6.18.7 Geotechnical site investigation in permafrost zones

6.18.7.1 Field assessment

Field assessment of permafrost conditions, if required, shall be carried out to confirm desktop evaluation and quantify information about permafrost conditions, environmental conditions, geomorphology, hydrology, and hydrogeology.

For high-consequence levels, site visits shall be undertaken under direction of an engineer during this phase of the investigations to obtain necessary site-specific data to plan subsurface site investigations.

6.18.7.2 Ground temperatures

Ground temperature data shall be collected and assessed as specified in Subsection 8.5.4 of CAN/BNQ 2501-500.

The potential impact of construction and groundwater flow on the ground temperature regime shall be addressed in the design and discussed in the geotechnical reports.

For high-consequence foundations and high risk sites (see Clause 6.18.2 of this Section), the geothermal regime used in the design shall be monitored to confirm continued performance over the design life, unless otherwise directed by the owner.

6.18.7.3 Site grading and drainage

If applicable, the potential impact of site grading, surface and subsurface drainage, and construction on geotechnical design shall be addressed in the design and discussed in geotechnical reports.

Final site grading shall direct drainage away from the foundation.

Existing and future site development shall be taken into consideration for drainage design.

6.18.7.4 Possible changes in geotechnical properties

Possible changes in geotechnical properties or ground response due to changes in the ground temperature regime shall be investigated and a range of possible values shall be estimated during the geotechnical site investigation.

6.18.7.5 Reporting and recommendations

The results of geotechnical site investigations shall be included in a report in accordance with Clauses 7.5 and 9 of CAN/BNQ 2501-500.

For the high-consequence level, where thermal modelling of permafrost-structure interaction is conducted, the geotechnical reports shall provide:
a) climatic characteristics that are representative of the site over the design life of the foundation;
b) ground temperature data used for the model calibration;
c) boundary conditions; and
d) ground thermal properties.

If applicable, recommendations for a monitoring program shall be included in the design documentation. Location of monitoring devices and ground temperature sensors shall be detailed in the design drawings.

Site drainage and snow management recommendations for construction and bridge operations shall be discussed.

The geotechnical report shall discuss how climatic variability and climate change will affect the permafrost conditions over the design life of the structure and how it is considered in the design.

6.18.8 Thermosyphons

Thermosyphons, when used, shall be designed in conformance to CAN/CSA-S500. Climatic variability and climate change and other factors potentially affecting heat exchange shall be considered in the thermosyphon foundation design. Surface and active layer drainage shall be considered in the thermosyphon foundation design.

6.19 Mechanically stabilized earth (MSE) wall systems

6.19.1 Application

6.19.1.1 General

The provisions of Clause 6.19 apply to the design of reinforced soil retaining wall systems. These systems typically consist of prefabricated facing elements, reinforced soil mass, and soil reinforcement elements consisting of metal strips, metal bar mats, metal wire mesh, or polymeric geogrids. Components made of materials that are not covered by this Code shall be used only when short- and long-term testing has established their suitability for the intended purpose. The testing shall establish all relevant properties, including those pertaining to durability, dimensional stability, and creep. The design of MSE wall systems shall take into consideration settlement, external stability, internal stability, facing stability, compound stability, and global stability. The requirements of Section 2 and other pertinent Sections shall apply in addition to the content of this Section.

6.19.1.2 Exclusions

The specifications provided herein for MSE wall systems do not apply to walls constructed with soil nails or polyester straps nor to geometrically complex systems such as tiered walls (walls stacked on top of one another), back-to-back walls, shored walls, and walls that have trapezoidal sections. RSS constructed at an angle 70° or less from the horizontal are considered to be reinforced slopes and not considered herein.

6.19.2 Design

The design of MSE wall systems shall be carried out by an engineer with qualifications acceptable to the owner. The design shall be based on accepted methods of analysis and shall take into consideration the:

a) magnitude of strains and load expected in the soil reinforcement elements;
b) facing elements;
c) connections between the soil reinforcement elements and the facing elements;
d) internal stability within the zone of soil reinforcement elements; and
e) site-specific external, compound, and global stability, and settlement of the MSE wall system.

