# CONCRETE THINKING
## IN AGRICULTURAL SOLUTIONS

### CONCRETE MANURE STORAGE STRUCTURES

SPECIFICATIONS
AND STANDARDS
IN CANADA

# SPECIFICATIONS AND STANDARDS IN CANADA

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 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 to not perform as intended.

## ACKNOWLEDGEMENTS

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# TYPES OF MANURE STORAGE STRUCTURES

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

1. **Pit type structures** – these are the manure collection pits or gutters inside the barn. Hog barn pits are usually covered by slatted floors through which manure drops to the holding pit. Pits, generally less than 1.2 m deep, hold manure for one to three weeks, when it is drained to long-term storage. Dairy facilities may incorporate similar manure collection and transfer trenches into which manure is mechanically scraped.
2. **Deep pit barns** – confinement livestock structures with basement-like deep pit manure storages that normally hold liquid manure for six to eight months. These pits are covered by fully slatted floors, and may be subdivided into compartments. Other livestock facilities, notably some poultry housing, occasionally employ concrete deep-pit manure collection.
3. **Transfer systems** for moving manure from in-barn storage or collection to long term storage. These are typically transfer trenches, or buried large diameter pipelines.
4. **Concrete pads or slabs**, with or without berms and umbrella style roofs, for storing solid or semi-solid manure outside the barns.

**Fig. 1. Fully slatted floor feeder hog barn, 22.4 x 76.0 m with 3.0 m deep manure pits that hold over 200 days storage.**

