ZCL COMPOSITES INC.

EDMONTON, ALBERTA

DRUMMONDVILLE,. QUEBEC

CALCULATION OF RESISTANCE FORCES TO UPHEAVAL FOR ZCL TANKS

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This document describes the method used to calculate the resistance to upheaval of ZCL tanks due to the weight of the backfill placed over the tanks.

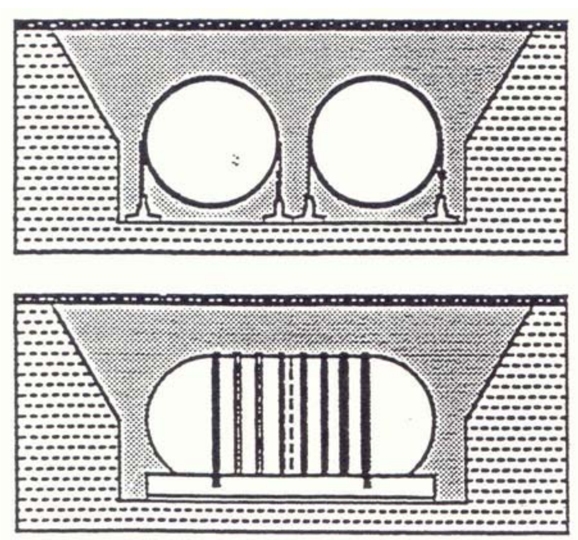
CALCULATION OF RESISTANCE FORCES TO UPHEAVAL FOR ZCL TANKS

Introduction

All underground tanks are subject to upheaval forces when the water table in the soil rises partway up or over the tank. These upheaval forces are resisted by a combination of factors; weight of the tank, weight of the backfill over the tank, weight of the liquid contained in the tank, weight of any attached anchoring system and the weight of backfill over such anchoring system. In a well designed tank installation, the resisting forces are always greater or equal to the upheaval forces, even under the worst conditions of flooding. The following paragraphs show the calculations for determining the resistance forces from backfill materials for ZCL Underground Storage Tanks for full flooding conditions. Calculations are given for tanks alone and for tanks with ZCL Tank Anchor System.

The ZCL Tank Anchor System consists of pre-cast concrete beams with an inverted “T” profile, which are placed in pairs beside and beneath the tanks. The beams are reinforced with an internal steel rebar structure to resist the lifting loads. High tensile strength fiberglass straps are attached to anchor points along the beams and are positioned over the tank to hold the tank in place. The beams in each Tank Anchor set are the same length as the tank to which they are attached. The beam cross sections vary according to the diameter of the tank to which they are attached.

Tank Size	Width of Base	Height
Model 40 (4’ dia)	457 mm (18 in)	305 mm (12 in)
Model 60 (6’ dia)	610 mm (24 in)	457 mm (18 in)
Model 86 (8’ dia)	610 mm (24 in)	457 mm (18 in)



ZCL Tank Anchor System

Data and Assumptions

The following data and assumptions will be utilized in the calculations:

1.) Weight of pea gravel or crushed stone backfill = 1.59 Tonne / cubic meter
(Specific Gravity = 1.59) (Ref: materials Suppliers)

2.) Weight of native soil (minimum) = 1.60 Tonne / cubic meter
(Specific Gravity = 1.60) (Ref: Mark's Standard Handbook for Mechanical Engineers)

3.) Weight of concrete = 2.30 Tonne / cubic meter
(Specific Gravity = 2.3) (Ref: Mark's Standard Handbook for Mechanical Engineers)

4.) Angle of internal friction for soils:
Pea gravel or crushed stone - 45 degrees
Native soil - 30 degrees
(Ref: Physical and Geotechnical Properties of Soils, Second Edition, J.E. Bowles, McGraw Hill Book Company, 1984)

