1 Introduction

1.1 Engineering prerequisites for applying the Recommendations (R l)

If no other stipulations are explicitly made in the individual Recommendations, they shall apply under the following engineering preconditions:

1. The complete height of the retaining wall is lined.
2. The soldier piles of soldier pile walls are installed such that intimate contact with the ground is ensured. The lining or infilling can consist of wood, concrete, steel, hardened cement-bentonite suspension or stabilised soil. It shall be installed such that the contact with the soil is as uniform as possible. Soil excavation should not advance considerably faster than plank installation. Also see DIN 4124.
3. Sheet pile walls and trench sheet piles are installed such that intimate contact with the ground is ensured. Toe reinforcement is permitted.
4. In-situ concrete walls are executed as diaphragm walls or as bored pile walls. Accidental or planned spacing between the piles is generally lined according to Paragraph 2.
5. In the horizontal projection, struts or anchors are arranged perpendicular to the retaining wall. They are wedged or prestressed such that contact by traction with the retaining wall is guaranteed.
6. Braced excavations are lined in the same manner on both sides with vertical soldier pile walls, sheet pile walls or in-situ concrete walls. The struts are arranged horizontally. The ground on both sides of the braced excavation displays approximately the same height, similar surface features and similar subsurface properties.

If these preconditions are not fulfilled, or those in the individual Recommendations, and no Recommendations are available for such special cases, this does not exclude application of the remaining Recommendations. However, the consequences of any deviations shall be investigated and taken into consideration.

1.2 Governing regulations (R 76)

1. Following its introduction, geotechnical analysis and design in Germany are controlled by DIN EN 1997-1: Eurocode 7: Geotechnical Design – Part 1: General Rules (Eurocode 7), in conjunction with the corresponding National Annex:

Recommendations on Excavations – EAB, 3rd edition.
Editors: German Geotechnical Society (Deutsche Gesellschaft für Geotechnik e. V.)

- DIN EN 1997-1/NA: National Annex – Nationally Determined Parameters – Eurocode 7: Geotechnical design – Part 1: General rules
  and
- DIN 1054: Subsoil – Verification of the Safety of Earthworks and Foundations – Supplementary Rules to DIN EN 1997-1.

These three coordinated standards are summarised in the 'Handbuch Eurocode 7, Band 1'.
The National Annex represents a formal link between the Eurocode EC 7-1 and national standards. It states which of the possible analysis methods and partial safety factors are applicable in the respective national domains. Remarks, clarifications or supplements to Eurocode EC 7-1 are not permitted. However, the applicable, complementary national codes may be given. The complementary national codes may not contradict Eurocode EC 7-1. Moreover, the National Annex may not repeat information already given in Eurocode EC 7-1.

2. In addition, the following Eurocode programme standards govern excavation structures:

EN 1990 Eurocode 0:	Basis of structural design
EN 1991 Eurocode 1:	Actions on structures
EN 1992 Eurocode 2:	Design of concrete structures
EN 1993 Eurocode 3:	Design of steel structures
EN 1995 Eurocode 5:	Design of timber structures
EN 1998 Eurocode 8:	Design of structures for earthquake resistance

3. The Eurocode 7 Handbook, Volume 1 contains general rules for geotechnical engineering. It is supplemented by the analysis standards which, where necessary, have been adapted to the partial safety factor approach. The following codes in particular also represent the governing standards for excavation structures:

DIN 4084:	Global stability analyses
DIN 4085:	Subsoil – Calculation of earth pressure
DIN 4126:	Cast-in-situ concrete diaphragm walls; design and construction
DIN 4093:	Design of ground improvement – Jet grouting, deep mixing or grouting

4. The standards covering ground exploration, investigation and description are not affected by the adaptation to partial safety factors and therefore remain valid in their respective latest editions, or are superseded by Eurocode 7 and EN ISO standards:

   EN 1997-2, Eurocode 7: Geotechnical design – Part 2: Ground investigation and testing

