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<tr>
<td>157 ft.</td>
<td>5&quot; x 5&quot; x 1/2&quot; L</td>
<td>@ 15.8# +2%</td>
<td>2,530#</td>
<td>@ 3c</td>
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<tr>
<td>184 cu. yds. brick masonry</td>
<td></td>
<td>@ $8.00</td>
<td>1472.00</td>
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<tr>
<td>8½ cu. yd. concrete</td>
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<td>@ $4.50</td>
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<td><strong>Total</strong></td>
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<td><strong>3,272.19</strong></td>
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Conical Bottom.

<table>
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<tbody>
<tr>
<td>237 ft.</td>
<td>5&quot; x 3½&quot; x 1/2&quot; L</td>
<td>@ 13.3# +2%</td>
<td>3,215#</td>
<td>@ 3c</td>
</tr>
<tr>
<td>637 sq. ft.</td>
<td>½&quot; plate</td>
<td>@ 20#</td>
<td>12,740#</td>
<td>15% for lap</td>
</tr>
<tr>
<td>3,960</td>
<td>3/4&quot; rivets</td>
<td></td>
<td>@ 4c</td>
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<td><strong>Total</strong></td>
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<td><strong>894.15</strong></td>
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Cost of Flat and Conical Bottoms for Tanks on Brick Towers.

Plate X.
The costs of the different bottoms are shown graphically in Plate X. It is seen that in every case the conical bottom is cheaper than the flat bottom for the same size of tank, and the cost of the flat bottom increases much more rapidly than does the cost of the conical bottom. The very rapid increase in cost of the flat bottoms as the diameter increases is due to the additional masonry required to give a sufficient bearing surface. The 17-inch wall is thick enough to carry the weight of the tank full of water if the weight be uniformly distributed over the
top of the wall, but with the flat bottom and its system of floor beams this uniform distribution of the weight is impossible.

For heights under 60 feet a brick tower is cheaper and has a better appearance than an iron or steel trestle; besides which its construction gives employment to home laborers and so promotes the general prosperity of the community. Frequently, too, the brick are a home production. For these reasons I think that it is better, at least for small cities in this neighborhood to construct their water tanks with conical bottoms and elevate them on brick towers.