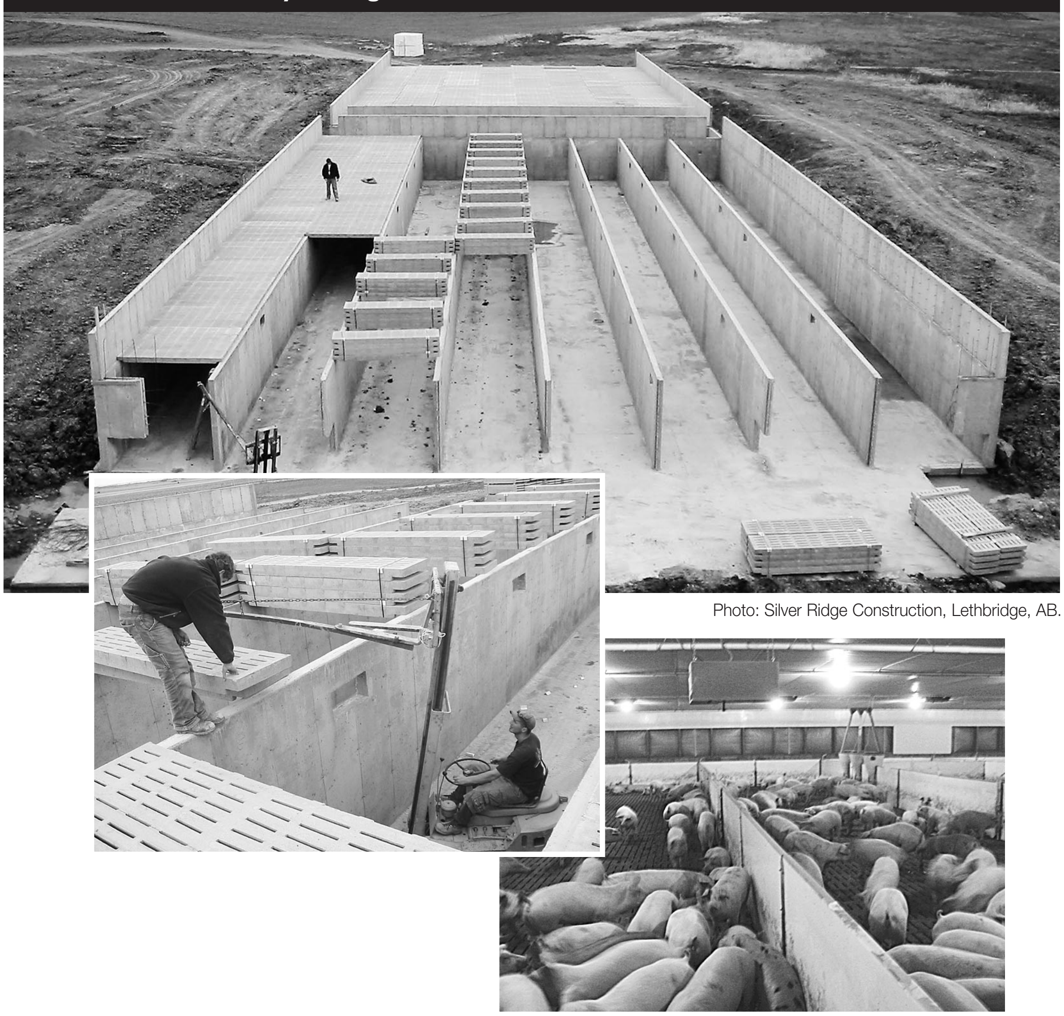


Photo: Silver Ridge Construction, Lethbridge, AB.

5. **Long-term storages** – These are the large volume outdoor storages required for storage of manure for specified periods, usually exceeding 200 days. Earthen storages and concrete or steel tanks are the most common types.

   Large concrete manure storages can be either circular or rectangular. Most common are large reinforced circular tanks, from 30 to 60 m in diameter, and up to 6 m deep. Rectangular tanks are more costly per unit volume, but have a place for specialised applications. These are usually of two types:
   - open-top structures with walls either cantilevered from the base, or laterally supported by perimeter beams or buttresses, and
   - structures with concrete tops that support the sides as an integrally designed unit.

6. **Precast and/or post-tensioned concrete tanks** – These are usually circular structures, assembled from precast panels, with vertical joints sealed and tightened by post tensioning. Standards for these structures are outside the scope of this guide, but are available from the precast industry.

**Fig 2. Large rectangular concrete manure tank with interior buttresses at a 200 cow dairy.**

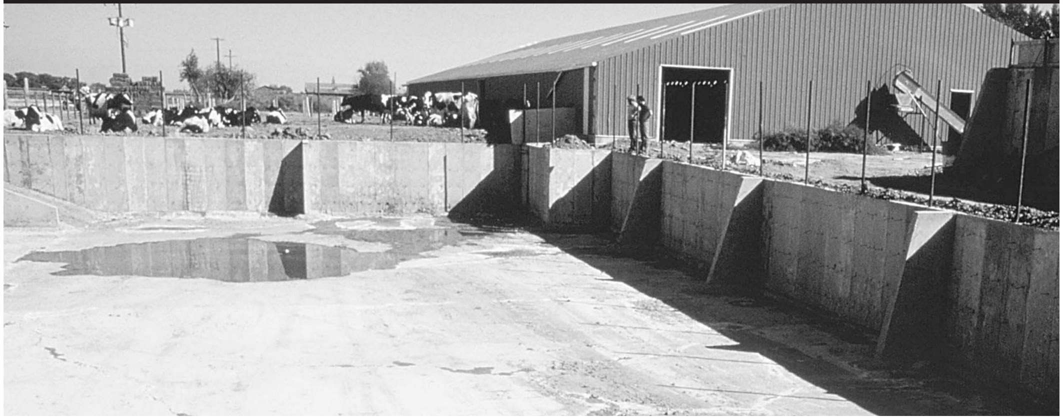


Photo: Dennis Darby

7. **Processing & value-added facilities** – A modern trend is to incorporate a variety of value-added or quality enhancing processes for livestock manure. 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 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. Concrete of high quality, water-tight design, properly placed and cured should not require any additional or exceptional treatment to provide satisfactory long term performance in these applications.

