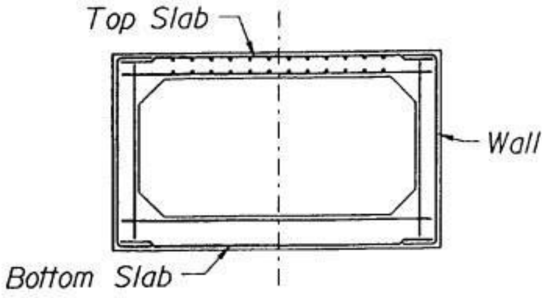


i. The length of wing walls shall be sufficient to eliminate any tendency of the embankment slope to slip into the stream.
ii. Construction joint between abutment and wing wall shall be provided to avoid overstressing at the junction due to differential settlement.
iii. The bearing shall be of reinforced bitumen laminated Kraft paper conforming to IS 1938. While concreting the slabs, care shall be taken to prevent the bearing material from being displaced.
iv. All space between foundation, masonry or concrete and the sides of excavation shall be refilled to the original surface in layers not exceeding 150 mm compacted thickness.
v. The backfill material around the structure shall be of granular type having plasticity index and liquid limit not exceeding 20 and 40 respectively. The fill material shall be deposited in horizontal layers not exceeding 200 mm compacted thickness.
vi. If the height and abutment and return over bed level is more than 2 m weep hole shall be provided 150 mm above low water level or ground level whichever is higher. In case of concrete/ masonry, around d the structure shall be of granular type having plasticity index and liquid limit not exceeding 20 and 40 respectively. The fill materials shall weep holes of 150 mm dia or 80 X 150 mm size in 1:20 slope shall be provided at 1 metre interval both horizontally and vertically. Refer IRC 40
vii. Water Spout shall be provided for large span culverts. For 5 and 6 m span, one water spout of 100 mm diameter shall be provided in the centre of slab on either side of the deck.
viii. In case of stone masonry, coarse rubble masonry is stipulated.
ix. Face stones shall be hammer dressed on all beds and joints so as to give them approximately rectangular shapes.
x. The hearting or interior filling of the wall shall consist of flat bedded stone carefully laid on their proper beds in mortar. While the use of chips shall be restricted to the filling of interstices between the adjacent stones in hearting and these shall not exceed 15 % of the quantity of masonry.
xi. Bond stones or headers shall be at 1.5 m or 1.8 m apart clears in every course. The headers shall overlap at least by 150 mm

xii. Face stone shall tail into the work for not less than their heights and at least one third of the stones shall tail into the work for a length not less than twice the height.

xiii. The face joint shall not be more than 20 mm thick.

Skew Slabs

If a road alignment crosses a river or other obstruction at an inclination different from 90^0, a skew crossing may be necessary. The inclination of the centreline of traffic to the normal to the centreline of the river in case of a river bridge or other corresponding obstruction is called the skew angle. Bottom reinforcement is to be placed perpendicular and parallel to the supports. Since the main bars in such an arrangement cut the free edge at an angle and are ineffective in resisting the bending moment at the centre of the free edge for want of adequate anchorage, extra steel rods are to be provided near the free edge parallel to the edge for a width sufficient to provide anchorage for the main bars. To reinforcement is particularly needed at the obtuse angled corner and the centre of the free edge. Short bars parallel to the long diagonal are provided at the obtuse angled corner. Transverse bars are provided parallel to the supports.

Wing walls and Hand rails

Wing walls may be either splayed at an angle of 45^0 or taken perpendicular to the abutment. If spayed, the height of wall will reduce as it extends away from the abutment. The splayed wing wall is particularly suited for high embankment. If the wall is at right angles to the abutment, it is known as return type wing wall or simply return wall. The earth filling behind the abutments and wings should be specially consolidated in order to avoid an excessive depression immediately clear of the bridge deck. A porous backfill of about 500 mm thickness should be provided immediately behind the abutment.

Hand rails or parapets should be provided over the kerbs on either side of the road over the deck slab. For small culverts, parapet walls of height 750mm will be adequate. For spans above 4m, a combination of R.C. posts and rails may be more pleasing.

9.2.25 Causeways and Submersible Bridges.

A causeway is a small submersible structure, which allows flood to pass over it.

Flush causeway: It is a paved dip built to cross a shallow water course. The top level shall be at the same level as that of the bed of the water course.

A low level or vented causeway: This is a structure provided with a few openings comprising of pipes, small span slabs or small arches etc. with a raised road top level to a moderate height upto 1.5 m height.

A high-level causeway: This is a submersible structure provided with larger openings comprising of a simply supported /continuous RCC slab or multiple arches or boxes and a raised road top level to a reasonable height 1.5 m to 3 m. The RCC Slab may be supported over a series of short piers (Masonry/ CC)

To avoid the heading up of water on the upstream side which results in producing high velocities leading to structural failure and out flanking, the top level of the causeway shall be kept as low as possible. The water way provided in the causeway shall not be less than 30 % of the area of the stream, measured between the stream bed level and the proposed top level of the road.The details for culvert and causeway design shall be referred to in IRC SP 20-2002.

9.2.26 Drainage Aspect

Drainage is the most important aspect for proper upkeep of roads. Strength and life of the pavement greatly depends on the moisture present in and below the pavement. Performance and durability of the pavement is inversely proportional to be quantum and duration of the presence of moisture in the road structure. Failure of bituminous pavement in rainy season is mainly due to the action of moisture on the various components of pavement.

9.2.26.1 Side Drains

Side drain must be provided to collect surface water from the roadway and lead to an outlet. It also acts as an outlet for the subsurface drains thereby protecting the base course of the roadway structure from getting saturated/ lost its load bearing capacity. Side drains are designed for open channel flow and generally provided on both sides of the road. Road drains in hilly terrain are constructed to parabolic, trapezoidal, triangular, V-shaped, Kerb and channel or U- shaped cross sections.IRC SP 20 and IRC 42 may be referred for details and design of drains.

9.2.26.2 Entry of Moisture

Moisture gets into the road structure through various sources like-rain water falling on the pavement, water flowing on the surface, moisture getting into pavement through cracks in the pavement, water seeping into the pavement through uncovered soil, moisture from below rising by capillary action, water getting in to the pavement by way of spring flow and pipe leaks and stagnation of water due to flooding or other reasons.

a) Action of Moisture on Pavement Components

Once moisture finds entry into the pavement structure it acts in various ways. It saturates the soil which reduces its bearing capacity and the pavement starts sinking. Moisture present in the WBM loosens the interlocking of the metal pieces and they move from their original position disturbing the upper layers. Moisture present in the bituminous courses reduces the adhesive property of the bitumen which results in to stripping of the aggregate. Such loose metal under the moving rubber tyres start grinding the surface. This grinding results in to further loosening of other aggregates in the pavement and with the sucking and churning effect of traffic the whole surface starts raveling. Water accumulated in depressions and pot holes continuously supplies moisture to lower layers weakening the

whole structure for the pavement. Prolonged contact of moisture affects all the components of the pavement.

b) Dealing with Moisture

Best approach to tackle the moisture problem lies in totally eliminating the water contact. However it is very difficult to have such an environment. So attempt should be to minimize the quantity of moisture entry and to reduce the duration of the moisture contact with pavement. This can be achieved by providing efficient drainage system to quickly carry away the surface water and quickly removing the subsoil water that has found entry into the structure. Also create such situation that the entry points of moisture penetration are effectively sealed. Problem of flooding on the road is dealt separately below.

9.2.24.3 For New Road

i. A drainage layer having good permeability with inverted choke should be provided below the pavement. Thickness should be minimum 150mm.
ii. In locations where water table is high, to prevent entry of soil particles into the drainage layer/capillary cut off, some capping layer should be provided such as geo-fabric, quarry spall, moorum etc
iii. Drainage layer and GSB should be provided for the full width up to road side gutters and weep holes should be provided at suitable level and suitable intervals in the gutter (Fig.2407 A)
iv. Road side edge of the open gutter should be lower than the edge of the pavement at that location.
v. Built up gutter should have min gradient of 1:400, however 1:300 is preferable. Invert gradient should be checked by third party.
vi. Curb inlets / Drop inlets should be at least 25-30 mm lower than the edge of the pavement. In case of pipe laterals depth of 50mm is preferable.
vii. Built up drains should finally lead to some natural water course or drainage system of sufficient capacity. This should be ensured by some third party inspection.
viii. In case of foot paths, proper edge gully and kerb inlet arrangement should be provided.
ix. Before issue of work order, fresh levels should be taken by the executing staff, invert levels of longitudinal drains and final disposal point should be determined. A working drawing should be prepared for the project and it should be available on the site all the time.
x. At the location of C.D work and bridges provision of one or two conduits cross wise and in the kerb is very useful in laying future utilities.
xi. The formation level shall be prepared so as to get necessary camber/ super elevation/ longitudinal gradient.

xii. Road formation should be at least 300mm higher than the general ground level except where the road passes through cutting. No land development above the road level should be permitted.
xiii. Minimum camber for bituminous surface should be 2.5% however 3% camber would be more desirable.
xiv. Camber should be attempted from the formation itself, and all pavement layers should have the desired camber during construction itself.
xv. Shoulder should have min side slope of 5% and should have good permeability.
xvi. Ancient natural drains are now being converted as pathways/ roads. Hence there shall be a provision for the disposal of rainwater under the road surface. A drain of sufficient capacity at the centre of this pathway shall be provided with a provision to clean it periodically.

