Concrete Manure Storage Structures: Specifications and Standards in Canada

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▪ Introduction

Concrete is a practical, economical and durable material for storage structures for manure. Manure storage structures must be designed for strength, durability and water-tightness. This demands a high quality of concrete, and a well designed structure. A concrete manure storage structure should provide a design that is structurally safe, durable, and which minimises cracking and leakage. The objective is to assure both functionality and public and environmental protection.

Development, design and construction of quality concrete manure storage structures requires the following:

- Correct evaluation and design of the structure.
- Durable, low permeability concrete.
- Proper placement of the concrete, reinforcement and other components such as control joints and water stops.
- Proper finishing.
- Curing to achieve the specified strength, durability and water-tightness.

The correct concrete mix for the job is just one step in the process. Durable high-performing concrete depends also on proper placement, consolidation, finishing and curing of the concrete. Lack of curing in particular will cause an otherwise high quality mix not to perform as intended.

▪ Types of Manure Storage Structures

Structures for manure storage can be divided into the following categories:

- Pit type structures.
- Deep pit barns.
- Transfer systems for moving manure from in-barn storage or collection to long term storage.
- Concrete pads or slabs, with or without berms and umbrella style roofs, for storing solid or semi-solid manure outside the barns.
- Long-term storages.
- Precast and post-tensioned concrete tanks.
- Processing & value-added facilities. Examples of these are:
  - composting operations.
  - bio-gas generation facilities.
  - manure management and compaction systems.

Manure processing facilities generally require the same diligence in design and concrete specifications as for manure storages. Concrete is an ideal construction product for most of these applications. Composting facilities generally require concrete pads, with concrete quality similar to that for moderate to severe outdoor exposure.

Biogas processing facilities are more complex operations. Besides the digester tanks, manure collection, handling and processing structures will also be part of the facility. Digesters and fermentation tanks involve biological processes subject to moderate levels of organic-based gasses such as methane and hydrogen sulphide.

The gaseous content of biogas generators is about 65% methane, over 30% carbon dioxide, with small amounts of ammonia and hydrogen sulphide. The latter has the most corrosive effect on concrete; however, this corrosive effect is rated “moderate or less” at these low concentrations. Effluent from these processes, as well as from stored manure, requires a good quality “manure storage grade” of concrete. With a water-tight design and concrete of high quality that is properly placed and cured, any additional or exceptional treatment should not be required to provide satisfactory long term performance in these applications.

Regulatory Processes in Canada

Two approaches are taken, with some variation between these .

- Provinces that require compliance of farm structures with the building code, deal with manure storage structures much like other farm buildings.
- For provinces where farm buildings are exempt from building codes (generally the Prairie Provinces), substantial compliance with prescribed standards for design and construction is required.

Types of Structures Regulated

For some provinces, these regulations apply only to large, long-term, manure storages located outside the barns; manure gutters, pits and floor collection systems in the barn are considered temporary storage structures that do not present significant hazard of contamination. Other provinces regulate the entire manure collection, transfer and storage structures.

Professional Responsibility

Regardless of the level of authority required for farm buildings and extended manure handling storage structures, professional engineering will be required for some components in this process.

Table 1. Summary of concrete manure storage regulations in Canada.

Province	Case
British Columbia	1, 4
Alberta	2, 3, 5
Saskatchewan	2, 4, 6
Manitoba	2, 3, 4, 6
Ontario	1, 3, 4
Quebec	1, 3, 4
New Brunswick	1, 4
PEI	1, 4
Nova Scotia	1, 4
Newfoundland	1, 4

Case Description
1. Comply with building code, incl the NFBC; manure storage handled like building permits.
2. Farm buildings exempt from the building code.
3. Detailed standards and regulations provided for manure storages.
4. Requires P.Eng responsible for manure storage design.
5. Some components need not have P.Eng responsible.
6. Regulations apply only to manure storages outside the barn, or deep pit in-barn storage.

