Earthquake and Wind Load Design Handbook

A Structural Evaluation of Load Cell Support Applications

Earthquake and Wind Load Design Handbook

BLH®

**BLH Electronics, Inc.
KIS & Z-BLOK
Weigh Modules**

**A Structural Evaluation of
Tank Support Applications
Under**

**Earthquake and Wind
Loads**

Prepared By

Stone & Webster Engineering Corp.

In Accordance With

American National Standards Institute Inc.

ANSI A58.1-1982

"Minimum Design Loads for Buildings and Other Structures"

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Earthquake and Wind Load Design Handbook

Summary Report

Pre-qualification of BLH Weigh Modules in Tank Support Applications Under Earthquake and Wind Loads

By

Stone & Webster Engineering Corporation

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INTRODUCTION

This report summarizes the qualification of BLH Load Modules, for use in the support system of industrial tanks, under either seismic or wind loads. The relationship between tank size/capacity and specific BLH products is summarized in a series of nomographs to provide a simple product selection method. In addition, suitable background material has been provided to assure the correct and unambiguous use of this approach by prospective users.

ANSI A58.1-1982 (Reference 1) has been used in this qualification to establish the governing design loads for tanks exposed to both wind and earthquake effects. Herein, the term "tank" refers to any silo, bin, hopper, or other vessel which approximates the typical tank configurations cited on page 9.

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REVIEW OF GOVERNING CRITERIA ANSI A58.1-1982

DESIGN LOAD COMBINATION (REF. 1, SECTION 2.3)

Total Load = DL + LL + (L_r or S or R) + (W or E)

Where, DL = Weight of Empty Tank, lb

LL = Weight of Tank Contents, lb

L_r = Roof Live Load (from Section 4.10, L_r = 20 for small, flat roof tank and L_r = 12 for small, spherical roof tank), lb/ft² of horizontal projection

S = Snow Loads, lb/ft² of horizontal projection

R = Rain Loads, lb/ft² of horizontal projection

W = Wind Load, lb/ft² of projection area normal to wind direction

E = Earthquake Load, lb (applied in any lateral direction, but nonconcurrently)

While Reference 1, Section 2.3.3 allows the use of a 0.75 factor in considering the above load combination, it is prudent to omit this factor when designing tanks (see additional discussion in Section A2.3.3 of Ref. 1). This is due to the fact that the tank is highly likely to be full when exposed to the peak wind or earthquake loads. However, due to the low probability of having any significant roof load in combination with the peak values of "LL" and "W" or "E," all roof loads will be considered insignificant and the following load combination used in this calculation:

TOTAL DESIGN LOAD = DL + LL + (W or E)

DETERMINE EARTHQUAKE DESIGN LOAD (E)

From Section 9 of Reference 1, it is seen that earthquake effects are considered by the application of lateral forces assumed to act nonconcurrently in the direction of each of the main axes of the structure. In the design of tanks, using the force distribution guidelines of Section 9.5 (Ref. 1), these lateral forces are distributed in accordance with the mass distribution and can be modeled as a single force applied at the center of gravity (C.G.) of the tank.

From Section 9.4 (Ref. 1), determine minimum total lateral force, V:

$$V = ZIKCSW \qquad \text{(Eq. 6, Ref. 1)}$$

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Where, Z = Seismic Zone Factor from Table 22, Ref. 1
(Zone 1: Z = 3/16; Zone 2: Z = 3/8; Zone 3: Z = 3/4; Zone 4: Z = 1.0)

I = 1.0, from Table 23 (Ref. 1), assuming tank does not provide an essential emergency function following a major earthquake. Tanks required as part of an essential facility, whose function is important to public safety, are beyond the scope of this calculation.

K = 2.0, from Table 24 (Ref. 1) for tanks or in the special case of elevated tanks supported on four or more cross-braced legs: K = 2.5, but $KCS \leq 0.29$.

C = $1/(15\sqrt{T})$, but ≤ 0.12, where T is the fundamental period of the tank and its supports in seconds.

S = 1.0 to 1.5 based on specific soil profile, but $CS \leq 0.14$.

W = Dead load (DL) + Design Live load (LL)

Inserting the above values into Equation 6 -

$V = (Z)(1.0)(2.0)(0.14)W$

$= 0.28\ ZW$ For Tanks in General

and

$V = (Z)(1.0)(0.29)W$

$= 0.29\ ZW$ For special case of elevated tanks supported on four or more cross-braced legs.

The above calculations are for a tank not supported on, or attached to, a main structure. For a tank on or part of a main structure, or for elevated tanks not supported as above, Section 9.10 of Reference 1 provides the following requirement for the lateral design force:

$V = ZIC_pW$ (Eq. 15, Ref. 1)

Where, Z, I, and W are as previously defined and C_p = 0.3 from Table 26, Ref. 1.

Inserting the above factors into Equation 15 gives

$V = (Z)(1.0)(.3)W$

$V = 0.3\ ZW$ Conservatively, use this value for all tank designs

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ESTABLISH WIND DESIGN LOAD (F_W)

From Table 4 of Reference 1, the design wind force on tanks is found from the following equation:

$$F_W = q_Z G_H C_f A_f$$

Where, q_Z = Velocity Pressure at Height Z, lb/ft^2

$= 0.00256\ K_Z (IV)^2$ [Eq. 3, Ref. 1]

K_Z = Exposure Coefficient from Table 6 at Height Z. Use Z = H, total tank height, for conservatism.

I = Importance Factor = 1.05, Peak Value from Table 5 for Category 1 structures.

G_H = Gust Response Factor from Table 8, Reference 1, at Height = H.

C_f = Force coefficient from Table 12, Ref. 1

For tanks with $H/D \leq 3$

C_f = 1.05 for square tanks (wind along diagonal)

C_f = 0.75 for round tanks

A_f = Projected area of tank normal to wind, ft^2

For H/D = 3: $A_f = H^2/3$, for round tank
$A_f = 1.414\ H^2/3$, for square tank

Given that H/D = 3:

For Round Tanks: $F_W = .000706\ K_Z G_H V^2 H^2$

For Square Tanks: $F_W = .00140\ K_Z G_H V^2 H^2$

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DETERMINE WIND LOAD FOR TANKS WITH H = 0 TO 50 FT

H (FT)	K_Z (1) $Z = H_{max}$	G_H (2) $H = H_{max}$	WIND LOAD FACTOR (F_W/V^2H^2) ROUND UPRIGHT	SQUARE UPRIGHT
0 - 15	1.2	1.15	.000973	.00193
15 - 20	1.27	1.14	.00102	.00203
20 - 25	1.32	1.13	.00105	.00209
25 - 30	1.37	1.12	.00108	.00215
30 - 40	1.46	1.11	.00114	.00227
40 - 50	1.52	1.10	.00118	.00234

(1) K_Z values are taken from Table 6 of Reference 1.

(2) G_H values are taken from Table 8 of Reference 1.

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ASSUMPTIONS

1. The weight of the empty tank is small in comparison to the weight of the tank contents and can be conservatively set equal to 25 percent of the tank's content weight for support evaluations.

2. Snow loads, rain loads, and roof live loads are considered to be insignificant to tank support designs which consider the full weight of the tank in combination with earthquake effects without use of load reduction factors. This assumption is based in part on discussions in Section A2.3.3 of Reference 1.

3. Tanks considered in this calculation do not provide an essential emergency function following a major earthquake.

4. Inside tanks are supported on very short supports whose height can be approximated as 5 percent of the total tank and support height.

5. For outside tanks, the tank support legs can be approximated as 10 percent of the overall tank and support height.

6. The overall height to diameter ratio (or height to width ratio in the case of upright, square tanks) will be assumed greater than or equal to 3 for outdoor tanks and greater than or equal to 2 for indoor tanks.

7. All tanks are considered to be filled to capacity with water at a density of 62.4 lbs/ft^3 (Ref. 2).

8. In developing the nomographs, all load cell limits for allowable overall tank height will be rounded down to the next full foot level except in those cases where the peak support load is within 102% of the next higher foot level allowable. In the latter case, the load cell limit will be rounded upward. This rounding upward is considered acceptable based on the conservative nature of this analysis and the fact that the BLH safe design load is only 50 percent of the load cell's ultimate load capacity.

REFERENCES

1. ANSI A58.1-1982, "Minimum Design Loads for Buildings and Other Structures," approved March 10, 1982, American National Standards Institute, Inc.

2. AISC Manual of Steel Construction, 8th Edition, American Institute of Steel Construction, Inc.

3. BLH Data Sheet PD 404, Specifications for KIS Series Weigh Modules, revised June 1988.

4. BLH Data Sheet PD 423, Z-Blok Weigh Modules, dated August 1988.

SCOPE OF STUDY

Based on the "typical" tank parameters provided by BLH, the following five tank arrangements will be evaluated:

1. Type C-O-4: (See sketch on Page 10)

   A cylindrical, upright tank located outdoors and supported on four symmetrically spaced legs.

2. Type S-O-4: (See sketch on Page 11)

   A square, upright tank located outdoors and supported on four symmetrically spaced legs.

3. Type C-O-3: (See sketch on Page 12)

   A cylindrical, upright tank located outdoors and supported on three equally spaced legs.

4. Type C-I-4: (See sketch on Page 13)

   A cylindrical, upright tank located indoors and supported on four symmetrically spaced legs.

5. Type C-I-3: (See sketch on Page 14)

   A cylindrical, upright tank located indoors and supported on three equally spaced legs.

