Training Program

Quality Control and Quality Assurance for Rural Roads including Protection and Drainage Structures

Indian Institute of Technology Guwahati

Retaining Walls for Hillslopes

Analysis to Assurance

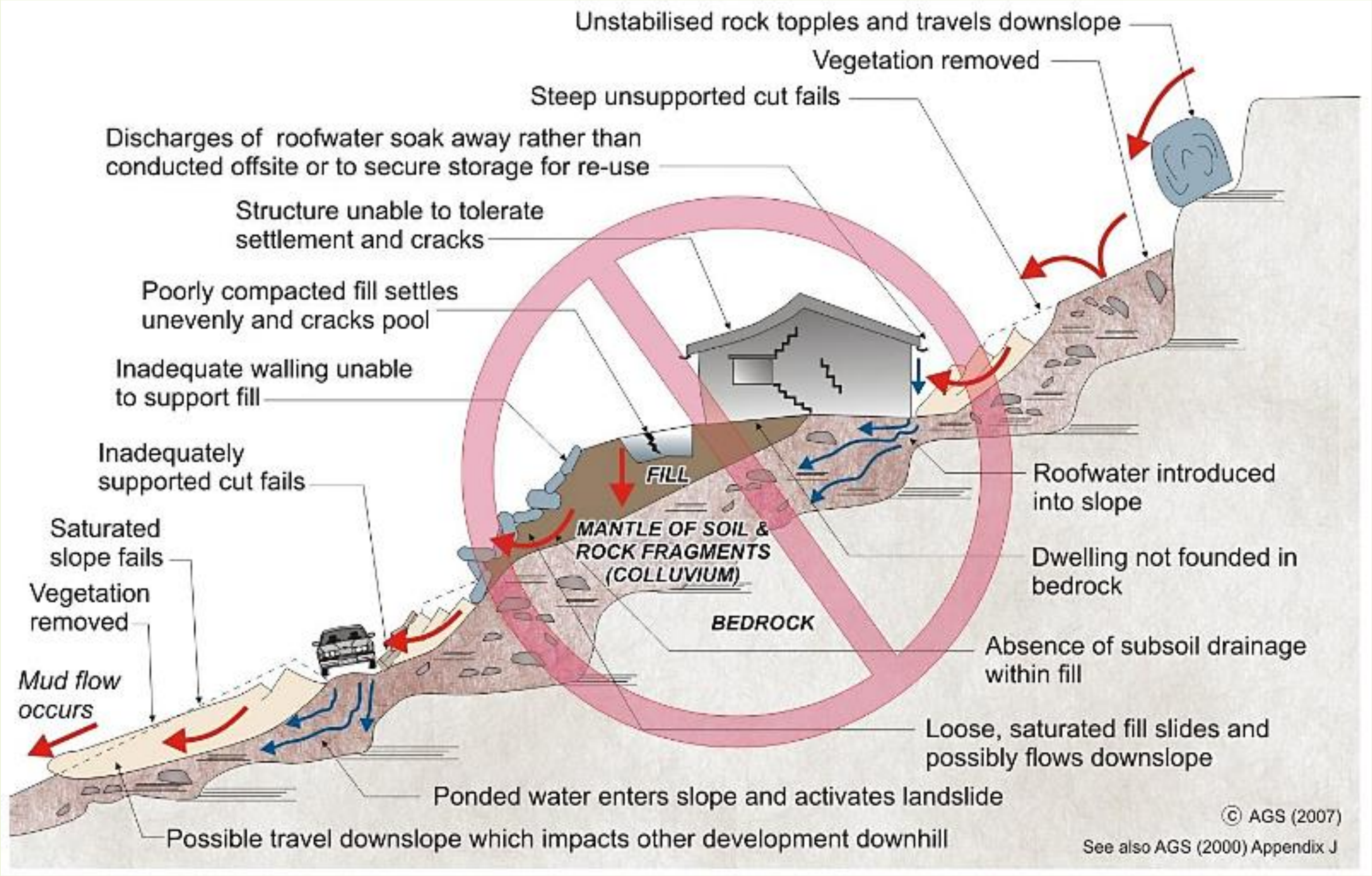
Arindam Dey

Department of Civil Engineering

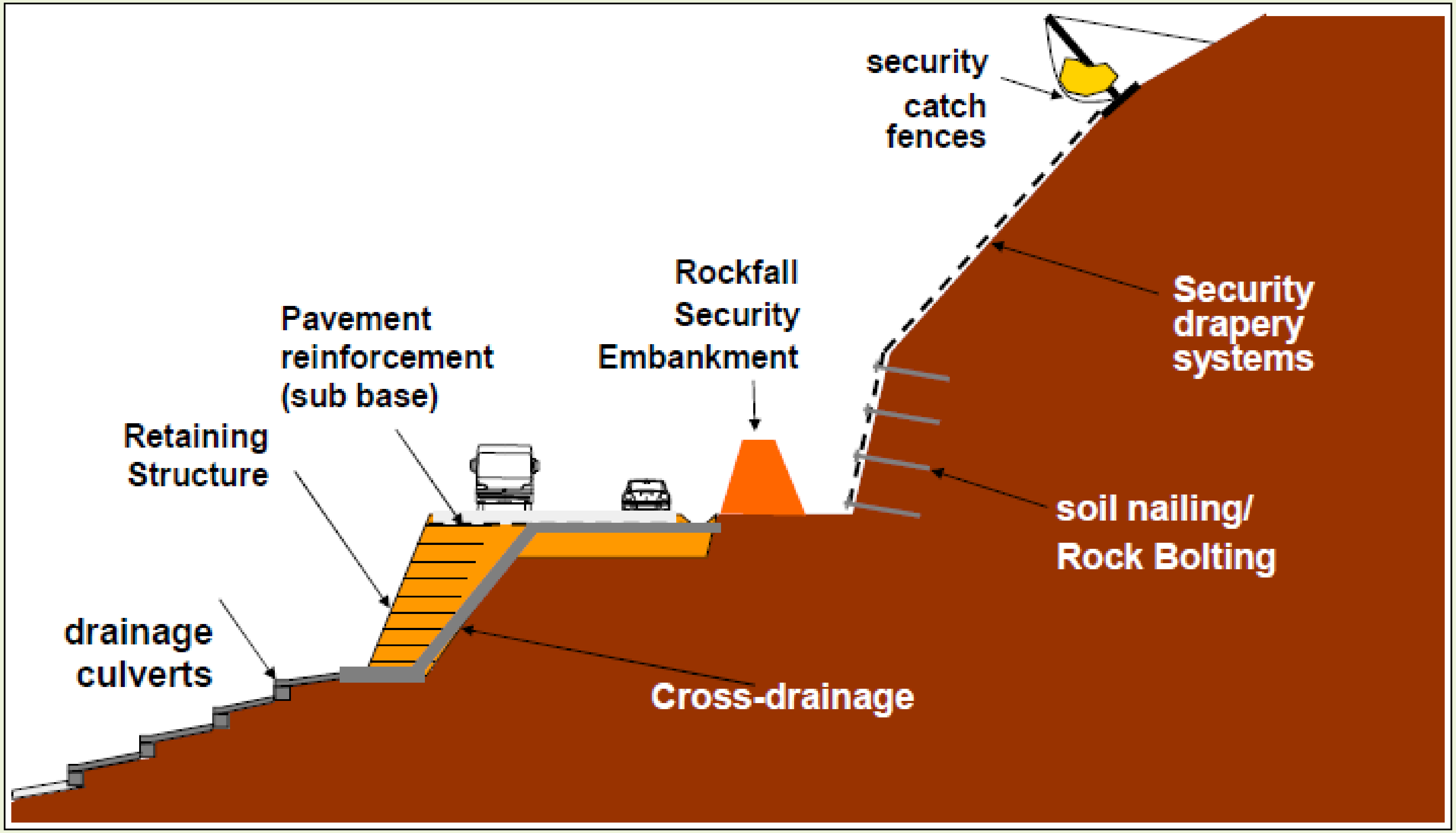
& Center for Disaster Management and Research

IIT Guwahati

Hillslope Movements and Failures



Slope Protection/Stabilization Measures

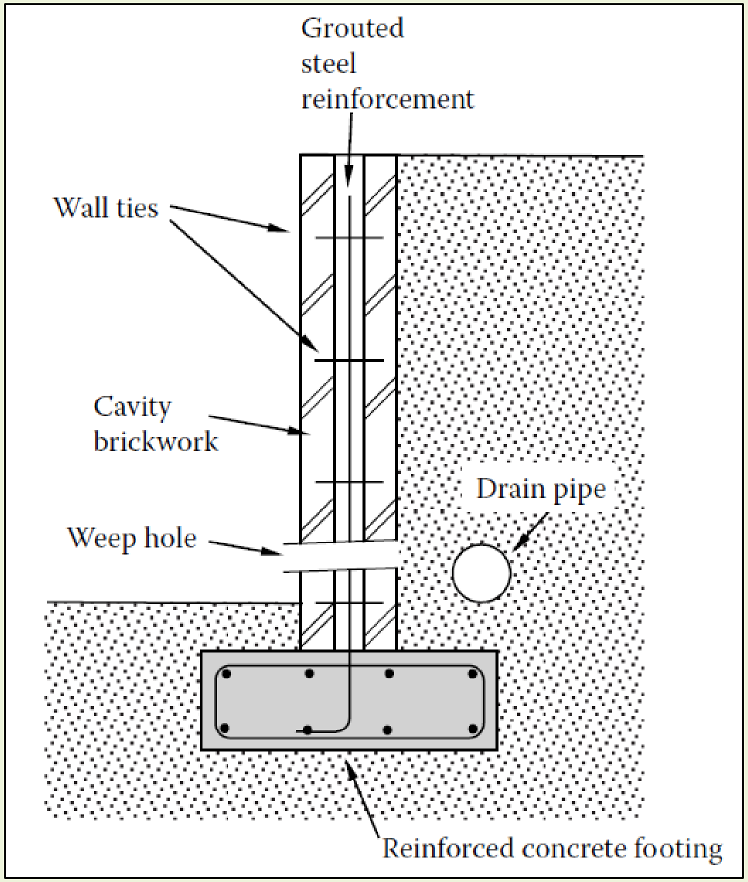


Slope Retention Systems and Typologies

- **Retention systems**
  - Structures built to retain vertical or near vertical earth slopes and resist lateral thrusts
  - Retention of water, natural soil or fill soil
- **Rigid retention systems**
  - Masonry Retaining Walls
  - Gravity Retaining Walls
  - Semi-gravity retaining walls
- **Semi-rigid retention systems**
  - Cantilever retaining walls
  - Counterfort retaining walls
- **Embedded flexible retention systems**
  - Cantilever Sheet pile walls
  - Anchored bulkheads
  - Bored pile walls
- **Surficial Flexible Retention System**
  - Crib Walls
  - Interlocking Block / Porcupine walls
  - Gabion Walls
- **Composite Retention Systems**
  - Reinforced Soil (MSE) Walls
  - Anchored Earth Walls
  - Soil Nailed / Nailed Soil Slopes

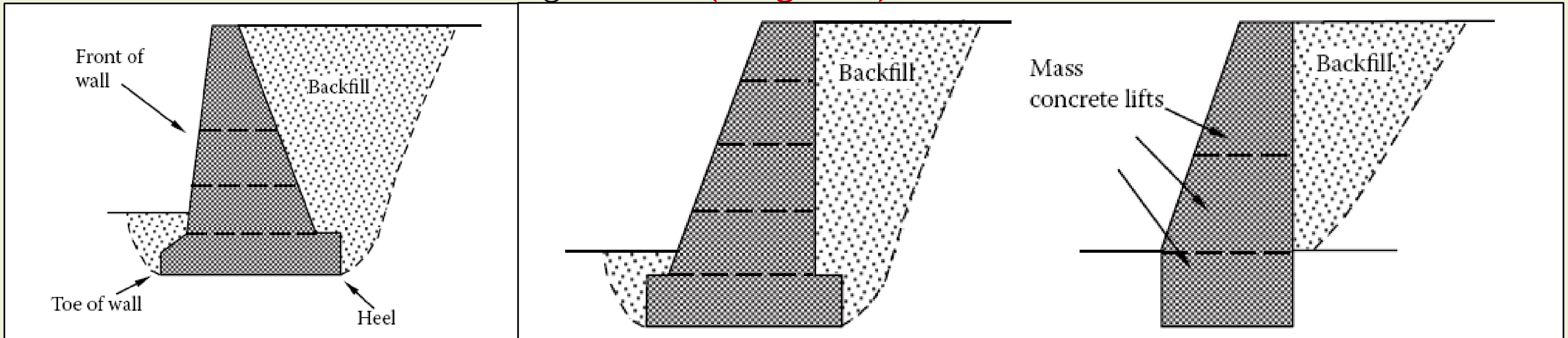
Rigid Retention Systems

- **Masonry Retaining Walls**
  - Load bearing brickwork
  - Design guidance provided by Brick Development Association **(Haseltine and Tutt 1991)**
  - Modest wall height up to 4 m
    - Mass brickwork suitable for short walls of 1 m
    - Quetta-bond brickwork can support walls up to 3 m
    - Double skinned reinforced and grouted cavity walls may be taller
  - Longevity is the main problem, as service life is lesser when affected by climatic conditions



Rigid Retention Systems

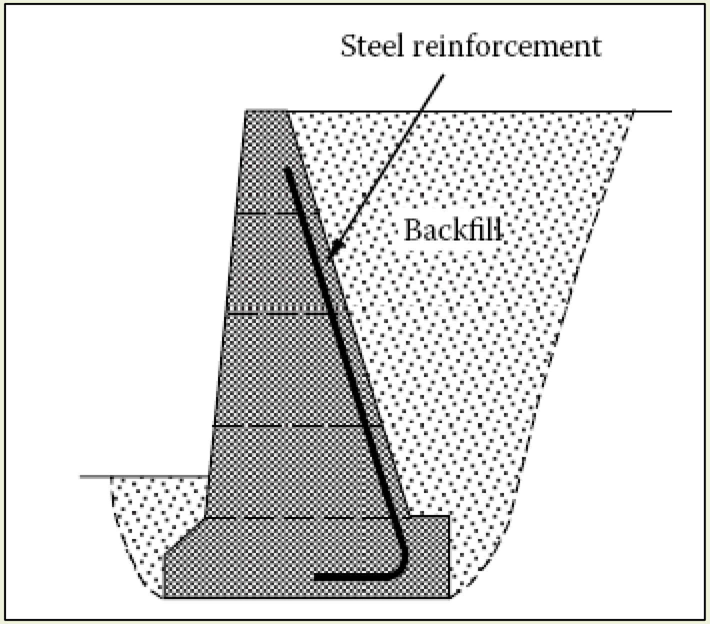
- **Gravity Retaining Walls / Breast Walls**
  - Stability and resistance to deformation is governed by their own weight **(Eurocode 7)**
  - Constructed with plain or reinforced concrete, stone masonry, blockwork, rubble masonry
  - May include base footing (with or without heels), ledge or buttress
  - Cross-section should be such that the resultant earth pressure should not produce any tensile stress in any part of the wall
    - Joints between concrete lifts and masonry blocks may fail in tension
  - Meant for smaller heights less than 3 m
    - Not economical for higher walls **(Teng 1962)**

