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1.1 Introduction

All Calculations have the same basic form:

1. Define the geometry of the wall section
   - wall height
   - back-slope and toe-slope conditions
   - minimum wall embedment
   - leveling pad geometry*

2. Define the parameters for design
   - moist unit weight of the soil \( \gamma \)
   - angle of friction \( \phi \)
   - cohesion \( c \) – if applicable
   - leveling pad type*
   - external surcharge loads and forces
   - seismic accelerations – if applicable
   - water location and elevation

3. Calculate the forces and moments of the geometry

After all the forces and moments have been calculated, the design methods suggest how the forces are applied and the resulting stability is determined. The basic design approach is the same regardless of the design method.

*ReCon walls may be constructed with either a crushed stone or an unreinforced concrete leveling pad. The subtle differences between the two types of leveling pads and its effect on design will be discussed throughout the manual as applicable.

1.2 Earth Pressure Theory

Earth pressures are generally calculated using closed form equations developed by Coulomb (1776) or Rankine (1857).
Both methods solve for the same geometry, but different assumptions on wall friction lead to different results. A linear failure plane is assumed to occur within the soil mass. The weight of that wedge of soil is calculated as \( W \), acting vertically down. Friction along the sliding plane defined by \( \phi \) yields an upward vector component. The lateral earth pressure (\( P_a \)) can be simplified to the following equation for cohesionless soils:

\[
P_a = \frac{1}{2} K_a \gamma H^2
\]

Where \( \gamma \) is the moist unit weight of the soil, \( H \) is the design height of the wall, and \( K_a \) is the coefficient of active earth pressure. \( K_a \) can be solved by either the Rankine or Coulomb method. The difference comes about by the assumption of wall friction at the back of the face.
1.2.1 **Coulomb**

Coulomb’s equation accounts for wall batter \( (i) \) and accounts for wall friction \( (\delta) \) returning much more realistic results.

The full coulomb equation is:

\[
K_a = \frac{\cos^2(\phi - i)}{\cos^2(i) \cos(\delta + i) \left(1 + \sqrt{\frac{\sin(\phi + \delta) \cdot \sin(\phi - \beta)}{\cos(\delta + i) \cdot \cos(i - \beta)}}\right)^2}
\]

All ReConWall gravity wall design options utilize Coulomb earth pressure theory to calculate lateral earth pressures.
1.2.2 Coulomb Trial Wedge

In situations where the slope breaks within the assumed failure plane, the closed form of the Rankine or Coulomb equation is no longer accurate. In the diagram below, notice that if the slope continued there would be more mass to the failure wedge, thus more earth pressure to retain.

The Coulomb equation can be rewritten as follows:

\[ P_a = \frac{\sin(\rho - \phi)}{\sin(90 + i + \delta - \rho + \phi)} W \]

Where \( W \) is the effective weight of the soil wedge. ReConWall calculates the area of the soil wedge and multiplies the area of the soil wedge by the density of the retained material. ReConWall calculates \( P_a \) for incremental values of \( \rho \), and returns the critical resultant.

1.2.3 Rankine

Rankine assumes \( \delta = \beta \) and does not account for wall batter, which produces much more conservative results.
Rankine assumes a plastic state of stress in the soil where the inner and outer failure planes are in the soil. Since there is no failure plane between the driving and resisting wedges, no wall friction can develop.
Chapter 1 - Design Theory

The full Rankine equation is:

\[ K_a = \cos \beta \cdot \frac{\cos \beta - \sqrt{\cos^2 \beta - \cos^2 \phi}}{\cos \beta + \sqrt{\cos^2 \beta - \cos^2 \phi}} \]

For walls with a level backslope (i.e. \( \beta = 0, \delta = 0 \)) the Rankine equation simplifies to:

\[ K_a = \tan^2 \left( 45 - \frac{\phi}{2} \right) \]

The assumption for the development of Rankine’s active pressure along the inner failure plane is theoretically correct if the shear zone is not obstructed by the stem of the wall. The Coulomb theory is necessary for the design of retaining walls for which the back face of the wall interferes with the development of the full sliding surfaces in the backfill soil assumed in the Rankine theory. Coulomb wedge theory applies for gravity, semi-gravity and prefabricated modular walls with relatively steep back faces, and concrete cantilever walls with short heels.

1.2.4 Cohesion

Cohesive soils are fine grained clay type soils (CH, CL). Cohesion is the force that holds together molecules or "like" particles within a soil. In geotechnical practice total stress and effective stress are used in design.

**Total Stress:**
The total stress case is short-term. Short-term being the time before drainage is achieved within the soil sample. In this case, soil cohesion or negative pore water pressure is the controlling force. For bearing capacity, short term slope stability, and construction cuts, total stress is assumed to control and must be checked.

**Effective Stress:**
Effective stress is the condition where drainage has occurred. In terms of soil mechanics, it is the total stress minus the pore water pressure.

\[ \sigma' = \sigma - u \]

For slope and retaining wall design, effective stress is considered the controlling design condition. ReConWall software does allow a moderate input of cohesion in the retained soil, though most design software and design manuals recommend ignoring cohesion for retaining wall design. WE STRONGLY RECOMMEND THAT THE USE OF COHESION IN DESIGN (EVEN IN
Chapter 1 - Design Theory

MODERATION) SHOULD ONLY BE USED BY AN ENGINEER THAT UNDERSTANDS THE PROPERTIES OF COHESIVE SOIL, IS AWARE OF HOW RECONWALL MODELS COHESION IN DESIGN, AND UNDERSTANDS THE FULL IMPACT OF COHESION ON THE RETAINING WALL DESIGN.

Calculations with cohesion:

In effective stress design, the earth pressure is calculated as $\gamma*H^2*ka$, where $ka$ is the active earth pressure coefficient. The active driving force is calculated as:

$$ Pa = \frac{1}{2} \gamma H^2 ka $$

With cohesive soil, the negative pore water pressure creates a negative force in the soil. As you can see below, the cohesive pressure is $2c\sqrt{ka}$ as determined from a Mohr Coulomb relationship. This negative pressure at the top of the wall eliminates any force being applied to that portion of the wall.

$$ Pa = \frac{1}{2} \gamma (H^2) ka - 2c\sqrt{ka} $$
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The height (h) where zero pressure exists is given as:

\[ h = \frac{2 \cdot c}{\gamma \cdot \sqrt{ka}} \]

The critical height (Hc) to which the soil could be excavated without failing is given as:

\[ Hc = \frac{4 \cdot c}{\gamma \cdot \sqrt{ka}} \]

In other words, "Hc" is the height to which ZERO force would be applied to a retaining wall (if the full cohesive force were maintained for the life of the wall).

For a fine grained soil weighing 120 pcf and having 100 psf of cohesion, the critical height could be in excess of 5 ft. (sample ka = .390). A cohesion of 400 psf would return a critical height of over 20 feet. This demonstrates the significant effect that cohesion can have on retaining wall design and emphasizes the CAUTION that must be used when considering cohesion in design. The analysis would say a 20 ft tall cut would be stable without any sort of retaining structure to stabilize the cut. This may be ok for short term cuts during construction, but the long term stress may exert considerably more force.

While the above equations demonstrate a negative earth pressure at the upper portion of a wall, this does not account for long term effects of cohesive soil such as tensile cracks or long term creep. Because of these long term effects, ReConWall does not consider the negative cohesion force generated near the top of the wall. To that point ReConWall assumes the pressure at the base of the wall is reduced by the full amount of cohesion, but that the location of zero force is always at the top of the wall. This method is demonstrated with the following pressure diagram:

\[ Pa = \frac{1}{2} \gamma (H^2)ka - cH\sqrt{ka} \]

\[ \gamma Hka - 2c\sqrt{ka} \]

The above graphic represents the full wall height "H". However, ReCon is modular and the earth pressure is calculated at each module. For the modules located above the location of ZERO
pressure, "h", the software will present no earth load.

**Drainage Stone**

One additional item to consider when designing with cohesion is the effect of drainage stone on the wall. The software does not have the capacity to model a Coulomb failure plane through more than one type of soil. When designing without cohesion the drainage stone is typically a higher quality material than the retained soil and thus it is conservative to ignore the impact of drainage stone on the design. The software may consider the shear strength of the drainage stone in consideration of the friction along the failure plane, but ReConWall does not consider the drainage stone in the consideration of earth pressure. When cohesion is introduced in design, it is possible that the drainage stone may impart more load on the wall than the retained soil, especially in the upper portions of the wall where the cohesive soil applies no pressure to the wall.

When a wall is constructed in cohesive soil, it is not uncommon to make a near vertical construction cut. Given the physical properties of a cohesive soil the wall is typically backfilled with a non-cohesive material that can be more easily compacted to the necessary density. Below is a typical cross section of a cut gravity wall in cohesive soil.

![Cross section](image)

You can see from the graphic that the majority of the load on the upper portions of the wall will be created from the backfill (drainage stone) as opposed to the "retained" (in situ) soil. As mentioned above, in most cases the wall backfill is a higher quality material and will produce less force than the assumed "retained" soil. Once cohesion is introduced in the retained soil this may no longer be the case. Where the software may assume ZERO load (top few courses of the wall) some load may exist due to the backfill material (typically drainage stone). **In many cases this load may not be enough to justify a block larger than 24 inches, but the designer MUST consider the condition to determine if the design is sufficient at all block layers.** One approach would be to design the upper portion of the wall as a separate design section with the retained soil modeled with the backfill (drainage stone) material.

**Surcharge Loads**
Surcharge loads create an additional force on the wall as a function of the surcharge load, "q". The pressure on the wall is calculated as $q \times ka$ with the uniform force, $q \times ka \times H$ applied at a height of $H/2$. Earth loads and surcharge loads are kept separate because of the load distribution and how they impact the wall.

Because a surcharge load is distributed uniformly across the wall height it is important that the surcharge force remain uniform. This means that when cohesion is introduced into the design the surcharge load will only be reduced once the earth pressure has been reduced to ZERO.

**WARNINGS:** (against using cohesive materials in wall construction)
1. High plastic clays can experience long term creep. When installed in a plastic state, they may creep and eventually exert an “at rest” earth pressure on the structure.
2. Clay soils do not drain well, thus hydrostatic pressures may build up behind the placed soil causing more outward driving forces.
3. In high plastic clays, the zone of zero tension at the top of the wall may develop into a tension crack and fill up with water. Most slope stability programs will include options for tension cracks in the analysis methods. ReConWall does not. Water pressure can exert a significant force on the upper portion of the slope.

**WARNINGS:** (against using cohesion in design)
1. As the soils drain they will tend back toward an effective state of stress where in the long term the soil may only have a fraction of the initial cohesive strength.
2. When cohesive soils become saturated, the cohesion may drop to less than 30% of the peak laboratory value.

### 1.3 Gravity Wall

A ReCon Gravity Wall is a structure that relies on the mass and batter of the ReCon blocks as a stabilizing force. Many specifications refer to these structures as Precast Modular Block (PMB) Walls. The basic stability calculations are similar to those for a mass gravity wall or shallow heal cantilever wall, however the stability calculations are calculated at each block layer.
1.3.1 Geometry

AASHTO LRFD Section 3.11.5.3 suggests that where the surface of sliding is restricted by the top of the wall that the lateral earth pressure be applied to a vertical line drawn from the tail upward and that the full weight of the soil to the left of the line be included as a resisting force.

Coulomb earth pressure is then applied to the vertical plane assuming a $\delta$ angle of $1/3$ to $2/3$ $\phi$. This was the original method used in ReConWall Version 1.

AASHTO LRFD section 3.11.5.9, Lateral Earth Pressure for Prefabricated Modular Walls suggests computing the earth pressure on a plane surface drawn from the upper back corner of the top module to the lower back heel of the bottom module using Coulomb earth pressure theory. Only the soil located between the failure plane and the wall units is used as a stabilizing force.

For this geometry AASHTO recommends using a $\delta$ angle of $\frac{3}{4}$ $\phi$ for a stepped back wall and a $\delta$
angle of $\frac{1}{2}\phi$ for a continuous pressure surface (i.e. uniform block depth).

This is the method used in the current version of ReConWall Analysis Software.

1.3.2 ReCon Wall Geometry

Geometry is the most basic element of design and the magnitude of the “driving” forces is determined by the geometry and strength parameters of the retained backfill. The magnitude of the resisting forces is determined by the geometry of the wall. Once the geometry is completely defined, the design process can begin. ReConWall is programmed around carefully defining and accurately calculating areas, forces, moments, and reactions. The graphics element of ReConWall accurately displays the geometry of the structure being calculated.

Resisting Forces

ReConWall divides the wall area into discrete rectangles and triangles to make it easier for the user to verify the results with hand calculations.

- $W_1$: weight of the wall facing units*
- $W_2$: weight of resisting soil (area defined by the back of the block and the failure plane)

*The sides of ReCon Block units are tapered to allow for the construction of a wall radius. This creates a slight pie shaped void when the blocks are set in a straight alignment. This void is filled with a free draining rock during construction. Because ReConWall assumes a rectangular shape for the block the unit weight of the block was conservatively reduced to account for the inclusion of rock between the blocks. The latest version of the ReCon Series 50 block file breaks each individual unit into volume of concrete and volume of stone and uses this blended unit weight in the design. As a result the, the latest version of the software may break down the resisting weight of the...
blocks into two components: W1, weight of the concrete portion of the block and W0, weight of the stone portion of the block. The default "ReCon Series 50" block files uses a concrete density of 145 pcf (W1) and a drainage stone density of 120 pcf (W0). These values can be adjusted by the user on the "Block Properties" tab.

**Driving Forces**

The driving forces are determined by Coulomb earth pressure theory outlined above.

### 1.3.3 Force/Moment Table

The force table is a summary of the resisting forces and the driving forces. The values shown match the results table shown in the detailed calculations.

<table>
<thead>
<tr>
<th>Name</th>
<th>Factory</th>
<th>Force (V)</th>
<th>Force (H)</th>
<th>X-len</th>
<th>Y-len</th>
<th>Mo</th>
<th>Mr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Blocks (W1)</td>
<td>1.00</td>
<td>5308</td>
<td></td>
<td>2.09</td>
<td></td>
<td></td>
<td>11079</td>
</tr>
<tr>
<td>Soil Fill (W0)</td>
<td>1.00</td>
<td>727</td>
<td></td>
<td>3.07</td>
<td></td>
<td></td>
<td>2232</td>
</tr>
<tr>
<td>Soil Wedge (W2)</td>
<td>1.00</td>
<td>232</td>
<td></td>
<td>3.37</td>
<td></td>
<td></td>
<td>781</td>
</tr>
<tr>
<td>Leveling Pad (W18)</td>
<td>1.00</td>
<td>715</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pa_h</td>
<td>1.00</td>
<td>2701</td>
<td></td>
<td>4.00</td>
<td></td>
<td></td>
<td>10805</td>
</tr>
<tr>
<td>Pa_v</td>
<td>1.00</td>
<td>1999</td>
<td></td>
<td>4.22</td>
<td></td>
<td></td>
<td>8440</td>
</tr>
<tr>
<td>Pq_h</td>
<td>1.00</td>
<td>938</td>
<td></td>
<td>6.00</td>
<td></td>
<td></td>
<td>5628</td>
</tr>
<tr>
<td>Pq_v</td>
<td>1.00</td>
<td>694</td>
<td></td>
<td>3.63</td>
<td></td>
<td></td>
<td>2661</td>
</tr>
<tr>
<td>Sum V/H</td>
<td>1.00</td>
<td>9674</td>
<td>3639</td>
<td></td>
<td>Sum Mom</td>
<td>16433</td>
<td>25194</td>
</tr>
</tbody>
</table>

*Note: live load forces and moments are not included in SumV or Mr as live loads are not included as resisting forces.*

Face Blocks (W1): Mass of ReCon Blocks (concrete)
Face Blocks (W0): Mass of ReCon Blocks (rock infill)
Face Soil (W2): Mass of soil (under the failure plane)
Leveling Pad (W18): Mass of Leveling Pad
Pa_h: Horizontal Component of Earth Pressure
Pa_v: Vertical Component of Earth Pressure
Pq_h: Horizontal Component of Live Load
Pq_v: Vertical Component of Live Load
Pqd_h: Horizontal Component of Dead Load
Pqd_v: Vertical Component of Dead Load

Force (V): Forces acting in the vertical direction.
Force (H): Forces acting in the horizontal direction.

X-len: Length of moment arm in the “X” axis (horizontal) direction.
Y-len: Length of moment arm in the “Y” axis (vertical) direction.

Mo: Overturning moment forces.
Mr: Resisting moment forces.
Once the Wall geometry has been defined the resisting forces and driving forces can be calculated and compared.

