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USAGE OF CONCRETE FOR FARM BUILDINGS AND MANURE STORAGES; SPECIFICATIONS, DURABILITY AND PRACTICAL CONSIDERATIONS

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ABSTRACT The Canadian standard association has published a 2004 revision of the A23.1, A23.2, A23.3 and A23.4 standards for the selection and design of concrete structures. In this latest edition, the CSA A23.1 has defined four classes of usage for the selection of the concrete constituents.
The latest standards for concrete require higher compressive strength, lower water/cement ration and other specifications. Consequently, the basic cost for concrete is increased by 15 % to 25 % from the cost concrete traditionally used for farm buildings and manure storages in Quebec.
Over 400 manure storage and barn floor inspection reports have been analysed in order to evaluate the real situation or problems related to practical farm construction projects. The objectives are: 1) to identify the problems related with concrete deterioration, 2) present the design considerations for the expected life of a concrete structure and 3) present practical recommendations for farm buildings.
Keywords: Concrete structure, farm buildings, manure storage.

INTRODUCTION Livestock production is the main agricultural activity in the province of Quebec, Canada. Since the early 1980s, livestock producers have built numerous storage structures for liquid and solid manure. Most liquid manure is stored in circular concrete tanks and solid manure is stored in platforms or rectangular storages of various shapes. The evolution of design methods for these storages led to the writing of the "manuel d'ingénierie 1992" (CPVQ-MAPAQ, 1992) engineering design manual. This manual specifies the appropriate loads, specific design equations for the sizing of the structure and for adequate concrete design work. The article 11.4.3.1 calls for the respect of the following three standards:

- "Concrete materials and methods of concrete construction / test methods and standard practices" by the Canadian Standards Association A23.1/A23.2, latest edition
- "Requirements for environmental engineering concrete structures and commentary", ACI-350 and related, by the American Concrete Institute, latest edition.

The basic design equations to respects must originate from “Circular concrete tanks without prestressing”, Portland Cement Association, ISO 72 and related, latest edition.

In the CPVQ-MAPAQ 1992 engineering manual, article 11.4.3.1.2 and 11.4.3.1.3 specify minimum requirements for concrete floors, foundations and walls. A regular concrete with a minimum compressive strength of 25 MPa at 28 days is required. This type of concrete is easily available in rural Quebec at a reasonable cost, making it feasible for agricultural producer to build manure storage structures.

The CPVQ-MAPAQ 1992 engineering manual proposed a very comprehensive table for adequate site supervision and quality control program (table 12.1) of manure storage construction. Although promoted, site supervision and quality control has been neglected; which contributed to most structure failures and law suits. From 1988 to 1992, MAPAQ, Service du Génie (1988-1992), produced a series of standard plans for circular, rectangular, covered and earthen manure storage structures (series 20700 and +). These standard plans called for 30 MPa concrete at 28 days.

Since 1980, generally, agricultural engineers in Quebec were using 25 MPa concrete for almost all manure storages.

In Ontario, the Ontario Ministry of Agriculture, Food and Rural Affaires (OMAFRA) produced a series of manure storage plans. The design was performed by Dr. Jan Jofriet, P. Eng., University of Guelph and five basics plans were made public in 1992. The concrete construction and workmanship had to be conform to standard specification CSA-CAN A23.1-M90. All structural concrete had 28 days compressive strength of 30 MPa, a minimum water ratio of 0.5 and 4.5 % ± 1 % of air entrained. The reinforcing steel had to be grade 400 conforming to the latest CSA standard G30.12.

Luymers (1996) produced an agricultural waste storage plan for the British Columbia Plan Service. This plan required a 28 day compressive strength of 25 MPa. The other BC manure storage plans are designed with 25 MPa concrete.

Ruel and Lelièvre (1994) and Pierre Giguère Consultants Inc. (1994) were mandated by the Quebec Ministry of Environment to develop a specialized analytic methodology to inspect farm manure storages and to provide a guide for the repair and maintenance of storages tanks. Ruel and Lelièvre (1994) inspected a total of 151 manure storages from 1992 to 1993. There were 141 circular tanks and 10 rectangular storages. 73 % of the storages were built for swine production; the remaining being for dairy and beef productions. Table 1 presents a summary of the findings.

