Macdonald Campus of McGill University

DESIGN OF AN ICE FORCE ABSORPTION DEVICE IN A MANURE TANK

by

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ABSTRACT

Every farm in few years will need to have their proper manure storage facility. The farmer has to make a choice between solid and liquid manure. For swine production the choice is obvious. As for other productions a majority of farmers choose liquid manure. This liquid manure has to be contained in a sealed reservoir which is capable of storing 250 days of production. The reservoir is made of either concrete or steel. The cost of a concrete reservoir is high but it is less than one made of steel. The price range on such a reservoir may vary from $30 000 to $50 000 depending on its size. The purpose of this project is to analyse a method which could reduce the cost by decreasing the quantity of reinforcement rods needed in such a concrete structure.

an abstract should be more than just an introduction, it should summarize the entire report.

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INTRODUCTION

The last few years the environment has grown in importance in our minds. In fact, the pollution problems have increased with the number and size of industrial and agricultural operations. Public opinion became more and more concerned with water and air pollution. Therefore, the government has no choice to adopt an environmental law which is called "Règlement eau-air-sol".

This legislation states that all new construction or modification of an agricultural structure which has for purpose to increase animal capacity has to conform to this environmental law. This law is not unique to Québec. In fact, Ontario has ~~is~~ its own law and North American States like Vermont and Maine will adopt a similar regulation. In Québec these concrete structures represent a market of 250 units per year. The cost of such a structure varies from 30 000$ to 90 000$. To the farmers, the cost of a concrete tank is much lower than a steel structure which is over $200 000.

OBJECTIVES

The main objective of this project is to reduce the cost of the concrete manure tank. The only way to achieve that goal is to reduce the amount of material used in this construction. The two principal components used are concrete and steel rods. The design calculations for this type of construction are dictated by the American Concrete Institute. It will be possible to observe in the following section that it is not possible to change the thickness of the walls, the only part that can be modified is the amount of steel rods in the concrete.

how about labour costs?

The calculated steel requirement is based on the forces applied in and on the tank. Two major forces are carefully calculated. These are liquid tension and ice tension. It is not possible to reduce liquid tension, but it might be feasible to reduce ice tension. The second objective, is to design a device which is capable of absorbing the ice force. This device would be installed in the reservoir. It would be made of a material which is capable of withstanding liquid pressure but would compress under the additional forces created by the volume expansion in the solidification process. This will hopefully result in an important decrease of stresses in the side walls. The device being compressed by the ice will take the additional volume required in the solidification process. In this project the goal is to establish the preliminary calculations such as the dimension and material to be used.

The main factor would be to find out if the chosen device is cost efficient and how much the farmer could save. After a few months of brainstorming, three major alternatives where retained. They are the absorption membrane, the donut and the noodle type.

METHODS AND RESULTS

Before entering in any detailed calculations, I think that an explanation of exactly what happens during the solidification process is necessary. It is possible to see in figure 1 the typical ice formation in a manure tank.

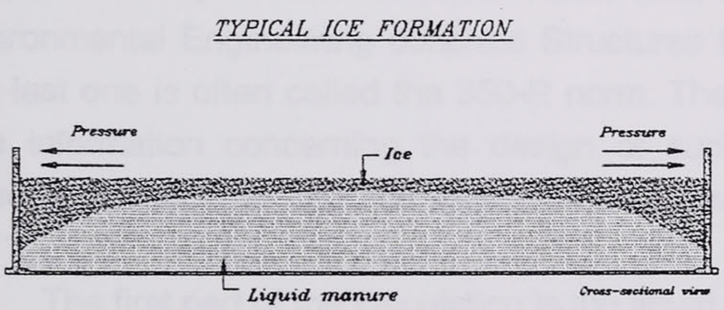


Figure 1

A graduate student from Université Laval, M. Stéphane Godbout, had for objectives in is master studies, the quantification of ice in a manure tank. He has evaluated the thickness of the ice cap to be 0.5 m at the centre. This thickness, from is research, seems to increase as it approaches the walls. The ice thickness near the wall usually covers the entire height of the liquid. The conclusion of his thesis was that the ice tension is very difficult to evaluate in a manure tank. It is caused by the presence in the liquid of many compressive particles such as straw and other organic materials. However, it is possible to say that this kind of ice tension will be less than one with pure water. The only way to establish a certain value is to test this tension on a real manure tank.

M. Godbout is presently doing is P.H.D on the same subject. He has tested the ice behaviour of different reservoirs by placing many compression sensors on the walls of such tanks. The conclusion of those tests are that every manure tank is covered by an ice cap in the winter time. The height of this ice cap varies from one year to another and its thickness can be assumed to be 0.5 m at the centre. The ice pressure on the wall can be evaluated at 75 kpa on the ice thickness. The calculation of the stresses in the wall should take into consideration the ice pressure, since this additional force has been found to be the cause of cracks in many cases.

The purpose of my calculations is first of all to determine the amount of steel (in kg) required for the construction of a tank. The second part is to determine the amount of steel that can be saved (in kg) by reducing or eliminating the ice stresses. With these differences and knowing the price of steel, it will be possible to evaluate the amount of money that can be saved. The results for these different variables are presented in table A, later in this section. Calculations are made on five different reservoir sizes. The sample calculations which are presented in the appendices are done on a 90 feet in diameter by 16 feet in height.

In the following section, the text will often refer to the appendices at the end of this report. All formulas and tables used came from two major publications. These publications are; Circular Concrete Tanks from Portland Cement Association and the Environmental Engineering concrete Structures from the American Concrete Institute. The last one is often called the 350-R norm. These two handbook comprise the up-to-date information concerning the design of such structures. All basic concepts are presented except the ice force section which is not very explicit.

The first part of the calculation is the liquid force as it is possible to see in section 1 and 1-A of the appendices on page 1. The liquid tension depends on the radius and the height of the tank. Since the density of the liquid varies from one tank to another its hydraulic weight is assumed to be the same as water, which is approximately 10 KN/m^3. The forces are applied as a triangular load and to take it into consideration a correction factor, called coeff. A has to be used. Its calculated values can be found in table A-5 on page 10. The maximum pressure is assumed to be applied at 0.4H. The liquid tension has been evaluated to be equal to 306.13 KN per meter of height.

The second part of the ice tension refers to section 1-B on page 2 of the appendices. As explained previously the ice is not uniformly distributed in the tank. To take account of this I take the centre ice thickness 0.5m spread on 3m of height since the tank is never full when it freeze. So the only variable will be the radius of the reservoir. It will be attempted to reduce this 75 kpa of ice pressure with the installation of the device. The calculated ice force came out to be 171.44 KN per meter of height.

For a structure of 12 feet in height the ice force counts for 43% to 48% of the total force on the walls. As for a 16 feet height structure it corresponds to variation of 35% to 37% of the total force if it is assumed that the maximum reservoir diameter is 130 feet.

