Tank Buoyancy and Anti-Flotation Measures

David Lentz, P.E.
Nobody Wants This...
Or This...

Why Do Tanks Float?
Archimedes’ Principle
Archimedes’ Principle:
The buoyant force is equal to the weight of the displaced water.

Scale reads 7 lbs

Scale reads 4 lbs

3 lbs of water displaced by weight.

https://physics.weber.edu/carroll/archimedes/principle.htm
Water displaced by the aircraft carrier weighs more than the ship, so the ship floats.
Water displaced by the iceberg weighs more than the iceberg
2019 Rocky Mountain Regional Conference
Archimedes’ Principle: The buoyant force is equal to the weight of the displaced water.

Scale reads 7 lbs

Scale reads 4 lbs

3 lbs of water displaced by weight
Heated Air
Lower Density Than Ambient Air
Creates Uplift Force

Ambient Air
Higher Density than Heated Air in Balloon
1,500 lbs
Balloon air
buoyant force
800 lbs
Balloon, basket, fuel weight
down

1,500 lbs
Balloon air buoyant force
up
800 lbs Balloon, basket, fuel weight

1,500 lbs Balloon air buoyant force

450 lbs People in basket weight
800 lbs  
Balloon, basket, fuel weight

1,500 lbs  
Balloon air buoyant force

450 lbs  
People in basket weight

900 lbs  
People on ground weight
800 lbs Balloon, basket, fuel weight
1,500 lbs Balloon air buoyant force

450 lbs People in basket weight
900 lbs People on ground weight

<table>
<thead>
<tr>
<th>Force Down (lbs)</th>
<th>Force Up (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>1,500</td>
</tr>
<tr>
<td>450</td>
<td>1,500</td>
</tr>
<tr>
<td>900</td>
<td>1,500</td>
</tr>
</tbody>
</table>

2,150 1,500
1,500 lbs Balloon air buoyant force

800 lbs Balloon, basket, fuel weight

450 lbs People in basket weight

900 lbs People on ground weight

Balloon Stays on Ground Net 650 lbs Down Force

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<thead>
<tr>
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<tbody>
<tr>
<td>800</td>
<td>1,500</td>
</tr>
<tr>
<td>450</td>
<td></td>
</tr>
<tr>
<td>900</td>
<td></td>
</tr>
<tr>
<td>2,150</td>
<td>1,500</td>
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</table>
What happens when the six people let go of the basket?

<table>
<thead>
<tr>
<th>Force Down (lbs)</th>
<th>Force Up (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>1,500</td>
</tr>
<tr>
<td>450</td>
<td></td>
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<tr>
<td>0</td>
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<tr>
<td>1,250</td>
<td>1,500</td>
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</table>
What happens when the six people let go of the basket?

800 lbs Balloon, basket, fuel weight

1,500 lbs Balloon air buoyant force

800

450

Net 250 lbs Up Force

450 lbs People in basket weight

<table>
<thead>
<tr>
<th>Force Down (lbs)</th>
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</thead>
<tbody>
<tr>
<td>800</td>
<td>1,500</td>
</tr>
<tr>
<td>450</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1,250</td>
<td>1,500</td>
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</tbody>
</table>
The balloon floats

Net 250 lbs Up Force

<table>
<thead>
<tr>
<th>Force Down (lbs)</th>
<th>Force Up (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
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<td>450</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>1,500</td>
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</table>
Archimedes’ Principle:
The buoyant force is equal to the weight of the displaced water.

3 lbs of water displaced by weight.
Archimedes’ Principle: The buoyant force is equal to the weight of the displaced water.

1 gallon water

??? pounds

How many pounds of force does it take to hold an empty milk jug under water?
Archimedes’ Principle: The buoyant force is equal to the weight of the displaced water

1 gallon water
8.3 pounds
Archimedes’ Principle: The buoyant force is equal to the weight of the displaced water.

1 gallon water is approximately 8.3 pounds.