Table 1. Summary of results, Ruel and Lelièvre (1994), circular and rectangular concrete manure storage, built from 1976 to 1988

Description	Percentage %
Presence of horizontal cracks (30% circumferential and 41% partial)	71
Trace of steel corrosion	40
Cold joints	26
Surface concrete chip spots	22
Inclined cracks	16
Honey comb holes	9
Foundation displacement signs	7

Basically, the survey revealed that:

- Workmanship had to be upgraded with regard to concrete pouring, vibration and cure.
- Steel and concrete design needed to be enhanced to reduce vertical and inclined cracks.
- Site supervision and quality control had to be enhanced.

With regard to the life expectancy of manure storages, Ruel and Lelièvre (1994) and Pierre Giguère Consultants Inc (1994) proposed that:

- Design life expectancy should be 30 years.
- Practical expected structure life duration could be longer depending on the care and maintenance of the concrete structure.
- A methodology to evaluate reparation versus demolition and reconstruction is well documented.
- The current CSA-CAN A-23.3 with a 28 days compressive strength of 30 MPa should be adopted by design engineers.

In Quebec, the CRAAQ (2002) published a technical guide for the design of manure and waste storages. The intent of this guide is to present the basic design references and recommended practices in the province of Quebec. This guide recommends related manure storage codes and standards. The article 3.3.2.1 requires a 28 days compressive strength of 25 MPa with 5-8 % of air entrained. Although the guide suggests following ACI-350 and CSA-CAN A23.3, generally, circular concrete tanks designed in Quebec did not respect certain aspects of these standards. The design carried out in Quebec usually called for:

- 28 days compressive strength of 25 MPa for foundation, floor and wall.
- Wall thicknesses of 200 and 250 mm for structure of 3.2 to 4.8 m high.
- Single row or reinforcement steel for 250 mm wall above 3.0 m high.

- No expansion control joints in the floor and in the wall for circular liquid manure tank.

- Minimum concrete coverage of 50 mm instead of 60 mm for gas exposed area.

The Quebec manure storage guide (CRAAQ 2002) also requires that agricultural engineers respect the latest edition of the CSA A23.1 to A23.4 standards. In 2004, CSA A23.1 and A23.2 standards for concrete selection introduced four agricultural classes from A-1 (severely exposed to manure gases) down to A-4 (lightly exposed to gases). CSA A23.1 and A23.2 require 25 MPa concrete for A-4 classes up to 35 MPa for A-1 class exposure. Consequently, the adoption of CSA A23.1 to A23.4 has major implications on the design and construction of manure storages as well as for livestock buildings such as:

- Availability of 30, 32 and 35 MPa concrete in rural Quebec area.

- Enhanced quality of workmanship for concrete pouring and especially for the curing process.

- Difficult finishing, surface cracking.

- Increased of the cost of construction.

In Quebec, there is no recent study on the status of quality of manure storages built with 25 MPa concrete to validate if the selection of 25 MPa concrete need to be modified.

OBJECTIVE The main objectives of this project are:

1. To perform a survey on circular concrete tanks built from 1979 to 2007 in order to observe concrete cracks.

2. To compare the results with regard to wall thicknesses of 150, 200 and 250 mm in relation with wall heights from 1.2 to 4.88 m.

3. Analyse data with regard to the tank diameter from 13.7 to 50 m in diameter.

4. Present the basic results of concrete quality of livestock barn floors and gutters.

5. Present an opinion on the selection of concrete for livestock buildings and manure storages.

PROCEDURES AND METHODS Ruel and Lelièvre (1994) and Pierre Giguère Consultants Inc. (1994) present a manure storage investigation procedure. They also proposed an evaluation grid of causes versus effects in relation to horizontal, vertical and inclined cracks. From 2003 up to 2009, the inspection reports of 110 circular concrete tanks were compiled. Numerous definitions of cracks, micro-cracks, vertically, horizontal and inclined factors have been presented by ACI 2008 SP-2 (07) and ACI (2005) 311.4 R-05. These guides were used to prepare the observation check list and measurement procedures.

For this investigation, a crack is considered to have a thickness of 0.1 mm and above for 50 mm of length. A micro-crack is under this thickness. The observer's difficulty resides in the identification of a crack and a micro-crack. In reality, cracks are vertical, horizontal or inclined but their immediate dimensions and direction varies widely from a multi-pattern, saw-tooth and other patterns according to the site loads. In practice, a crack should be repaired in order to insure the durability of the manure storage where a micro-crack could be surface repaired or simply coated for durability only.

In the province of Quebec, manure storages that show signs of leaking are considered as non-conform. This leaking requires immediate repairs to the structure to stop the leaks. Leaks are easy to detect with strips of concentrated liquid manure over the exterior surface of the tank. Underground leaks between the vertical wall and footing or floor are detectable by the peripheral drain. Manure odours and brownish colors are evident from the subsurface drain collector basin.