6.19.3 Structure dimensions

6.19.3.1 General

An illustration of the MSE wall element dimensions required for design is provided in Figure 6.9. The size and embedment depth of the reinforced soil mass shall be determined based on:

a) requirements for stability and geotechnical strength, as specified in Clause 6.19.9 consistent with requirements for gravity walls;

b) requirements for structural resistance within the reinforced soil mass itself, as specified in Clause 6.19.10, for the facing units, and for the development of reinforcement beyond assumed active zones; and

c) traditional requirements for reinforcement length not less than 70% of the wall height, except as noted in Clause 6.19.3.2.

6.19.3.2 Minimum wall base width and length of soil reinforcement

The minimum base width of the wall system, *B*, shown in Figure 6.9, which includes the depth of the facing elements, shall be 70% of the system height, as measured from the levelling pad to the top of the reinforced soil mass at the top of the wall, *H*, unless substantiating evidence indicates that a reduced length is acceptable and is approved by the owner. Reinforcement lengths, *L*, calculated as the wall base width, *B*, less the depth of the facing elements, shall be used throughout the height of the wall system.

6.19.3.3 Minimum front face embedment

The minimum vertical embedment depth of the bottom of the reinforced soil mass (top of the levelling pad) shall be based on bearing resistance, settlement, and stability requirements determined in accordance with standard geotechnical review and the relevant provisions of this Section.

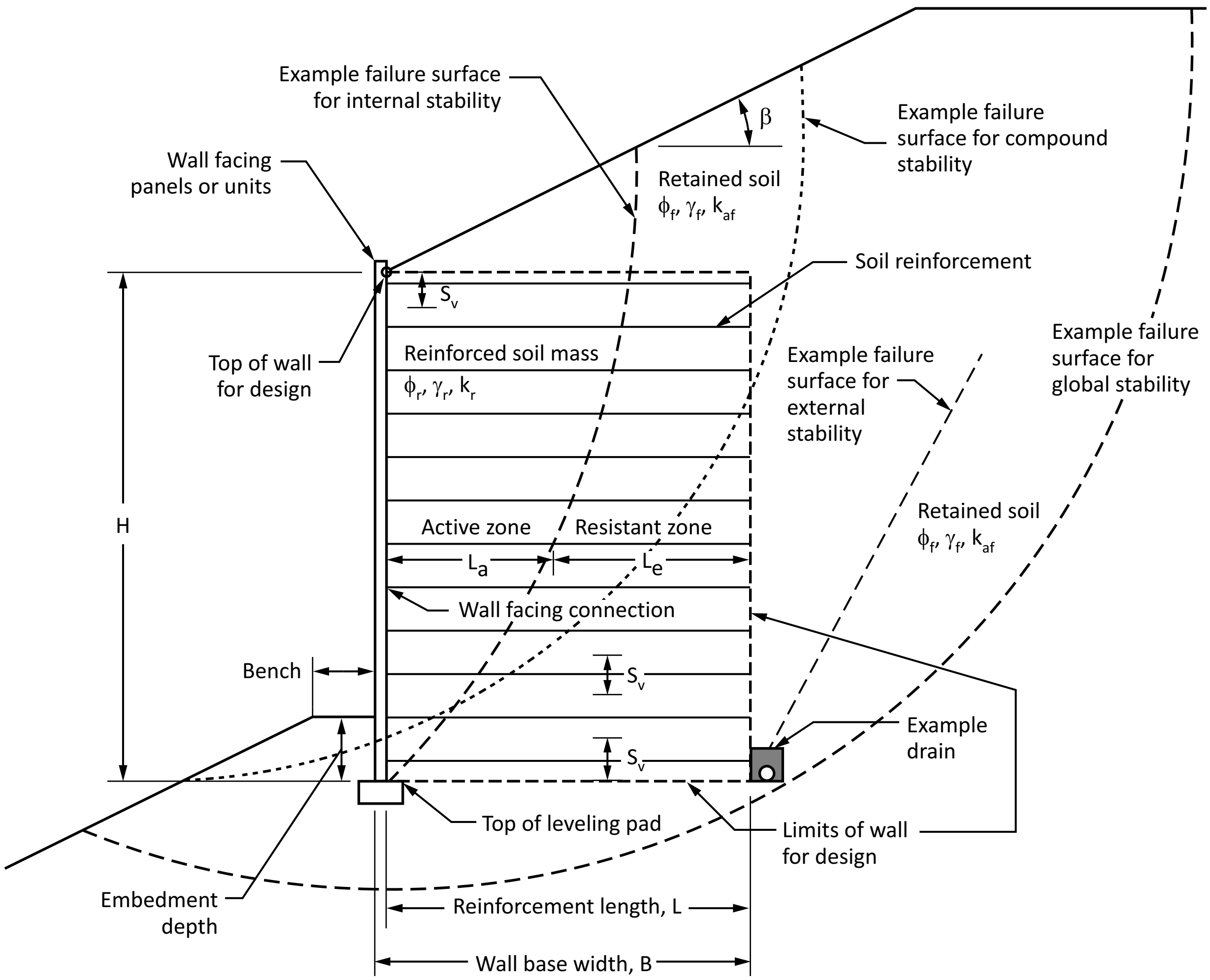
Unless constructed on rock, the embedment at the front face of the wall shall not be less than a depth based on the external stability requirement, or 600 mm, whichever is greater.