1.3.4 Allowable Stress Design (NCMA 09, AASHTO 2002)

The ratio between the available strength and required strength for stability is defined by the factor of safety. In other words, the available strength must be greater than the applied load by a certain amount determined by the desired degree of safety. For various stability analysis the minimum factor of safety should exceed the minimum prescribed value. ReConWall utilizes the Allowable Stress Design for the NCMA 09 and AASHTO 2002 design options. The published minimum factors of safety for each are displayed below.

- NCMA

For Gravity Walls, delta (\( \delta \)) is set to 2/3 phi for single depth walls and 3/4 phi for multi-depth walls.

### Factors of Safety

<table>
<thead>
<tr>
<th></th>
<th>Static</th>
<th>Seismic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Overturning</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Gravity OT</td>
<td>1.50</td>
<td>1.50 G.Found</td>
</tr>
<tr>
<td>Gravity OT (Grav)</td>
<td>1.50</td>
<td>FoS Block/Block</td>
</tr>
<tr>
<td>Bearing (Grav)</td>
<td>2.00</td>
<td>2.00</td>
</tr>
<tr>
<td>Bearing (MSE)</td>
<td>2.00</td>
<td>2.00</td>
</tr>
</tbody>
</table>

#### Local Stability

- Shear: 1.50
- Bending: 1.50

#### Reinforcing FoS

- Uncertainties: 1.50
- Pullout: 1.50

#### Connection

- Peak Conn: 1.50

Seismic [seismic is 75% of static]:
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• AASHTO 2002

For Gravity Walls, delta (δ) is set to 1/2 phi for single depth walls and 3/4 phi for multi-depth walls.

### Factors of Safety

<table>
<thead>
<tr>
<th>Static</th>
<th>Seismic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding</td>
<td>Sliding</td>
</tr>
<tr>
<td>Overturning</td>
<td>Overturning</td>
</tr>
<tr>
<td>Gravity OT</td>
<td>Gravity OT</td>
</tr>
<tr>
<td>Gravity OT</td>
<td>Gravity OT</td>
</tr>
<tr>
<td>Bearing (Grav)</td>
<td>Bearing</td>
</tr>
<tr>
<td>Bearing (MSE)</td>
<td>Bearing</td>
</tr>
</tbody>
</table>

#### Static

| Sliding | 1.50 FoS |
| Overturning | 2.00 FoS |
| Gravity OT | 2.00 FoS Foundation |
| Gravity OT | 1.50 FoS Block/Block |
| Bearing (Grav) | 2.00 FoS |
| Bearing (MSE) | 2.00 FoS |

#### Seismic

<table>
<thead>
<tr>
<th>Sliding</th>
<th>Overturning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity OT</td>
<td>Gravity OT</td>
</tr>
<tr>
<td>Bearing</td>
<td>Bearing</td>
</tr>
</tbody>
</table>

| Sliding          | 1.125 FoS |
| Overturning      | 1.500 FoS |
| Gravity OT       | 1.500 FoS |
| Gravity OT       | 1.125 FoS |
| Bearing          | 1.500 FoS |
| Bearing          | 1.500 FoS |

#### Local Stability

| Shear          | Bending       |

| Shear          | 1.50 FoS |
| Bending        | 1.50 FoS |

#### Reinforcing FoS

| Uncertainties | Pullout       |

| Uncertainties | 1.50 FoS |
| Pullout       | 1.50 FoS |

#### Connection

| Peak Conn      | 1.50 FoS |

For the purposes of block-to-block overturning requirements in gravity walls, the block-to-block interface may be considered as a block on a "rock" foundation. Factor of safety minimums are defined in Section 5.5.5 of the AASHTO 2002 code.

1.3.4.1 External Stability

External stability refers to:

- Sliding
- Overturning
- Bearing capacity

For Gravity walls, ReConWall calculates stability at each block layer, treating each block, and the blocks above it as a rigid structure. ReConWall calculates the driving and resisting forces at each block layer and displays the Factors of Safety of sliding and overturning at each block layer in the results table.
The long printout details the calculations for the tallest section only.

1.3.4.1.1 Sliding

Sliding resistance is the frictional resistance along the base of the structure that is acting to resist the external earth pressure forces applied by the retained soil.

ReConWall calculates sliding between the base block and the leveling pad. ReConWall also checks a secondary location between the leveling pad and the foundation soils.

**Sliding (Between the base block and the leveling pad)**

The Driving Force (Df) in the sliding calculation is the sum of the Horizontal forces (Pa_h, Pq_h)

The resisting force (Rf1) in the sliding calculation is the sum of the vertical forces on the wall (W0, W1, W2, Pa_v, Pq_v) times the friction between the base block and the leveling pad material. Section 10.6.3.4 of the AASHTO manual suggests that if the soil beneath the footing is cohesionless, the nominal sliding resistance shall be taken as:
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\[ Rc = N \tan \delta \]

where:

\[ \tan \delta = 0.8 \tan \phi_f \] for precast concrete footing.

If, for a crushed stone leveling pad, \( \phi_f \) is assumed to be 40°, then the sliding resistance becomes:

\[ Rc = N \tan (33.8) \]

Where, in this case, \( N \) is defined as Sum_V, the sum of all vertical forces.

Actual ReCon sliding test data supports this value, thus the sliding resistance for a base block on a crushed stone leveling pad is simplified to the AASHTO default shown above for all block depths. ReCon test data also shows an insignificant difference in results between a crushed stone leveling pad and a concrete leveling pad. While a case could be made to use a higher friction value for a concrete on concrete interface, the same friction resistance discussed above is used regardless of leveling pad material.

**Sliding (between the leveling pad and the foundation soil)**

ReConWall also checks the sliding calculation between the leveling pad and the foundation soils. In the calculation between the leveling pad and the foundation soils, the weight of the wall is assumed to distribute through the leveling pad at a 1:2 angle.

![Diagram](image)

The calculation of sliding resistance between the leveling pad and the foundation soils is calculated in ReConWall by the following equation:
Rf2 = (\text{Sum}_V + \text{LP})*\tan(\text{phi}) + c*\text{L} + \text{PPlp}

Where:

\text{LP} = \text{weight of the leveling pad material}
\text{phi} = \text{the lesser shear strength of the leveling pad material or the foundation soil}
\text{c} = \text{cohesion}
\text{L} = \text{length along the bottom of the leveling pad.}
\text{PPlp} = \text{Passive pressure developed in front of the leveling pad.**}
PPlp is estimated using Rankine’s equation for passive earth pressure:

\[ P_p = \frac{1}{2} K_p \gamma H^2 \]

\[ K_p = \tan^2 (45 + \phi/2) \]

*Previous version of ReConWall software fixed the leveling pad material properties at \( \phi = 40 \) degrees, \( c = 0 \), and \( \gamma = 130 \text{pcf} \). While ReCon considers these to be reasonable values to be used in design, the leveling pad properties have been added as an input option on the software’s Soils input tab.

**By default ReConWall uses passive pressure only in front of the leveling pad and only for the calculation for sliding of the leveling pad on the foundation soil. At no point should the leveling pad be exposed. Minimum embedment should be determined so that the leveling pad should not be exposed because of scour or other reasons. The option to ignore passive pressure in front of the leveling pad, or to alternately define the depth at which to consider passive pressure in front of the leveling pad has been added to the "Preferences" section of the design software.

A concrete leveling pad greater than 1 ft. in thickness is considered, for design purposes, a "structural" element. In effect, the software will treat the concrete leveling pad as another "block" in the wall with the geometry as defined on the "geometry" tab of the software. The software will consider the design height of the wall to the base of the leveling pad and will analyze sliding along the full base of the leveling pad. Concrete leveling pad properties can be set on the Soils property tab.

### 1.3.4.1.2 Overturning

Overturning is the resistance of the wall blocks to rotating about the front toe.

![Diagram of Overturning](image)

Overturning/Rotation

\[ \text{Force}_1 \]

\[ \text{Width}_1 \]

\[ H \]

Simply stated, the factor of safety of overturning is the ratio of the resisting moments to driving
moments. The overturning and resisting moments can be viewed in the results table.

<table>
<thead>
<tr>
<th>Name</th>
<th>Factor</th>
<th>Force (V)</th>
<th>Force (H)</th>
<th>X-len</th>
<th>Y-len</th>
<th>Mo</th>
<th>Mr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Blocks (W1)</td>
<td>1.00</td>
<td>5308</td>
<td>–</td>
<td>2.09</td>
<td>–</td>
<td>–</td>
<td>11079</td>
</tr>
<tr>
<td>Soil Fill (W0)</td>
<td>1.00</td>
<td>727</td>
<td>–</td>
<td>3.07</td>
<td>–</td>
<td>–</td>
<td>2232</td>
</tr>
<tr>
<td>Soil Wedge (W2)</td>
<td>1.00</td>
<td>232</td>
<td>–</td>
<td>3.37</td>
<td>–</td>
<td>–</td>
<td>781</td>
</tr>
<tr>
<td>Lvl Pad (W18)</td>
<td>1.00</td>
<td>715</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Pa_h</td>
<td>1.00</td>
<td>–</td>
<td>2701</td>
<td>–</td>
<td>4.00</td>
<td>–</td>
<td>10805</td>
</tr>
<tr>
<td>Pa_v</td>
<td>1.00</td>
<td>1999</td>
<td>–</td>
<td>4.22</td>
<td>–</td>
<td>–</td>
<td>8440</td>
</tr>
<tr>
<td>Fq_h</td>
<td>1.00</td>
<td>–</td>
<td>938</td>
<td>–</td>
<td>6.00</td>
<td>–</td>
<td>5628</td>
</tr>
<tr>
<td>Fq_v</td>
<td>1.00</td>
<td>694</td>
<td>–</td>
<td>3.83</td>
<td>–</td>
<td>–</td>
<td>2681</td>
</tr>
<tr>
<td>Sum V / H</td>
<td>1.00</td>
<td>9674</td>
<td>3639</td>
<td>Sum Mom 16433 25194</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: live load forces and moments are not included in Sum V or Mr as live loads are not included as resisting forces.

From the software "Long Printout"  

**OVERTURNING ABOUT THE TOE**  
Overturning at the base is checked by assuming rotation about the front toe by the block mass and the soil retained on the blocks. Allowable overturning can be defined by eccentricity (e/L). For concrete leveling pads eccentricity is checked at the base of the pad.

\[ \text{Moments resisting eccentricity} = M1 + M2 + MSoilInfill + MLvlPad + MPav + MPqv \]
\[ 11079 + 2232 + 781 + 8440 + 2661 \]
\[ \text{Mr} = 25194 \text{ ft-lbs} \]

\[ \text{Moments causing eccentricity} = MPah + MPq + MPqv \]
\[ 10805 + 5628 \]
\[ \text{Mo} = 16433 \text{ ft-lbs} \]

\[ e = L/2 - (\text{Mr} - \text{Mo})/N1 \]
\[ e = 5.00/2 - (25194 - 16433) / 9674 \]
\[ e = 1.52 \]
\[ e/L = 0.30 \]

\[ FSct = Mr / Mo \]
\[ FSct = 25194 / 16433 \]
\[ FSct = 1.53 \]

The "Force and Moments" table in the software, as well as the long printout calculation, only show the values for the tallest wall section. However, the results table shows the results of the overturning calculation at each block layer.
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1.3.4.1.3 Bearing

Bearing capacity is the ability of the soil to safely carry the pressure placed on the soil from any engineered structure without undergoing a shear failure with accompanying large settlements. Applying a bearing pressure which is safe with respect to failure that does not ensure that settlement of the foundation will be within acceptable limits. Settlement analysis is beyond the scope of the ReConWall software and a separate settlement analysis should be performed.

For ReConWall, bearing capacity is calculated at the base of the leveling pad (on the native soil). The weight of the wall is distributed though the leveling pad at a 1H:2V angle.

![Stress distribution through leveling pad](image)

For a structural concrete leveling pad (>12 inches), the weight of the wall system is distributed along the full base of the leveling pad.
1.3.4.1.3.1 Ultimate Bearing Capacity

Ultimate bearing capacity \( Q_{\text{ult}} \) is calculated according to the following equation (for a strip foundation):

\[
Q_{\text{ult}} = cN_c + qN_q + 0.5\gamma B'N_g
\]

Where the quantities \( N_c \), \( N_q \), and \( N_g \) are dimensionless bearing capacity coefficients (after Vesic) and:

\[
c = \text{cohesion} \\
q = \gamma \times D \quad (D = \text{depth of soil from finished grade to bottom of leveling pad}) \\
\gamma = \text{unit weight of foundation soils}. \\
B' = \text{effective footing width at the base of the leveling pad}. \quad (B' = B - 2e + lvlpad)
\]

Eccentricity causes the resulting force to be forward of the center of the base, reducing the effective bearing area, and in turn, increasing the applied bearing stresses.

Eccentricity can be calculated as follows:

\[
e = L/2 - (\sum M_r - \sum M_o) / \sum V
\]

Where:

\[
e = \text{eccentricity} \\
L = \text{Length of the base block} \\
\sum M_r = \text{Sum of resisting moments} \\
\sum M_o = \text{Sum of overturning moments} \\
\sum V = \text{Sum of vertical forces}
\]

1.3.4.1.3.2 Allowable Bearing Capacity

The allowable bearing capacity, \( Q_a \), is the ultimate bearing capacity \( Q_{\text{ult}} \), divided by an appropriate factor of safety, FS.

\[
Q_a = \frac{Q_{\text{ult}}}{FS}
\]

In the case where the allowable bearing capacity is specified by a site specific geotechnical report, the designer may choose to evaluate the calculated applied bearing capacity to the specified allowable bearing capacity rather than the allowable bearing capacity calculated by the software. The user should however consider the assumptions made by the geotechnical report when specifying
that allowable bearing capacity. Often times a higher factor of safety has been applied to the
allowable bearing capacity specified by a typical geotechnical report than what is typically applied to
modular wall designs. The factor of safety for cast in place foundations is often in the range of 2 to 4
and is intended to limit settlement to less than 1 inch. For modular systems like ReCon that can
tolerate settlement the minimum factor of safety for bearing is typically 2.0.

1.3.4.1.3.3 Applied Bearing Pressure

Applied Bearing pressure is calculated according to the following equation:

$$\sigma = \left(\sum \frac{V}{B'}\right) + \text{(leveling pad thickness} \times \gamma)$$

The factor of safety is calculated as $Q_{ult} / \sigma$.

1.3.5 Load and Resistance Factor Design (AASHTO LRFD)

LRFD assumes that there are uncertainties with both load and resistance. LRFD takes the approach
of reducing failure resisting components and increasing failure driving loads, each by its respective
factor. The factored resistance must be greater than the factored load. The ratio between the
reduced resistance and the increased load is referred to as the Capacity Demand Ration (CDR) and
must be greater than 1 (unless otherwise noted).

The load and resistance factors used in ReConWall are taken from the AASHTO LRFD manual
and are as follows:

- AASHTO LRFD (6th Edition)

Load Factors from Table 3.4.1-1 and Table 3.4.1-2

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Str Max</th>
<th>Str Min</th>
<th>Extreme Max</th>
<th>Extreme Min</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Str I Dead Load (DC)</td>
<td>1.25</td>
<td>0.90</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Soil Load Driving (EH)</td>
<td>1.50</td>
<td>0.90</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Str I Vert Earth Load (EV)</td>
<td>1.35</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Dead Load Surcharge (ES)</td>
<td>1.50</td>
<td>0.75</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Live Load (LL, PL, LS)</td>
<td>1.75</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Resistance Factors for MSE Walls from Table 11.5.7-1
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Resistance Factors for Prefabricated Modular Walls from Table 10.5.5.2.2-1

<table>
<thead>
<tr>
<th>Gravity Resistance Case</th>
<th>Bearing Resistance (RFbr)</th>
<th>Precast Concrete to Stone (RFsl_c)</th>
<th>Stone to Soil (RFsl_s)</th>
<th>Passive EP (RFep)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Factor</td>
<td>0.45</td>
<td>0.90</td>
<td>0.90</td>
<td>0.50</td>
</tr>
</tbody>
</table>

1.3.5.1 External Stability

External stability refers to:
- Sliding
- Eccentricity and Overturning
- Eccentricity and Bearing Capacity

For Gravity Walls, ReConWall calculates stability at each block layer, treating each block, and the blocks above it as a rigid structure. ReConWall calculates the driving and resisting forces at each block layer and displays the CDR for sliding and eccentricity at each block layer in the results table. Eccentricity is displayed as a function of e/L.

AASHTO LRFD deviates from an overturning requirement (as found in older versions, AASHTO 2002) to an eccentricity requirement in regards to the overturning of the wall. AASHTO LRFD states that "for foundations on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds of the base width. For foundations on rock, the location of the resultant of the reaction forces shall be within the middle nine-tenths of the base width." (Section 11.6.3.3) In other words, for foundations bearing on soil, the value of e/L must be less than 0.33. For foundations
for the purposes of block-to-block overturning eccentricity requirements in gravity walls, the block-to-block interface may be treated as a block on a "rock" foundation. By default the block-to-block eccentricity requirement is set to e/L < 0.45. when a concrete leveling pad greater than 1 ft thick is used, the software will consider the leveling pad as "structural" and will check eccentricity on the base block as if it is founded on rock. Consequently the leveling pad will be checked for eccentricity e/L < 0.33 as the leveling pad is bearing on soil.