9.2.24.4 For Existing Roads

i. When road work is taken for improvement or relaying etc. pot hole filling and camber correction should be done in advance.
ii. Due to creep if the edges of the pavement are higher than the adjoining portion they should either be chopped out or leveling courses should be so adjusted that the finished surface is at desired camber.
iii. Existing drainage system should be thoroughly checked by some experienced and responsible person. Any deficiencies noted, modifications suggested etc should be duly undertaken on priority, preferably before main work of pavement is taken up.
iv. Leaking pipes, spring flows, chronic damage spots and cracked up portions should be investigated and proper corrective measures should be taken before the main work.
v. Edge gutter/gully, inlet etc should be examined for their levels and clearance.
vi. Provision of shoulder drains should be made where soft shoulders exist. Similarly in case of roads in cutting and at chronic spots, provision of subsoil drains should be made.
vii. At the end of the flyovers and ramps water flowing along the slopes should be arrested and diverted to drainage system by providing a slotted/cattle trap type drain at the foot of the slope.
viii. Water flowing through water spouts of the flyovers should be led through suitable pipes to the ground chambers and connected to drainage system.
ix. Wearing coat on the flyover and bridges should be 15 to 20 cm short from the kerbs. The notch formed will serve as a drainage gully. This will avoid stagnation on the bridge decking and avoid damages to wearing coat.

9.3 EARTH RETAINING STRUCTURES

A retaining wall is a structure that retains any material, usually earth and prevents it from sliding or eroding away. It is designed so that to resist the material pressure of the

material that it is holding back. Retaining walls shall be designed to withstand lateral earth and water pressures, the effects of surcharge loads, the self-weight of the wall. Earth pressure is the pressure exerted by the retaining material on the retaining wall. This pressure tends to deflect the wall outward. The types of earth pressures are

- Active earth pressure or earth pressure and
- Passive earth pressure

Active earth pressure tends to deflect the wall away from the backfill.

Following conditions must be satisfied for stability of wall (IS:456-2000).

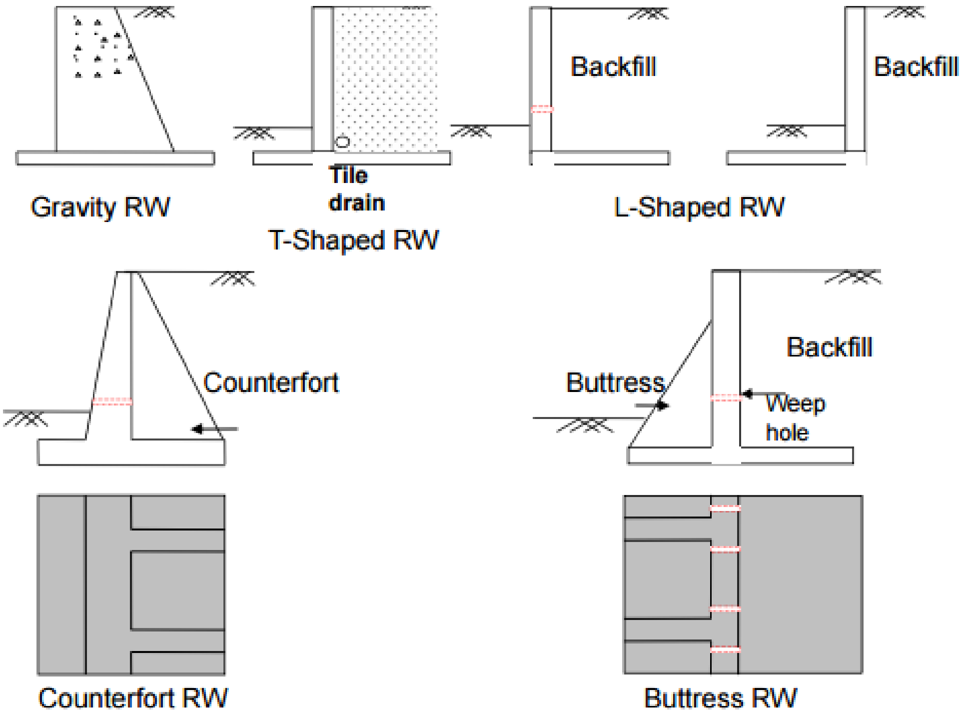
- It should not overturn
- It should not slide
- It should not subside, i.e Max. pressure at the toe should not exceed the safe bearing capacity of the soil under working condition

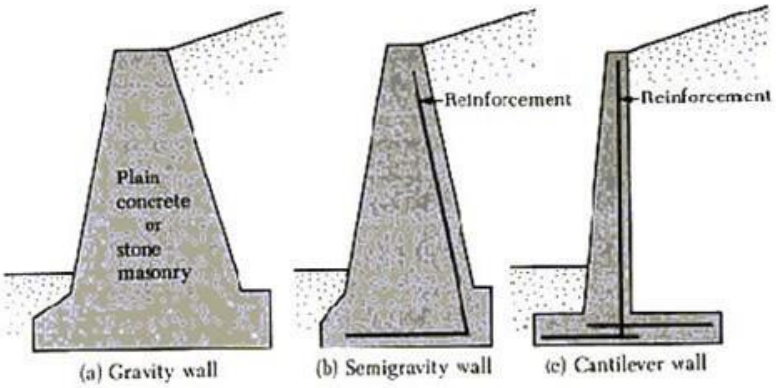
Retaining walls shall be designed for a service life based on consideration of the potential long-term effects of material deterioration on each of the material components comprising the wall. Permanent retaining walls should be designed for a minimum service life of 50 years. Permanent walls shall be designed to retain an aesthetically pleasing appearance, and be essentially maintenance free throughout their design service life.

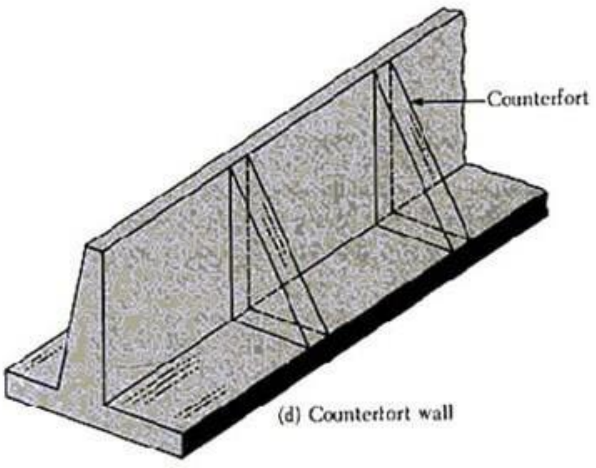
9.3.1 Types of Retaining Walls

An earth retaining structure can be considered to have the following types:

- Gravity Retaining walls-Masonry or Plain concrete
- Concrete Cantilever retaining wall (Inverted T and L)
- Counter-fort/ Buttress retaining wall
- Precast concrete retaining wall
- Sheet piling
- Reinforced Soil Walls
- Soil Nailing
- Gabion walls
- Anchored Retaining walls



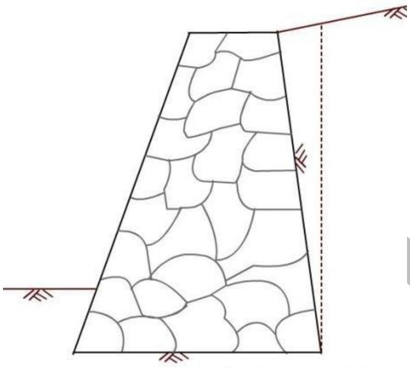




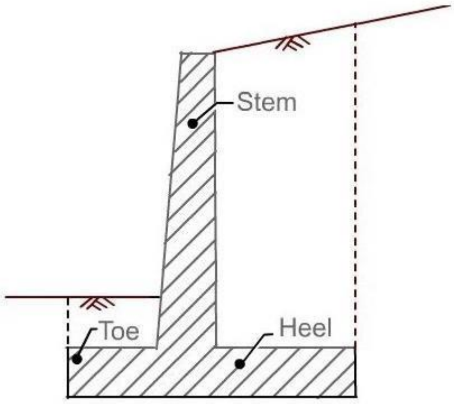
Gravity walls derive their capacity to resist lateral loads through dead weight of the wall. The gravity wall type includes rigid gravity walls, mechanically stabilized earth (MSE) walls, and prefabricated modular gravity walls. Semi-gravity walls are similar to gravity walls, except they rely on their structural components to mobilize the dead weight of

backfill to derive their capacity to resist lateral loads. Non-gravity cantilevered walls rely on structural components of the wall partially embedded in foundation material to mobilize passive resistance to resist lateral loads. Anchored walls derive their capacity to resist lateral loads by their structural components being restrained by tension elements connected to anchors and possibly additionally by partial embedment of their structural components into foundation material. The anchors may be ground anchors (tiebacks), passive concrete anchors, passive pile anchors, or pile group anchors. The ground anchors are connected directly to the wall structural components whereas the other type anchors are connected to the wall structural components through tie rods. Earth can also be retained by using geocells for preventing sliding of earth. (Refer 9.4)

