Portland Cement Association

CONCRETE INFORMATION

Small Concrete Gravity Retaining Walls

Gravity retaining walls are relatively simple structures. They can be built with unskilled labor and local materials, and are inherently solid and durable, requiring little or no upkeep. This publication presents sample designs for several small gravity retaining walls along with other information about the construction of these walls.

Sample Designs

Tables 1 through 4 show several small gravity retaining wall designs. These walls were designed using the criteria given in the Appendix and will assist the reader in choosing an appropriate design for local site conditions.

The two types of backfill used in the designs are in the middle range of the four types listed in the Appendix (see Fig. 4). Type 2 backfill is a coarse-grained soil of low permeability due to blending with silt-size particles. Type 3 backfill is composed of fine silty sand, granular materials with conspicuous clay content, and residual soil with stones.

The tables give eight different wall designs for each of four cases:

- Level backfill with Type 2 soil
- Level backfill with Type 3 soil
- Sloping backfill with Type 2 soil
- Sloping backfill with Type 3 soil

A surcharge, which is defined as a transient load on the surface of the ground, is included in each design. The surcharge is 200 psf (975 kg/m^2) for level backfill and 40% of that for sloping backfill.

The approximate soil pressures at toe and heel are also tabulated. These should be compared to the allowable soil pressure given in Table 5.

In the sample designs, the concrete density used is 145 pcf (2300 kg/m^3).

Construction Details

The depth below grade to the bottom of the base is determined by the depth of excavation necessary to reach soil with suitable bearing capacity. Bearing capacity of soil varies with the depth and frequency of frost. If frost heave develops beneath a retaining wall, the consequences are not as severe as they would be with a building. Still, it is recommended that taller walls rest deeper in the ground.

Constructing the base or footing with a level surface creates a working platform on which the wall forms can be set. The fresh concrete surface should only be struck off rough and keyed joints always installed. Any loose material should be removed before concreting of the wall stem above begins.

It is important to provide drainage from behind the wall (Fig. 1), either by weepholes or by a back drain.

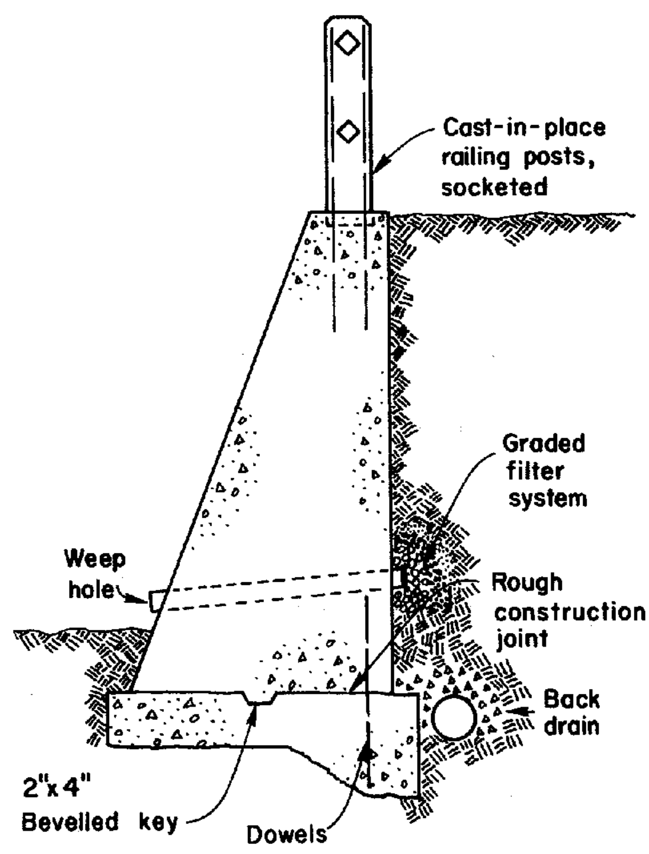


Fig. 1. Construction details. (1 in. = 25 mm)