It is now necessary to combine both forces, liquid and ice, because in winter time those two act together. Is it also in this third part that a safety factor is added to the pressure. The ACI 350-R handbook reads that for both lateral liquid and earth pressure, which is negligible in our case, the safety factor should be taken as 1.7. For sanitary structures such as municipal structures, this factor should be multiplied by 1.3. In this case the 1.7 safety factor will be adequate; the two forces add together and is then multiplied by 1.7 which turns out to be 811.87 KN per meter of height.

The next step is to find the area of steel required. The details of these calculations are presented in section 1-D. The steel recommended should have a tensile strength of 0.4 Gpa or 400 Mpa. This force has to be multiplied by a reduction coefficient of 0.9 since the rods are placed in concrete. The area has been calculated to be 2255 mm^2 for the 90 by 16 feet reservoir which is consider in this report.

Manure tanks are made of reinforced concrete to support tensile and compressive stresses. Those reinforcements are provided by vertical and horizontal rods seen in figure 2.

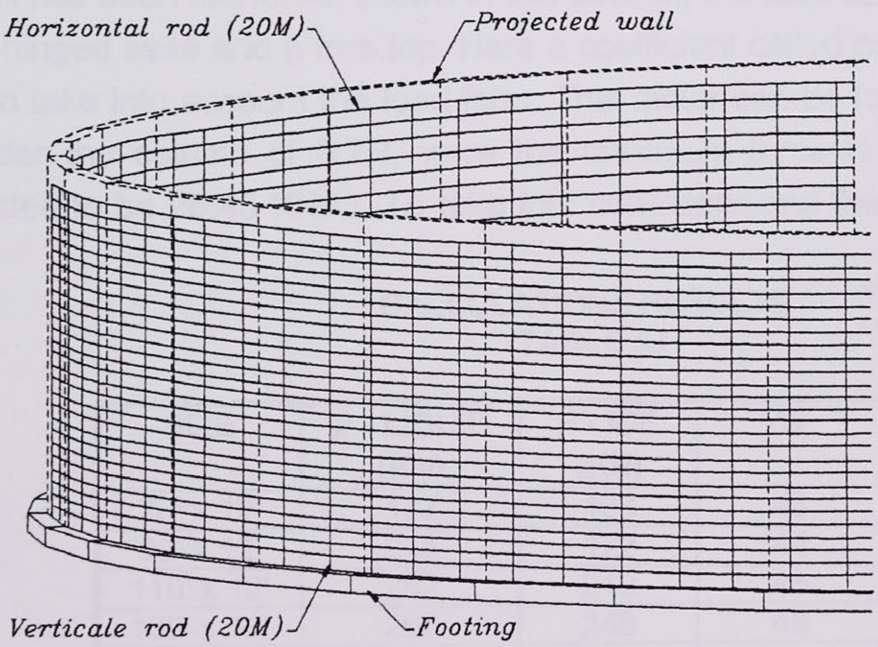


Figure 2 - caption

The number of horizontal rods required is found in section 1-E on page 3 of the appendices. The area of steel required is divided by the cross-sectional area of the bar chosen. This area can be found for a variety of bar in table 1 on page 8. One bar is added to be placed at the bottom of the wall. The bars are then spread all along the height except the first 0.1m which is kept for installation considerations. A concrete cover of 0.1m should be kept above the last rod since this part is used as a security. For a 15M bar it will necessitate 57 bars spread at 84 mm or 3" 5/16 from each other. If a 20M bar is used I will need 38 bars spread at 126 mm or 5" centre to centre will be necessary.

To choose the appropriate bar type. A crack factor has to be verified for both types. Other factors should also be considered in this decision such as the ease of installation. The crack factor (Z) is presented in section 1-F for the 20m bar. From the ACI recommendation the Z factor should be less than 20. This factor represents how large and how fast this crack will occur in concrete. For this case, the crack factor has been found to be 18.76.

The next step is to determine the concrete strength. This part is done with the English units; Two conversion factors are used to transform the metric value to imperial. The required resistance has been found to be 3267 psi then 25 Mpa concrete or 3626 psi will be adequate.

From the ACI 350-R norm the minimum acceptable spacing for vertical rods, to prevent the flexural cracks, is 12 inches or 305 mm. This is to keep the water tightness of the structure. In section 1-H on page 5 of the appendices, the maximum moment in the wall has been found. As shown in this section, the load applied is a trapezoidal one with a hinged base and a free top. Here a coefficient called coeff. B is multiplied by the force to take into account the load form. This factor can be found in table A-1 on page 12 under the column of 0.7H, were the maximum force is applied. The moment is calculated to be 26.45 KN/m. To take into considerations the losses in strength of the

CALCULATIONS RESULTS - use a more descriptive title
(TABLE A)

SIZE	F - LIQUID (KN)	F - ICE (KN)	%	STEEL (Kg)
70' x 12'	177	133	43	5406
90' x 12'	215	172	44	8005
110' x 12'	252	210	45	11075
130' x 12'	266	248	48	14055
90' x 16'	**306**	**171**	**36**	**13150**
110' x 16'	361	210	37	17700
125' x 16'	398	238	37	22721

steel in concrete, a reinforcement should be added. In table 2.3 of page 9 of the appendices, the reinforcement ratio (RO), in percentage, is found to be depending on the concrete strength used and the resistance factor Kr. With those values, the area of steel per meter of circumference can be calculated. Two options were found: Use 15M rods at each 10 inches or 20M rods at 12 inches. It has been decided to use 20M rods for the horizontal as for the vertical rods.

To establish the weight of the steel structure, the total length of rod needed has to be calculated. It is possible to see these calculations in section 1-I of the appendices. All the vertical and horizontal rods have been added together plus the footing reinforcement rods and the tie rods. A 20% factor has also been added to take into consideration the losses due to overlapping. In fact, the ACI recommends an overlap of 10% at each end of the rod. The total length is then multiplied by a linear weight of 2.355 Kg/m for the 20M rod and 1.57 kg/m for the 15M rods. The value for different rod types can be found in table 1 of page 8.

DEVICE ALTERNATIVES

As mentioned previously the main objective is to reduce the ice pressure on the walls. To achieved this objective three alternatives were kept as being feasible. These alternatives are; the absorption membrane, the donut and the noodle type. The reasons for choosing the third alternative and rejecting the other two will be discussed in the following pages.

The first alternative is the absorption membrane shown in figure 3 and 3-2. The concept of this alternative is very easy. A layer of a compressive material such as rubber or an impermeable foam is glued all around the tank. This cushion should be designed to resist to the liquid pressure but will compress when the pressure is greater.