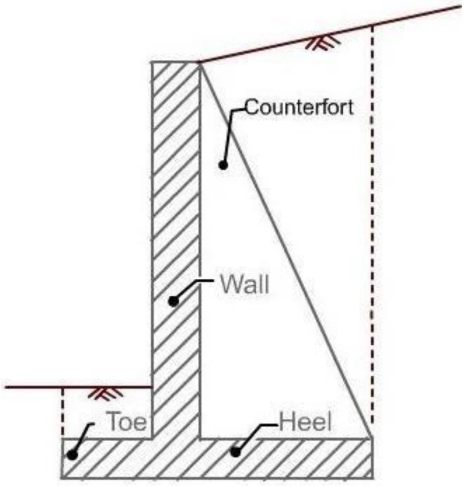
Selection of appropriate wall type is based on an assessment of the design loading, depth to adequate foundation support, presence of deleterious environmental factors, physical constraints of the site, cross-sectional geometry of the site both existing and planned, settlement potential, desired aesthetics, constructability, maintenance, and cost.



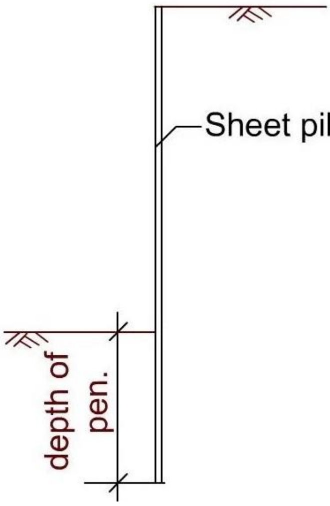
Masonry retaining wall



Cantilever retaining wall

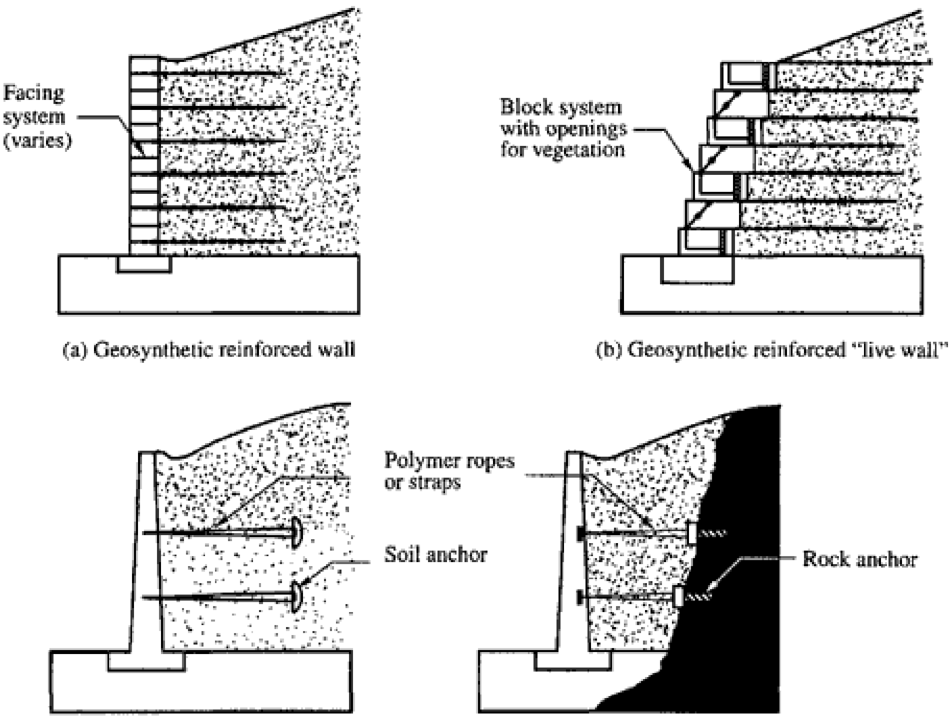


Counterfort retaining wall



Sheet pile walls

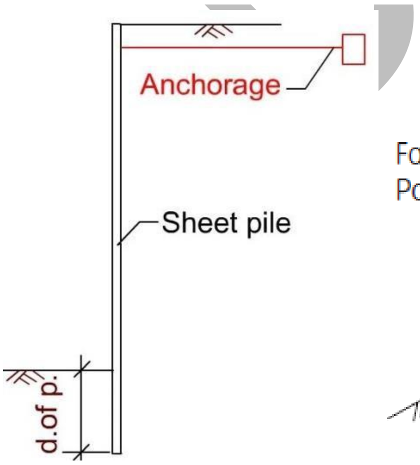
Precast concrete walls

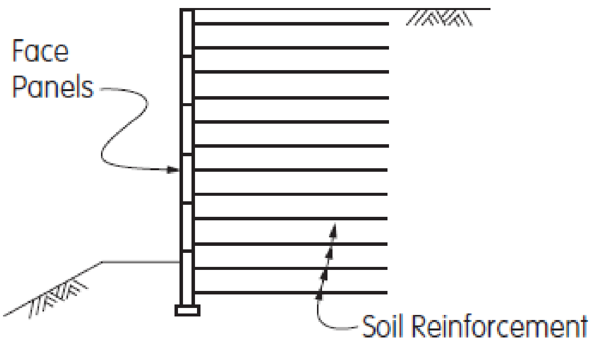


(a) Geosynthetic reinforced wall

(b) Geosynthetic reinforced "live wall"

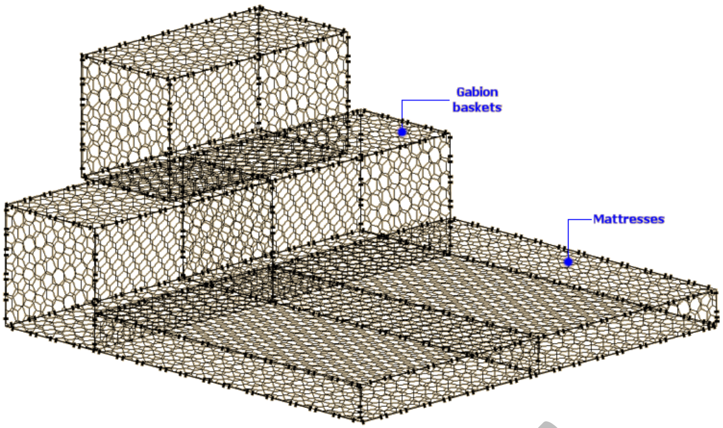
(c) Future types of geosynthetic anchorage





Anchored retaining walls

Soil Reinforcement



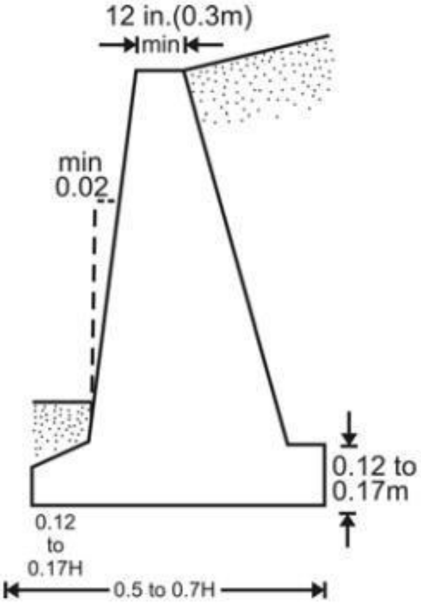
Gabion Walls

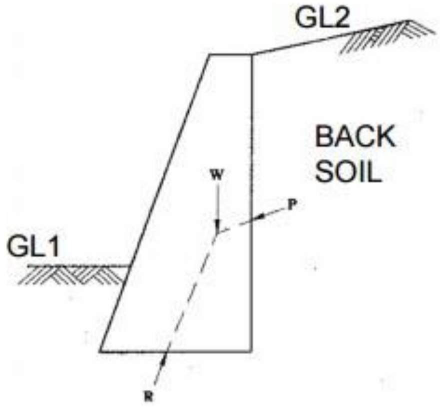
9.3.2 Gravity Retaining Walls

Rigid gravity walls may be constructed of stone masonry, unreinforced concrete, or reinforced concrete. These walls can be used in both cut and fill applications. They are generally not used when deep foundations are required. They are most economical at low wall heights.