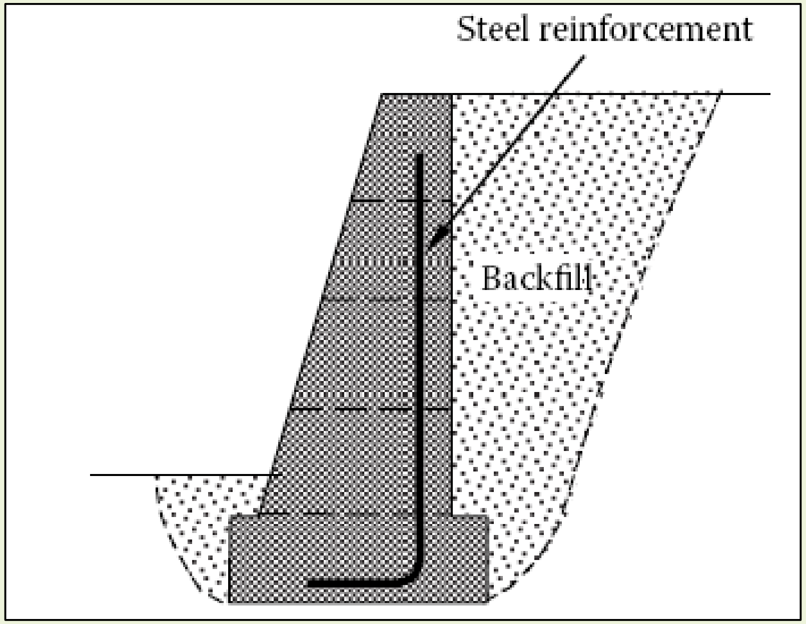



Rigid Retaining Structures

Rigid Retention Systems

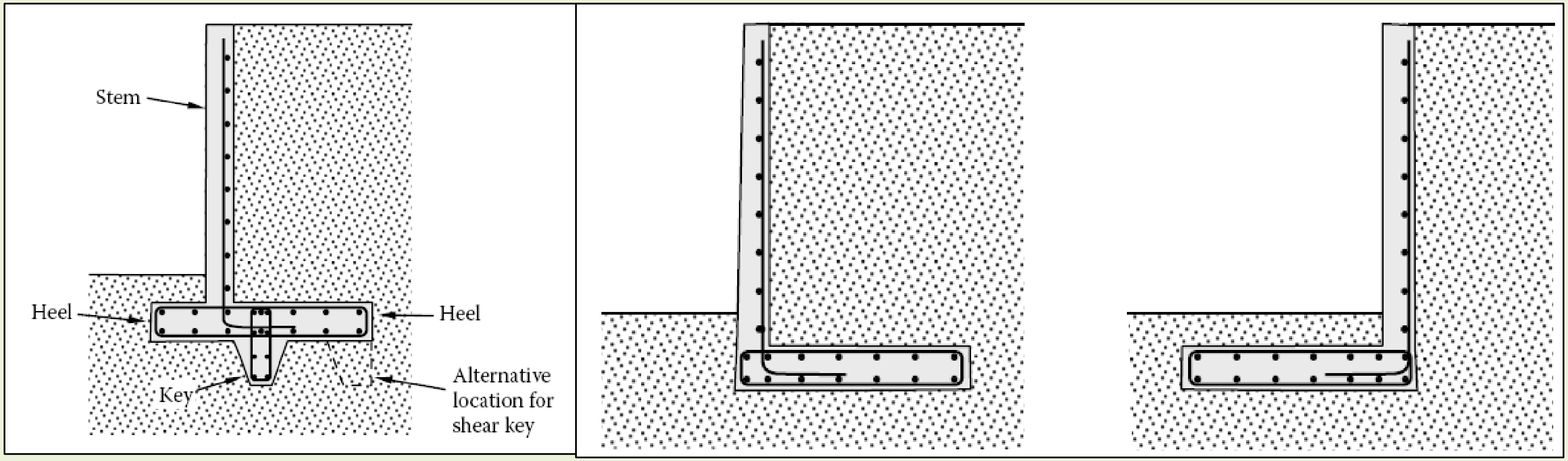
- **Semi-Gravity Retaining Walls**
  - Rely more on internal resistance to bending and shear
    - Less on self-weight than gravity walls
  - Utilization of steel connection between the base and stem, or between concrete lifts
    - Reduces mass of concrete, makes the stem slender, minimize the size of wall sections
    - Induces tensile stiffness across the concrete lifts





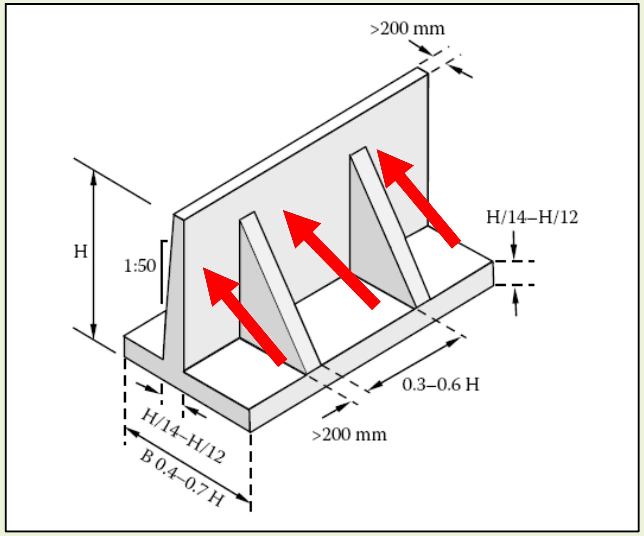
Semi-Rigid Retention Systems

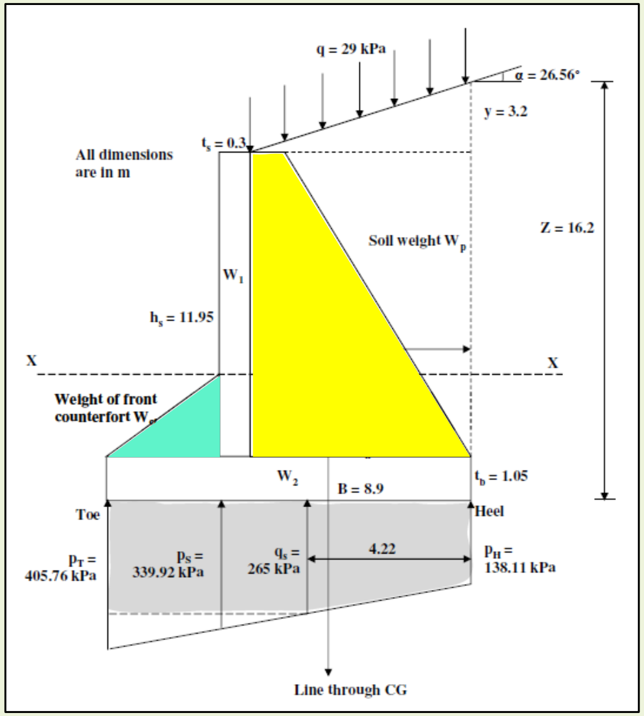
- **Cantilever Retaining Walls**
  - Inverted T- or L-shaped structures
  - Consist of a thin stem and a base slab
  - Economical to a height of about 6-8 m
  - The stem retains the soil mass behind the wall by cantilever action
  - Stability is achieved from the weight of the soil on the heel portion of the base slab
  - **Shear key** may be used to augment sliding resistance



Semi-Rigid Retention Systems

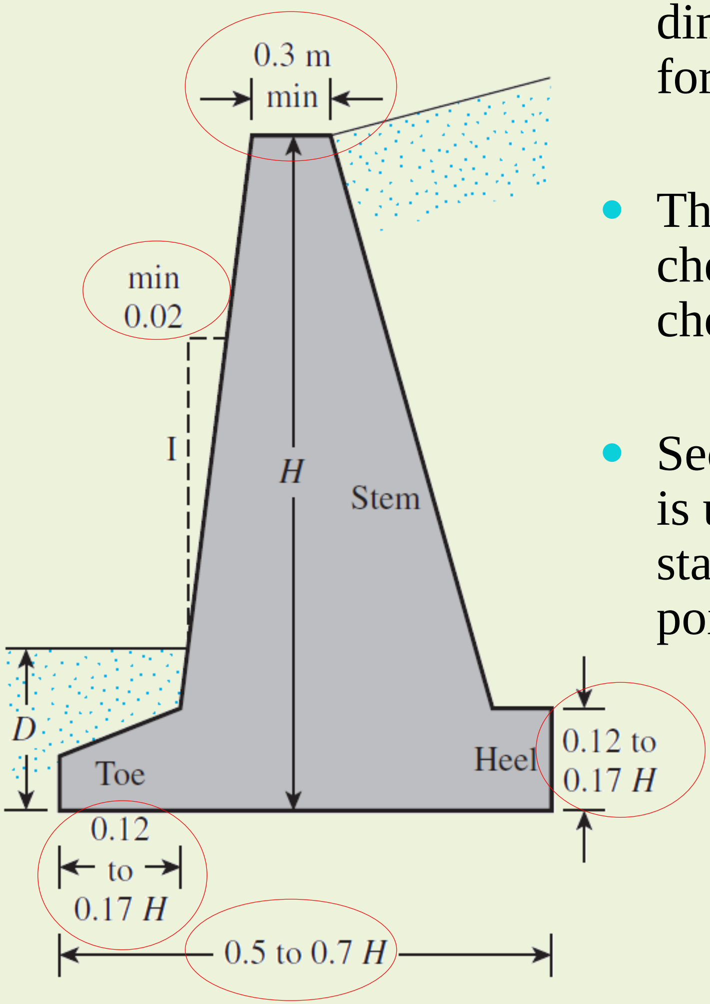
- **Counterfort Retaining Walls or Buttressed Walls**
  - Similar to cantilever walls
  - Counterforts are thin vertical concrete slabs that tie the wall stem and the base slab together
    - Placed at regular intervals along the length of the wall
    - Subjected to tensile stresses
  - Counterforts reduce the bending moments and shear stresses in the stem of the wall
  - Applicable to withstand high lateral pressure originating from the retained backfill
    - Used for very tall walls, 10-12 m high
  - Can have both main and front counterforts
    - Front counterfort is termed as ‘buttress’
    - Subjected to compressive stresses





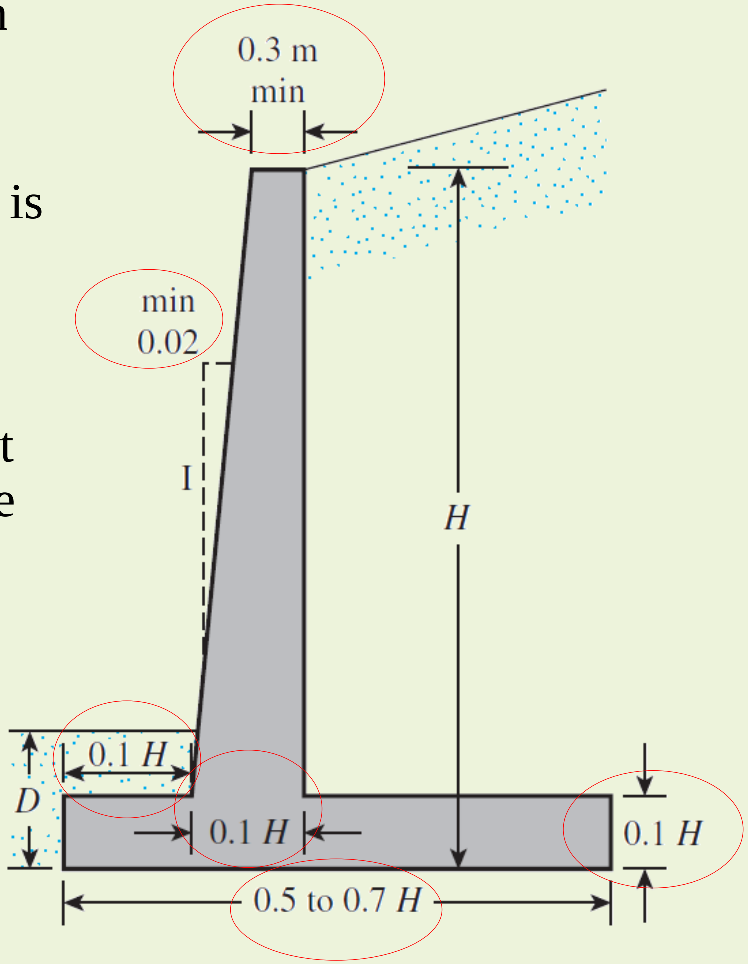
Retaining Wall Design: Proportioning

Gravity



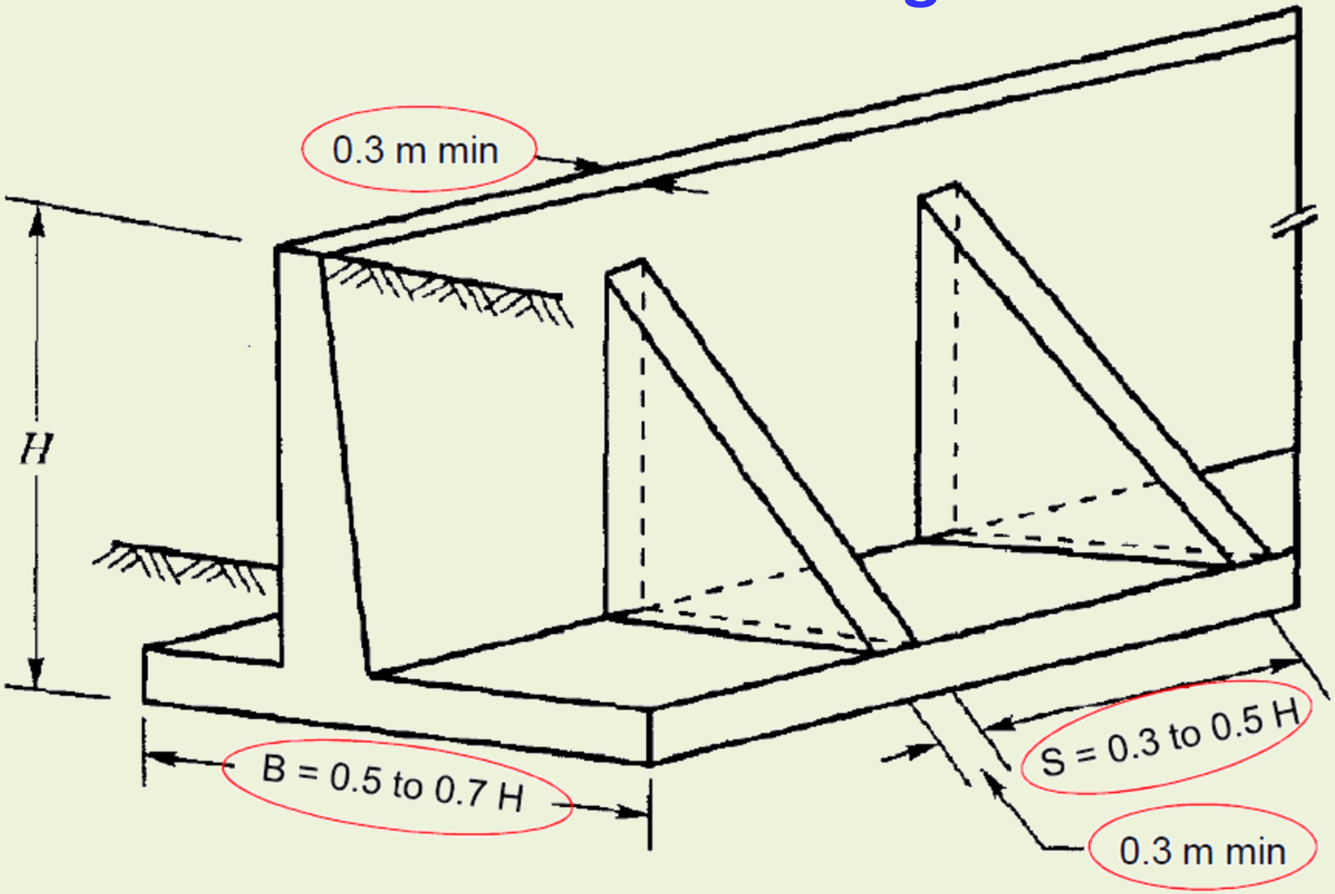
- First, approximate dimensions are chosen for the retaining wall
- Then, stability of wall is checked against these chosen dimensions
- Section is changed if it is undesirable from the stability or economy point of view