Design of Manure Storages

Functional Design

In addition to proper structural design, and leak-free construction, most manure storage structures must also be functionally planned and designed to perform the task required. Some of these considerations should be:

- Storage volumes as specified by the regulating authority.
- Freeboard for reserve capacity for emergency situations, plus precipitation if applicable.
- Connections for valves, pumps and pipelines.
- Ramps or services for loading, unloading and agitation of the tank contents.
- Secondary containment for fail-safe operation if required by the local authority.
- Safety fencing and signage if required.

High water table, or flooding by other causes, will seriously damage storage floors; it is not reasonable to design floors for uplift pressure. These conditions must, therefore, be avoided. Some measures to consider are:

- Undertake a thorough site evaluation, supplemented with geotechnical studies as required, to avoid high water table situations.
- Sub-grade structure below floors should have positive drainage through granular base construction, drain tile or a combination of these. Ensuing drainage should flow freely to an observation station or device.
- Assure that all surface runoff flows freely away from the manure storage structure.

Structural Design

Structural design of concrete manure storages should provide structural integrity considering all the design loads that apply to these structures. In addition, the design must prevent leakage by minimising cracking and utilising appropriate joint and sealant techniques. Design criteria include:

- Design loads.
- Reinforced concrete design standards.
- Specifications for leak control.
- References for specific components, such as walls, floors and tops.
- Exposure conditions and mix requirements for concrete.

Manure storage structures should be designed to withstand all loads and load combinations reasonably anticipated during construction and operation in accordance with the most recent version of the National Building Code (NBC), incorporating the National Farm Building Code of Canada (NFBC). Design shall be in accordance with CSA A23.3 (Design of Concrete Structures) and related CSA Standards for concrete structures (CSA A23.1.2).

Concrete tank design shall follow standard structural engineering analysis, based on CSA A23.3. The individual design will vary according to the type of structure and the conditions imposed by the site and usage. Several excellent references provide design guidelines for most of the common storage types. One widely used reference is ACI 350 "Code Requirements for Environmental Engineering Concrete Structures". Designers should be aware that ACI 350 and its related committee reports (350.1, 350.2 & 350.3) provide excellent techniques and guidelines, however some design details are not entirely consistent with Canadian standards. Canadian codes and standards are for the Limit States Design method as specified by Part 4, Structural Design, of the National Building Code of Canada.

It should be noted that the NBC is under review in 2003 - 2004, with a major revision to adopt an "Objective Based Codes" approach. The most significant changes proposed are revisions to the climatic loads, load factors for principal loads, as well as a broader scope of load definitions and load combinations with the introduction of the "companion loads" concept. Since manure storages are primarily concerned with liquid and earth loads, these changes will have minimum effect on that design process.

Specified Loads

- **Liquid Loads** - walls and floor of a manure storage structure should be designed for liquid loads.
- **Ice Loads** – Walls and other structural components should be designed for ice loads in accordance with the NFBC.
- **Soil and Backfill Loads** – Recommended design values for earth loads on underground storage facilities are provided in the NFBC, Section 2.2.1.13. Horizontal soil pressures may be used to offset the pressure exerted by the manure in storage if the engineer responsible specifies the backfill material and the required compaction. Backfill should be installed around the foundation of manure storages to provide adequate cover for frost protection, unless other methods are employed.
- **Exterior walls below grade** should be designed for surcharge loading from anticipated wheel traffic such as manure tankers and tractors. Design values for vehicle traffic are provided in the NFBC and NBC. The design should allow for increased loads due to uneven grades or ramps where required.

- **Frost Loads** – Adequate protection from frost action should be provided to footings, floors, and walls. Under normal operation, frost action is not a concern because the storage contains unfrozen manure of sufficient depth to prevent freezing. The problem occurs if the storage is left unused over winter; this requires special precautions to prevent frost heaving and damage (such as covering the floor with straw or liquid).
- **Temperature Stress** – The design of a concrete manure storage facility should account for temperature-induced stresses, during both summer and winter seasons.
- **Wind Loads -** The specified external pressure, or suction, due to wind on part or all of a surface of a wall should be calculated according to Part 4 of the NBC. For concrete tanks, wind loads are usually insignificant compared to other product loads.
- **Vehicular loads** of tankers or tractors near the side walls.
- **Other Live Loads** – For some manure tanks that have solid tops, or tops integral with livestock floors, loads due to snow, livestock or other traffic need to be considered. Design should follow the NBC or NFBC for appropriate load determination.