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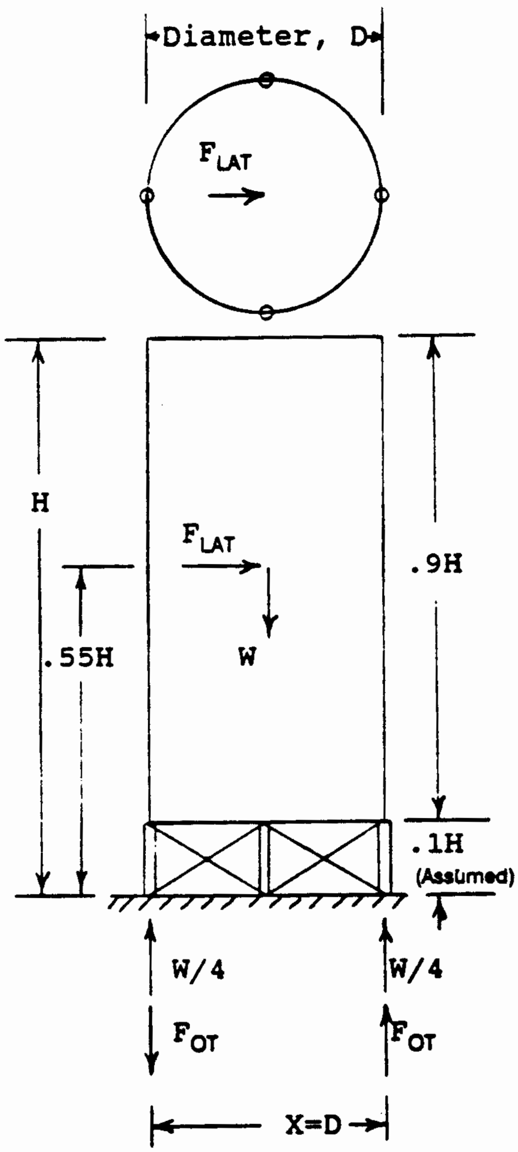
"TYPICAL" TANK INSTALLATIONS: (UNITS: FEET, POUNDS)

CYLINDRICAL, OUTDOOR TANK WITH 4 SUPPORTS: TYPE C-O-4



H/D = 3 (Assumed)

Volume:

$V_T = \pi/4\ D^2(1.0H)$

$V_T = \pi/4\ (H/3)^2(1.0H)$

$V_T = 0.0873H^3$

Max. Ht. Used to Provide Conservative Upper Bound

Weight:

$W = DL + LL$

$DL = .25LL$ (Assumed)

$LL = V_T \times 62.4$ PCF (Assuming Water in Tank)

$W = 1.25(.0873H^3)(62.4)$

$W = 6.81\ H^3$

Peak Support Load, P

$P = W/4 + F_{OT}$

$P = W/4 + (.55H)\ F_{LAT}/(H/3)$

$P = W/4 + 1.65\ F_{LAT}$

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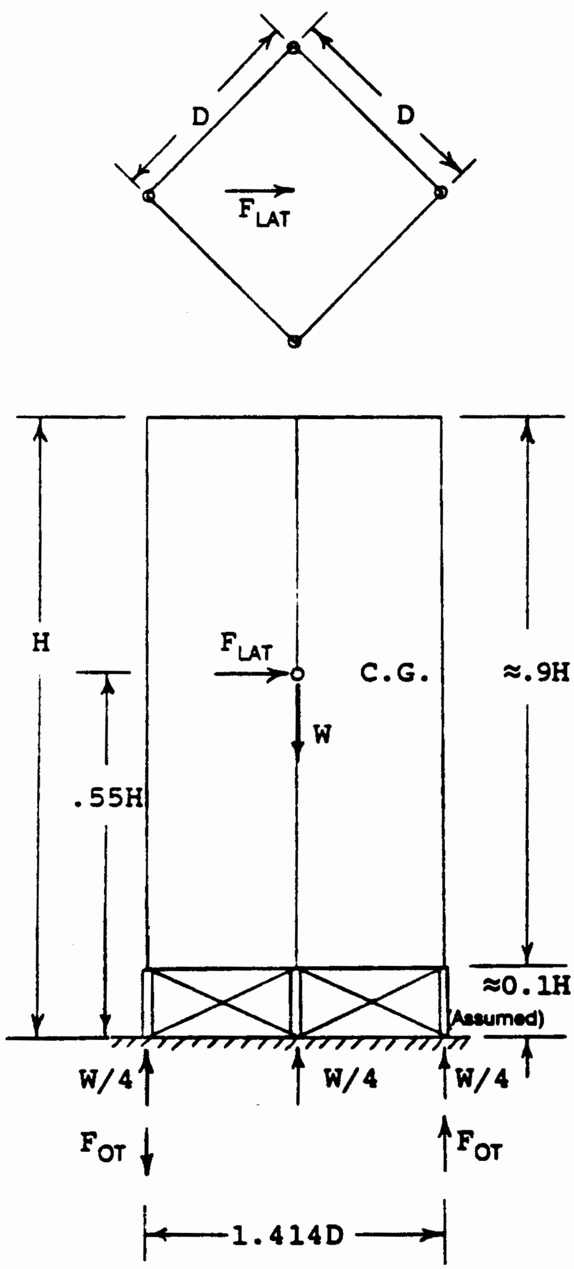
"TYPICAL" TANK INSTALLATIONS: (UNITS; FEET, POUNDS)

SQUARE, OUTDOOR TANK WITH 4 SUPPORTS: TYPE S-O-4



H/D = 3 (Assumed)

Volume: (using Tank HT. = H)

$V_T = D \times D \times H$

$V_T\ (H/3)(H/3)H = 0.111\ H^3$

Weight:

$W = DL + LL$

Assume DL = 25% LL and Tank Filled with Water

$W = (1.25)V_T \times 62.4$ PCF

$W = 8.67\ H^3$

Peak Support Load, P

$P = W/4 + F_{OT}$

$P = 8.67\ H^3/4 + (.55H)F_{LAT}/\frac{1.414H}{3}$

$P = 2.168H^3 + 1.167\ F_{LAT}$

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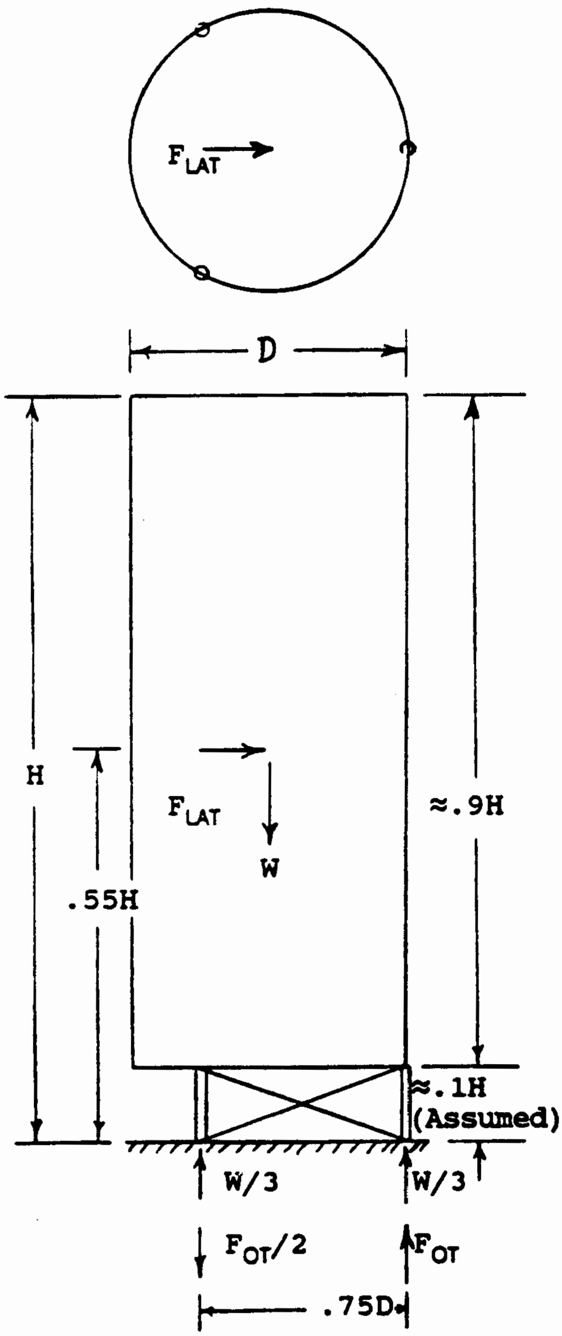
"TYPICAL" TANK INSTALLATIONS: (UNITS: FEET, POUNDS)

CYLINDRICAL, OUTDOOR TANK WITH 3 SUPPORTS: TYPE C-O-3



H/D = 3 (Assumed)

Volume:

$V_T = \pi/4\ D^2(1.0H)$, Max. Ht.

$V_T = \pi/4\ (H/3)^2\ H$

$V_T = 0.0873\ H^3$

Weight:

$W = DL + LL$

$DL = (0.25) LL$ (Assumed)

$LL = V_T$ (62.4 PCF) Assuming Water in Tank

$W = 1.25\ V_T\ (62.4)$

$W = 6.81\ H^3$

Peak Support Load, P

$P = W/3 + F_{OT}$

$P = W/3 + (.55H) F_{LAT} / (.75\ H/3)$

$P = W/3 + 2.2\ F_{LAT}$

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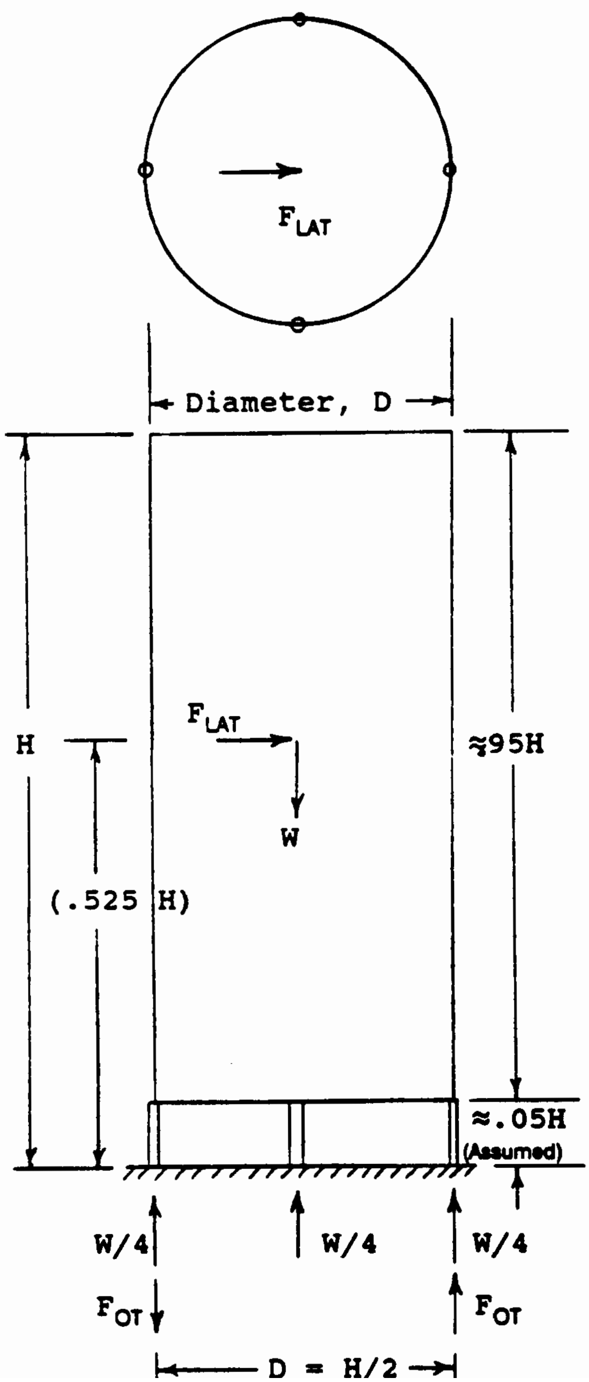
<u>"TYPICAL" TANK INSTALLATIONS: (UNITS: FEET, POUNDS)</u>