- 4 gals ~ 33 lbs
- 500 gals ~ 4,000 lbs
- 1,200 gallons ~ 10,000 lbs
- 1,700 gallons ~ 14,000 lbs
Tank Buoyant Force Comparison

33 lbs Beach Ball
4,000 lbs 500-gal Pump Tank
10,000 lbs 1,000-gal Septic Tank
14,000 lbs 1,500-gal Septic Tank
Tank Buoyant Force Comparison

**Beach ball**

- 33 lbs Beach Ball
- 4,000 lbs 500-gal Pump Tank
- 10,000 lbs 1,000-gal Septic Tank
- 14,000 lbs 1,500-gal Septic Tank
Tank Buoyant Force Comparison

Beach ball

Ford F150

33 lbs Beach Ball
4,000 lbs 500-gal Pump Tank
10,000 lbs 1,000-gal Septic Tank
14,000 lbs 1,500-gal Septic Tank
# Tank Buoyant Force Comparison

<table>
<thead>
<tr>
<th>Item</th>
<th>Weight</th>
<th>Volume</th>
</tr>
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<tbody>
<tr>
<td>Beach ball</td>
<td>33 lbs</td>
<td></td>
</tr>
<tr>
<td>Ford F150</td>
<td>4,000 lbs</td>
<td>500-gal</td>
</tr>
<tr>
<td>Skid steer</td>
<td>10,000 lbs</td>
<td>1,000-gal</td>
</tr>
<tr>
<td>Septic Tank</td>
<td>14,000 lbs</td>
<td>1,500-gal</td>
</tr>
</tbody>
</table>
Tank Buoyant Force Comparison

Beach ball  
- 33 lbs Beach Ball

Ford F150  
- 4,000 lbs 500-gal Pump Tank

Skid steer  
- 10,000 lbs 1,000-gal Septic Tank

Mini-Excavator  
- 14,000 lbs 1,500-gal Septic Tank
Balloon air buoyant force

800 lbs Balloon, basket, fuel weight

1,500 lbs Balloon air buoyant force

450 lbs People in basket weight

900 lbs People on ground weight
Buried Tank Force Analysis
Key Buoyancy Control Factors

• Depth of soil cover over tank

More soil over tank top = more resisting force

• Expected position of groundwater outside of tank

Shallower groundwater = greater buoyant force
Buried Tank Force Analysis

Buoyancy is like a tug of war, except vertical

Upward buoyant force vs. Downward resisting forces
Geotechnical Engineering

Keywords:
- Geophysical sources
- Water
- Centrifuge
- Steel
- Volumetric
- Butressed property
- Structure
- Void
- Segmental
- Deep
- Construction
- Lateral
- Floating
- Shear
- Penetration
- Bear
- Stability
- Geotechnical gravity
- Geotechnical engineering
- Geotechnical engineer
- Geotechnical engineering
- Geotechnical engineering
Buried Tank Force Analysis

Empty tank and riser buoyant force 100%
Buried Tank Force Analysis

Installation A

Buoyant force

Groundwater 24” above tank bottom

Installation B

Groundwater 42” above tank bottom

Buoyant force
### IM-Series Installation Instructions

#### Table 2: Nominal Volume Chart

<table>
<thead>
<tr>
<th>Height</th>
<th>in</th>
<th>cm</th>
<th>U.S. Gal</th>
<th>Liters</th>
<th>U.S. Gal</th>
<th>Liters</th>
<th>U.S. Gal</th>
<th>Liters</th>
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<td>7.5</td>
<td>3</td>
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<td>3</td>
<td>11</td>
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<td>64</td>
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<td>2</td>
<td>5</td>
<td>12.7</td>
<td>8</td>
<td>30</td>
<td>13</td>
<td>49</td>
<td>34</td>
<td>128</td>
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<td>14</td>
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<td>28</td>
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<td>10</td>
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<td>21</td>
<td>80</td>
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<td>33</td>
<td>29</td>
<td>109</td>
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<td>94</td>
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<td>37</td>
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<tr>
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<td>104</td>
<td>150</td>
<td>566</td>
<td>357</td>
<td>1,351</td>
<td>531</td>
<td>1,892</td>
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<td>749</td>
<td>2,463</td>
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<tr>
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<td>796</td>
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<td>2,606</td>
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<td>138</td>
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<td>861</td>
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<tr>
<td>24</td>
<td>60</td>
<td>143</td>
<td>235</td>
<td>890</td>
<td>549</td>
<td>2,052</td>
<td>917</td>
<td>2,892</td>
</tr>
</tbody>
</table>

