5 RETAINING STRUCTURES

5.1 GENERAL

5.1.1 Scope

1 The provisions of this Part 5 apply to retaining structures in general. These are structures used to retain ground comprising soil, rock or backfill and water and this at an angle steeper than the angle they would normally adopt without the presence of those structures. Common retaining structures used within the state of Qatar taking into account the prevailing geologic conditions are:

(a) Sheet Piles
(b) Bored and Cast in Place Concrete Piles
  (i) Contiguous Piles
  (ii) Secant Piles
(c) Diaphragm Walls
(d) Composite Shoring Systems
(e) Concrete Retaining Walls
  (i) Cantilever Retaining Wall
  (ii) Counter Fort Retaining Wall
  (iii) Gravity Retaining Wall
  (iv) Buttressed Retaining Wall
(f) Reinforced Soil Retaining Structures
  (i) Geogrid and Geotextile Reinforced Earth Systems
  (ii) Galvanized Strips Reinforced Earth System
(g) Soil and Rock Nailing Systems

2 This revision of Section 4 – Part 5 is considered preliminary and shall be reviewed and amended as needed in the next revision to elaborate on various subjects not covered herein.

3 This revision of Section 4 – Part 5 is based generally on “EN1997-1” Eurocode 7.

4 Section 4 – Part 5 will cover at this stage the general design aspects knowing that the construction procedures shall be added in future revisions of this Section. Hence, at this stage, the construction related subjects of the retaining structures will follow relevant Parts of the QCS.

5 The purpose of QCS is to provide as a general technical guide for acceptable construction work practices in the State of Qatar, considering this; any addition for technology, material, specification, standard that are not mentioned in this section or their modification, shall be subject to approval as stated in the introduction of QCS (00-02)

5.1.2 References

1 The following standards and other documents are referred to in this Part:

EN 1997 .....Eurocode 7: Geotechnical design
EN 1997-1 .....Eurocode 7: Geotechnical design - Part 1: General rules
EN 1992 .....Eurocode 2: Design of concrete structures
EN 1993 .....Eurocode 3: Design of steel structures
EN 1994 .....Eurocode 4: Design of composite steel and concrete structures

EN 1995 .....Eurocode 5: Design of timber structures

EN 1996 .....Eurocode 6: Design of masonry structures

5.2 LIMIT STATES

1 During the design of retaining structures the following typical limit states should be considered:

5.2.1 Ultimate Limit State

1 Loss of overall stability: it should be demonstrated that an overall stability failure is unlikely.

2 Foundation failure of retaining structures with footings: it should be demonstrated that the foundation pressures (lateral and vertical) do not exceed neither the ground allowable bearing capacity nor the sliding resistance. Uplift pressures under the foundation due to water seepage should also be included in the analysis.

3 Foundation failure of gravity walls, which is the loss of equilibrium of the wall considered as a rigid body.

4 Failure of embedded walls by rotation or horizontal translation or by lack of vertical equilibrium.

5 Failure of a structural element such as a wall, anchorage, wale or strut, including failure of the connection between those elements.

6 Failure of a retaining structure by hydraulic heave, internal erosion or piping, unacceptable leakage of water, or transport of soil particles through or under the wall caused by excessive hydraulic gradients.

5.2.2 Serviceability Limit State

1 Unacceptable movement of the retaining structure, which may affect the appearance or functionality of the structure itself, or other neighbouring structures or utilities influenced by the movement.