EN 1997-2/NA: National Annex – Nationally Determined Parameters – Eurocode 7, Part 2: Ground investigation and testing
DIN 4020: Geotechnical investigations for civil engineering purposes – Supplementary rules to DIN EN 1997-2
DIN 4023: Geotechnical investigation and testing – Graphical presentation of logs of boreholes, trial pits, shafts and adits
EN ISO 22475-1: Geotechnical investigation and testing – Sampling by drilling and excavation and groundwater measurements – Part 1: Technical principles for execution, supersedes DIN 4021 and DIN 4022
EN ISO 14688-1: Geotechnical Investigation and testing – Identification and classification of soil – Part 1: Identification and description, superseded by DIN 4022-1
EN ISO 14688-2: Geotechnical Investigation and testing – Identification and classification of soil – Part 2: Principles for classification, superseded by DIN 4022-1
EN ISO 14689-1: Geotechnical Investigation and testing – Identification and classification of rock – Part 1: Identification and description, superseded by DIN 4022-1
EN ISO 22476-2: Dynamic probing
EN ISO 22476-3: Standard Penetration Test
DIN 4094-2: Subsoil – Field testing – Part 2: Borehole dynamic probing
DIN 18121 to DIN 18137: Investigation of soil samples
DIN 18196: Soil classification for civil engineering purposes
DIN 1055-2: Soil properties

5. The Eurocode 7 Handbook, Volume 1, only replaces the analysis section of the previous standards DIN 4014 “Bored piles”, DIN 4026 “Driven piles”, DIN 4125 “Ground anchorages – Design, construction and testing” and DIN 4128 “Grouted piles (in-situ concrete and composite piles) with small diameter”. The new European standards from the “Execution of special geotechnical works” series now take the place of the execution sections of these standards:

EN 1536:	Bored piles
EN 1537:	Grouted anchors
EN 1538:	Diaphragm walls
EN 12063:	Sheet pile walls
EN 12699:	Displacement piles
EN 12715:	Grouting
EN 12716:	Jet grouting
EN 12794:	Precast concrete – foundation piles
EN 14199:	Micropiles

6. The following execution standards are not affected by the adaptation to European standards and therefore continue to govern excavation structures:

DIN 4095:	Drainage systems protecting structures
DIN 4123:	Excavations, foundations and underpinnings in the area of existing buildings
DIN 4124:	Excavations and trenches

1.3 Safety factor approach (R 77)

1. In contrast to the original probabilistic safety factor approach, this safety factor approach, upon which both the new European standards generation and the new national standards generation are based, no longer rests on probability theory investigations, e.g. the beta-method, but on a pragmatic splitting of the previously utilised global safety factors into partial safety factors for actions or effects and partial safety factors for resistances.

2. The foundation for stability analyses is represented by the characteristic or representative values for actions and resistances. The characteristic value is a value with an assumed probability which is not exceeded or fallen short of during the reference period, taking the lifetime or the corresponding design situation of the civil engineering structure into consideration; it is characterised by the index “k”. Characteristic values are generally specified based on testing, measurements, analyses or empiricism.

   Variable actions can also be given as representative values, thus taking into consideration that not all variable, unfavourable actions occur simultaneously at their maximum values.

3. If the bearing capacity in a given cross-section of the retaining wall or in an interface between the retaining wall and the subsoil needs to be analysed, the effects in these sections are required:

   - as action effects, e.g. axial force, shear force, bending moment;
   - as stresses, e.g. compression, tension, bending stress, shear stress or equivalent stress.

   In addition, further effects of actions may occur:

   - as oscillation effects or vibrations;
   - as changes to the structural element, e.g. strain, deformation or crack width;
   - as changes in the position of the retaining wall, e.g. displacement, settlement, rotation.