For walls constructed along rivers or streams, or for any submerged walls, embedment depth shall extend a minimum of 600 mm below design scour depth as determined by a hydraulic engineer, and as specified in Clauses 1.9.4 and 1.9.5, but in no case shall the embedment depth be less than 1 m.

A minimum horizontal bench width of 1 m shall be provided in front of walls founded on slopes as shown in Figure 6.9.

The lowest backfill reinforcement layer shall not be located above the long-term ground surface in front of the wall.

Figure 6.9
MSE wall element dimensions needed for design — Potential failure surfaces are examples only
(See Clauses 6.19.3.1 to 6.19.3.3, 6.19.9.4, 6.19.9.5, and 6.19.10.2.2.)



Note: *For external and internal stability calculations, the weight and dimensions of the facing elements shall be ignored. For internal stability calculations, the wall dimensions shall begin at the back of the facing elements. For sliding and bearing resistance calculations, the facing dimensions and weight shall be included.*

6.19.3.4 Facing elements

6.19.3.4.1 General

Facing elements for wall systems shall be designed to resist the horizontal force in the soil reinforcement at the reinforcement to facing connection, as specified in Clause 6.19.10.2.3, as well as the horizontal forces applied by the soil.

In addition to these horizontal forces, the facing elements shall also be designed to resist potential compaction stresses occurring near the wall face during erection of the wall.

The distributed load acting on the back of the facing unit in the vicinity of each connection shall be computed as the maximum reinforcement tension load divided by the reinforcement tributary area.

The facing shall be designed to satisfy deformation serviceability limit states, as defined by the owner.

Concrete mix design shall be acceptable to the engineer and approved by the owner.

6.19.3.4.2 Concrete panel facing units

Concrete panel facing units shall be structurally designed in accordance with Section 8. The minimum thickness for concrete panels at and in the zone of stress influence of embedded connections shall be 140 mm.

6.19.3.4.3 Modular block facing units

For modular block facing units, facing stability calculations shall include an evaluation of the maximum vertical spacing between reinforcement layers, the maximum allowable facing height above the uppermost reinforcement layer, inter-unit shear capacity, and resistance of the facing to bulging. The maximum vertical spacing between reinforcement layers shall be limited to twice the depth, D_u, of the modular block facing unit, or 800 mm, whichever is less. If the height of the modular block facing unit exceeds 800 mm, the maximum vertical spacing between reinforcement layers shall be 1 m.

The maximum facing height up to the wall surface grade above the uppermost reinforcement layer shall be limited to $2D_u$, as illustrated in Figure 6.23 or 600 mm, whichever is less, provided that the facing above the uppermost reinforcement layer is demonstrated to be stable against a toppling failure through detailed calculations. If the height of the modular block facing unit exceeds 600 mm, then the maximum facing height above the uppermost reinforcement layer shall be the height of the modular block facing unit.