Table 1. Gravity Retaining Walls with Level Backfill of Type 2 Soil

Wall dimensions				Overturning safety factor	Sliding friction		Soil pressure, psf		Volume of concrete, yd³/ft
h	a	b	c		H′/V′	Shear stress, psf	Toe	Heel	
10′0″	13″	6′6″	20″	2.1	0.28	330	2200	120	1.69
9′0″	12″	6′0″	18″	2.1	0.30	320	2000	90	1.41
8′0″	11″	5′6″	17″	2.1	0.30	300	1900	70	1.17
7′0″	10″	5′0″	16″	2.1	0.31	270	1700	50	0.95
6′0″	9″	4′6″	15″	2.1	0.31	240	1600	40	0.75
5′0″	8″	4′0″	14″	2.1	0.31	210	1300	30	0.58
4′0″	7″	3′6″	13″	2.1	0.32	180	1100	20	0.43
3′0″	6″	3′0″	12″	2.2	0.32	140	1000	10	0.30

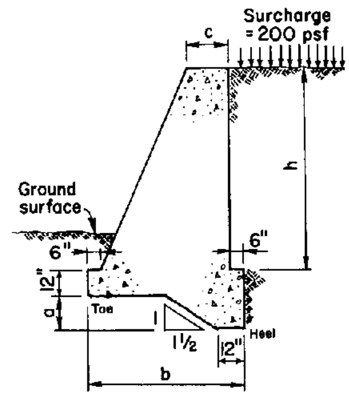


Table 2. Gravity Retaining Walls with Level Backfill of Type 3 Soil

Wall dimensions				Overturning safety factor	Sliding friction		Soil pressure, psf		Volume of concrete, yd³/ft
h	a	b	c		H′/V′	Shear stress, psf	Toe	Heel	
10′0″	21″	7′0″	24″	2.2	0.25	340	2400	370	1.96
9′0″	19.5″	6′6″	24″	2.3	0.24	310	2200	380	1.68
8′0″	18″	6′0″	24″	2.3	0.23	270	1950	390	1.42
7′0″	16.5″	5′6″	24″	2.4	0.22	240	1750	390	1.18
6′0″	15″	5′0″	24″	2.5	0.21	210	1500	390	0.96
5′0″	13.5″	4′6″	24″	2.7	0.20	170	1300	380	0.76
4′0″	12″	4′0″	24″	2.8	0.19	140	1100	360	0.59
3′0″	10.5″	3′6″	24″	3.0	0.20	120	850	340	0.40

1 in. = 25 mm
1 ft = 0.3 m
100 psf = 488 kg/m²
1 yd³/ft = 2.5 m³/m

Table 3. Gravity Retaining Walls with Sloped Backfill of Type 2 Soil

Wall dimensions				Overturning safety factor	Sliding friction		Soil pressure, psf		Volume of concrete, yd³/ft
h	a	b	c		H′/V′	Shear stress, psf	Toe	Heel	
9′11″	13″	6′6″	20″	2.8	0.23	330	1800	1100	1.68
9′0″	12″	6′0″	18″	2.8	0.23	310	1700	1000	1.41
8′1″	11″	5′6″	17″	2.8	0.23	280	1500	900	1.18
7′2″	10″	5′0″	16″	2.8	0.23	250	1400	800	0.96
6′3″	9″	4′6″	15″	2.8	0.23	220	1300	700	0.77
5′4″	8″	4′0″	14″	2.8	0.22	190	1100	600	0.61
4′5″	7″	3′6″	13″	2.8	0.22	160	900	600	0.46
3′6″	6″	3′0″	12″	2.8	0.21	130	700	600	0.33