4. Two types of ground resistances are differentiated:

   a) The characteristic shear strength of the soil is the decisive basic resistance parameter. For consolidated soils or soils drained for testing these are the shear parameters φ'_k and c'_k, and for unconsolidated soils or soils not drained for testing the shear parameters $\varphi_{u,k}$ and $c_{u,k}$. These variables are defined as cautious estimates of the mean values, because the shear strength at a single point of the slip surface is not the decisive value but the average shear strength in the slip surface.
   b) The soil resistances are derived from the shear strength, directly:

      – the sliding resistance;
      – the bearing capacity;
      – the passive earth pressure;

      and indirectly via load tests or empirical values:

      – the toe resistance of soldier piles, sheet pile walls and in-situ concrete walls;
      – the skin resistance of soldier piles, sheet piles walls, in-situ concrete walls, and of ground anchors and soil and rock nails.

   The term “resistance” is only used for the failure state of the soil. As long as the failure state of the soil is not achieved by effects, the term “soil reaction” is used.

5. The cross-section and internal resistance of the material are the decisive factors in the design of individual components. The detailed specification standards continue to be the governing standards here.

6. The characteristic values of the effects are multiplied by partial safety factors, those of the resistances are divided. Where necessary, representative values should be adopted by applying combination factors. The variables acquired in this way are known as the design values of effects or resistances respectively and are characterised by the index *d*. Five limit states are differentiated for stability analyses, in line with R 78 (Section 1.4).

7. In terms of the GEO 2 and STR limit state safety analyses according to R 78, Paragraph 4 (Section 1.4), Eurocode EC 7-1 provides three options. DIN 1054 is based on design approach 2 inasmuch as the partial safety factors are applied to the effects and to the resistances. To differentiate between this and the other permitted scenario, in which the partial safety factors are not applied to the effects but to the actions, this procedure is designated as design approach 2* in the Commentary to Eurocode EC 7-1 [134].

8. In addition to the actions, the design situation shall be taken into consideration in the analyses. To this end the existing load cases LC 1, LC 2 and

LC 3, adopted for use in analyses to DIN 1054:2005-01, have been superseded by the design situations for use in analyses to the Eurocode 7 Handbook, Volume 1, and DIN EN 1990 as follows:

DS-P (persistent situation);
DS-T (transient situation) and;
DS-A (accidental situation).

The former LC 2/3 corresponds to design situation DS-T/A. In addition, there is the seismic design situation, DS-E. More detailed information can be found in the Eurocode 7 Handbook, Volume 1.

1.4 Limit states (R 78)

1. The term "limit state" is used with two different meanings:

   a) In soil mechanics, the state of the soil in which the displacement of the individual soil particles against each other is so great that the mobilisable shear strength achieves its greatest values in either the entire soil mass, or at least in the region of a failure plane, is known as the *limit state of plastic flow*. It cannot become greater even if more movement occurs, but may become smaller. The limit state of plastic flow characterises the active earth pressure, passive earth pressure, bearing capacity, slope stability and overall stability.
   b) A limit state in the sense of the new safety factor approach is a state of the load-bearing structure where, if exceeded, the design requirements are no longer fulfilled.

2. The following limit states are differentiated in conjunction with the partial safety factor approach:

   a) The ultimate limit state is a condition of the structure which, if exceeded, immediately leads to a mathematical collapse or other form of failure. In the Eurocode 7 Handbook, Volume 1, it is referred to as ULS (ultimate limit state). Five cases of ULS are differentiated, see Paragraphs 3, 4 and 5.
   b) The serviceability limit state (SLS) is a condition of the structure which, if exceeded, no longer fulfils the conditions specified for its use. In the Eurocode 7 Handbook, Volume 1, it is referred to as SLS (serviceability limit state).

3. Eurocode 7 defines the following limit states:

   a) EQU: loss of equilibrium of the structure, regarded as rigid, without the influence of soil resistances.

b) STR: inner failure or very large deformation of the structure or its components, whereby the strength of the materials is decisive for resistance.
c) GEO: failure or very large deformation of the subsoil, whereby the strength of the soil or rock is decisive for resistance.
d) UPL: loss of equilibrium of the structure or ground due to uplift or water pressure.
e) HYD: hydraulic failure, inner erosion or piping in the ground, caused by a hydraulic gradient.