- **Installation A**: 549 gal water displaced
- **Installation B**: 1,044 gal water displaced

---

IM = IM-540
IM-1060
IM-1530
Buried Tank Force Analysis

**Installation A**
- Buoyant force
- 549 gal Water Displaced

**Installation B**
- Buoyant force
- 1,044 gal Water Displaced
Buried Tank Force Analysis

Soil weight
90%

Empty tank
and riser
buoyant force
100%
Buried Tank Force Analysis

**Installation A**
- 12” soil cover
- Soil weight

**Installation B**
- Soil weight
- 6” soil cover
Buried Tank Force Analysis

Soil weight 90%

Breakout wedge 67%

Empty tank and riser buoyant force 100%
Buried Tank Force Analysis

- Breakout wedge: 67%
- Soil weight: 90%
- Soil in/above corrugations: 90%
- Empty tank and riser buoyant force: 100%
Buried Tank Force Analysis

- Breakout wedge: 67%
- Soil weight: 90%
- Soil in/above corrugations: 90%
- Sidewall friction: 50%
- Empty tank and riser buoyant force: 100%
Effect of Lateral Earth Pressure
Effect of Lateral Earth Pressure
Buried Tank Force Analysis

**Installation A**

- 12” soil cover
- Groundwater 24” above tank bottom

**Installation B**

- 6” soil cover
- Groundwater 42” above tank bottom
<table>
<thead>
<tr>
<th>Force</th>
<th>Installation A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Down (lbs)</td>
</tr>
<tr>
<td>Soil cover</td>
<td>5,130</td>
</tr>
<tr>
<td>Corrugation soil</td>
<td>3,126</td>
</tr>
<tr>
<td>Failure wedge</td>
<td>664</td>
</tr>
<tr>
<td>Friction</td>
<td>2,960</td>
</tr>
<tr>
<td>Corrugation water</td>
<td>371</td>
</tr>
<tr>
<td>Riser voids</td>
<td>0</td>
</tr>
<tr>
<td>Displaced water</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>12,251</strong></td>
</tr>
</tbody>
</table>

**Net force**

**Net 7,103 lbs down**

**NO CONTROLS NEEDED**
<table>
<thead>
<tr>
<th>Force</th>
<th>Installation A</th>
<th>Installation B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Down (lbs)</td>
<td>Up (lbs)</td>
</tr>
<tr>
<td>Soil cover</td>
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<td>0</td>
</tr>
<tr>
<td>Corrugation soil</td>
<td>3,126</td>
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</tr>
<tr>
<td>Failure wedge</td>
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<td>0</td>
</tr>
<tr>
<td>Riser voids</td>
<td>0</td>
<td>659</td>
</tr>
<tr>
<td>Displaced water</td>
<td>0</td>
<td>4,489</td>
</tr>
<tr>
<td>Total</td>
<td>12,251</td>
<td>5,148</td>
</tr>
<tr>
<td>Net force</td>
<td><strong>Net 7,103 lbs down</strong></td>
<td><strong>NO CONTROLS NEEDED</strong></td>
</tr>
</tbody>
</table>
Buried Tank Force Analysis

**SOLUTION:**
- Provide minimum 1.5 factor of safety for design
- Minimum buoyancy control force = **1,805 lbs**
Buried Tank Force Analysis

**SOLUTION:**
- Provide minimum 1.5 factor of safety for design
- Minimum buoyancy control force = $1,805 \text{ lbs} \times 1.5 = 2,707 \text{ lbs}$
Buried Tank Force Analysis

