Reinforced Concrete Wall Design Basics

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Structural Concrete Design Requirements

- “American Concrete Institute Building Code Requirements for Structural Concrete (ACI 318)” which is referenced in NRCS Conservation Practice Standard 313 – Waste Storage Facility.
Typical Structural Concrete Wall Loadings

- Lateral Soil Backfill Loads (depends on soils type)
- Lateral Equipment Loads
- Vertical Wall Loads (structural slab or push-off ramp bearing on top of wall)
- Lateral Manure Loads
Structural Loadings

Common External Loadings
- Backfill pressure
- Equipment Loads

Common Internal Loadings
- Manure Fluid Pressure

Other Loadings to Consider
- Impact Loads
- Hydrostatic Pressure (Lateral and Uplift)
- Internal Ice Pressures (Lateral)
- Frost Pressure (Lateral and Uplift)
STABILITY VS. STRENGTH DESIGN

• STABILITY DESIGN
  ✓ OVERTURNING
  ✓ SLIDING
  ✓ BEARING PRESSURE

STABILITY DESIGN USES ACTUAL LOADS AND SAFETY FACTORS AND ASSUMES THE WALL AND FOOTING ARE INFINITELY STIFF
STABILITY VS. STRENGTH DESIGN

• STRENGTH DESIGN
  ✓ BENDING
  ✓ SHEAR
  ✓ (TORSION)
  ✓ (BUCKLING)

STRENGTH DESIGN USES:
• LOAD FACTORS AND
• STRENGTH REDUCTION FACTORS

RATHER THAN “SAFETY FACTORS”
STRENGTH DESIGN

EXAMPLE OF ONE FACTORED LOAD COMBINATION

\[ \phi U \geq 1.2D + 1.6H + 1.6L \]

- CAPACITY (STRENGTH) OF REINFORCED CONCRETE
- STRENGTH REDUCTION FACTOR VARIES FROM 0.90 FOR BENDING TO 0.75 FOR SHEAR
- LOAD FACTORS
- LOAD FACTOR FOR BACKFILL RESISTING “FULL MANURE” CASE IS 0.90
- DEAD LOAD
- LATERAL EARTH PRESSURE
- LIVE LOADS (EQUIPMENT)

LOAD FACTOR FOR BACKFILL RESISTING “FULL MANURE” CASE IS 0.90
LOAD SCENARIO 1: MAXIMUM EXTERNAL LOADS AND EMPTY INSIDE

Backfill side with Equipment Loads

Manure side: Empty

Equipment Load Diagram: Equivalent to an additional 2 feet of uniform soil loading
LOAD SCENARIO 2: FULL INSIDE WITH MINIMUM BACKFILL

Backfill side without Equipment Loads

Manure side: Empty

Backfill Height

Manure Pressure Diagram

Backfill Pressure Diagram
WALL SUPPORT

Cantilevered Wall

Free Top

Fixed Base
(requires either embedded or expansive waterstop)

Simply Supported Wall
(740 Drawing Series Tanks)

Pinned Top
(either tied to slab or supported internally by beams)

Pinned Base
(movement joint requiring embedded waterstop)
MAXIMUM BENDING STRESSES IN WALL STEM

Cantilevered Wall

- Load
- Wall movement under load (exaggerated)
- Maximum Stress Point at Wall Base
- Tension Face

Simply Supported Wall

- Load
- Wall movement under load (exaggerated)
- Maximum Stress Point at approximately Mid-Height of wall
- Tension Face
MAXIMUM BENDING STRESSES IN FOOTINGS

Cantilevered Wall (Fixed Base)

- Tension Face Heel
- Footing movement under load (exaggerated)
- Heel

- Maximum Stress Point in Footing is at Face of Wall
- Footing movement under load (exaggerated)
- Tension Face Toe

- Load
- Toe

USDA
FOOTING BEARING PRESSURE

LOAD: Lateral soil and equipment surcharge

Backfill side

LOAD: Weight of wall and footing

Backfill weight

Manure side: Empty

Soil Bearing Pressure

Maximum Bearing Pressure
STRENGTH STEEL – CANTILEVERED “T” WALL

- Backfill side
- Wall Stem
- Manure side
- Footing

Strength steel for external loading
Strength steel for internal loading
Footing strength steel
HORIZONTAL STEEL (Temperature and Shrinkage Steel)
What Determines the Strength of a Reinforced Concrete Section (rebar and concrete acting together)?