The maximum facing height below the lowest reinforcement layer shall be limited to 1.5 D_u or 500 mm, whichever is less.

6.19.3.4.4 Flexible wall facing units

If welded wire, expanded metal, geocell, or similar facings are used, they shall be designed to prevent excessive bulging at the wall face and settlement of the reinforced soil mass behind the facing.

Geosynthetic facing elements shall be designed to resist UV deterioration over the design life of the wall.

6.19.3.4.5 Corrosion issues for MSE wall facing elements

Steel-to-steel contact between the soil reinforcement connections and the concrete facing steel reinforcement shall not be allowed. In addition, no dissimilar metals shall be in contact with each other.

6.19.4 Reinforced soil material

The reinforced soil material selected shall have engineering properties such that design limit states and all performance requirements, as specified by the owner, are satisfied. Surface and subsurface drainage shall be designed taking into account the reinforced soil material selected.

6.19.5 Reinforcement elements

Reinforcement elements shall consist of metal strips, metal bar mats, metal wire mesh, or polymeric geogrids suitable for soil reinforcing.

6.19.6 Loading, load factors, and resistance factors

For design of MSE systems, loadings and load factors shall be taken from Section 3 with the following considerations:

a) in addition to the specifications provided in Clause 3.5.2.2, the minimum load factor for dead load of backfill, α_D, shall be 1.0 for horizontal sliding, soil reinforcement rupture, and soil reinforcement pullout design; and
b) in Table 3.1, ULS Combination 5, all factors that are not equal to zero shall be 1.0.

For design of MSE systems, resistance factors shall be taken from Table 6.2 and consequence factors from Table 6.1.

Application of loads for external and internal stability shall be taken as specified in Clauses 6.19.9 and 6.19.10, respectively.

6.19.7 Vertical and lateral displacements

6.19.7.1 Vertical displacement

The allowable settlement of MSE wall systems shall be acceptable to the engineer, approved by the owner, and be established based on the longitudinal settlement tolerance of the facing elements and the purpose of the MSE wall system.

Differential settlement from the front to the back of the wall shall also be evaluated, especially regarding the effect on facing deformation, alignment, and connection loads.

6.19.7.2 Lateral displacement

Lateral MSE wall system displacements shall be estimated as a function of overall structure stiffness, compaction intensity, soil type, reinforcement type (extensible and inextensible), reinforcement length, tolerance in reinforcement-to-facing connections, and deformability of the facing system or based on monitored system performance. Acceptable lateral displacements limits shall be specified by the owner.

6.19.8 Active lateral earth pressure coefficient

The general equation for the active earth pressure coefficient, k_a, shall be as follows:

$$k_a = \frac{\sin^2(\theta+\phi)}{C\left[\sin^2\theta\sin(\theta-\delta)\right]}$$

where

$$C = \left[1+\sqrt{\frac{\sin(\phi+\delta)\sin(\phi-\beta)}{\sin(\theta-\delta)\sin(\theta+\beta)}}\right]^2$$

For the case $\delta = 0$ and $\beta = 0$, k_a shall be as follows:

$$k_a = \frac{\sin^2(\theta+\phi)}{\sin^3\theta\left(1+\frac{\sin\phi}{\sin\theta}\right)^2}$$

6.19.9 External stability

6.19.9.1 General

The reinforced soil mass of MSE wall systems is assumed to be a rigid body for the purpose of external stability calculations, and shall be proportioned to satisfy sliding stability, bearing capacity, and eccentricity criteria normally associated with gravity wall structures.

The active earth pressure coefficient, k_{af}, used to compute the earth pressure from the retained soil acting against the reinforced soil mass shall be calculated using the friction angle of the retained soil, ϕ_f, in Clause 6.19.9.2. In the absence of specific data, a maximum friction angle of 30° shall be used for granular soils. Tests should be performed to determine the friction angle of cohesive soils considering both drained and undrained conditions.