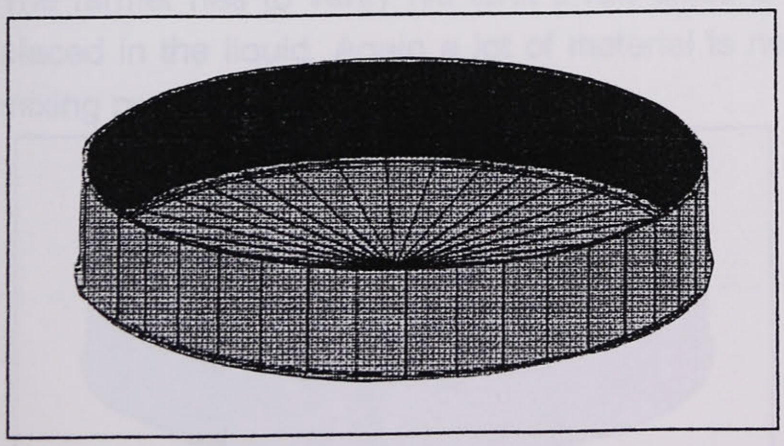
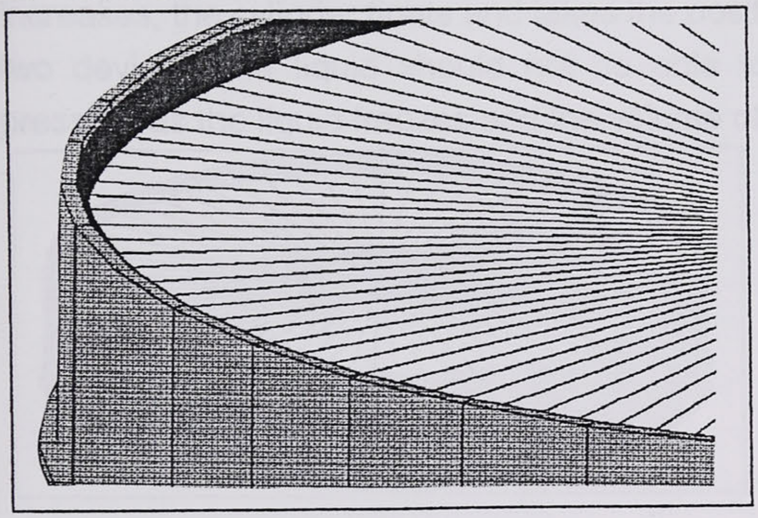
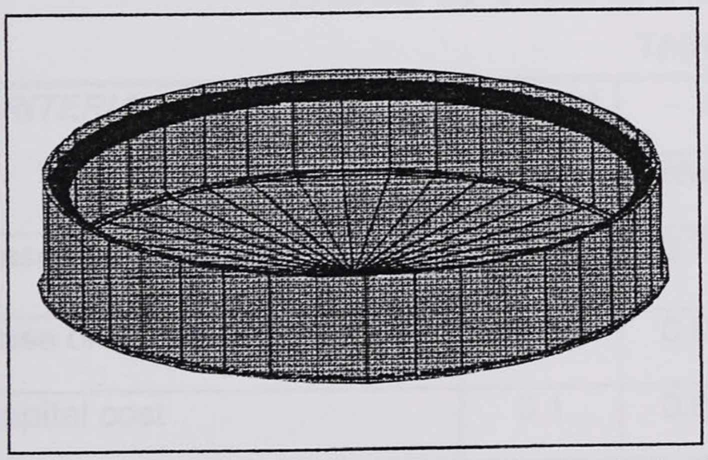


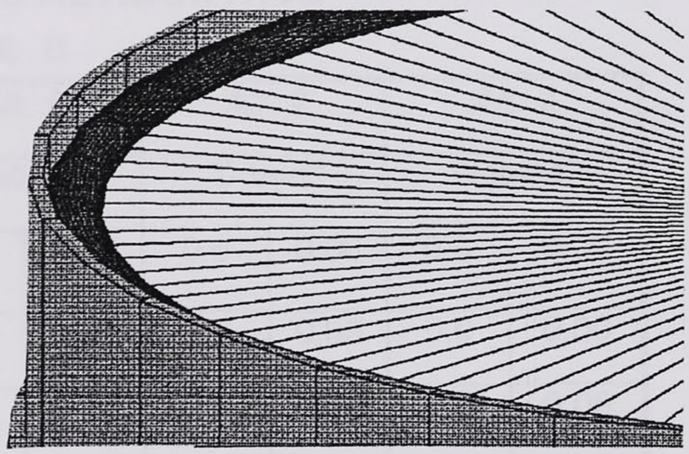
Figure #

The good point of this device is that the operation is very easy and because it is uniformly distributed it will compress equally on all sides. The weak points are that is very long to install and a lot of material has to be used then, the cost efficiency will be difficult to achieve with this type of device. Any material installed around a tank in this fashion can be easily damaged when the time has come to empty the tank. The main reason is that the content of the tank has to be mixed and it is usually done with a large pump. This pump uses the liquid manure as a powerful jet to break up the solids present in the tank.

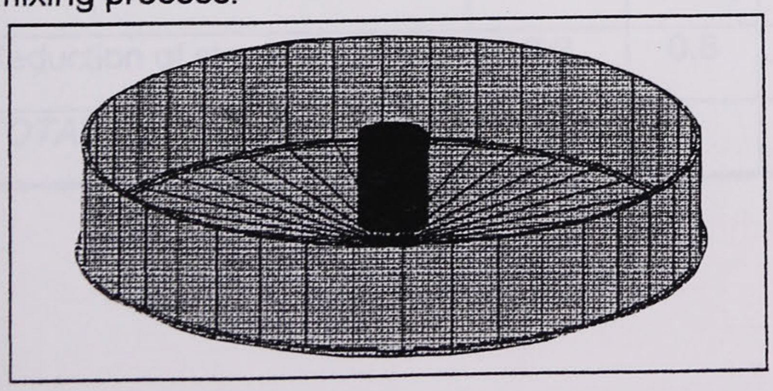


The second alternative shown in figure 4 and 4-2, is based on the first one. A big donut made of rubber is installed all around the reservoir. The strength here again should be calculated to resist to the liquid pressure and compress under additional one. The donut is attach to the top of the manure tank as shown in figure 4-2 with adjustable cables. A mass should also be added into the donut to kept it in the liquid manure.

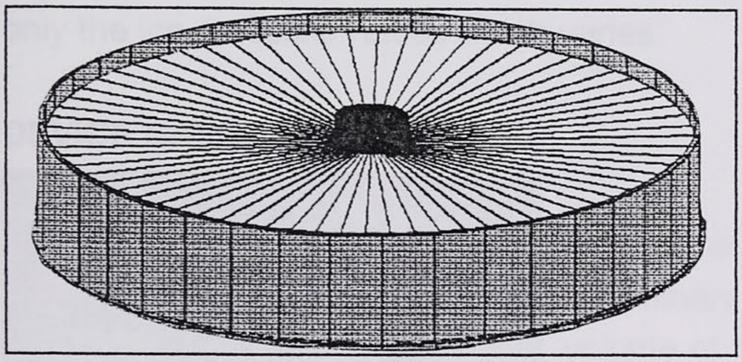




The weak point with this device is that the installation and operation is not easy. The farmer has to verify his tank a few times a week to make sure that it is correctly placed in the liquid. Again a lot of material is needed and it could be damaged in the mixing process.



The third alternative is the noodle type presented in figure 5 and 5-2. This device is easy to install and to operate. A cylinder made of rubber or impermeable foam is attached with a corrosion treated chain at the centre of the reservoir. When the level of liquid increases, the cylinder floats and takes the position shown in those figures. Like the first two devices, the liquid should not be able to compress it except under additional pressure as the liquid freezes and the volume of liquid expands.