- 28 day compressive strength of concrete ($f'_c$)
  - 3,500 or 4,000 psi minimum
- Grade of Rebar ($f_y$)
  - Usually Grade 60 (60,000 psi yield strength)
- Amount of rebar ($A_s$)
  - (size and spacing)
- Location of Rebar relative to compressive face of concrete ($d$)

Let’s take a look at these in a little more detail and see what happens if the parameters for a particular design are not met.
STRENGTH OF REINFORCED CONCRETE SECTIONS

✓ 28 day compressive strength of concrete ($f'_c$)

If the concrete strength requirements are not met:

- Durability will be affected
- Possibly failure under high loads, particularly in the long term when water (freeze-thaw) have deteriorated the sand/cement matrix of the concrete.
STRENGTH OF REINFORCED CONCRETE SECTIONS

✓ Grade of Rebar ($f_y$)

The project calls for Grade 60 and Grade 40 is used:

Example: 10” thick wall
3500 psi concrete
2.5” clear to strength steel
#5@10

BENDING STRENGTH OF THE SECTION HAS BEEN REDUCED BY OVER 30%
STRENGTH OF REINFORCED CONCRETE SECTIONS

✓ Amount of rebar ($A_s$)

The project calls for #5@10” and #5@12” are used:

**Example:** 10” thick wall
3500 psi concrete
2.5” clear to strength steel
#5@12” rather than the designed #5@10”

BENDING STRENGTH OF THE SECTION HAS BEEN REDUCED BY ABOUT 16%
LET’S TRY THAT AGAIN A LITTLE DIFFERENTLY

✓ Amount of rebar ($A_s$)

The project calls for $#5@10”$ and $#4@10”$ are used:

Example: 10” thick wall
3500 psi concrete
2.5” clear to strength steel
$#4@10”$ rather than the designed $#5@10”$

BENDING STRENGTH OF THE SECTION HAS BEEN REDUCED BY ABOUT 35%
STRENGTH OF REINFORCED CONCRETE SECTIONS

✓ Location of Strength Rebar relative to compressive face of concrete (d)

  What does “compressive face” mean?

  What does “strength rebar” mean?
COMPRESSIVE FACE & STRENGTH REBAR

Cantilevered Wall

Simply Supported Wall

Load

Wall movement under load (exaggerated)

Compressive Face

Tension Face

Load

Wall movement under load (exaggerated)

Compressive Face

Compressive Face

Tension Face
Cantilevered Wall
(Fixed Base)

Load

Compressive Face

Tension Face Toe

Footing movement under load (exaggerated)

Tension Face Heel

Compressive Face

Footing movement under load (exaggerated)

Heel

Toe
COMPRESSIVE FACE & STRENGTH REBAR

Cantilevered Wall

- **Load**
- **Compressive Face of Wall**
- **Compressive Face of Footing Toe**
- **Compressive Face of Footing Heel**
- **Backfill side**
- **Strength Rebar**

- **Manure Side**
- **Load**
- **Strength Rebar**

- **Backfill side**
- **Compressive Face of Wall**
- **Compressive Face of Footing Heel**
- **Compressive Face of Footing Heel**

- **USDA**
STRENGTH OF REINFORCED CONCRETE SECTIONS

Load

Strength Rebar

Rebar

$d$

[Diagram showing the strength of reinforced concrete sections with load applied and rebar reinforcement indicated.]
The location of the strength rebar relative to the compressive face of the concrete (d) is measured from the center of the strength steel to the compression face of the concrete. "Clear cover" is measured from the tension face of the concrete to the surface of the "strength" steel.
STRENGTH OF REINFORCED CONCRETE SECTIONS

✓ Location of Strength Rebar relative to compressive face of concrete (d)

The project calls for clear cover of 2 inches and the strength steel is installed with a clear cover of 3 inches:

Example: 10” thick wall
3500 psi concrete
#5@10
3” clear rather than the designed 2” clear

BENDING STRENGTH OF THE SECTION HAS BEEN REDUCED BY ABOUT 15%

SHEAR STRENGTH AT WALL BASE HAS BEEN REDUCED BY ABOUT 14%
SUMMARY
STRENGTH OF REINFORCED CONCRETE SECTIONS

• 28 day compressive strength of concrete ($f'_c$)
  3,500 or 4,000 psi minimum
• Grade of Rebar ($f_y$)
  Usually Grade 60 (60,000 psi yield strength)
• Amount of rebar ($A_s$)
  (size and spacing)
• Location of Rebar relative to compressive face of concrete ($d$)
New 8 Ft and 10 Ft Fixed Based (Cantilevered) wall designs:

• now posted on the Engineering pages of the Wisconsin NRCS Website
  ✓ 8-ft walls x 10 inches thick
  ✓ 8-ft walls x 12 inches thick
  ✓ 10-ft walls x 12 inches thick

• Also, new joint drawings posted
  ✓ Slab to slab joints
  ✓ Wall to footing joints
  ✓ Wall to wall joints

http://www.nrcs.usda.gov/wps/portal/nrcs/detail/wi/technical/engineering/?cid=nrcs142p2_025429
Questions / Comments?

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