2 Unacceptable change in the groundwater regime.

5.3 ACTIONS AND GEOMETRICAL DATA

5.3.1 Actions

1 Generally, the forces exerted on retaining structure with values assumed known at the beginning of the calculation are considered as 'actions', while forces with initially unknown values, to be determined by the interaction of the retaining structure with support elements (ground springs, anchorages, struts, etc.), are considered as 'reactions'. The following actions are to be taken into account:

(a) Weight of backfill material
(b) Surcharges
(c) Weight of water
(d) Wave forces for marine projects
(e) Seepage forces
(f) Collision forces
(g) Temperature effects
(h) Forces from propping elements (i.e. post-tensioned anchors)
(i) Siesmic related effects

2 The above actions should result in the determination of various earth pressures acting on the retaining structure.

5.3.2 Geometrical data

1 This paragraph covers the uncertainties in the geometrical data namely excavation and water levels. In general, small variations in geometrical data are considered to be covered by the safety factors included in the calculations. However, since the design of retaining structures is sensitive to ground and water levels, special requirements are included in this paragraph, mainly for unforeseen over-dig in front of the wall and groundwater levels change on both sides of the wall.

2 Unforeseen over-dig in front of the wall

In Ultimate Limit State design calculations, where the wall stability depends on the earth resistance in front of the wall, the level of the resisting soil should be lowered below the nominally expected level by an amount which depends on the degree of control on the excavation level. With a normal degree of control the expected difference in resisting soil level should be:

(a) Equal to 10% of the wall height above excavation level (up to a maximum of 0.5 m), for cantilever walls;

(b) Equal to 10% of the distance between the lowest support and the excavation level (up to a maximum of 0.5 m), for supported walls.

3 Groundwater levels in front of and behind the wall

The selection of the levels of the phreatic surfaces in front of and behind the wall must consider long-term variations of the groundwater regime and/or the ground permeability, the presence of perched or artesian aquifers and the possibility that drainage behind the wall may cease to function with time.

5.3.3 Design Situations

1 The following conditions shall be considered during the design of retaining structures:

(a) Anticipated variations in soil properties

(b) Variations in actions and the ways they are combined

(c) Excavation, scour or erosion in front of the retaining structure

(d) The effect of compaction of the backfill behind the retaining structure

(e) The effect of anticipated future structures and surcharge loads/unloads

(f) Anticipated ground movements

(g) Inclination of the wall to the vertical

(h) Variations in groundwater table and the seepage forces in the ground

(i) Horizontal as well as vertical equilibrium for the entire retaining structure

(j) The shear strength and weight density of the ground

(k) The rigidity of the wall and the supporting system

(l) The wall roughness

(m) Seismic effect on the various forces

5.4 DESIGN AND CONSTRUCTION CONSIDERATIONS

1 The design of retaining structures requires consideration of all relevant Ultimate Service States and Service Limit States.

2 For retaining structures without strict serviceability requirements, the geometry is usually determined by Ultimate Limit State design calculations and checked by Service Limit State calculations (if relevant). For the retaining structures with strict serviceability requirements, the Service Limit State requirements often govern the design.

3 The design and construction considerations should cover the following:

(a) Demonstrate that vertical equilibrium can be achieved for the assumed pressure distributions and actions on the wall.

(b) Verification of vertical equilibrium may be achieved by reducing the wall friction parameters.

(c) Retaining walls should be designed in such a way that there are visible signs of the approach of an ultimate limit state. The design should prevent brittle failure of the structure, e.g. sudden collapse without conspicuous preliminary deformations.

(d) A critical limit state should be considered to occur if the wall has displaced enough to cause damage to nearby structures or services. Although collapse of the wall may not be imminent, the degree of damage may considerably exceed a serviceability limit state in the supported structure.

(e) The design methods and partial factor values recommended by "EN1997-1:2004+A1:2013" are usually sufficient to prevent the occurrence of ultimate limit states in nearby structures, provided that the soils involved are of at least medium density or firm consistency and adequate construction methods and sequences are adopted. Special care should be taken, however, with some highly over-consolidated clay deposits in which large at rest horizontal stresses may induce substantial movements in a wide area around excavations.