The inspection data of a total of 110 circular concrete tanks has been compiled and analysed. Data from numerous dairy and swine units are used for the comments on the barn floor concrete selection.

RESULTS AND DISCUSSION Table 2 presents the primary results with regard to the occurrence of cracks and micro-cracks as a function of the concrete tank wall thickness and tank diameter.

Over the years, manure storages vary in diameter from 13.7 m up to 50 m. The wall heights vary from 1.2 m up to 4.8 m. The most commonly used heights are 3.66 m and 4.88 m. Older tanks were built with 150 mm thick walls. The typical steel reinforcement yield is 400 MPa. All inspected manure tanks were built using 25 MPa concrete.

Table 2. Circular concrete tank, summary of the results for the cracks and micro-cracks

For ease of interpretation, figures 1 and 2 illustrate the basic results.

Circular tank diameter (m)	Wall thickness (mm)	Number of storage structure	Length of micro-cracks per storage (m)	Number of micro-cracks per storage	Length of cracks per storage (m)	Number of cracks per storage
13.7 to 22.5	152	18	7.1	9	38.7	12
	203	12	3.2	6	1.3	3
	254	1	0.0	0	0.0	0
22.9 to 31.7	152	2	0.0	0	17.1	14
	203	47	7.7	14	2.0	3
	254	4	2.3	9	0.0	0
32.0 to 40.8	152	2	55.0	1	62.6	2
	203	17	15.6	10	9.5	13
	254	3	0	0	0	0
41.2 and +	152	0	0	0	0	0
	203	2	5.3	53	1.8	1
	254	2	0	0	0	0

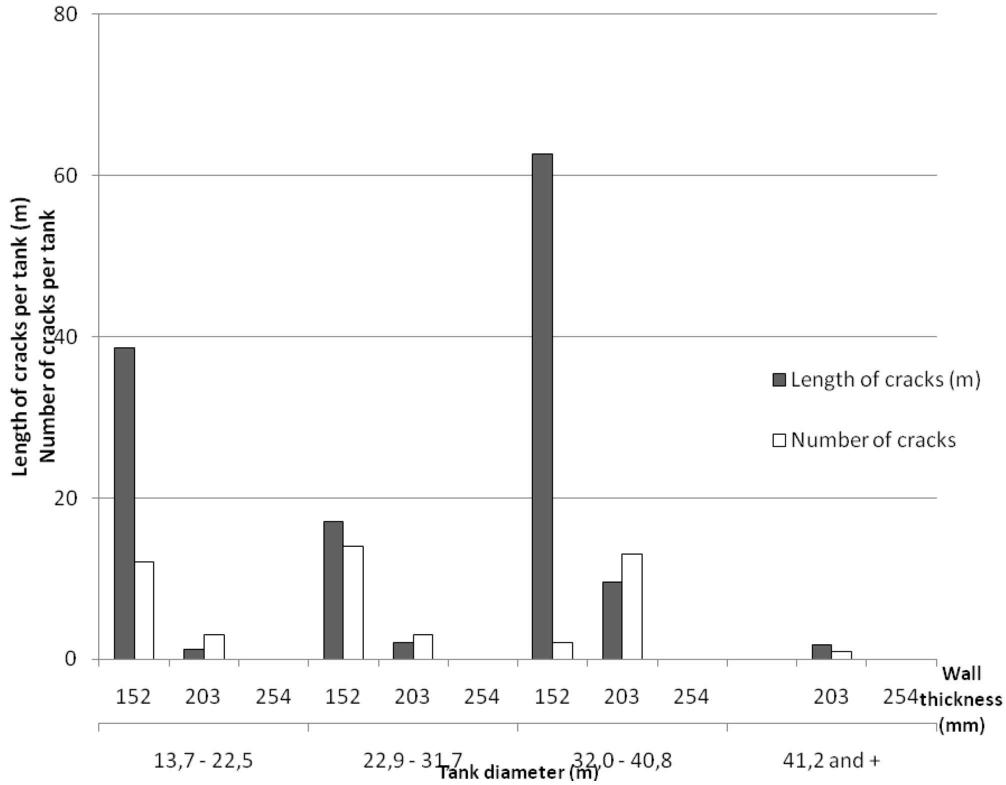

Figure 1. Crack length and number (per tank)