<table>
<thead>
<tr>
<th>Name</th>
<th>Elev.(dpth)</th>
<th>ka</th>
<th>Pa</th>
<th>Paq</th>
<th>Paqd</th>
<th>(PaT)</th>
<th>CDRai (base of leveling pad)</th>
<th>e/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>10.67[1.33]</td>
<td>0.277</td>
<td>33</td>
<td>92</td>
<td>0</td>
<td>0</td>
<td>122</td>
<td>30.87</td>
</tr>
<tr>
<td>24</td>
<td>9.33[2.67]</td>
<td>0.277</td>
<td>118</td>
<td>185</td>
<td>0</td>
<td>0</td>
<td>303</td>
<td>13.00</td>
</tr>
<tr>
<td>39</td>
<td>8.00[4.00]</td>
<td>0.432</td>
<td>414</td>
<td>432</td>
<td>0</td>
<td>0</td>
<td>846</td>
<td>6.63</td>
</tr>
<tr>
<td>39</td>
<td>6.67[5.33]</td>
<td>0.385</td>
<td>657</td>
<td>514</td>
<td>0</td>
<td>0</td>
<td>1171</td>
<td>4.72</td>
</tr>
<tr>
<td>39</td>
<td>5.23[6.67]</td>
<td>0.359</td>
<td>959</td>
<td>599</td>
<td>0</td>
<td>0</td>
<td>1558</td>
<td>3.60</td>
</tr>
<tr>
<td>39</td>
<td>4.00[8.00]</td>
<td>0.343</td>
<td>1318</td>
<td>686</td>
<td>0</td>
<td>0</td>
<td>2004</td>
<td>2.87</td>
</tr>
<tr>
<td>60</td>
<td>2.67[9.33]</td>
<td>0.430</td>
<td>2247</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>3249</td>
<td>2.27</td>
</tr>
<tr>
<td>60</td>
<td>1.33[10.67]</td>
<td>0.406</td>
<td>2774</td>
<td>1084</td>
<td>0</td>
<td>0</td>
<td>3858</td>
<td>1.95</td>
</tr>
<tr>
<td>72</td>
<td>0.00[12.00]</td>
<td>0.436</td>
<td>3794</td>
<td>1307</td>
<td>0</td>
<td>0</td>
<td>5070</td>
<td>1.15 (1.35)</td>
</tr>
</tbody>
</table>

1.3.5.1.1 Sliding

Sliding resistance between the base block and the leveling pad is defined as:

$$\tau = (N \tan(slope) + \text{intercept}) \phi_{\tau}$$

Where $\phi_{\tau}$ is the sliding reduction factor and $N$ is now defined as the factored sum of the vertical forces:

$$N = W_1(DCr) + W_2(EV_r) + P_{av}(EH_d) + P_{qV}(LL_d)$$

Sliding resistance between the leveling pad and the foundation soil is defined as:

$$\tau = (N + LP(EV_r)) \tan(slope) + \text{intercept}) + cL(\phi_{\tau}) + PPp(\phi_{ep})$$

Where:

- $LP =$ weight of the leveling pad material (assumed unit weight of 130 pcf)
- $\phi =$ the lesser shear strength of the leveling pad material or the foundation soil
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\[
c = \text{cohesion} \\
L = \text{length along the bottom of the leveling pad.} \\
P_{Pplp} = \text{Passive pressure developed in front of the leveling pad.} \\
\varphi_{ep} = \text{resistance factor for passive resistance}
\]

The driving force in the sliding calculation is simply the factored horizontal loads:

\[
P_{ah}(EH_{d}) + P_{qh}(LL_{d})
\]

1.3.5.1.2 Eccentricity and Overturning

LRFD measures overturning stability as a function of eccentricity. In rigid retaining wall structures it is typical to require the eccentricity to be within the two-thirds of a foundation bearing on soil and in the middle nine-tenths of a foundation bearing on rock. In other words \(e/L < 0.33\) (soil) or \(e/L < 0.45\) (rock or block/block) where:

\[
e = \frac{L/2 - (\sum M_r - \sum M_o)}{\sum V}
\]

and:

\[
e = \text{eccentricity} \\
\sum M_r = \text{Sum of resisting moments} \\
\sum M_o = \text{Sum of overturning moments} \\
\sum V = \text{Sum of vertical forces}
\]

\[
\sum M_r = M_1(DC_r) + M_2(EV_r) + MP_{av}(EH_{d}) + MP_{qv}(LL_{d}) \\
\sum M_o = MP_{ah}(EH_{d}) + MP_{q}(LL_{d}) \\
\sum V = W_1(DCr) + W_2(EV_r) + P_{av}(EH_{d}) + P_{qv}(LL_{d})
\]

When the concrete leveling pad is considered structural an additional component, \(W_{18}\) (weight of leveling pad) is treated like a block and is added to the above calculations.

1.3.5.1.3 Eccentricity and Bearing

Under the Load and Resistance Factor design method, eccentricity can take on two different values depending on which load factors (maximum or minimum) are applied to the moments. For eccentricity related to overturning the critical eccentricity correlates to the minimum load factors applied to the wall components (\(W_1\) and \(W_2\)) and the maximum load factors applied to the lateral earth pressure components (\(Pa\)). For bearing calculations the critical eccentricity correlates to the maximum load factors applied to the wall components and the lateral earth pressure components:

\[
e = \frac{L/2 - (\sum M_r - \sum M_o)}{\sum V}
\]
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Where:

\[ \Sigma M_r = M_1(DC_d) + M_2(EV_d) + MP_{av}(EH_d) + MP_{qv}(LL_d) \]
\[ \Sigma M_o = MP_{ah}(EH_d) + MP_q(LL_d) \]
\[ \Sigma V = W1(DC_d) + W2(EV_d) + P_{av}(EH_d) + P_{qv}(LL_d) \]

Applied Bearing Pressure:

\[ \sigma = (\Sigma V / B') + (\text{leveling pad thickness} \times \gamma)(EV_d) \]

Ultimate Bearing Capacity:

\[ Q_{ult} = (cN_{c} + qN_{q} + 0.5\gamma B'N_{g})*(\varphi_b) \]

Where the quantities \( N_c \), \( N_q \), and \( N_g \) are dimensionless bearing capacity coefficients (after Vesic) and:

- \( c = \text{cohesion} \)
- \( q = \gamma \times D \) (\( D = \text{depth of soil from finished grade to bottom of leveling pad} \))
- \( \gamma = \text{unit weight of foundation soils} \)
- \( B' = \text{effective footing width at the base of the leveling pad}. \) (\( B' = B - 2e + lvlpad \))
- \( \varphi_b = \text{bearing Reduction Factor} \)

When the concrete leveling pad is considered structural an additional component, \( W18 \) (weight of leveling pad) is treated like a block and is added to the above calculations.

Calculated CDR for Bearing:

\[ Q_{ult} / \sigma \]

1.3.6 Seismic

Under seismic conditions, a wall is subjected to horizontal inertial force (PIR) and dynamic horizontal thrust (PAE) in addition to the static earth pressures. The horizontal inertial force can be estimated by multiplying the weight of the retained soil mass \((0.5*H2)\) by \( A_m \), where \( A_m \) is the acceleration coefficient as described in the following paragraphs. The dynamic horizontal thrust can be estimated using the pseudo-static approach presented by Mononobe-Okabe.

A seismic horizontal ground acceleration coefficient, "A", is required to estimate the dynamic forces due to seismic activity. A qualified engineer should be consulted to obtain an "A" value or local code
books and seismic hazard maps may be used to estimate a preliminary value of "A". The effects of vertical acceleration are generally ignored based on the presumption that the horizontal and vertical acceleration associated with a seismic event do not coincide.

Appendix A11 of the AASHTO LRFD Bridge Design Specifications, 6th Edition, 2012 discussed the favorable performance of retaining walls observed during seismic events with an acceleration coefficient of 0.5g or less. This section does discuss some observed wall failures and notes that in those cases, either the peak ground acceleration coefficient exceeded 0.5g or the failure was attributed to significant liquefaction of soils behind or beneath the walls.

New to AASHTO LRFD, 6th Edition, 2012, is Section 11.5.4.2 which outlines a list of criteria that, if met, would exclude the wall from mandatory seismic analysis.

If a seismic analysis is required, ReConWall is programmed to analyze wall sections using the pseudo-static Mononobe-Okabe design method.

### 1.3.6.1 Precast Modular Block

The following section outlines the process for analyzing a precast modular gravity wall as directed by AASHTO LRFD 6th Edition, 2012.

Precast Modular Blocks (Article 11.11)

Article 11.11.6 states that the provisions of Article 11.6.5 shall apply.

Article 11.6.5 – Seismic Design for Abutments and Conventional Retaining Walls

- Resistance factors shall be as specified in Article 11.5.8
- Eccentricity shall be:
  - within the middle 2/3 (e/L < 0.33) for γEQ = 0.0
  - within the middle 8/10 (e/L < 0.40) for γEQ =1.0

*By default, ReConWall is set with γEQ =1.0 and e/L < 0.40 for eccentricity about the foundation. For block to block eccentricity the default seismic requirement is set as static requirement. These settings can be adjusted by the user.*

- The total lateral force to be applied to the wall due to seismic and earth pressure loading, Pseis, should be determined considering the combined effect of PAE and PIR
  - PIR = kh(Ww + Ws) (11.6.5.1-1)
  - PAE = 0.5γh2KAE (11.6.5.3-2)
- The following two cases should be investigated:
  - Combine 100 percent of the seismic earth pressure PAE with 50 percent of the wall inertial force PIR and
- Combine 50 percent of PAE but no less than the static active earth pressure force, with 100 percent of the wall inertial force PIR.

- Seismic loads shall be applied as shown in Figure 11.6.5.1-1

- Load Factors for Extreme Event I shall be 1.0 as shown in Figure C11.5.6-4
Article 11.6.5.2 – Calculation of Seismic Acceleration Coefficients for Wall Design

The seismic horizontal acceleration coefficient \( (k_h) \) for computation of seismic lateral earth pressure and loads shall be determined on the basis of the PGA at the ground surface:

- \( k_{h0} = F_{PGA} \cdot PGA = A_s \) where
  - \( k_{h0} \) is the seismic horizontal acceleration coefficient assuming zero wall displacement.
  - \( A_s \) is determined as specified in Article 3.10

- \( k_v \) should be assumed to be zero for the purposes of calculating lateral earth pressures

If the wall is free to move laterally under the influence of seismic loading and if lateral wall movement during the design seismic event is acceptable to the Owner, \( k_{h0} \) should be reduced to account for the allowed lateral wall deformation.

Where the wall is capable of displacements of 1.0 to 2.0 in. or more during the design seismic event, \( k_h \) may be reduced to 0.5\( k_{h0} \) without conducting a deformation analysis using the Newmark Method or a simplified version of it. This reduction shall be considered applicable to the investigation of overall stability of the wall and slope.

*In summary, if a minimum amount of displacement is allowed, which is the case with most...*
ReCon walls, then the horizontal acceleration coefficient shall simply be reduced by 50%. A further reduction could be calculated using a simplified relationship based on the Newmark method as described in Appendix 11.

Appendix A.11.5.1

A simplified relationship based on the Newmark sliding analysis may be used for displacements greater than 1.0 in or less than 8 in:

\[ K_h = 0.74A_s (A_s/d)^{0.25} \]  
(A11.5.1-1)

Where:

- \( A_s \) = earthquake ground acceleration coefficient as specified in Eq. 3.10.4.2-2
- \( K_h \) = horizontal seismic acceleration coefficient
- \( d \) = lateral displacement (in.)

Article 11.6.5.3 – Calculation of Seismic Active Earth Pressure

For seismic earth pressure, either the Mononobe-Okabe (M-O) method or the generalized Limit Equilibrium (GLE) Method should be used.

ReConWall uses the M-O method. For this method to be valid the criteria outline in Article 11.6.5.3 shall be met. The complete M-O equation for \( K_{AE} \) as provided in Appendix A11 is:

\[
K_{AE} = \frac{\cos^2(\phi - \theta_{MO} - \beta)}{\cos \theta_{MO} \cos^2 \beta \cos (\delta + \beta + \theta_{MO})} \times \left[ 1 - \sqrt{\frac{\sin (\phi + \delta) \sin (\phi - \theta_{MO} - i)}{\cos (\delta + \beta + \theta_{MO}) \cos (i - \beta)}} \right]^{-2}
\]

Once \( K_{AE} \) is determined, the seismic active force \( P_{AE} \) shall be determined as:

\[ P_{AE} = 0.5 \gamma h^2 K_{AE} \]

where:

\( K_{AE} \) = seismic active earth pressure coefficient
\( \gamma \) = the soil unit weight behind the wall
\( h \) = the total wall height

Any method required other than the Mononobe-Okabe method for analyzing seismic forces is beyond the current scope of the ReConWall design software.
1.3.7 Water

Water adds many design challenges that need to be addressed in wall and slope design. The key challenges are:

- Buoyancy (of the wall blocks and the soil)
- Bearing capacity of submerged (or partially submerged) foundation soil
- Differential water pressure (rapid draw down)
  - Hydrostatic Forces
  - Increased driving forces on the reinforcing and wall facing elements

1.3.7.1 Buoyancy

Buoyancy is an upward force exerted by a fluid, in this case water. When objects are fully submerged in water the effective weight of the object is reduced by buoyant forces. A partially or fully submerged wall results in both lower resisting forces and driving forces. The presence of a level water surface may or may not control the design, but because both the resisting forces and driving forces are influenced by water the wall should be analyzed for this condition. The wall should be analyzed for the maximum water elevation. However, the highest water elevation may not control the design. Water elevation should also be checked at lower water elevations to search for the critical water level.

1.3.7.1.1 Soil Unit Weight

The unit weight of soil is described in terms of:

- Dry unit weight
- Moist unit weight
- Saturated unit weight

1.3.7.1.1.1 Dry Unit Weight

Dry unit weight is an oven dried sample of soil. This consists only of solids and air voids. The table below from NAVFAC DM-7 shows the typical dry unit weights for a variety of soil types.
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The dry unit weight is the unit weight of a soil when all the voids are completely filled with air (no water). The formula for dry unit weight is:

$$\gamma_d = \frac{\gamma_s \gamma_w}{1 + e} = \frac{\gamma}{1 + W}$$

1.3.7.1.2 Moist Unit Weight

Moist unit weight is soil with moisture in the structure. It is recommended that soil be compacted at or near optimum moisture content. The typical moist unit weights is the dry unit weight including the optimum moisture. For example, a silty sand may have a dry density of 110 pcf. If the optimum moisture content is 14%, the moist unit weight would be 125 pcf. NOTE, the compacted density is generally 95% of maximum, so the field density would be approximately 120 pcf.

The formula for moist unit weight is:
Where:

- $g_s$ - is the moist unit weight of the material
- $\gamma_w$ - is the unit weight of water
- $w$ - is the moisture content of the material
- $G_s$ - is the specific gravity of the solid
- $e$ - is the void ratio

### 1.3.7.1.1.3 Saturated Unit Weight

Saturated unit weight, which is the unit weight of a soil when all void spaces of the soil are completely filled with water (no air voids). The formula for saturated unit weight is:

$$\gamma_s = \frac{(G_s + e)\gamma_w}{1 + e}$$

Where

- $\gamma_s$ - is the saturated unit weight of the material
- $\gamma_w$ - is the unit weight of water
- $w$ - is the moisture content of the material
- $G_s$ - is the specific gravity of the solid
- $e$ - is the void ratio

Submerged unit weight is defined as the difference between the saturated unit weight and the unit weight of water. It is often used in the calculation of the effective stress in a soil.

The formula for submerged unit weight is:

$$\gamma' = \gamma_s - \gamma_w$$

Where

- $\gamma'$ - is the submerged unit weight of the material
- $\gamma_s$ - is the saturated unit weight of the material
- $\gamma_w$ - is the unit weight of water

If we can assume a dry unit weight and a specific gravity of 2.7, we can approximate the void ratio of a compacted soil. The following figure is from NAVFAC DM7.
40

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If we assume we have a well compacted fill at 13% moisture with a density of 125 pcf, the dry unit weight would be 125/(1+0.13) = 110 pcf. The void ratio would be roughly between 0.33 and 0.98 (assume 0.4). The saturated unit weight would be \[(2.7 + 0.4) * 62.4\]/1.4 = 138. The buoyant unit weight (γb) would then be 138 – 62.4 ≈ 76 pcf.

This is somewhat simplistic, but gives a range of expected values.

For the purposes of the software, we will default to a moist unit weight of 120 pcf and a void ratio of 0.4 for a saturated unit weight of 138 pcf.

