How loadings Applied to Retaining Wall

(in design of WI NRCS standard wall drawing for manure storage)

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Wall in field
Wall in field
Wall in field
Wall in Field
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Wall on drawing
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### STEEL SCHEDULE (GRADE 60)

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* Marks (J & K) bars for corner details.

### STEEL DETAILS

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<tr>
<th>MARK</th>
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<th>BEND DIAMETER (INCHES)</th>
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<tr>
<td>#0</td>
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<td>3 - 3/4</td>
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**SLIDING RESISTANCE**

Walls are intended for ag waste storage facilities (WSF) with an opposing wall and similar backfill depths on all sides for sliding restraint. Other conditions require sliding restraint to be analyzed using a coefficient of friction between concrete and soil of 0.5 or less.

**DESIGN VALUES**

Earth backfill: 80 PSF/ft, equivalent fluid pressure 115 PSF (soil weight) and 0 to 100% fines
Water: 72 PSF/ft, equivalent fluid pressure
Machine loading: 170 PSF equal fluid pressure representing machinery load on soil (2-2,500 lb wheel loads 4 feet away)
Ultimate strength design (ACI 318-11)
Concrete: Strength 3,500 psi
Rebar: Grade 60
Coefficient of friction (soil/concrete) = 0.5
Minimum sliding factor of safety = 1.5
Wall sliding restraint required
Minimum overturning factor of safety = 2.0 min.
Footing reaction resultant in module (one-three)
Allowable surcharge bearing capacity = 1500 PSF
Vertical wall load for slabs bearing on walls or push-off = 1000 lbs/ft

Not designed to support buildings or roofs
Wall on design board
Source of Loadings:

• From backfill soil
  We use soil density of 110 lb/ft$^3$ for all soils.

• From machinery
  Also called *surcharge*. We limit it to *2-5000 lb wheel loads 4 feet apart*.

• From Manure
  We conservatively use 72 lb/ft$^3$ for all types of manure.
How Soil Exerts Loading to Wall?

- Soil weight generates vertical pressures to wall footing.
- Pressure on wall footing is proportional to backfill depth (H).
- Total weight ($W_s$) of soil on footing:
  $$W_s = \gamma_s H L$$
How Soil exerts loading to Wall? (cont.)

Soil, like fluid generates lateral pressure to the wall stem. As depth (h) increases, vertical pressure in soil increases, so lateral pressure increases proportional:

$$P = K_o \gamma_s h$$

$K_o$ is soil lateral pressure coefficient. It is complicated, varies with soil types and how wall reacts to soil pressure. For simplicity and to be conservative, we treat wall as it is _At-Rest_ and use just two values of $K_o$ to cover all types soil.
How Soil Exerts Loading to Wall? (cont.)

For light soils (less than 50%, GP, GW, SP, SW, SM, SC, GM, GC), \( K_o = 0.545 \)

So, \( P = K_o \gamma_s h = (0.545)(110)(h) = 60h \) (lb/ft\(^2\)-ft)

The 60 is **Equivalent Fluid Pressure (EFP)** for light soil.

For heavily soil (more than 50% fine, MLCL, MH, CH), \( K_o = 0.773 \)

So, \( P = K_o \gamma_s h = (0.773)(110)(h) = 85h \) (lb/ft\(^2\)-ft)

The 85 is **Equivalent Fluid Pressure (EFP)** for heavy soil.
Machinery Loading Types

- Machinery on Soil.
- Machinery on Structural Slab on Wall.
- Machinery on Non Structural Slab.
Machinery on Soil

Beyond 1:1 line, the machinery has no or little effect on wall. In our design we still allow equipment less then 2000 IB inside 1:1 line.
Within 1:1 line, machinery causes additional vertical pressure and lateral pressure to wall. Simplified pressure diagram resembles the effect of additional soil on top of ground. We use additional **two feet** of soil for machinery surcharge as required by NRCS 313 standard:

“If heavy equipment will be operated near the wall, an additional surcharge equivalent to two feet of soil shall be applied in the wall analysis.”
Machinery on Soil (Cont.)

The “two feet additional soil” as machinery loading will increase lateral pressure on wall by:

for light soil, \[ \Delta p = (2)(\gamma_s)(K_o) \]
\[ = (2)(110)(0.545) \]
\[ = 120 \text{ (lb/ft}^2) \]

for heavy soil, \[ \Delta p = (2)(\gamma_s)(K_o) \]
\[ = (2)(110)(0.733) \]
\[ = 170 \text{ (lb/ft}^2) \]
Machinery on Structural Slab on Wall

No increase to lateral pressure due to “bridge” effect.