<u>CYLINDRICAL, INDOOR TANK WITH 4 SUPPORTS: TYPE C-I-4</u>



$H/D = 2$ (Assumed)

$F_{LAT} = 0.3\ ZW$ (Due to Seismic Load)

Volume (Max):

$V_T = \pi/4\ D^2H$

$V_T = \pi/4\ (H/2)^2\ H$

$V_T = 0.1963H^3$

Weight:

$W = DL + LL$

$DL = 0.25 \times LL$ (Assumed)

$LL = V_T\ (62.4\ PCF)$ (Assuming Water in Tank)

$W = 1.25\ V_T\ (62.4)$

$W = 15.32\ H^3$ (lb)

Peak Support Load, P

$P = W/4 + (.525H)\ F_{LAT}/D$

$P = W/4 + (.525H)(.3ZW)/(H/2)$

$P = (0.25 + .315Z)\ W$

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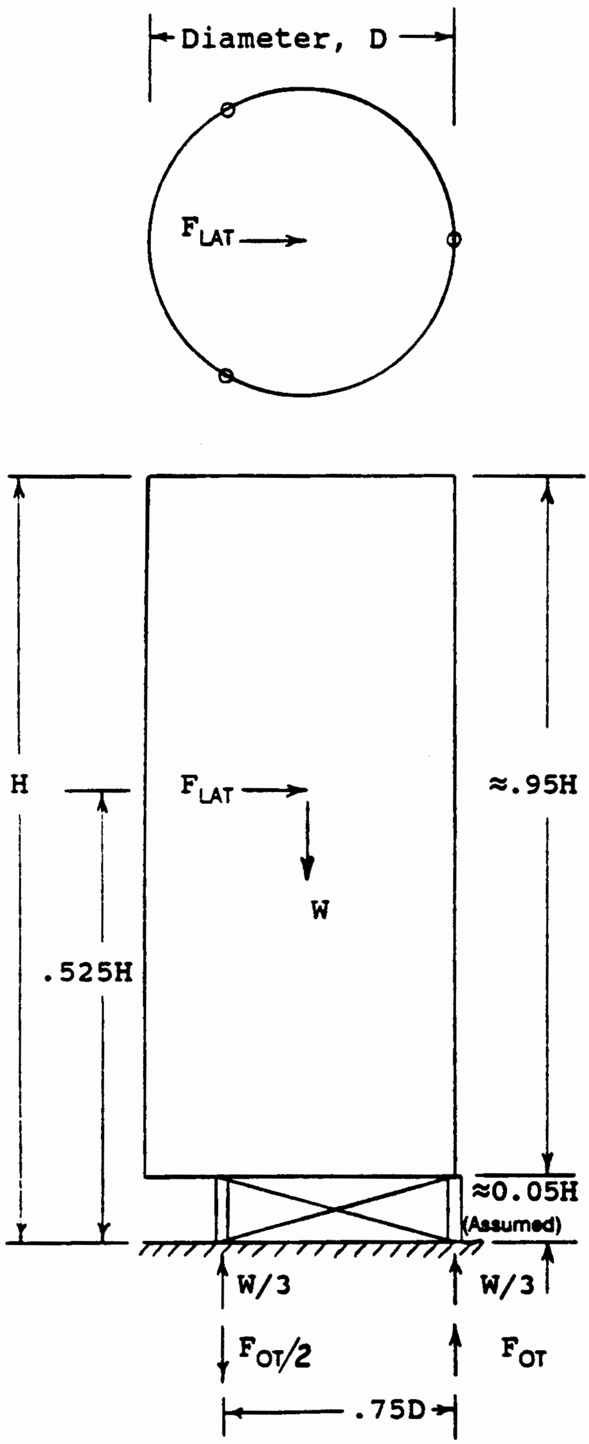
"TYPICAL" TANK INSTALLATIONS: (UNITS: FEET, POUNDS)

CYLINDRICAL, INDOOR TANK WITH 3 SUPPORTS: TYPE C-I-3



$H/D = 2$ (Assumed)

$F_{LAT} = 0.3ZW$ (Due to Seismic)

Volume (Max.):

$V_T = \pi/4\ D^2H$

$V_T = \pi/4\ (H/2)^2H$

$V_T = 0.1963H^3$

Weight:

$W = DL + LL$

$DL = 0.25 \times LL$ (Assumed)

$LL = V_T$ (62.4 PCF) (Assuming Water in Tank)

$W = 1.25\ V_T\ (62.4)$

$W = 15.32\ H^3$ (lbs)

Peak Support Load, P

$P = W/3 + F_{OT}$

$P = W/3 + (.525H) F_{LAT}/.75d$

$P = W/3 + 1.4\ F_{LAT}$

$P = W/3 + 1.4\ (0.3ZW)$

QUALIFICATION SUMMARY

A) CRITICAL LOADS IN THE DESIGN OF TANK SUPPORTS

1) Governing Design Load Combination = DL + LL + (E or W)

where,
DL = Tank Dead Load or Empty Weight
LL = Tank Live Load or Content Weight
E = Load Due to Earthquake Effects
W = Load Due to Wind Effects

2) For Tanks, E = 0.3Z (DL + LL)

where, Z = Seismic Zone Factor with the following values:

Zone 1; Z = 3/16
Zone 2; Z = 3/8
Zone 3; Z = 3/4
Zone 4; Z = 1.0

3) Wind load, W, is a function of the wind velocity, the projected area of the tank, and an exposure category that adequately reflects the characteristics of ground surface irregularities. Four exposure categories are used to represent the various site terrains ranging from large city centers (Exposure A) to flat, unobstructed coastal areas (Exposure D). The surrounding terrain affects both the wind pressure coefficient (K_Z), which increases from A to D, and the gust response factor (G_H), which decreases from A to D. Exposure category D, which results in the largest product of these two factors and therefore the largest load, is conservatively used in all wind load evaluations.

B) BLH PRODUCT SELECTION NOMOGRAPHS

1) Under wind plus gravity loads:

The three outdoor tanks (Type C-O-4, S-O-4, and C-O-3) have been evaluated for the resulting peak support load resulting from the most conservative application of tank gravity loads (DL + LL) and wind loads (W) evaluated at wind speeds of 70, 80, 90, and 100 MPH. These resulting peak loads are established as a function of the overall tank and support height (H) and compared against the BLH components' safe design capacity to provide a direct relationship between the tank overall height and the BLH component that is suitable for the stated design condition. The Nomographs addressing these wind loading conditions are provided on pages 20 through 22. See discussions under Section C below on conservatisms contained in these evaluations.

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2) Under seismic plus gravity loads:

All five postulated tank configurations have been evaluated for the resulting peak support load resulting from the most conservative application of tank gravity loads (DL + LL) and seismic loads (E) evaluated for seismic zones 1 through 4. These resulting peak loads are established as a function of the overall tank and support height (H) and compared against the BLH components' safe design capacity to provide a direct relationship between the tank overall height and the BLH component that is suitable for the stated design conditions. The nomographs addressing these seismic loading conditions are provided on pages 23 through 27. See discussions under Section C below on the conservatisms contained in these evaluations.

C) <u>DISCUSSION OF CONSERVATISMS IN APPROACH</u>

1) Gravity loads are maximized:

All support evaluations were based on a completely filled tank with a relatively dense substance (water). In addition, the tank empty weight was conservatively taken as 25 percent of the content weight. The estimated tank weight considered in the analysis is provided in all nomographs. While highly unlikely, if any evaluated tank is known to have a weight in excess of the stated value, use the estimated weight column to establish the correct BLH component rather than H. It should be noted that due to this conservatism and the fact that, for the tank configurations analyzed, uplift loads never govern, any partially loaded tank is a less severe design condition than that analyzed.

2) Support spacing to resist overturning moment is minimized:

Tank support legs are conservatively located to coincide with the tank diameter or side (i.e., no lugs or attachments to the tank sides are used to spread the support base). By using minimum support spacing and applying lateral loads in a "worst" case direction, the calculated support peak load will be conservatively minimized.

3) "Worst" case direction selected for lateral loads:

In the evaluation of wind effects ,the wind is assumed to act in a direction normal to the plane of the tank which results in the maximum projected area. In addition, the relative orientation of the tank supports and the applied lateral force (either wind or seismic) is selected to maximize the peak axial load seen by any support. This assures that for any of the five tank configurations evaluated, the worst possible design condition has been addressed for the postulated wind and seismic loads.

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4) Overturning moment is maximized:

In establishing the tank C.G., the assumed tank support height is used to obtain the maximum moment arm for the applied lateral force. However, in establishing this lateral force, the tank support height is taken as zero to maximize the force. While this combination of factors results in overestimating the resulting moment, this conservative approach is used to account for any non-uniform weight distribution in the tank and to assure that any tank which meets both the weight and height limits of the nomograph will not overload the weigh module recommended.

5) Wind loads are maximized:

While wind forces increase with height, the wind load is calculated at the top of the tank and assumed uniform over the total projected area of the tank. In addition, this resulting force is applied at the conservatively calculated tank C.G. (see item 4 above) used for seismic load evaluations to simplify the analysis.

