NCMA TEK

CONCRETE MASONRY GRAVITY RETAINING WALLS

TEK 15-6
Structural   (1995)

Keywords: **allowable stress design,** lateral loads, plain concrete masonry, retaining wall, unreinforced concrete masonry

INTRODUCTION

Retaining walls support soil and other materials laterally. That is, retaining walls "retain" earth, keeping it from sliding. Retaining walls must resist overturning and sliding, and the pressure under the toe (front bottom edge of footing) should not exceed the bearing capacity of the soil. Finally, the wall must be strong enough to prevent failure at any point in its height due to the pressure of the retained material. Concrete masonry retaining walls meet these requirements admirably.

Three different types of concrete masonry retaining walls are illustrated in Figure 1. They are the simple unreinforced vertical face gravity retaining wall, the steel reinforced cantilever retaining walls, and the segmental retaining wall. This TEK addresses the unreinforced gravity retaining walls only. Each of these retaining wall systems has its advantages, and the choice may depend on a number of factors including aesthetics, constructibility, cost, and suitability for a particular project. The gravity wall is much simpler in design and construction, and can be an effective choice for smaller projects. It is thicker at the base than the cantilever and segmental, and hence could cost more to construct on larger projects. Gravity retaining walls also have greater resistance to sliding because of their large mass, whereas segmental and cantilever retaining

walls are designed to resist sliding by using reinforcement. Because of their large mass, gravity retaining walls may not be appropriate for use on soils with low bearing capacities.

An engineer who is familiar with local conditions can assist in the choice of retaining wall type. Where especially unfavorable soil conditions occur or where piling is required under a retaining wall, the assistance of an engineer is essential for design and construction.

DESIGN

The primary force acting on a retaining wall is the pressure exerted by the retained material at the back of the wall and on the heel of the footing. The magnitude and direction of this pressure will be dependent on the height and shape of the surface and on the nature and properties of the backfill. One common method of estimating backfill pressure is the equivalent fluid weight method. In this method, it is assumed that the retained earth will act as a fluid in exerting pressure on the wall. Assumed equivalent fluid pressures vary with the type of soil. Representative soil types with their equivalent fluid pressures are shown in Table 1.

Since the stability of the gravity type retaining wall depends mainly on its weight, the thickness required at its base will increase with height of backfill, or wall height. Uplift pressure at the back of the wall (the heel) is avoided by designing the gravity retaining wall thick enough at the base so that the resultant of all forces (overturning force and vertical loads) falls within a zone called the kern, which is the

Gravity retaining wall   Cantilever retaining wall   Segmental retaining wall
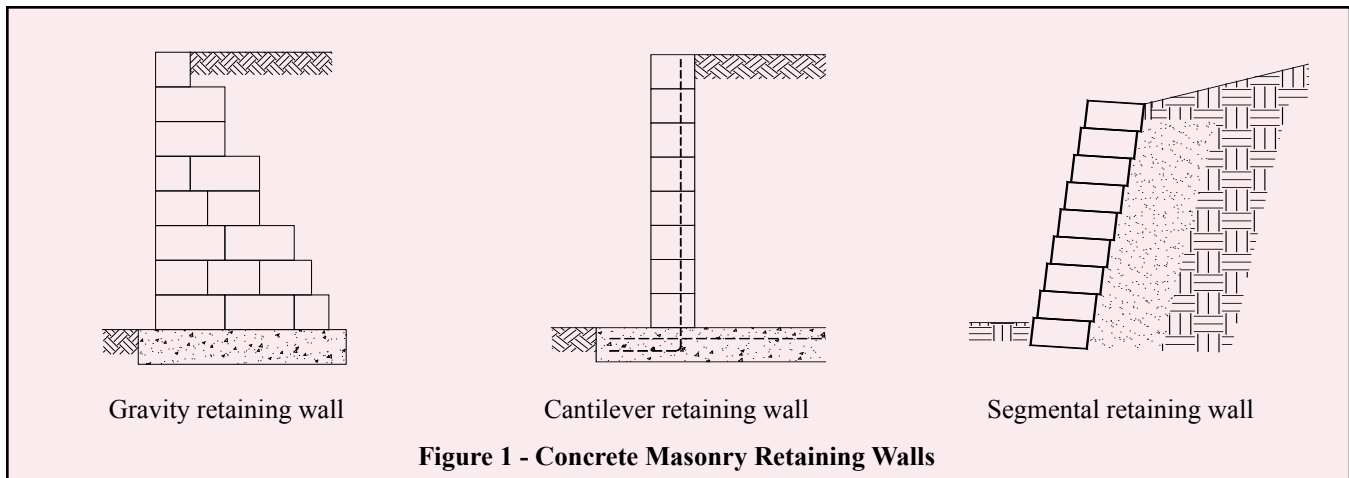
Figure 1 - Concrete Masonry Retaining Walls