Cantilever

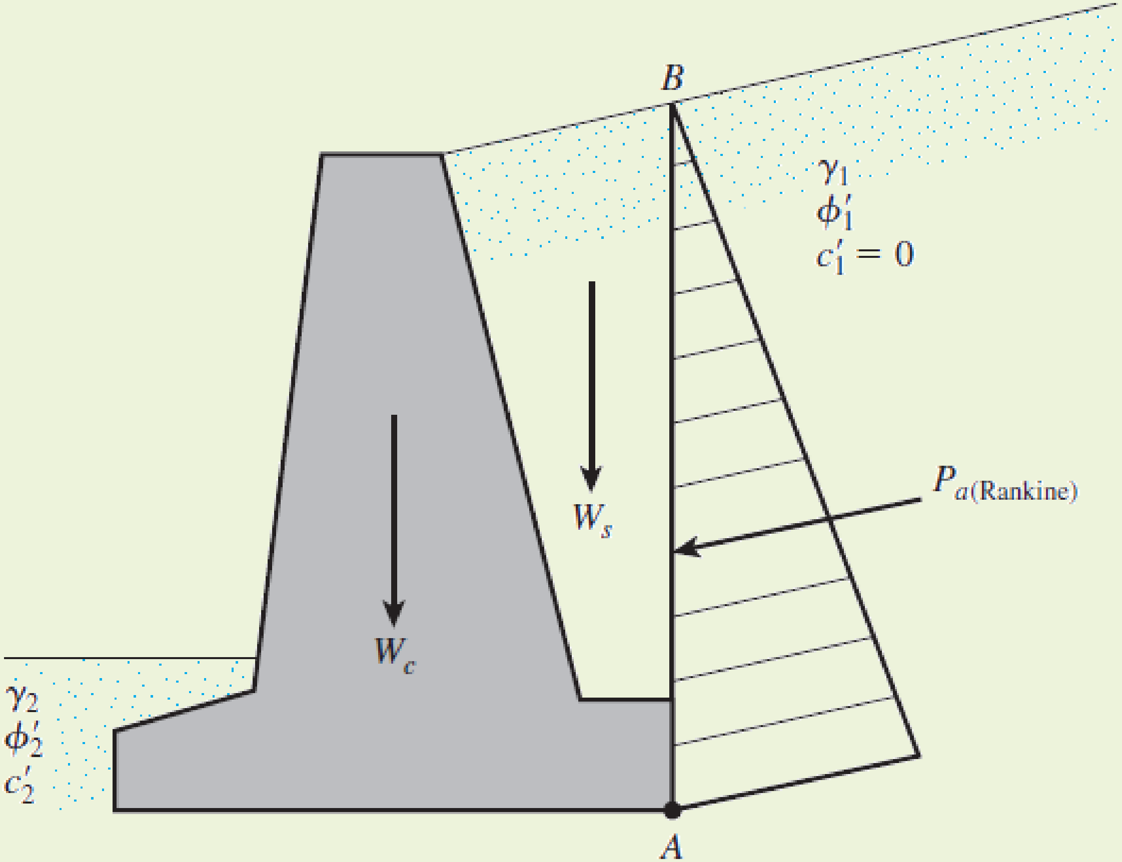


Retaining Wall Design: Proportioning

Counterfort Retaining Wall

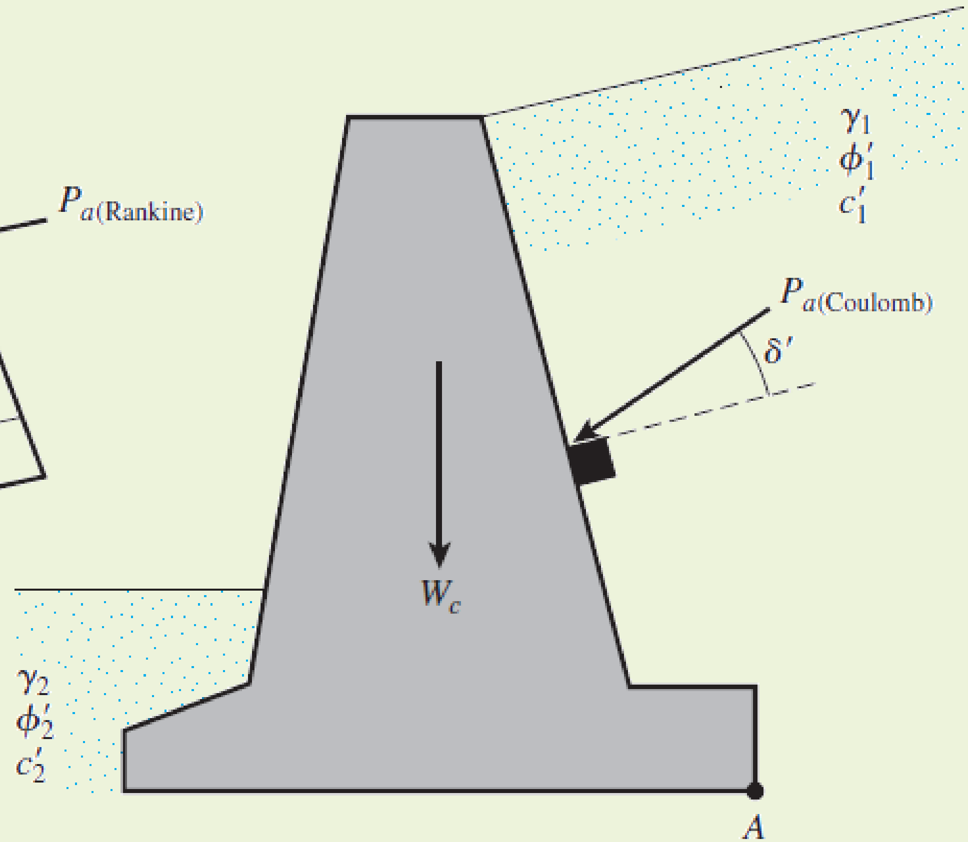


Earth Pressure on Gravity Retaining Wall



Active Earth Pressure on a Vertical Backface with Inclined Backfill made of Granular Material

Active Lateral Thrust on an Inclined Backface with Inclined Backfill made of Granular Material

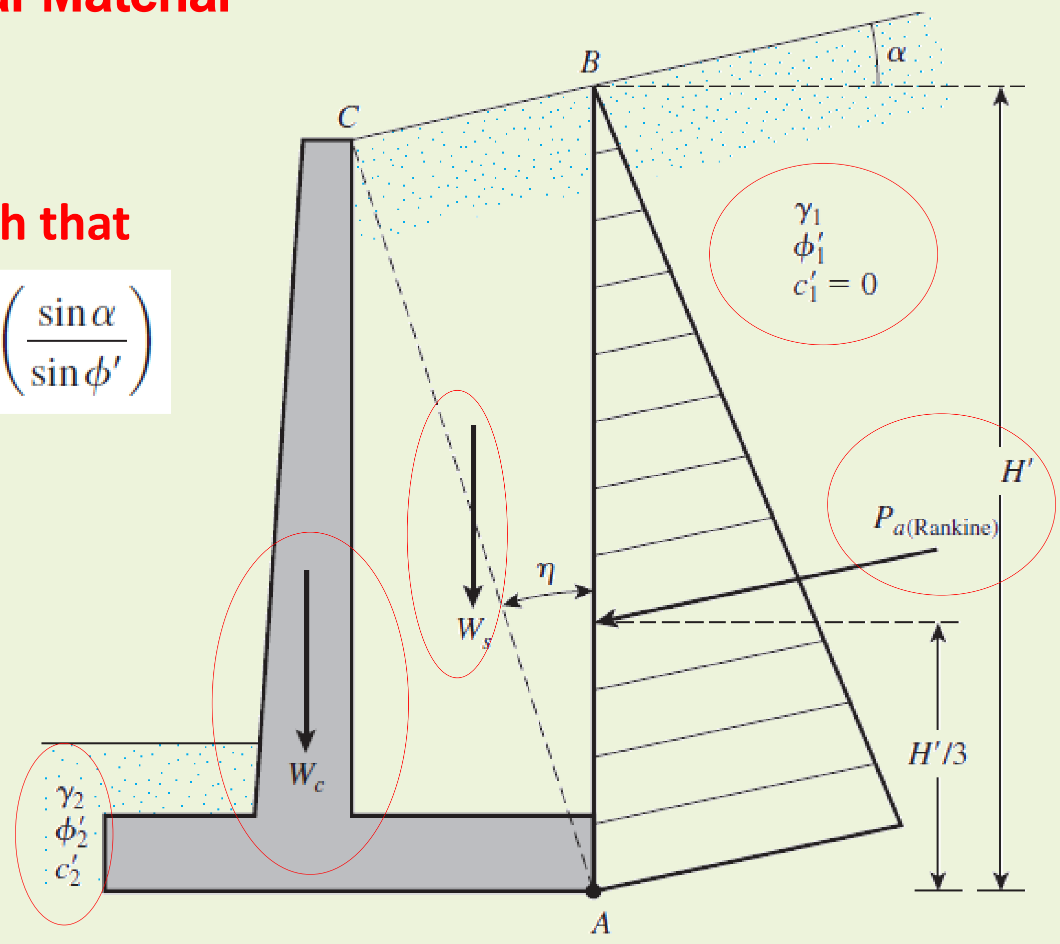


Earth Pressure on Cantilever Retaining Wall

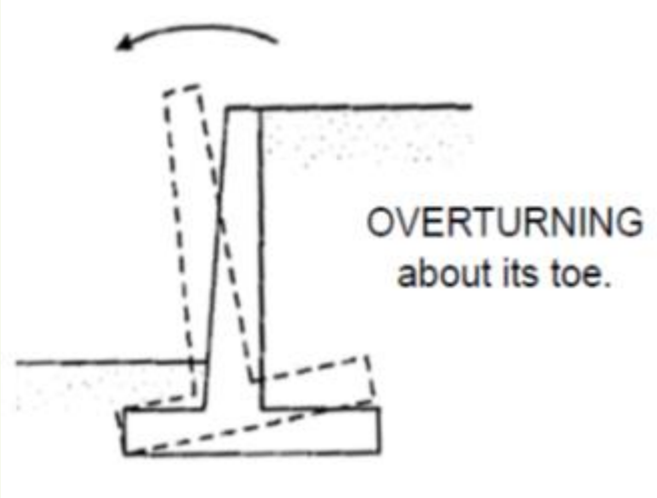
Earth pressure may be calculated at the vertical section going through the heel of wall → **Active Earth Pressure on a Vertical Backface with Inclined Backfill made of Granular Material**

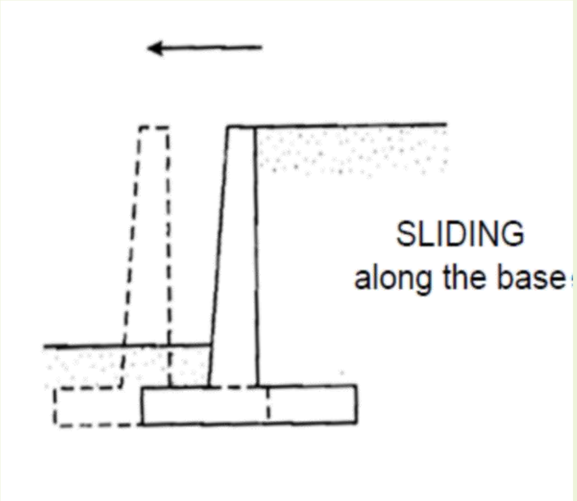
Proportioning of heel such that

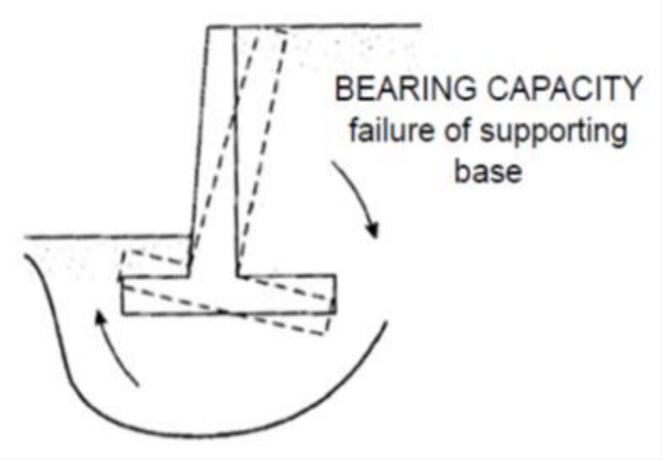
$$\eta \leq 45 - \frac{\phi'}{2} + \frac{\alpha}{2} - \frac{1}{2}\sin^{-1}\left(\frac{\sin\alpha}{\sin\phi'}\right)$$



Stability of Retaining Wall

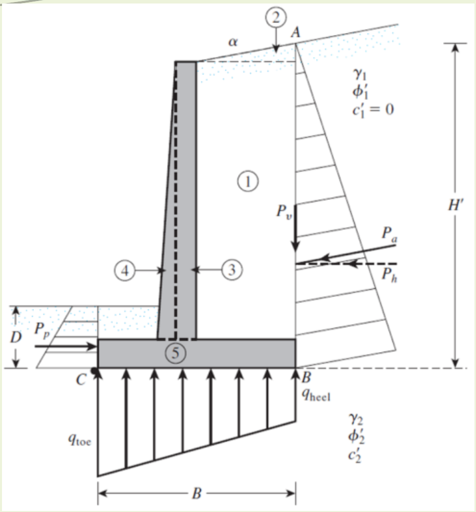






Excessive SETTLEMENT may occur if weak soil layer is located below the foundation within 1.5 times foundation width.