(f) The complexity of the interaction between the ground and the retaining structure sometimes makes it difficult to design a retaining structure in detail before the actual execution starts. In this case, use of the observational method for the design should be considered. The observational method consists of setting criteria enabling monitoring during construction, allowing necessary corrective actions to be taken to rectify the design. Hence, the following requirements shall be set before construction:

(i) Acceptable limits of behaviour

(ii) The range of potential behaviour shall be analysed showing acceptable probability that the actual behaviour will be within the acceptable limits

(iii) A plan of monitoring shall be established (including necessary instruments and procedures) enabling the comparison of the actual behaviour to the acceptable limits. The monitoring shall allow early detection of nonconformities, allowing enough time for corrective actions to be taken successfully.

(iv) A list of contingency actions shall be established which could be used if the actual observed behaviour is outside of the acceptable limits.

(g) The effects of constructing the wall, including:

(i) The provision of temporary support to the sides of excavations;

(ii) The changes of in situ stresses and resulting ground movements caused both by the wall excavation and its construction;

(iii) Disturbance of the ground due to driving or boring operations;

(iv) Provision of access for construction;

(h) The required degree of water tightness of the finished wall;

(i) The practicability of constructing the wall to reach a stratum of low permeability, so forming a water cut-off. The resulting equilibrium ground-water flow problem shall be assessed;

(j) The practicability of forming ground anchorages in adjacent ground;

(k) The practicability of excavating between any propping of retaining walls;

(l) The ability of the wall to carry vertical load;

(m) The ductility of structural components;

(n) Access for maintenance of the wall and any associated drainage measures;

(o) The appearance and durability of the wall and any anchorages;

(p) For sheet piling, the need for a section stiff enough to be driven to the design penetration without loss of interlock;

(q) The stability of borings or slurry trench panels while they are open;

(r) For fill, the nature of materials available and the means used to compact them adjacent to the wall.

(s) Drainage systems

If the safety and serviceability of the designed structure depend on the successful performance of a drainage system, the consequences of its failure shall be considered, taking into account both safety and cost of repair. One of the following conditions (or a combination of them) shall apply:

(i) A maintenance program for the drainage system shall be specified and the design shall allow access for this purpose;

(ii) It shall be demonstrated both by comparable experience and by assessment of any water discharge that the drainage system will operate adequately without maintenance.

The quantities, pressures and eventual chemical content of any water discharge should be taken into account.

5.5 DETERMINATION OF EARTH PRESSURES

5.5.1 General

1 The Determination of the earth pressures shall take into account the acceptable mode and amount of any movement and strain, which may occur at the limit state under consideration.

2 In the following context the words "earth pressure" should also be used for the total earth pressure from soft and weathered rocks and should include the pressure of ground-water.

3 Calculations of the magnitudes of earth pressures and directions of forces resulting from them shall take account of the issues highlighted under paragraph “5.3.3”.

4 The amount of mobilized wall friction and adhesion should be considered as a function of:

(a) The strength parameters of the ground

(b) The friction properties of the wall-ground interface

(c) The direction and amount of movement of the wall relative to the ground

(d) The ability of the wall to support any vertical forces resulting from wall friction and adhesion

5 A concrete wall or steel sheet pile wall supporting sand or gravel may be assumed to have a design wall ground interface parameter $\delta_d = k.\varphi_{cv;d}$. k should not exceed 2/3 for precast concrete or steel sheet piling. For concrete cast against soil, a value of k = 1.0 may be assumed. For a steel sheet pile in clay under undrained conditions immediately after driving, no adhesive or frictional resistance should be assumed. Increases in these values may take place over a period of time.

6 In the case of structures retaining rock masses, calculations of the ground pressures shall take into account the effects of discontinuities, with particular attention to their orientation, spacing, aperture, roughness and the mechanical characteristics of any joint filling material.

7 Account shall be taken of any swelling potential of the ground when calculating the pressures on the retaining structure.

5.5.2 At rest values of earth pressure

1 When no movement of the wall relative to the ground takes place, the earth pressure shall be calculated from the at rest state of stress. The determination of the at-rest state shall take into account the stress history of the ground.

5.5.3 Limiting values of earth pressure

1 Limiting values of earth pressures shall be determined taking into account the relative movement of the soil and the wall at failure and the corresponding shape of the failure surface.