D) EXAMPLE USE OF NOMOGRAPHS

1) A square, upright tank located outdoors with 4 support legs, a width of 8 feet and a height of 28 feet. This tank is located in a seismic zone 3 area subject to wind speeds of 80 mph.

This is a type S-0-4 tank which meets the requirement for a H/D ratio greater than 3 (i.e., 28/8 = 3.5). Using the S-0-4 wind nomograph on page 21 with a height of 28 feet and a wind speed of 80 mph,

Est. tank weight = 190,300 lb

Recommended BLH weigh modules:

KIS-1 (200 KN)
Z-BLOK (50,000 lb)

using the S-0-4 seismic nomograph on page 24 with a height of 28 feet and zone 3,

Recommended BLH weigh modules:

KIS-1 (500 KN)
Z-BLOK (100,000 lb)

In this case the seismic condition governs and the higher capacity weight modules required for this condition will also support the wind load condition.

Document Number: 12222
Revision 11-May-06

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2) Same tank as above, but located in seismic zone 1 with design wind speeds of 100 mph.

Using the S-0-4 wind nomograph (page 21), H = 28 feet, and V = 100 mph.

Recommended BLH weigh modules:

KIS-1 (200 KN)
Z-BLOK (50,000 lb)

Using the S-0-4 seismic nomograph (page 24), H = 28 feet, and zone 1,

Recommended BLH weigh modules:

KIS-1 (200 KN)
Z-BLOK (50,000 lb)

In this case the same BLH products would be selected for either load condition.

3) A round, upright tank with 3 support legs located indoors with a height of 20 feet and a diameter of 10 feet. This tank is located in a seismic zone 4 area.

This is a type C-I-3 tank which meets the requirement for a H/D ratio greater than or equal to 2 (i.e., 20/10 = 2). Using the C-I-3 seismic nomograph on page 27,

Est. tank weight = 122,600 lb

Recommended BLH weigh modules:

KIS-1 (500 KN)
Z-BLOK (100,000 lb)

E) LIMITATION OF NOMOGRAPHS

1) Nomographs are limited to tank/support arrangements which match the associated tank type evaluated.

2) The H/D ratio for any evaluated tank must satisfy the following criteria:

Indoor Tanks: H/D $\geq$ 2
Outdoor Tanks: H/D $\geq$ 3

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or, if the above criteria is not met, the nomographs can be used to select a suitable BLH weigh module using a modified, artificial tank height based on the tank diameter (or width) as follows:

For indoor tanks: H' = 2 x D
For outdoor tanks: H' = 3 x D

3) The estimated tank weight will typically be conservative for the actual tank with height, H. However, should any case arise where the actual tank weight exceeds the estimated value, use the BLH weigh modules that correspond to an estimated weight in excess of the actual value even though this corresponds to a greater H value. (Example: A type C-O-3 tank has a height of 20 ft and a weight of 60,000 lb - use H = 22 ft for nomograph.)

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CYLINDRICAL, OUTDOOR TANK WITH 4 SUPPORTS: TYPE C-O-4

<table>
<tr><th rowspan="2">TANK HEIGHT H (FT)</th><th rowspan="2">EST. TANK WEIGHT[1] (DL + LL) (LBS)</th><th colspan="8">RECOMMENDED BLH WEIGH MODULE UNDER WIND PLUS GRAVITY LOADS</th></tr>
<tr><th colspan="2">V = 70 MPH</th><th colspan="2">V = 80 MPH</th><th colspan="2">V = 90 MPH</th><th colspan="2">V = 100 MPH</th></tr>
<tr><td>10</td><td>6,800</td><td rowspan="2">KIS-2,3 (10 KN)</td><td rowspan="10">Z-BLOK (10 K)</td><td>KIS-2,3 (10 KN)</td><td rowspan="9">Z-BLOK (10 K)</td><td>KIS-2,3 (10 KN)</td><td rowspan="9">Z-BLOK (10 K)</td><td>KIS-2,3 (10 KN)</td><td rowspan="9">Z-BLOK (10 K)</td></tr>
<tr><td>11</td><td></td><td rowspan="4">KIS-2,3 (20 KN)</td><td rowspan="3">KIS-2-3 (20 KN)</td><td rowspan="3">KIS-2,3 (20 KN)</td></tr>
<tr><td>12</td><td>11,800</td><td rowspan="3">KIS-2,3 (20 KN)</td></tr>
<tr><td>13</td><td></td></tr>
<tr><td>14</td><td>18,700</td><td rowspan="6">KIS-1 (50 KN)</td><td rowspan="5">KIS-1 (50 KN)</td></tr>
<tr><td>15</td><td></td><td rowspan="6">KIS-1 (50 KN)</td><td rowspan="5">KIS-1 (50 KN)</td></tr>
<tr><td>16</td><td>27,900</td></tr>
<tr><td>17</td><td></td></tr>
<tr><td>18</td><td>39,700</td></tr>
<tr><td>19</td><td></td><td rowspan="6">Z-BLOK (20 K)</td><td rowspan="5">Z-BLOK (20 K)</td><td rowspan="6">KIS-1 (100 KN)</td><td rowspan="5">Z-BLOK (20 K)</td></tr>
<tr><td>20</td><td>54,500</td><td rowspan="5">Z-BLOK (20 K)</td><td rowspan="6">KIS-1 (100 KN)</td><td rowspan="5">KIS-1 (100 KN)</td></tr>
<tr><td>21</td><td></td><td rowspan="5">KIS-1 (100 KN)</td></tr>
<tr><td>22</td><td>72,500</td></tr>
<tr><td>23</td><td></td></tr>
<tr><td>24</td><td>94,100</td><td rowspan="9">Z-BLOK (50 K)</td><td rowspan="9">Z-BLOK (50 K)</td></tr>
<tr><td>25</td><td></td><td rowspan="9">Z-BLOK (50 K)</td><td rowspan="9">Z-BLOK (50 K)</td><td rowspan="7">KIS-1 (200 KN)</td><td rowspan="7">KIS-1 (200 KN)</td></tr>
<tr><td>26</td><td>119700</td><td rowspan="7">KIS-1 (200 KN)</td><td rowspan="7">KIS-1 (200 KN)</td></tr>
<tr><td>27</td><td></td></tr>
<tr><td>28</td><td>149500</td></tr>
<tr><td>29</td><td></td></tr>
<tr><td>30</td><td>183900</td></tr>
<tr><td>31</td><td></td></tr>
<tr><td>32</td><td>223200</td><td rowspan="12">KIS-1 (500 KN)</td><td rowspan="12">KIS-1 (500 KN)</td></tr>
<tr><td>33</td><td></td><td rowspan="12">KIS-1 (500 KN)</td><td rowspan="12">KIS-1 (500 KN)</td><td rowspan="9">Z-BLOK (100 K)</td><td rowspan="9">Z-BLOK (100 K)</td></tr>
<tr><td>34</td><td>267700</td><td rowspan="10">Z-BLOK (100 K)</td><td rowspan="9">Z-BLOK (100 K)</td></tr>
<tr><td>35</td><td></td></tr>
<tr><td>36</td><td>317700</td></tr>
<tr><td>37</td><td></td></tr>
<tr><td>38</td><td>373700</td></tr>
<tr><td>39</td><td></td></tr>
<tr><td>40</td><td>435800</td></tr>
<tr><td>41</td><td></td></tr>
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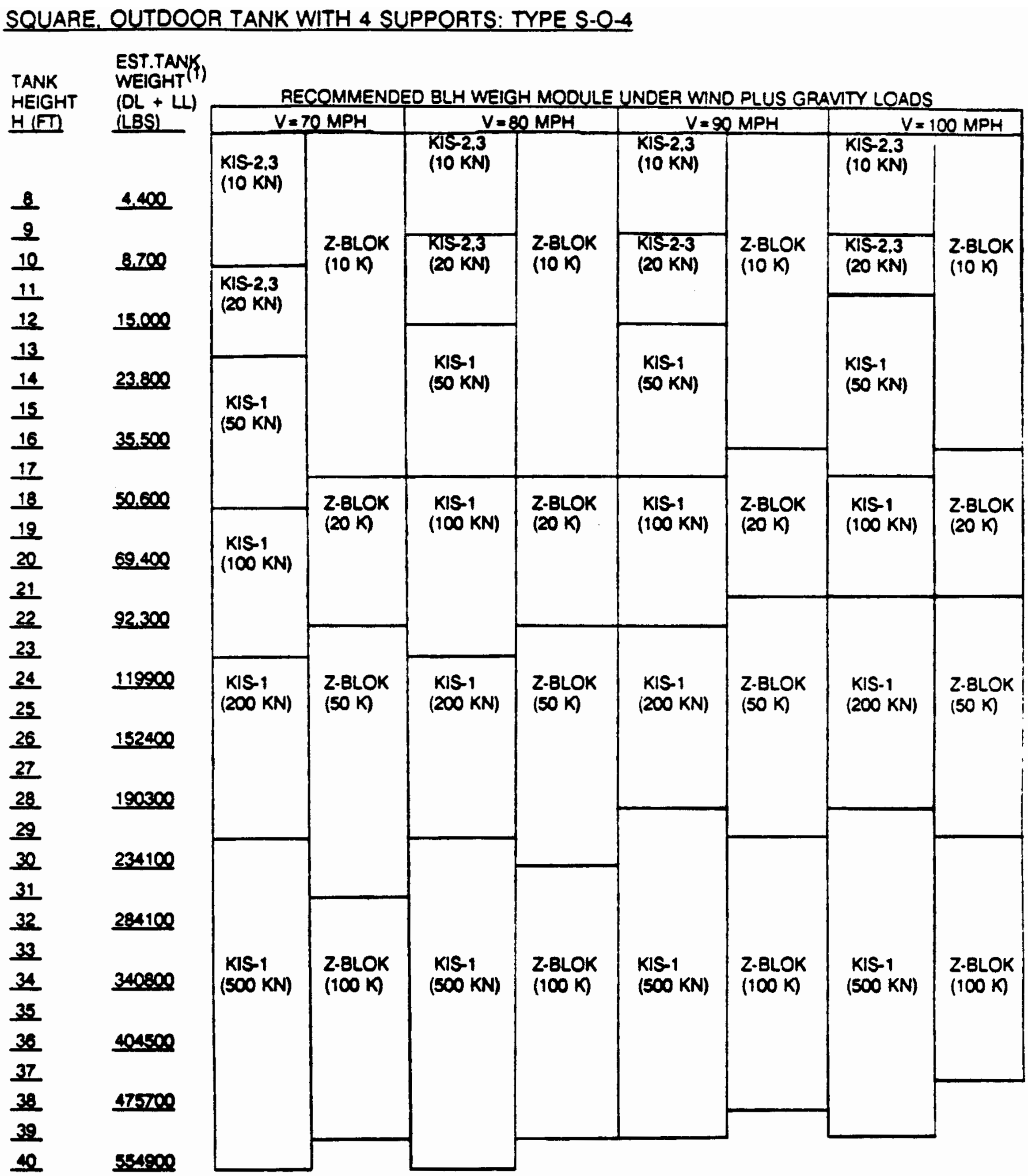
[1] Est. Wt. = $6.81\ H^3$ (Assumes tank filled with water and tank weight equal to 25% of content weight)

Earthquake and Wind Load Design Handbook



(1) Est. Wt. = $8.67\ H^3$ (Assumes tank filled with water and tank shell weight equal to 25% of content weight.)