# REGULATORY PROCESS IN CANADA

Every provincial jurisdiction in Canada is concerned with the proper design and construction of manure storages to assure high standards are met. The objective is structural safety and to minimise the risk for leakage and pollution. The approach taken varies between provinces based on how they choose to manage the review and inspection process. For concrete manure storages the concern is for structural design plus the quality of materials and construction.

Two approaches are taken, though there is some variation between these styles. These differences relate to the broader jurisdictional consideration as to whether or not farm buildings are regulated in that province, and hence are required to comply with the National Farm Building Code (NFBC). It should be noted that the approval process for structures is separate to that for siting or locating large confinement livestock operations, though the latter will require manure management that meets prescribed standards.

**THE REGULATORY PROCESS IN CANADA IS CONTINUALLY EVOLVING**

1. Provinces that require compliance of farm structures with the building code deal with manure storage structures much like other farm buildings. Design and professional responsibility is handled through the building permit process, often by the local authority. The structure usually must be designed by a professional engineer of record who is responsible for compliance with appropriate design codes, and for quality of construction.

   This group generally includes the Maritime Provinces and British Columbia. Ontario and Quebec provide for a variation on this; though their farm buildings must comply with the NFBC, they also have set out detailed standards for manure storage structures, including those of concrete. These standards are more explicit than the simple compliance with building codes.

2. 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. Manure storages generally require design and responsibility by a professional engineer of record, though this may be at the discretion of the regulator. Depending on the complexity of the structure, the engineer will probably be required to provide design notes and a report. Manure components deemed less critical may be exempt, or may be built according to a recognised plan without professional responsibility, subject to approval.

### Types of Structures Regulated

There is some variation in the types of structures covered by provincial manure storage regulations. 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. Where the building code applies to farm structures, there is of course an implied level of building standard for all components of the manure management system.

### Professional Responsibility

Regardless of the level of authority required for the farm buildings and extended manure handling storage structures, professional engineering will be required for some components in this process. The Engineer of Record will be required to submit or reference design notes and appropriate standards used in the design. Records on concrete mix design, construction, and leak prevention techniques, reinforcement and proper placement and curing procedures should be considered.

It is evident that an independent reference on concrete storage quality and design will be helpful to regulating authorities, builders, producers and the engineering community. This is one objective of this guide.

**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.

Note:
1. This information pertains to the design and construction of concrete manure storage and handling facilities; it is outside of the scope of overall permit and siting process for confinement livestock operations.
2. The permits and approval process for livestock operations in Canada is undergoing rapid development, thus procedures and details are subject to change.

# 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 for the anticipated manure production and required storage period.
- Freeboard for reserve capacity for emergency situations, plus precipitation if applicable.
- Connections for valves, pumps and pipelines for filling or emptying the storage.
- Ramps or services for loading, unloading and agitation of the tank contents.
- Secondary containment for fail-safe operation if required by the local authority. This may include berms, membrane systems and leak detection devices, or other methods determined by the designer to meet these requirements.
- 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. (See “Types of Manure Storage”). 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. For load combinations not including earthquake loading, the factored load shall be:

Factored Load = $\alpha_D D + \gamma\psi(\alpha_L L + \alpha_W W + \alpha_T T)$, where:

- D = dead load,
- L = live load due to intended use and occupancy,
- W = live load due to wind,
- T = load due to contraction or expansion caused by temperature changes, creep, or movement due to differential settlement or a combination thereof,
- $\alpha$ = load modification factor for the limit states under consideration,
- $\gamma$ = importance factor for loads other than the dead load to account for the relative consequences of collapse related to the use and occupancy of the structure; and
- $\psi$ = load combination factor applied to the factored loads other than the dead load to account for the reduced probability of a number of loads acting simultaneously.

The NFBC allows the importance factor, $\gamma = 0.8$ for farm structures of low human occupancy. For manure storages, however it is recommended that this factor remain as 1.0 because these structures are not considered "low importance" due to the consequences of failure to public safety and environment.