1.3.7.1.2 Block Weight

When a block becomes submerged in water, the effective unit weight of the concrete is the buoyant unit weight. The buoyant unit weight is simply the difference between the density of the concrete and the density of water (145 pcf - 62.4 pcf = 82.6 pcf). For the drainage fill between the ReCon units, the unit weight of the fill is again based on the buoyant weight of a saturated soil.
1.3.7.1.3 Buoyant Earth Pressure

As we saw in an earlier section, the lateral earth pressure \( (P_a) \) can be simplified to the following equation for cohesionless soils:

\[
P_a = \frac{1}{2} K_a \gamma H^2
\]

Where \( \gamma \) is the moist unit weight of the soil, \( H \) is the design height of the wall and \( K_a \) is the coulomb coefficient of earth pressure.

For saturated backfill soil, the lateral earth pressure \( (P_a) \) can be simplified to the following equation for cohesionless soils:

\[
P_a = \frac{1}{2} K_a \gamma_b H^2
\]

Where \( \gamma_b \) is the buoyant unit weight of the soil, \( H \) is the design height of the wall and \( K_a \) is the coulomb coefficient of earth pressure.
Where:

1. \( P_a = \frac{1}{2} K \gamma H_1^2 \)
2. \( P_a = K \gamma H_1 H_2 \)
3. \( P_a = \frac{1}{2} K \gamma b H_2 \)
1.3.7.2 Bearing Capacity with a Water Table

Up to this point, evaluation of the ultimate bearing capacity is based on the assumption that the water table is located well below the foundation. If the water table is close to the foundation of the wall the bearing capacity should be adjusted depending on the location of the water table. The weight of the soil below the water table is reduced due to buoyancy \( (\gamma' = \gamma_{sat} - \gamma_w) \) resulting in a reduced bearing capacity. The bearing capacity equation can be rewritten to account for buoyancy depending on the location of the water table. For simplification, we conservatively assume \( \gamma' = 1/2 \gamma \) for these bearing calculations.

**Case I: Water table above the footing base.**

If the water table is located so that \( 0 < ZW1 < Di \), the bearing capacity equation takes the form

\[
Q_{ult} = cN_c + \gamma DiN_q RW1 + 0.5 \gamma' B'N_g
\]

Where \( RW1 = \frac{1}{2} (1 + ZW1/Di) \)

\[
\gamma DiRW1 = ZW1 \gamma + (Di - ZW1) \gamma'
\]
\[
\gamma' = \frac{1}{2} \gamma
\]
\[
\gamma DiRW1 = ZW1 \gamma + (Di - ZW1)^{1/2} \gamma
\]
\[
DiRW1 = ZW1 + (Di - ZW1)^{1/2}
\]
\[
DiRW1 = ZW1 + \frac{1}{2} Di - \frac{1}{2} ZW1
\]
\[
DiRW1 = \frac{1}{2} ZW1 + \frac{1}{2} Di
\]
\[
RW1 = \frac{1}{2} ZW1/Di + \frac{1}{2} Di/Di
\]
\[
RW1 = \frac{1}{2} (1 + ZW1/Di)
\]
Also, the value of $\gamma$ in the last term of the equation has to be replaced by $\gamma' = 1/2 \gamma$

**Case II:** Water table below the base of the footing, $0 < ZW2 < B'$

In this case the soil above the footing is moist and the soil below the base of the footing may be fully or partially submerged.

$$Q_{ult} = cNc + \gamma'DINq + 0.5\gamma'B'NgRW2$$

Where

$$RW2 = \frac{1}{2} \left( 1 + \frac{ZW2}{B'} \right)$$

$$B'\gammaRW2 = ZW2\gamma + \gamma'(B' - ZW2)$$
$$B'\gammaRW2 = ZW2\gamma + \frac{1}{2}\gamma'(B' - ZW2)$$
$$B'RW2 = ZW2 + \frac{1}{2}(B' - ZW2)$$
$$B'RW2 = ZW2 + \frac{1}{2}B' - \frac{1}{2}ZW2$$
$$B'RW2 = \frac{1}{2}ZW2 + \frac{1}{2}B'$$
$$RW2 = \frac{1}{2}ZW2/ B' + \frac{1}{2}B'/ B'$$
$$RW2 = \frac{1}{2} \left( 1 + \frac{ZW2}{B'} \right)$$

**Case III:** If the water table is located a distance below the footing $ZW2 > B'$, the water will have no effect on the ultimate bearing capacity.

### 1.3.7.3 Rapid Drawdown

Situations where the wall may be influenced by a fluctuating water level may require the wall to be designed for rapid drawdown conditions. If the water surface is level, the hydrostatic forces behind the wall are balanced by the hydrostatic forces on the face of the wall and the only effect on the wall design is due to buoyancy of the material below the water surface. Where the water surface in front of the wall is allowed to drain at a more rapid rate than the water can drain from behind the wall a hydrostatic pressure may be applied as an overturning force on the back of the wall. This is what is referred to as a Rapid Drawdown condition.
The hydrostatic pressure acting on the back of the wall is defined by $P_{wd}$.

$$P_{wd} = \left(\frac{1}{2}\right)\gamma_w (H_1)^2$$

The hydrostatic pressure acting on the front of the wall is defined by $P_{wr}$.

$$P_{wr} = \left(\frac{1}{2}\right)\gamma_w (H_2)^2$$

This resultant net hydrostatic force acting on the back of the wall is defined by $P_w$.

$$P_w = P_{wd} - P_{wr}$$
In addition to differential water pressure, the change in total stress conditions within the soil (during a drawdown event) results in excess pore pressure within the mass as there is more internal pressure (pore pressure) than external pressure. *Excess pore pressure in low permeable soils may not dissipate quickly enough, and may reduce the effective stresses inside of the soil, which in turn may cause a reduction of the shear strength in the soil.*

AASHTO recommends that for structures along rivers and streams, a minimum differential hydrostatic pressure equal to three feet of water should be considered for design. This load should be applied at the high water level. Alternatively, however, a rapidly draining backfill material such as open graded course gravel can be used as backfill in order to eliminate the potential for a rapid drawdown.

For gravity wall applications a three ft. differential hydrostatic pressure can have a significant effect on the design requirements of the wall (depending on the maximum height of the water). Because of the significant effect of hydrostatic pressure and the potential for reduced shear strength of low permeable soil in a rapid drawdown condition, ReCon recommends the use of a rapidly draining backfill (generally placed at a 1H:1V slope from the heal of the base block) in most gravity wall water applications to eliminate the potential for a rapid drawdown condition.

### 1.4 MSE Wall

ReConWall offers the designer 3 options for MSE wall design: NCMA 09, AASHTO 2002, and AASHTO LRFD (6th edition). Reference the respective design manual for details on each.
1.4.1 NCMA 09

NCMA 09 follows the design guidelines of the Design Manual for Segmental Retaining Walls, third edition. NCMA 09 uses Coulomb earth pressure with internal and external delta angles. External forces are used in the resisting force calculations. For internal calculations delta is set to 2/3 phi MSE walls.

For more specific details on the NCMA design approach for MSE Walls please refer to the Design Manual for Segmental Retaining Walls, Third Edition.
1.4.2 AASHTO 2002

AASHTO 2002 is an allowable stress approach to designing retaining walls. AASHTO 2002 uses Coulomb earth pressures for internal and external forces. For MSE walls, delta is set equal to the the back slope angle. The internal failure plane is fixed at 45 + phi/2 for pullout calculations. Very few DOT's still reference the allowable stress version of the AASHTO code. Unless otherwise specified the user should design to the most recent edition of the AASHTO manual (LRFD). ReCon has left this allowable stress version of AASHTO design code in the design software for the occasional specification requirement and for general reference.

1.4.3 AASHTO LRFD

AASHTO LRFD uses Coulomb earth pressures for internal and external forces. For MSE walls delta is set equal to the the back slope angle. The internal failure plane is fixed at 45 + phi/2 for pullout calculations. (For Gravity Walls, delta is set to 1/2 phi for single depth walls and 3/4 phi for multi-depth walls.) ReCon wall has been updated to reflect the AASHTO LRFD Bridge Design Specifications, 6th Edition (2012).
For more specific details on the AASHTO LRFD design approach for MSE Walls please refer to the AASHTO LRFD Bridge Design Specification.
1.4.4 Internal Stability

Internal Stability is the ability of the mass to act as a coherent gravity structure. Stability checks for internal stability include:

- Tensile over-stress of the reinforcement
- Pullout capacity of the reinforcement from the stable zone
- Connection capacity of the reinforcing to the facing elements
- Local shear and bending

1.4.4.1 Tensile Stress

In the NCMA and AASHTO methods, the tensile stress is simply the earth pressure from half way to the layer above to half way to the layer below. T calculation is:

$$ T = \gamma z k_a s_v $$

where:

- $\gamma$ = moist unit weight of the reinforced fill
- $z$ = depth below the top to the center of the area supported (for uniformly spaced layers, it is the layer depth)
- $k_a$ = coefficient of active earth pressure
- $s_v$ = vertical distance supported, (or grid spacing) typically no greater than 32”

In Allowable Working Stress designs, a factor of safety is applied to the $T_{\text{Allowable}}$ of the reinforcing.

In LRFD methods, the loads are increased by load factors for earth load, live load and dead load, higher factors for the more uncertainties of the surcharge. The resisting force of the reinforcing is reduced by a resistance factor. The combination of load factor and resistance factor should approximately equal the factor of safety of 1.5 used in working stress design.
For the calculation of tension in the top grid, the vertical distance supported (sv) is taken from the midpoint to the grid below all the way to the top of the wall.

For the calculation of tension in the bottom grid, the vertical distance supported (sv) can be taken from the midpoint to the grid above to the bottom of the wall.

Due to the presence of friction along the base of the wall this can be an overestimation of the tension in the bottom grid. If the friction along the bottom of the wall is assumed, then the tension in the bottom grid could be calculated for a supported vertical distance (sv) measured from the midpoint to the grid above to the midpoint between the bottom grid and the base of the wall. **ReConWall allows the designer to assume friction along the base of the wall or to ignore friction along the base of the wall. This selection may be made on the "Preferences" tab in the design software.**

**ReConWall** will analyse the tensile capacity of the grid and the capacity of the grid connection and compare the critical value to the calculated tensile stress at each reinforcement layer.
1.4.4.1.1 Tensile Overstress

Tensile Over-stress is the over-stress of the reinforcing that could lead to stress rupture. The plane of maximum force is assumed to be at the Coulomb or Rankine failure plane.

The Long term design strength of the geogrid is analyzed for tensile over-stress.

The Long Term Design Strength (LTDS) is calculated as:

\[ LTDS = \frac{T_{ult}}{RF_{cr} \times RF_{d} \times RF_{id}} \]

Where:

- \( T_{ult} \) = minimum average roll value (MARV) ultimate tensile strength.
- \( RF_{cr} \) = strength reduction factor to prevent long term creep rupture of the reinforcement.
- \( RF_{d} \) = strength reduction factor to prevent rupture of reinforcement due to chemical and biological degradation
- \( RF_{id} \) = strength reduction factor to account for installation damage to reinforcement.
1.4.4.1.2 Connection Capacity

Connection capacity is the available tensile strength of the unit to grid connection at the face of the wall.

ReCon blocks have been tested for connection with a variety of types of geogrid reinforcement. A typical connection curve is shown below.

The allowable connection capacity is determined by the normal load within the wall facing (confining pressure). The confining pressure is calculated based on the force of the blocks located over the reinforcement layer. The normal load is calculated and the corresponding connection capacity is determined based on the appropriate connection curve.

1.4.4.1.2.1 NCMA 09

For NCMA, the connection capacity should be divided by the required factor of safety for connection and compared to the tensile stress in each grid layer. The minimum required factor of safety for connection for NCMA is 1.5.

1.4.4.1.2.2 AASHTO 2002

AASHTO 2002 States that the capacity of the connection shall be reduced from Tult for the backfill reinforcement using the connection strength determined from laboratory tests. The connection strength is based on the lesser of the pullout capacity of the connection, the long term rupture strength of the connection and Tal as determined in article 5.8.6.1.2
It should be noted than many states have their own requirements for connection and each project specification should be considered by the designer.

1.4.4.1.2.3 AASHTO LRFD

Section C11.10.6.4.4b of the AASHTO LRFD manual notes that if rupture is the mode of failure, the long term effects of creep and durability on the geosynthetic reinforcement at the connection must be taken into account. If pullout is the mode of failure, the capacity of the connection is controlled by the frictional interface between the facing blocks and the geosynthetic reinforcement. It is assumed for design that this interface is not significantly affected by the time dependent mechanisms such as creep or chemical degradation.

The AASHTO LRFD manual suggests that a long term connection test would address the long term capacity of the connection. If the long term connection test is not performed, AASHTO suggests to conservatively apply the creep reduction (\(RF_{cr}\)) factor and the durability reduction factor (\(RF_{d}\)) of the grid to the short term connection test.

It should be noted than many states have their own requirements for connection and each project specification should be considered by the designer.

1.4.4.1.3 Pullout Capacity

Pullout capacity is the ability of the reinforcing to maintain anchorage in the stable zone of the reinforced soil. The reinforcement pullout resistance is checked at each level against pullout failure. Only the effective pullout length which extends beyond the theoretical failure surface is used in this calculation.

Pullout capacity is calculated as:
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PO = 2*N*Le*tan(\(\phi\))*Ci  (note: ReConWall will limit the pullout capacity to the tensile capacity of the grid)

Where:

N = normal force directly above the layer
Le = length of embedment from the failure plane to the free end
\(\phi\) = angle of internal friction of the soil interacting with the reinforcement
Ci = coefficient of interaction between the soil and the geosynthetic

A factor of safety of 1.5 is generally acceptable for pullout.

1.4.5 External Stability

If internal stability requirements meet the necessary design requirements, the MSE wall may be assumed to act as a composite mass defined by the geometry of the mass (from the face of the block to the tails of the geogrid). External stability calculations should be performed on composite mass as they would be on a gravity wall defined by the same geometry. External stability shall be checked for sliding, overturning, and bearing.

1.4.6 Seismic

The "No Analysis" criteria outlined in Section 11.5.4.2 is applicable to internal and external stability of MSE Walls. As with gravity walls, if a seismic analysis is required, ReConWall is programmed to analyze wall sections using the pseudo-static Mononobe-Okabe design method.


1.4.7 Water in MSE Walls

1.4.7.1 External Stability

The effects of water on the external stability of an MSE wall is similar to the effect of water on the external stability of a gravity wall. The same principles applied to a submerged gravity wall are applied to a submerged MSE wall where the composite mass is considered a gravity structure. The effects of water on the external stability of an MSE wall are less likely to control the external stability design compared to a traditional gravity wall.

1.4.7.2 Internal Stability

The tensile stress in the geogrid for portions of the wall submerged is calculated as follows:

\[ T = (\gamma z + \gamma b(z-zw))k sv \]
Chapter 1 - Design Theory

where:

\[ \gamma_b = \text{buoyant unit weight of the reinforced fill} \]

\[ z = \text{depth below the top to the center of the area supported (for uniformly spaced layers, it is the layer depth)} \]

\[ zw = \text{depth below the top of the wall to the water level} \]

\[ ka = \text{coefficient of active earth pressure (internal)} \]

\[ sv = \text{vertical distance supported, (or grid spacing) typically no greater than 32”} \]

Note that for a fully submerged wall the equation simplifies to:

\[ T = \gamma_b z k_a sv \]

1.4.7.2.1 Tensile Overstress

In the case of a submerged MSE the tensile stress in the grid is reduced because the buoyant weight of the submerged reinforced fill is less than the moist unit weight of the reinforced fill. However, the tensile capacity of the geogrid is unaffected by the water. For a level water surface, the tensile capacity required under dry conditions will always be greater than that required under submerged conditions and should not control the design.

1.4.7.2.2 Connection Capacity

The connection capacity of a frictional connection is dependent on the confining pressure on the grid between two blocks. In a submerged wall condition, the weight of the blocks is reduced due to buoyancy in addition to the reduced weight of the reinforced fill due to buoyancy. In other words, the wall experiences a reduction in the grid tension and the connection capacity. Similar to the external stability of a gravity wall, it is not apparent if the presence of water will control the design or not.

It is relevant to note that the tensile stress in the geogrid due to a surcharge load is not affected.
(reduced) by the presence of water. While the tensile stress due to earth pressure will be reduced, the tensile stress due to a surcharge load will remain at the same magnitude, but will now represent larger percentage of the total stress in a submerged wall.

As with gravity walls, the presence of a level water surface may or may not control the design, but because both the resisting forces and driving forces are influenced by water the wall should be analyzed for this condition. The wall should be analyzed for the maximum water elevation. However, the highest water elevation may not control the design. Water elevation should also be checked at lower water elevations to search for the critical water level.