Earthquake and Wind Load Design Handbook

CYLINDRICAL, OUTDOOR TANK WITH 3 SUPPORTS: TYPE C-O-3

TANK HEIGHT H (FT)	EST. TANK WEIGHT[1] (DL + LL) (LBS)
8	3,500
9	
10	6,800
11	
12	11,800
13	
14	18,700
15	
16	27,900
17	
18	39,700
19	
20	54,500
21	
22	72,500
23	
24	94,100
25	
26	119700
27	
28	149500
29	
30	183900
31	
32	223200
33	
34	267700
35	
36	317700
37	
38	373700
39	
40	435800

RECOMMENDED BLH WEIGH MODULE UNDER WIND PLUS GRAVITY LOADS

Wind speed	Module	Tank height H (FT)
V = 70 MPH	KIS-2,3 (10 KN)	8 – 10
	KIS-2,3 (20 KN)	11 – 13
	KIS-1 (50 KN)	14 – 18
	KIS-1 (100 KN)	19 – 23
	KIS-1 (200 KN)	24 – 29
	KIS-1 (500 KN)	30 – 40
	Z-BLOK (10 K)	8 – 17
	Z-BLOK (20 K)	18 – 22
	Z-BLOK (50 K)	23 – 30
	Z-BLOK (100 K)	31 – 39
V = 80 MPH	KIS-2,3 (10 KN)	8 – 9
	KIS-2,3 (20 KN)	10 – 12
	KIS-1 (50 KN)	13 – 17
	KIS-1 (100 KN)	18 – 22
	KIS-1 (200 KN)	23 – 29
	KIS-1 (500 KN)	30 – 40
	Z-BLOK (10 K)	8 – 16
	Z-BLOK (20 K)	17 – 21
	Z-BLOK (50 K)	22 – 30
	Z-BLOK (100 K)	31 – 38
V = 90 MPH	KIS-2,3 (10 KN)	8 – 9
	KIS-2-3 (20 KN)	10 – 12
	KIS-1 (50 KN)	13 – 17
	KIS-1 (100 KN)	18 – 22
	KIS-1 (200 KN)	23 – 28
	KIS-1 (500 KN)	29 – 39
	Z-BLOK (10 K)	8 – 16
	Z-BLOK (20 K)	17 – 21
	Z-BLOK (50 K)	22 – 29
	Z-BLOK (100 K)	30 – 37
V = 100 MPH	KIS-2,3 (10 KN)	8 – 9
	KIS-2,3 (20 KN)	10 – 11
	KIS-1 (50 KN)	12 – 16
	KIS-1 (100 KN)	17 – 21
	KIS-1 (200 KN)	22 – 28
	KIS-1 (500 KN)	29 – 39
	Z-BLOK (10 K)	8 – 16
	Z-BLOK (20 K)	17 – 20
	Z-BLOK (50 K)	21 – 29
	Z-BLOK (100 K)	30 – 37

[1] Est. Wt. = $6.81\ H^3$ (Assumes: Tank filled with water, DL = 25% LL, and H/D = 3.)

Earthquake and Wind Load Design Handbook

CYLINDRICAL, OUTDOOR TANK WITH 4 SUPPORTS: TYPE C-O-4

TANK HEIGHT H (FT)	EST. TANK WEIGHT[1] (DL + LL) (LBS)	RECOMMENDED BLH WEIGH MODULE UNDER SEISMIC PLUS GRAVITY LOADS							
		ZONE 1		ZONE 2		ZONE 3		ZONE 4	
8	3,500	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
9		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
10	6,800	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
11		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
12	11,800	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
13		KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
14	18,700	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
15		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)
16	27,900	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
17		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
18	39,700	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
19		KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
20	54,500	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
21		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
22	72,500	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
23		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
24	94,100	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)
25		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
26	119700	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
27		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
28	149500	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
29		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
30	183900	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
31		KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
32	223200	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	
33		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)		
34	267700	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)			
35		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
36	317700	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
37		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
38	373700	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)					
39		KIS-1 (500 KN)	Z-BLOK (100 K)						
40	435800	KIS-1 (500 KN)	Z-BLOK (100 K)						
41		KIS-1 (500 KN)							
42	504500								

[1] Est. Wt. = $6.81\ H^3$ (Assumes tank filled with water and tank shell weight equal to 25% of content weight.)

Earthquake and Wind Load Design Handbook

CYLINDRICAL, OUTDOOR TANK WITH 4 SUPPORTS: TYPE C-O-4

TANK HEIGHT H (FT)	EST. TANK WEIGHT[1] (DL + LL) (LBS)
8	3,500
9	
10	6,800
11	
12	11,800
13	
14	18,700
15	
16	27,900
17	
18	39,700
19	
20	54,500
21	
22	72,500
23	
24	94,100
25	
26	119700
27	
28	149500
29	
30	183900
31	
32	223200
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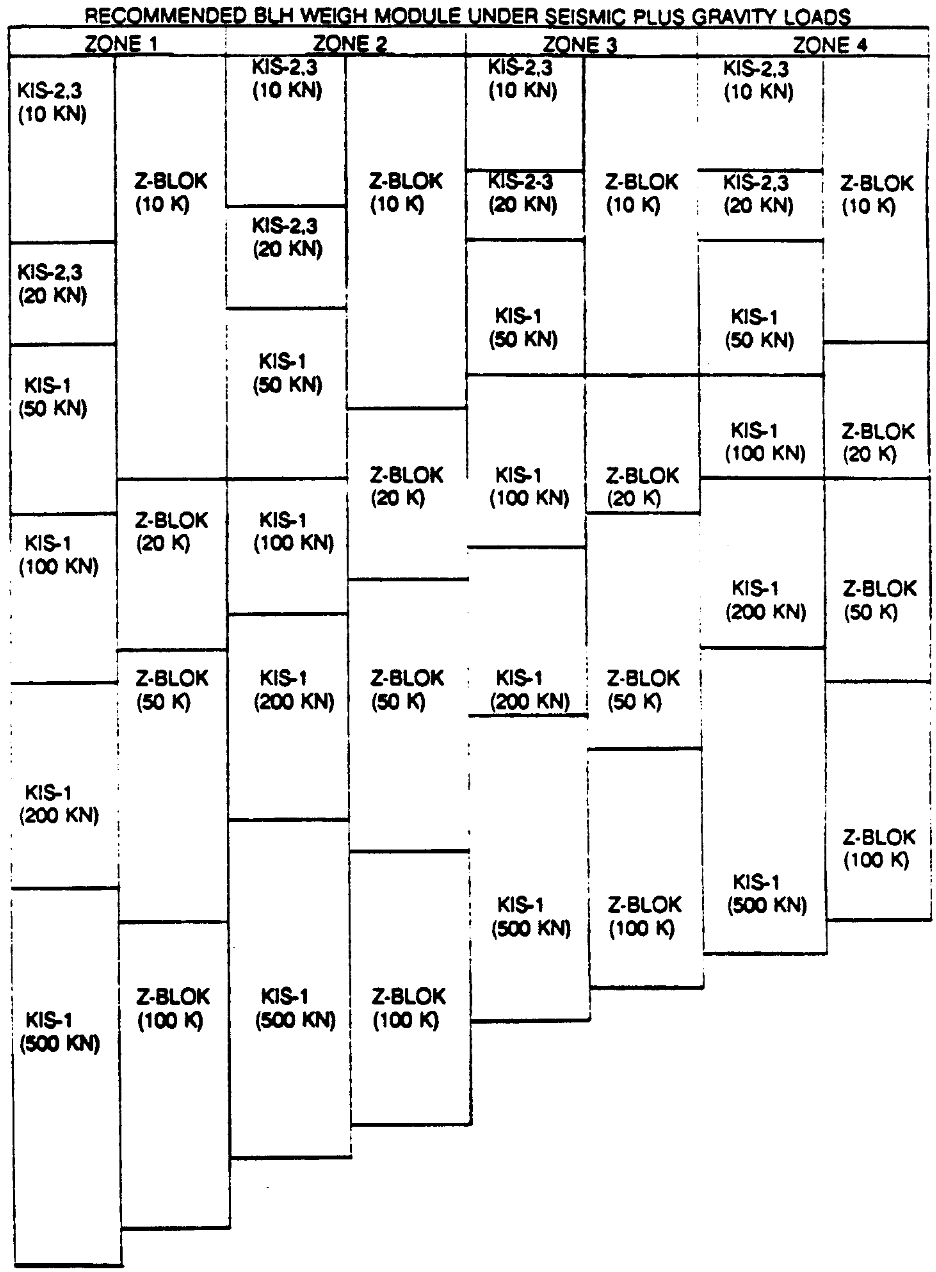
36	317700
37	
38	373700
39	
40	435800
41	
42	504500



[1] Est. Wt. = $6.81\ H^3$ (Assumes tank filled with water and tank shell weight equal to 25% of content weight.)