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**

1. **Liquid Loads** - walls and floor of a manure storage structure should be designed for liquid loads based on the following criteria:
   - Load factor $\alpha_L = 1.25$; this load factor is similar to that for dead loads, since the liquid load can be accurately calculated, and is not subject to the variability of other live loads, such as climatic or livestock loads.
   - Equivalent fluid density for liquid or slurry manure of 10 $kN/m^3$.
   - A liquid head equal to the maximum height of liquid that the facility can contain.
   - An allowance for unequal liquid levels on each side of an interior partition. A minimum uniform pressure differential of 0.5 kPa is recommended for all walls even if equal liquid levels can be maintained on each side of the wall.
   - Inward hydraulic loads from high water table; this should normally not be encountered if appropriate planning and design is undertaken.

2. **Ice Loads** – Walls and other structural components should be designed for ice loads in accordance with the NFBC. Load due to ice varies considerably depending on climate, type of manure and loading conditions.

3. **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.

4. **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).

5. **Temperature Stress** – The design of a concrete manure storage facility should account for temperature-induced stresses, during both summer and winter seasons, resulting from:
   - Temperature variation between the above and below ground portions of the wall, and
   - Temperature differences between the inside and outside faces of the wall.
   - Seasonal changes in temperature.

6. **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.

7. **Vehicular loads** of tankers or tractors near the side walls.

8. **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 for the intended design loads and serviceability.
- Joints are properly spaced, sized, and constructed for the application.
- Joints and penetrations are made watertight with the appropriate use of water-stops, caulking, gaskets, or sealants.
- 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”.

- The design method should provide for adequate structural strength and serviceability.
- The minimum thickness of all slabs on grade in permanent liquid nutrient storage facilities should be 125 mm or as required to satisfy concrete cover requirements.
- Floor slabs on grade should be designed as reinforced concrete slabs and should support the intended loads and meet serviceability requirements. Reinforcement is provided in both directions and spaced no further apart than 3 times the slab thickness or 500 mm. The minimum reinforcement steel ratio is 0.002.

- Cracking should be controlled by the proper use and construction and control joints, expansion joints, and isolation joints as specified by the engineer.
- Alternatively, an acceptable method of construction is an appropriately designed joint-free slab with enough reinforcing to control shrinkage cracks. Such a design, however, may be limited by the floor area and loading criteria. Floors may be designed by the methods outlined in th PCA Bulletin “Concrete Floors on Ground”.
- Plain concrete footings or slabs on grade should only be used where there is assurance that a suitable amount of impermeable subsoil exists, and the strength of plain concrete can resist the design loads applied in accordance with CSA A23.3.

**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:

1. 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.
2. 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. Walls of this type designed to prevent leakage should be reinforced to support the intended loads with:

- A minimum area of vertical reinforcement of 0.0015 x gross section area;
- A minimum area of horizontal reinforcement of 0.002 x gross section area;
- Vertical and horizontal reinforcement spaced no further apart than 500 mm or 3 times the wall thickness.
- 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. ACI 350 recommends steel ratios ranging from 0.002 to 0.006 for lengths exceeding 30 m. For in-barn shallow gutters that are arguably less critical than municipal sewage structures or deep manure tanks, the amount of steel can be reduced to midrange of these values. 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 (See “Specified Loads”). 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.