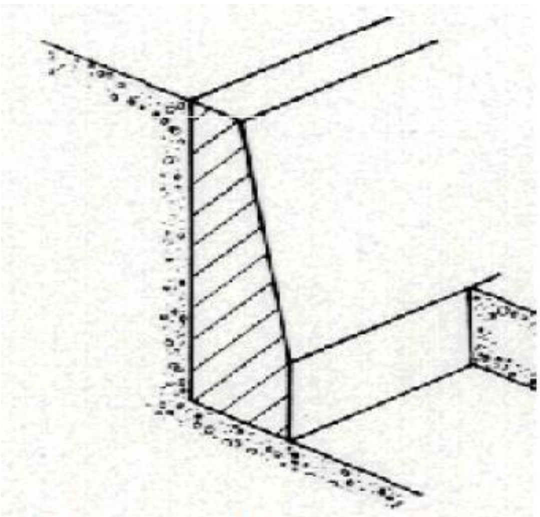
It is that type of retaining wall that relies on their huge weight to retain the material behind it and achieve stability against failures. In case of masonry retaining wall, the thickness of wall increases with height because masonry resists the lateral pressure by its weight. Thus it is also called gravity retaining wall. Gravity Retaining Wall can be constructed from concrete, stone or even brick masonry. Gravity retaining walls are much thicker in section. Geometry of these walls also help them to maintain the stability. Mass concrete walls are suitable for retained heights of up to 3 m. The cross section shape of the wall is affected by stability, the use of space in front of the wall, the required wall appearance and the method of construction.

The soil can be retained by dry rubble retaining wall having adequate base width. The dry rubble may be constructed above a RCC slab and additional RCC belts may be provided at intermediate levels, nearly 2.5 to 3m. If the length of the retaining wall is large, vertical RCC belts may also be provided at 10-15m intervals.

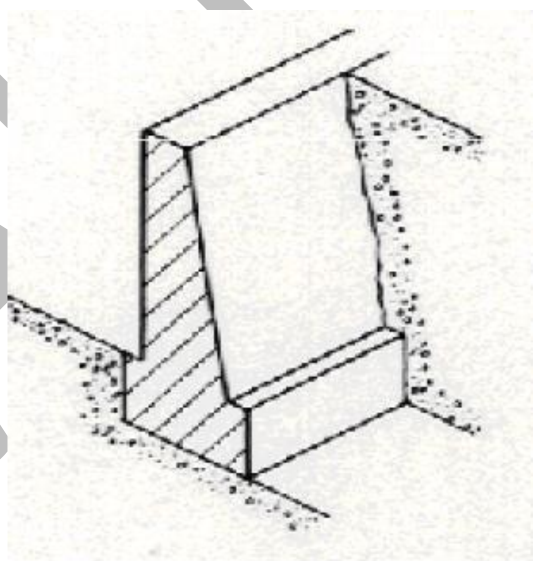




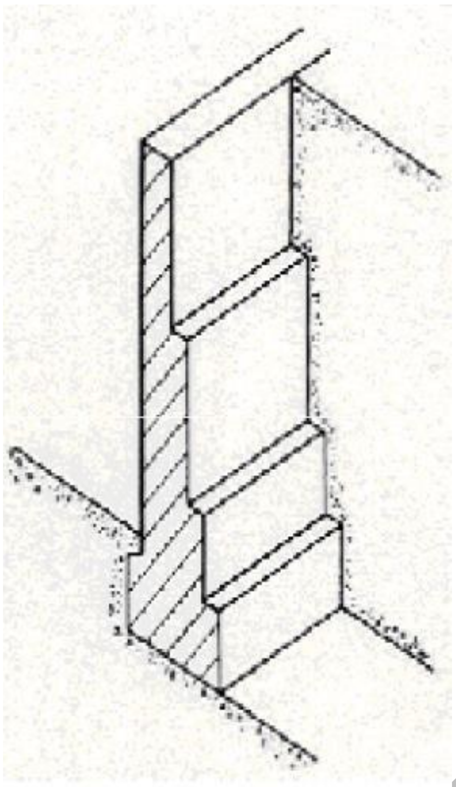
Gravity retaining wall



Mass concrete with battered face.



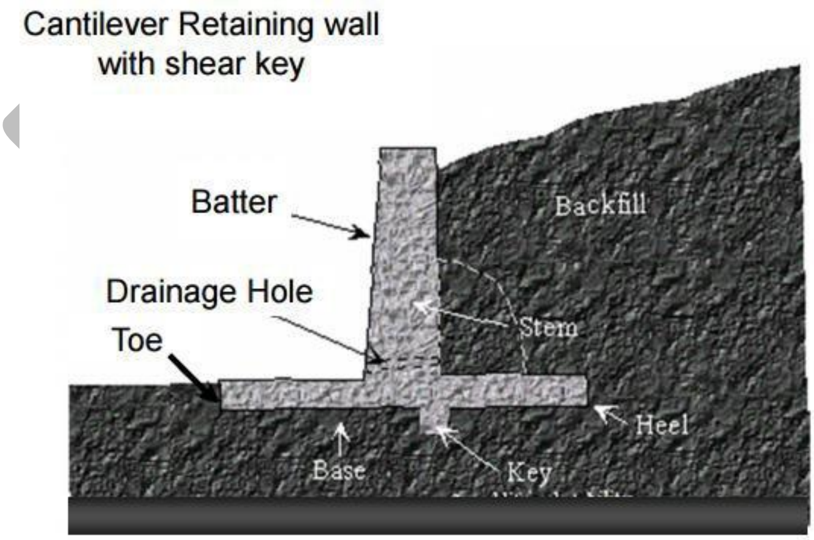
Mass concrete with battered back.

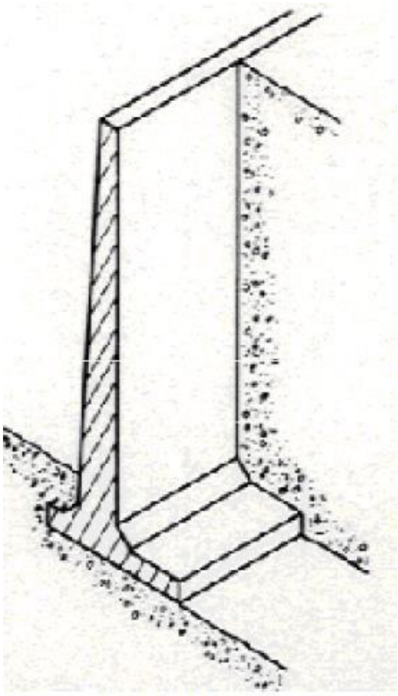


Mass concrete with stepped back.

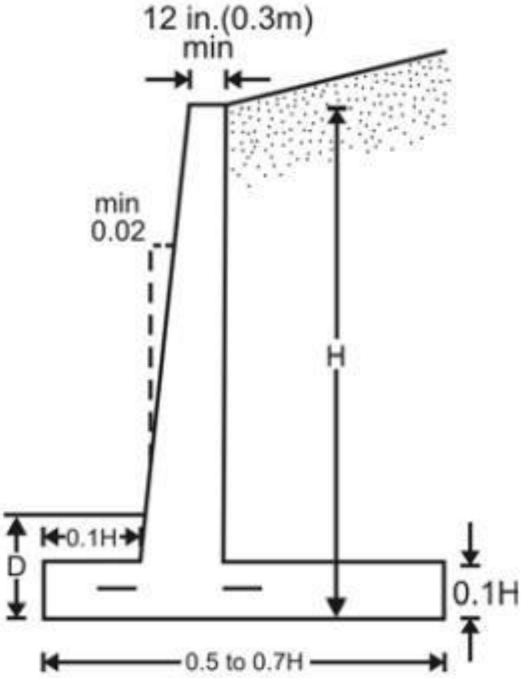
9.3.3 Cantilever Retaining Walls

Cantilever retaining walls are most commonly and widely used type of retaining wall. The following **figure** shows the cantilever retaining wall.





T-shaped walls.



A cantilever retaining wall is one that consists of a wall which is connected to foundation. A cantilever wall holds back a significant amount of soil, so it must be well engineered. They are the most common type used as retaining walls. Cantilever wall rest on a slab foundation. This slab foundation is also loaded by back-fill and thus the weight of the back-fill and surcharge also stabilizes the wall against overturning and sliding.

9.3.3.1 Parts of a Cantilever Retaining Wall and its Actions:

1. Vertical Stem: Vertical stem in cantilever retaining wall resists earth pressure from backfill side and bends like a cantilever. The thickness of cantilever slab is larger at the base of stem and it decreases gradually upwards due to reduction of soil pressure with decrease in depth.