Wall Settlements



➢ Settlement of soil below the wall:

- ✓ Immediate settlement in granular soil
- ✓ Consolidation settlement in cohesive soil

➢ Differential settlement (between heel and toe):

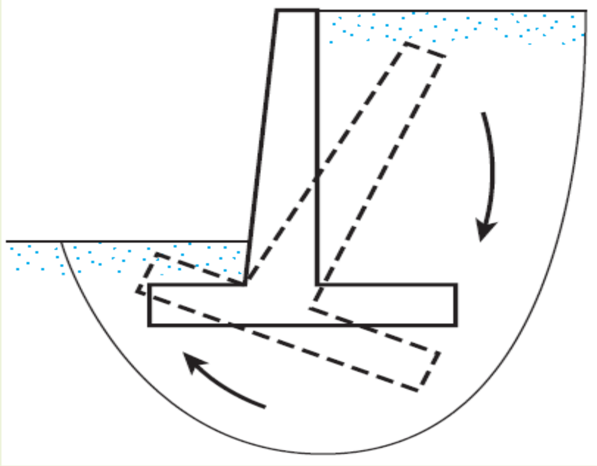
- ✓ Heel settlement is larger when there is substantial increase in backfill load

- ✓ Toe settlements are produced by lateral earth pressure.
  - ✓ To minimize toe settlements, ground may be strengthened
    - ✓ Sand piles, Rock columns, Grouting, Structural piles

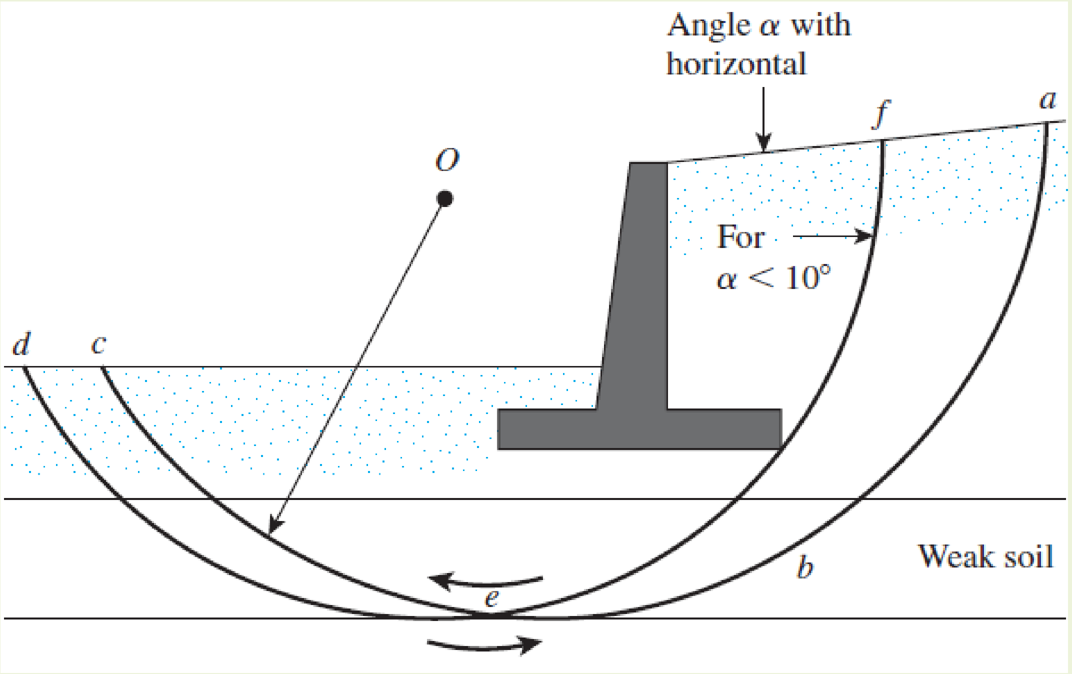
- ✓ Differential settlements along the length of wall may produce cracks in wall.
  - ✓ Can be monitored during construction itself
  - ✓ Preventive action may be taken such as ensuring proper compaction of the ground

Stability of Retaining Wall

- Deep seated shear failure may occur if there is a weak soil layer below the foundation within a depth of about 1.5 times width of foundation.

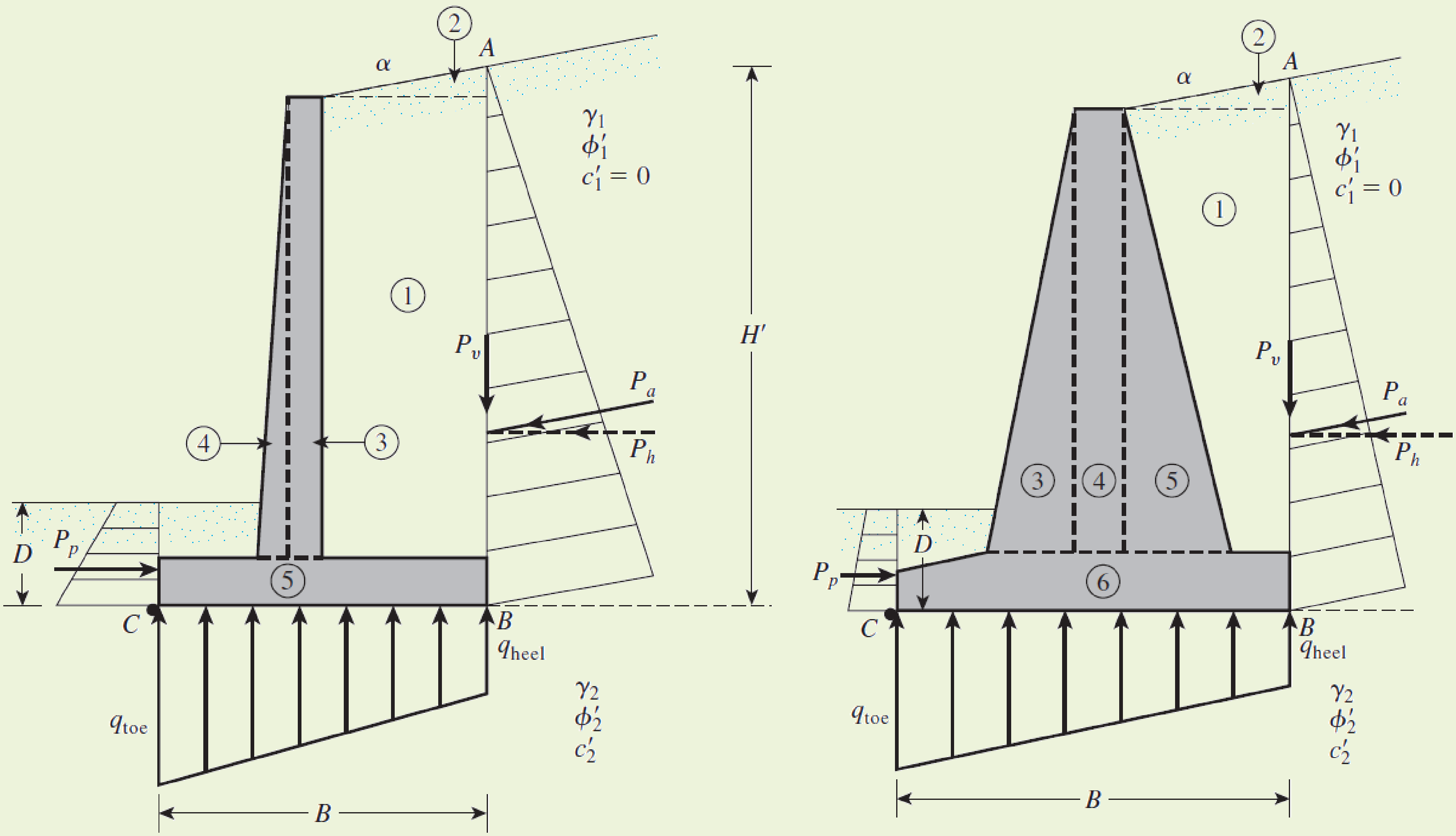


- The failure surface may be assumed to have cylindrical shape and critical failure surface for sliding may be determined through analysis → Similar to a slope stability analysis.



- For backfill with its slope less than 10^0, the critical sliding surface may be assumed to pass through heel of the retaining wall.

Check Against OVERTURNING



Check Against OVERTURNING

- The wall must be safe against overturning about the toe

$$FOS = \frac{\sum M_R}{\sum M_O}$$

$\sum M_R$ ⟵ Resisting Moment

$\sum M_O$ ⟵ Overturning Moment

$$FOS = \frac{P_{av}.B + \sum W_i.x_i}{P_{ah}.\overline{y}_a - P_P.\overline{y}_p} \geq 2$$

FOS = 1.5, if wind/seismic forces are considered

- Location of Resultant force from toe can be determined as

$$\left(P_{av} + \sum W_i\right).\overline{x} = \sum M_R - \sum M_O$$

$$\overline{x} = \frac{\sum M_R - \sum M_O}{P_{av} + \sum W_i}$$

Note: In the design of cantilever retaining wall, it is preferred that the stem center is right above the location of resultant force at the base (resultant of soil reaction)