Table 1 - Equivalent Fluid Pressures of Soils

Soil Description	Equivalent Fluid Pressure, pcf (kN/m³)
granular soil	30 (4.7)
drained silty sand or silty clay	45 (7.1)
clay soil	60 (9.4)

Figure 2 - Relationship of Gravity Retaining Wall Height to Width at Base

middle one third of the base. The eccentricity of the resultant force is equal to or less than one-sixth of the base width. When the eccentricity, *e*, is equal to one-sixth the base width exactly, the maximum footing pressure on the soil at the front edge of the base (toe) will be twice the average pressure on the soil.

The horizontal force of the retained material causes the overturning moment on the gravity retaining wall. For a given wall height, the required thickness at the base will depend not only on height, but also on the magnitude of the equivalent fluid pressure of the retained soil. The two forces act in opposition; the horizontal force tends to overturn the wall, while the vertical forces tend to stabilize it via gravity. The ratio of wall height to base width will vary with the ratio of vertical pressure to horizontal pressure. More properly, the relationship between thickness of base and wall height can be expressed:

$$\frac{L^2}{H^2} = \frac{Q}{W}$$

where: H = height of gravity retaining wall, in. (mm)
L = width of gravity retaining wall at base, in. (mm)
Q = equivalent fluid pressure of retained material acting horizontally as overturning moment, pcf (kg/m³)
W = average weight of masonry, soil and other material acting vertically to retain soil, pcf (kg/m³)

This relationship between wall height and base width for gravity retaining walls is shown in Figure 2 for different ratios of horizontal to vertical unit loads. The relationship shown in Figure 2 is employed in the selection of dimensions for small gravity retaining walls of up to six or eight feet (1.8 to 2.4 m) high.

Having selected the height-base proportions for a gravity retaining wall from Figure 2, the trial design should be analyzed for safety against overturning, safety against sliding, bearing pressure on the soil, and flexural and shear stress in the wall.
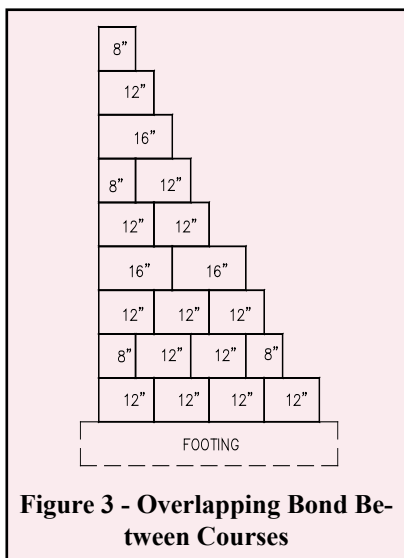
Figure 3 - Overlapping Bond Between Courses
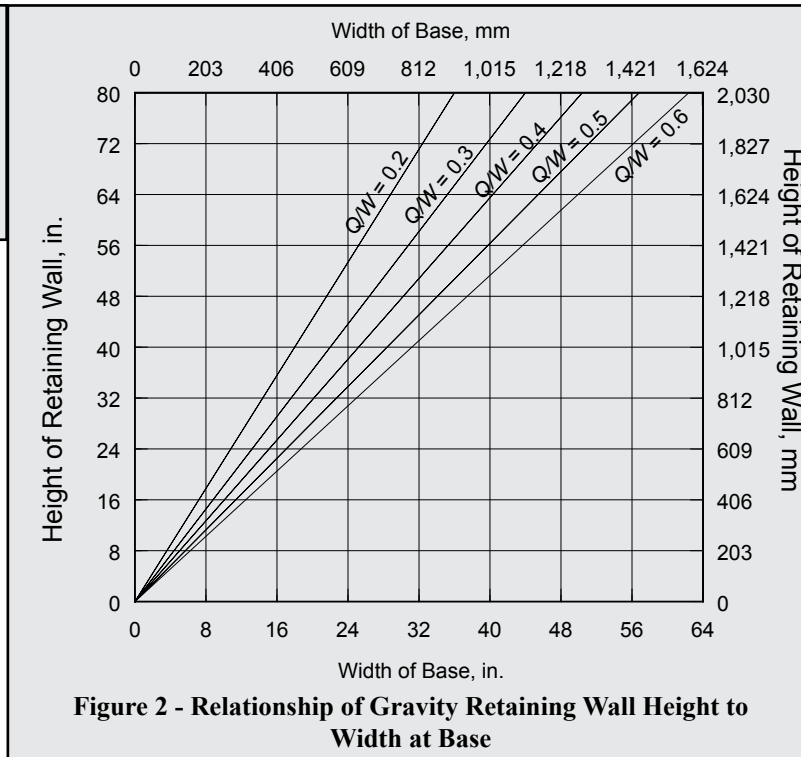
CONSTRUCTION AND MATERIALS

Each course of the retaining wall should be constructed with full-size concrete masonry units, with an overlapping bond pattern between courses, as shown in Figure 3.