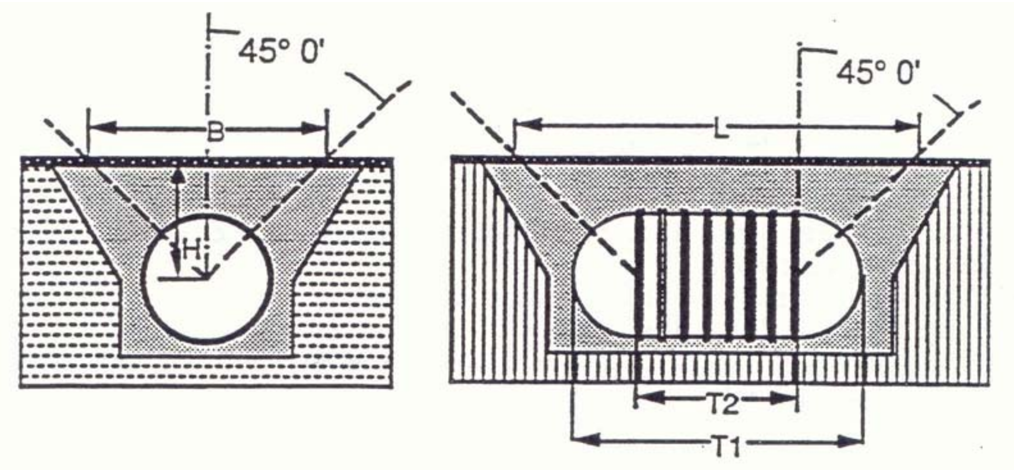
5.) The worst conditions for upheaval are assumed to be with the tank empty and the water table at the surface of the ground (full flood.)

6.) The weight of the tank itself is considered insignificant and is ignored in the calculations.

7.) It is assumed that the tanks are installed according to ZCL Composites Inc. Installation Instructions, especially with respect to the choice of backfill materials and minimum spacing between tanks and sides of excavation.

CASE 1.) TANKS WITHOUT ANCHOR SYSTEMS

Consider a single tank installed with pea gravel backfill.



The material in the zone above the tank (within the dashed lines) contributes to holding down the tank. Because the backfill material is solid and granular, and is able to sustain frictional forces, the effective zone spreads out further than just the tank diameter. The angle at which this zone spreads out depends upon the properties of the backfill material, specifically upon the property called Angle of Internal Friction. For pea gravel or crushed stone in the compacted state, this angle is approximately 45 degrees. Other backfill materials may have different angles of internal friction; most common soils have less than 45 degrees. Materials with smaller angles of internal friction have zones which spread less quickly and are therefore less effective in resisting upheaval forces.

The resisting force for upheaval can be easily calculated by computing the volume of backfill within the effective zone and multiplying by the effective weight of the backfill material. Note that if the site is flooded to grade, the effective weight of the backfill is the weight while submerged under water. This is because the backfill material is itself partially buoyed up by the water. This effective weight can be calculated by subtracting the valued 1.00 from the Specific Gravity of the backfill material. For the case of pea gravel (S.G. = 1.59), the effective Specific Gravity is 1.59 – 1.00 = 0.59, and therefore the effective weight is 0.59 Tonne / cubic meter.

The shape of the effective zone is an inverted wedge with beveled ends. The volume of this zone can be calculated as the sum of volume of a right pyramid (with bas = B, height = H) and a triangular wedge (base = B, Height = H, length = T2). Within this zone is a portion of the tank which does not contribute to the hold-down forces, and must be subtracted from the effective zone. For ease of calculation, for these cases where the angle of internal friction is 45 degrees, the volume of the tank within the zone is assumed to be ¼ of the total tank volume. This is a slightly conservative estimate because the tanks are dome-shaped at the ends, and in fact slightly less than ¼ of the tank volume lies within the effective zone, but this will not significantly effect the accuracy of our calculations.