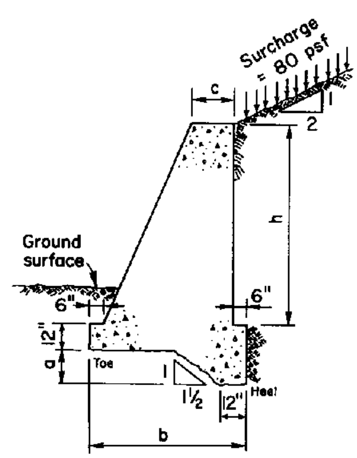


Table 4. Gravity Retaining Walls with Sloped Backfill of Type 3 Soil

Wall dimensions				Overturning safety factor	Sliding friction		Soil pressure, psf		Volume of concrete, yd³/ft
h	a	b	c		H′/V′	Shear stress, psf	Toe	Heel	
9′11″	19.5″	6′6″	24″	2.5	0.18	310	2300	1100	1.81
9′0″	18″	6′0″	24″	2.5	0.17	280	2100	1100	1.55
8′1″	16.5″	5′6″	24″	2.6	0.17	250	1950	1000	1.31
7′2″	15″	5′0″	24″	2.6	0.16	220	1800	900	1.09
6′3″	13.5″	4′6″	24″	2.6	0.15	190	1600	800	0.89
5′4″	12″	4′0″	24″	2.7	0.15	170	1500	700	0.71
4′5″	10.5″	3′6″	24″	2.7	0.14	140	1400	600	0.55
3′6″	9″	3′0″	24″	2.7	0.13	110	1200	500	0.41

1 in. = 25 mm
1 ft = 0.3 m
100 psf = 488 kg/m²
1 yd³/ft = 2.5 m³/m

Table 5. Allowable Bearing Pressures on Soils

Type of soil	Maximum pressure, psf
Organic soil	0
Filled ground or loam	500
Inorganic silt—compact	2,500
Sand—silty and compact	3,000
Sand—compact and clean	5,000
Clay—very soft	500
Clay—soft	1,500
Clay—stiff	2,500
Clay—tough	3,500
Clay—very tough	4,500
Clay—hard	6,000
Gravel	6,000
Hardpan	12,000
Solid rock	200,000

1000 psf = 4880 kg/m²
Source: Reference 11.
Note: Where the bearing materials directly under a foundation overlie a stratum having lower allowable bearing values, these lower values shall not be exceeded at the level of such stratum. Computation of the vertical pressure in the bearing materials at any depth below a foundation shall be made on the assumption that the load is spread uniformly at an angle of 60° with the horizontal.

Table 6. Description of Bearing Soils

Organic Soil. Soil containing significant percentage of partly or wholly decomposed organic matter. According to the character of the constituents, the term organic clay, organic silt, or peat is used.

Inorganic Silt. Cohesionless aggregate of grains ranging in size from 0.002 mm to 0.66 mm. Aggregate is nonplastic and consists of grains not distinguishable by the naked eye. Deposits of inorganic silt are described as loose or compact. A lump of the air-dried material has very little resistance to crushing.

Sand. Cohesionless aggregate of rock fragments or grains ranging in size from 0.06 mm to ¼ in. Deposits of sand are described as loose or compact.

Clay. Cohesive soil, plastic within wide range of water content. The consistency of a clay is defined by the strength of a fairly undisturbed cylinder whose length is from 1.5 to 2 times its diameter, as follows:

Consistency	Field identification	Unconfined compressive strength, psf
Very soft	Easily penetrated a couple of inches by fist	Less than 700
Soft	Easily penetrated a couple of inches by thumb	700 to 1,199
Stiff	Penetrated several inches by thumb with moderate effort	1,200 to 1,999
Tough	Readily indented by thumb but penetrated only with great effort	2,000 to 3,999
Very tough	Readily indented by thumbnail	4,000 to 7,999
Hard	Indented with difficulty by thumbnail	8,000 to 16,000

Gravel. Cohesionless aggregate of rounded to angular rock fragments ranging in size from ¼ to 8 in.

Hardpan. Cohesive or cemented material that offers great resistance to hand-excavating tools.

Solid Rock. Sound, unweathered rock without visible voids.

1 in. = 25 mm, 1000 psf = 4880 kg/m²
Adapted from References 10 and 11.

Weepholes must be constructed so that they will drain freely without allowing the backfill to wash out. Suitable weepholes are provided by 4-in. (100-mm) plastic pipe spaced about 10 ft (3 m) on centers, each pipe having a slight pitch for drainage. At the back end of the weephole a filter system is needed. The back end of the pipe should be covered with a rustproof, nonbiodegradable cloth or insect screen. A heavier screen or guard is needed for protection during backfilling. Behind the guard is a pocket of 2 cu ft (0.06 m³) of gravel or stone, covered on the top and sides with about 6 in. (150 mm) of pea gravel. This is then covered and surrounded with 6 in. (150 mm) of coarse sand. This system constitutes a graded filter and should keep most backfills from eroding through the weepholes.