5.5.4 Intermediate values of earth pressure

1 Intermediate values of earth pressure occur if the wall movements are insufficient to mobilize the limiting values. The determination of the intermediate values of earth pressure shall take into account the amount of wall movement and its direction relative to the ground.

2 The intermediate values of earth pressures may be calculated using, for example, various empirical rules, spring constant methods or finite element methods.

5.5.5 Compaction effects

1 The determination of earth pressures acting behind the wall shall take into account the additional pressures generated by any placing of backfill and the procedures adopted for its compaction.

5.6 WATER PRESSURES

1 Determination of characteristic and design water pressures shall take account of water levels both above and in the ground.

2 When checking the ultimate and serviceability limit water pressures shall be accounted for in the combinations of actions considering the possible risks of flooding or change in groundwater levels from either sides of the retaining structure.

3 For structures retaining earth of medium or low permeability (silts and clays), water pressures should normally be assumed to act behind the wall. Unless a reliable drainage system is installed, or infiltration is prevented, the values of water pressures should normally correspond to a water table at the surface of the retained material.

4 Where sudden changes in a free water level may occur, both the non-steady condition occurring immediately after the change and the steady condition shall be examined.

5 Where no special drainage or flow prevention measures are taken, the possible effects of water-filled tension or shrinkage cracks shall be considered.

5.7 ULTIMATE LIMIT STATE DESIGN

5.7.1 General

1 The design of retaining structures shall be checked at the ultimate limit state for the design situations appropriate to that state, as specified in 5.3.3, using the design actions or action effects and design resistances.

2 All relevant limit modes shall be considered. These will include, as a minimum, limit modes of the types illustrated in Figures 5.1 to 5.6 for the most commonly used retaining structures.

3 Calculations for ultimate limit states shall establish that equilibrium can be achieved using the design actions or effects of actions and the design strengths or resistances. Compatibility of deformations shall be considered in assessing design strengths or resistances.

5.7.2 Overall stability

1 Principles and calculations should be used as appropriate to demonstrate that an overall stability failure will not occur and that the corresponding deformations are sufficiently small taking into account progressive failure and liquefaction into account as relevant.

5.7.3 Foundation failure of gravity walls

1 The principles of foundation design shall be used as appropriate to demonstrate that a foundation failure is sufficiently remote and that deformations will be acceptable. Both bearing resistance and sliding shall be considered. Failure modes shown in Figure 5.2 should be verified as a minimum.

5.7.4 Rotational failure of embedded walls

1 It shall be demonstrated by equilibrium calculations that embedded walls have sufficient penetration into the ground to prevent rotational failure. As a minimum, limit modes of the types illustrated in Figure 5.3 should be considered.

2 The design magnitude and direction of shear stress between the soil and the wall shall be consistent with the relative vertical displacement, which would occur in the design situation.

5.7.5 Vertical failure of embedded walls

1 It shall be demonstrated that vertical equilibrium can be achieved using the design soil strengths or resistances and design vertical forces on the wall. As a minimum, the limit mode of the type illustrated in Figure 5.4 should be considered.

2 Where downward movement of the wall is considered, upper design values shall be used in the calculation of pre-stressing forces, such as those from ground anchorages, which have a vertical downward component. The design magnitude and direction of shear stress between the soil and the wall shall be consistent with the check for vertical and rotational equilibrium. If the wall acts as the foundation for a structure, vertical equilibrium shall be checked using the principles of Pile Foundations Design.

5.7.6 Structural design of retaining structures

1 Retaining structures, including their supporting structural elements such as anchorages and props, shall be verified against structural failure in accordance with EN1997-1 “2.4 Geotechnical Design by Calculation” and EN1992, EN1993, EN1995 and EN1996. As a minimum, limit modes of the types illustrated in Figure 5.5 should be considered.