Passive pressure from the soil in front of the wall (embedment) shall be ignored for stability calculations.

6.19.9.2 Loading for external stability

In addition to loading as defined in Section 3, the following shall be used for external stability calculations.

The active earth pressure coefficient k_{af}, shall be calculated using the general equation for the active earth pressure coefficient k_a in Clause 6.19.8 with $\phi = \phi_f$. δ shall not be greater than $(2/3)\phi_f$ or $(2/3)\phi_r$, whichever is less.

For the design of MSE wall systems having a horizontal back slope and no surcharge loading, the geometry, external pressures, and active force in Figure 6.10 shall be used in sliding, bearing capacity, and eccentricity calculations.

For horizontal back slope and continuous traffic surcharge loads, Figure 6.11 shall apply. The continuous traffic surcharge loads shall be considered to act beyond the end of the reinforced soil mass for sliding and eccentricity calculations.

Other dead load conditions, if present, shall be considered in accordance with Clause 6.19.13.

Design of MSE wall systems with sloping backfill and broken back slopes shall use the geometry, earth pressures, and loads shown in Figures 6.12 and 6.13. For more complicated back slope geometries, conventional limit equilibrium methods using circular, non-circular, and wedge type analyses may be used to compute the active force at the back of the reinforced soil mass.

Figure 6.10
External stability for MSE wall with horizontal back slope (β = 0)
(See Clause 6.19.9.2 and Figure 6.18.)

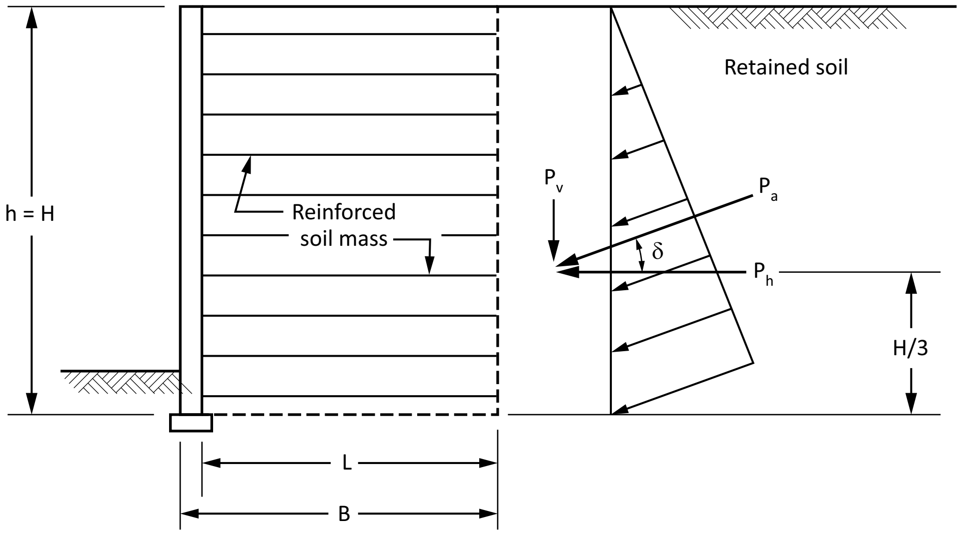


Figure 6.11
External stability for MSE wall with horizontal back slope (β = 0) and traffic surcharge
(See Clause 6.19.9.2.)