Weepholes have two shortcomings: they fill with ice in cold climates, and they do not relieve the water pressure behind the wall to a sufficient depth. A 10-in.-diameter (250-mm) continuous back drain near the bottom can be provided instead. The back drain is pitched and connected to a sewer or a ditch.

Many retaining walls require railings for safety. Examples of concrete railings appear in Fig. 2.

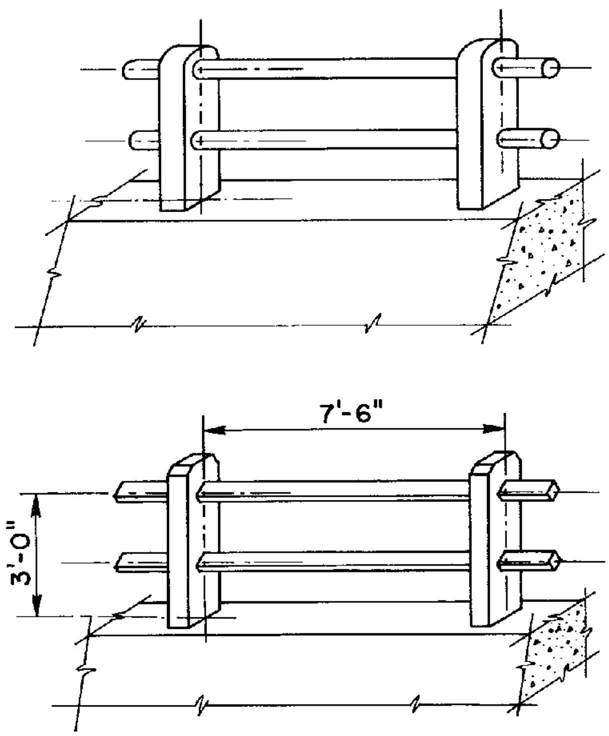


Fig. 2. Concrete railings.

Where appearance is a consideration, control joints should be provided in the wall at about 15-ft (4.6-m) spacing. A control joint is a groove deep enough to attract cracking caused by drying shrinkage and temperature, thus reducing random, unsightly cracking. Control joints are not needed in the base of the wall. As a rule, the grooves should be built into one or both sides of the wall to a total depth of one-fourth of the wall thickness. A sealant or covering for the grooves will reduce seepage and staining on the face of the wall.

Vertical construction bulkheads can also serve as control joints if bond is prevented between successive concrete placements. This is done by applying paint, oil, or another bondbreaker to the end of one section before the next section of concrete is cast. Keyways should be provided in vertical construction joints to keep the wall sections in alignment. Consideration should be given to providing expansion joints in walls not having a sealant in the control joints. Over a long period, sand and clay might infiltrate cracked control joints, preventing expansion during hot weather. An expansion or isolation joint is always recommended where a retaining wall meets a building or other structure.

Reinforcing steel dowels between the base and stem of the wall provide positive anchorage of the stem to the base. The dowels are No. 4 vertical reinforcing bars 4 ft (1.20 m) long at 2-ft (0.6-m) intervals, placed 4 in. (100 mm) or so from the earth side of the wall.

Concrete Work

It is relatively easy to place concrete in a gravity retaining wall, particularly in a footing built in a trench without formwork. Concrete slump should be a maximum of 3 in. (75 mm) if the concrete will be consolidated by handrodding or spading. If mechanical vibration is used, a 2-in. (50-mm) maximum slump is recommended.

Concrete strength is not an overriding consideration, but for the sake of quality control, a minimum strength of 4000 psi (27.6 MPa) is suggested.

To resist freezing and thawing or deicer chemicals, maximum water-cement ratio should be 0.53 (see Reference 1*). Where sulfate exposure will occur, the ratio should not exceed 0.45. Air entrainment is also necessary if the concrete will be exposed to freezing and thawing. The mortar fraction (cement, sand, and water) of the concrete should contain about 9% air.

If it is locally available, large coarse aggregate—say 4 in. (100 mm) maximum—can be used. With large coarse aggregate, the concrete may be more economical and have less heat of hydration and shrinkage, thereby reducing the potential for cracking.