5.7.7 Failure by pull-out of anchorages

1 It shall be demonstrated that equilibrium can be achieved without pull-out failure of ground anchorages. Anchors shall be designed in accordance with Anchorage Design procedures with minimum the limit modes of the types illustrated in Figure 5.6 (a, b) should be considered. For dead-man anchors, the failure mode illustrated in Figure 5.6 (c) should also be considered.

5.8 SERVICEABILITY LIMIT STATE DESIGN

5.8.1 General

1 The design of retaining structures shall be checked at the serviceability limit state using the appropriate design situations as specified in 5.3.3. The assessment of design values of earth pressures should take account of the initial stress, stiffness and strength of the ground and the stiffness of the structural elements.

2 The design values of earth pressures should be derived taking account of the allowable deformation of the structure at its serviceability limit state. These pressures need not necessarily be limiting values.

5.8.2 Displacements

1 Limiting values for the allowable displacements of walls and the ground adjacent to them shall be established for a particular deformation is the value at which a serviceability limit state, such as unacceptable cracking or displacement of adjacent structures or utilities, is deemed to occur. This limiting value shall be agreed during the design, taking into account the tolerance to displacements of supported structures and services.

2 If the initial cautious estimate of displacement exceeds the limiting values, the design shall be justified by a more detailed investigation including displacement calculations.

3 It shall be considered to what extent variable actions, such as vibrations caused by traffic loads behind the retaining wall, contribute to the wall displacement.

4 Displacement calculations should also be considered in the following cases:

(a) where the wall retains more than 6m of cohesive soil of low plasticity,

(b) where the wall retains more than 3m of soils of high plasticity;

(c) where the wall is supported by soft clay within its height or beneath its base.

5 Displacement calculations shall take into account the stiffness of the ground and structural elements and the sequence of construction.

6 The effect of vibrations on displacements shall be considered with regard to the following:

(a) Foundations for structures subjected to vibrations or to vibrating loads shall be designed to ensure that vibrations will not cause excessive settlements.

(b) Precautions should be taken to ensure that resonance will not occur between the frequency of the dynamic load and a critical frequency in the foundation-ground system, and to ensure that liquefaction will not occur in the ground.

(c) Vibrations caused by earthquakes shall be considered using the guidelines of the designated section of the QCS.