2. Base Slab: The base slab form the foundation of the retaining wall. It consists of a heel slab and the toe slab. The heel slab acts as a horizontal cantilever under the combined action of the weight of the retaining earth from the top and the soil pressure acting from the soffit. The toe slab also acts as a cantilever under the action of the soil pressure acting upward. The stability of the wall is maintained by the weight of the earth fill and on the heel slab together with the self-weight of the structural elements of the retaining wall. Cantilever type retaining walls are suitable upto 6m depth of backfill.

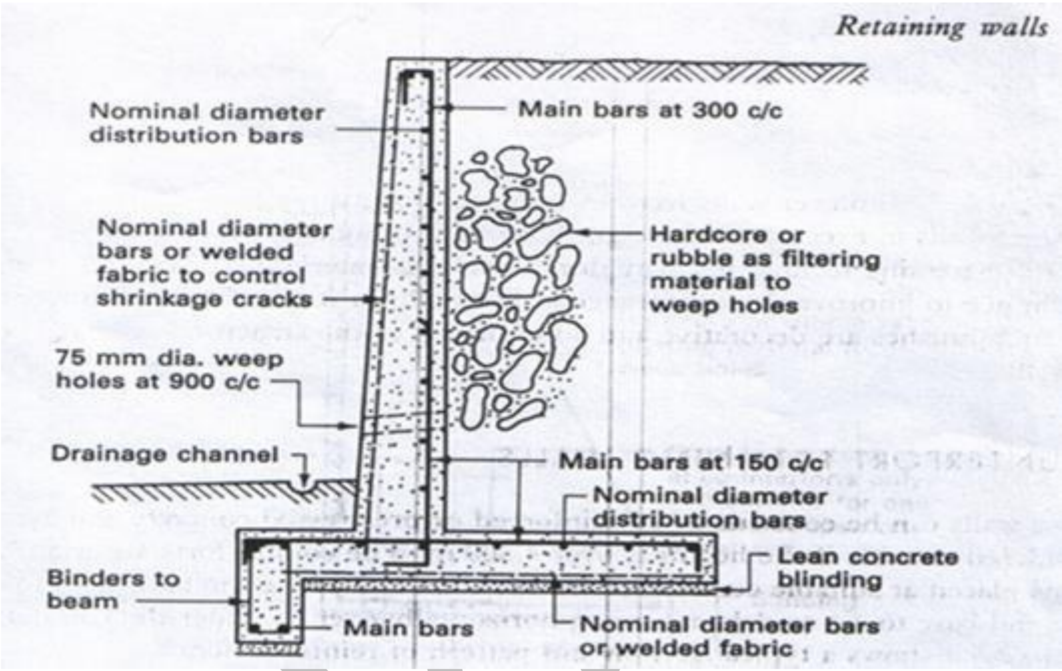
The effect of two forms of earth pressure need to be considered during the process of designing the retaining wall that is:

a. Active Earth Pressure: It is the pressure that at all times are tending to move or overturn the retaining wall

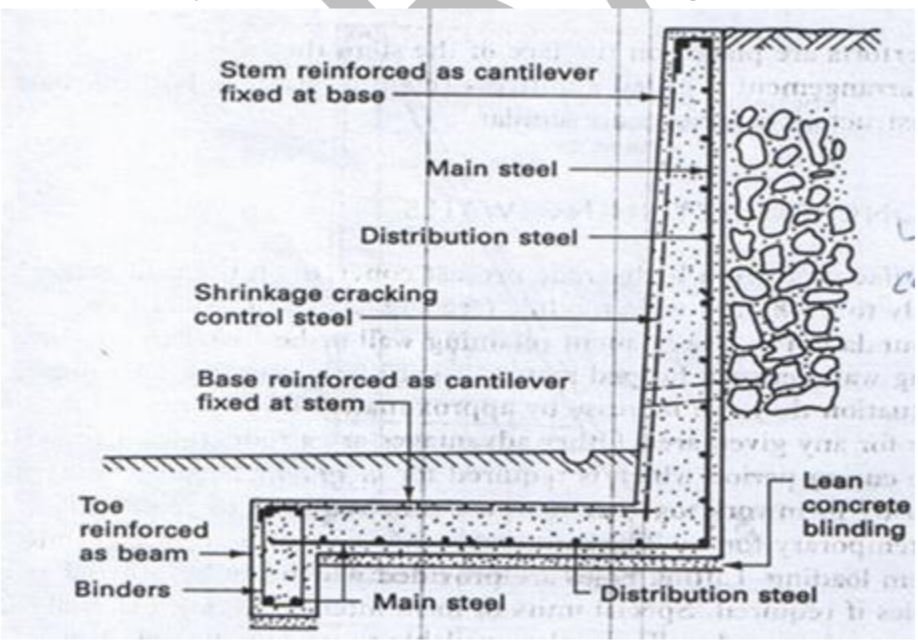
b. Passive Earth Pressure: It is reactionary pressures that will react in the form of a resistance to movement of the wall.

9.3.3.2 Two Basic Form of Cantilever Wall

1) A base with a large heel so that the mass of earth above can be added to the wall for design purposes



If form 1 is not practicable, a cantilever wall with a large toe must be used.



The main steel occurs on the tension face of the wall and nominal steel (0.15% of the cross-sectional area of the wall) is very often included in the opposite face to control the shrinkage which occurs in in-situ concrete work.

9.3.3.3 Cantilever Wall Failure

- Effect of water: Ground water behind a retaining wall, whether static or percolating through a subsoil, can have adverse effects upon the design and stability.
- Slip circle failure: sometimes encountered with cantilever wall in clay soils particularly if there is a heavy surcharge.
- Low quality of material that use in cantilever construction
- Low design reinforcement in cantilever wall.
- Mistake in calculate height of water table, nature & type of soil.
- Subsoil water movements.

9.3.3.4 Identifying Failure of Cantilever Wall

- Cantilever wall be in sloping position.
- Cantilever wall had curve on its surface/wall.
- Crack on wall structure.
- Cantilever wall awashed.

9.3.3.5 Advantages of Cantilever Wall

- Reinforced cantilever walls have an economic height range of 1.200 to 6.000 m; walls in excess of this height have been economically constructed using prestressing techniques.
- Cantilever walls offer an unobstructed open excavation
- Cantilever walls do not require installation of tiebacks below adjacent properties
- Cantilever walls offer a simpler construction procedure as the construction staging is much simpler.

9.3.3.6 Disadvantages of Cantilever Walls:

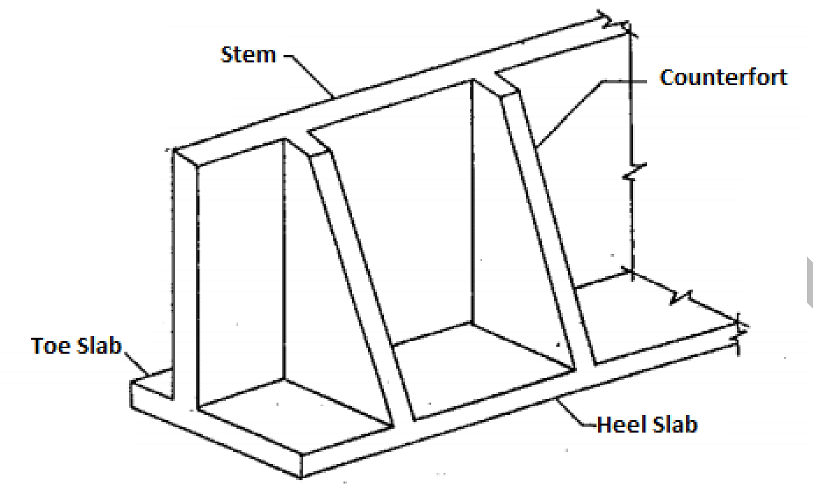
- Maximum excavation for cantilever walls is rather limited, typically to 6m maximum.
- It is generally not recommended to use cantilever walls next to adjacent buildings.
- Control of lateral wall displacements depends on the mobilization of passive earth resistance.
- For deeper cantilever excavations the wall stiffness may have to be considerably increase. This can limit the available space within the excavation.