Minimising Leakage

The ability of the facility to minimise leakage will be reasonably assured if:

- Adequate structural resistance is provided.
- Joints are properly spaced, sized, and constructed.
- Joints and penetrations are made watertight.
- Exposure conditions are clearly identified and accounted for in the design.
- Design of reinforcement is made to assure crack width in concrete is minimised and cracking is evenly distributed.
- Impervious protective coatings or sealants are used where required.

Foundations and Floors

Soil Bearing Capacity and Uniformity of Base – The engineer should ensure that the allowable bearing capacity and uniformity of base materials is appropriate for the foundation loads and method of construction. Normally a minimum sub-grade of 150 mm of compacted granular fill is required.

Sub-Grade Preparation The existing sub grade should be cleared of all stones, topsoil, wood, mud and other deleterious material. Soft areas should be over-excavated and replaced with fill approved by the engineer, placed in 150 mm lifts and compacted to 98% Modified Proctor Density. The sub-grade should be free of frost before concrete placement begins.

Structural Design The design of concrete footings and floor slabs on grade in permanent manure storage facilities should conform to the requirements of CSA A23.3 “Design of Concrete Structures”.

Concrete Walls

The design of concrete walls in manure storage facilities should conform to the requirements of CSA A23.3 “Design of Concrete Structures”. Steel reinforcing in walls subjected to bending or direct tension should be so proportioned to limit crack width, and to distribute small cracks evenly rather than allow fewer large cracks to occur.

There are generally two significantly different applications for wall design for concrete manure storages:

- Shallow storages, generally less than 2.4 m deep, where the wall is a structural component of the barn, or otherwise not subject to high design loads.
- Large volume, free-standing storage structures subject to high design loads due to contents and soils.

Walls of shallow storages are usually manure gutters, trenches or below-floor pits. Typically these also support the barn. Additional steel is usually required to meet the structural strength requirements of larger or deeper structures in this category.

Long walls require greater than minimum reinforcing to effectively control shrinkage cracks. It is generally acknowledged that small hairline cracks will seal with organic matter but the degree of sealing and crack sizes have not been quantified.

Wall design for large manure storage structures must be designed for all loads in accordance with NBC/CSA Standards. Circular storages are subject to high tensile forces, and it is a challenge to control shrinkage cracks. Rectangular storages will have high bending moments, often in both directions, which generally governs the strength design.

Minimum Wall Thickness - For concrete manure storages 3.6 m or greater in depth, the minimum wall thickness recommended by ACI 350 and CSA 23.3 is 300 mm. This is required to provide for a minimum 50 mm cover for reinforcing steel and to allow the required amount of steel for strength design. Reinforcement shall be in two layers. The maximum spacing of horizontal steel shall be 300 mm. Greater numbers of smaller diameter reinforcing bars, rather than fewer large bars, achieves best control of crack width and spacing.

Unreinforced concrete storage walls should be used only where the wall is non-structural and not intended to prevent the leakage of the contents; they should be designed in accordance with CSA A23.3.

Joints in Walls

Leakage through tank walls occurs mostly at joints, so these require special attention. Horizontal joints in walls should be avoided. Water-tight joint construction can be achieved by either of the following three methods or other approved methods, the first of which is recommended for deep storage structures:

- A mechanical water stop, usually of PVC or similar approved material.
- Construct a 10 mm full length joint caulked with appropriate concrete caulking, or
- a strip of expanding caulking or bentonite in the middle of the wall between the pit wall and floor.