Further discussion of concrete mixtures and placement appears in the Portland Cement Association publication *Design and Control of Concrete Mixtures* (Reference 2).

Mass Concrete

By their very nature, the larger concrete gravity retaining walls illustrated here constitute mass concrete, which the American Concrete Institute defines as any volume of concrete with dimensions large enough to require measures to cope with heat generation from hydration of the cement and attendant volume change to minimize cracking (Reference 3).

A low cement content in the concrete will limit heat of hydration. Using ice in the mix will lower the maximum temperature of the concrete, as will working on a cool day or starting work early in the morning.

*References are listed at the end of this publication.

Control joints have already been discussed. They will cause any shrinkage cracks to be formed in inconspicuous places as the temperature of the concrete drops. Heat of hydration could cause a 50°F (28°C) heat rise, creating an expansion of up to 1/16 in. (1.6 mm) in 15 ft (4.6 m); upon subsequent cooling, the contraction cracks would be almost as wide. Such cracks are inconspicuous within a control joint.

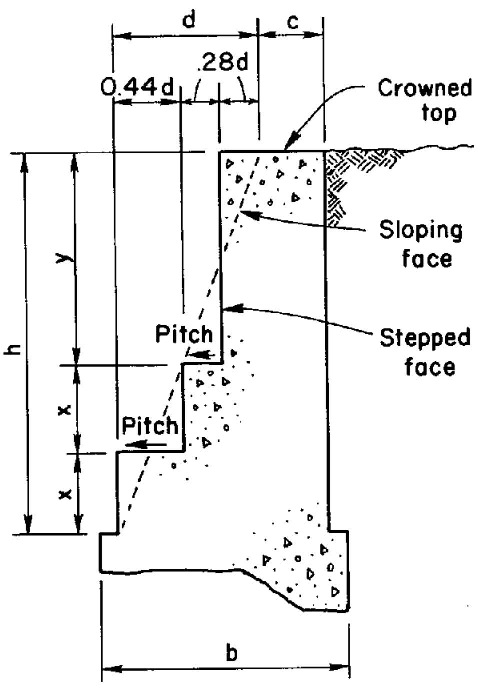
If there is a 27°F (15°C) temperature difference between the surface and interior of the concrete, surface cracking may occur. This will not have a significant effect on the useful life of the retaining wall. The differential temperature can be lowered during construction by reducing the temperature rise with the methods discussed above. In addition, if the forms are left on for several days, the surface of the concrete will cool more slowly as the interior of the concrete cools. In effect, this reduces internal stress in the concrete.

A further discussion of mass concrete appears in Reference 4 and temperature effects are discussed in References 5 and 6.

Formwork Buoyancy

The formwork for the sloping face of a wall must be securely anchored to the base to avoid flotation caused by the upward hydrostatic pressure of the fresh concrete. If the anchorage is not rigid, the formwork will lift slightly off the base and fresh concrete paste will leak under the form.

An alternate method of building the sloping face is to create steps with vertical forms. The stepped wall, as shown in Fig. 3, also has the advantage of providing



h	x	y
10'0"	2'3"	5'6"
9'6"	2'1½"	5'3"
9'0"	2'0"	5'0"
8'6"	1'10½"	4'9"
8'0"	1'9"	4'6"
7'6"	1'7½"	4'3"
7'0"	1'6"	4'0"
6'6"	1'5"	3'8"
6'0"	1'4"	3'4"
5'6"	1'2½"	3'1"
5'0"	1'1"	2'10"
4'6"	1'0"	2'6"
4'0"	11"	2'2"
3'6"	9½"	1'11"
3'0"	8"	1'8"

Fig. 3. Stepped gravity walls with vertical faces make concreting easier and avoid buoyancy of sloping forms. (1 in. = 25 mm, 1 ft = 0.3 m)

several openings for placement of concrete. The treads of the steps need not be formed; concrete with a low slump can be placed slowly so that it is not forced up and out at the steps. With the dimensions given in Fig. 3, the stepped walls have the same safety factors and bearing pressures as the sloped walls.

Decorative Finishes

Since retaining walls are usually exposed to public view, care in form construction is required to obtain an attractive appearance. Forms should be stiff to prevent bulging and tight to prevent leakage.