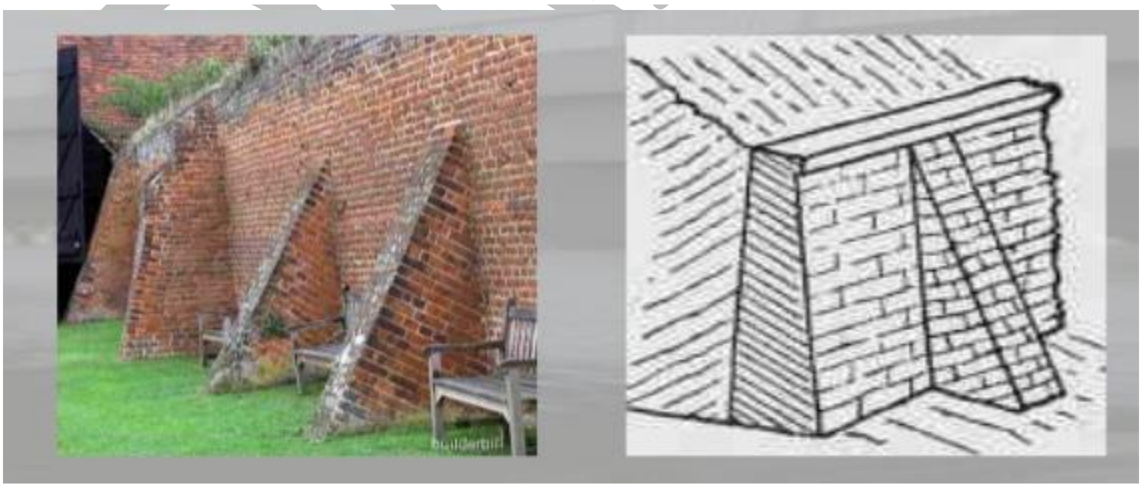
9.3.4 Counterfort and Buttress Walls

These are constructed of reinforced concrete. They can be used in both cut and fill applications. They have relatively narrow base widths. They can be supported by both

shallow and deep foundations. The position of the wall stem relative to the footing can be varied to accommodate right-of-way constraints. These walls can support soundwalls, sign structures, and other highway features.They are most economical at low to medium wall heights. Due to the rigidity of rigid gravity walls and semi-gravity walls they should only be used where their foundations can be designed to limit total and differential settlements to acceptable values.

In this type of retaining wall, counterforts (cantilevers) are provided on the earth side between wall and footing to support the wall, which essentially spans as a continuous one-way slab horizontally. Counterfort walls seldom find application in building construction. A temporary condition in which basement walls may be required to behave as counterfort retaining walls occurs though, if outside fill is placed before the floors are constructed. Under this condition of loading, each interior cross wall and end basement wall can be regarded as a counterfort





Non-gravity cantilevered walls are constructed of vertical structural members consisting of partially embedded soldier piles or continuous sheet piles. Soldier piles may be constructed with driven steel piles, treated timber, precast concrete or steel piles placed in drilled holes and backfilled with concrete or cast-in-place reinforced concrete. Continuous

sheet piles may be constructed with driven precast prestressed concrete sheet piles or steel sheet piles. Soldier piles are faced with either treated timber, reinforced shotcrete, reinforced cast-inplace concrete, precast concrete or metal elements.

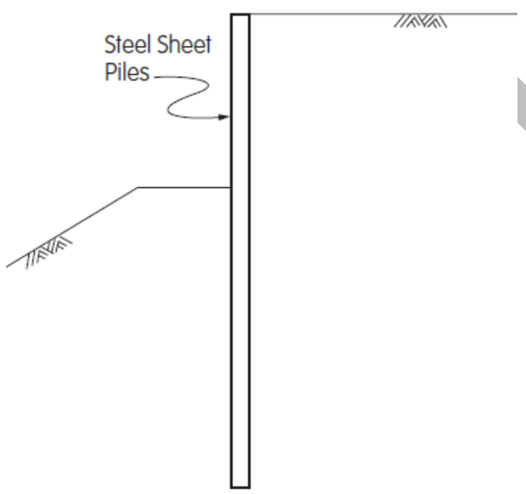
This type wall is suitable for both cut and fill applications but is most suitable for cut applications. Because of the narrow base width of this type wall it is suitable for situations with tight space constraints or right-of-way constraints.

When the height of earth to be retaining exceeds 5m, the bending moment developed in the stem, heel and toe slabs are very large which results in large thickness of structural elements and becomes uneconomical. Thus, counterfort type retaining wall is adopted for larger heights.Counterfort retaining wall consists of a stem, toe slab and heel slab as in case of cantilever retaining wall. But it also consists of counterforts at regular interval which divides the stem. The stem with combination of counterfort behaves like a tee-beam with varying width.

The stem and heel slabs are effectively fixed to counterforts so that the stem bends horizontally between the counterforts due to lateral earth pressure. Thus the thickness of stem and the heel slab is considerably reduced due to the reduction of moment due to fixity of these slabs between counterforts.

Counterfort walls are cantilever walls strengthened with counter forts monolithic with the back of the wall slab and base slab. The counter-forts act as tension stiffeners and connect the wall slab and the base to reduce the bending and shearing stresses. To reduce the bending moments in vertical walls of great height, counterforts are used, spaced at distances from each other equal to or slightly larger than one-half of the height Counter forts are used for high walls with heights greater than 6 m.

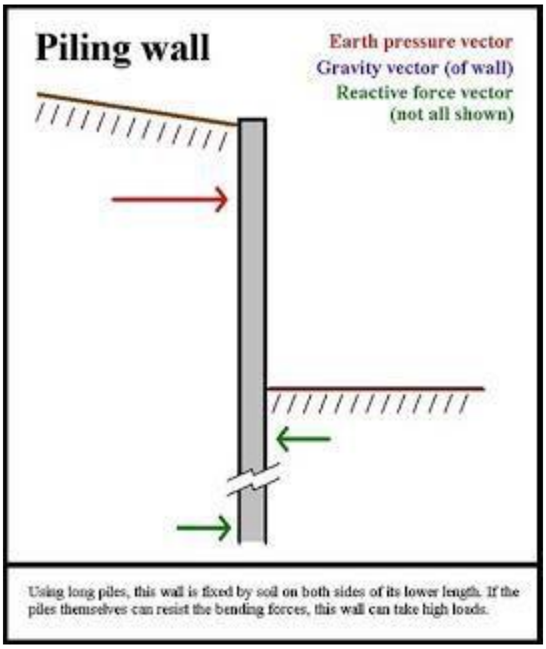
9.3.5 Sheet Piling

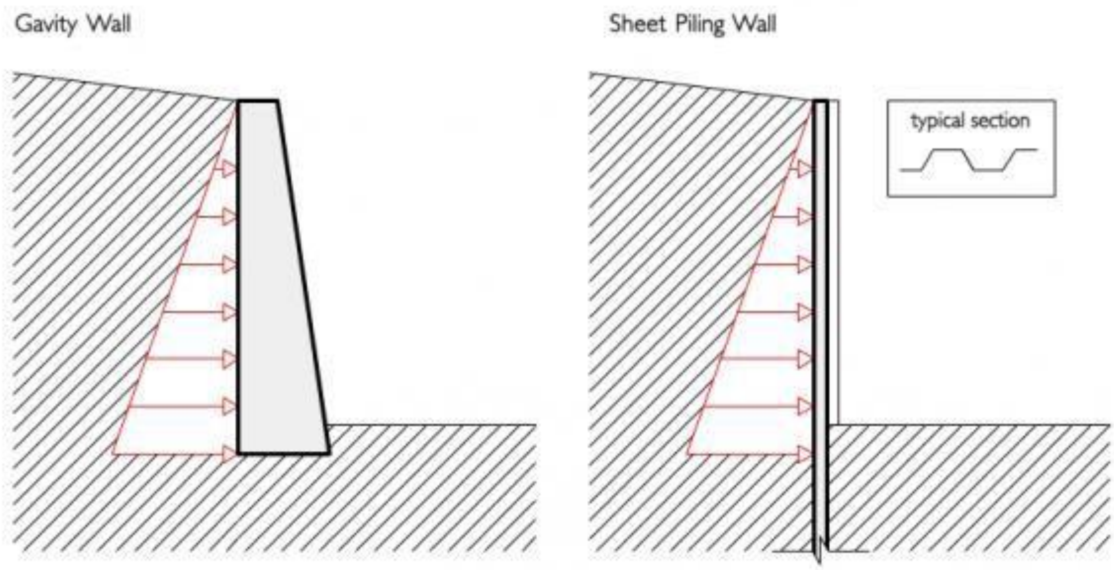


Sheet piling

Steel sheet pile walls are constructed by driving steel sheets into a slope or excavation upto the required depth. Their most common use is within temporary deep

excavations. They are considered to be most economical where retention of higher earth pressures of soft soils is required. It cannot resist very high pressure.





Sheet piling is an earth retention and excavation support technique that retains soil, using steel sheet sections with interlocking edges. Sheet pile walls are constructed by driving prefabricated sections into the ground. Soil conditions may allow for the sections to be vibrated into ground instead of it being hammer driven. The full wall is formed by connecting the joints of adjacent sheet pile sections in sequential installation. Sheet pile walls provide structural resistance by utilizing the full section. Steel sheet piles are most commonly used in deep excavations, although reinforced concrete sheet piles have also being used successfully. They are installed in sequence to design depth along the planned excavation perimeter or seawall alignment. The interlocked sheet piles form a wall for permanent or temporary lateral earth support with reduced groundwater inflow. Anchors can be included to provide additional lateral support if required.