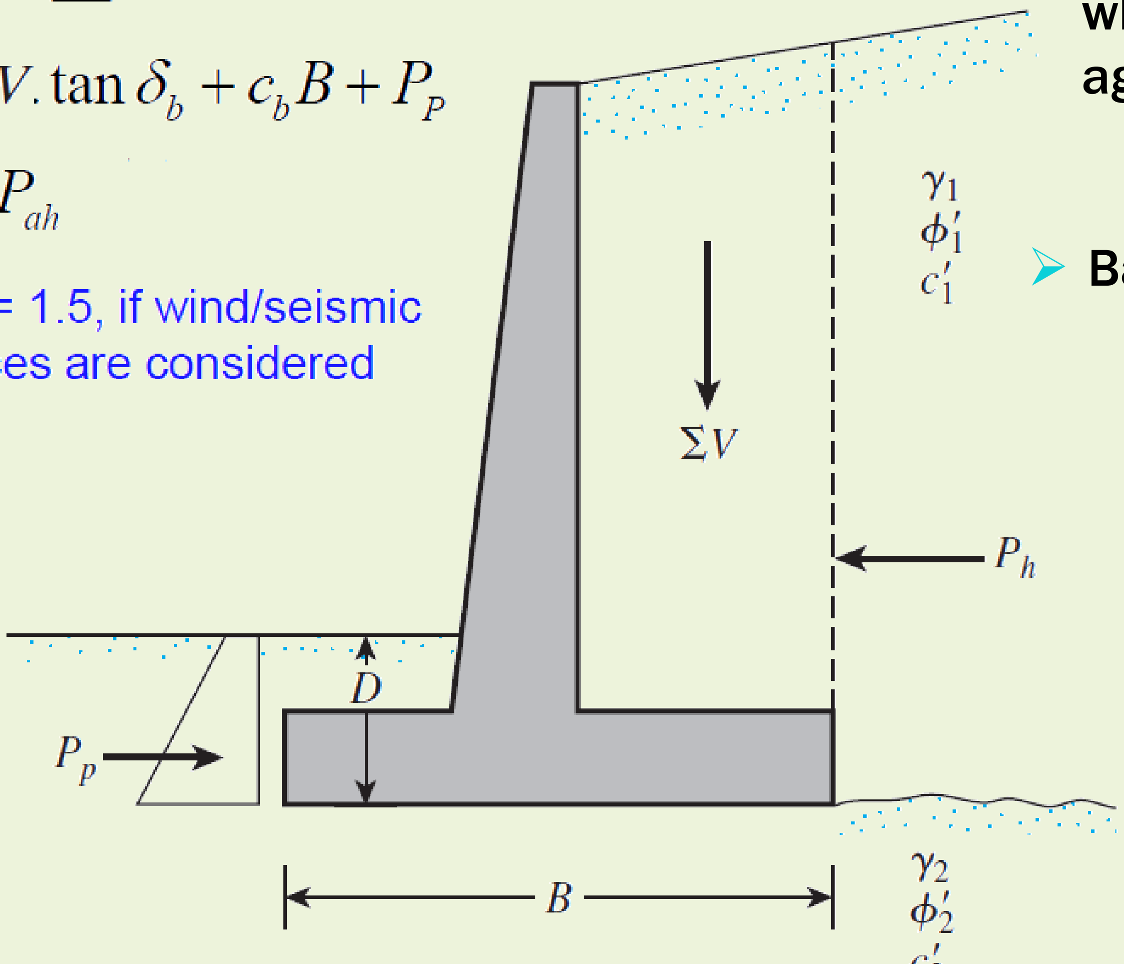
Check Against SLIDING

$$FOS = \frac{\sum F_R}{\sum F_S} \geq 1.75$$

$$F_R = \Sigma V.\tan\delta_b + c_b B + P_P$$

$$F_S = P_{ah}$$

FOS = 1.5, if wind/seismic forces are considered

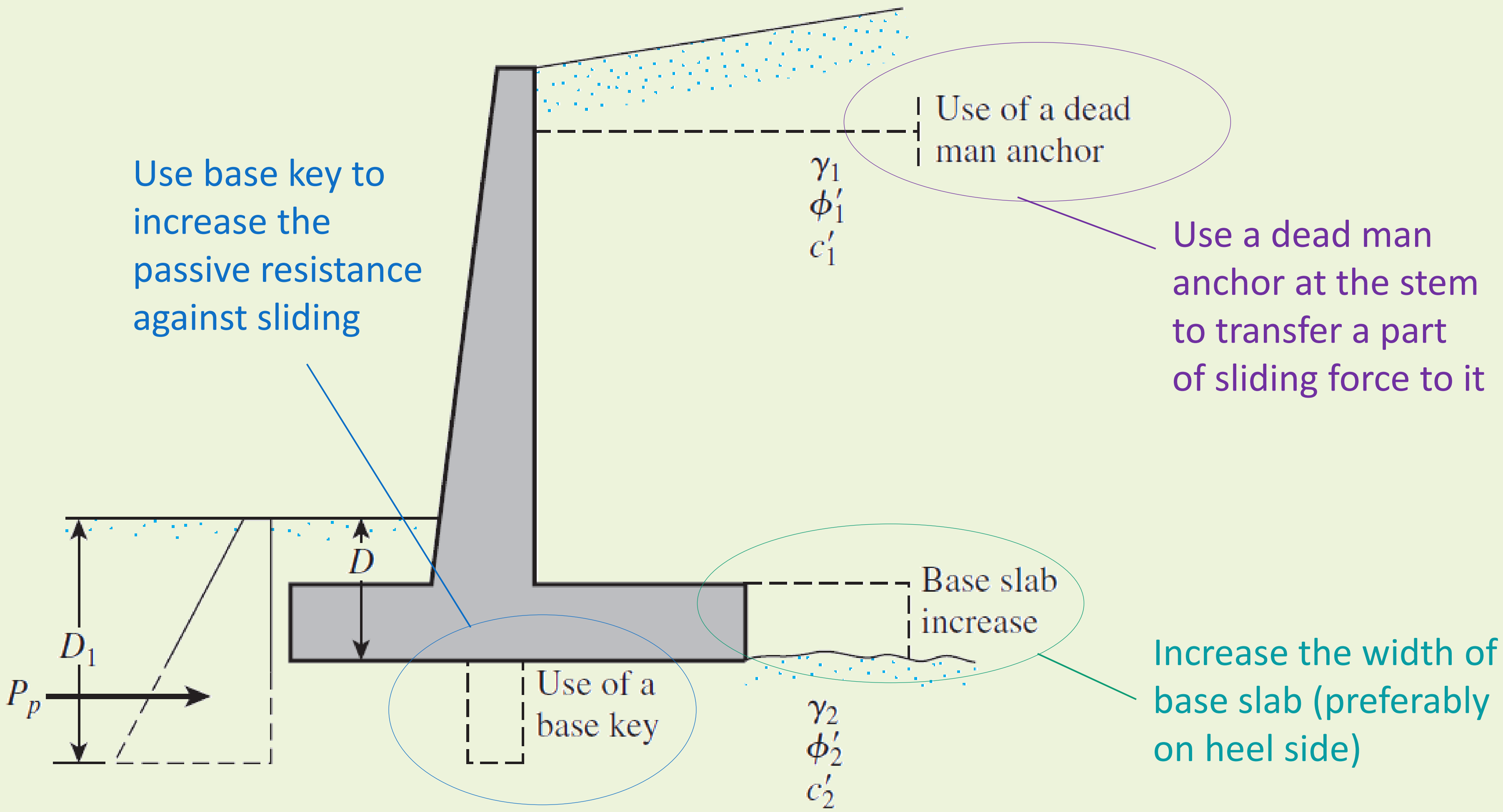


- In most cases passive earth pressure is ignored while calculating FOS against sliding
- Base friction and adhesion may be taken by the following assumption

$$\delta_b = \left(\frac{1}{2} \text{ to } \frac{2}{3}\right).\phi'_2$$

$$c_b = \left(\frac{1}{2} \text{ to } \frac{2}{3}\right).c'_2$$

Alternative for Improving FoS against SLIDING



Check for Bearing Capacity Failure

$$R = \sqrt{\left(P_{av} + \sum W_i\right)^2 + \left(P_{ah} - P_P\right)^2}$$

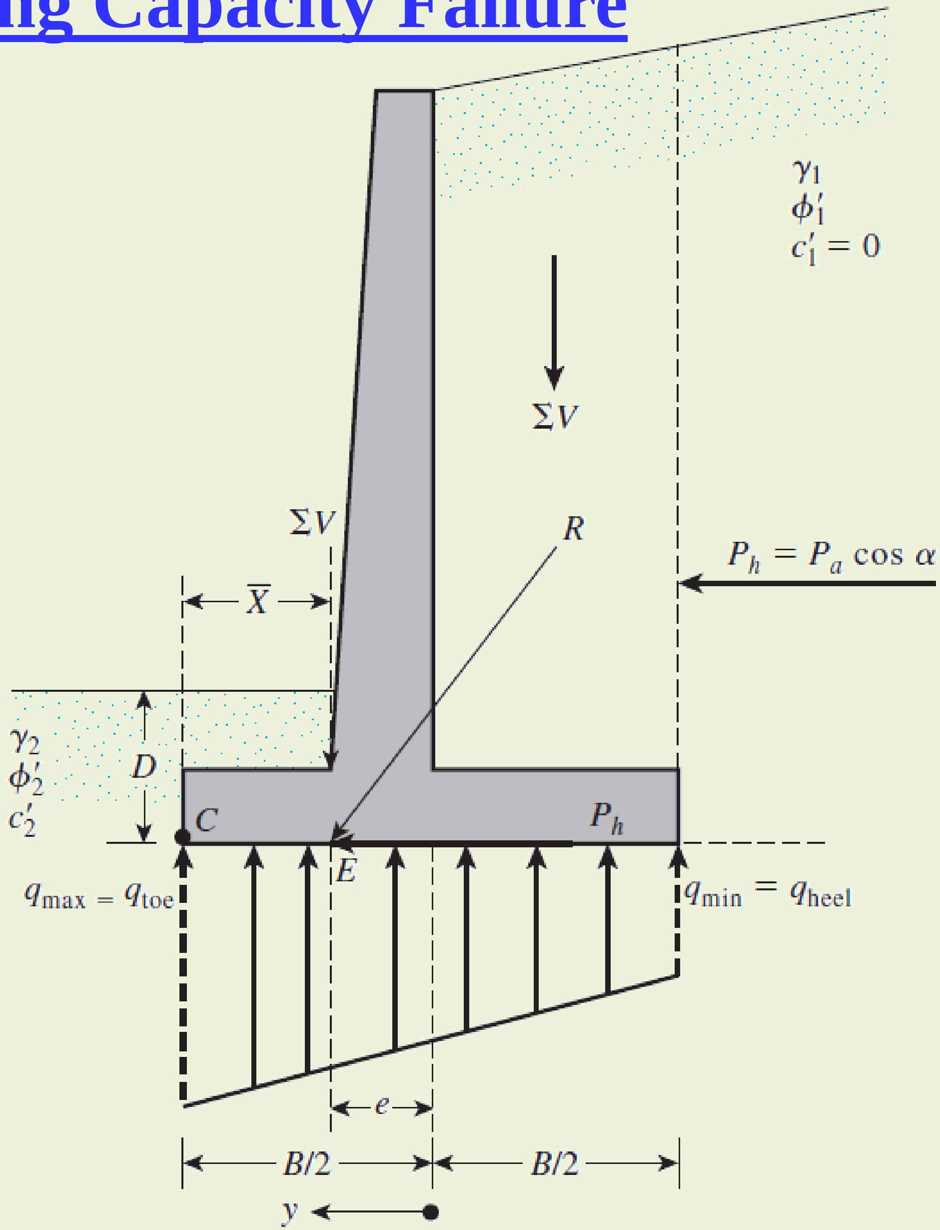
$$CE = \bar{x} = \frac{\sum M_R - \sum M_O}{P_{av} + \sum W_i}$$

Eccentricity: $e = \frac{B}{2} - \bar{x}$

$$q_{max} = \frac{Q}{B}\left(1 + \frac{6e}{B}\right) = \frac{\left(P_{av} + \sum W_i\right)}{B}\left(1 + \frac{6e}{B}\right)$$

$$q_{min} = \frac{Q}{B}\left(1 - \frac{6e}{B}\right) = \frac{\left(P_{av} + \sum W_i\right)}{B}\left(1 - \frac{6e}{B}\right)$$

For e > B/6, q_{min} becomes negative, i.e. tensile force. This is not desirable and re-proportioning is required



Check for Bearing Capacity Failure

- Bearing capacity of soil from general bearing capacity equation

$$q_u = c.N_c.s_c.d_c.i_c + q.N_q.s_q.d_q.i_q + 0.5\gamma.B.N_\gamma.s_\gamma.d_\gamma.i_\gamma$$

- Following consideration have to make during the analysis
  - ✓ The eccentricity of load on the foundation can be incorporated using effective area method. The bearing capacity is calculated assuming the width of foundation as *B'*

$$B' = B - 2e$$

  - ✓ Inclination of resultant force has to taken into account

$$\tan\beta = \frac{P_{ah} - P_P}{P_{av} + \sum W_i}$$

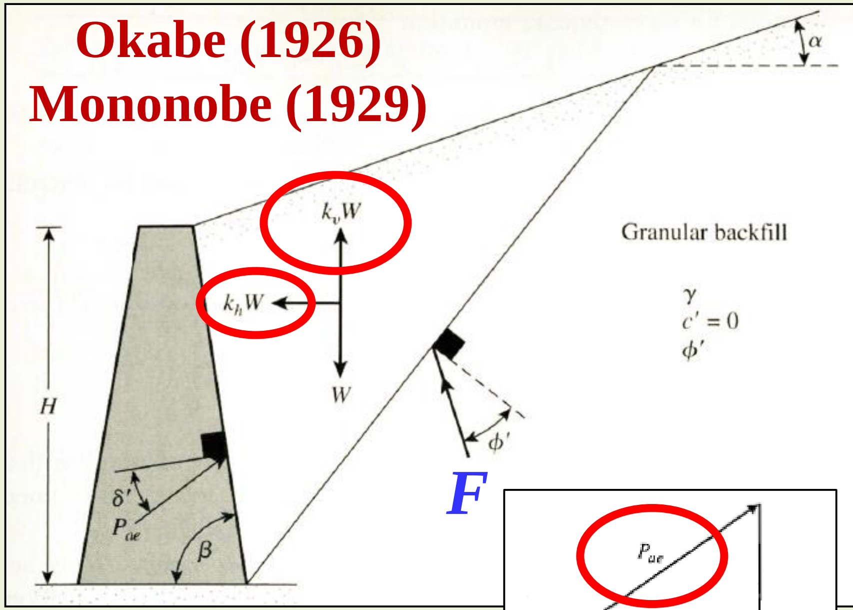
Factor of safety against bearing capacity:

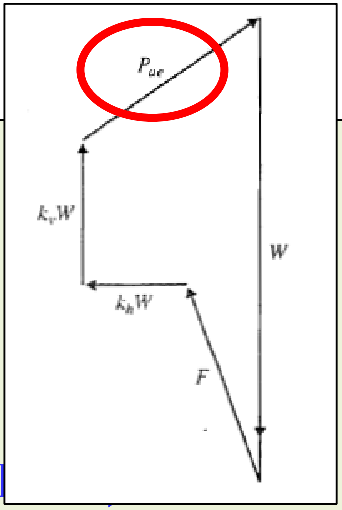
$$FOS = \frac{q_u}{q_{av}}$$

[2 for granular soil
3 for cohesive soils

Mononobe-Okabe Method: Pseudostatic Active Pressure

- **Pseudostatic active earth pressure condition on a slant rough wall with sloping granular backfill (Extension of Coulomb's theorem)**





❖ Consideration of pseudo-static forces

- Pseudo-static horizontal force = k_hW
- Pseudo-static vertical force = k_vW

$$k_h = \frac{\text{Horizontal earthquake acceleration component}}{\text{Acceleration due to gravity, } g}$$

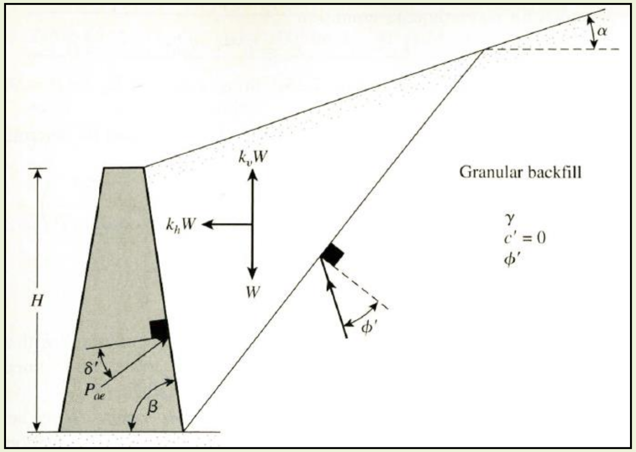
$$k_v = \frac{\text{Vertical earthquake acceleration component}}{\text{Acceleration due to gravity, } g}$$

❖ Directions of pseudostatic forces

- Force direction leading to worst instability condition of the wall
  - *k_h acting towards the wall produces excess disturbing force*
    - Produces excess overturning moment
  - *k_v acting away from gravity lowers the restoring force*
    - Lowers the weight of the soil wedge

❖ Solve for the force polygon to estimate P_{ae} *(acts at H/3 from the wall*

Mononobe-Okabe Method: Pseudostatic Active Pressure



- **Pseudostatic active earth pressure condition on a slant rough wall with sloping granular backfill**
  - Active force per unit length of the wall **(Mononobe-Okabe Equations)**

$$P_{ae} = \frac{1}{2}\gamma H^2 (1-k_v) K_{ae}$$

    - The point of action of the total pseudo-static thrust is assumed to be the same as that of the static thrust
    - K_{ae} → Coefficient of active earth pressure under pseudo-static condition

$$K_{ae} = \frac{\sin^2(\phi' + \beta - \theta')}{\cos\theta' \sin^2\beta \sin(\beta - \theta' - \delta')\left[1 + \sqrt{\frac{\sin(\phi'+\delta')\sin(\phi'-\theta'-\alpha)}{\sin(\beta-\delta'-\theta')\sin(\alpha+\beta)}}\right]^2}$$

$$\theta' = \tan^{-1}\left[\frac{k_h}{(1-k_v)}\right]$$

  - Horizontal component of pseudo-static thrust

$$P_{aeh} = P_{ae}\cos\left(90 - \beta + \delta'\right)$$

    - Required for sliding stability analyses of retaining wall
    - For vertical backface, $\beta = 90$ $P_{aeh} = P_{ae}\cos\delta'$
  - For no earthquake condition $k_h = k_v = 0 \Rightarrow \quad \theta' = 0 \Rightarrow \quad K_{ae} = K_a$

Mononobe-Okabe Method: Pseudo-static Active Pressure

- **Mononobe-Okabe Method for Pseudo-static Analyses**

$$\theta' = \tan^{-1}\left[\frac{k_h}{(1-k_v)}\right]$$

$$K_{ae} = \frac{\sin^2(\phi' + \beta - \theta')}{\cos\theta' \sin^2\beta \sin(\beta - \theta' - \delta')\left[1 + \sqrt{\frac{\sin(\phi' + \delta')\sin(\phi' - \theta' - \alpha)}{\sin(\beta - \delta' - \theta')\sin(\alpha + \beta)}}\right]^2}$$

$$P_{ae} = \frac{1}{2}\gamma H^2 (1-k_v) K_{ae}$$

Table 7.6 Values of K_{ae} [Eq. (7.43)] for $\beta = 90°$ and $k_v = 0$

			ϕ'(deg)				
k_h	δ' (deg)	α(deg)	28	30	35	40	45
0.1	0	0	0.427	0.397	0.328	0.268	0.217
0.2			0.508	0.473	0.396	0.382	0.270
0.3			0.611	0.569	0.478	0.400	0.334
0.4			0.753	0.697	0.581	0.488	0.409
0.5			1.005	0.890	0.716	0.596	0.500
0.1	0	5	0.457	0.423	0.347	0.282	0.227
0.2			0.554	0.514	0.424	0.349	0.285
0.3			0.690	0.635	0.522	0.431	0.356
0.4			0.942	0.825	0.653	0.535	0.442
0.5			—	—	0.855	0.673	0.551
0.1	0	10	0.497	0.457	0.371	0.299	0.238
0.2			0.623	0.570	0.461	0.375	0.303