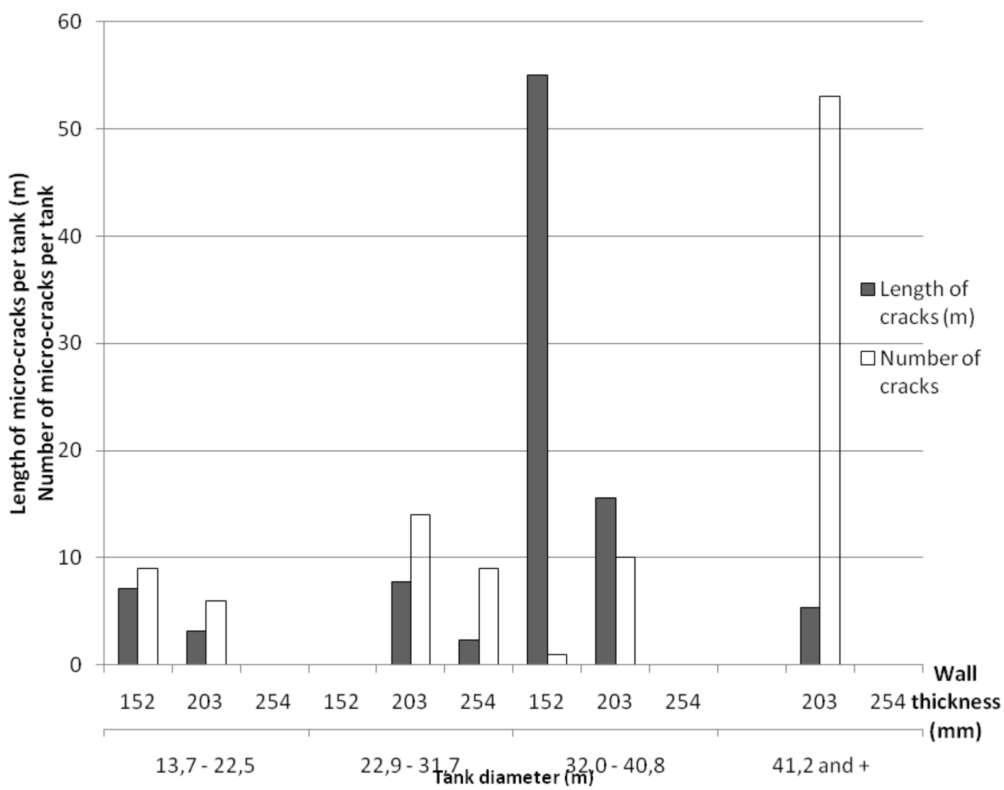

Figure 2. Micro-crack length and number (per tank)

Circular manure tanks designed with a wall thickness of 150 mm present numerous cracks. The last 10 years, there has been almost no new circular manure tank built with 150 mm thick walls.

The commonly used wall thickness is 208 m for 78 of 110 tanks studied. The average number of cracks per storage tank was 3 for 13.7 m to 31.7 m of diameter. In practice, this low number of cracks would be considered as acceptable since none of these tanks had leaked or cracked width above 0.3 mm. Withs tank diameters ranging from 32 to 40.8 m, the average number of cracks was 13. Again, none of these structures showed effluent leaks. When surveyed, the cracks were categorized among vertical, horizontal or oblique cracks. The horizontal cracks are related to the initial workmanship. At these diameters, the tank builder would often have difficulty in achieving adequate vibration and refreshing of the concrete surface due to the large quantity of concrete and circumference of the tank.

The size of the concrete pumps, the number of workers placing the concrete and adequate vibration are the limiting factors. In fact, 6 of the 13 cracks were horizontal. The remaining were 6 vertical cracks and 1 oblique crack. The vertical cracks are mainly associated with curing time. In practice, the builders remove the wooden forms after 12 to 18 hours following the end of the concrete pour. Generally, tank walls are not protected and not kept humid to assure a good cure. Considering these difficult conditions, the number of vertical cracks is very low with the actual design and 25 MPa concrete.

Table 3 presents the results associated with the effects of wall height in relation with the wall thickness.

Table 3. Circular concrete tanks, summary of the results, wall height and thickness in relation to crack numbers

Circular tank wall height (m)	Wall thickness (mm)	Number of storage	Number of cracks per storage	Number of micro-cracks per storage
1.22 – 1.83	203	6	11	15
2.44 – 3.05	152	3	0	27
	203	12	2	8
3.66	152	18	12	4
	203	43	2	6
	254	4	0	8
3.96 – 4.88	152	2	17	2
	203	17	1	7
	254	6	1	3

For wall heights of 1.22 to 1.83 m, there were a relatively high number of cracks and micro-cracks. There is no data for 152 mm or 254 mm thick walls. The designer should be careful with regard to the load with relatively shallow manure storage.