1.4.7.2.3 Pullout Capacity

Pullout capacity is primarily dependent on the volume and weight of the soil on the portion of the geogrid past the failure plane. If this soil is submerged and the effective weight is reduced then the pullout capacity is reduced. If there is no surcharge on the wall, then the tensile stress in the grid and the pullout capacity of the grid will be reduced by the same ratio. In the case of a submerged wall with a surcharge it is possible that the buoyant weight of the soil could cause the pullout factor of safety to be reduced. If this is the case it is likely to occur only in the top layer of geogrid, as the geogrid layers lower in the wall generally have much larger pullout capacities than are required for design.

1.4.7.3 Rapid Drawdown

As with gravity walls a hydrostatic differential can create a significant driving force on a retaining wall. For MSE walls we will look at a hydrostatic differential on the external stability of the wall and a hydrostatic differential on the internal stability of the wall. Rapid drawdown for External Stability and Internal Stability will need to be checked separately as modeled below.

1.4.7.3.1 External Stability

The hydrostatic differential on the external stability of the wall will be applied in the same manner as for a traditional gravity wall. If there is a water surface differential between the back of the MSE structure and the face of the blocks then this pressure differential will be applied to the “composite mass” of the MSE structure.
Chapter 1 - Design Theory

Rapid Drawdown modeled for External Stability in ReConWall 4.0

Graphical representation of hydrostatic pressure differential for a drawdown condition (External Stability)
1.4.7.3.2 Internal Stability

Internal stability drawdown is modeled with an additional tensile load "WL (Pw)" due to the water differential pressure. The pressure at each grid layer is calculated in a similar manner where the tension due to water is the differential water pressure at the midpoint of the tributary area multiplied by the tributary area for each grid layer.

Rapid Drawdown modeled for Internal Stability in ReConWall 4.0
Graphical representation of hydrostatic pressure differential for a drawdown condition (Internal Stability)

The tension due to the hydrostatic differential "WL (Pw)" is then added to the value "Tmax".

1.5 Channel Block

ReCon offers a number of different wall batter options:

- 3.58 Degrees: The standard wall batter is 3.58 degrees, up 16" and back 1".
- 7.16 Degrees: A modification to the wall batter can be made by the wall installer by introducing a “spacer bar” that is 1” thick. Now the wall batter will be 7.16 degrees, up 16" and back 2”. See Help Menu, User Input, Input, Geometry, Batter for a discussion on the limitation on wall heights when using the spacer bar given the tested shear strength of the bar.
- 26.6 Degrees: The Channel Block results in a modification to the “Tongue” and “Groove” of the ReCon Block before production begins. With this modification, the wall batter will be 26.6 degrees, up 16” and back 8”.

Channel Block AWARENESS Notes:

- When designing a ReCon Wall using the Channel Block, the minimum depth of the block must be 39” with the exception of the Top Block which can be 24”.
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- Normally the Channel Block Wall will be designed as a Gravity Wall. However, if grids are desired in combination with the Channel Block, please contact ReCon for block to grid connection data specific to the Channel Block.

Channel Block, Hinge Height, and Walls vs. Slopes:
- Channel Block results in a wall batter of 26.6 degrees. This would be considered a SLOPE, not a WALL. As such, Global Stability should govern, not the external Factors of Safety for Overturning, Sliding and Bearing.
- When a Wall has a batter between 8 degrees and up to 20 degrees, it has features from a design perspective of both a WALL and a SLOPE. As a result, ReConWall 4.0 analyzes both the traditional external Factors of Safety for Overturning, Sliding and Bearing as well as Global Stability. Both the FOS and the Global must be analyzed. However, the analysis of the external FOS must be done with consideration of the concept of “hinge height”. This is discussed below.
- For any wall that has 20 degrees of batter or more, the ReConWall 4.0 OUTPUT page will contain a NOTE that says: “Batter > 20 deg, Design for Slope Stability”

With the large face batter, a typical gravity wall analysis using Coulomb earth pressured does not give safe results. The basic assumption is the full weight of the wall is applied to the base unit. This yields higher factors of safety for sliding than would be calculated by other methods.

FS_{Sl} = 2.16 (OK)

By limiting the weight of the units to the 'hinge height', the factor of safety yields:
FS_{sl} = 1.04 (NG)

The use of hinge height also yields results that are more compatible with a global analysis used for slope design.

1.5.1 Hinge Height

"Hinge height is the height to which SRW units can be stacked in an isolated column at a batter without toppling." The concept was developed for calculating normal load on the block interface for connection
capacity.

NCMA has since dropped the requirement for hinge height but AASHTO and FHWA still require a design check for walls with a batters over 8 degrees. (AASHTO 11.10.6.4.4B)

\[ H/h = 2 \times \left( \frac{W/u - G/u - 0.5H/u \tan(i)}{\tan(\omega + i)} \right) \cos(i) \]

where:
- \( W_u = 12 \text{ in} \) (block width)
- \( G_u = 6 \text{ in} \) (centroid)
- \( \omega = 5 \text{ deg} \) (batter)
- \( i = 0 \text{ deg} \) (tilt)

### 1.5.2 Hinge Height PMB Single Depth

Hinge height has not been a concept introduced into PMB walls since they are primarily used as gravity structures. However the stability of the walls is based on sliding and overturning resistance of the wall to hold back the retained earth. The use of 'hinge height' allows a better evaluation of the bearing pressures of the base unit on the foundation soils for calculation of sliding resistance.

When wall batter exceeds 8 deg., a global stability check should be done as the structure is acting more like a slope than a vertical retaining wall structure. The use of hinge height gives a better alignment of results between a retaining wall analysis and a slope analysis.
\[ \frac{H}{h} = 2 \times \left( \frac{(W_u - G_u - 0.5H_u \tan(i)) \cos(i)}{\tan(\omega + i)} \right) \]

where:

- \( W_u = 39 \) in (block width)
- \( G_u = 19.5 \) in (centroid)
- \( \omega = 26.6 \) deg (batter)
- \( i = 0 \) deg (tilt)

\[ \frac{H}{h} = 6.49 \text{ ft} \]
1.5.3  **Hinge Height PMB Multi-Depth**

Compound stability is a global analysis where the failure surface may go from outside of the reinforced mass through the mass, or it may extend from behind the mass and pass through the foundation. There are several analysis methods available for global stability such as the Ordinary Method of Slices, Simplified Bishop Method, Spencer’s Method, Janbu’s Simplified Method, Morgenstern-Price Method and more. The Simplified Bishop’s method is the most commonly used.

1.6  **Compound Stability**

For multi-depth depth walls, the AASHTO equation does not work for the analysis. A manual calculation of the wall centroid is required.

\[ CG_x = \frac{\Sigma M}{\Sigma W} \]

The moment includes the weight of the unit and the stone fill over the units.
1.6.1 Unreinforced Walls and Slopes

The Ordinary Method of Slices and Simplified Bishop use a circular failure surface. The area within the circular arc is divided into slices. Each slice is then resolved into forces and moments rotating about the center of the trial circle. The Simplified Bishop Method (1955) assumes all the side forces act horizontally.

The general form of the equation for factor of safety is given as:

\[
F' = \frac{\sum_{i=1}^{n} (cL_i + M_i \tan \phi)}{\sum_{i=1}^{n} (W_i + q_i) \sin \theta_i}
\]
Chapter 1 - Design Theory

The radius term, \( R \), cancels out of the numerator and denominator in the above equation.

When a phreatic surface is present, the vertical force \( W \) is reduced by the height of the water above the base of the slice.

In the Simplified Bishop’s Method the mobilized shear strength of the soil is obtained by dividing the shear strength by a factor of safety.

\[
\tau = \frac{cL_i + N_i \tan \phi}{F}
\]

Substituting the mobilized shear strength for \( N_i \) we get:

\[
N_i = \frac{(W_i + q_i) - (cL_i \tan \theta)/F}{\cos \theta + (\sin \theta \tan \phi)/F}
\]

Substituting \( N_i \) into the general form equation, the factor of safety then becomes:

\[
F = \frac{\sum_{i=1}^{n} cL_i + (W_i + q)\tan \phi}{\sum_{i=1}^{n} [(W_i + q)\sin \theta]}
\]

A \( \alpha \) term is used to simplify the above equation:
Where:

\[ m_\alpha = \cos \theta + (\sin \theta \tan \phi) / F \]

The above equations simplifies to:

\[ F' = \frac{\sum_{i=1}^{n} (c Li + (W_i + q_i) \tan \phi) / m_\alpha}{\sum_{i=1}^{n} [(W_i + q_i) \sin \theta]} \]

### 1.6.2 Reinforced Walls and Slopes

The previous equations apply to slopes and walls that have no internal reinforcing elements. When internal reinforcing is added to a slope, if the failure surface passes through a reinforcing layer, additional resisting moments are added and an increased resulting factor of safety is achieved.

The ‘Comprehensive Bishop’ method used in the ReSSa software includes the reinforcing as a reduction on the resisting side of the equation by reducing the normal load on the failure plane and includes the same component to reduce the driving moment, thereby maintaining vertical force and moment equilibrium.

The equation used for the Comprehensive Bishop method is:

\[ F = \frac{\sum_{i=1}^{n} \left[ c_i L_i + (W_i + q_i - t_i \sin \alpha_i) \tan \phi \right] m_\alpha}{\sum_{i=1}^{n} \left[ (W_i + q_i) \sin \theta_i - t_i \cos (\theta_i - \alpha_i) \right]} \]

Where:

\[ \alpha = \text{angle of rotation of the reinforcing} \]
\[ ti = \text{Tavailable of the reinforcing (LTDS not reduced for a FS of uncertainty)} \]

For most designs the rotation of the reinforcing, \( \alpha \), is assumed zero.

### 1.6.3 Reinforced Walls w/ Facing

The primary function of the wall facing is erosion protection at the face of the reinforced mass and to aid in the construction and compaction of the soils near the outer edge of the structure. However, it does add to the stability of the wall system and the benefits of the facing are taken into account in the design.

As the mass begins to mobilize, trying to move along the failure plane, the end of the arc is generally at a reinforcing interface. For the face to yield, shear key will yield first, followed by a rotation in the wall face. The intent of the design is to keep the movement from occurring. It can be seen from this illustration that for shorter walls, the failure surface may not intersect any reinforcing layers, thus the resistance is provided by the soil friction along the surface and resistance in the facing element. For design, ReConWall uses the block to block shear strength as the resistance:

\[ T_{pk} = 6775 \text{ plf} \]

This resistance is then added to the factor of safety equation as follows:

\[
F = \frac{\sum_{i=1}^{n} \left( c_i L_i + T_{pk} + (W_i + q_i - t_i \sin\alpha_i)\tan\phi \right) m_\alpha}{\sum_{i=1}^{n} \left[ (W_i + q_i)\sin\theta_i - t_i \cos(\theta_i - \alpha_i) \right]}
\]

Note that since the face is included with the soil resistance, the shear strength of the face is reduced by a factor of safety the same as the soil shear strength is reduced.
1.6.4 Global Stability

Global stability is a failure plane passing below the toe of the reinforced soil mass (where compound stability is passing through the face of the mass). ReConWall uses a bishop’s method of analysis for computing global stability.

\[
\tau = \frac{cL_i + T_{pk} + N_i \tan \phi}{F}
\]

Where the geotechnical parameters are well defined, and the slope does not support or contain a structural element a factor of safety greater than 1.3 is acceptable. Where the geotechnical parameters are based on limited information, or the slope contains or supports a structural element then a factor of safety of 1.5 is required.
Chapter 2 - User Input
2 Chapter 2 - User Input

ReConWall was designed to be user friendly, easy to navigate and easy to use. To accomplish easy navigation, an Outlook™ type menu bar is used to navigate through the program. The designer clicks on the window or type of input desired and the active window displays the input fields.

"Easy to use" is accomplished by using default data in all the fields so the user can see what type of data is typically required.

"User friendly" is accomplished by organizing the data in a natural progression for design. Returning to the geometry and soils pages the user can begin to design site specific walls.

2.1 Main

The Main section of the menu is Project Information. This information is global to the whole project and not specific to the design and individual sections.

2.1.1 Project Information

Project Dialog contains information about the overall project:
Chapter 2 - User Input

- Date - defaults to system date on first design
- Project Name
- Client (optional)
- Designer (optional)
- Location (optional)
- Designer - (optional)
- Block Type
- Geogrid Reinforcing (for MSE walls)
- Available Blocks

**Available Blocks**: ReConWall will design the cross section with the most efficient combination of blocks, however, it will only design with the blocks that are checked under the available blocks section. If the designer wants to limit the blocks used in the design, then the designer should only select the blocks desired for the design. Most notably this section allows the designer to chose between the use of a full height top cap (TC) or a 6.5” cap (C6.5) for the top of wall finish. Only one of these options should be selected.

### 2.2 Input

- Section Information
- Wall geometry
- Soils parameters
- Factors of Safety (or Load Factors)
- Block Properties
- Geogrid Properties
Section Information

Section Information contains information about the specific section of the project being designed. This is also the primary location to add or remove sections to the design file. This may be desirable for a project that has more than one wall, or a wall that has a variety of geometries and/or loading conditions.

Name: Each Section can have a unique name to help identify it when designing projects with multiple sections. (limited to 20 characters)

Design Method: ReConWall is setup to design to a variety of design standards. The design method selected should be based on designer preference or specific project requirements. The current design options include:

- NCMA 09 – Design methodology as published by the National Concrete Masonry Association
- AASHTO 2002 – Design methodology as published by AASHTO, based on the 2002 publication based on Allowable Stress Design

Force a Reinforced Design: If the design works as a gravity wall with all 24" deep blocks then the solution will be shown as a gravity wall even if "Reinforced Design" is selected. If the user would like to force geogrid into the solution then the "Force a Reinforced Design" should be checked.

Crushed Stone Over Blocks: In this version of the software, the back face of the wall is defined by assuming a line drawn from the back lower corner of the base block to the back upper corner of the top block. The amount of friction along the back of the wall is a function of the shear strength of the material along this surface.
By default, ReConWall uses a value of $\delta = \frac{3}{4} \theta_{\text{retained}}$. In cases where the retained soil is suitable to be placed and compacted back behind the blocks during wall construction, this is a reasonable estimation of wall friction. In cases where the wall is constructed in a material unsuitable for placement behind the blocks (e.g. clay or other fine material), the wall is typically backfilled with a more select material, such as sand or gravel. In this case $\delta = \frac{3}{4} \theta_{\text{retained}}$ is an overly conservative estimate of the wall friction. By selecting the "Crushed Stone Over Blocks" option, the user is able to differentiate between the retained soil and the material placed behind the blocks during wall construction and more accurately estimate the appropriate friction along the back of the wall. The user can input the value of the shear strength, $\theta$, of this material (typically between 34° and 40°). ReConWall will limit the wall friction ($\delta$) to the lesser of $\frac{3}{4} \theta_{\text{crushed stone}}$ or $\theta_{\text{retained}}$. The friction ($\delta$) will never be greater than the shear strength of the retained material.

Checking this box only affects the friction between the wall and the retained soil. The shear strength of this material is not considered in calculating the magnitude of the lateral earth pressure applied by the retained soil. It is important that if the Engineer utilizes this option in design that the construction documents make it clear to the contractor that the wall must be constructed with a material placed over the tails of the blocks meeting the minimum shear strength specified in the design. To be conservative, the crushed stone should fill the area defined by a line drawn vertical from behind the tail of the base block to finished grade (as seen in the graphic above).

**Zero delta for single depth walls:** This check box will only be available for AASHTO designs. The purpose of this check box is to limit the height of single depth gravity walls by conservatively ignoring the vertical component of earth pressure for single depth gravity walls. The title of this box is not entirely correct in that the friction angle is still utilized to reduce the lateral earth pressure to the
horizontal component only. Checking this box will also limit the number of 24" deep blocks at the top of taller gravity walls. The use of this option is entirely up to the designer's engineering judgment for each project. By default, this box is checked on installation, but may be updated with the "save defaults" option. This option affects gravity walls only.

For NCMA design options the user will be able to select one of two options:

<table>
<thead>
<tr>
<th>NCMA Options [For Single Depth Gravity  MSE Walls]</th>
</tr>
</thead>
<tbody>
<tr>
<td>☐ Ignore Vertical Delta Force</td>
</tr>
<tr>
<td>☐ Include Vertical Delta Force (Global check Should be Done)</td>
</tr>
</tbody>
</table>

For gravity walls, the effect is the same as the "zero delta for single depth walls" for AASHTO designs. The main difference is that the NCMA option is applied to both single depth gravity walls and MSE walls. For MSE walls, including vertical delta force may allow for shorter grid lengths. In some cases the grid length may be shorter than what may be required for global stability making the global stability analysis more critical for certain applications.