Hollow or solid concrete masonry units used in gravity retaining walls should meet the requirements of ASTM C 90 (ref. 2) and preferably have an oven-dry density of 125 lb/ft³ (2002 kg/m³) or more. Cores of hollow units are typically filled to increase the weight of the wall. Bond is important to ensure sufficient shear resistance to withstand the pressure exerted by the retained earth. Type M or S mortars complying to ASTM C 270 (ref. 3) are recommended.

Concrete footings should be placed on firm undisturbed soil. In areas where freezing is expected, place the base of the footing below the frost line. If the soil under the footing consists of soft or silty clay, it is usually advisable to place 4 to 6 inches (102 to 152 mm) of well compacted sand under the footing before pouring the concrete. Since the retaining wall is unreinforced, it is not necessary to reinforce the footing.

If heavy equipment is employed for backfilling, it should not be allowed to approach closer to the top of the wall than a distance equal to the wall height. Care should also be taken to avoid large impact forces on the wall as could occur by a large mass of moving earth.

Provision should be made to prevent water accumulation behind the retaining wall. Accumulated water causes increased pressure, seepage, and in areas subject to frost action, an expansive force of considerable magnitude near the top of the wall. In most instances, weep holes located at 5 to 10 foot (1.5 to 3 m) spacing along the base of the wall are sufficient.

DESIGN EXAMPLES

1. 4-foot (1.2 m) high gravity retaining wall

equivalent fluid pressure of soil = 30 pcf (4.7 kN/m³)
soil weight = 100 pcf (15.7 kN/m³)
soil friction coefficient = 0.55
soil bearing capacity = 2000 lb/ft² (0.096 MPa)
100% solid concrete masonry units, 120 pcf (18.9 kN/m³)
concrete footing, 150 pcf (23.6 kN/m³)
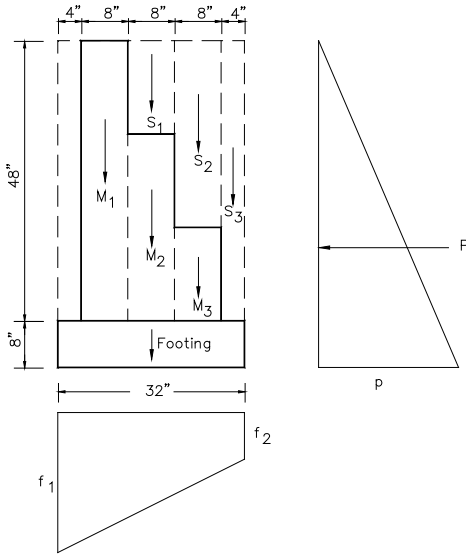
First, determine the width of the wall base:

$$\frac{Q}{W} = \frac{30}{(120 + 100)/2} = 0.273$$

From Figure 2, the base of the wall is 24 inches (610 mm), which can be accomplished using three 8-inch (203 mm) block. Note that the footing weight was not included in the calculation of average unit weight of the materials acting vertically, so that the width determined from Figure 2 would be the width of the masonry wall at its base.

Determine overturning moment:
pressure at the base of the wall, p = footing depth x equivalent fluid pressure of soil
p = (4.67 ft)(30 pcf) = 140 lb/ft² (6703 Pa)
resultant pressure, $P = \frac{1}{2}(p)$ (total soil height)
$P = \frac{1}{2}$ (140 lb/ft²)(4.67 ft) = 327 lb/ft (4.8 kN/m)

Determine resisting moment (about the toe):
First, determine the weight of each element, then determine the resisting moment of each weight, then sum the resisting moments to determine the total resisting moment.