Many surface textures are available for concrete walls. For example, board-marked surfaces show the lines of rough or dressed lumber in the forms. Narrow wood strips can be placed in the forms to create a wide variety of patterns and designs. Form plywood and thin plywood liners are available in a variety of textures—smooth, striated, and sandblasted. Other materials and methods for producing various wall textures are described in References 7 and 8.

APPENDIX

Stability Design

Traditional retaining-wall design is based on the classic theories of Rankine and Coulomb, which use an angle of internal friction to determine the active earth forces. For small projects, where a soil investigation is not feasible, it is difficult to know which angle to use. It has therefore become common to assume a conservative angle of 33°; the earth pressure is then determined by the classic theories using this angle of internal friction.

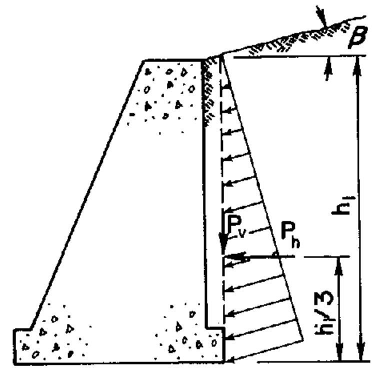
A more practical design method is the equivalent fluid theory presented in 1948 by Terzaghi and Peck (Reference 9) and modified in 1953 (Reference 10). Four broad types of soil are used (see Fig. 4). The fluid pressures are chosen from Fig. 4 depending on the slope of the backfill and the type of soil; pressures are then computed as illustrated in the figure.

Pressures for surcharge are computed as follows: Convert the surcharge pressure, w, to an equivalent height of soil, s, by assuming a soil density of 125 pcf (2000 kg/m³). Thus, $s = w/125$.

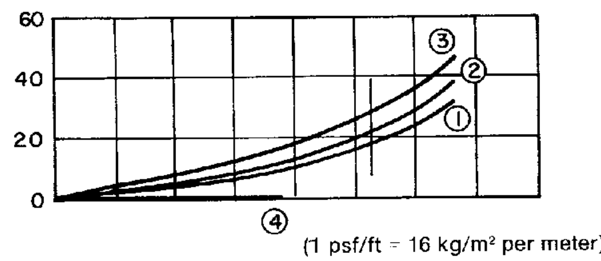
Surcharge causes a uniform horizontal pressure for which the total force is $P_{hs} = k_h s h_1$.

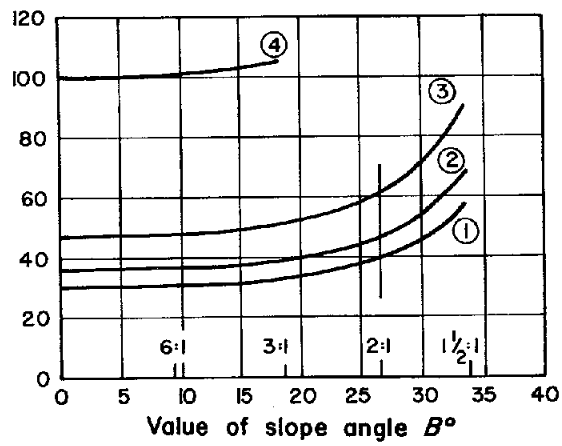
The total vertical force due to surcharge is $P_{vs} = k_v s h_1$ and it is considered to be acting directly over the edge of the heel.

For the general case of a wall having sloping backfill with a surcharge, the total horizontal force $\Sigma H = P_h$ plus P_{hs}. The total vertical force, ΣV, includes P_v plus P_{vs} plus total weight of concrete plus weight of soil directly between the wall and the end of the heel.



$$P_h = \tfrac{1}{2} k_h h_1^2$$
$$P_v = \tfrac{1}{2} k_v h_1^2$$





Type 1. Backfill of coarse-grained soil without admixture of fine particles, very permeable, as clean sand or gravel.

Type 2. Backfill of coarse-grained soil of low permeability due to admixture of silt-size particles.

Type 3. Backfill of fine silty sand, granular materials with conspicuous clay content, and residual soil with stones.