Earthquake and Wind Load Design Handbook

CYLINDRICAL, OUTDOOR TANK WITH 3 SUPPORTS: TYPE C-O-3

RECOMMENDED BLH WEIGH MODULE UNDER SEISMIC PLUS GRAVITY LOADS

TANK HEIGHT H (FT)	EST. TANK WEIGHT[1] (DL + LL) (LBS)	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
8	3,500	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
9		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
10	6,800	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
11		KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
12	11,800	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
13		KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
14	18,700	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
15		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
16	27,900	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
17		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)
18	39,700	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
19		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
20	54,500	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
21		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
22	72,500	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)
23		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
24	94,100	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
25		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
26	119700	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
27		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
28	149500	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
29		KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	
30	183900	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)		
31		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)			
32	223200	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
33		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
34	267700	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)					
35		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)					
36	317700	KIS-1 (500 KN)	Z-BLOK (100 K)						
37		KIS-1 (500 KN)							
38	373700	KIS-1 (500 KN)							

(1) Est. Wt. = 6.81 H^3 (Assumes: Tank filled with water, DL = 25% LL, and H/D = 3.)

Earthquake and Wind Load Design Handbook

CYLINDRICAL, INDOOR TANK WITH 4 SUPPORTS: TYPE C-I-4

RECOMMENDED BLH WEIGH MODULE UNDER SEISMIC PLUS GRAVITY LOADS

TANK HEIGHT H (FT)	EST. TANK WEIGHT[1] (DL + LL) (LBS)	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
4	1,000	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
5		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
6	3,300	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
7		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
8	7,800	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
9		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2-3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
10	15,300	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
11		KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
12	26,500	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
13		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
14	42,000	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
15		KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
16	62,800	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
17		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
18	89,300	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
19		KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
20	122600	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (50 K)
21		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
22	163100	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
23		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
24	211800	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
25		KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
26	269300	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
27		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	
28	336300	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)			
29		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
30	413600	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
31		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)					
32	50200	KIS-1 (500 KN)							
33		KIS-1 (500 KN)							
34	602100								

[1] Est. Wt. = $15.32\ H^3$ (Assumes: Tank filled with water, DL = 25% LL, and H/D = 2.)

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CYLINDRICAL, INDOOR TANK WITH 3 SUPPORTS: TYPE C-I-3

RECOMMENDED BLH WEIGH MODULE UNDER SEISMIC PLUS GRAVITY LOADS

TANK HEIGHT H (FT)	EST. TANK WEIGHT[(1)] (DL + LL) (LBS)	ZONE 1		ZONE 2		ZONE 3		ZONE 4	
4	1,000	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
5		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
6	3,300	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)
7		KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
8	7,800	KIS-2,3 (10 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)
9		KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
10	15,300	KIS-2,3 (20 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
11		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)
12	26,500	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
13		KIS-1 (50 KN)	Z-BLOK (10 K)	KIS-1 (50 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)
14	42,000	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)
15		KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
16	62,800	KIS-1 (100 KN)	Z-BLOK (20 K)	KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
17		KIS-1 (100 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
18	89,300	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)
19		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
20	122600	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
21		KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
22	163100	KIS-1 (200 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
23		KIS-1 (500 KN)	Z-BLOK (50 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)
24	211800	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	
25		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)			
26	269300	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
27		KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)	Z-BLOK (100 K)				
28	336300	KIS-1 (500 KN)	Z-BLOK (100 K)	KIS-1 (500 KN)					
29		KIS-1 (500 KN)	Z-BLOK (100 K)						
30	413600	KIS-1 (500 KN)							

(1) Est. Wt. = $15.32\ H^3$ (Assumes: Tank filled with water, DL = 25% LL, and H/D = 2.)

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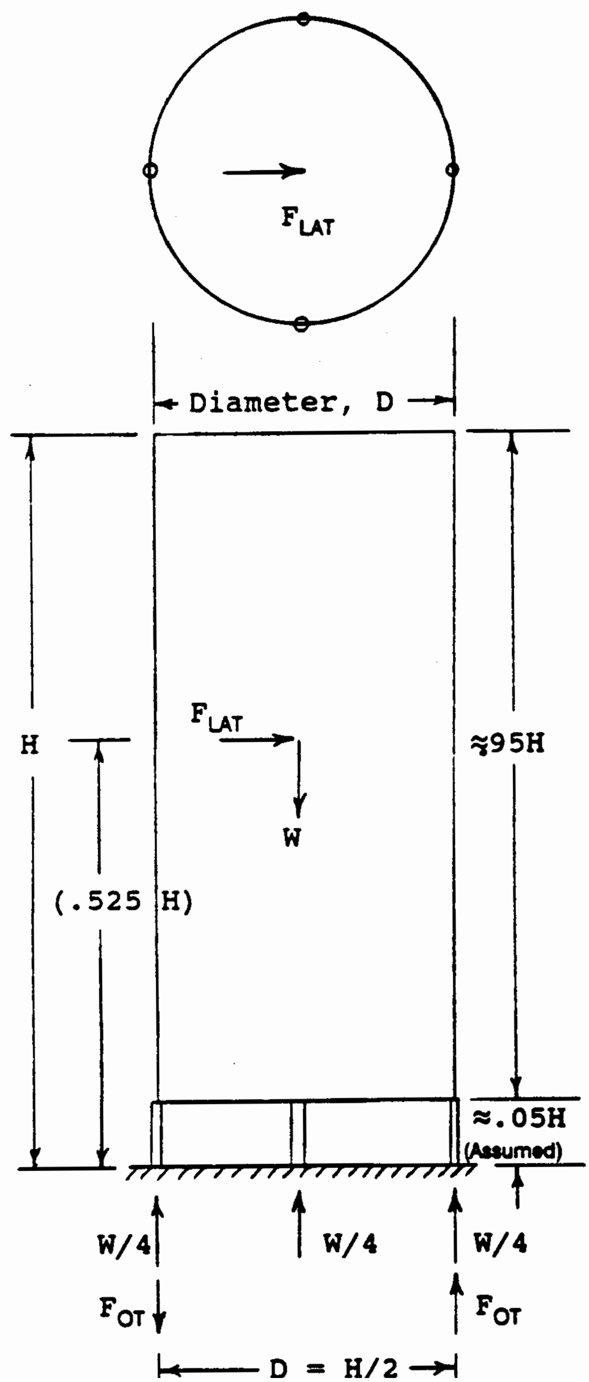
"TYPICAL" TANK INSTALLATIONS: (UNITS: FEET, POUNDS)

CYLINDRICAL, INDOOR TANK WITH 4 SUPPORTS: TYPE C-I-4



H/D = 2 (Assumed)

$F_{LAT} = 0.3\ ZW$ (Due to Seismic Load)

Volume (Max):

$V_T = \pi/4\ D^2H$

$V_T = \pi/4\ (H/2)^2\ H$

$V_T = 0.1963H^3$

Weight:

$W = DL + LL$

$DL = 0.25 \times LL$ (Assumed)

$LL = V_T$ (62.4 PCF) (Assuming Water in Tank)

$W = 1.25\ V_T\ (62.4)$

$W = 15.32\ H^3$ (lb)

Peak Support Load, P

$P = W/4 + (.525H)\ F_{LAT}/D$

$P = W/4+(.525H)(.3ZW)/(H/2)$

$P = (0.25 + .315Z)\ W$

Earthquake and Wind Load Design Handbook

Adverse Loads on High Capacity Weigh Modules for Silos

By Bulent Bulat

Introduction

A silo is a particular type of large storage vessel, erected generally outdoors, to store dry, solid, granular materials. To facilitate flow and to reduce the real estate sprawl, silos are typically constructed tall with high aspect (height-to-width) ratios.

Weigh modules are installed as structural elements in a silo system and provide not only weight information, but also serve to support and anchor the silo.

When adverse forces are created by wind, rain, snow, thermal expansion, and earthquakes; a tall profile presents particular loading problems to the supporting structure. ANSI A58.1 is a national standard that formulates minimum design loads and characterizes the United States with respect to prevalent wind conditions and probable earthquakes, so that structures can be designed to tolerate predictable loads.

Silos

Dry granular or powder solids have settling patterns that make level measurement in bulk storage unreliable. Total weight measurement has been progressively established as one of the preferred means of measurement for inventory and custody transfer. With ever-increasing materials processing around the world, larger silos are being built, and measurement of forces to 300,000 lbs or more per point are becoming commonplace.

Structural strength requirements

There is no structure designed and economically built to stand all natural conditions. Consequently, sizing decisions are made on the basis of the probabilities of structural failure under varying conditions, and the severity of consequences that one is willing to accept in view of those odds. Many decisions are constrained by legislated or accepted rules or codes; such as the Uniform Building Code, where conservatism and "overdesign" are the norm.

Total design forces on a tank consists of the dead load (DL), the live load (LL), plus the wind (F_W) or earthquake force (F_E) (but not both at the same time).

Seismic forces

Earthquake forces are predicted as follows:

$F_E = Z * I * K * C * S * W$

where

Z = Seismic zone factor
I = Importance factor
K = Horizontal force factor
C = a constant related to the resonance frequency of the vessel
S = Soil profile factor
W = DL + LL

When all factors are estimated conservatively, the preceding formula simplifies to approximately

$F_E = 0.3 Z * W$

The resultant is applied at the center of gravity of the full tank. Total seismic forces acting on a Zone 4 vessel

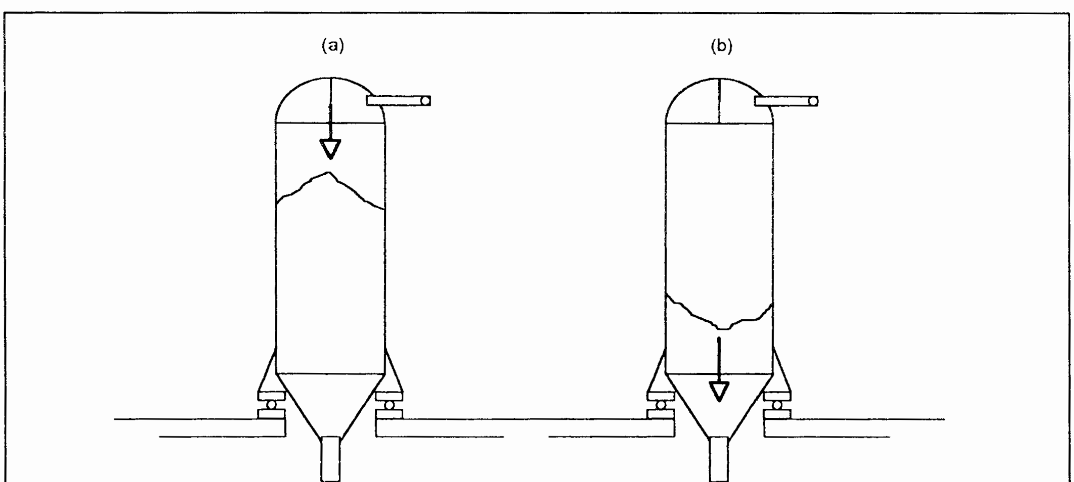


Figure 1 Contents of silo during (a) loading and (b) unloading

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are therefore estimated to be approximately 30% of the maximum total vertical load (See Table 1 and Fig. 4).