Sample Calculation #1: (ZCL Model M-86SW-25000L Tank)

Diameter of tank	=	2.59 m
Length of tank (T2)	=	6.06 m
Volume of tank	=	25,000.00 L
	=	25.00 m^3
Depth of backfill	=	1.00 m

T2 = T1 – Dia
= 6.06 m – 2.59 m
= 3.47 m

H = Depth of Backfill = ½ Tank Diameter
= 1.5 + (0.5)(2.59)
= 2.80 m

B = 2H
= 5.60 m

Volume of Effective Zone = Pyramid + Wedge – ¼ Tank Volume
= (1/3)(B)(B)(H) + ½(B)(H)(T2) – ¼(25.00)
= (.33)(5.60)(5.60)(2.80) + (0.50)(5.60)(2.80)(3.47) – (0.25)(25.00)
= 49.93 m^3

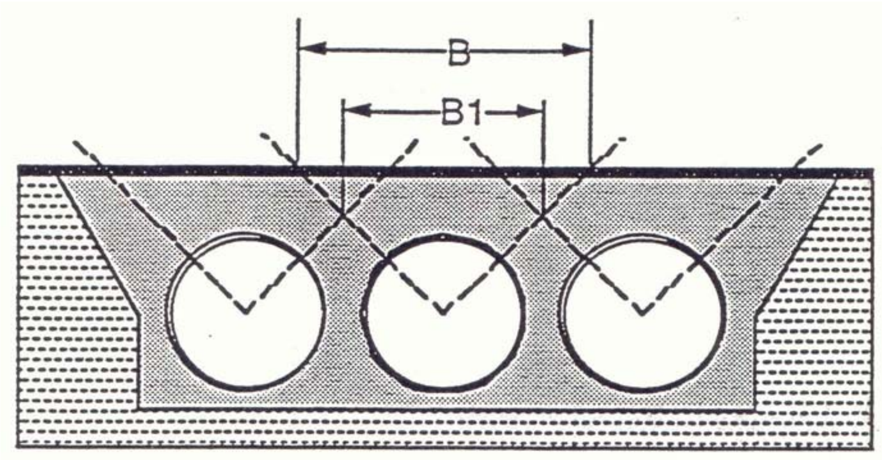
Weight of Effective Zone = (Volume of Zone) x (Effective Density)
= 49.93 m^3 x 0.59 Tonne/m^3
= 29.49 Tonnes

Uplift Force = (Volume of Tank) x (Density of Water)
= 25.00 m^3 x 1.00 Tonne/m^3
= 25.00 Tonnes

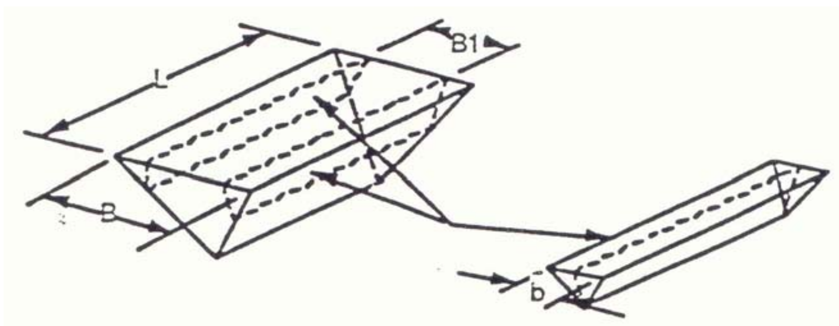
For this installation, the tank will not rise due to upheaval.

CASE 2) MULTIPLE TANKS WITHOUT ANCHORS

Consider an installation with multiple tanks buried at minimum allowable spacing.



The spread-out zones above the tanks now overlap. The effective zone is limited to a maximum width equal to B1. This zone is somewhat smaller than the zone for single tanks. The distance B1 is determined by the tank diameter and the spacing between the tanks. Tank spacing is specified in the ZCL Installation Instructions at a minimum of 610 mm. To calculate the volume of the effective zone for central tanks in a multiple tank installation it is simplest to calculate the volume of the full zone (as in Case 1) and to subtract away the overlap zone. The overlap zone can be considered as another triangular wedge shaped volume with beveled end with dimensions; base (b) = (B)=(B!); height (h) = ((B) – (B1).2), and length = L



EFFECTIVE ZONE AND OVERLAP ZONE

Sample Calculation #2:

Consider a multiple tank installation of the same size tanks as in Sample Calculation #1, with the same backfill depth of 2.00 m. The tanks are buried with the minimum allowable spacing of 610 mm between the tanks.