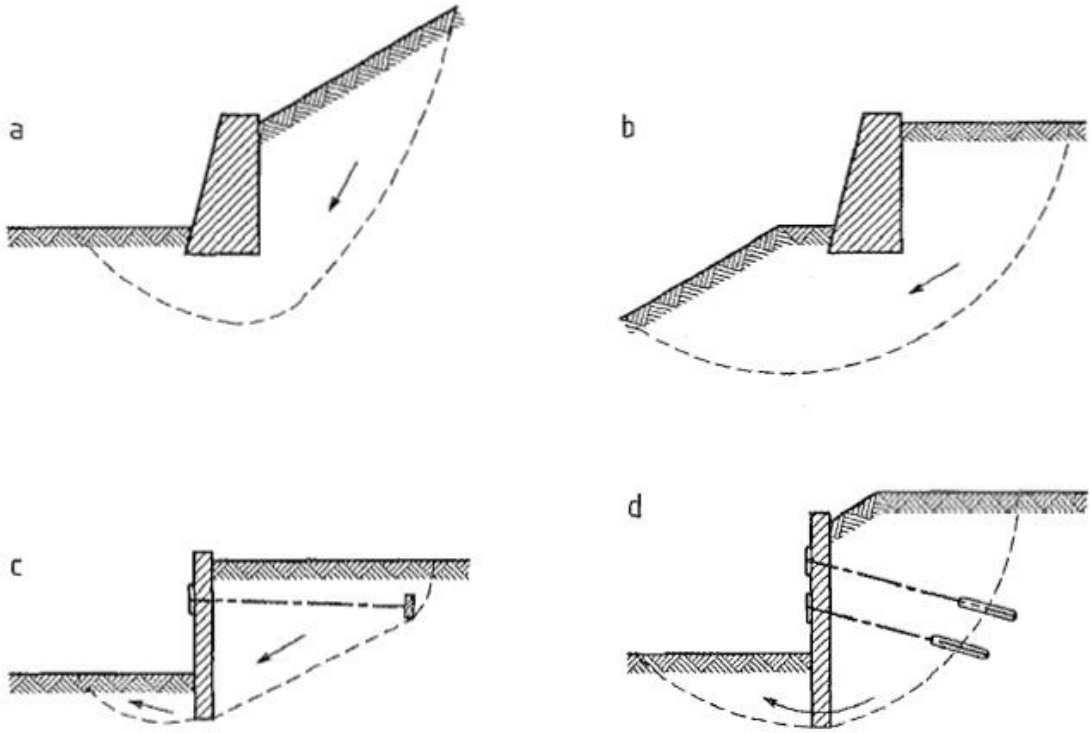

Figure 5.1 – Examples of Limit Modes for Overall Stability of Retaining Structures (EN 1997-1:2004+A1:2013)

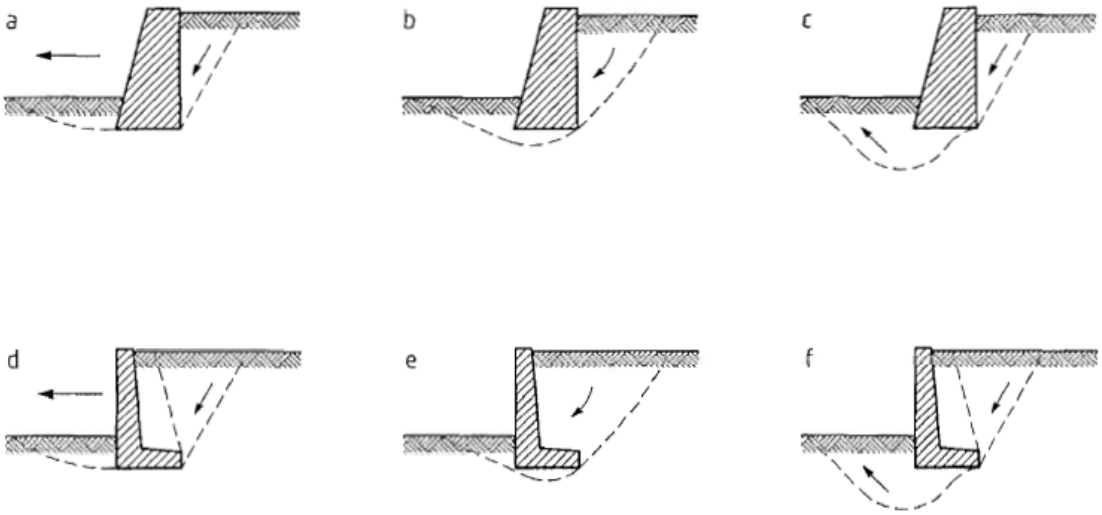

Figure 5.2 – Examples of Limit Modes for Foundation Failures of Gravity Walls (EN 1997-1:2004+A1:2013)