Element:	Weight
S_1	(0.67 ft)(1.33 ft)(100 pcf) = 89 lb (396 N)
S_2	(0.67 ft)(2.67 ft)(100 pcf) = 179 lb (796 N)
S_3	(0.33 ft)(4.0 ft)(100 pcf) = 132 lb (587 N)
M_1	(0.67 ft)(4.0 ft)(120 pcf) = 322 lb (1432 N)
M_2	(0.67 ft)(2.67 ft)(120 pcf) = 214 lb (952 N)
M_3	(0.67 ft)(1.33 ft)(120 pcf) = 107 lb (476 N)
F	(2.67 ft)(0.67 ft)(150 pcf) = 268 lb (1192 N)

Element:	Weight, lb (N) x Arm, ft (m) =		Moment, ft-lb (N-m)
S_1	89 (396)	1.33 (0.41)	118.5 (161)
S_2	179 (796)	2.00 (0.61)	357.8 (485)
S_3	132 (587)	2.50 (0.76)	330.0 (447)
M_1	322 (1432)	0.67 (0.20)	215.5 (292)
M_2	214 (952)	1.33 (0.41)	285.5 (387)
M_3	107 (476)	2.00 (0.61)	213.9 (290)
F	268 (1192)	1.33 (0.41)	356.4 (483)
Total	1311 (5832)		1878 (2546)

Determine the overturning moment, M:
$M = (P)(\frac{1}{3}$ x total height of sol)
$M = (327$ lb/ft)$(\frac{1}{3}$ x 4.67 ft) = 509 ft-lb/ft (2.28 kN-m/m)

Check safety factors:
overturning moment safety factor = 1878/509 = 3.7
    3.7 > 2 OK
sliding safety factor = (1311 lb)(0.55)/(327 lb/ft) = 2.2
    2.2 > 1.5 OK

Check pressure on soil:
location of P and eccentricity, e:
arm = (1878 - 509 lb/ft)/(1311 lb) = 1.04 ft (0.32 m) from the toe (within middle third)
$e = \frac{1}{2}(2.67$ ft) - 1.04 ft = 0.30 ft (0.09 m)

$$f = \frac{P}{A} \pm \frac{6Pe}{bD^2} = \frac{1311\,\text{lb}}{(2.67\,\text{ft})(1\,\text{ft})} \pm \frac{6(1311\,\text{lb})(0.30\,\text{ft})}{(1\,\text{ft})(2.67\,\text{ft})^2}$$

$$= 491 \pm 331\,\text{lb/ft}$$

$f_1 = 822$ lb/ft $(12$ kN/m$) < 2000$ lb/ft   OK

$f_2 = 160$ lb/ft $(2.3$ kN/m$)$

Since the concrete masonry used in this example is assumed solid or fully grouted, the calculations do not include a check of shear stresses and flexural stresses in the wall. Flexural and shear stresses are checked in the second design example, and it is seen that they are very low in magnitude. Flexural and shear stresses in gravity retaining walls will almost always be of minor importance.

2. 6-foot (1.8 m) high gravity retaining wall

equivalent fluid pressure of soil = 40 pcf (7.1 kN/m³)
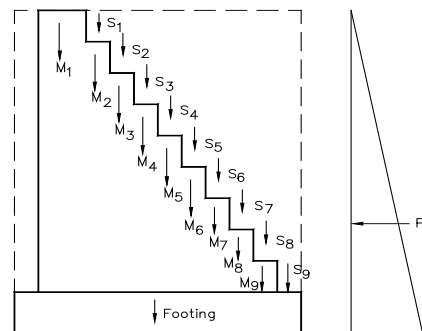soil weight = 100 pcf (15.7 kN/m³)
soil friction coefficient = 0.55
soil bearing capacity = 2000 lb/ft² (0.096 MPa)
hollow concrete masonry units, 130 pcf (20.4 kN/m³), units will be filled with sand, resulting in a combined weight of 115 pcf (18.1 kN/m³)
f'_m = 1500 psi (10.3 MPa)

Type S portland cement-lime mortar
concrete footing, 150 pcf (23.6 kN/m³)

First, determine the width of the wall base:

$$\frac{Q}{W} = \frac{40}{(100+115)/2} = 0.372$$

From Figure 2, try a base width of 42 in. (1067 mm), with
a footing width of 50 in. (1270 mm)

Determine overturning moment:

$p = (6.67\text{ ft})(40\text{ pcf}) = 267\text{ lb/ft}^2\ (0.013\text{ MPa})$

$P = \frac{1}{2}(267\text{ lb/ft}^2)(6.67\text{ ft}) = 890\text{ lb/ft}\ (13\text{ kN/m})$

$M = (890\text{ lb/ft})(\frac{1}{3} \times 6.67\text{ ft}) = 1978\text{ ft-lb/ft}\ (8.81\text{ kN-m/m})$

Determine resisting moment (about the toe):