The ice pressure should then be sensibly decreased in the walls. It is possible to see the device calculations section that a minimum quantity of material is required. Any risk of damaging the device in the mixing process is almost eliminated. Since this third alternative is placed at the centre of the tank. If this device is as efficient as it seems, it could be a good method of reducing the costs related to such structure.

The criteria of selection and the results of each alternatives are presented in table B.

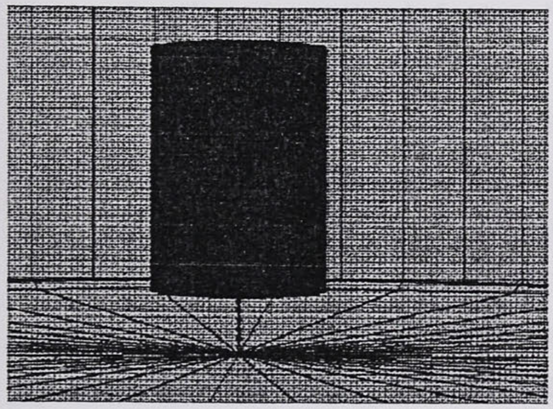
TABLE OF PREFERRED ALTERNATIVE

TABLE B

CRITERIA	***Weight***	***Alt. 1***		***Alt. 2***		***Alt. 3***	
		'Membrane"		***'Donut"***		***'Noodle"***	
Ease of instalation	0.1	0.7	0.07	0.6	0.06	0.9	0.09
Ease of operation	0.1	0.9	0.09	0.5	0.05	0.9	0.09
Capital cost	0.1	0.6	0.06	0.6	0.06	0.8	0.08
Simplicity of design	0.15	0.8	0.12	0.6	0.09	0.8	0.12
Durability	0.15	0.7	0.11	0.6	0.09	0.7	0.11
Reduction of total cost	0.2	0.7	0.14	0.7	0.14	0.8	0.16
Reduction of stress in walls	0.2	0.8	0.16	0.8	0.16	0.7	0.14
TOTAL			**0.75**		**0.65**		**0.79**

Section 1-J and 1-K of the appendices on page 6 presents the calculation concerning the amount of steel required if the ice force could be reduce or eliminate. Table C below shows the difference in weight of steel for five reservoir sizes. It is possible to see in the appendices, that the basics of calculation stays the same. It is only the ice pressure values which varies.

DEVICE CALCULATION



One of the objectives was to perform the preliminary calculations for the device. In fact, the volume of the cylinder to be prepared for field tests will be evaluated. Section 2 on page 7 of the appendices shows the calculations performed. The ice volume is found to be 295.5 cubic meter. The expansion during solidification for manure is unknown. It is known that the volumetric expansion of water when freezing is 9%. In these calculations, it was assumed that the volume increased by 7%. This expansion occurs on all sides of the ice block. In these calculations just the lateral expansion is important. The lateral is found to be 3.5% of the total expansion or 3.5% of 21 cubic meter. With a safety factor of 2, it results in a noodle of 1.5 cubic meter. The cylinder should have a length of 3m to correctly cover the top part of the reservoir. The first two feet can be safely neglected.

FINANCIAL IMPACT

The main objective of this project is to find a way to reduce the manure reservoir cost. By adding a device in the tank, the amount of steel required in the construction of

TABLE OF STEEL AND MONEY DIFFERENCE
(TABLE C)

SIZE	75%	STEEL	*$$$$$*	100%	STEEL	*$$$$$*
		Diff. (Kg)	*SAVED*		Diff. (Kg)	*SAVED*
70' x 12'	4810	596	*477*	4096	1310	*1048*
90' x 12'	6936	1069	*855*	5715	2290	*1832*
110' x 12'	9398	1677	*1342*	7721	3354	*2683*
130' x 12'	11744	2311	*1849*	9433	4622	*3698*
90' x 16'	**11735**	**1415**	***1132***	**10132**	**3018**	***2414***
110' x 16'	15721	1979	*1583*	13486	4214	*3371*
125' x 16'	20182	2539	*2031*	17324	5397	*4318*

such a tank can be reduced. This will also reduce the total cost. To find by how much those prices can be decreased, the price of steel has to be established. Contractors such as Construction Acton Vale Ltee. or Construction BRN have been contacted to establish an average price paid by these companies. The price varies significantly depending on the period of year or the length of bars purchased. Even with such fluctuations a conservative price of 0.80 $/kg was obtained.

Another important factor that I can't compile here is the time saved by the contractor. In fact, if 30% to 40% less steel is used it is going to decrease by the same amount the time to complete the steel structure. It represents a large amount of money if the contractor uses five workers at twelve dollars per hour. Considering this factor a price for this device was not included. This means that the contractor could include the costs of this device in is total construction costs. The time saved by its installation will pay for the device costs. Then the amount saved by the farmer will be in the steel costs. By looking in table C it is possible to see the money saved for different reservoir sizes. This table is also divided in two parts which are 50% and 100% ice force reduction. For the size of tank used in this paper the amount saved is 1132 $ for 50% up to 2414 $ for 100% ice force reduction.

DISCUSSION

For a large diameter reservoir the noodle type can be quite interesting. It is possible to see in table C that the difference between using the device or not can be over 4000$. For this kind of construction and investment a difference of 1000$ should be the psychological barrier to look at different alternatives. The farmer will probably not be interested if this device ~~can't saved~~ cannot save him more than 1000$.

The use of this device, should be recommended in reservoirs larger than 90 feet in diameter. It could also be very important in the construction of super structure. Engineers do not have to design very often structures larger than 140 or 150 feet in diameter. With the use of such devices, those super structures could be more affordable for farmers. To be cost efficient the device should reduce the ice force by about 90%. Bellow that value it will be difficult to justify the use of that kind of device.

It has been calculated that for a 90 feet by 12 feet tank, the absorption noodle should have a volume of 1.5m^3. This addition in volume will not affect the dimension of the structure since those tanks are always designed with a security of at least 15m³. The device can be made of different materials. It as to be easily compressible and take back its initial form in the spring. The material has to be resistant and cheap so as to have a long life span. A few examples of material that could be used are an impermeable foam or a rubber cylinder made of recycle tires.

CONCLUSION

It is possible to conclude that the objectives were met. Three alternatives were retained to reduce construction costs of manure tank by decreasing the ice pressure. Then calculations were performed to establish preliminary requirements such as volume and efficiency of such a design. The only sure way to establish the final parameters and discover whether this device could be viable, is to test it on a real reservoir.

To accomplish such a device it should be constructed with the given parameters. Then it should be installed in a reservoir equipped with compression sensor on the side walls. Enough data should then be collected from different tank to establish a good average. These results will enable to assess the needs for the device and on how to proceed. Even though the concept is not very well known and tested, it still remains a good costs related to such structures.