Foundation Design Guidelines

- IS: 6403

IS 6403 : 1981
(Reaffirmed 2011)
(Reaffirmed 2016)

Indian Standard

CODE OF PRACTICE FOR
DETERMINATION OF BREAKING CAPACITY
OF SHALLOW FOUNDATIONS

(First Revision)

Seventh Reprint AUGUST 2004

- IS: 8009 (Part I)

IS : 8009 (Part I) - 1976
(Reaffirmed 2003)
(Reaffirmed 2013)

Indian Standard

CODE OF PRACTICE FOR CALCULATION OF
SETTLEMENTS OF FOUNDATIONS

PART I SHALLOW FOUNDATIONS SUBJECTED TO
SYMMETRICAL STATIC VERTICAL LOADS

(Fifth Reprint MARCH 1999)

- SP 7: Group 2: Part 6: Section 2

NATIONAL BUILDING CODE OF INDIA

PART 6 STRUCTURAL DESIGN

Section 2 Soils and Foundations

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6403_1981_Shallow_Foundation_BC.pdf (SECURED) - Adobe Acrobat Reader DC (32-bit)

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5.1.2 The ultimate net bearing capacity obtained in **5.1.1** for strip footing shall be modified to take into account, the shape of the footing, inclination of loading, depth of embedment and effect of water table. The modified bearing capacity formulæ are given as under:

a) In case of general shear failure q_d $= cN_c s_c d_c i_c + q(N_q - 1) s_q d_q i_q + \frac{1}{2} B\gamma N_\gamma s_\gamma d_\gamma i_\gamma W'$

b) In case of local shear failure q'_d $= \frac{2}{3} cN'_c s_c d_c i_c + q(N'_q - 1) s_q d_q i_q + \frac{1}{2} B\gamma N'_\gamma s_\gamma d_\gamma i_\gamma W'$

iii)	Square	1·3	1·2	0·8
iv)	Circle	1·3	1·2	0·6

Use B as the diameter in the bearing capacity formula.

8

Heavily overconsolidated clays	0·2 to 0·5

5.09 x 7.37 in

5.91 x 8.38 in

Table 4 Permissible Differential Settlements and Tilt (Angular Distortion) for Shallow Foundations in Soils

(*Clause* 7.1.3)

Sl No.	Type of Structure	Isolated Foundations						Raft Foundations					
		Sand and Hard Clay			Plastic Clay			Sand and Hard Clay			Plastic Clay		
		Maximum settlement mm	Differential settlement mm	Angular distortion mm	Maximum settlement mm	Differential settlement mm	Angular distortion mm	Maximum settlement mm	Differential settlement mm	Angular distortion mm	Maximum settlement mm	Differential settlement mm	Angular distortion mm
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
i)	For steel structure	50	.003 3*L*	1/300	50	.003 3*L*	1/300	75	.003 3*L*	1/300	100	.003 3*L*	1/300
ii)	For reinforced concrete structures	50	.001 5*L*	1/666	75	.001 5*L*	1/666	75	.002 1*L*	1/500	100	.002 0*L*	1/500
iii)	For multistoreyed buildings												
	a) RC or steel framed buildings with panel walls	60	.002*L*	1/500	75	.002*L*	1/500	75	.002 5*L*	1/400	125	.003 3*L*	1/300
	b) For load bearing walls												
	1) *L*/H = 2*	60	.000 2*L*	1/5 000	60	.000 2*L*	1/5000	← Not likely to be encountered →					
	2) *L*/H = 7*	60	.000 4*L*	1/2 500	60	.000 4*L*	1/2500						
iv)	For water towers and silos	50	.001 5*L*	1/666	75	.001 5*L*	1/666	100	.002 5*L*	1/400	125	.002 5*L*	1/400

NOTE — The values given in the table may be taken only as a guide and the permissible total settlement/different settlement and tilt (angular distortion) in each case should be decided as per requirements of the designer.

L denotes the length of deflected part of wall/raft or centre-to-centre distance between columns.

H denotes the height of wall from foundation footing.

* For intermediate ratios of *L*/*H*, the values can be interpolated.

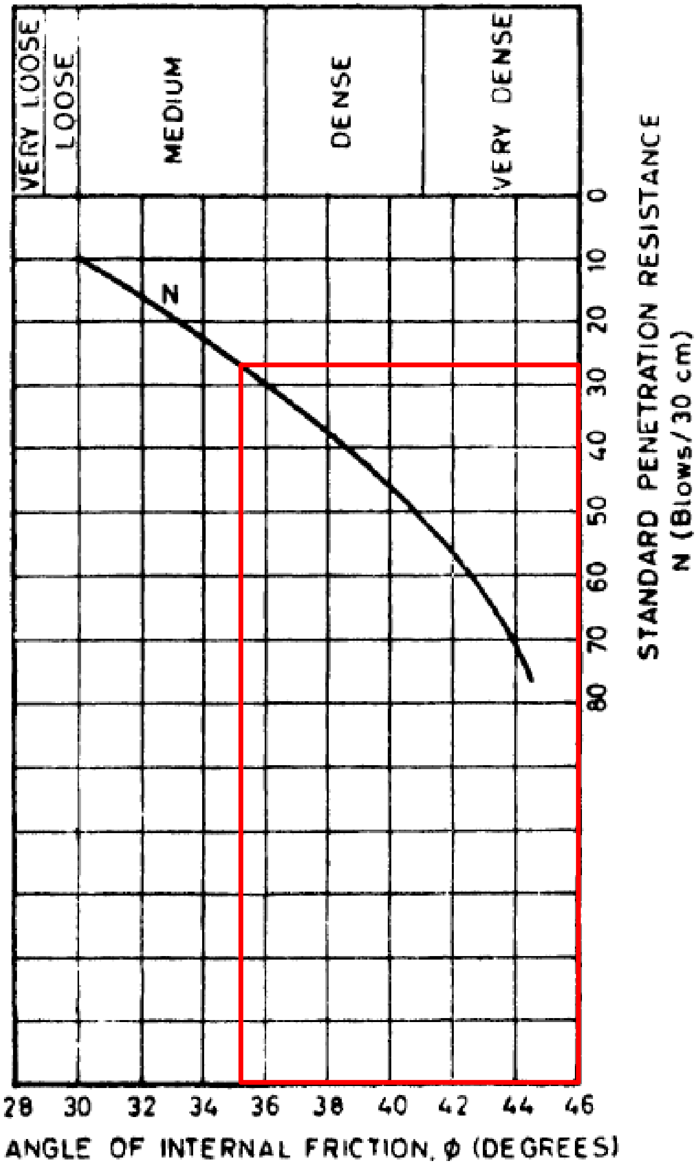


FIG. 1 RELATIONSHIP BETWEEN ϕ AND N

TABLE 1 BEARING CAPACITY FACTORS

(*Clause* 5.1.1)

ϕ (Degrees)	Bearing Capacity Factors N_c	N_q	N_γ
0	5·14	1·00	0·00
5	6·49	1·57	0·45
10	8·35	2·47	1·22
15	10·98	3·94	2·65
20	14·83	6·40	5·39
25	20·72	10·66	10·88
30	30·14	18·40	22·40
35	46·12	33·30	48·03
40	75·31	64·20	109·41
45	138·88	134·88	271·76
50	266·89	319·07	762·89

NOTE — For obtaining values of N'_c, N'_q and N'_γ, calculate $\phi' = \tan^{-1}(0.67 \tan \phi)$. Read N_c, N_q, and N_γ, from the Table corresponding to the value of ϕ' instead of ϕ which are values of N'_c, N'_q, N'_γ respectively.

Retaining Wall Design Guidelines

- IS: 14458 (Part2)

IS 14458 (Part 2) : 1997

Indian Standard

RETAINING WALL FOR HILL AREA — GUIDELINES

PART 2 DESIGN OF RETAINING/BREAST WALLS

IS.14458.2.1997.pdf - Adobe Acrobat Reader DC (32-bit)

Home Tools IS.14458.2.1997.pdf ×

5.2 Retaining walls and breast walls shall be designed as rigid walls, using following criteria:

a) Factor of safety against overturning > 2.0 (static loads), > 1.5 (with earthquake forces) (*see also* IS 1904)

b) Factor of safety against sliding > 1.5 (static loads), > 1.0 (with earthquake forces)

NOTE — The live loads and imposed loads adding to stability of the structure shall not be considered in working out the factors of safety given in **5.2**(a) and **5.2**(b).

c) Maximum base pressure ≤ q_a (allowable bearing capacity)

≤ 1.33 q_a (during earth-quake)

d) Minimum base pressure > 0 (zero) [*see also* IS 4247 (Part 3)]

e) Factor of safety against floatation > 1.25 [*see also* IS 4247 (Part 3)]

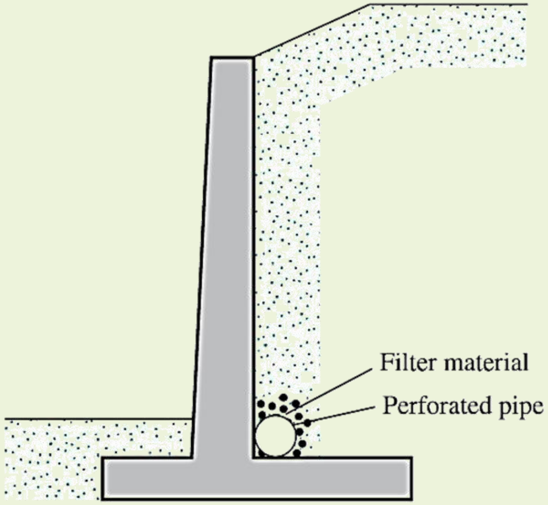
f) In case of steep hills, the factors of safety for slip surface below foundation shall be greater than 1.5 and 1.0 in static and seismic conditions respectively.

The design of wall foundations shall meet the requirements of IS 1080 and IS 1904.

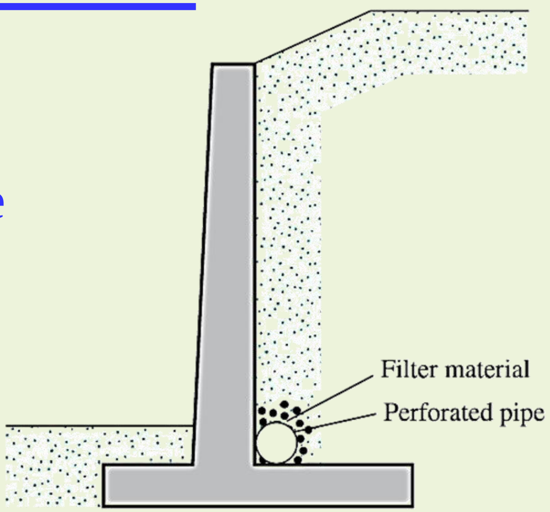
Construction and Longevity of Retaining Walls

- **Typical construction processes**
  - Site assessment and wall design
  - Excavation and site preparation
  - Construction of the foundation
  - Installation of the drainage system
  - Wall construction
  - Backfilling and compaction
  - Finishing and landscaping

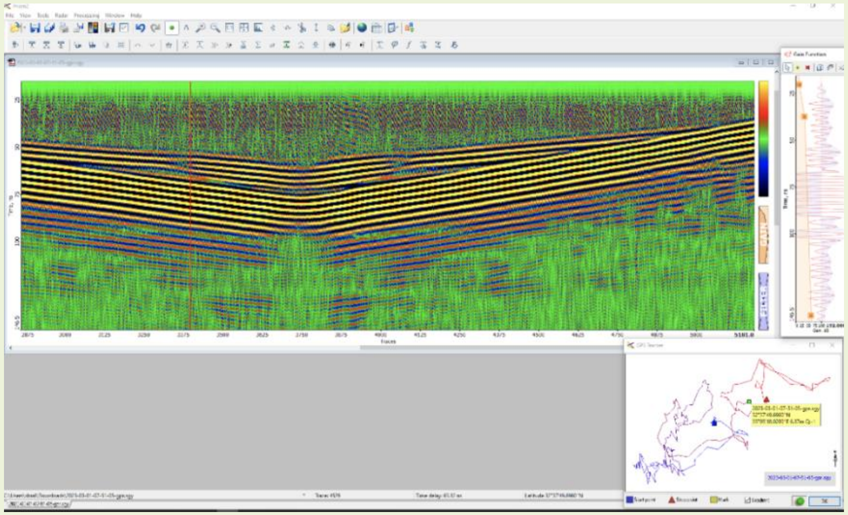
- **Drainage is the most important measure**
  - Perforated drainage pipes
  - Layers of gravel or permeable material
  - Geotextiles for filtration
  - Surface drainage systems
    - A well-designed and executed drainage system ensures optimal performance and longevity of the retaining wall



Maintenance of Retaining Walls



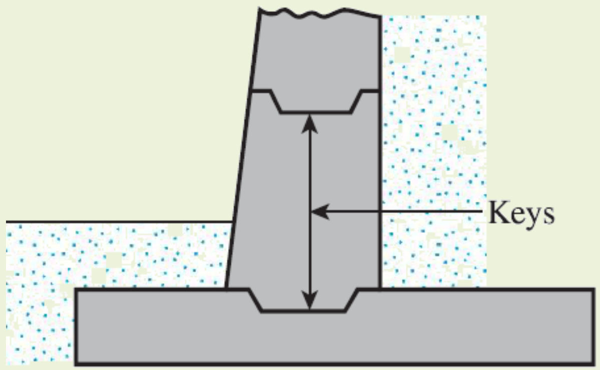
- **Longevity and optimal performance**
  - Regular inspections for signs of wear or damage
  - Cleaning and maintaining drainage systems
  - Repairing cracks or minor damage
  - Monitoring for movement or settlement
  - Maintaining associated landscaping
  - Non-destructive quality control of long retaining wall construction with drone-based GPR (**Prism2** software)

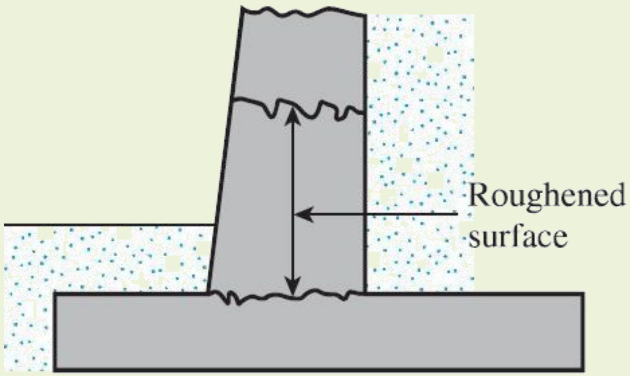


Wall Joints

➢ Construction Joints:

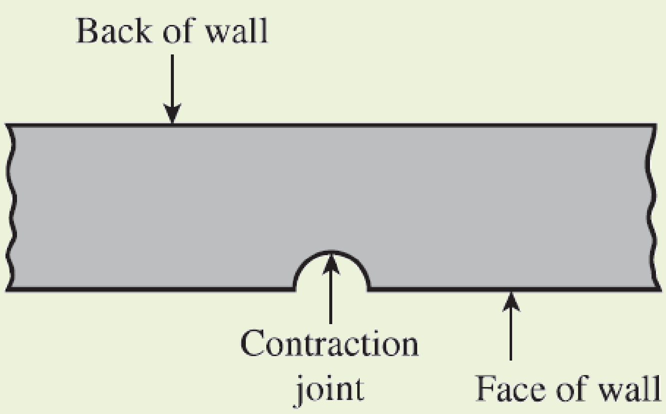
- ✓ Vertical or horizontal joints are placed between two successive pour of concrete.
- ✓ To increase shear resistance at the joints, keys may used as shown in the figure below.