**Print Trial Wedge**: ReCon has tried to be as open as possible as it pertains to the equations and calculation used in this design software. As outlined in an earlier section, ReConWall will resort to a trial wedge calculation for more complicated geometries. If this box is checked, then a file titled "TrialWedge" will be written to the "ReCon Wall" folder in your "documents" folder. This allows the user to view some of the data that was used to generate the result when a trial wedge approach is used. The main purpose of this option is to help the user get comfortable with the design software and the result that the software generates. The "TrialWedge" file will overwrite itself every time a new calculation is generated, so if the data is desired to be saved, then the file must be manually saved in another location before another trial wedge calculation is initiated.

**Print Preliminary Disclaimer**: ReConWall is intended to be used by Professional Engineers as a tool to aid in the analysis of ReCon retaining walls. Design calculations performed by ReConWall should be checked and verified by a registered Professional Engineer who is familiar with the site conditions and project materials. By default the program will print the following message on all pages of the calculation printout: "Note: Calculations and quantities are for Preliminary Analytical Use Only and Must Not be used for final design or construction without the independent review, verification, and approval by a qualified professional engineer". Only when the calculations have been checked and verified by a registered professional engineer should this message be removed from the printout. The calculations should be stamped and sealed by an engineer registered in the state where the wall is to be constructed.

### 2.2.2 Geometry

The geometry tab is where the designer defines the geometry of the retaining wall
Chapter 2 - User Input

**Section Geometry**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height (HT)</strong></td>
<td>12.00 ft</td>
</tr>
<tr>
<td><strong>Batter</strong></td>
<td>3.58 deg</td>
</tr>
<tr>
<td><strong>Embed</strong></td>
<td>1.2 ft</td>
</tr>
<tr>
<td><strong>Leveling Pad Depth</strong></td>
<td>1 ft</td>
</tr>
<tr>
<td><strong>Leveling Pad Width</strong></td>
<td>0.5 ft</td>
</tr>
<tr>
<td><strong>Slope Angle</strong></td>
<td>0.0 deg</td>
</tr>
<tr>
<td><strong>Slope Length</strong></td>
<td>0.0 ft</td>
</tr>
<tr>
<td><strong>Slope Toe Offset</strong></td>
<td>0.0 ft</td>
</tr>
<tr>
<td><strong>Allowable Bearing</strong></td>
<td>0.00 psf</td>
</tr>
</tbody>
</table>

**Settings for MSE Design**

- **Min L/H**: 60.00 %
- **MinLen**: 4.00 ft
- **Max Grid Spacing**: 2.67 ft

**Live Load**

- **Live Load**: 250 psf
- **LL Offset**: 0 ft
- **LL Width**: 100 ft
- **Dead Load**: 0 psf
- **DL Offset**: 0 ft
- **DL Width**: 0 ft

**Second Live Load**

- **Live Load 2**: 0
- **LL2 Offset**: 0
- **LL2 Width**: 0

**Parapet Wall**

- **Height**: 0.00
- **Depth**: 0.00
- **Density**: 0.00

---

**Height (HT)**: Height of the wall measured from the top of the leveling pad to the top of finished grade. The user should consider full block heights (16 inch increments) when determining the design height of the wall.

**Batter**: ReCon has a built-in batter of 1” per course (3.58 degrees). The batter can be doubled to 7.2 degrees if the wall is constructed with a 1” ReCon spacer bar. **NOTE. The spacer bar was tested and found to have an average peak shear capacity of 3773 lb/ft. Caution should be used when designing with the spacer bar not to exceed a lateral earth pressure on the wall that may cause the spacer bar to shear.**

**Embedment**: Embedment is the distance from the finished grade in front of the wall to the top of the leveling pad. As a general rule of thumb this value should be a minimum of 10% of the wall height and no less than 6” for a level toe slope in front of the wall. Embedment should be increased to account for a sloping toe in front of the wall.

**Leveling Pad Depth**: Sets the thickness of the leveling/bearing pad. This should be a minimum of 6”. ReConWall distributes the weight of the wall blocks through the bearing pad at a 1:2 ratio. In cases of poor foundation soils it may be necessary to increase the thickness of the leveling pad. This input may be used to model a sub-cut of poor foundation soil.

**Leveling Pad Width**: Concrete leveling pad widths may be increased to solve for sliding.
overturning, and eccentricity. Gravel leveling pads are fixed at 12 inches (6 in. in front, 6 in. in back) larger than the base blocks.

**Slope Angle**: Slope angle specifies the angle (in degrees) of the soil as it slopes away from the top of the wall.

**Slope Length**: Specifies how far the slope angle extends.

**Slope Toe Offset**: Specifies where the slope angle at the top of the block begins. A value of zero will start the slope off the back of the top block.

**Live Load**: A uniform load that represents transient or temporary loads applied to the surface above the wall. Units are in lbs/sf or kN/m²

**LL Offset**: The horizontal distance from the back of the top block to the front of the uniform live load (ft or m)

**LL Width**: The width of the live load placed above the wall. This is used for strip loadings (e.g. roads, railroads, etc.)

**Dead Load**: A uniform load that represents a permanent load applied to the surface above the wall.

**DL Offset**: The horizontal distance from the back of the top block to the front of the uniform dead load

**DL Width**: The width of the dead load placed above the wall

**Toe Slope Angle**: Slope angle specifies the angle (in degrees) of the soil as it slopes away from the toe of the wall. The toe slope geometry has a direct effect on the global stability.

**Toe Slope Length**: Specifies how far the slope angle extends.

**Toe Slope Bench**: Allows the user to specify a minimum level bench in front of the wall before the topography slopes down.

**Settings for MSE Design**

**Min L/H**: Sets a minimum grid length based on the overall height of the wall. The grid lengths will never be set below this minimum even if the design calculations would allow for shorter grids. NCMA code sets this minimum at 60% while AASHTO requires this minimum to be set at 70%. For the AASHTO design, there is a check box on the "Preferences" tab that sets whether the 70% minimum is measured from the face of the block or from the back of the block.

**MinLen**: Sets a minimum overall grid length. The lengths will never be set below this minimum even if the design calculations would allow for shorter grids. NCMA code sets this minimum at 4 feet while AASHTO requires a minimum of 8 feet.
**Max Grid Spacing:** Sets the maximum spacing between geogrid reinforcement layers. AASHTO specifies a maximum spacing of 2.7 ft (32 inches).

**NEW Features to ReConWall 4.0 (Geometry)**

**Water w/in B Depth:** Previous version of ReConWall software assumed that the water table is located well below the foundation. ReConWall can now consider the effect of water on the design of a wall.

The user can specify a maximum water level located below the footing to consider the effects on bearing capacity of the soil.

![Water w/in B depth](image)

The user may also consider the effect of water above the footing up to a height equal to the top of the wall.

![Water w/in B depth](image)

The user may consider the effects of a level water surface by setting the height of water at the back of the units and the front of the wall at the same elevation. The user may also consider a "Rapid Drawdown" condition by setting the height of water in front of the wall lower than the height of the water at the back of the units. It is the responsibility of the engineer to determine when a rapid drawdown condition should be considered and the the height of drawdown that should be analyzed. The designer should consider the economic impact of designing the wall for a rapid drawdown condition vs. specifying the construction of the wall in a manner that will minimize or eliminate a rapid drawdown condition (e.g. specifying a rapidly draining backfill material such as open graded course gravel).
The best method to use when considering water in design is to first design the wall under dry conditions. The user can then add the water to the design and then "Update Design"* to see the effect that water has on the stability of the wall. For a rapid drawdown condition the "worst case" will likely always be located at the high water elevation. For a level water surface that may not always be the case. The user should start at the high water elevation, but should also check the results at intermediate locations all the way to the base of the foundation. If the presence of water causes the design to be insufficient at any layer, the user can manually increase the depth of the block at that layer.

Design Summary:
1. Design for dry conditions.
2. Input maximum water elevation (level water surface) and "Update Design"*.
3. Manually increase depth of blocks as necessary to satisfy the design.
4. Repeat steps 2 and 3 at intermediate elevations between the high water level and the foundation of the wall (e.g. every block layer)
5. Input maximum rapid drawdown condition at maximum elevation (when applicable) and "Update Design".
6. Manually increase depth of blocks as necessary to satisfy the design.

Update Design button in the upper right corner.

*It is important in this process to use the "Update Design" button rather than generate a "New Design". Update design allows the user to control the blocks used in the design whereas "New Design" returns to the default values determined by the software.

Gravity walls are an ideal solution for most water applications. However MSE walls may also be used in some water applications. The same method of design outlined above would apply to an MSE wall as well. Regarding the potential for Rapid Drawdown the user can consider the effects of drawdown on the external stability and internal stability. How to design for each was outlined in Chapter 1 of this manual. As with gravity walls, the high water level may not be the worst case scenario. The water level should be checked at various elevations between the base of the wall and the high water level.

Second Live Load: In an effort to more accurately model actual site conditions, the user may now specify two different live loads with a unique load, offset, and width. This may be useful, for example, in an application where a retaining wall has a roadway offset a certain distance from the top of the wall. Whether that distance between the wall and the roadway is a sidewalk or just open space the user may now model a traffic load offset from the wall and a pedestrian load in between.

Show Cut Dim.: This feature is for visual reference only. If the designer is specifying that a 45 degree construction cut is required, then this can be shown on the cross section to give a value to how much room is required to construct the wall.

Parapet Wall: In the past, ReConWall was unable to account for the portion of the wall that extends above the finished grade behind the wall. In regards to overturning and sliding it is
conservative to ignore in that a parapet wall creates no additional driving moment but increases the resisting moment through an increased resisting normal load. In cases where bearing capacity may control the design, it may be important to include the additional dead load from a parapet in the design of the wall. This section allows the user to account for the additional dead load created from the ReCon Fence Block stacked above grade or from another cast-in-place parapet. The width of the parapet should be limited to the width of the top block in the ReCon wall. **NOTE:** This does not take into account any lateral load that could be applied to a free-standing wall including (but not limited to) a vehicle impact. Further analysis should be done for a traffic barrier on top of a ReCon Wall and is beyond the scope of this software.
2.2.3 Soils

This tab is where the design specifies the soil properties for the soil zones that affect retaining wall design.

<table>
<thead>
<tr>
<th>Soil Properties</th>
<th>Zone</th>
<th>phi</th>
<th>Coh</th>
<th>gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforced</td>
<td>34</td>
<td>0.00</td>
<td>120.00</td>
<td></td>
</tr>
<tr>
<td>Retained</td>
<td>30</td>
<td>0.00</td>
<td>120.00</td>
<td></td>
</tr>
<tr>
<td>Foundation</td>
<td>30</td>
<td>0.00</td>
<td>120.00</td>
<td></td>
</tr>
<tr>
<td>Leveling Pad</td>
<td>40</td>
<td>0.00</td>
<td>130.00</td>
<td></td>
</tr>
</tbody>
</table>

**Reinforced**: Soil zone where geogrid reinforcement is placed in MSE design. This data is only recalled for MSE design and will not affect a gravity wall design.

**Retained**: Soil zone behind the wall. This zone starts behind the blocks in a gravity wall design and behind the reinforced soil zone in a MSE wall design.

**Foundation**: Soil zone under the wall.

**Leveling Pad (NEW)**: Previous versions of the software had hard-coded values of phi and gamma for the leveling pad. The phi angle of 40 degrees was used because it was a good match to ReCon's actual sliding test data. ReCon still recommends the use of 40 degrees as a valid input for the shear strength of the leveling pad material as this value is only used to calculate a friction coefficient for the base block sliding on the leveling pad. The user should find that using 40 degrees for this value will results in a friction coefficient consistent with ReCon's sliding test values. This input was primarily added to give the user more flexibility in determining the weight of the leveling pad material in regards to bearing considerations.

**Phi** ($\phi$) is the internal shear strength of the soil (in degrees).

**Coh** is the cohesion of the soil (in pcf or kN/m²) typically set at zero. The full implications of cohesion on the design of a retaining wall should be understood before use in design. The user should, at minimum, review the section on cohesion in Chapter 1 of this manual.

**Gamma** ($\gamma$) is the unit weight of the soil (in pcf or kN/m²)

Soil parameters used in the design of retaining walls should be obtained from a geotechnical engineer familiar with site specific conditions.
Chapter 2 - User Input

ReCon testing showed similar results for a ReCon base block sliding on either a crushed stone or a concrete leveling pad. For simplicity, the same friction coefficient for sliding is used regardless of leveling pad material. A concrete leveling pad thicker than 1 ft will be treated by the program as a structural element with the dimensions as defined on the geometry tab. The use of a concrete leveling pad may improve global stability.

**NEW Features to ReConWall 4.0 (Soil)**

When water is considered in design the soil table is updated to reflect the void ratio (e) and the saturated unit weight (GammaSat) of the soil.

The saturated unit weight is calculated based on the void ratio of the material. See the section on Saturated Unit Weight in Chapter 1 of this manual.

**Use Select Fill Zone**: When poor onsite soils are encountered or in most water applications it may be desired to excavate behind the wall and replace the on site soil with a Select Fill. AASHTO states, "In the absence of specific data, if granular backfill is used behind the prefabricated modules within a zone of at least 1V:1H from the heel of the wall, a value of 34 degrees may be used for $\phi_f$" (3.11.5.9 - AASHTO LRFD, 6th Edition)

When "Select Fill Zone" is selected the user should note that the "Reinforced" soil input box is replaced with the "Select Fill" soil zone. Per the AASHTO recommendations this soil zone has been fixed at an angle of 45 degrees (1H:1V).
Chapter 2 - User Input

The user can now specify soil parameters to be placed in this zone. If a value greater than 34 degrees is to be used, then testing should be performed to verify the soil parameters.

Unlike the "Crushed Stone over Blocks" option, the lateral earth pressure on the wall is calculated based on the soil parameters in this zone. As with the "Crushed Stone over Blocks" option, it is important that if the Engineer utilizes this option in design that the construction documents make it clear to the contractor that the wall must be constructed with a select fill zone extending 1V:1H from the heel of the wall and that the material meets the minimum shear strength and unit weight specified in the design.
2.2.4 Factors of Safety

The Factors of Safety tab sets the target design parameters for external, internal (for MSE walls), and local stability (for Allowable Stress Design). In the ReConWall program, the values in italics are the minimum* values prescribed by each specific design method. Seismic factors are typically taken as 75% of the static requirements. The designer is responsible for the proper selection of factors based on site conditions and uncertainties.

NCMA 09

![Table of Factors of Safety](image)
Chapter 2 - User Input

AASHTO 2002

### Factors of Safety

<table>
<thead>
<tr>
<th>Static</th>
<th>Seismic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sliding</td>
<td>Sliding</td>
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<tr>
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<td>Overturning</td>
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<tr>
<td>Gravity OT</td>
<td>Gravity OT</td>
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<td>Bearing</td>
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<tr>
<td>Bearing (MSE)</td>
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<table>
<thead>
<tr>
<th>Local Stability</th>
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<th>Reinforcing FoS</th>
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<table>
<thead>
<tr>
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<th>Seismic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Conn</td>
<td>Peak Conn</td>
</tr>
</tbody>
</table>

[seismic is 75% of static]

For gravity walls, AASHTO suggests a minimum factor of safety requirement for Bearing of 3.0, but does allow for a reduction for MSE walls to as low as 2.0.

For overturning, the default assumption is that the base block is bearing on a soil foundation (Gravity OT FoS > 2.0). Overturning is also checked at each block interface. For all other middle blocks in the wall, where the blocks bear on the block beneath it, the overturning is checked as if the block is bearing on rock (Gravity OT FoS > 1.5). If the base block is also bearing on rock then the user can change the overturning requirement for the base block.

#### 2.2.4.1 Load Factors

The load factors listed for ReConWall's LRFD design are taken from the AASHTO LRFD Bridge Design Specifications (Sixth Edition 2012). To the best of our knowledge, the load and resistance factors are being applied to the appropriate loads as recommended by the design code. Ultimately it is the users responsibility to ensure the design meets the project specifications.
AASHTO LRFD does not provide a target CDR for overturning. Rather an eccentricity limit is prescribed in Article 11.6.3.3. ReConWall displays this eccentricity limit as $e/L$, where $L$ is the depth of the block.

**11.6.3.3—Eccentricity Limits**

For foundations on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds of the base width.

For foundations on rock, the location of the resultant of the reaction forces shall be within the middle nine-tenths of the base width.
For eccentricity, the default assumption is that the base block is bearing on a soil foundation ($e/L < 0.33$). Eccentricity is also checked at each block interface. For all other middle blocks in the wall, where the blocks bear on the block beneath it, the eccentricity is checked as if the block is bearing on rock ($e/L < 0.45$). If the base block is also bearing on rock then the user can change the eccentricity requirement for the base block.

### 2.2.5 Block Input

**Block Properties**

The Block Properties tab is, for the most part a reference to the physical properties of the ReCon Blocks.

