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VOLUME I: DESIGNING

SECTION 1: ROAD DESIGNING

Part 2: ENGINEERING-GEOLOGICAL and GEOTECHNICAL INVESTIGATIONS and TESTING

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2.1 INTRODUCTION

A precondition to prepare a good design is, in addition to exact geodetic survey of the area, also a proper geotechnical investigation. For the purpose of uniform implementation and documentation of this investigation in terms of the form and contents, a group of experienced geologists and geotechnicians has prepared a description of individual work, which is indispensable in geotechnical investigations. This has resulted in a written document providing individual contractors with equal bases, better quality of the work and more reliable results. In addition to the above, this document also enables the investor to prepare an appropriate tender documentation for the investigations considered.

The Recommendations, among others, logically take into account the Eurocodes, which have been recently introduced into the civil engineering and geotechnical practice.

2.2 PURPOSE OF RECOMMENDATIONS

The Recommendations have been prepared in such a way, that they can be primarily used as an aid and guide to the person, who prepares the programme of geological and geotechnical investigations both in the tender and implementation stages, and can later on assist the contractor of these investigations.

The primary purpose of the Recommendations is to define the type, scope and method of implementation of individual investigations in relation to:

- Geotechnical conditions in the area of the road's route with appertaining facilities; and
- Stage of geotechnical investigations and the level of preparation of the design documentation.

However, the "engineering assessment" on the type and quantity of investigations is basically the right and duty of the responsible geologist and geo-technician whereby this assessment must be in line with the basic requirements set in this and similar documents. And last but not least, the purpose of the Recommendations is also to limit the subjective influence of the person preparing the programme of investigations to the quantity and type of investigations. Both the responsible geologist and the responsible geo-technician are members of the design team, that, under the leadership of the responsible designer (or project coordinator) of a particular facility, appointed in accordance with the law, prepares geotechnical conditions of construction of the facility

2.2.1 COMPOSITION OF RECOMMENDATIONS

The Recommendations consist of the main (substantive) part and the supplementary (annexes) part.

The substantive part includes five chapters, consisting of the following:

- **The basic pu**rpose of preparation of the document;
- **The appro**ach to implementation of geotechnical investigations including the initial cabinet work, field research work, laboratory tests and calculative analyses;
- **The course of geotechnical investigations**, which depends on the stage / design level for which the geotechnical investigations are performed;
- **Contents of geotechnical reports and studies**;
- **Description of individual type of investigations** and the envisaged implementation procedure.

The Recommendations are supplemented by annexes (Chapter 6) including the implementation method for individual types of investigations, aligned with the applicable law. The annexes shall be promptly supplemented and adjusted to the expert requirements.

2.2.2 STAGES OF GEOTECHNICAL INVESTIGATIONS AND THE DESIGN DOCUMENTATION LEVELS

Rules of the geotechnical field of expertise, which has found its place in the modern European and other standards, have been formed by the rational approach to obtaining data on composition of the soil and conditions of the envisaged construction. These rules divide investigations in three stages following each other as specified below:

Table I:

TEST STAGE	OBJECTIVE
Preliminary investigations	**Rough knowledge of the composition and properties of the soil, in order to enable:** – Selection of the most suitable construction method; – Decision of suitability of the location of the envisaged construction; – Specifying the preliminary design of the structure's foundations / the construction method of geotechnical structures; – Defining the type and scope of investigations in the subsequent stage by taking into account the preliminary design of the facility.
Main investigations	**Obtain all necessary geological and geotechnical data for integrated design of the road's layout and foundations of the structures.**
Supplementary investigations	**Supplement the data obtained in previous stages, e.g. in the following cases:** – If the analysis of previously obtained data points to their unreliability or deficiency; – The design or location of the facility has changed; – Field conditions have changed.

In addition to these three stages there are also:

- *Preparation for investigations*, required for preparing the tender for the preliminary stage of investigations. Generally, they are performed by expert services of the Client.
- *Current (accompanying) investigations* performed in line with the advance of geotechnical construction (characteristic for tunnels and deep cuts, conditionally also for excavations for foundations and similar).
- *Control investigations* whereby design assumptions are confirmed and quality of performed work controlled.

The interpretation of each subsequent test stage shall include all findings of previous stages.

The applicable legislation and practice in motorway design envisage design in several stages (studies of alternatives, preliminary design, construction permit design, tender design, implementation design, as-built design). The relation between design stages and geotechnical test stages in road planning is as follows:

Table II

DESIGN STAGE	GEOTECHNICAL TEST STAGE
Study of alternatives	Preliminary investigations
Preliminary design	Main investigations
Construction permit design	
Tender design	Supplementary investigations
Implementation design	
As-built design	Current (accompanying) and control investigations

2.3 APPROACH TO IMPLEMENTATION OF GEOTECHNICAL INVESTIGATIONS

It is recommended to implement the geological – geotechnical investigations in the following order and with the indicated contents:

2.3.1 CABINET WORK – COLLECTION OF EXISTING DATA

- Cabinet review of the layout and/or structure design
- Review of existing geological and morphological maps and geodetic bases
- Review of any existing geotechnical documentation (e.g. reports on preliminary test stages)
- Obtaining and reviewing the documentation on any past constructions in the vicinity
- Review of data on behaviour of existing relevant adjacent facilities
- Obtaining and reviewing stereoscopic pairs of air photos and other remote data
- Obtaining and reviewing geotechnical data from the existing digital databases