B1 =(Dia of Tank) + Min. Spacing)
= (2.59) + (0.61)
= 3.20 m

b =(B) – (B1)
= (5.60) – (3.20)
= 2.40 m

h = b/2.00
= 1.20 m

L = T2 + B
= (3.47) + (5.60)
= 9.07 m

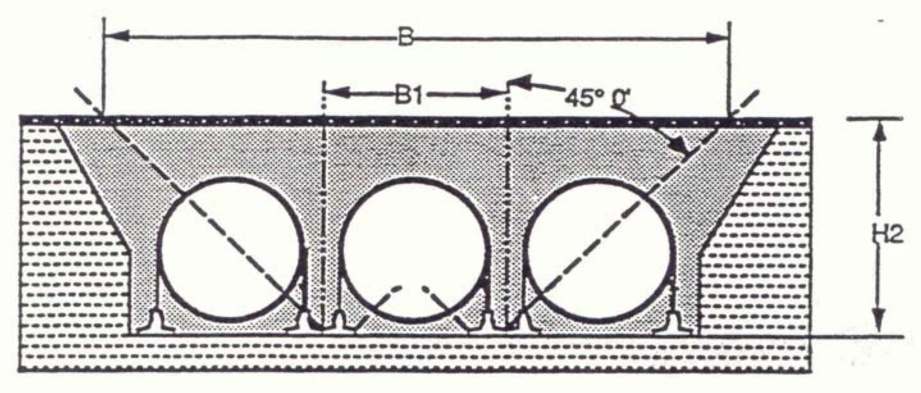
Calculate the volume of the overlap wedge similarly to calculation #1.
$Vol_{Overlap}$ = pyramid =+ wedge
= (1/3)(b)(b)(h) + ½(b)(h)(L-b)
= (0.33)(2.40)(2.40)(1.20) + (0.50)(2.40)(1.20)(9.07 – 2.40)
= 11.89 m^3

Effective Weight of backfill in Overlap Zone =
= 11.89 m^3 x 0.59 Tonne/m^3
= 7.01 Tonnes

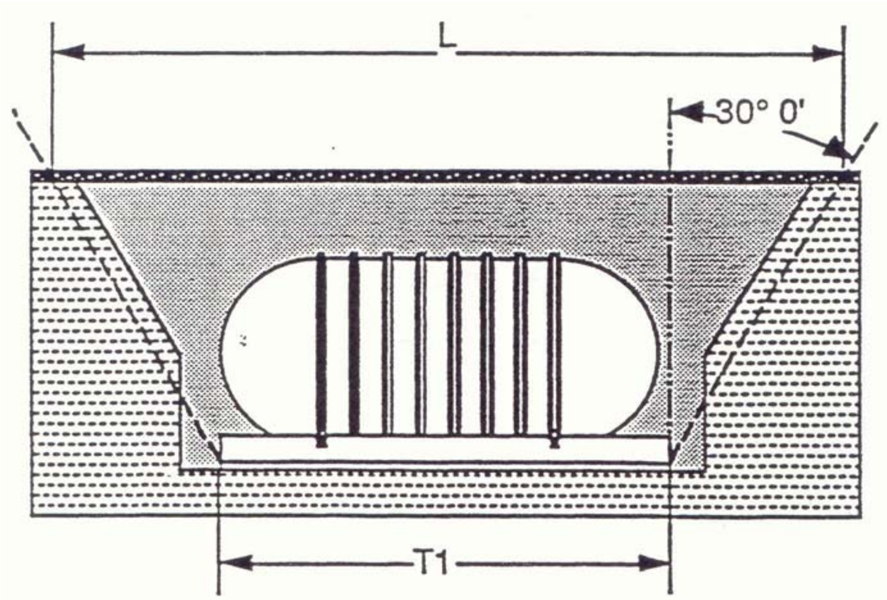
Hold-down Force on central tank = Effective Zone – Overlap
= 29.46 – 7.01
= 22.45 Tonnes

This central tank <u>may lift</u> due to buoyancy forces under a full flood condition.