**NEW:** Previous versions of ReConWall software treated each block as a rectangular section. The unit weight of the concrete was reduced to a default value of 140 pcf to account for the "pie shaped voids" between the blocks that were filled with crushed stone. This version of the software uses the actual shape of the block and the dimensions of the pie shaped void to calculate an equivalent unit weight of the rectangular block used in the design. This allows the program to store the actual unit weight of the concrete and the actual unit weight of the stone in the pie shaped voids. The default values for the concrete and the stone are 145 pcf and 120 pcf respectively as seen in the table below.
Chapter 2 - User Input

The designer can modify the unit weight values by clicking the "Modify Block Densities" button.

The designer can enter the new unit weight of concrete and the new unit weight of stone. The user must also enter in a three letter code that will differentiate the new block file from the default block file.

For example:
When the user selects "Make New Unit" the program will cycle through a series of text boxes that inform the user that the block file was created and where it is saved.

To use the new block file the user should select the new file on the "Project Information" tab.

**Important Note:** The default program data files are stored in "Computer/C/Program Data/ReCon Wall". Because of Windows security controls the software is not able to save new data files directly to this folder. New block data files are by default saved to the user's "Documents/ReCon Wall" folder. When creating data files, new files will be available immediately as long as the program remains open. In order to be able to access new data files after the program is closed the new data files must be transferred to the "Computer/C/Program Data/ReCon Wall" folder. We have attempted to simplify this process with a file restore data files function. After creating a new data file and before closing the program, the user should select "Restore Data Files" from the "File" drop down menu:
In some cases Windows security may still not allow the software to transfer this file. In that case the user may need to manually copy the new file from one folder to the other. This may require the user to have administrative permission on the computer.

**Shear Properties**

Shear Properties displays the block-to-block shear properties and the leveling pad sliding properties.

<table>
<thead>
<tr>
<th>Name</th>
<th>Inter-Unit Slope</th>
<th>Inter-Unit Intercept (psf/kNm²)</th>
<th>Leveling Pad Crush Stone Slope</th>
<th>Leveling Pad Crushed Stone Intercept</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
<tr>
<td>39</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
<tr>
<td>45</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
<tr>
<td>60</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
<tr>
<td>66</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
<tr>
<td>72</td>
<td>22.00</td>
<td>6775.00</td>
<td>33.87</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Aside from concrete and soil density, changes to the block properties can only be made by ReCon.
2.2.6 Geogrid Properties

The Geogrid Properties tab displays the characteristics of the geogrid brand selected for design (on the project information tab). The user can specify the strength of grid desired and can select the type of material in the geogrid reinforced zone (Stone, Sand, Silt or Clay).

The only geogrid strengths that are available for design are those that have been tested in connection with ReCon Series 50 blocks.

Geogrid Properties

Definitions:
- **Tult**: the ultimate strength of the geogrid in short term testing
- **RFcr**: the reduction factor to account for creep reduction strength due to long term creep under load.
- **RFd**: the reduction factor to account for reduction in strength due to chemical or biological degradation
- **RFid**: the reduction factor to account for damage during installation and compaction efforts
- **LTDS**: Long Term Design Strength is the strength of the reinforcement less the above mentioned reductions
Chapter 2 - User Input

- Ta: Allowable tension is the LTDS / factor of safety for uncertainties OR the ultimate connection capacity / factor of safety for connection. The design uses the lesser of the two.

Ci and Cd are interaction coefficients used in the calculations for pullout and internal sliding respectively. These values are recommended by the grid manufacturer’s based on the type of reinforced soil material.

The selection of stone, silt, sand, or clay will affect the values of Rd, Ci, and Cd.

The **Block Connection Properties** section reflects the connection pullout based on actual test data. The data peak slope and peak intercept model the connection curve for the corresponding test data.

**Conn Creep** allows the user to input a creep reduction factor on the connection for a rupture connection. ReCon would consider the failure mode of its current frictional connections with Mirafi, Stratagrid, and Synteen as pullout failures. Some state DOT’s may require creep reduction on a pullout failure to conservatively apply. If this is the case, the user must check the "Rup Conn" (Rupture Connection) check box and input the appropriate creep reduction factor.

**The Shear Properties** reflect ReCon’s block to block shear test data. This is a conservative estimate in that the shear key was not tested to failure.

The user must select a strength of reinforcement for MSE design. Only those grids that have connection test data will be available for design. The order of operation for grid layout is as follows:

- Grid design starts from the top down.
- The program will use the lightest grid that will work for the design from the grids selected.
- The software will try to maintain maximum spacing (32") whenever possible.
- If more than one grid strength is selected, the program will choose the stronger grid if it will allow for the maximum spacing.
- Once the stronger grid is used, the software will use that grid strength through the rest of the wall. (it will never place a weaker grid below a stronger grid by default)
- If strength of geogrid is more critical to the design than grid spacing, then only one grid strength should be selected for design.

The results of the default grid design can be manually adjusted after the initial results are computed. The following adjustments can be made:

- Increase/decrease grid strength.
- Increase/decrease grid length.
- Shift a grid layer up/down
- Insert/delete grid layer.

### 2.2.7 Seismic

ReConWall performs a pseudo-static seismic analysis using the Mononobe-Okabe method.
Chapter 2 - User Input

A more detailed explanation of seismic theory is outlined in Chapter 1 of this help menu. The application of the M-O method is slightly different for NCMA and AASHTO. For both methods the user should input a Peak Ground Acceleration and an allowable displacement (kv is assumed to be 0).

Seismic analysis will be performed if the "Enable" box is checked.

Peak ground accelerations greater than 0.45 are beyond the scope of the ReConWall software.

2.3 Results

2.3.1 Gravity Results

If a gravity design is desired select "Gravity Design". The most efficient design will be computed. The software will check overturning and sliding at each block layer starting from the top and working to the base of the wall. The software will attempt to satisfy all design criteria with the smallest block selected on the project information tab. If the design criteria cannot be met, the software will check the next larger block available for design. A summary of the external stability results will be displayed in the lower right hand corner of the results screen. This summary displays the critical values for the overall wall height.
"OK" indicates that the results meet the required design parameters. "NG" indicates the design parameters were not met.

In addition to the External Stability results of the overall system, the results of overturning and sliding are displayed at each block layer in the "results" table.

**Static Table (no water)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Elev [depth]</th>
<th>ka</th>
<th>Paw1</th>
<th>Paw2</th>
<th>Paw3</th>
<th>Pawd</th>
<th>Pawr</th>
<th>Paq</th>
<th>Paqd</th>
<th>(PaC)</th>
<th>PaT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>10.67[1.33]</td>
<td>0.273</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>91</td>
<td>0</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>24</td>
<td>9.33[2.67]</td>
<td>0.273</td>
<td>116</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>182</td>
<td>0</td>
<td>0</td>
<td>290</td>
</tr>
<tr>
<td>39</td>
<td>8.00[4.60]</td>
<td>0.432</td>
<td>414</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>432</td>
<td>0</td>
<td>0</td>
<td>846</td>
</tr>
<tr>
<td>39</td>
<td>6.67[5.33]</td>
<td>0.385</td>
<td>657</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>514</td>
<td>0</td>
<td>0</td>
<td>117</td>
</tr>
<tr>
<td>39</td>
<td>5.33[6.67]</td>
<td>0.359</td>
<td>959</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>599</td>
<td>0</td>
<td>0</td>
<td>155</td>
</tr>
<tr>
<td>39</td>
<td>4.00[8.60]</td>
<td>0.343</td>
<td>1318</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>686</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>60</td>
<td>2.67[9.33]</td>
<td>0.430</td>
<td>2247</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>324</td>
</tr>
<tr>
<td>60</td>
<td>1.33[10.57]</td>
<td>0.406</td>
<td>2774</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1084</td>
<td>0</td>
<td>0</td>
<td>385</td>
</tr>
<tr>
<td>60</td>
<td>0.00[12.00]</td>
<td>0.389</td>
<td>3360</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1167</td>
<td>0</td>
<td>0</td>
<td>452</td>
</tr>
</tbody>
</table>

**Static Table (with water)**

<table>
<thead>
<tr>
<th>Name</th>
<th>Elev.[depth]</th>
<th>ka</th>
<th>Paw1</th>
<th>Paw2</th>
<th>Paw3</th>
<th>Pawd</th>
<th>Pawr</th>
<th>Paq</th>
<th>Paqd</th>
<th>(PaC)</th>
<th>PaT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>10.67[1.33]</td>
<td>0.273</td>
<td>29</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>91</td>
<td>0</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>24</td>
<td>9.33[2.67]</td>
<td>0.273</td>
<td>116</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>182</td>
<td>0</td>
<td>0</td>
<td>290</td>
</tr>
<tr>
<td>39</td>
<td>8.00[4.60]</td>
<td>0.432</td>
<td>414</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>432</td>
<td>0</td>
<td>0</td>
<td>846</td>
</tr>
<tr>
<td>39</td>
<td>6.67[5.33]</td>
<td>0.385</td>
<td>657</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>514</td>
<td>0</td>
<td>0</td>
<td>117</td>
</tr>
<tr>
<td>39</td>
<td>5.33[6.67]</td>
<td>0.359</td>
<td>959</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>599</td>
<td>0</td>
<td>0</td>
<td>155</td>
</tr>
<tr>
<td>39</td>
<td>4.00[8.60]</td>
<td>0.343</td>
<td>1318</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>686</td>
<td>0</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>60</td>
<td>2.67[9.33]</td>
<td>0.430</td>
<td>2247</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1003</td>
<td>0</td>
<td>0</td>
<td>324</td>
</tr>
<tr>
<td>60</td>
<td>1.33[10.57]</td>
<td>0.406</td>
<td>2774</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1084</td>
<td>0</td>
<td>0</td>
<td>385</td>
</tr>
<tr>
<td>60</td>
<td>0.00[12.00]</td>
<td>0.389</td>
<td>3360</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1167</td>
<td>0</td>
<td>0</td>
<td>452</td>
</tr>
</tbody>
</table>

**Abbreviations:**

- **Name:** Unit name
- **Elev [depth]:** elevation above the base, [or depth from the top].
- **ka:** active earth pressure coefficient of active earth pressure
- **Paw1:** force from active earth pressure above the water level (ppf)
- **Paw2:** force from active earth pressure of Paw1 carried below the water level (ppf)
- **Paw3:** force from submerged active pressure below the water level (ppf)
Chapter 2 - User Input

**Pawd**: driving force from the water (ppf)
**Pawr**: resisting force from the water (ppf)
**Paq**: force from live load surcharge (ppf)
**Paqd**: force from dead load surcharge (ppf)
**PaC**: negative force from soil cohesion (ppf)
**PaT**: total force
**FSsl**: factor of safety for sliding
**FoS OT**: factor of safety for Overturning
**%D/H**: the ratio of the base width (D) to the wall height (H)

The user can manually adjust the block layout from the default results if desired by clicking on the block the user would like to adjust and following the instructions along the bottom screen of the software. The results will automatically update.

In general, a larger unit should not be placed on a smaller unit without a further analysis of the results. In this case the results should be verified with a hand calculation.

### 2.3.1.1 Gravity Seismic

When seismic analysis is enabled seismic results will be displayed in addition to the static results, both for the overall system and at each block layer.

```
FoS Overturning = 1.53...OK
FoS Sliding = 1.82 / 1.70...OK [base / foundation]
Bearing = 3139.32...OK  Quilt/FSbr.4415.38
FoS Bearing = 2.81
Length = 5.00
---
L / H =41.7%

======= seismic =====
FoS Overturning = 1.35...OK
FoS Sliding = 1.74 / 1.63...OK
Bearing = 2774.37 < OK  8830.76
FoS Bearing = 3.18
Length = 5.00
---
```
2.3.2 Reinforced Results

If a reinforced MSE design is required, then select "Reinforced Design". The most efficient design will be computed based on the selection of grid properties. A summary of the external stability results will be displayed in the lower right hand corner.

<table>
<thead>
<tr>
<th>Name</th>
<th>Elev.</th>
<th>ka</th>
<th>kae</th>
<th>Pa</th>
<th>Pse</th>
<th>Pir</th>
<th>- PaC</th>
<th>FSsl</th>
<th>FoS OT</th>
<th>siesFSsl</th>
<th>FoS SeisO</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC</td>
<td>10.67</td>
<td>0.273</td>
<td>0.327</td>
<td>29</td>
<td>35</td>
<td>31</td>
<td>0</td>
<td>60.19</td>
<td>5.17</td>
<td>100.00</td>
<td>8.87</td>
</tr>
<tr>
<td>24</td>
<td>9.33</td>
<td>0.273</td>
<td>0.327</td>
<td>116</td>
<td>140</td>
<td>63</td>
<td>0</td>
<td>24.77</td>
<td>2.35</td>
<td>36.02</td>
<td>3.37</td>
</tr>
<tr>
<td>39</td>
<td>8.00</td>
<td>0.432</td>
<td>0.503</td>
<td>414</td>
<td>482</td>
<td>114</td>
<td>0</td>
<td>11.85</td>
<td>3.43</td>
<td>15.64</td>
<td>3.73</td>
</tr>
<tr>
<td>39</td>
<td>6.67</td>
<td>0.385</td>
<td>0.452</td>
<td>657</td>
<td>771</td>
<td>165</td>
<td>0</td>
<td>8.34</td>
<td>2.50</td>
<td>9.90</td>
<td>2.54</td>
</tr>
<tr>
<td>39</td>
<td>5.33</td>
<td>0.359</td>
<td>0.423</td>
<td>959</td>
<td>1129</td>
<td>217</td>
<td>0</td>
<td>6.30</td>
<td>1.96</td>
<td>6.99</td>
<td>1.90</td>
</tr>
<tr>
<td>39</td>
<td>4.00</td>
<td>0.343</td>
<td>0.405</td>
<td>1318</td>
<td>1557</td>
<td>268</td>
<td>0</td>
<td>4.98</td>
<td>1.59</td>
<td>5.28</td>
<td>1.50</td>
</tr>
<tr>
<td>60</td>
<td>2.67</td>
<td>0.430</td>
<td>0.501</td>
<td>2247</td>
<td>2617</td>
<td>346</td>
<td>0</td>
<td>3.84</td>
<td>2.03</td>
<td>3.99</td>
<td>1.88</td>
</tr>
<tr>
<td>60</td>
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<td>0.406</td>
<td>0.475</td>
<td>2774</td>
<td>3241</td>
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<td>0</td>
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<td>1.75</td>
<td>3.29</td>
<td>1.57</td>
</tr>
<tr>
<td>60</td>
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<td>0.389</td>
<td>0.456</td>
<td>3360</td>
<td>3936</td>
<td>502</td>
<td>0</td>
<td>1.82[1.70]</td>
<td>1.53</td>
<td>1.74[1.63]</td>
<td>1.35</td>
</tr>
</tbody>
</table>

2.3.2 Reinforced Results

If a reinforced MSE design is required, then select "Reinforced Design". The most efficient design will be computed based on the selection of grid properties. A summary of the external stability results will be displayed in the lower right hand corner.

In addition to the External Stability results of the overall system, the internal stability results are displayed at each grid layer in the "results" table.
Chapter 2 - User Input

Abbreviations
ID: Layer above the base
Height: elevation above the base (ft / m)
Length: length of the geogrid from the face (ft / m)
Geogrid: geogrid name
Tallow: the allowable tension in the geogrid (see Geogrid window)
EP (Pa): force from the active earth pressure (ppf)
LL (Pql): force from the live load surcharge (ppf)
DL (Pqd): force from the dead load surcharge (ppf)
TMax: maximum force in the geogrid layer (EP + LL + DL) (ppf)
FS Str: factor of safety for strength (Tallow / Tmax)
Tal Cn: allowable tension on the Connection (ppf)
FS Pk Cn: factor of safety on the connection (Tal Cn * FScn / Tmax)
FS PO: factor of safety on pullout (Tpo / Tmax without live load included)
FS Sidg: factor of safety of sliding on geogrid layer or base level

More detailed information can be viewed on the "Forces & Moments" tab and the "All Forces" tab.

The user can also adjust the design from the default results. The user can shift the geogrid layers up or down, made longer or shorter, made stronger or weaker, and layers can be deleted or added.

There is also a shortcut to adjusting grid elevations in the upper right hand corner of the software:

Pressing the "Up" button will shift all grid layers up one course of blocks and pressing the "Down" button will shift all grid layers down one course of blocks.

2.3.2.1 Reinforced Seismic

When seismic analysis is enabled seismic results will be displayed in addition to the static results, both for the overall system and at each grid layer.
Chapter 2 - User Input

2.3.3 Global

The importance of compound and global stability and the process for analyzing the compound and global stability of a ReCon wall is outlined in Chapter 1. The ReConWall software, by default, produces a design cross section that meets Internal and External stability. The internal and external stability results must be checked to ensure that they meet the Compound and Global stability requirements.
As explained in Chapter 1, ReConWall assumes a circular failure mode and the factor of safety is calculated based on the path of the arc. Numerous failure surfaces are analyzed to determine the critical failure surface. The number of potential failure surfaces that are checked is determined by the “Search Increments” and the “Point Increments”. The default values of 0.5 and 20% are typically adequate for the simple geometries found in ReConWall.