➢ Contraction Joint:

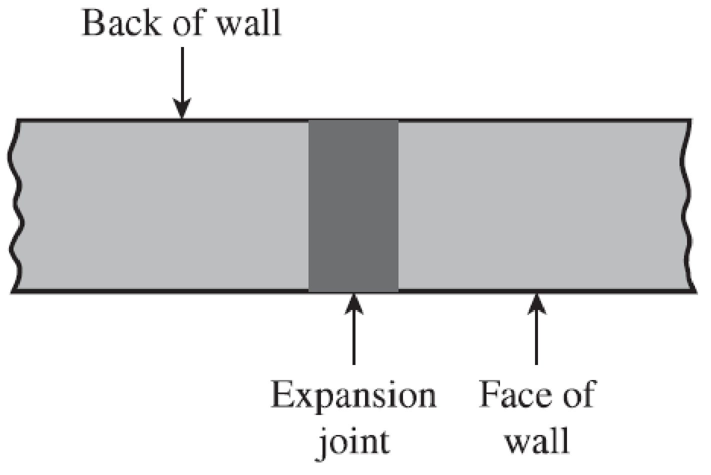
- ✓ These are vertical joints placed in the wall (from top of base slab to the top of wall) that allow the concrete to shrink without noticeable harm.
- ✓ The groove may be 6-8 mm wide, 12-16 mm deep, and they are placed at 8-12 m spacing.



Wall Joints

➢ Expansion Joint:

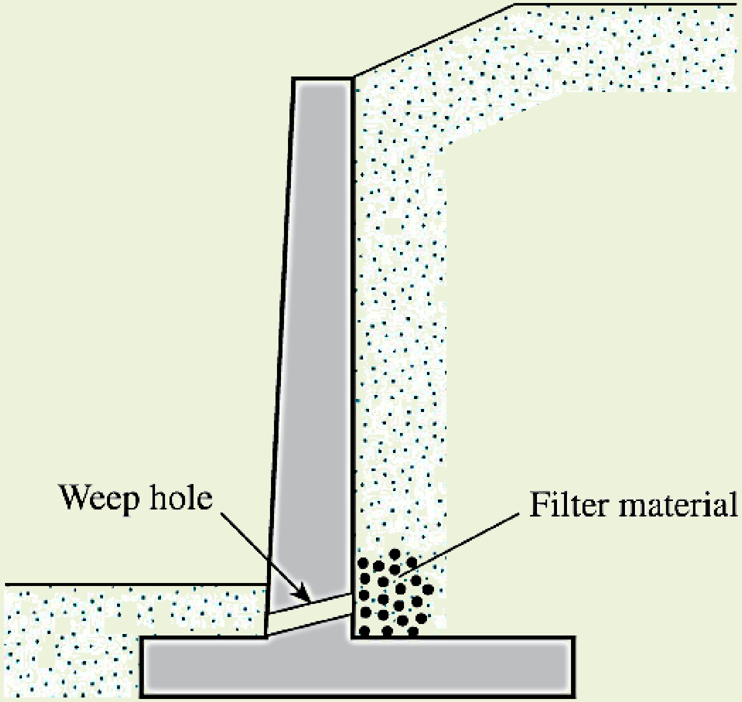
- ✓ These vertical joints are provided in large retaining walls to allow for the expansion of concrete due to temperature changes and they are usually extended from top to bottom of the wall.
  - ✓ These joints may be filled with flexible joint fillers.
  - ✓ Horizontal reinforcing steel bars running across the stem are continuous through all joints. However, the current thinking is that the large resistance to expansion/contraction on the back face of wall from lateral pressure + the friction resistance of the base, these joints are practically useless.

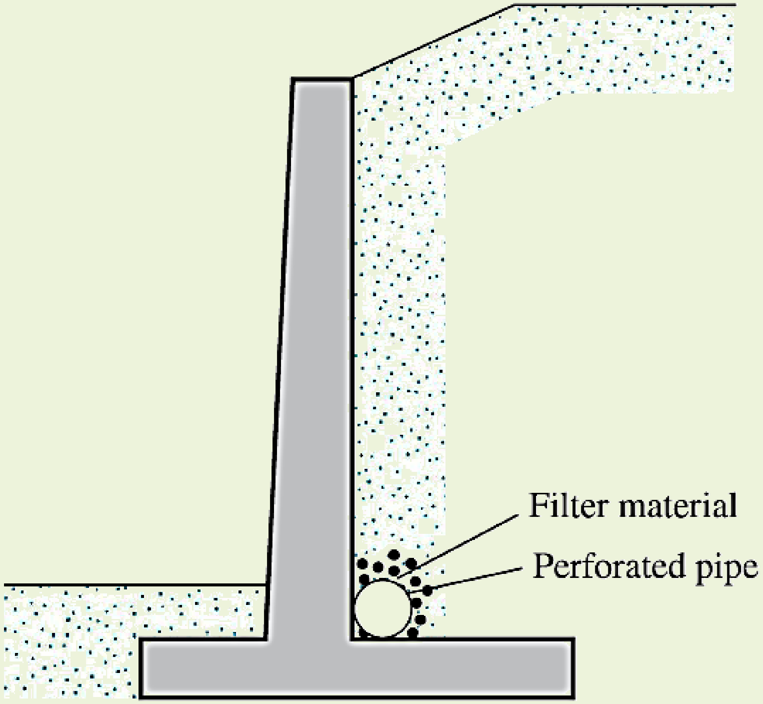


Wall Drainage

- Accumulation of rain water in the back fill results in its saturation, and thus a considerable increase in the earth pressure acting on the wall. This may eventually lead to unstable conditions.

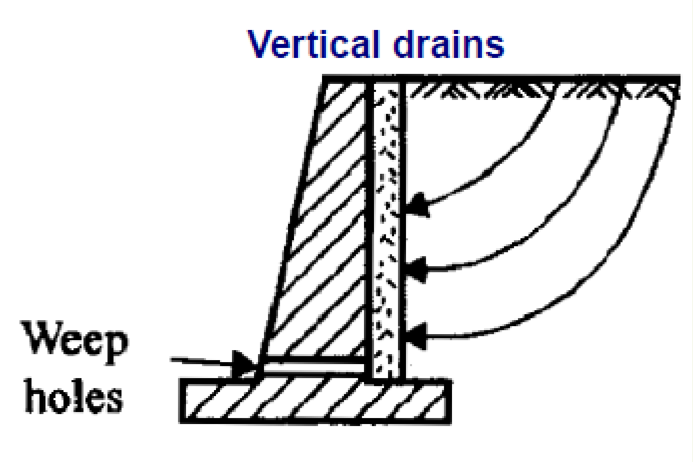
- Two of the options to take care of this problem are the following:
  - ✓ Provision of weep holes w/o geotextile on the back-face of wall
  - ✓ Perforated pipe draining system with filter

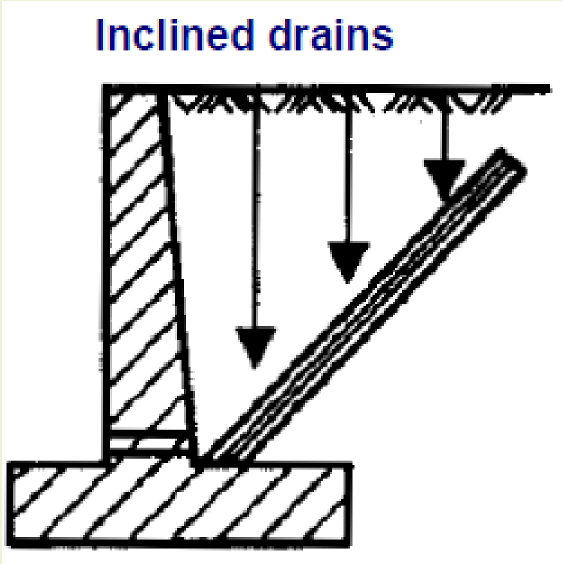


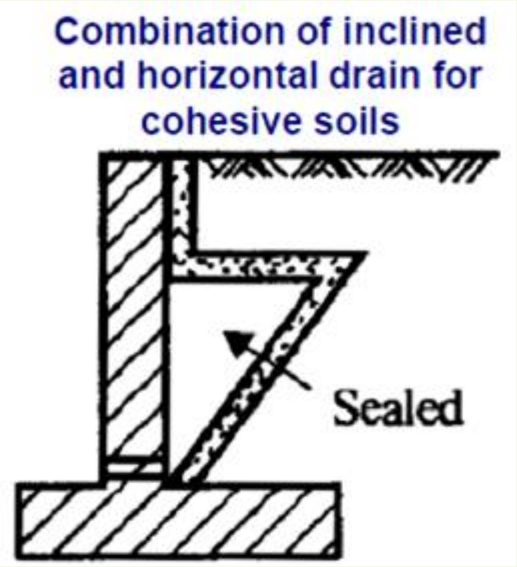


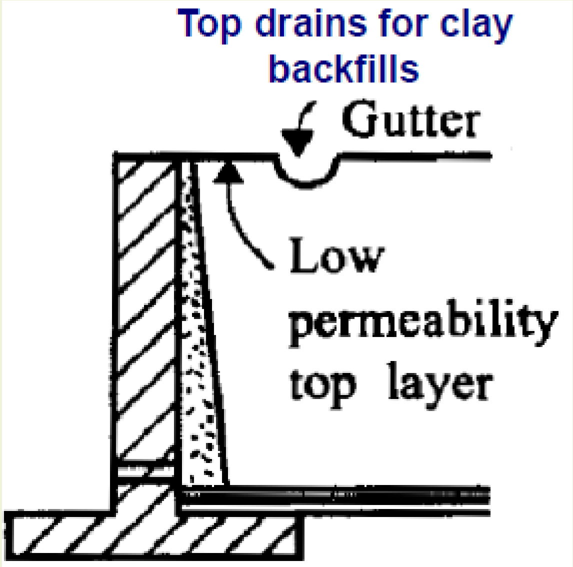
Wall Drainage

- Geotextile material or a thin layer of some other filter may be used on the back face of wall for the full height
  - Prevent the backfill material entering the weep holes and eventually clogging them.









Wall Drainage

➢ Perforated Pipes:

These are provided horizontally along the back face of wall at the bottom of stem. The filter material around the perforated pipe should satisfy the following requirements.

- ✓ The soil to be protected should not wash into the filter

$$\frac{D_{15(Filter)}}{D_{85(Backfill)}} < 5$$

- ✓ Excessive hydraulic pressure head is not created in the soil due to low permeability

$$\frac{D_{15(Filter)}}{D_{15(Backfill)}} > 4$$

Quality Inspection Checklist

CORNERSTONE
WALL SOLUTIONS INC.

The following checklist is a tool to help assure that all aspects of the retaining wall project have been properly constructed. Not all items in this checklist will be applicable for all projects.

Prior To Construction Verify

☐ Site design drawings and specification documents.

☐ Utility location details.

☐ Site elevation grading details.

☐ List of project products and attached specifications Qualified engineered stamped designed package.

☐ During construction site water control plan.

General Excavation

☐ Locate and mark all utilities, etc. before starting excavation.

☐ Call local gas companies before excavation.

☐ Excavation of base leveling pad and wall reinforced zone meets construction drawings and specifications.

☐ Excavated back-cut has been terraced to follow engineer specifications or in accordance to OHSA requirements (site specific exceptions may apply if approved by engineer).

☐ All water issues that have been uncovered due to excavation for the wall have been addressed and taken care of.

Recommended photos taken during construction

1. Trench for Leveling Pad
2. Leveling pad completion
3. At each course of block
4. At each layer of compacted backfill
5. At each layer of installed geogrid
6. The finished project

Quality Inspection Checklist

Site Survey

☐ Locations and elevations of all stakes should match construction drawings.

☐ Each base elevation change should have corresponding stake.

☐ Foundation soils should match or exceed design assumed types and strengths.

☐ Retained soils should match or exceed design assumed types and strengths.

☐ Site soils should not be frozen.

☐ Wall heights do not exceed design.

☐ Slopes above and below wall do not exceed design.

☐ Loading should not exceed design.

☐ Site water conditions should match the design.

Foundation Soils and Preparation

☐ The sub-grade soils meet the minimum requirements as by the specified soil type.

☐ Any sub-grade soils that are unsuitable have been removed and replaced.

☐ The replaced or disturbed sub-grade soils must be compacted to 95% Standard Proctor Density.

☐ All changes have been documented and noted on the construction drawings.

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WALL SOLUTIONS INC.

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Quality Inspection Checklist

Base Leveling Pad

☐ Base leveling pad gravel is as specified in installation guidelines.

☐ The base leveling pad depth and width is in accordance with installation guidelines.

☐ The compaction density meets the requirements of the specifications.

☐ The base leveling pad is level horizontally and back to front.

☐ The minimum burial depth of the base leveling pad at each elevation base change and that the location meet construction drawings.

☐ The base stabilization fabrics installation is in accordance to the installation guidelines.

Drainage/Unit Infill

☐ Drainage gravel should be 1/2 to 3/4 inch clear crush gravel with no fines.

☐ Clear crush gravel should be filled into all unit voids.

☐ Unit voids should be filled no more than one (1) course at a time.

☐ Perforated drainage pipe (if needed) should be sloped properly and daylight at proper intervals.

CORNERSTONE
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The following checklist is a tool to help assure that all aspects of the retaining wall project have been properly constructed. Not all items in this checklist will be applicable for all projects.

Quality Inspection Checklist

Geosynthetic Reinforcements

☐ All reinforcements should be placed in the correct orientation.