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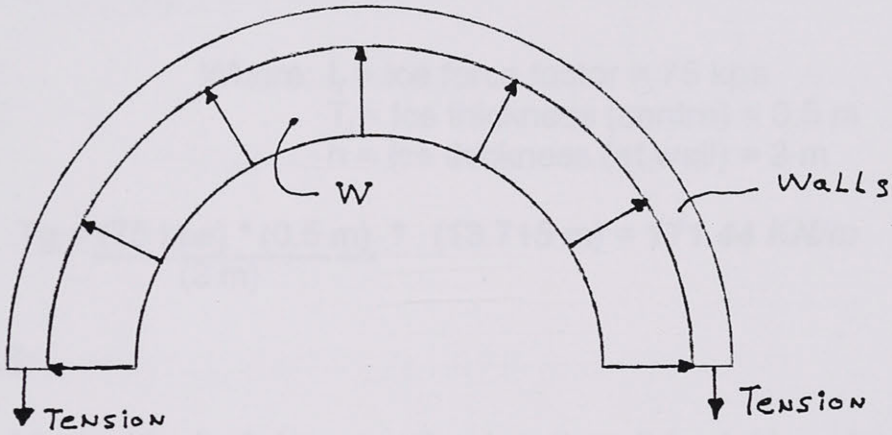
APPENDICES

1- TENSION IN CIRCULAR WALL:

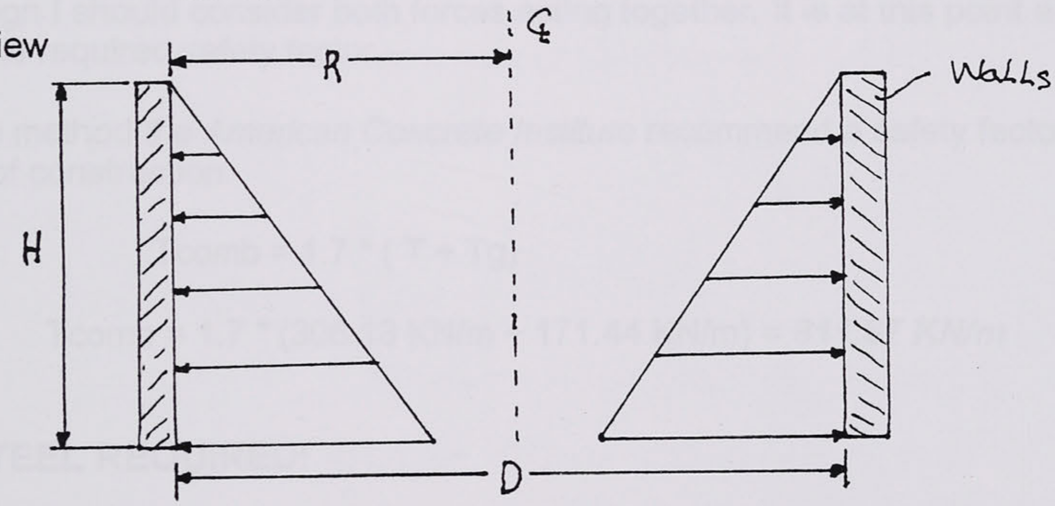
In those calculation examples I will analyse the structure of a typical manure tank size which is:

Diameter = D = 27.43m (90')
Height = H = 4.88m (16')
Thickness = T = 0.254m (10")

Top view of stresses:



Cross-sectional view



A) LIQUID TENSION

Assume: Triangular load, hinged base-free top

Tension T = (Coeff.A) * (W) * (H) * (R)

Where W = Hydraulic weight

Assume water: **W** = 1000 kg/m^3 * 9.8 n/kg = 9800 N/m^3 = **10 KN/m^3**

From table A-5 H^2/DT = $4.88^2/(27.43*0.254)$ = **3.42**

Coeff.A at 3.42 and 0.4H is equal to **0.4574**

Then T = (0.4574) * (10 KN/m^3) * (4.88m) * (13.715m) = ***306.13 KN/m***

Here the tension is obtained per meter of height

B) ICE TENSION:

$$Tg = \frac{(I_f) * (T_i)}{(h)} * (R)$$

Where: I_f = Ice force factor = 75 kpa
T_i = Ice thickness (centre) = 0.5 m
h = Ice thickness (at wall) = 3 m

Then $$Tg = \frac{(75\ kpa) * (0.5\ m)}{(3\ m)} * (13.715\ m) = \mathbf{171.44\ KN/m}$$

C) COMBINED FORCES:

In the design I should consider both forces acting together. It is at this point also that I introduce the required safety factor.

As explain in the method the *American Concrete Institute* recommend a safety factor of 1.7 for that type of construction.

Tcomb = 1.7 * (T + Tg)

Tcomb = 1.7 * (306.13 KN/m + 171.44 KN/m) = ***811.87 KN/m***

D) AREA OF STEEL REQUIRED:

$$As = \frac{Tcomb}{(Steel\ resistance) * (Concrete\ reduc.coeff.)}$$

Where: Sresist. = 400 Mpa = 0.4 Gpa
Red. coeff. = 0.9

$$As = \frac{811.87\ KN/m}{(0.4) * (0.9)} = \mathbf{2255\ mm^2/m}$$ (of height)

2255 mm^2/m * 4.88m = 11004 mm^2

E) NUMBER OF 15M HORIZONTAL BAR REQUIRED and SPACING

Number of bar = (Area needed / Bar cross-sect. area) + 1
Cross-sect. area can be founded in table 1

Number of bar = (11004 mm^2 / 200 mm^2) + 1 = **57 bars**

For the spacing:

Sp = h / (Number of bar -1)

Where h = Height (mm) - SF - remaining

h = 4880 mm -100 mm -100 mm = 4680 mm

Sp = 4680mm / (57 -1) = **84 mm or 3" 5/16**

NUMBER OF 20M HORIZONTAL BAR REQUIRED and SPACING

Number of bar = (Area needed / Bar cross-sect. area) + 1
Cross-sect. area can be founded in table 1

Number of bar = (11004 mm^2 / 300 mm^2) + 1 = **38 bars**

For the spacing:

Sp = h / (Number of bar -1)

Where h = Height (mm) - SF - remaining

h = 4880 mm -100 mm -100 mm = 4680 mm

Sp = 4680mm / (38 -1) = **126 mm or 5"**

For convenience explain in the method the 20M bars will be more efficient.