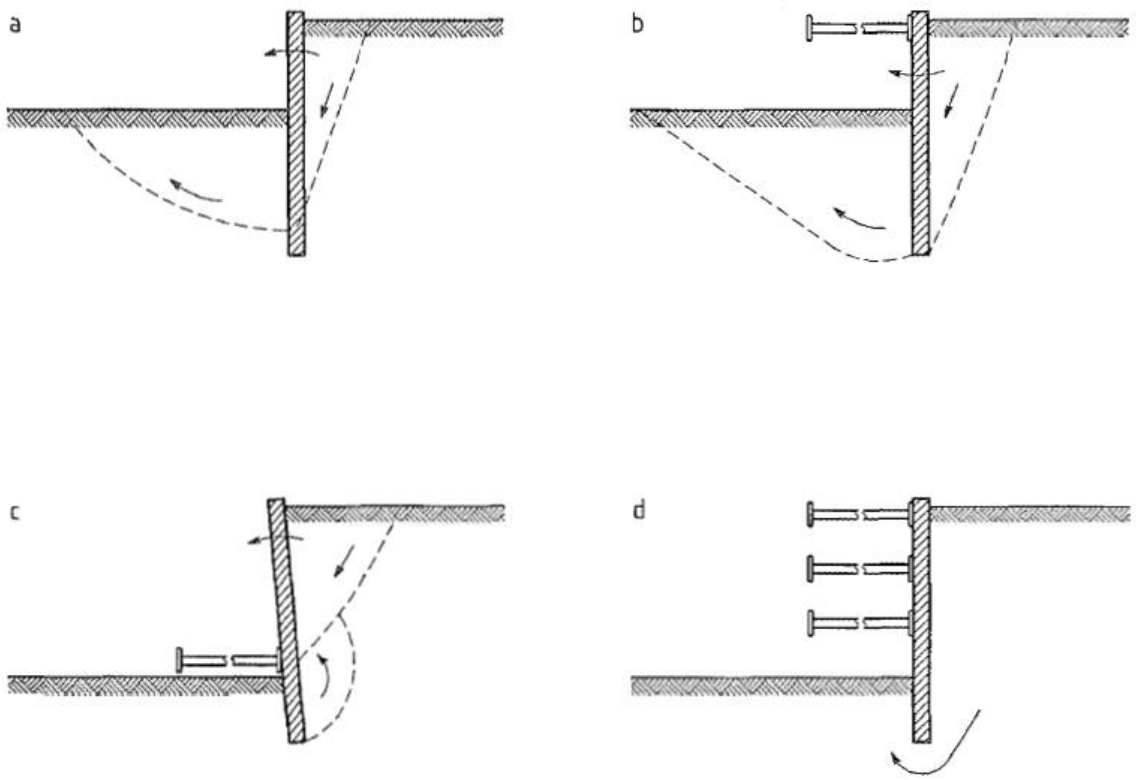

Figure 5.3 – Examples of Limit Modes for Rotational Failures of Embedded Walls (EN 1997-1:2004+A1:2013)

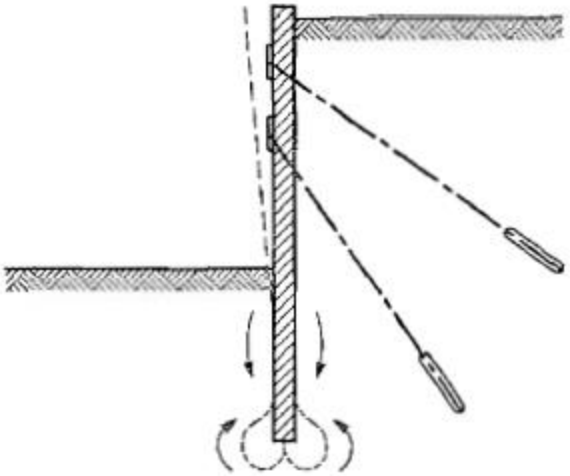

Figure 5.4 – Example of a Limit Mode for Vertical Failure of Embedded Walls (EN 1997-1:2004+A1:2013)