4. In order to transfer it to the provisions of DIN 1054 the GEO limit state shall be divided into GEO 2 and GEO 3 limit states:

   a) GEO 2: failure or very large deformation of the subsoil in conjunction with identification of the action effects and dimensions; i.e. when utilising the shear strength for passive earth pressure, sliding resistance and bearing resistance and when analysing lower failure plane.
   b) GEO 3: failure or very large deformation of the ground in conjunction with analysis of overall stability, i.e. when utilising the shear strength for analysis of the safety against slope failure and global failure and, generally, when analysing the stability of engineered slope stabilisation measures.

5. The previous limit states are replaced as follows:

   a) The previous limit state GZ 1A now corresponds without restrictions to the EQU, UPL and HYD limit states.
   b) The previous limit state GZ 1B corresponds without restrictions to the STR limit state. In addition, the GEO 2 limit state applies in conjunction with external design, i.e. when utilising the shear strength for passive earth pressure, sliding resistance and bearing capacity and when analysing lower failure plane.
   c) The previous GZ 1C limit state corresponds to the GEO 3 limit state, in conjunction with analysis of overall stability, i.e. when utilising the shear strength for analysis of safety against slope failure and overall stability.

   Analysis of the stability of engineered slope stabilisation measures is always allocated to the GEO limit state. Depending on the specific design and function they may be dealt with:

   – either in the sense of the previous limit state GZ 1B adopting the provisions of the GEO B limit state;
   – or in the sense of the previous limit state GZ 1C adopting the provisions of the GEO C limit state.

6. The EQU, UPL and HYD limit states describe the loss of static equilibrium:

   – analysis of safety against overturning EQU;
   – analysis of safety against uplift UPL;
   – analysis of hydraulic heave safety HYD.

   Only actions are associated with these limit states, no resistances. The governing limit state condition is:

   $F_d = F_k \cdot \gamma_{dst} \leq G_k \cdot \gamma_{stb} = G_d$

   i.e. the destabilising action F_k, multiplied by the partial safety factor $\gamma_{dst} \geq 1$, may only be as large as the stabilising action G_k, multiplied by the partial safety factor $\gamma_{stb} < 1$.

7. The STR and GEO 2 limit states describe the failure of structures and structural elements or the failure of the ground. They include:

   – analysis of the bearing capacity of structures and structural elements subjected to soil loads or supported by the soil;
   – verification that the bearing capacity of the soil is not exceeded, e.g. by passive earth pressure, bearing capacity or sliding resistance.

   Verification that the bearing capacity of the ground is not exceeded is performed exactly as for any other construction material. The limit state condition is always the governing condition:

   $E_d = E_k \cdot \gamma_F \leq R_k/\gamma_R = R_d$

   i.e. the characteristic action effect E_k, multiplied by the partial safety factor γ_F for actions or γ_E for effects, may only become as large as the characteristic resistance R_k, divided by the partial safety factor γ_R.

8. The GEO 3 limit state is peculiar to geotechnical and ground engineering. It describes the loss of overall stability. They include:

   – analysis of safety against slope failure;
   – analysis of safety against global failure of retaining structures.

   The limit state condition is always the governing condition:

   $E_d \leq R_d$

   i.e. the design value E_d of the effects may only become as large as the design value of the resistances R_d. The geotechnical actions and resistances are determined using the design values for shear strength:

   $\tan \varphi'_d = \tan \varphi'_k/\gamma\varphi'$ and $c'_d = c'_k/\gamma_c'$ or
   $\tan \varphi_{u,d} = \tan \varphi_{u,k}/\gamma\varphi'$ and $c_{u,d} = c'_k/\gamma_{cu}$

i.e. the tangent of the angle of internal friction φ and the cohesion c are reduced by applying the partial safety factors γ_{φ}' and γ_c'.