For more complex geometries, such as tiered walls, global stability should be analyzed in a third party software (such as G-Slope or ReSSA) that is capable of accurately modeling the site conditions.

### 2.3.3.1 Compound Stability

Compound stability check for failure surfaces through the wall face. Given the stiffness of the wall facing and the current limit on grid spacing compound stability should not control for a ReCon Wall.
While many failure surfaces are analyzed the graphic will only display those surfaces that have a factor of safety less than that shown in the "Max. FS to Show" input box. If there are no results lower than the "Max. FS to Show" value, then the curve with the lowest factor of safety will be displayed.

2.3.3.2 Global Stability

The global stability failure plane passes below the toe of the wall.
Chapter 2 - User Input

2.4 Preferences

As features are added to the ReConWall design software, many of them are placed on the preferences tab in the form of a check box option. In general these design options should be used only by the advanced designer. Below is a brief explanation of each option on the preferences tab.

**Force Height to Block Height:** Forces the design height of the wall on the geometry page to the nearest full block or cap. For example if 10’ is entered into the wall geometry, the wall will be analyzed for a wall height of 10.67’ if this box is checked.

**Use Specified Delta Angles:** The delta angle is preset as a certain percentage of the phi angle of the retained soil based on the minimum requirements of the NCMA or AASHTO design code. Checking this box reveals an additional input box on the Section Geometry tab which can be used to specify the delta angle as a percentage of phi.

**Include Base Friction in Geogrid Tension:** Accounts for the friction between the base block of the facing unit and treats this resisting force as a reinforcement layer when determining the tributary area for the tension in the base grid.

**Ignore Passive Resistance of Leveling Pad:** By default the passive pressure in front of the retaining wall blocks is ignored, but is considered in front of the leveling pad when calculating the sliding resistance of the leveling pad. If the designer prefers to ignore the passive pressure contribution in front of the leveling pad then this box should be checked.
Chapter 2 - User Input

**Depth for Passive Pressure Calc:** In cases where embedment of the facing blocks exceeds the frost and/or scour depth, it may be acceptable to consider passive pressure of soil in front of the wall. If this option is to be utilized, then the box must be checked and the depth at which passive pressure should be considered must be specified.

**0.7H From Back of Face:** If this box is checked then the minimum length of reinforcement for AASHTO designs will be measured from the back face of the block.

**Exclude Face Shear from Sliding on the Reinforcing:** The ReCon block facing and its substantial shear key provides significant resistance to sliding on a reinforcement layer. MSEW design software currently conservatively ignores the wall facing in direct sliding contributions. If it is desired to match the ReConWall output with the MSEW Software output, this box should be checked in order to also ignore the facing contributions to sliding.

**Assume Zero Embedment for Bearing:** If this box is checked then the ultimate bearing capacity equation will ignore the soil from the top of the leveling pad to the top of finished grade in the equation for Qult.

**Use Soil Wedge for Pif (Gravity Calcs):** There is a wedge of soil between the back of the block and the theoretical back of the wall. When this box is checked the mass of that soil wedge is included in the mass of the wall when calculating Pif for seismic design.

**Use Block Shear in Total Pullout:** Adds block to block shear to the total pullout resistance.

**Forces to base of Concrete Leveling Pad:** N/A. For MnDOT designs only

**Show Partial Coverage:** Checking this box reveals an additional input box on the geometry tab that allows the user to adjust the percent coverage for geogrid. By default, the software uses 100% geogrid coverage.

**Show Min Embedment Length:** N/A

**Unit Weight of Drainage Stone:** Allows the user to input the unit weight of the stone located between the theoretical back of wall and the back of the blocks for a multi-depth gravity wall (Not the same as the drainage stone in the pie shaped voids - The weight of the drainage stone in the pie shaped voids is defined on the Block Input tab).

**Show Eccentricity Check for LRFD/ASD Design:** For LRFD design, checking this block will display the equivalent Factor of Safety value. This is for reference only.

**Include MnDOT Surcharge:** For MnDOT projects only. Consult ReCon for further information.

**Use NHI Design:** NHI recommends a live-load load factor of 1.35 for the live load located over the reinforced zone. The default AASHTO load factor is 1.75. Checking this box will defer to the NHI recommendations.
**Show Preliminary Analysis:** By default, the program will install with the "Print Preliminary Disclaimer" option checked on the Section Information tab. This box will be checked every time the program opens (even if the box is unchecked and the user selects "save defaults" with the box unchecked). If it is desired to remove this disclaimer from the printout, this box must be unchecked each time the software is opened. Unchecking this box, "Show Preliminary Analysis" on the preferences tab will allow the user to uncheck the "Print Preliminary Disclaimer" on the Section Information tab and then "save defaults". If this is done, then the "Print Preliminary Disclaimer" box on the Section Information tab will be unchecked by default. **This option should only be utilized by a Professional Engineer that has reviewed all software calculations and output for accuracy.**

**Make Geogrids the Same Length:** Checking this box will make all of the geogrid the same length for the default results. The lengths may still be adjusted manually from the results screen. AASHTO code requires geogrid to be the same length at every layer (see the AASHTO manual for the few notable exceptions to this requirement). While NCMA has no such requirement, making geogrid layers the same length is generally good practice and reduces the likelihood of mistakes during construction. Also, while shorter grids at the base of the wall may satisfy internal and external stability requirements, this could lead to decreased global stability.

**Min Geogrid Increment:** This sets the minimum increment that the software will use for geogrid lengths. For ease of construction we recommend not varying the geogrid length by more that 0.5 ft.

**Allow Geogrids on Leveling Pad:** Allows the user to place a layer of geogrid at the base of the wall.
3 Registration

This program requires a RECON.license file to operate. Registration is based on the designer’s email address and the unique machine code. A registration code is only valid for the PC from which the original registration was sent. Please fill out the registration information and email it back to ReCon Wall Systems, Inc. A license file will be returned with the license information necessary to run the program.

Fill out the registration form. Select the "I Accept the Terms of Usage and I Acknowledge the Disclaimer and Request Registration" button. The registration file is located in "Documents/ReCon Wall". If Outlook is being used as the primary mail server then an email will automatically be sent to ReCon with the registration information. If Outlook is not being used then this registration file must be attached to another email and sent to sales@reconwalls.com.

1. This software requires a ReCon.license file to operate. Please fill out the registration information (above) and email it back ReCon Wall Systems, Inc. A license file will be returned with the license information necessary to run the software.

2. Please read the Acceptance of Terms of Usage and Acknowledgment of Disclaimer that follows and check the Acceptance Button before emailing your registration request.
4 References

The Process
The process of developing design methods and design tools requires:
1. Investigating what exists in the industry.
2. Investigating the successes and failures to see if the methods / products work.
3. Analyzing and designing walls to see what the designer requires and how it is best used.
4. Developing tools that are accurate, provide safe designs for the products, and are easy to understand and use.

References
Gravity earth retaining wall structures have been around for centuries. The basics of the analysis are:
1. Establish the geometry and loading for the proposed wall.
2. Establish the correct loading parameters based on the geology at the site.
3. Design a structure that can:
   · Resist the loading applied.
   · Provide a design life suitable to the structure.
   · Give a pleasant appearance to enhance the beauty of the area.

Design References
References used to develop the design coding for the program were:


National Concrete Masonry Association (NCMA) 2009, *Design Manual for Segmental*
Retaining Walls, 3rd Edition, National Concrete Masonry Association, Herndon, VA.

Naval Facilities Engineering Command, Design Manuals (DM)
- DM-7.01 Soil Mechanics, 1986
- DM-7.02 Foundation & Earth Structures, 1986
5 Acceptance and Disclaimer

Acknowledgement and Acceptance of Terms of Usage and Disclaimer

a. The user of this ReConWall Analysis Software, as a condition of using this software, hereby acknowledges that he/she has read and understands, and agrees to, all of the terms of usage and disclaimers set forth below.

b. This software has been created as a tool to assist in the analysis of ReCon unreinforced gravity walls and reinforced geo-grid walls. The user must read the entire contents of the Help Menu before using the software, including ensuring his or her understanding of the Design Theory explained in Chapter 1 of the Help Menu. The user acknowledges and agrees that an understanding of the concepts explained in the Help Menu is essential to the proper usage of this software.

c. Final design and construction for a specific application are the sole responsibility of the user. **ANYONE MAKING USE OF THIS SOFTWARE AND ITS CALCULATIONS DOES SO AT HIS OR HER OWN RISK AND ASSUMES ANY AND ALL LIABILITY RESULTING FROM SUCH USE.**

d. This software and the calculations that it generates are for **PRELIMINARY USE ONLY** and **SHALL NOT UNDER ANY CIRCUMSTANCES BE USED OR RELIED UPON FOR ANY SPECIFIC DESIGN OR CONSTRUCTION APPLICATION WITHOUT THE INDEPENDENT REVIEW, VERIFICATION, AND APPROVAL BY A QUALIFIED PROFESSIONAL ENGINEER (“P.E.”)” of the accuracy, suitability, and applicability of all specific design and construction decisions. Such engineer must be familiar with the site conditions, project materials, retaining wall design theory and methodology, and all other factors that do or may affect the suitability of the specific design or construction application. A final project-specific design must be prepared by the P.E., who must be licensed in the country and state of the project and meet all other professional licensing and other requirements to perform the work, and the final project-specific design must meet all local building code and design requirements.

e. The information utilized by and produced from ReConWall, including, but not limited to, all technical engineering data figures, tables, designs, drawings, details, and suggested specifications are for **GENERAL ANALYSIS only**. Because soils, drainage, and other site specific conditions may vary, such general analysis must not be used or relied upon as being accurate, adequate, or suitable to produce a desired result at a specific site. The final design must be based on project specific geometry, loadings, soils and other material used in construction.

f. ReConWall contains **DEFAULT VALUES** for several data inputs that the USER MUST CHANGE OR VERIFY AS APPROPRIATE for the specific wall system components and project conditions being analyzed. These **DEFAULT VALUES DO NOT ENSURE A CONSERVATIVE DESIGN** for any wall component or site condition. The
final design must provide proper wall drainage to prevent the buildup of hydrostatic pressures over the service life of the ReCon wall.

g. The software analyzes Global Stability only for the simple geometry and the broad classifications of retained and foundation soil (excluding groundwater) as allowed by the limits of the software input. The suitability of the soil beneath the structure to support the structure is NOT addressed by this software and must be evaluated by the project P.E. Structures may experience many types of loading that are NOT addressed by this software, such as surcharge loads above or on the structures in excess of the load options provided, tiered retaining walls, seismic loads, snow loads, wind loads, and water loads (including the effects of groundwater), and all potential load factors must be evaluated by the project P.E.

h. **RECON WALL SYSTEMS, INC. AND REA, LLC DISCLAIM ANY AND ALL EXPRESSED OR IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE WITH REGARD TO ANY AND ALL USE OF THE SOFTWARE, INCLUDING ITS DESIGN CALCULATIONS, AND WITH REGARD TO ANY INFORMATION OR PRODUCTS CONTAINED OR REFERRED TO HEREIN.**

All rights to this software are reserved by ReCon Wall Systems, Inc. No part of this ReConWall software may be reproduced in any form without permission in writing from ReCon Wall Systems, Inc.

**I HEREBY ACKNOWLEDGE THAT I HAVE READ AND UNDERSTAND, AND AGREE TO, ALL OF THE TERMS OF USAGE AND DISCLAIMERS.**
6 About the Software Author

Race Engineering Assoc., LLC
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www.REA-llc.com

Robert Race, PE, MBA, is a professional engineer results driven and motivated by new products and sales. With over 20 years of experience in analysis, design, sales and construction of civil engineering projects there is a wealth of experience to draw from. He was licensed in over 40 states as a professional engineer and has presented papers, technical training and sales seminars throughout the US and in over 30 countries around the world. Since 1994 he has traveled extensively through Latin America, South America, Europe, Asia, Africa, The Middle East, Japan, and the South Pacific countries of New Zealand and Australia training and providing technical and sales support for Mechanically Stabilized Earth structures using steel and geosynthetic reinforcement.

Receiving a Bachelor of Science degree from Cornell University in Civil Engineering, he worked as a site engineer designing steel frame and concrete structures on new plant construction. During this time he earned a Master's in Business Administration degree. After completing his MBA he returned to university, attending Purdue University earning a Masters of Science degree in Geotechnical Engineering.

Education:
Cornell University: Bachelor of Science (BS) in Civil Engineering
Georgia College: Masters in Business Administration (MBA)
Purdue University: Masters in Geotechnical Engineering (MS)

Employment History:
REA, LLC: 2006 to present - Independent consultant specializing in earth structures, new innovations, technical sales & marketing. Interests focus on earth retaining wall structures (SRW walls, big block wall, GREEN solutions, forensic engineering, software development, and new product consulting)
Envirolok: Consulting Engineering marketing and selling a "GREEN" solution to slopes and walls using geosynthetic modular units.
Deltalok USA: Consulting Engineering marketing and selling a "GREEN" solution to slopes and walls using geosynthetic modular units.
Millenia Wall Solutions: Consulting Engineer developing and marketing a polymer retaining wall system.
Keystone Retaining Walls: Vice President / International Markets developing, marketing and engineering modular block walls using zero-slump concrete products. Managed the international market for business development, developed new products, and worked with national committees on design methodology, durability, and installation.
The Tensar Corporation: Manager of Engineering developing polymer soil reinforcing systems for MSE walls and slopes. Managed a team of 18 designers designing and estimating projects across the nation and interfaced with Tensar International for world wide projects.
CRS Sirrine: Geotechnical manager for geotechnical design for civil engineering projects, waste to energy facilities, pulp and paper facilities and power plants. CRS Sirrine was voted the largest design build firm in the country.
Stone & Webster Engineering: Sr Geotechnical engineer designing for nuclear, fossil and hydro-electric power facilities.

Experience:
Global experiences training, engineering, selling and installing earth systems. National exposure to Federal and State DOT projects, specifications and submittals. Worked on many national design and support committees. Had to opportunities to work with some of the leaders in the industry with new technologies.

After graduate school he accepted a position with Stone and Webster Engineering in Denver, Colorado. For the next five years he had to opportunity to work with some of the leaders in the industry (Dr. Chuck Ladd, Dr. Ralph Peck, Dr. Gary Brierly) on major dam projects, hydro-electric projects and nuclear power facilities. These projects were located all across the US and Alaska giving him exposure to varying site conditions and unusual loading conditions.

The 80's were a slow time in the power and energy industry prompting him and many others to seek alternate industries. A move to consulting in tunneling was an opportunity to see some of the largest tunnel boring machines (TBM's) in the world, to work on hard rock tunneling projects and get exposure to blasting and it's affects on surface structures. The tunneling division was part of the larger CRS Sirrine Consulting, the number one design build firm in the country. A move to North Carolina followed with consulting on geotechnical design issues in the pulp and paper industry within CRS Sirrine.

The Tensar Corporate made their first HDPE geogrid reinforcing manufactured in the US at their new plant in Morrow, GA. Sounding like an interesting and challenging new application, synthetic soil reinforcement, he joined Tensar as a senior engineer. Being at the start of a whole new industry was a lot of work but rewarding being part of the team developing applications.

Later, having worked closely with Keystone Retaining Wall Systems in Minneapolis since joining Tensaer it was a natural transition to move from one startup industry to now another new industry, the SRW industry. From the time Keystone first introduced a segmental retaining wall block that could be used with geosynthetic reinforcement, to the year 2006, the SRW industry grew to over a $3 billion in construction, installing over 300 million square feet per year in the US and International markets. The many years with the SRW industry proved to very rewarding, traveling the world developing friends and business acquaintances around the globe. The opportunity to work in all the different countries and interact on a personal and business level with so many talented individuals was priceless.

2006 brought another opportunity, the chance to move to another stage in one's career, independent consulting. Traveling was rewarding but it got to the point that spending 50 percent of the time on the other side of the world was too much (does Platinum on two airlines seem like a road warrior?). With a couple of projects lined up and some fairly good prospects the choice was made to leave Keystone.

After leaving Keystone he has worked on developing a polymer retaining wall system. The application was good, the system performed well, but the economy and the cost of polymer materials made the product less feasible in the market. He spent a year developing a US market for a GREEN retaining wall / slope product. The product works well, performs well, and has a good potential future. He also has written and supports several computer design programs, tools that help the designers do a better and quicker job of designing earth structures.

He is currently working with GREEN products, Big Block Retaining Walls, SRW walls, geotechnical consulting and permeable paver solutions. There are still many new opportunities to explore.

Robert lives in Minneapolis with his wife and their two daughters.
7 Revision History

ReConWall v4.0 (2015)