CASE 3) MULTIPLE TANKS WITH ZCL TANK ANCHOR SYSTEM

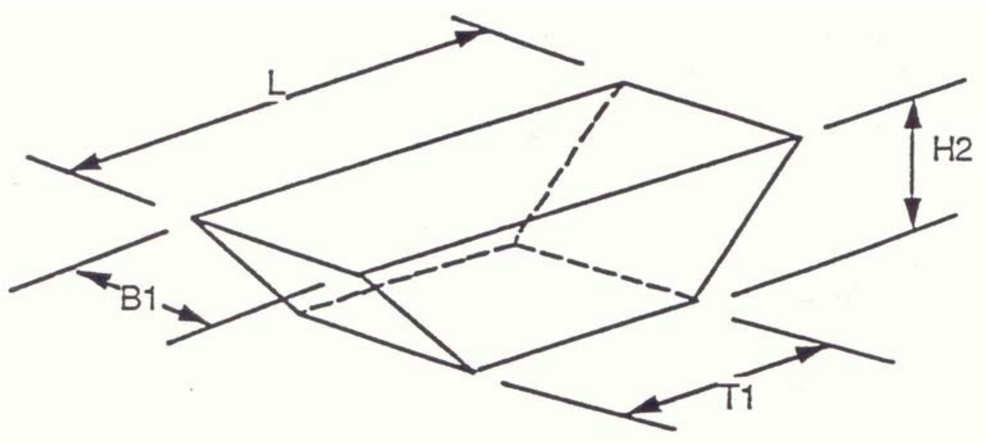


Consider the same multiple tank installation using the ZCL Tank Anchor System. The effective zone now spreads upward and outward from the top of the concrete beams placed below the tanks. In a single tank installation, the effective zone would be defined by the dimensions B and H2. This zone is considerably larger than the equivalent zone for tanks without anchors. For the multiple tank installation, the width of the effective zone is again limited by the overlapping of adjacent zones, and thus is defined by the dimensions B1 and H2. However, this zone is also larger than the tank without anchors.



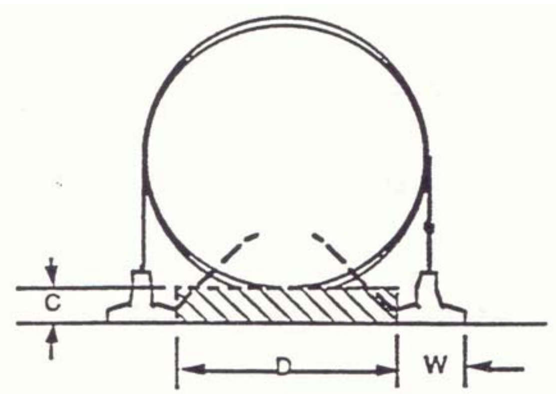
Viewing the installation from the side, it can be seen that the effective zone extends again upward and outward from the top of the Tank Anchors. However, in this case, the effective zone may pass through native soil, which may have a lower angle of internal friction. For design calculations, the angle of the effective zone at the ends of the Tank Anchors is presumed to be 30 degrees.

The volume of the effective zone for the central tank is a multi-tank installation using the ZCL Tank Anchor System can be calculated as a beveled prism, with top surface dimensions L + B1, bottom surface dimensions T1 x B1, and height H2.



VOLUME OF EFFECTIVE ZONE

In calculating the effective weight of this zone, it is necessary to subtract the volume of the tank itself and an additional small volume of material directly beneath the tank which does not form part of the effective zone. To simplify the calculations, this small zone under the tank is approximated by the dimensions shown in the following diagram.