Element:	Weight, lb (N)	x Arm, ft (m) =	Moment, ft-lb (N-m)
S_1	22 (98)	1.50 (0.46)	33 (45)
S_2	44 (196)	1.83 (0.56)	80 (108)
S_3	66 (294)	2.17 (0.66)	143 (194)
S_4	88 (391)	2.50 (0.76)	220 (298)
S_5	110 (489)	2.83 (0.86)	311 (422)
S_6	132 (587)	3.17 (0.97)	418 (566)
S_7	154 (685)	3.50 (1.07)	539 (731)
S_8	176 (783)	3.83 (1.17)	674 (914)
S_9	198 (881)	4.17 (1.27)	826 (1120)
M_1	690 (3070)	0.83 (0.25)	575 (780)
M_2	202 (899)	1.50 (0.46)	303 (411)
M_3	177 (787)	1.83 (0.56)	325 (441)
M_4	152 (676)	2.17 (0.66)	329 (446)
M_5	126 (560)	2.50 (0.76)	316 (428)
M_6	101 (449)	2.83 (0.86)	287 (389)
M_7	76 (338)	3.17 (0.97)	241 (327)
M_8	50 (222)	3.50 (1.07)	177 (240)
M_9	25 (111)	3.83 (1.17)	97 (132)
F	419 (1864)	2.08 (0.63)	872 (1182)
Total	3008 (13,380)		6766 (9173)

Check safety factors:

overturning moment safety factor = 6766/1978 = 3.4
    3.4 > 2 OK
sliding safety factor = (3008 lb)(0.55)/(890 lb/ft) = 1.9
    1.9 > 1.5 OK

Check pressure on soil:

location of P and eccentricity, e:
arm = (6766 - 1978 lb/ft)/(3008 lb) = 1.59 ft (0.49 m)
    (within middle third)

$e = \frac{1}{2}(4.17\text{ ft}) - 1.59\text{ ft} = 0.495\text{ ft}\ (0.015\text{ m})$

$$f = \frac{P}{A} \pm \frac{6Pe}{bD^2} = \frac{3008\text{ lb}}{(1\text{ ft})(4.17\text{ ft})} \pm \frac{6(3008\text{ lb})(0.495\text{ ft})}{(1\text{ ft})(4.17\text{ ft})^2}$$

$= 721 \pm 514\text{ lb/ft}$

$f_1 = 1235\text{ lb/ft}\ (18.0\text{ kN/m}) < 2000\text{ lb/ft}$ OK

$f_2 = 207\text{ lb/ft}\ (3.0\text{ kN/m})$

Check flexural stresses:

At 6 ft (1.8 m) depth:

$P = \frac{1}{2}(6\text{ ft})(40\text{ pcf})(6\text{ ft}) = 720\text{ lb}\ (3203\text{ N})$

$M = (720\text{ lb})(\frac{1}{3} \times 6\text{ ft}) = 1440\text{ lb-ft}\ (1952\text{ N-m})$

Assume mortar bed is 50% of gross area:

Area, $A = bD = (42\text{ in.})(12\text{ in.})(0.5) = 252\text{ in.}^2\ (0.16\text{ m}^2)$

$$\frac{P}{A} = \frac{720\text{ lb}}{252\text{ in.}^2} = 2.9\text{ psi}\ (0.02\text{ MPa})$$

Section modulus, $S = \dfrac{bD^2}{6} = \dfrac{(252\text{ in.}^2)(42\text{ in.})}{6}$

$= 1764\text{ in.}^3\ (0.03\text{ m}^3)$

$$f_t = \frac{M}{S} = \frac{(1440\text{ ft-lb})(12\text{ in./ft})}{1764\text{ in.}^3} = 9.8\text{ psi}\ (0.07\text{ MPa})$$

$F_t = 25$ psi from Table 6.3.1.1 of ref. 1
$F_t > 9.8$ psi   OK

Check shear stresses:

$$f_v = \frac{VQ}{Ib} \approx \frac{3V}{2A} = \frac{3(720\text{ lb})}{2(252\text{ in.}^2)} = 4.3\text{psi}\ (0.03\text{ MPa})$$

$F_v = 1.5\sqrt{f_m'}$ (ref. 1)

$= 58$ psi (9.4 MPa)

$F_v > 4.3$ psi   OK

REFERENCES

1. Building Code Requirements for Masonry Structures, ACI 530-95/ASCE 5-95/TMS 402-95. Reported by the Masonry Standards Joint Committee, 1995.
2. *Standard Specification for Load-Bearing Concrete Masonry Units*, ASTM C 90-94. American Society for Testing and Materials, 1994.
3. *Standard Specification for Mortar for Unit Masonry*, ASTM C 270-92a. American Society for Testing and Materials, 1992.

Provided by: Chandler Concrete Company Inc.