With wall heights of 2.44 to 3.05 m, the number of cracks with 152 mm thick wall is nil. For wall height above 3.05 m, the 152 mm wall thickness present numerous cracks and micro-cracks. This wall thickness should be avoided.

The result with the 203 mm wall thickness shows very few cracks and micro-cracks for tank heights up to 4.88 m. In comparing with table 1 and figure 1, this is consistent with manure tank diameters from 13.7 m up to 41.2 m and more. The actual design and construction methods for 203 mm walls are consequently well mastered by engineers and builders.

Most designers use a wall thickness of 203 mm for wall height up to 4.2 m and then use 254 mm walls for wall heights from 4.2 to 4.88 m. With 254 mm wall (25 MPa concrete), there was only 1 crack per tank observed for small to large 41.2 m diameter and more.

USE OF HIGHER CONCRETE COMPRESSIVE STRENGTH, ADVANTAGES AND DISADVANTAGES In Quebec, almost every circular concrete manure tank has been built with 25 MPa concrete. Before the adoption of higher concrete strength of 30, 32 of 35 MPa, the following points should be considered:

1. The strength of a circular concrete tank is provided by the structural steel assembly with a proper surface cover. The increase in tensile strength in concrete is minimal as compressive strength is increased.

2. Horizontal cracks and some oblique cracks are caused by the concrete pouring methods. With tank diameters of 30 m and above, concrete pumping capability and concrete in-form vibration are two limiting factors.

3. With common on-farm applications, the use of 30, 32 or 35 MPa concrete creates numerous construction problems such as:

    a. Fluidity for ease of pumping.

    b. Use of super-plasticizer, added cost.

    c. Difficult concrete vibration.

    d. Rapid surface curing, surface crack problems

    e. Extra wet curing with water sprinkler or surface covers.

    In 2008 and 2009, there were many more cracks observed with 30 and 32 MPa concrete tanks as compare to the 25 MPa standard tanks.

4. The overall longevity and quality of manure tanks as well as livestock barn floors are much more linked to micro-cracks and surface cracks as compare to 25 vs 30 and 32 MPa. Cracks are a preferential way to reach the structural steel as well as show surface deterioration due to freeze-thaw cycles. On a risk assessment basis, crack control is more important than compressive strength potentially related to gas durability.

5. Generally, circular concrete tanks have open tops. Consequently, the walls are not exposed to high gas levels. Covered concrete tanks with wood or steel roofs are not sealed. Gas levels are relatively low.

6. After 20 years and more, there are more top wall problems associated with the steel fence posts initially sunk in the concrete walls. These problems would occur in 30, 32 MPa concrete as well.

7. For an expected like expectancy of 30 years, 25 MPa concrete is adequate. In fact, with proper and regular maintenance, manure storage should be usable for 50 years and more.

BARN FLOORS AND GUTTERS In practice, concrete durability is directly affected by the initial surface finish quality as compared to the compressive strength. In fact, initial floor or gutter cracks results in short term chipping and surface deterioration. Almost every Quebec barn has been built with on-farm concrete mixes or 25 MPa concrete and less. Over the years numerous floor inspections have been carried out for leaks and cracks, the compressive strength performance of the concrete is not considered to be a factor.

In fact, the use of 30, 32 or 35 MPa concrete means the use of expansion control joints and/or undesirable surface cracks. The use of these concrete creates an increased risk for the appearance of surface cracks at the moment of execution with regard to surface cracks.

DESIGN CONSIDERATIONS FOR CIRCULAR CONCRETE TANKS Based on the results of the survey and discussions with other Quebec design agricultural engineers, the following summerize the observations and present some guidelines:

1. 25 MPa concrete should be used for the conventional open top concrete manure tanks.

2. For manure tanks with a sealed roof, the concrete should be selected in accordance to the anticipated manure gas levels.

3. Steel coverage should respect CSA-A23, latest edition or more.

4. Barns gutters and floors should be designed with 25 MPa concrete. Maintenance and surface repairs have to be part of the general barn maintenance program. Initial floor and gutters surface cracks should be minimized.

5. Site inspections are required for tank floors and walls construction. Builders need to have the proper high volume concrete pumping and vibration capability especially with 30 m and above tank diameters.

6. On-farm concrete curing is the major problem encountered. Site inspection related to curing procedures and efficiency should be enforced.

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