Will add a vertical loading on top of wall and increase loading to wall footing, hence affect on the pressure the footing to the foundation soil (contact pressure).
Machinery on Non Structural Slab Adjacent to or on Wall

- Will increase soil lateral pressure to wall but less than machinery directly on soil due to slab’s pressure dissipating effect. Instead of 170 lb/ft² (two feet heavy soil’s EFP), we use 45 EFP as surcharge from machinery on non structural stab on 8 feet backfill. Non structural slab’s “cushion effect” decreases as backfill depth decreases. When backfill is less than 4 feet, no reduction is considered.

- All new 8 feet wall has been designed for machinery on soil. The use of non structural slab doesn’t come into design for steel saving purpose.
Manure loading to Wall

Manure likes liquid puts vertical pressure to Wall footing and lateral pressure to wall stem.

In design, we use 72 lb/ft$^3$ as manure unit weight ($\gamma_m$), therefore the lateral pressure $p$ on wall at depth $h$ (from surface of manure) is:

$$p = \gamma_m(h) = (72)(h)$$
Loading Condition One (LCD1)

In design, we use the term of LCD1 for worst loading combination. Typical it is:

- Full backfill.
- Machinery on soil.
- No manure inside.

This loading condition normally generates the highest bending stress (bending moment) and shear stress at wall base (A) and at end of toe (B).

We start design (structural analysis) with LCD1, then check against the Loading Condition Two (LCD2) and other situation as needed.
Loading Condition Two (LCD2)

Loading Condition Two (LCD2) is the opposite to LCD1, which alternates the tension and compression faces of wall stem and footing in the LCD1 and results in the extreme values also. Typical it is:

• Lowest backfill.
• No machinery surcharge.
• Full manure inside

This loading condition causes wall bend to backfill side and results wall stem tension face to be on manure side and also generates highest bending (and shear) stress at wall base (A). The footing normally has the highest bending (and shear) stress at end of heel (B).
Wall Needs Steel for Reinforcement

- Concrete has high compression strength ($f_c$) and relatively low flexural strength or tensile strength ($f_t$) we speak of in this presentation.
- Normally, $f_t=(0.07 \sim 0.12)(f_c)$. For concrete of 35,00 psi, $f_t=(0.07)(3500)=245$ psi
- Steel has very high tensile strength. For grade 60 steel, $f_t=60,000$ psi
- Put steel in wall’s tension stress region can greatly increases wall’s flexural strength.
- Structural analysis need identifies:
  - $A_s$ – the minimum amount steel needed (rebar size, spacing).
  - $d$ – the steel location in the wall (from compression surface to the center of steel).
Wall Stability (No Overturning)

- All lateral forces (pressures) to wall tend to overturn the wall.
- All vertical forces (pressures) on footing including footing weight resist wall overturning.
- The resultant overturning resisting moment \((M_r)\) must be greater than resultant overturning moment \((M_o)\).
- \(M_r/M_o \geq 2.0\) is used in our design as the minimum overturning safety factor.
Wall Stability (No negative pressure under footing)

- The contact pressure under the footing shall be less than foundation soil’s bearing capacity.
- Under any loading conditions, there shall be no negative pressure under the footing. Pressure at both toe and heel of the footing shall be positive.
Wall Stability (No Sliding)

- Horizontal force (P) to wall push wall for sliding. Sliding resistance comes from the friction force generated by the total weight (W) (weight of wall plus any soil’s weight over the footing) and resistant force from soil the wall sliding into, if there is.

- If sliding resistant force (R) is less then 1.5 times of sliding driving force (P), additional source of sliding resistance must be added, like adding restraint slab to increase the total friction force.
Closing Thoughts for the Presentation:

• Do not deviate from standard wall drawing requirements.

• Pay close attention to wall base (the bottom of wall stem) construction since it is the most critical section of wall stem in wall design. Steel has very high tensile strength, but can bend easily due to its small cross section. Missing concrete or pool consolidation, and foreign object intrusion in the wall base section will reduce support to the steel and can cause wall failure.
Possible Modes of Failure for Free-Standing Concrete Cantilever Retaining Wall (Bring to Home Images)