C =thickness of bedding material beneath tanks
= 305.00 mm (min) for all ZCL tanks

D =Diameter of Tank – Width of Tank Anchor

Length of small zone = T1 = Length of Tank Anchor = Length of Tank

And finally, to simplify the calculations further, we will assume that the density of the concrete in the ZCL Tank Anchors is equivalent to that of pea gravel. This will be a conservative assumption because the density of concrete is significantly greater than pea gravel, yet we will ignore this difference in the force calculations.

Sample Calculation #3:

Consider the same multiple tank installation as in Calculation #2, with 1.50 m backfill, installed with ZCL Tank Anchors.

H2 =Depth of Bedding + Diameter of Tank + Depth of Backfill
= .305 m + 2.59 m 1.50 m
= 4.40 m

L = T1 + (2.00)(H2)(sin30)
= 6.06 + (2.00)(4.40)(0.50)
= 10.46 m

D =dia of Tank – width of Tank Anchor
= 2.59 m – 0.61 m
= 1.98 m

Volume of Effective Zone =
=volume of prism – volume of tank – volume of small zone
= (B1)(L)(H2) – ½(B1)(L-T1)(H2) – (Vol_{Tank}) – (C)(D)(T1)
= (3.20)(10.46)(4.40) – (0.50)(3.20)(10.46 – 6.06)(4.40) – (25.00) – (0.305)(1.98)(6.06)
= 87.64 m^3

Weight of Effective Zone =
= 87.64 m^3 + 0.59 Tonne/m^3
= 51.71 Tonnes

This central tank is now secure against upheaval forces.

Sample Calculation #4:

Consider the same situation as Calculation #3, except that the backfill depth is reduced to 0.50 meters.

H2	=	3.40 m
L	=	9.46 m
Vol	=	55.77 m^3
Effective Weight	=	32.90 Tonnes

Use of the ZCL Tank Anchor has allowed the overburden to be reduced by 1.00 meter and yet allows for safer installation.

BACKFILL DEPTH CALCULATIONS FOR ALL ZCL TANKS

Calculations have been done on all models of ZCL Tanks to determine the minimum depth of backfill required to prevent upheaval of the tanks under full flooding conditions. The following table gives the results of these calculations for tanks without anchors, and for tanks using the ZCL Tank Anchor System. The backfill depth given is the minimum depth required such that the weight of the backfill exceeds the upheaval forces by 10%.

NOTE: These are not minimum recommended burial depths. The minimum recommended burial depth is determined by consideration of factors other than just upheaval, such as traffic loads, piping clearances, etc.. Refer to the ZCL Installation Instructions for minimum recommended burial depths for all models of ZCL Tanks.

DEPTH OF BACKFILL TO PREVENT UPHEAVAL OF ZCL TANKS
(Backfill weight exceeds buoyancy forces by 10%)

TANK DESCRIPTION				BACKFILL DEPTH (m)	
Model #	Volume (L)	Diameter (m)	Length (m)	Without Anchors	With ZCL Tank Anchors
Z40-2,500L	2,500	1.22	2.25	0.65	0.00
Z40-5,000L	5,000	1.22	4.22	0.84	0.13
Z60-5,000L	5,000	1.93	2.53	1.01	0.00
Z60-10,000L	10,000	1.93	4.46	1.24	0.00
Z60-15,000L	15,000	1.93	6.40	1.37	0.13
Z60-20,000L	20,000	1.93	8.33	1.45	0.26
Z60-25,000L	25,000	1.93	10.26	1.50	0.35
Z86-10,000L	10,000	2.59	2.97	1.31	0.00
Z86-15,000L	15,000	2.59	3.98	1.53	0.00
Z86-25,000L	25,000	2.59	6.06	1.79	0.20
Z86-35,000L	35,000	2.59	8.14	1.94	0.45
Z86-50,000L	50,000	2.59	11.26	2.10	0.70