**Fig. 3. Three methods for wall-to-floor sealing for typical shallow gutter hog barns.**

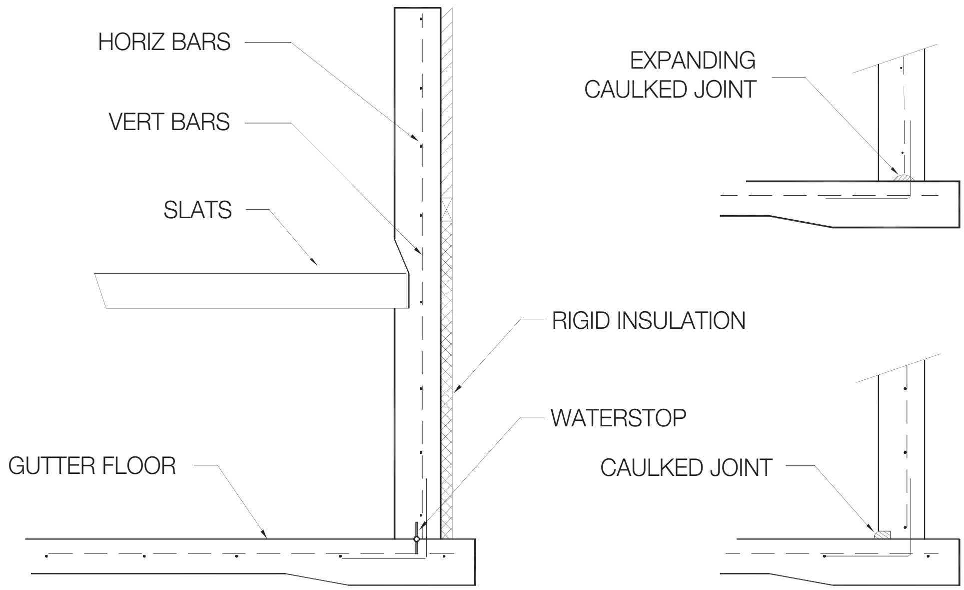
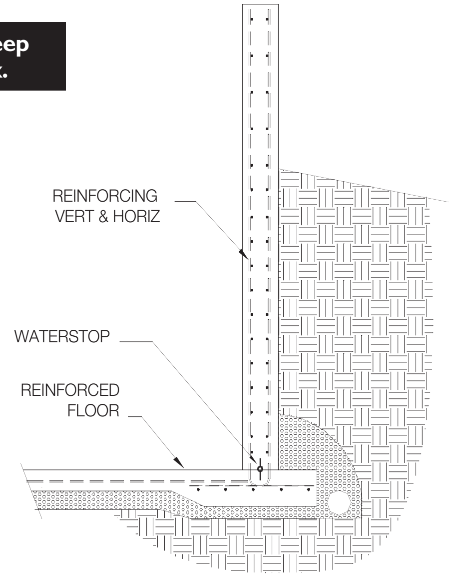



**Fig. 4. Typical detail for a deep circular manure tank.**



**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/CM Ratio [1*] | Typical Strength [2* 3*] |
|---|---|---|---|
| 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, 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 |

1* W/CM "water to cementing materials ratio" is used to indicate that cementing material other than portland cement is available and often recommended for modern concrete mixes.
2* Strength varies with the type of cement, type and amounts of cementing materials, and properties of the aggregates.
3* Type 50, sulphate resistant cement, and mixes with fly ash, cure more slowly than normal portland cement; reference strength of 56 days is recommended for these vs 28 day for normal Type 10 cement. CSA A23.1 (2000), Table 12.

**Table 3. Properties of concrete as related to the W/CM ratio. 1***

| W/CM Ratio 1* | Approx. Strength MPa 2* 3* | Attack by Sulphates 4* Type - 10 | Attack by Sulphates 4* Type - 50 | Permeability ($10^{-12}$ m/s) 5* |
|---|---|---|---|---|
| 0.65 | 18 – 23 | 4.8 | 4.3 | 25 |
| 0.55 | 22 – 27 | 4.6 | 3.2 | 8 |
| 0.45 | 30 – 35 | 4.4 | 2.3 | 3 |
| 0.35 | 40 – 48 | 1.3 | 1.2 | 1 |

1* W/CM "water to cementing materials ratio" is used to indicate that cementing material other than portland cement is available and often recommended for modern concrete mixes.
2* Strength varies with the type of cement, type and amounts of cementing materials, and properties of the aggregates.
3* Type 50, sulphate resistant cement, and mixes with fly ash, cure more slowly than normal portland cement; reference strength of 56 days is recommended for these vs 28 day for normal Type 10 cement. CSA A23.1 (2000), Table 12.
4* From PCA "Effects of Substances on Concrete" (2001), Fig. 2. (Visual rating: 1 = best; 5 = worst)
5* From "Design and Control of Concrete Mixtures" (Canadian edition).