9. The serviceability limit state describes the state of a structure at which the conditions specified for its use are no longer fulfilled, without a loss of bearing capacity. It is based on verification that the anticipated displacements and deformations are compatible with the purpose of the structure. For excavations, the SLS includes the serviceability of neighbouring buildings or structures.

1.5 Support of retaining walls (R 67)

1. Retaining walls are called unsupported if they are neither braced nor anchored and their stability is based solely on their restraint in the ground.
2. Retaining walls are called yieldingly supported if the wall support points can yield with increasing load, e.g. in cases where the supports are heavily inclined toward the excavation base and when using non-prestressed or only slightly prestressed anchors.
3. Retaining wall supports are called slightly yielding in the following cases:
   a) Struts are at least tightly connected by frictional contact (e.g. by wedges).
   b) Grouted anchors are prestressed and locked off to at least 80 % of the computed characteristic effect required for the next construction stage, see Section 7.
   c) A tight connection via frictional contact is established with piles, which verifiably display only a small head deflection under load.
4. Retaining wall supports are known as nearly inflexible if designed according to R 22, Paragraph 1 (Section 9.5), utilising increased active earth pressure, and the struts and anchors are prestressed and locked off according to R 22, Paragraph 10.
5. Retaining wall supports are defined as inflexible only if they are designed either for reduced or for the full at-rest earth pressure according to R 23 (Section 9.6) and the supports are prestressed accordingly. Furthermore, the anchors of anchored retaining walls shall be socketed in non-yielding rock strata or be designed substantially longer than required by calculations.

   If the requirements of Paragraphs 4 or 5 are fulfilled and, in addition:

   – a rigid retaining wall is installed and;
   – excessive toe deflections are avoided;

an excavation structure may be regarded as a low-deflection and low-deformation structure.

1.6 Planning and examination of excavations (R 106)

1. If the planner is not in possession of sufficient expertise and experience, a suitable planner shall be contracted for the geotechnical design of the excavation in line with the Eurocode 7 Handbook, Volume 1, Paragraph 1.3, A 3.

2. The term "geotechnical expert" used in the Recommendations is understood as it is used in the Eurocode 7 Handbook, Volume 2, Paragraph A 2.2.2.

3. Excavations are classified as Geotechnical Category GC 1, GC 2 or GC 3. Annex A5 lists criteria for classifying excavations based on the Eurocode 7 Handbook, Volume 1, Paragraph A 2.1.2.

4. A Geotechnical Design Report in line with the Eurocode 7 Handbook, Volume 1, Paragraph 2.8 shall be compiled for excavations.

   With regard to Geotechnical Categories GC 2 and GC 3, the Geotechnical Design Report for the excavation should contain the following points:

   – Description of the plot and its environs, in particular adjacent buildings;
   – Description of ground conditions with reference to the Geotechnical Report in accordance with the Eurocode Handbook, Volume 2, Paragraph A 7;
   – Description of the proposed excavation structure;
   – Description of the actions from adjacent structures;
   – Description of the impacts on adjacent areas and structures;
   – Characteristic values of soil and rock properties, and of water levels and flows;
   – Proposal for excavation structure and identification os possible risks;
   – Design situation and partial factors;
   – Where necessary, an explanation of the necessity, suitability and sufficiency of the observational method;
   – Analyses, including information on the analysis method and plans;
   – Specifications for manufacturing controls, e.g. load tests;
   – Specifications for measurements and monitoring.

5. Where excavations are classified as Geotechnical Category GC 3 a geotechnical expert shall be consulted.

6. When executing excavations classified as Geotechnical Category GC 2 or GC 3, it is recommended to employ a suitable site supervisor in possession of the appropriate experience and excavation knowledge. For excavations classified as Geotechnical Category GC 3 it is recommended to also employ the geotechnical expert discussed in Section 5 to check the detailed design and to assess the results of measurements and monitoring.