Table 1 Seismic forces

Symbol	Parameter	Values	References*
F_E	Lateral force	= ZIKCSW = 0.3 ZW	Ref. 1 Eq. 6
Z	Seismic zone factor	= 3/16 (Zone 1) = 3/8 (Zone 2) = 3/4 (Zone 3) = 1.0 (Zone 4)	Ref. 1 Table 22
I	Importance factor	= 1.0	Ref. 1 Table 23
K		= 2.0 generally = 2.5 for vessels with > 3 cross braced legs, but KCS < 0.29	Ref. 1 Table 24
C	Resonance factor	= $(1/15)T^{-0.5}$, but < 0.12	calculated
S	Soil profile factor	= 1.0 to 1.5, but CS < 0.14	Determined by the civil engineer
W	Total Weight	= DL + LL	calculated
T	Fundamental period of the vessel		Determined by the civil engineer

(*) Ref. 2 will yield similar results, although intermediate variables may be different due to the use of different coefficients.

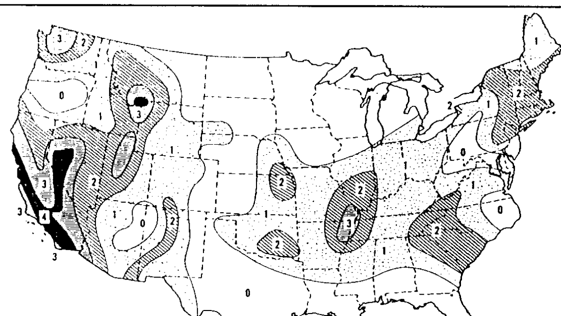

Figure 4 Map of Seismic Zones in the U.S.

Therefore, in a Zone 4 application, the tangential forces on two of the weigh modules each supporting 25% of the total weight, will be approximately 15% of total weight. If the modules are sized for a full scale (FS) of W/4, then the tangential forces will be 60% FS maximum per module.

Uplift forces are also significant. The uplift force on the module to the left of Fig. 5 (a) is obtained by letting the sum of moment equal zero. The force is then equal to

F_E * (D/d) - W/4
= 0.3 * W* D/d -0.25 * W
= (0.3 * D/d + 0.25) * W

If D/d = 1, then the uplift force is then only 20% FS, whereas the down forceon the opposite side is 220% FS. However, if D/d is 2.0, then the uplift force is 140% FS, while the down force on the opposite side is 340% FS, for FS = W/4. The aspect ratio has clearly a major effect on peak forces.

Similarly, for a 3-point system, the uplift force is given by

F_E * 4/3 * D/d - W/3
= 0.3 * W * 4/3 * D/d - 0.33 * W
= (0.4 * D/d - 0.33) * W

If D/d = 1 or 2, then the uplift force is 20 % FS or 140 % FS respectively, for each weigh module, because the weigh modules are 33 % larger, for FS = W/3.

Winds

Basic wind speeds in the U.S. are described in Fig.6. Most structures are designed to withstand a minimum 70 mph, but in areas vulnerable to hurricanes, they must survive winds in excess of 110 mph. Special conditions may apply in certain mountainous and lakeside regions.

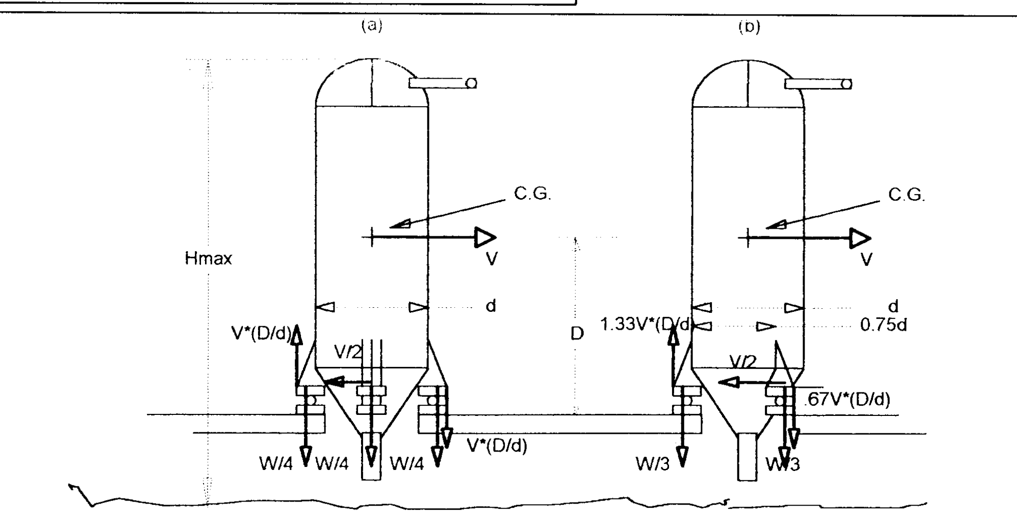

Figure 5 Silo under seismic or wind loading (a) 4-point support and (b) 3-point support structures

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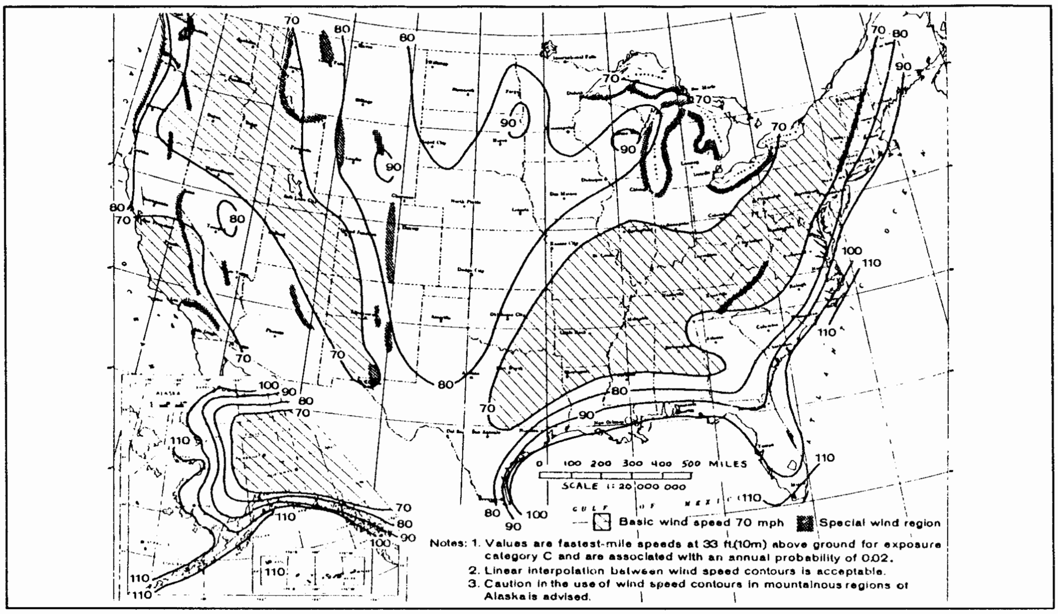

Figure 6 Design wind speeds in the U.S. (per Ref. 1 Fig. 1)

Wind forces may be predicted from the following:

$F_W = q_Z * G_H * C_f * A_f$

where

q_Z = Velocity pressure at height Z
G_H = Gust response factor
C_f = Force coefficient
A_f = Area (cross section) exposed to wind.

Wind force is maximized by calculating wind pressure at the top of the tank and assuming that it is uniform over the full height. The resultant is applied at the height of the calculated center of gravity (C.G.). Hence

$q_Z = 0.00256 * K_Z * (I * V)^2$,

where

K_Z = Exposure coefficient
I = Importance factor
V = wind velocity

The parameters are summarized in Table 2:

Table 2 Wind forces

Symbol	Parameter	Value	Reference
q_Z	Velocity pressure at height Z	$= 0.00256K_Z(IV)^2$	calculated
F_W	Wind force	$= q_ZG_HC_fA_f$ $= 0.00256G_HC_fA_fK_Z(IV)^2$	calculated
A_f	Cross sectional area exposed to wind	= HD for round silos = 1.414 HD for square silos	calculated
C_f	Force coefficient	= 1.05 for square silos = 0.75 for round silos	Ref. 1 Table 12
G_H	Gust response factor	= 1.10 at 50 feet	Ref. 1 Table 8 $H = H_{max}$ for conservatism
I	Importance factor	= 1.05 for "category 1" buildings	Ref. 1 Table 5
K_Z	Exposure coefficient	= 1.52 at 50 feet	Ref. 1 Table 6 $Z = H_{max}$ for conservatism
V	Wind velocity	See maps	Determined by the civil engineer
C.G.	Center of gravity (of empty vessel)	$H_{max}/2$	Calculated by civil engineer

Sample application

Table 3 lists the approximate dimensions and calculated forces on a sample application of BLH weigh module KDH-1A, similar to the installations pictured in Figs. 2 and 3.

Table 3

d_1	Diameter	21.3 feet
H	Height	80.4 feet
D	Height of C.G.	33.7 feet
LL	Live load	495,000 lbs
DL	Dead load	44,000 lbs
W	Total operating weight	539,000 lbs
h	Height of installation	27.9 feet
F_W	Wind force	107,700 lbs
F_E	Seismic force	161,700 lbs (max horizontal force)
M_{OT}	Over turning moment	6.533 million foot-lbs
d_2	Diameter of support circle	21.6 feet
W/4	Load per module	134,750 lbs
$F_E/2$	Max load horizontal force per module	80,850 lbs
$F_E*D/d_2 + W/4$	Max vertical (down) force per module (full vessel)	302,800 lbs
F_W*D/d_2	Max. vertical (up) force per module (empty vessel)	168,000 lbs

Thermal expansion

Vessels with long horizontal dimensions experience significant thermal expansion and contraction. A 25-foot diameter vessel will expand or contract nearly 1/2 inch during the course of a year in daily and seasonal cycles. This expansion is accommodated by making weigh modules rigid in one horizontal direction, while allowing free movement in the other horizontal direction. Consequently in a 4 module system, only two modules can support side forces in any given direction. This is significant in rating modules for side loads.