**Notes**

- Water/cementing materials ratio is the principal design property of the mix. It is evident from Tables 2 & 3 that the water-tightness and chemical resistance are significantly affected. Strength is proportional to the w/cm ratio, but also varies with properties of the aggregate.

- Air entrainment - enhances water tightness, durability and resistance to chemical attack and freeze-thaw cycles. All concrete for manure storage should have entrained air in accordance with CSA A23.1 (2000), Tables 10 and 12.

**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 50 cement is recommended for improved sulphate resistance; it is readily available and normally supplied in the Prairie Provinces. In areas where Type 50 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). Manure pits ventilated by open floor slats or equivalent, receive sufficient curing in use that the severe condition above need not apply.

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.)

**CURE, CURE, THEN CURE SOME MORE!**

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. CSA A23.1 and other references provide extensive recommendations for meeting these conditions.

**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.

For large or environmentally sensitive projects, or for any job for that matter, the following documentation and quality control is recommended:

- Retain a copy of the concrete suppliers "mix/delivery ticket" which states all the pertinent properties of the concrete mix.
- 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 plus the curing and protection applied by the contractor.

**Cover for Reinforcing Steel**

Adequate concrete cover is required to protect reinforcing steel from corrosive environments and to develop the required design strength. CSA A23.1 and A23.3 provide specific references for concrete cover. The following table is from CSA A23.1.

Given that liquid manure is a moderately corrosive environment with exposure to sulphates and hydrogen sulphide, the more severe of the above requirements is recommended.

**Table 4. Minimum cover for reinforcing steel, from CSA A23.1-2000 (Table 9).**

| Application | Bar Size | Cover (mm) | |
|---|---|---|---|
| | | Normal | Corrosive |
| Cast Against Earth | All | 75 | n/a |
| Liquid Manure | 20M – 50M<br>10M, 15M | 50<br>40 | 60<br>60 |
| Solid Manure | All | 40 | 60 |

**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.

**IT USUALLY PAYS TO EXCEED MINIMUM STANDARDS WHEN IT COMES TO CONCRETE SPECIFICATIONS**

# REFERENCES

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

**References on Concrete Manure Storages**

| REFERENCE | TITLE |
|---|---|
| ACI - 350 | Code Requirements for Environmental Engineering Concrete Structures, and Commentary (2001) |
| ACI - 504 | Report: "Guide to Joint Sealants for Concrete Structures" |
| CPCI | Precast/Prestressed Concrete Effluent Treatment and Storage Tanks |
| CSAE Journal | Structural design of liquid manure tanks, Vol 38, No 1, 1996 |
| NFBC | National Farm Building Code of Canada |
| CFBA | Canadian Farm Builders Association Concrete Specifications |
| CSA - A23.3 | Design of Concrete Structures |
| CSA - A23.1 | Concrete Materials and Methods of Concrete Construction. |
| ASAE EP 393.2 | Manure Storages (Environmental practices bulletin) |
| MWPS-18 | Manure Storages |
| MWPS TR-9 | TR-9: Circular Concrete Manure Tanks |
| MWPS-36 | Concrete Manure Storages Handbook |
| NBC | National Building Code of Canada |
| CAC | Design and Control of Concrete Mixtures, 7th Can. Edition |
| CRMCA | Links to provincial ready mix associations |
| PCA | Circular Concrete Tanks Without Prestressing<br>Rectangular Concrete Tanks<br>Concrete Floors on Ground<br>Effect of Substances on Concrete (2001) |

**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

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