Sheet pile walls have been used to support excavations for below grade parking structures, basements, pump houses and foundations, construct cofferdams, and to construct seawalls and bulkheads. Permanent steel sheet piles are designed to provide a long service life. Vibratory hammers are used to install sheet piles. If soils are too hard or dense, an impact hammer can be used to complete the installation. At certain sites where vibrations are a concern, the sheets can be hydraulically pushed into the ground. Sheet pile walls are constructed by:

a. Laying out a sequence of sheet pile sections and ensuring that sheet piles will interlock.
b. Driving (or vibrating) the individual sheet piles to the desired depth.
c. Driving the second sheet pile with the interlocks between the first sheet pile and second "locked"
d. Repeating steps 2 & 3 until the wall perimeter is completed
e. Use connector elements when more complex shapes are used.

This type wall depends on passive resistance of the foundation material and the moment resisting capacity of the vertical structural members for stability, therefore its

maximum height is limited by the competence of the foundation material and the moment resisting capacity of the vertical structural members. Because this type wall depends on the passive resistance of foundation material, it should not be used where it is likely that foundation material will be removed in front of the wall during its service life. The economical height of this type wall is generally limited to a maximum height of 6m or less.

9.3.5.1 Advantages

Sheet piles are also a sustainable option since recycled steel is used in their construction, and the piles can often be reused. Steel sheet piling is the most common because of several advantages over other materials:

- Provides high resistance to driving stresses.
- Light weight
- Can be reused on several projects.
- Long service life above or below water with modest protection.
- Easy to adapt the pile length by either welding or bolting
- Joints are less apt to deform during driving.

9.3.5.2 Disadvantages

Disadvantages of Sheet pile wall are:

- Sections can rarely be used as part of the permanent structure.
- Installation of sheet piles is difficult in soils with boulders or cobbles. In such cases, the desired wall depths may not be reached.
- Excavation shapes are dictated by the sheet pile section and interlocking elements.
- Sheet pile driving may cause neighbourhood disturbance
- Settlements in adjacent properties may take place due to installation vibrations

9.3.6 Precast Concrete Retaining Wall Panels

Interlocking prestressed horizontal concrete panels span between steel support columns / kingposts to produce foundation free, uniform, smooth, robust, retaining walls & push walls. Horizontal precast concrete walling, supported by steel building or stub columns, can provide anything from a single retaining wall to a multi building bulk storage system.

9.3.6.1 Advantages of the Precast Concrete Wall System

The PCC kingpost retaining wall system is designed to provide rapid construction for single or multi store bulk facilities in new or existing/refurbished buildings. Precast concrete is the ideal solution for those looking for Modern Methods of Construction of bulk retaining walls. The advantages of the precast concrete wall system are;

- Durable
- Rapid Installation
- Smooth Finish

- Movable

9.3.7 Reinforced Soil Retaining Walls

Mechanically stabilized earth walls are those structures which are made using steel or GeoTextiles soil reinforcements which are placed in layers within a controlled granular fill. Reinforced Earth is a composite material formed by cohesion less soil and flexible metal reinforcing strips. The earth and the reinforcement are combined through friction. The result is a monolithic mass that acts cohesively, supporting its own weight and applied loads.

The visible part of the structure is structurally the least significant. The facing skin can be in precast concrete (with anyone of a number of architectural finishes), semi-elliptical steel sections, treated timber or even wire mesh. Construction of a Reinforced Earth wall is straightforward and simple. Merely place a layer of facing panels, bolt on the reinforcing strips then backfill and compact. Repeat this cycle until the appropriate wall height has been reached. Properly compacted to a uniformly high density, the earth combines with the reinforcement to produce a strong, durable structure with predictable performance characteristics.

Reinforced retaining walls have evolved as viable technique and contributed to infrastructure in terms of speed, ease of construction, economy, aesthetics etc. It is a technology that needs to be understood well in terms of its response, construction features etc.

9.3.7.1 Advantages

- **Exceptional Wall Heights:** Theoretically, Reinforced Earth can be constructed to any height. Irrespective of the wall height, the details and technique used in the construction of Reinforced Earth wall remain the same. This allows for uniformity in construction control and monitoring. On the other hand, the detailing for

conventional walls vary substantially with the height, as the design changes from a cantilever wall to counterfort wall.

- **High Load-Carrying Capacity:** Reinforced Earth wall is capable of supporting large loading, and is most suitable for use in bridge abutment construction. In abutment where the bridge loading are structurally supported on piles, reinforced Earth wall and embankments are used as a working platform to support the loading and dead loads during the casting of the cross beams or bank seats.
- **Structural Flexibility:** The modular nature of Reinforced Earth wall and the reinforced granular backfill allows for significant differential movement along the wall. Its flexible mass produces uniform bearing pressure at the base, resulting in lower design bearing pressure, hence requiring lesser foundation treatment at the base.
- **Fast-Track Construction:** In the construction of highways, the construction time is directly related to the cost of construction. Speedy construction helps to cut down machinery costs and overheads.
- **Minimum Working Area:** Highways interchanges are mostly required in developed areas, where working area is limited. Reinforced Earth is constructed from the rear side, and requires very little working area in front of the wall. This minimises traffic disruption and allows for uninterrupted construction.
- **Long-Term Durability:** Reinforced Earth walls can be designed to 100 years design life or more. Highway operators are often required to take responsibility for the highway for the duration of their operation, which sometimes exceeds 30 years.
- **Cost Effectiveness:** Reinforced Earth designs are optimised to ensure maximum cost effectiveness. Its simple and repetitive construction technique simplifies control and management, and helps to minimize wastage and pilferage on site.
- **Aesthetic Appearance:**Precast Reinforced Earth panels can be easily modified to allow for specific architectural finishes. Combinations of geometrical shapes (such as ribbed, embossed, logo) and concrete textures (such as plain, rock finishes) provide for infinite possibilities in the finished product.

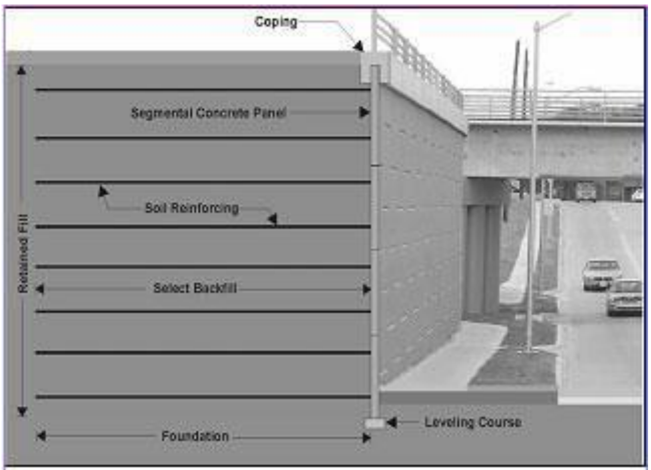
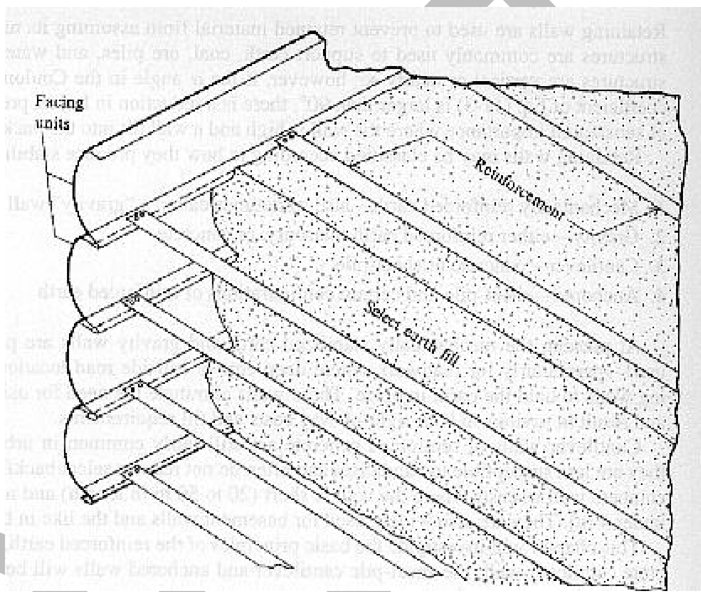


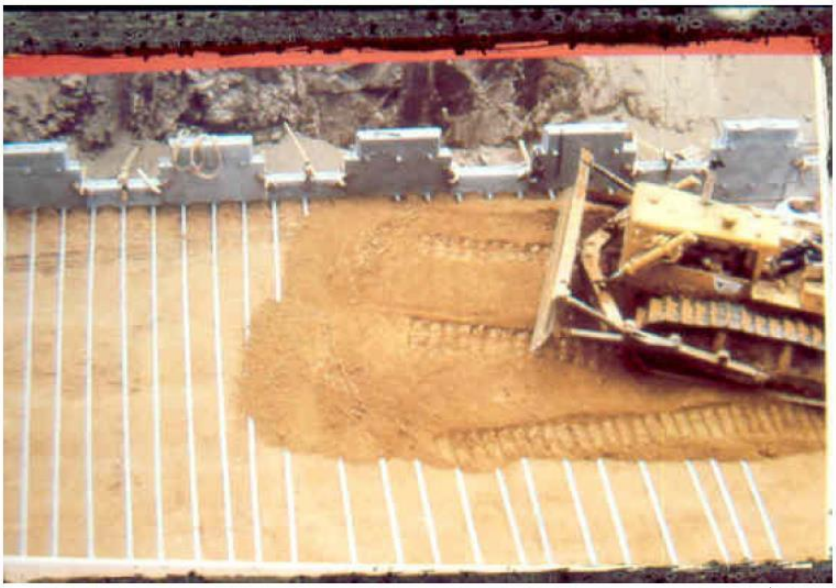
Photo 1. MSE wall: typical components



Galvanized metal strips are laid out behind the wall.