SOLUTION:
• Minimum buoyancy control force = 2,707 lbs
• Minimum force per tank side = 2,707 lbs / 2 sides = 1,354 lbs
Buried Tank Force Analysis

SOLUTION:

- Minimum buoyancy control force = 2,707 lbs
- Minimum force per tank side = \( \frac{2,707 \text{ lbs}}{2 \text{ sides}} = 1,354 \text{ lbs} \)

Soil columns above control provide downward force.
Infiltrator IM-Series Tank Design Method

1. Final amount of soil cover over tank?

2. Groundwater position above tank bottom?
   • If the uninterrupted saturated soil outside the tank exceeds the height of the outlet pipe saddle, then do not install
Infiltrator IM-Series Tank Design Method

1. Final amount of soil cover over tank?

2. Groundwater position above tank bottom?
   - If the uninterrupted saturated soil outside the tank exceeds the height of the outlet pipe saddle, then do not install
Infiltrator IM-Series Tank Design Method

1. Final amount of soil cover over tank?

2. Groundwater position above tank bottom?
   • If the uninterrupted saturated soil outside the tank exceeds the height of the outlet pipe saddle, then do not install

![Diagram of tank design method](image)
NO Buoyancy Control is Required if...

- *Soil cover is greater than 12 inches over the top of tank*

<table>
<thead>
<tr>
<th>Parameter I: Position of uninterrupted saturated soil conditions above tank bottom</th>
<th>Parameter II: Soil cover depth above tank top</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>1   Above outlet pipe saddle (greater than 43” [1,075 mm])</td>
<td>Do not install</td>
</tr>
<tr>
<td>2   36” (900 mm) to 43” (1,075 mm) (to outlet pipe saddle)</td>
<td>All models</td>
</tr>
<tr>
<td>3   30” (750 mm) to 36” (900 mm)</td>
<td>IM-1530</td>
</tr>
<tr>
<td>4   Less than 30” (750 mm)</td>
<td>Not Required</td>
</tr>
</tbody>
</table>
IM-Series Instructions

IM-Series Installation Instructions
IM-Series Tanks Buoyancy Control Guidance
EZsnap Riser Tank Connection Guidance

IM-Series Product Specifications

IM-540 (.pdf) | (.dwg)
IM-1060 (.pdf) | (.dwg)
IM-1530 (.pdf) | (.dwg)

IM-Series Potable Water Tank

IM-Series Potable Water Tank Cutsheet
IM-Series Potable Water Tank Installation Instructions
# Roth Multi-Tank Buoyancy Calculations

## Buoyancy Calculations

<table>
<thead>
<tr>
<th>Material</th>
<th>#/CF</th>
<th>#/GAL</th>
</tr>
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<tbody>
<tr>
<td>SOIL (dry)</td>
<td>100</td>
<td></td>
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<tr>
<td>SOIL (saturated)</td>
<td>117</td>
<td></td>
</tr>
<tr>
<td>SOIL (net)</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>WATER</td>
<td>62.4</td>
<td>8.34</td>
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<tr>
<td>CONCRETE</td>
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</table>

## Vessel

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Weight (Pounds)</th>
<th>Volume (Gallons)</th>
<th>Area ( SQ FT)</th>
<th>Cover (#/INCH)</th>
<th>Weight Displaced</th>
<th>Buoyant Force (Pounds)</th>
<th>Cover Required (INCHES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST-500</td>
<td>225</td>
<td>537</td>
<td>21.8</td>
<td>150.8</td>
<td>4478.58</td>
<td>4253.58</td>
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<td>ST-750</td>
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<td>254.5</td>
<td>8398.38</td>
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<tr>
<td>ST-900</td>
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<td>1147</td>
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<td>9565.98</td>
<td>9115.98</td>
<td>30.4</td>
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<td>ST-1060</td>
<td>520</td>
<td>1337</td>
<td>50</td>
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<td>10630.58</td>
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<td>1464</td>
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<td>389.4</td>
<td>12209.76</td>
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<td>68.9</td>
<td>476.6</td>
<td>14770.14</td>
<td>14130.14</td>
<td>29.7</td>
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</table>