Concrete Specifications

Concrete for manure storage structures must be durable, of low permeability, resistant to corrosive gasses and chemicals, and of specified strength to meet structural design requirements. Concrete that meets the first three conditions will probably meet or exceed strength criteria. Concrete mix design has a variety of modern tools and materials for enhancing these qualities. Some of these are water reducing admixtures, supplementary cementing materials such as fly ash, slag and silica fume, and a variety of proprietary commercial admixtures.

Concrete materials and method of mix design should be based on CSA A23.1, with concrete supplied by a certified ready mixed concrete facility. If batched on site, either a cement industry or independent qualified professional should design the concrete mix. The batching facility should be capable of a high degree of quality control.

Concrete mix design will be based on the following properties:

- Water-cementing materials (w/cm) ratio.
- Air entrainment.
- Type of cement and supplementary cementing materials.
- Admixtures or additives.
- Aggregate type and size.
- Class of exposure.

The important properties of durability and impermeability (water-tightness) have traditionally been based on the water-cement ratio of the concrete mix. For modern concrete mix technology combinations of other ingredients and admixtures can provide effective alternatives, and should be considered. The most significant options are the use of supplementary cementing materials such as fly ash and slag to improve the performance of the binder, and water reducing admixtures to improve the workability of the concrete. For manure storages, these requirements are summarised in **Table 2**.

Table 2. Recommended concrete mix design for manure storage applications.

Category	Typical Storage Application	W/C Ratio	Typical Strength
Exposed to manure gasses in confined space	Covered tanks, slatted floors, beams, columns	0.40	35 MPa
Exposed to manure, freezing/thawing	Most manure tanks in barns, outdoor tanks and slabs	0.45	32 MPa
Short term and shallow storages, with little freeze-thaw action	Shallow pits and gutters in barns, transfer trenches	0.50	30 MPa
Building components with little freeze-thaw action	Foundations, utility area floors, Cattle barns, poultry, etc.	0.55	25 MPa

Classes of Exposures: CSA A23.1 (2000), Table 11, 12 & 14, and Type of Cement/cementing materials.

CSA Standard A23.1 provides for Concrete Exposure Classifications; the Canadian Farm Builders Association and the ready mix industry have similar or parallel designations. Manure contains a widely ranging mix of chemical ingredients that are mild to moderately corrosive to concrete. The most serious of these are the sulphates, which may also be present in soil and groundwater, particularly in the Prairie Provinces.

CSA A23.1 (Table 12) lists exposure conditions for sulphate in categories S1, S2 and S3, for “Very Severe, Severe, and Moderate”, respectively. Manure typically has from 1500 to 2500 mg/L of sulphates, which would place it in the S-3 (moderate) to S-2 (severe) category. Structures exposed to manure tank environments, such as slats and tank tops, are often subject to some hydrogen sulphate (H2S) attack, requiring a category S-2 or better concrete.

Manure storage and handling structures thus require at least a class S-3 quality of concrete, and structures or components exposed to H2S a category S-2. Thin critical structural components like beams, columns and slats should be designed for “very severe” S-1 exposure. The build-up of H2S in unventilated spaces is a particularly serious environment for concrete. These conditions should be avoided as much as possible or particular care given to the mix design.

Type HS (formerly Type 50) cement is recommended for improved sulphate resistance; it is readily available and normally supplied in the Prairie Provinces. In areas where Type HS is less available or costly, an equivalent level of sulphate resistance can be achieved by appropriate mix design and supplementary cementing materials such as fly ash or slag.

Admixtures play an increasingly important role in the mix design, as they economically and effectively increase concrete quality. This is achieved by reducing the w/cm ratio without sacrificing workability. These products may include, but are not limited to:

- Water-reducing agents and plasticizers, which reduce the water demand of the mix yet allow the desired workability (slump). These admixtures aid in dispersing the cementing materials and improve the performance and uniformity of the concrete.
- Supplementary cementing materials such as fly ash, slag and silica fume; these greatly reduce permeability and thus improve corrosion resistance and durability of most concrete mixes. Silica fume is particularly effective and should be considered for severe exposure conditions such as beams, columns and slats in unventilated manure pits.