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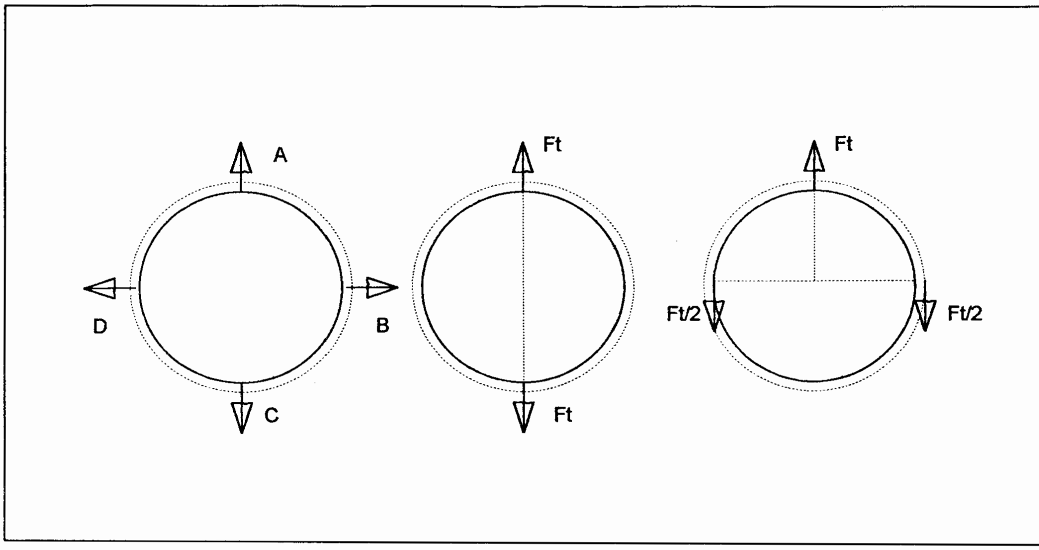

Figure 7 Top view of a round storage vessel

Viewing a round silo from the top, as depicted in Fig. 7, the thermal expansion radial force, F_t, exerted by the tank on a weigh module at point A is significant. On a weigh module permitting sliding motion radially, F_t, is equal to the vertical force multiplied by the coefficient of static friction, C_s. F_t may easily be as much as 40% of the applied force. The reaction to this force may, some of the time, be at point C in equal magnitude but opposite direction. Otherwise, it will occur as tangential forces shared equally at points D and B.

Rain and floods

Although load cells are not, in general, designed for continuous submerged operation, they must routinely survive rain, snow, ice, hose down, and accidental submersion. The added weight of rain, snow and ice are generally structural in tall installations with relatively small top profiles, but the effects on accuracy of measurement must be recognized by the user. The traditional BLH C2P canister (column) load cells and KDH series weigh modules, discussed below, are rated IEC IP67 [4] for enclosure integrity.

Trade-offs

Typical installations contain 3 or 4 load cells, although 8, as in Fig. 2, or more load cells have been used. Instrument engineers prefer 3 load cells for ease of weight equalization and calibration. On the other hand structural and civil engineers invariable prefer a 4 point support for ease of design and construction. This is especially so, when elevated supports are required, as is the case with vessels terminating in inverted cones (or hoppers) at the bottom. It may be assumed that under normal conditions, weights are equally distributed among the modules. When 6 or more weigh modules are used, the flexibility of the supporting structure is a major factor in weight distribution, and must be optimized by the designers.

Lateral and uplift forces generated by adverse conditions are not always equally distributed. Under the worst case conditions on a 3 and 4-point system, only two modules may support the lateral forces, and only one may support the uplift force.

Typically, when a vessel is full the worst uplift forces occur due to earthquakes, but when it is empty, the worst is due to winds. In general, the most damaging forces on a tall structure are assumed to be due to the horizontal, not the vertical, motion from a quake generated ground wave.

New load cells for silo applications

BLH is currently offering a new family of load cell weigh modules, designated KDH-1A and KDH-3, for large silo applications (Fig. 8). Designed orginally for inventory weighing, these products exhibit good accuracy, and thus may also be used for process batch weighing, as well as railroad car loading by measurement of weight loss.

A complete module consists of a beam and the mounting hardware. The cylindrical shape of the beam permits internal strain gaging without external cavities, and reduces the risk of leakage by making welded joints or potting compounds unnecessary.

All structurally significant components of the KDH-1A are made from super-strength alloy steels, with a zinc plated beam and painted mounting hardware. They are available currently in capacities from 50K lbs through 300K lbs full scale.

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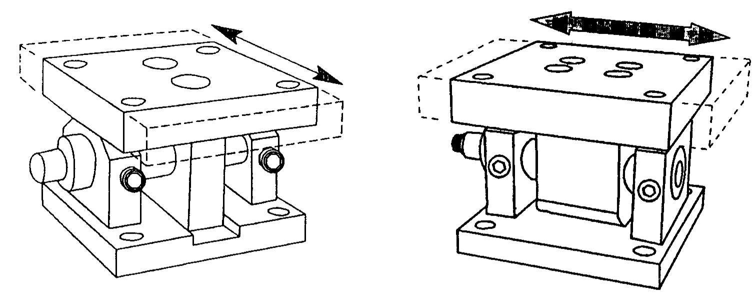

Figure 9 Thermal Expansion Provision

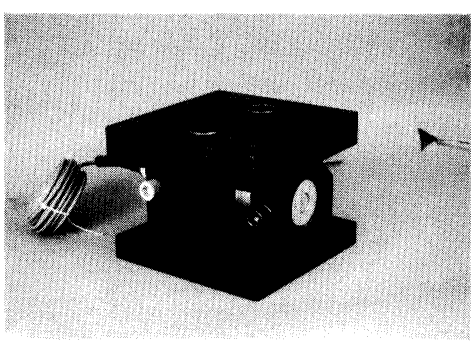

Figure 8a KDH-1A

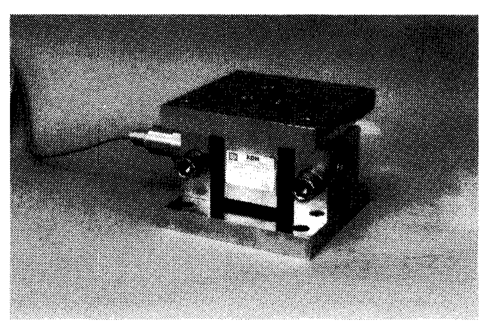

Figure 8b KDH-3

KDH-3 components are made from high strength stainless steels. The modules are currently available in metric capacities from 100 KN through 500 KN, but the concept is readily scaleable up to much higher capacities.

Both types of modules are designed to accommodate significant thermal expansions, as shown in Fig. 9. The free direction is axial and transverse to the beam in KDH-1A and KDH-3 respectively. The KDH-3 boasts an integral load button, which reduces contact stresses to optimal levels for stainless steel, while achieving repeatability in load placement. This arrangement also maximizes the strength of the beam and the mounting hardware for both loads transverse to the beam. Furthermore, the beam can be removed for convenient calibration or replacement, (Fig.10), with savings on costly mounting hardware. Although the current KDH-3 hardware is designed for transverse loads to 100% FS, simple improvements in the mounting hardware can achieve 150% safe and 300% ultimate load ratings in all directions transverse to the beam, including uplift.

Conclusions

Load cells and weigh modules must be designed to perform well, not only under benign and precise loading in a laboratory, but also in real installations, under adverse environmental conditions of temperature, humidity, winds, seismic events and misdistributed load. New BLH weigh modules are designed to meet such needs under tall and heavy storage vessels. However, in all installations, performance and safety are ultimately the responsibility of the system designers, who must select the components with regard to their suitability. A component manufacturer does not have the resources to inspect and approve all uses.

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Acknowledgments
This article is based in part on previous work by Ronald Burke and fruitful discussions with Edgar Laderoute, both of BLH Electronics, Inc.

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2. "Uniform Building Code", International Conference of Building Officials
3. Stone & Webster Engineering Corp. "A structural evaluation of Tank Support Applications", BLH document TD-070, Jan. 1990.
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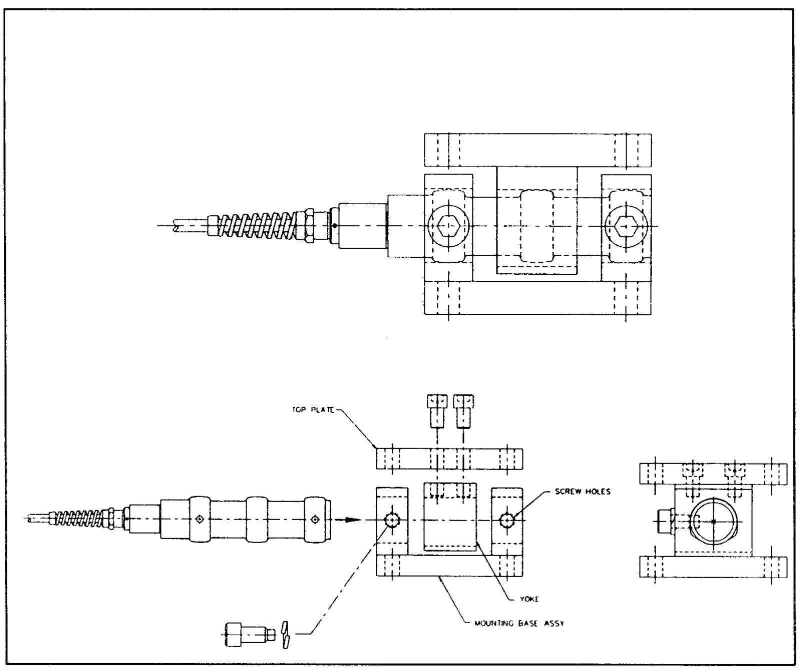

Figure 10 KDH-3 Weigh Module Assembly

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Document Number: 12222
Revision 11-May-06