F) CRACK FACTOR (Z):

The crack factor and crack width are function of concrete cover and bar spacing.

$$Z = \frac{Fy * Fi}{1.5} * \frac{\text{As required (H)}}{\text{As given}} * \sqrt[3]{2 * Dc^2 * Sp}$$

Where : Dc= concrete cover = 50 mm
Fi = constant = 0.85

Fy = Steel resistance = 0.4 Gpa

$$Z = \frac{0.4 * 0.85}{1.5} * \frac{11004\ mm^2}{11400\ mm^2} * \sqrt[3]{2 * 50^2 * 126\ mm}$$

Z = **18.76 < 20**

As explain in the method the crack factor should be less than 20

<u>Conclusion of this part:</u> *38 bars of 20M at 126 mm (5") will be adequate*

G) CONCRETE RESISTANCE:

(for 1 feet of wall)
Ac = Area of concrete = thickness * 12 in = 10" * 12" = 120 in^2
As = Area of steel = 2255 mm^2 * 0.0004723 = 1.065 in^2
Tmax = (306.13 KN/m + 171.44 KN/m) * 68.522 = 32754 psi

Where 0.0004723 and 68.522 are conversion factor

$$F_{concrete} = \frac{((8700 * As) + Tmax)}{(Ac + (8 * As))} * 10$$

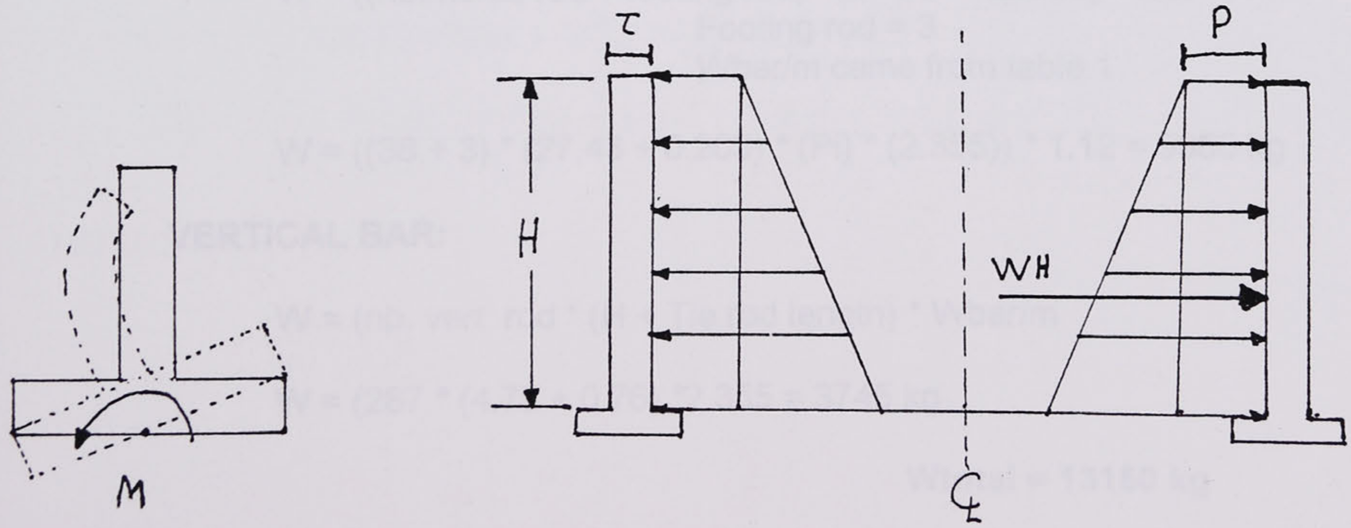
$$F_{concrete} = \frac{((8700 * 1.065) + 32754)}{(120\ in^2 + 8\ (1.065\ in^2))} = 326.72 * 10 = \mathbf{3267\ psi < 3626\ psi}$$

3626 psi = 25 Mpa. *Then 25 Mpa concrete will be adequate*

H) VERTICAL BARS:

As explain in the method the maximum acceptable spacing between vertical rod is 12".

Distribution of the forces in the wall



Moment in cylindrical wall (trapezoidal load, hinged base-free top)

$M = SF * (Coeff.B * W * H^2)$

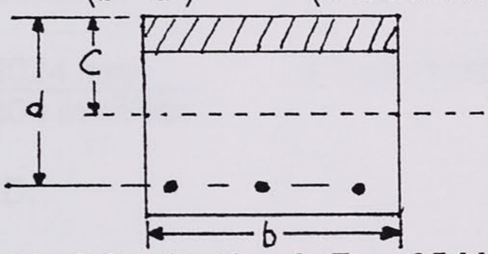
For coeff.B $\quad H^2 / DT = 3.42$

In table A-7 for 3.42 at 0.7H coeff.B = 0.01339

$M = 1.7 * (0.01339 * 10 * 4.88^2) = 26.45$ KN/m

Reinforcement ratio RO (%) For resistance factor Kr (Mpa)

$$Kr = \frac{Mr\,(10^6)}{(b * d^2)} = \frac{26.45 \text{ KN/m}}{(1000 \text{ mm/m} * 0.115^2 \text{mm})} = 2$$



From table 2.3 with Kr = 2, Fc = 25 Mpa, RO = 0.64%

As = 0.0064 * 1000 mm/m * 115 mm = **736mm²/m**

Two option: 15M at 254 mm (10") = 787 mm²/m
20M at 300 mm (12") = 984 mm²/m

For reasons given in the method the best choice will be:
20M at 300 mm (12")

I) WEIGHT OF STEEL REQUIRED:

HORIZONTAL BAR:

W = ((nb. horiz. rod + footing rod) * D * Pi * Wbar/m) * lost
Footing rod = 3
Wbar/m came from table 1

W = ((38 + 3) * (27.43 + 0.203) * (Pi) * (2.355)) * 1.12 = 9388 kg

VERTICAL BAR:

W = (nb. vert. rod * (H + Tie rod length) * Wbar/m

W = (287 * (4.78 + 0.76) *2.355 = 3745 kg

Wtotal = 13150 kg

J) STEEL REQUIRED IF THE ICE FORCE IS REDUCED BY 50%

The new ice force will be 171 KN/m * 0.5 = 85.5 KN/m

From there the procedure is the same as section B, C, D

T = 306 KN/m
Tg = 85.5 KN/m

Tcomb = 1.7 * (306 +85.5)KN/m = 665.6 KN/m

$$As = \frac{665.6 \text{ KN/m}}{(0.4 * 0.9)} = 1849 \text{ mm}^2\text{/m} * 4.88 \text{ m} = \mathbf{9024 \text{ mm}^2}$$

HORIZONTAL ROD:

$$\frac{9024 \text{ mm}^2}{300 \text{ mm}^2\text{/bar}} + 1 \text{ bar} = \mathbf{32 \text{ bars}}$$

KG REQUIRED:

Same as procedure I

I have found that I will need **11735 kg**

K) STEEL REQUIRED IF THE ICE FORCE IS REDUCED BY 100%

The new ice force will be 0 KN/m

From there the procedure is the same as section B, C, D

T = 306 KN/m
Tg = 0 KN/m

Tcomb = 1.7 * (306 +0)KN/m = 520.2 KN/m

$$As = \frac{520.2 \text{ KN/m}}{(0.4 * 0.9)} = 1445 \text{ mm}^2\text{/m} * 4.88 \text{ m} = \mathbf{7052 \text{ mm}^2}$$

HORIZONTAL ROD:

$$\frac{7052 \text{ mm}^2}{300 \text{ mm}^2\text{/bar}} + 1 \text{ bar} = \mathbf{25 \text{ bars}}$$

KG REQUIRED:

Same as procedure I

I have found that I will need **10132 kg**

2- DEVICE CALCULATIONS:

For my example the ice volume will be

$$Vg = Pi * R^2 * Hg$$

Where Hg = Ice thickness = 0.5 m

$$Vg = Pi * (13.715\ m)^2 * 0.5m$$

$$Vg = \mathbf{295.5\ m^3}$$

Assume volume increase by 7%

$$Vi = 295.5\ m^3 * 0.07 = \mathbf{21\ m3}$$

Assume that the 7% increase occur equally on all sides on the ice cylinder so that the only interesting part for my design is the lateral expansion.

$$Ae = \text{Lateral area / total area}$$

$$Ae = (2 * Pi * R * H) / ((2 * Pi * R * H) + (2 * (Pi * R^2)))$$

$$Ae = (2 * Pi * 13.715m * 0.5m)/((2 * Pi * 13.715m * 0.5m) + (2 * Pi * 13.715^2 m))$$

$$Ae = \mathbf{0.035}$$

The lateral expansion will be 3.5% of the total one so:

$$21\ m^3 * 0.035 = 0.735\ m^3$$

A **SF of 2** should be enough for that type of installation.