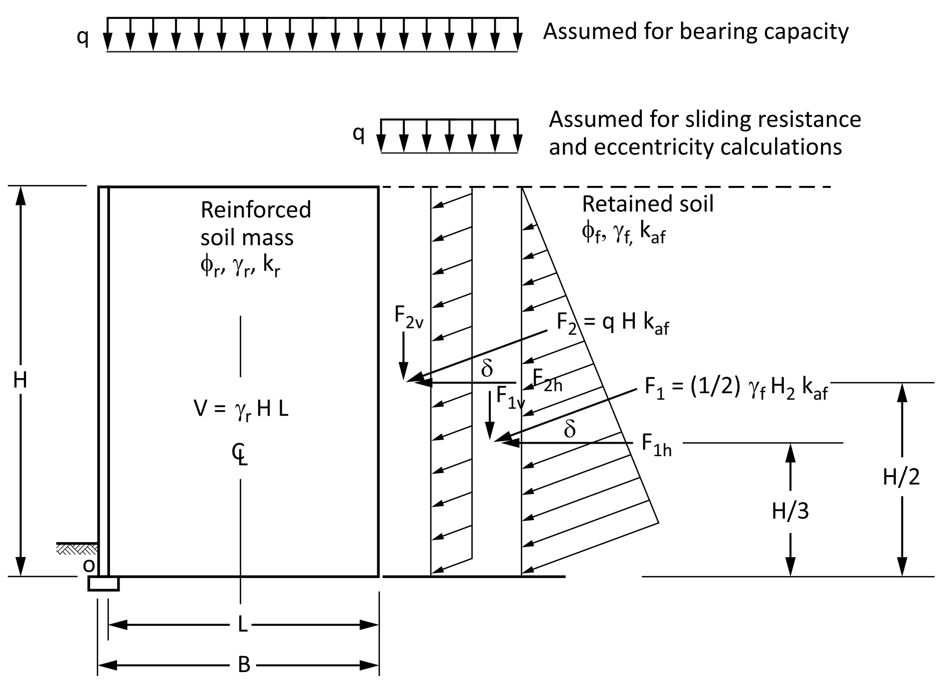


Figure 6.12
Earth pressure distribution for MSE wall with sloping backfill surface
(See Clause 6.19.9.2.)

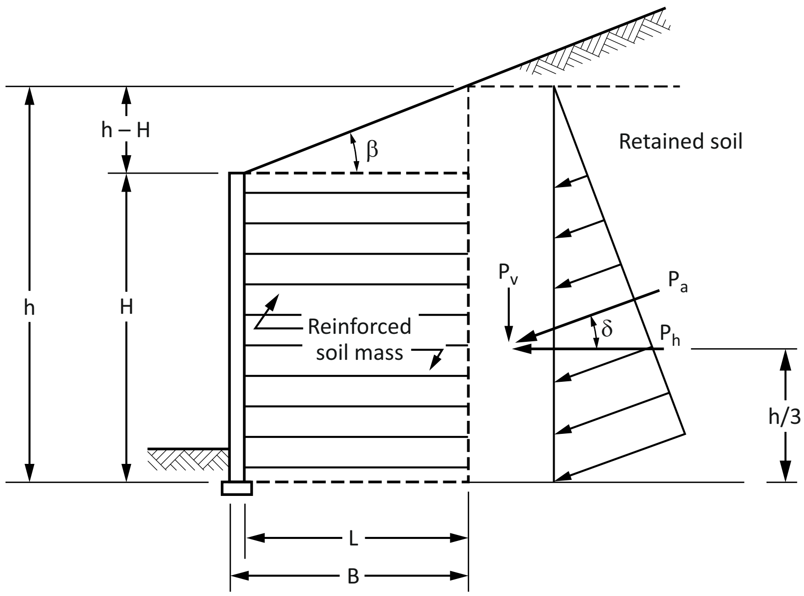
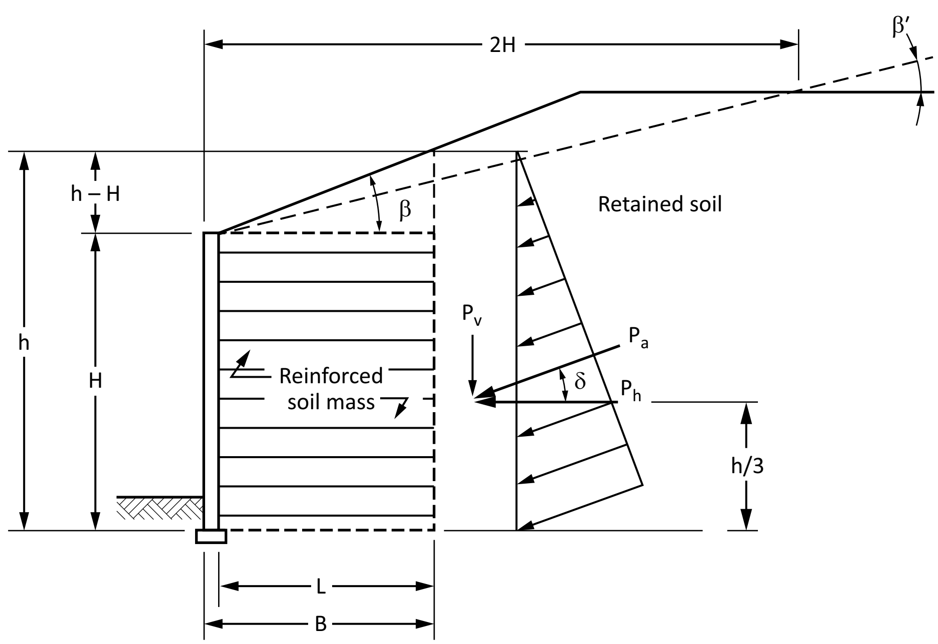