## Notes:

1. Area of tanks is calculated without manholes.
2. Buoyancy force is assuming saturated soil (worst case scenario).
3. The numbers can be changed by changing the dry soil weight for site conditions.
4. Wet soil weight is indexed to dry soil.
5. Tank is assumed to be fully submerged, if only 50% submerged, forces are halved.
6. All calculations are based on an empty tank.
7. Please see the Roth Restraining Collar Drawing for high groundwater.
   The safety factor noted on the drawing does not consider the loading of the earth on top of the tank.

Roth Multi-Tank Restraining Collar Design

RESTRAINING COLLAR FOR HIGH GROUNDWATER

GENERAL NOTE:
1. THE BUOYANCY RESTRAINING COLLAR DESIGN IS BASED ON BUOYANCE CALCULATIONS AVAILABLE ON REQUEST FROM FRALO PLASTECH, LLC.

CONCRETE NOTES:
1. PROVIDE CONCRETE TO OBTAIN THE MINIMUM COMPRESSION STRENGTH OF 3000 PSI AT 28 DAYS.
2. CONCRETE MATERIALS AND WORKMANSHIP SHALL BE IN ACCORDANCE WITH ACI-318-99 (BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE) AND ACI-301-LATEST EDITION (SPECIFICATIONS FOR STRUCTURAL CONCRETE FOR BUILDINGS).

REINFORCING STEEL:
1. ALL REINFORCEMENT STEEL SHALL BE BILLET STEEL CONFORMING TO STANDARDS OF ASTM A615, GRADE 60.

CONCRETE COLLAR SPECS

<table>
<thead>
<tr>
<th>TANK MODEL</th>
<th>ST-500</th>
<th>ST-750</th>
<th>ST-1060</th>
<th>ST-1250</th>
<th>ST-1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH (FT)</td>
<td>7'-0&quot;</td>
<td>7'-0&quot;</td>
<td>7'-6&quot;</td>
<td>7'-6&quot;</td>
<td>7'-6&quot;</td>
</tr>
<tr>
<td>LENGTH (FT)</td>
<td>7'-0&quot;</td>
<td>10'-6&quot;</td>
<td>12'-0&quot;</td>
<td>14'-0&quot;</td>
<td>16'-6&quot;</td>
</tr>
<tr>
<td>FACTOR-OF-SAFETY AGAINST FLOATING</td>
<td>2.96</td>
<td>2.15</td>
<td>2.09</td>
<td>2.10</td>
<td>2.02</td>
</tr>
</tbody>
</table>

# Infiltrator IM-Series Tank Design Method

## Table 2: Buoyancy Control Method Selection

<table>
<thead>
<tr>
<th>Tank Model</th>
<th>Parameter I: Position of uninterrupted saturated soil conditions above tank bottom</th>
<th>Parameter II: Soil cover depth above tank top</th>
<th>Minimum supplemental downward force required (total, both tank sides)</th>
<th>Buoyancy Control Methods</th>
<th>Concrete collar (min. width x min. height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM-540</td>
<td>36 in (900 mm) to outlet pipe saddle²</td>
<td>6 in (150 mm) to 12 in (300 mm)</td>
<td>2,200 lbs (1,010 kg)</td>
<td>Concrete-filled half pipe (min. length/side)</td>
<td>6 in (150 mm) x 9 in (225 mm)</td>
</tr>
<tr>
<td>IM-1060</td>
<td>36 in (900 mm) to outlet pipe saddle²</td>
<td>6 in (150 mm) to 12 in (300 mm)</td>
<td>2,700 lbs (1,225 kg)</td>
<td>Concrete parking bumpers (min. length/side)</td>
<td>12 in (300 mm) x 9 in (225 mm)</td>
</tr>
<tr>
<td>IM-1530</td>
<td>30 in (750 mm) to outlet pipe saddle²</td>
<td>6 in (150 mm) to 12 in (300 mm)</td>
<td>4,300 lbs (1,955 kg)</td>
<td>Concrete traffic barriers (min. length/side)</td>
<td>12 in (300 mm) x 9 in (225 mm)</td>
</tr>
</tbody>
</table>