Which gives me a noodle of **1.5 m³**.

3. Ordering Information

3.1

For specifying or ordering purposes, the full description for steel bars for concrete reinforcement shall be provided. This includes reference to
(a) CSA designation, ie, G30.18-M92; and
(b) Grade designation, including
  (i) yield strength level (300, 400, or 500), and
  (ii) chemical composition type (R or W), eg, G30.18-M92 Grade 400R; or G30.18-M92 Grade 500W.

Note: *Failure to include the grade for bars will result in the supply of Grade 400R reinforcing bars. Failure to include the chemical composition type (R or W) with the yield strength level will result in the supply of regular (R) reinforcing bars.*

4. General Requirements

4.1

A deformed bar is defined as a bar which is intended for use as reinforcement in reinforced concrete construction. The surface of the bar is provided with lugs or protrusions (hereinafter called "deformations"). The deformations inhibit longitudinal movement of the bar relative to the concrete which surrounds the bar in such construction and conform to the provisions of this Standard. The standard sizes and their number designations shall be those listed in Table 1.

Table 1
Deformed Bar Designation Numbers*, Nominal Dimensions†, Unit Masses, and Deformation Requirements

	Nominal dimensions				Deformation requirements, mm		
Bar designation number	Cross-sectional area, mm^2	Diameter, mm	Perimeter, mm	Mass (weight) per unit length, kg/m	Maximum average spacing	Minimum average height	Maximum gap chord of 12.5% of nominal perimeter
10	100	11.3	35.5	0.785	7.9	0.45	4.4
15	200	16.0	50.1	1.570	11.2	0.72	6.3
20	300	19.5	61.3	2.355	13.6	0.98	7.7
25	500	25.2	79.2	3.925	17.6	1.26	9.9
30	700	29.9	93.9	5.495	20.9	1.48	11.7
35	1000	35.7	112.2	7.850	25.0	1.79	14.0
45	1500	43.7	137.3	11.775	30.6	2.20	17.2
55	2500	56.4	177.2	19.625	39.4	2.55	22.2

**Bar numbers are based on the nominal diameter of the bars in millimetres.*
†The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass per metre as the deformed bar.

4.2

Hot-rolled plain rounds in straight bars and in coils in sizes from 50 mm^2 (8 mm diameter) to 500 mm^2 (25 mm diameter) shall be furnished under this Standard in Grades 300R, 400R and 500R. Bending properties and test provisions of the nearest nominal diameter

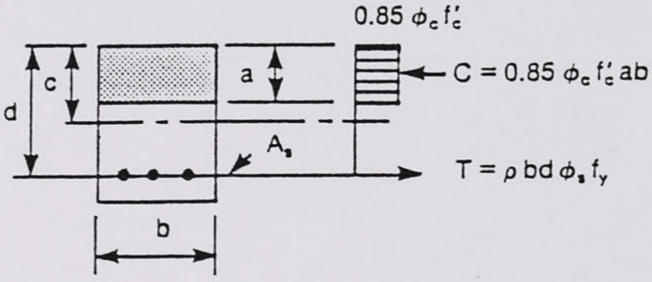
BARRE VERTICALE

Table 2.3
Rectangular Beams
Reinforcement Ratio ρ (%) for Resistance Factors K_r (MPa)
Reinforcement $f_y = 400$ MPa

K_r (MPa)	f'_c	20	25	30	35	40
0.5		0.15	0.15	0.15	0.15	0.15
0.6		0.18	0.18	0.18	0.18	0.18
0.7		0.21	0.21	0.21	0.21	0.21
0.8		0.25	0.24	0.24	0.24	0.24
0.9		0.28	0.27	0.27	0.27	0.27
1.0		0.31	0.31	0.30	0.30	0.30
1.1		0.34	0.34	0.34	0.33	0.33
1.2		0.38	0.37	0.37	0.37	0.36
1.3		0.41	0.40	0.40	0.40	0.40
1.4		0.44	0.44	0.43	0.43	0.43
1.5		0.48	0.47	0.47	0.46	0.46
1.6		0.51	0.50	0.50	0.49	0.49
1.7		0.55	0.54	0.53	0.53	0.52
1.8		0.59	0.57	0.56	0.56	0.56
1.9		0.62	0.61	0.60	0.59	0.59
2.0		0.66	0.64	0.63	0.63	0.62
2.1		0.70	0.68	0.67	0.66	0.65
2.2		0.74	0.72	0.70	0.69	0.69
2.3		0.78	0.75	0.74	0.73	0.72
2.4		0.82	0.79	0.77	0.76	0.75
2.5		0.86	0.83	0.81	0.80	0.79
2.6		0.90	0.86	0.84	0.83	0.82
2.7		0.94	0.90	0.88	0.87	0.86
2.8		0.99	0.94	0.92	0.90	0.89
2.9		1.03	0.98	0.95	0.94	0.92
3.0		1.07	1.02	0.99	0.97	0.96
3.1		1.12	1.06	1.03	1.01	0.99
3.2		1.17	1.10	1.07	1.05	1.03
3.3		1.22	1.15	1.11	1.08	1.07
3.4		1.27	1.19	1.15	1.12	1.10
3.5		1.32	1.23	1.19	1.16	1.14
3.6		1.37	1.28	1.23	1.19	1.17
3.7		1.43	1.32	1.27	1.23	1.21
3.8		1.49	1.37	1.31	1.27	1.25
3.9			1.41	1.35	1.31	1.28
4.0			1.46	1.39	1.35	1.32
4.2			1.56	1.48	1.43	1.40
4.4			1.66	1.57	1.51	1.48
4.6			1.77	1.66	1.60	1.55
4.8			1.89	1.75	1.68	1.63
5.0				1.85	1.77	1.72
5.2				1.95	1.86	1.80
5.4				2.06	1.95	1.88
5.6				2.17	2.05	1.97
5.8				2.29	2.14	2.06
6.0					2.24	2.15
6.2					2.35	2.24
6.4					2.46	2.34
6.6						2.44
6.8						2.54
7.0						2.64
7.2						2.75
7.4						

$$K_r = \frac{M_f\,10^6}{bd^2} = \rho\,\phi_s f_y\left[1 - \frac{\rho\,\phi_s f_y}{1.7\,\phi_c f'_c}\right]$$

$$\rho = \frac{A_s}{bd}$$



$$\rho = \frac{K_R}{\phi_s f_y\left[1 - \frac{\rho\,\phi_s F_y}{1.7\,\phi_c f'_c}\right]}$$