Construction

Good construction techniques must be followed in order to ensure a long-lasting, leak-free high quality structure. This requires proper placement, finishing and curing, plus attention to details in reinforcement and proper jointing, including water-stops or caulking.

Placement – concrete for manure storages should be placed with the aid of vibrator to assure proper consolidation, resulting in dense concrete of minimum permeability, free of honey-combing and similar blemishes. This also assures excellent bonding with reinforcing steel, joints and water stops, where applied.

Low w/cm mixture, higher strength concrete can be more difficult to place and finish. Slump enhancing admixtures and mechanical vibrators should be considered to reduce labour and improve the quality of the concrete job.

Curing – Failure to properly cure fresh concrete is arguably the single greatest cause of poor quality concrete in farm structures. Proper curing is required to ensure the concrete obtains its potential design strength and durability. CSA 23.1, clause 21.1.4, states that the normal curing period for concrete shall be at least three days at a minimum temperature of 10°C, or until 40% of the 28-day strength is achieved. For moderate to severe exposure to freeze-thaw and sulphates, curing for a period of seven days or to 70% of the specified 28-day compressive strength of the concrete is required (Clause 21.1.5).

A variety of approved curing methods may be used, including:

- leaving the forms in place for the required time.
- covering with wet fabric, water-proof film or damp sand.
- application of a fine mist.
- application of approved curing compounds. (For most projects, time is critical and this is often the most expedient method.)

Proper curing should thus be encouraged. At the same time, the owner should be aware and accept that this relatively small added expense has to be covered by the project cost.

Protection of Concrete – special precautions must be taken for both cold and hot weather protection of concrete. Concrete must not be allowed to freeze until sufficient curing has been achieved, and sufficient air drying has occurred (ACI recommends 28 days following curing). Likewise, hot weather presents problems for loss of moisture, high temperatures and rapid setting.

Testing and Quality Control

Quality control of the mix design, placement, finishing and curing is critical to the success of any concrete project. Once concrete is placed it is no longer possible to affect changes in a concrete job, except for the negative effect of poor curing or protection. It is likewise difficult to verify hidden construction detail, or location of reinforcement in a wall section.

The following documentation and quality control is recommended:

- Retain a copy of the concrete suppliers "mix/delivery ticket".
- Sampling and collection of test cylinders for strength determination.
- Random slump measurements.
- Take pictures of formwork, reinforcement, joint sealants or any other critical components.
- Take note of weather conditions and the curing and protection applied by the contractor.

Related Concrete Components

Though the focus of this guide is the design and construction of concrete manure structures, other building components are closely related and benefit from the same quality concrete technology. Barn floors, curbs, pen walls and feed structures may be excluded from the regulatory process; however, these are subjected to severe treatment from animal traffic, corrosive feed ingredients and high-pressure cleaning.

Typically the specification for concrete floors in barns is for a w/cm ratio of 0.55, or about 25 MPa concrete. Increasing the standard to 0.50 or 0.45 w/cm ratio (30 - 35 MPa) will greatly increase the longevity of these components. Similarly, milking parlour floors and processing rooms require top quality concrete for long effective service. It is critical to follow the same rigorous standards for placement, finishing and curing to achieve excellent results. The greatest shortcoming, particularly in terms of durability, of many concrete floor and foundation jobs, is the lack of proper curing.

References

The following lists standards and useful technical references on the design of concrete manure storages for Canada.

Where references are made in this guide to standards or codes, the latest edition is implied.

ASAE	–	American Society of Agricultural Engineers
ACI	–	American Concrete Institute
CPCI	–	Canadian Precast/Prestressed Concrete Institute
CRMCA	–	Canadian Ready Mix Concrete Association
CSA	–	Canadian Standards Association, Mississauga, ON
CSAE	–	Canadian Society of Agricultural Engineering
MWPS	–	Midwest Plan Service, Ames, Iowa
PCA/CAC	–	Portland Cement Association/ Cement Association of Canada