Galvanized metal strips are laid out behind the wall.

The galvanized metal strips are bolted to embedded anchor tabs in the concrete panels



After the metal strips are bolted to the panels, the granular fill (high) is spread in 15 to 30 cm lifts.

RE Panel walls are a composite system of a face panel - generally concrete and a steel reinforcement element - either in the form of a steel strip or welded mesh, that is positively connected one to the other such that a stable unified gravity soil mass may be formed. The facing panel is generally a precast concrete unit that provides local soil stability and a “face” for compaction of the retained soil. The panel may incorporate some special colour, texture or pattern to enhance the visual effect of the structure.

The steel reinforcing elements extend from the rear face of the concrete panel into the retained soil mass such that there is an effective increase in the shear capacity of the soil. The use of steel soil reinforcement elements allows the construction of retaining walls to very tall heights with the ability to withstand very large vertical and horizontal loads that

are commonly associated with mining, bridge and highway structures. These specialist panel wall types are generally recognized as the single most appropriate technical solution to many specific retaining wall applications, where the tensile stresses generated within the structure are of such magnitude, that the use of alternate polymeric solutions such as a geogrid, becomes technically not feasible or uneconomical to use.

Generally the very critical application of these wall types will require a detailed analysis of foundation conditions, applied loadings, service life, soil properties and potential environmental issues, both long and short term that may be associated with the wall construction. Any changes to the size, shape and position of surcharge loads originally adopted for the wall design as a result of change of vehicle loadings, additional embankment height or structure loadings may compromise the wall design.

For specific environmental concerns, specialty concrete mixes may be suggested in the manufacture of panels as well as special treatments for the steel reinforcement supplied. It is important that surface water run-off and ground water movement is controlled over the life of the structure. Water that contains corrosive contaminants may have an adverse effect on both metallic and concrete components.

RE Panel walls are available in a broad range of colours and textures. Local materials are used in the production of these precast panels and the exposed panel surface can be coloured to compliment the natural surroundings. RE Panel wall systems are able to accommodate curves, transitions and abrupt changes in direction easily. For walls of a temporary nature alternate facing systems such as mesh may be incorporated rather than the concrete facing panel. This category covers walls which use soil, reinforced with reinforcing bars, to provide a stable earth retaining system and includes reinforced soil and soil nailing.

9.3.8 Soil Nailing

Constructing a soil nailed wall involves reinforcing the soil as work progresses in the area being excavated by the introduction of bars which essentially work in tension, called Passive Bars. These are usually parallel to one another and slightly inclined downward. These bars can also work partially in bending and in shear. The skin friction between the soil and the nails puts the nails in tension.

Soil nailing is a construction technique that can be used as a remedial measure to treat unstable natural soil slopes or as a construction technique that allows the safe over-steepening of new or existing soil slopes. The technique involves the insertion of relatively slender reinforcing elements into the slope – often general purpose reinforcing bars (rebar) although proprietary solid or hollow-system bars are also available. Solid bars are usually installed into pre-drilled holes and then grouted into place using a separate grout line, whereas hollow bars may be drilled and grouted simultaneously by the use of a sacrificial drill bit and by pumping grout down the hollow bar as drilling progresses. Kinetic methods of firing relatively short bars into soil slopes have also been developed. Bars installed using

drilling techniques are usually fully grouted and installed at a slight downward inclination with bars installed at regularly spaced points across the slope face. A rigid facing (often pneumatically applied concrete, otherwise known as shotcrete) or isolated soil nail head plates may be used at the surface. Alternatively a flexible reinforcing mesh may be held against the soil face beneath the head plates. Rabbit proof wire mesh and environmental erosion control fabrics and may be used in conjunction with flexible mesh facing where environmental conditions dictate.

Soil nail components may also be used to stabilize retaining walls or existing fill slopes (embankments and levees); this is normally undertaken as a remedial measure. Four main points to be considered in determining if soil nailing would be an effective retention technique are as follows. First, the existing ground conditions should be examined. Next, the advantages and disadvantages for a soil nail wall should be assessed for the particular application being considered. Then other systems should be considered for the particular application. Finally, cost of the soil nail wall should be considered. Soil nail walls can be used for a variety of soil types and conditions. The most favorable conditions for soil nailing are as follows: The soil should be able to stand unsupported one to two meters high for a minimum of two days when cut vertical or nearly vertical. Also all soil nails within a cross section should be located above the groundwater table. If the soil nails are not located above the groundwater table, the groundwater should not negatively affect the face of the excavation, the bond between the ground and the soil nail itself. Based upon these favorable conditions for soil nailing stiff to hard fine-grained soils which include stiff to hard clays, clayey silts, silty clays, sandy clays, and sandy silts are preferred soils. Sand and gravels which are dense to very dense soils with some apparent cohesion also work well for soil nailing. Weathered rock is also acceptable as long as the rock is weathered evenly throughout (meaning no weakness planes). Finally, glacial soils work well for soil nailing.

A list of unfavorable or difficult soil conditions for soil nailing can include dry, poorly graded cohesion-less soils, soils with a high groundwater table, soils with cobbles and boulders, soft to very soft fine-grained soils, highly corrosive soils, weathered rock with unfavorable weakness planes, and loess. Other difficult conditions include prolonged exposure to freezing temperatures, a climate that has a repeated freeze-and-thaw cycle, and granular soils that are very loose

After a preliminary analysis of the site, initial designs of the soil nail wall can be begin. This begins with a selection of limit states and design approaches. The two most common limit states used in soil nail wall design is strength limit and service limit states. The strength limit state is the limit state that addresses potential failure mechanisms or collapse states of the soil nail wall system. The service limit state is the limit state that addresses loss of service function resulting from excessive wall deformation and is defined by restrictions in stress, deformation and facing crack width under regular service conditions. The two most common design approaches for soil nail walls are limit state design and service load design.

Initial design considerations include wall layout (wall height and length), soil nail vertical and horizontal spacing, soil nail pattern on wall face, soil nail inclination, soil nail length and distribution, soil nail material and relevant ground properties. With all these variables in the mind of the design engineer the next step is to use simplified charts to preliminarily evaluate nail length and maximum nail force. Nail length, diameter and spacing typically control external and internal stability of the wall. These parameters can be adjusted during design until all external and internal stability requirements are met. After the initial design is completed, final design progresses where the soil nail wall has to be tested for external and internal failure modes, seismic considerations and aesthetic qualities. Drainage, frost penetration and external loads such as wind and hydrostatic forces also have to be determined and included in the final examination of the design. Soil nail walls are not ideal in locations with highly plastic clay soils. Soils with high plasticity, a high liquid limit and low undrained shear strengths are at risk of long-term deformation (creep).

9.3.8.1 Construction

With the design complete, construction is the next step. Most soil nail wall construction follows a specific procedure. First a cut is excavated and temporary bracing is put in place if necessary. This is done with conventional earth moving equipment and hydraulic drills. Next, holes for the soil nails are drilled at predetermined locations as specified by the design engineer. The equipment used for this step is dependent on the stability of the material in which the soil nail wall is supporting. Rotary or rotary percussive methods using air flush or dry auger methods can be used with stable ground. For unstable ground, single tube and duplex rotary methods with air and water flush or hollow stem auger methods are used. With the holes drilled, the next step is to install and grout the nails into place. After all nails are inserted, a drainage system is put into place. Synthetic drainage mat is placed vertically between the nail heads, which are extended down to the base of the wall where they are most commonly connected to a footing drain. A layer of shotcrete is applied and bearing plates are installed before a final facing is put in place to complete the soil nail wall. Variations of the steps described above may be necessary to accommodate additional preparation tasks or supplementary activities for specific project conditions.

In terms of construction, soil nail walls have a decisive advantage over other alternatives. They require a smaller right-of-way than ground anchor walls and have less environmental impact. Installation of soil nail walls is relatively rapid and typically uses less materials and smaller construction equipment than ground anchor walls.

One great advantage of soil nail walls is their cost-effectiveness over other alternatives. When conventional soil nailing construction procedures are used, they are much more economical than concrete gravity walls and similarly or more cost effective than ground anchor walls.

Inspection activities play a vital role in the production of high-quality soil nail walls because conformance to project plans and specifications should result that will perform its intended duty for its designed duration. Inspections usually involve evaluation of the