1. Installation B

---

**Installation B**

- 15 in [375 mm] to 18 in [450 mm]
- Steel Rebar
- Concrete Collar
- Section View

![Installation Image](image-url)
Parking Bumpers
Spare 24-inch Concrete Tank Lid
6” x 6” Pressure-Treated Wood
Installation Best Practices – Excavation Size

Adjust excavation width to accommodate anchors

- Anchors must be offset from side of tank
- Additional excavation width required
- Adjust to allow workers to operate
- Adhere to OSHA excavation safety requirements
Installation Best Practices – Strap Placement

Balance straps along tank axis

- Balanced loading to tank
- Balance resisting force
- Uniform connection to buoyancy controls
Installation Best Practices – Strap Placement

Single Downward Anchor Force

Upward Water Pressure Force
Installation Best Practices – Strap Placement

Multiple Downward Anchor Forces

Upward Water Pressure Force
Balanced anchor placement
Installation Best Practices – Strap Tightening

Establish tight strapping

- Prevents tank uplift
- Prevents change to inlet-to-outlet invert drop
- Prevents breakage of inlet and outlet piping
- Tighten using ratchet or turnbuckle
Tight straps
Tight straps
Installation Best Practices – Strap Capacity

Verify strap capacity

- Determine tank uplift
- Determine tension in straps
- Verify that adequate strap safety factor exists

Safety Factor = \frac{\text{Resisting Force}}{\text{Driving Force}} = \frac{10,000 \text{ lb capacity}}{5,000 \text{ lb uplift}} = 2.0
Installation Best Practices – Anchor Placement

Place anchors per manufacturer’s instructions

• Some anchor designs require several feet of soil coverage to function properly
• Weight of soil cover over anchor resists uplift
• Weight of anchor is small compared to soil resistance
Installation Best Practices – Anchor Placement

Installation B

Soil columns above control provide downward force
Correct anchor placement: offset from tank
Correct anchor placement: offset from tank

Improper anchor placement: tucked under tank, so no soil column above anchor
Installation Best Practices – Backfilling

Backfill between anchors and tank

- Place backfill around entire tank
- Work soil into space between tank and anchors
- Compact soil per manufacturer’s instructions
Correct anchor placement: offset from tank

Improper anchor placement: tucked under tank – no space for backfill placement
Buoyancy Problem 1

Where is the Buoyant Force Greater?

Pump Tank

Septic Tank

Groundwater table
Buoyancy Problem 1

Where is the Buoyant Force Greater?

Pump Tank

Septic Tank

Neutral Buoyant Force

Groundwater table
Buoyancy Problem 2

Where is the Buoyant Force Greater?

Pumped Septic Tank          Septic Tank

Groundwater table
Buoyancy Problem 2

Where is the Buoyant Force Greater?

- **Pumped Septic Tank**
  - Large Buoyant Force

- **Septic Tank**
  - Neutral Buoyant Force

Groundwater table
Buoyancy Problem 3

Where is the Buoyant Force Greater?

Pumped Septic Tank  Empty Tank

Groundwater table
Buoyancy Problem 3

Where is the Buoyant Force Greater?

Pumped Septic Tank  Empty Tank

Buoyant Force is Zero

Groundwater table
This buoyancy control design should be effective.

A. True
B. False
How to Use this Information

- Consider buoyancy for any type of tank material
- Check the two biggest factors:
  - Soil cover depth over tank
  - Height of water above tank bottom
- Follow manufacturer installation instructions
- Make sure buoyant force loses the tug-of-war

≥1.5 x LARGER THAN UPLIFT