Figure 6.13
Earth pressure distribution for MSE wall with broken back slope surface
(See Clauses 6.3.1 and 6.19.9.2.)



6.19.9.3 Sliding resistance

The coefficient of sliding friction at the base of the reinforced soil mass shall be determined using the friction angle of the foundation soil. For discontinuous reinforcements, e.g., strips, the angle of sliding friction shall be taken as the lesser of ϕ_r of the reinforced soil and the friction angle of the foundation soil. For continuous reinforcements, e.g., grids and sheets, the angle of sliding friction shall be taken as the lesser of ϕ_r, the friction angle of the foundation soil, and ρ, where ρ is the soil reinforcement interface friction angle. In the absence of specific data, a maximum foundation friction angle of 30°, and a maximum soil-reinforcement interface angle, ρ = 2/3 times the foundation soil friction angle, may be used.

6.19.9.4 Bearing resistance

For the purpose of calculating the bearing resistance of the gravity mass of the MSE wall system at ultimate limit states, an equivalent strip footing shall be assumed having width of dimension *B* at the foundation level, as shown in Figure 6.9. Bearing resistance shall be calculated using a uniform base pressure distribution over an effective width *B′* as determined in accordance with Clause 6.10.

Bearing resistance at ultimate limit states under the levelling pad shall also be checked. The load on the levelling pad shall be taken to be not less than twice the weight of the facing.

6.19.9.5 Global and compound stability

The overall stability of the MSE wall system, retained soil, and foundation soil or rock shall be evaluated for all walls using limiting equilibrium methods of analysis. The overall stability of temporary cut slopes to facilitate construction shall also be evaluated. More comprehensive exploration, testing, and analyses might be required for bridge abutments or retaining walls constructed over soft deposits.

Global stability shall be checked for all MSE systems. Where the MSE system is located on sloping ground, either above or below, or soft ground where overall stability might be inadequate, compound failure surfaces (circular and non-circular) which pass through a portion of the reinforced soil mass, for example as illustrated in Figure 6.9, shall be investigated.

The long-term strength of each soil reinforcement layer intersected by the failure surface shall be considered as a restoring force in the limit equilibrium slope stability analysis.

6.19.10 Internal stability

6.19.10.1 General

Safety against internal failure limit states shall be evaluated with respect to pullout, connection, and rupture of the soil reinforcement. The size of the stabilized soil mass for pullout stability calculations shall be determined using the potential failure surface geometries shown in Figure 6.18.

6.19.10.2 Loading

6.19.10.2.1 General

The load in the soil reinforcement shall be determined at the location of the potential failure surface in the reinforced soil mass shown in Figure 6.18.

The maximum friction angle, ϕ_r, used for the computation of the horizontal force within the reinforced soil mass shall be assumed to be 35°, unless the project-specific backfill is tested for frictional strength by triaxial or direct shear testing methods accepted by the geotechnical engineer. A design friction angle of greater than ϕ_r = 40° shall not be used with the simplified method even if the measured friction angle is greater than 40°.