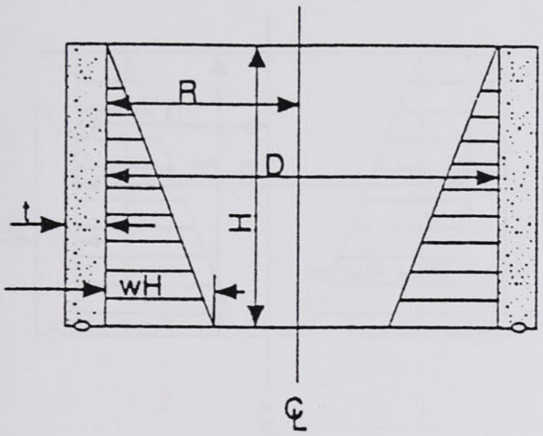


Table A-5— Tension in circular rings

T = coef. × wHR lb per ft
Positive sign indicates tension

	Coefficients at point									
$\frac{H^2}{Dt}$	0.0H	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H
0.4	+0.474	+0.440	+0.395	+0.352	+0.308	+0.264	+0.215	+0.165	+0.111	+0.057
0.8	+0.423	+0.402	+0.381	+0.358	+0.330	+0.297	+0.249	+0.202	+0.145	+0.076
1.2	+0.350	+0.355	+0.361	+0.362	+0.358	+0.343	+0.309	+0.256	+0.186	+0.098
1.6	+0.271	+0.303	+0.341	+0.369	+0.385	+0.385	+0.362	+0.314	+0.233	+0.124
2.0	+0.205	+0.260	+0.321	+0.373	+0.411	+0.434	+0.419	+0.369	+0.280	+0.151
3.0	+0.074	+0.179	+0.281	+0.375	+0.449	+0.506	+0.519	+0.479	+0.375	+0.210
4.0	+0.017	+0.137	+0.253	+0.367	+0.469	+0.545	+0.579	+0.553	+0.447	+0.256
5.0	-0.008	+0.114	+0.235	+0.356	+0.469	+0.562	+0.617	+0.606	+0.503	+0.294
6.0	-0.011	+0.103	+0.223	+0.343	+0.463	+0.566	+0.639	+0.643	+0.547	+0.327
8.0	-0.015	+0.096	+0.208	+0.324	+0.443	+0.564	+0.661	+0.697	+0.621	+0.386
10.0	-0.008	+0.095	+0.200	+0.311	+0.428	+0.552	+0.666	+0.730	+0.678	+0.433
12.0	-0.002	+0.097	+0.197	+0.302	+0.417	+0.541	+0.664	+0.750	+0.720	+0.477
14.0	0.000	+0.098	+0.197	+0.299	+0.408	+0.531	+0.659	+0.761	+0.752	+0.513
16.0	+0.002	+0.100	+0.198	+0.299	+0.403	+0.521	+0.650	+0.764	+0.776	+0.536

Supplemental Coefficients

	Coefficient at point				
$\frac{H^2}{Dt}$	.75H	.80H	.85H	.90H	.95H
20	+0.812	+0.817	+0.756	+0.603	+0.344
24	+0.816	+0.839	+0.793	+0.647	+0.377
32	+0.814	+0.861	+0.847	+0.721	+0.436
40	+0.802	+0.866	+0.880	+0.778	+0.483
48	+0.791	+0.864	+0.900	+0.820	+0.527
56	+0.781	+0.859	+0.911	+0.852	+0.563

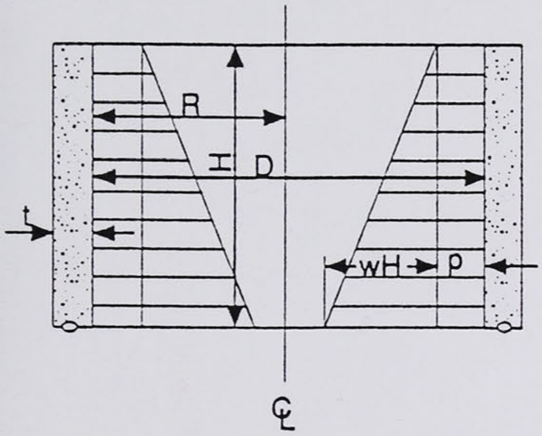


Table A-7— Moments in cylindrical wall

Mom. = coef. × $(wH^3 + pH^2)$ ft-lb per ft
Positive sign indicates tension in the outside

	Coefficients at point									
$\frac{H^2}{Dt}$	0.1H	0.2H	0.3H	0.4H	0.5H	0.6H	0.7H	0.8H	0.9H	1.0H
0.4	+.0020	+.0072	+.0151	+.0230	+.0301	+.0348	+.0357	+.0312	+.0197	0
0.8	+.0019	+.0064	+.0133	+.0207	+.0271	+.0319	+.0329	+.0292	+.0187	0
1.2	+.0016	+.0058	+.0111	+.0177	+.0237	+.0280	+.0296	+.0263	+.0171	0
1.6	+.0012	+.0044	+.0091	+.0145	+.0195	+.0236	+.0255	+.0232	+.0155	0
2.0	+.0009	+.0033	+.0073	+.0114	+.0158	+.0199	+.0219	+.0205	+.0145	0
3.0	+.0004	+.0018	+.0040	+.0063	+.0092	+.0127	+.0152	+.0153	+.0111	0
4.0	+.0001	+.0007	+.0016	+.0033	+.0057	+.0083	+.0109	+.0118	+.0092	0
5.0	.0000	+.0001	+.0006	+.0016	+.0034	+.0057	+.0080	+.0094	+.0078	0
6.0	.0000	.0000	+.0002	+.0008	+.0019	+.0039	+.0062	+.0078	+.0068	0
8.0	.0000	.0000	-.0002	.0000	+.0007	+.0020	+.0038	+.0057	+.0054	0
10.0	.0000	.0000	-.0002	-.0001	+.0002	+.0011	+.0025	+.0043	+.0045	0
12.0	.0000	.0000	-.0001	-.0002	.0000	+.0005	+.0017	+.0032	+.0039	0
14.0	.0000	.0000	-.0001	-.0001	-.0001	.0000	+.0012	+.0026	+.0033	0
16.0	.0000	.0000	.0000	-.0001	.0002	-.0004	+.0008	+.0022	+.0029	0

Supplemental Coefficients

	Coefficient at point				
$\frac{H^2}{Dt}$	.75H	.80H	.85H	.90H	.95H
20	+.0008	+.0014	+.0020	+.0024	+.0020
24	+.0005	+.0010	+.0015	+.0020	+.0017
32	.0000	+.0005	+.0009	+.0014	+.0013
40	.0000	+.0003	+.0006	+.0011	+.0011
48	.0000	+.0001	+.0004	+.0008	+.0010
56	.0000	.0000	+.0003	+.0007	+.0008