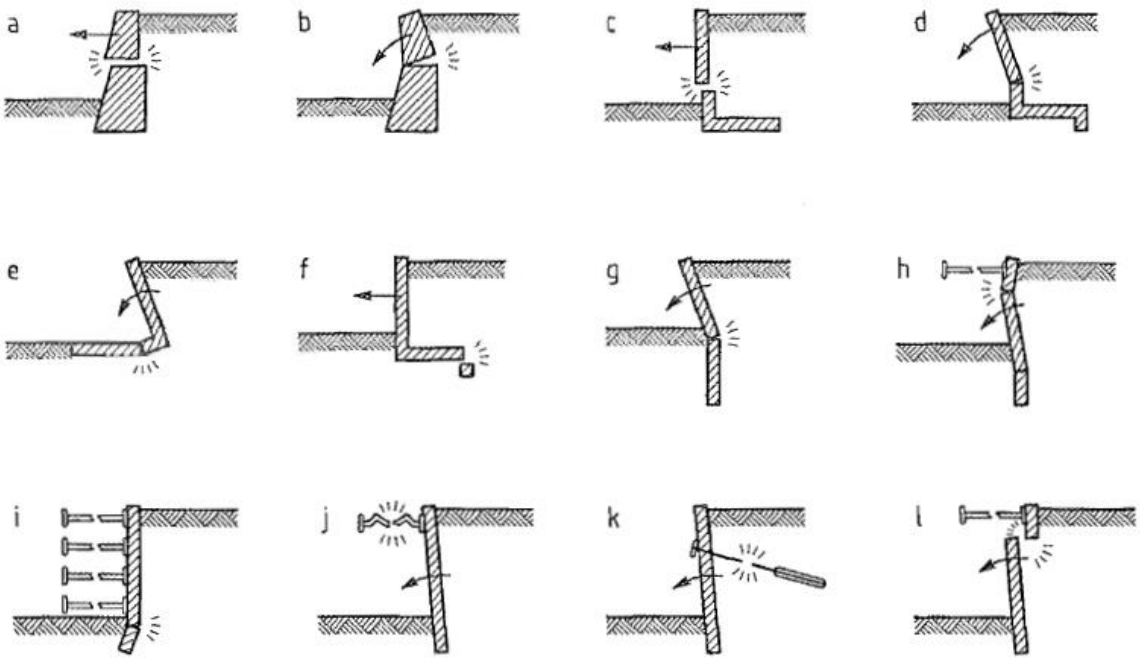

Figure 5.5 – Examples of Limit Modes for Structural Failure of Retaining Structures (EN 1997-1:2004+A1:2013)

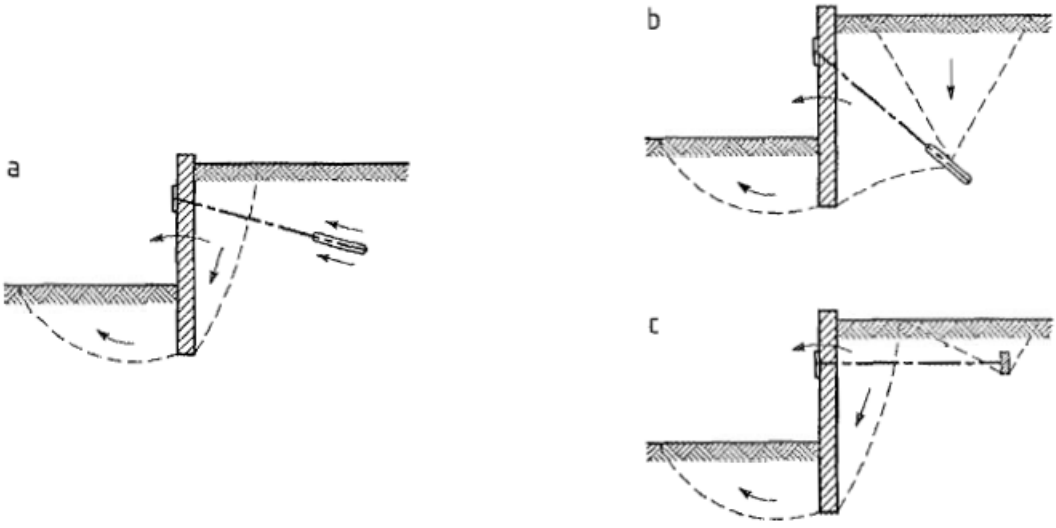

Figure 5.6 – Examples of Limit Modes for Failure by Pull-out of Anchoes (EN 1997-1:2004+A1:2013)

END OF PART