Type 4. Backfill of very soft or soft clay, organic silt, or silty clay.

Fig. 4. Chart for estimating pressure of backfill against retaining walls supporting backfills with plane surfaces. Use of chart limited to walls no higher than about 20 ft (6.1 m). (Source: Reference 10)

Safety Factors

In keeping with common practice, safety against overturning has been determined by the ratio of the restoring moment to the overturning moment about the toe of the base. A minimum safety factor of two was used as the design criterion.

For overturning moments caused by lateral earth pressure, height of the wall above the center of the base was used for simplicity of calculation. Horizontal pressure below the center point of the base creates a small restoring moment and is an additional safety factor.

The total horizontal force to the bottom of the base was used to determine the sliding resistance of the base.

According to Reference 10, the coefficient of friction for concrete cast on soil is 0.55 for coarse-grained soil without silt, 0.45 for coarse-grained soil with silt, and 0.35 for silt. For the sample designs, the maximum ratio of sliding forces to normal forces was limited to 0.32 and the calculated values are listed in the tables. Thus, the reader can determine whether the sample design would be safe for the actual soil at the site.

For footings resting on clay, the shearing resistance against sliding is 50% of the unconfined compressive strength of the soil (Reference 10). A tough clay might have an unconfined compressive strength of 2000 psf (96 kPa). Therefore, the shearing resistance would be 1000 psf (48 kPa), and the safe shearing stress would be 500 psf (24 kPa). The calculated shear stresses of the sample designs are tabulated. A guide to unconfined compressive strengths is given in Table 6.

In the preliminary designs of retaining walls for this publication, level or horizontal footing bottoms were used, but safety against sliding was found to be insufficient. Therefore, some improved method was needed to resist sliding friction and horizontal movement. Shear lugs were chosen to increase sliding resistance.

The soil may shear off on a line to the bottom of the lug, so to increase the length of the shear plane, the lug is placed at the heel of the base. Forces normal and parallel to the base are then determined using an approximate profile shown in Fig. 5, in which $\tan \alpha = a/b$.

The shear and overturning moments were checked at the construction joints on the top of the base. In each case the ratio of the restoring moment about the toe of the stem to the overturning moment exceeds 1.33.

The horizontal force on the construction joint sometimes exceeds 0.40 of the vertical force there. This is an allowable coefficient of friction for concrete-on-concrete. Therefore, keyways in the joint are always specified. For wide walls, or where space permits, two longitudinal keyways should be used.

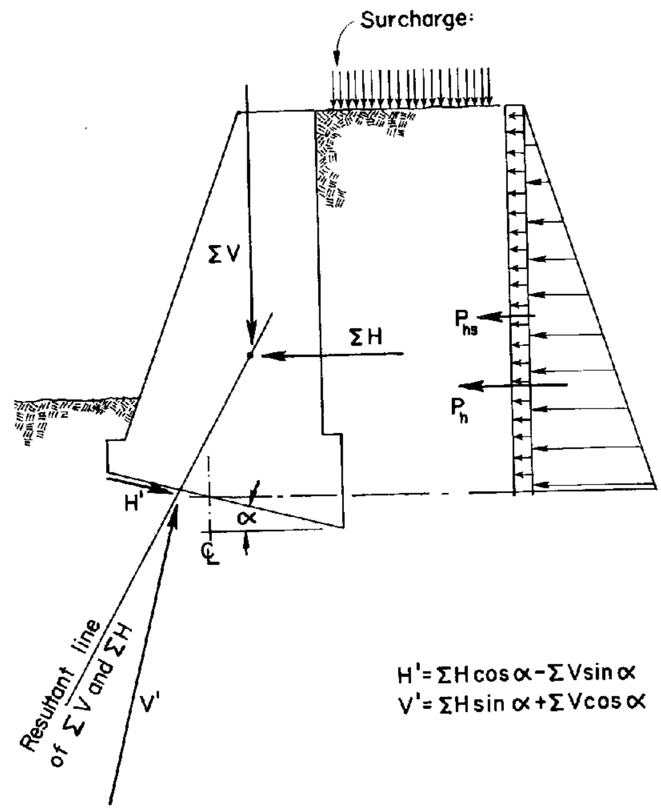


Fig. 5. Normal forces at the sloping base of a retaining wall.