☐ Reinforcements should be placed at the proper horizontal levels in the wall.

☐ Reinforcements should be of correct length as shown on design.

☐ Reinforcements should be properly connected to the units.

☐ Reinforcements should be properly tensioned before backfilling retained soils.

☐ Equipment should not be driven on the reinforcement.

☐ Reinforcements installed in curves, corners or other special applications should follow the design details or as per geosynthetic manufacturer's specification.

Geosynthetic Fabrics

☐ Geosynthetic fabrics should be used as per installation guidelines.

Backfill soil

☐ Soils should not be frozen.

☐ Soils should be at ultimate moisture (not too dry or too wet).

☐ Soils should be compacted in lifts not greater than 6-8 inches and to 95% Standard Proctor or greater.

☐ Soils on SRW geogrid layers should be flat and level to the top of the units.

☐ Soils should be placed and compacted to 95% Standard Proctor at the front or toe of wall to the design wall burial depth.

CORNERSTONE WALL SOLUTIONS INC.

The following checklist is a tool to help assure that all aspects of the retaining wall project have been properly constructed. Not all items in this checklist will be applicable for all projects.

Quality Inspection Checklist

Block Units

☐ The delivered and installed units are the same as indicated on the construction drawings and specifications.

☐ The unit size, color, and dimension tolerances meet or exceed the minimum requirements.

☐ Units are level side to side and front to back.

☐ Units are placed tightly to each other.

☐ Units setback and alignment should be checked and corrected on each row.

☐ All units are sound and free of cracks or other defects.

☐ All unit connectors should be properly engaged.

Top of Wall Units

☐ Cap units as per design.

☐ Capping units should be adhered to the last row of units using SRW adhesives and with adequate surface adhesive coverage.

Above and Below Wall Finish Grading

☐ Final grades should meet design plans heights and tolerance.

☐ All grades, slope lengths and drainage swales should be in accordance to the design.

☐ Temporary erosion controls should be in place until final surface treatments have been established.

CORNERSTONE
WALL SOLUTIONS INC.

The following checklist is a tool to help assure that all aspects of the retaining wall project have been properly constructed. Not all items in this checklist will be applicable for all projects.

Control Measures

- **Wall Cracks**
  - ❖ Cracks or fissures appear in the retaining wall structure due to internal or external factors. Causes include uneven foundation settlement, temperature-induced expansion and contraction, poor construction quality, and material aging or deterioration.

Control Measures

- **Wall Cracks**
  - Cracks or fissures appear in the retaining wall structure due to internal or external factors. Causes include uneven foundation settlement, temperature-induced expansion and contraction, poor construction quality, and material aging or deterioration.
- **Control measures**
  - **Monitor the cracks**, recording their width, length, and depth to assess their development.
  - For **surface cracks, use sealants or waterproof coatings** to prevent moisture intrusion.
  - For **deeper cracks, use chemical or cement grouting** to fill and reinforce the structure.
  - For **cracks affecting structural safety, increase support or alter the structural form**, such as using anchor reinforcement, cast-in-place reinforced concrete panels, or lattice beam supports.

Control Measures

- **Local deformation**
  - ❖ Structural shape and size change, causing wall bulging due to external loads (soil pressure, water pressure) and internal factors (material aging, temperature changes). Causes include abrupt soil pressure changes, material expansion or contraction from temperature changes, increased water pressure eroding the wall, and inadequate concrete compaction during construction.

Control Measures

- **Local deformation**
  - ❖ Structural shape and size change, causing wall bulging due to external loads (soil pressure, water pressure) and internal factors (material aging, temperature changes). Causes include abrupt soil pressure changes, material expansion or contraction from temperature changes, increased water pressure eroding the wall, and inadequate concrete compaction during construction.
- **Control Measures**
  - ❖ **Improve the drainage system** to reduce water pressure on the retaining wall.
  - ❖ **Install appropriate pressure relief structures** behind the wall, such as drainage trenches, to reduce soil pressure.
  - ❖ **For aged or deteriorated materials, remove the deformed wall sections and rebuild**, adding a coping beam to enhance overall performance.

Control Measures

- **Wall Displacement**
  - ❖ The retaining wall moves relative to its original position due to reduced sliding resistance under soil and water pressure. Causes include poor drainage leading to saturated soil and increased lateral pressure, environmental effects like rainwater infiltration and freeze-thaw erosion, or chemical degradation causing concrete to weaken.

Control Measures

- **Wall Displacement**
  - The retaining wall moves relative to its original position due to reduced sliding resistance under soil and water pressure. Causes include poor drainage leading to saturated soil and increased lateral pressure, environmental effects like rainwater infiltration and freeze-thaw erosion, or chemical degradation causing concrete to weaken.
- **Control measures**
  - **Set temporary supports** to stabilize the retaining wall until the cause of displacement is addressed.
  - **Remove excess load from the top or back** of the wall.
  - Reinforce the structure by adding anchors, supports, or using buttresses or cantilever piles to prevent collapse.

Control Measures

- **Wall Settlement**
  - ❖ The retaining wall sinks vertically relative to its original position due to reduced foundation soil strength. Causes include insufficient foundation bearing capacity, excessive self-weight or upper load, uneven foundation settlement, and changes in groundwater levels.

Control Measures

- **Wall Settlement**
  - The retaining wall sinks vertically relative to its original position due to reduced foundation soil strength. Causes include insufficient foundation bearing capacity, excessive self-weight or upper load, uneven foundation settlement, and changes in groundwater levels.
- **Control measures**
  - **Remove some soil or redistribute soil load** to reduce the load on the wall.
  - **Improve the drainage system to prevent water accumulation** near the wall, reducing soil saturation and lateral pressure.
  - **Use deep mixing or pressure grouting to reinforce the foundation**.
  - Increase the thickness or height of the wall, or use cast-in-place reinforced concrete slabs combined with support columns to enhance the structure.

Control Measures

- **Wall Collapse**
  - ❖ Complete loss of structural stability, resulting in severe damage and collapse of the retaining wall. Causes include insufficient foundation bearing capacity, drainage system failure, design and construction defects, overload, and natural disasters.
- **Control measures**
  - ❖ **In cases of severe damage, the only solution is to demolish the entire wall and rebuild a new retaining wall**.

Quality Assurance Statements

General (all Retaining Walls):

Check that the following items have been addressed:

- ☐ 1. Reviewed requirements of the governing jurisdiction, and documented all other codes, specifications, and guidelines used.
- ☐ 2. Established design criteria based on applicable codes and confirmed criteria with owner.
- ☐ 3. Completed a site assessment to determine site factors to be incorporated into the Retaining Wall design and construction.
- ☐ 4. Conducted geotechnical investigation to determine site conditions and appropriate geotechnical parameters for analysis and design.
- ☐ 5. Determined external loading conditions (for example, traffic and construction surcharge loads, potential scour, or flooding).
- ☐ 6. Provided lateral earth pressures recommendations for static and seismic loading (these will vary based on the type of wall used).
- ☐ 7. Analyzed static global stability of slope – minimum factor of safety >1.5 for N! cases where N is the number of terraces
- ☐ 8. Analyzed seismic global stability of slope, if applicable – minimum factor of safety 1.1 or acceptable wall displacement
- ☐ 9. Assessed liquefaction potential (provided mitigation measures, if applicable).
- ☐ 10. Provided recommendations for general site and wall drainage.
- ☐ 11. Provided recommendations for erosion protection, Slope Protection/Wall Facing.
- ☐ 12. Assessed the potential impact of wall construction on the slopes above and below the wall.
- ☐ 13. Assessed the potential impact of the wall on adjacent structures.

Quality Assurance Statements

Gravity Walls:

Check that the following items have been addressed:

- ☐ 1. Analyzed for overturning, sliding, and bearing capacity under static conditions.
- ☐ 2. Analyzed for overturning, sliding, and bearing capacity under seismic conditions, if applicable.
- ☐ 3. Completed internal design of the wall (structural design).
- ☐ 4. Detailed an adequate drainage system.
- ☐ 5. Provided appropriate information and guidance for wall construction, including placement specifications, temporary slopes, drainage works, quality control requirements.

Quality Assurance Statements

Stacked Rock Walls:

Check that the following items have been addressed:

- ☐ 1. Analyzed for overturning, sliding, and bearing capacity under static conditions.
- ☐ 2. Analyzed internal stability, including sliding between rocks at different heights within the wall.
- ☐ 3. Analyzed for overturning, sliding, and bearing capacity under seismic conditions, if applicable.
- ☐ 4. Detailed an adequate drainage system.
- ☐ 5. Demonstrated by previous performance or laboratory testing that the rock proposed for use in the wall will be durable.
- ☐ 6. Provided appropriate information and guidance for wall construction, including placement specifications, rock sizes/weights and stacking requirements, temporary slopes, drainage works, quality control requirements.

Quality Assurance Statements

Mechanically Stabilized Earth Walls:

Check that the following items have been addressed:

- ☐ 1. Analyzed for overturning, sliding, and bearing capacity and internal stability under static conditions.
- ☐ 2. Analyzed for overturning, sliding, and bearing capacity and internal stability under seismic conditions, if applicable.
- ☐ 3. Analyzed the adequacy of the wall facing to withstand applicable loads, including the loads from connections to soil reinforcement.
- ☐ 4. Provided specifications for soil reinforcement.
- ☐ 5. Confirmed that minimum soil reinforcement length is 70% of the wall height, or provided justification for alternate length.
- ☐ 6. Detailed an adequate drainage system.
- ☐ 7. Provided appropriate information and guidance for wall construction, including placement specifications, temporary slopes, drainage works, quality control requirements.

Quality Assurance Statements

Reinforced Concrete Cantilever Retaining Walls:

Check that the following items have been addressed:

- ☐ 1. Analyzed for overturning, sliding, and bearing capacity under static conditions.
- ☐ 2. Analyzed for overturning, sliding, and bearing capacity under seismic conditions, if applicable.
- ☐ 3. Completed internal design of the wall (structural design).
- ☐ 4. Detailed an adequate drainage system.
- ☐ 5. Provided appropriate information and guidance for wall construction, including placement specifications, temporary slopes, drainage works, quality control requirements.

Final Submittals

Submittals:

Check that the following items have been addressed:

- ☐ 1. Site plan showing wall location; wall footprint; existing and proposed ground slopes behind and in front of wall; locations of roads, structures, utilities, and all other facilities in the vicinity of the wall; and locations of the wall foundation drainage and other appurtenant drains, including associated discharge locations.
- ☐ 2. Profile along the length of the wall showing variations in wall height, fill height behind the wall, invert elevations of wall foundation drains, and all other features that are included in the design or in close proximity to the wall.
- ☐ 3. Cross-section showing typical wall details, including wall batter, foundation preparation, leveling pad details, drainage provisions, erosion protection of exposed slopes above the wall, guardrail details (if required), and other features that are included in the wall design.
- ☐ 4. Specifications for backfill and retained soil gradation and all other materials to be incorporated into the Retaining Wall (i.e., geosynthetics, concrete, anchors, drainage media), placement and compaction requirements, field review and compaction testing to meet stability and performance design requirements, drains, erosion control during construction, and concrete, reinforcement, and other structural components.
- ☐ 5. Monitoring and maintenance plan, if applicable.

Field Reviews:

Check that the following item has been addressed:

- ☐ 1. The obligation for field reviews as per Bylaw 14(b)(3) has been fulfilled to ascertain whether the implementation or construction of the work substantially complies in all material respects with the design.

Allowable Specific Tolerances

- **As per codal provisions**

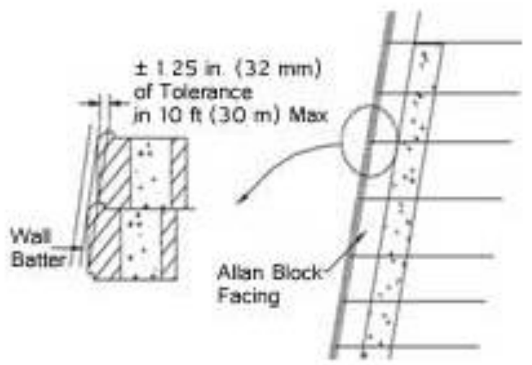

Figure 13: Vertical Control

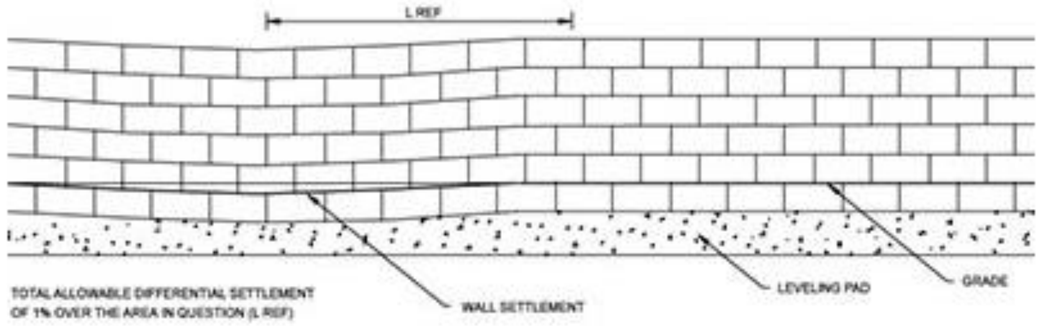

Figure 14: Differential Settlement

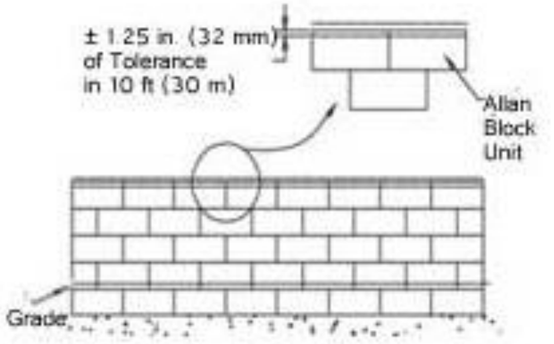

Figure 15: Horizontal Control

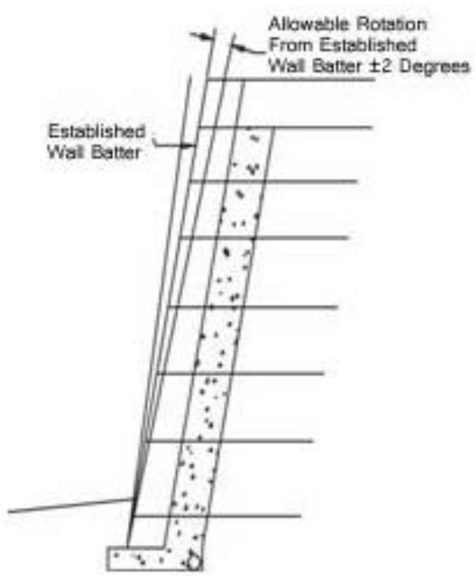

Figure 16: Rotation

References and Acknowledgments to Open Sources

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