References

1. Standard Specifications for Structural Concrete for Buildings, ACI Committee 301 report, American Concrete Institute, Detroit, 1981.
2. *Design and Control of Concrete Mixtures*, Portland Cement Association publication EB001T, 1979.
3. *Cement and Concrete Terminology*, ACI Committee 116 Report, American Concrete Institute, Detroit, 1978.
4. *Concrete for Massive Structures*, Portland Cement Association publication IS128T, 1979.
5. *Building Movements and Joints*, Portland Cement Association publication EB086B, 1982.
6. ACI Committee 207, "Mass Concrete for Dams and Other Massive Structures," *Journal of the American Concrete Institute*, April 1970, pages 270-309.
7. *Bushhammering of Concrete Surfaces*, Portland Cement Association publication IS051A, 1972.
8. *Color and Texture in Architectural Concrete*, Portland Cement Association publication SP021A, 1980.
9. Terzaghi, Karl; and Peck, Ralph B., *Soil Mechanics in Engineering Practice*, John Wiley and Sons, Inc., New York, 1948.
10. Peck, Ralph B.; Hanson, Walter E.; and Thornburn, Thomas H., *Foundation Engineering*, John Wiley and Sons, Inc., New York, 1953.
11. Municipal Code of Chicago Relating to Buildings, Chapter 70, 1980.

NOTATION

ΣH = summation of horizontal forces acting on the wall
ΣV = summation of vertical forces acting on the wall plus weight of wall
H' = component of resultant force on base (mostly horizontal)
P_h = horizontal component of total earth force
P_{hs} = horizontal component of total force due to surcharge
P_v = vertical component of total earth force
P_{vs} = vertical component of total force due to surcharge
V' = component of resultant force on base (mostly vertical)
a = depth of lug of base
b = width of base
c = width of top of sloped wall
d = (b - c - 1 ft)
h = height of wall above base
h_1 = vertical distance from bottom of heel to intersection with the surface of the earth above the heel of the base
k_h = horizontal component of equivalent fluid pressure of backfill or surcharge, s
k_v = vertical component of equivalent fluid pressure of backfill or surcharge, s
s = surcharge height as an equivalent soil load
w = surcharge pressure
x = height of lower risers of stepped face
y = height of top riser of stepped face
α = slope angle of bottom of base
β = slope angle of backfill

The drawings in this publication are typical designs and should not be used as working drawings. They are intended to be helpful in the preparation of complete plans which should be adapted to local conditions and should conform with legal requirements. Working drawings should be prepared and approved by a qualified engineer or architect.

Other helpful references from the Portland Cement Association. . .

Design and Control of Concrete Mixtures (EB001T)

Best-selling concrete manual discusses properties of cement-water paste and hardened concrete with effects of component materials; procedures of concrete mix proportioning, batching, mixing, transporting, handling, placing, and consolidation; curing procedures; causes and methods of minimizing volume changes; special types of concrete. Outlines commonly used control tests for quality concrete.

Building Movements and Joints (EB086B)

Describes causes of movements and length changes in concrete buildings; tells how to design and locate joints to accommodate these movements and avoid costly maintenance and repairs due to cracking, leaking, and other troublesome problems. Also discusses behavior of masonry and composite walls.

Bushhammering of Concrete Surfaces (IS051A)

Describes techniques of bushhammering to obtain attractive surfaces; suggests specifications.

Color and Texture in Architectural Concrete (SP021A)

Discusses decorative surface finishes, describes and illustrates methods of obtaining attractive surfaces on both precast and cast-in-place concrete. Full color.

Concrete for Massive Structures (IS128T)

Information on concrete used in dams, locks, large bridge piers or caissons, and foundations. Emphasizes economy in use of large volumes of concrete.

These publications are avialable for purchase from the Portland Cement Association. To order, write or call:

Order Processing
Portland Cement Association
5420 Old Orchard Road
Skokie, IL 60077-1083
(708) 966-6200, ext 564

Portland Cement Association *5420 Old Orchard Road, Skokie, Illinois 60077-1083*

An organization of cement manufacturers to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

Printed in U.S.A.

IS222.01T