2.3.2 FIELD RESEARCH WORK

- Review and recognition of the ground (full field inspection of the area of influence of the route in an appropriate width, detection of characteristic morphological, geological, engineering geological, hydrogeological and other phenomena)
- Geological mapping in the area of influence of the route (structural geological, hydrogeological and engineering geological mapping)
- Detailed geological mapping of the direct area of the route (structural geological, hydro-geological and engineering geological mapping)
- Test pits, test shafts and outcrops (excavation, mapping, sampling, geotechnical measurements in shafts)
- Exploratory drilling (implementation, monitoring parameters of drilling, recording of cores, RQD, taking of intact and disturbed samples, geotechnical investigations in boreholes (SPT, FVT, pressuremeter, borehole-logging, geophysical measurements), equipping the borehole for further monitoring – piezometer, inclinometer)
- Geomechanical investigations (measurements and evaluation of results):
  - *Standard penetration test – SPT*
  - *Field Vane test - FVT*
  - *Dynamic probing - DP*
  - *Cone penetration test – CPT*
  - *Pressuremeter test - PMT*
  - *Dilatometer test - DMT*
  - *Plate Loading Test - PLT*
- Hydrogeological investigations (measurements and evaluation of results):
  - *Measuring piezometer levels of water in the aquifer and determining the ground water flow*
  - *Performing and evaluating pumping and pouring tests*
  - *Sampling of ground water for chemical and bacteriological analyses*
  - *Hydrogeological classification with regard to the aquifer type and the necessary protection of the ground water*
- Geophysical investigations (measurements and evaluation of results):
  - *Performing and evaluating field measurements (geoelectricity, geoseismicity, georadar and others if needed)*

- *Performing and evaluating measurements in boreholes (borehole-logging, between the boreholes, between the surface and the borehole)*

o Other Field testing (measurements and evaluation of results):

- *Geodetic measurements*
- *Inclinometer measurements*
- *Piezometer measurements*
- *Extensiometer measurements*
- *Static and dynamic load tests of piles pile driving tests*
- *Other special geotechnical measurements (stresses in the ground, advancement of discontinuities, vibrations and other)*
- *Implementation of probing excavations and test fields right before construction of embankments (the need for improving the original subgrade, use of specific materials, use of new technologies…)*
- *Anchorage testing (partial and full load tests of anchors, tests of electro resistance)*

2.3.3 LABORATORY TESTS

o Examination of submitted samples and preparation of a detailed programme of geotechnical laboratory tests

o Soil tests

- *Identification (classification) tests*
- *Determining the unit weight*
- *Tests of strength parameters*
- *Tests of deformability*
- *Tests of permeability*
- *Tests of suitability for construction of embankments*
- *Basic chemical tests of soils*

o Tests of rocks

- *Preparing samples for testing*
- *Classification and identification of rocks (petrographic and mineralogical tests)*
- *Tests of strength parameters*
- *Determination of swelling properties*
- *Tests of deformability*
- *Tests of usability of rock material for processing into rock aggregates*
- *Tests of suitability for construction of embankments*

o Geological tests

- *Paleontological*
- *Stratigraphic*
- *Sedimentological*
- *X-ray*
- *Other*

2.3.4 CALCULATIVE ANALYSES

- **Back analyses for verification of obtained characteristics**
  - *Back analyses of stability of avalanche areas*
  - *Back analyses of documented behaviour of relevant facilities near the location of the planned construction*
- **Calculative analyses for the geological geotechnical report**
  - *Global stability analysis*
  - *Calculation of bearing capacity of soil*
  - *Calculation of settlement and their development in time*
  - *Numeric modelling*
  - *Other computer analyses with regard to the project nature*

2.4 COURSE OF GEOTECHNICAL INVESTIGATIONS

A detailed description of the most appropriate course of individual stages of geotechnical investigations is given below:

2.4.1 PREPARATION FOR INVESTIGATIONS

2.4.1.1 Objective

- *Preliminary evaluation of the design and geotechnical conditions from the point of view of planning geotechnical investigations*
- *The objective of this stage is to prepare a tender for the preliminary stage of geotechnical investigations.*

2.4.1.2 Implementer

- *Expert service of the Client*
- *Research institution (ordered by the Client – if necessary)*

2.4.1.3 Required bases

- *The most current version of the design (layout, longitudinal section, cross sections)*
- *Archive geotechnical data (if available)*

2.4.1.4 Stages and methods of investigations

- *Selection of cabinet work methods (see 1.1.2.1.1)*
- *Examination and recognition of the ground (see 1.1.2.1.2)*

2.4.1.5 Final document

- *The project of the preliminary stage of geotechnical investigations*

2.4.1.6 Review

- *In particularly complex (in geological, morphological, geotechnical terms) motorway routes, the expert review of the preliminary stage of geotechnical investigations is required.*

2.4.2 PRELIMINARY INVESTIGATIONS

2.4.2.1 Objective

- *Obtaining basic data on composition and properties of the soil (see Table I)*
- *Obtaining appropriate data for preparing the programme of main investigations*

2.4.2.2 Implementer

- *Research institution with suitable references in the area of geotechnical investigations*

2.4.2.3 Required bases

- The most current version of the design (layout 1:1000, longitudinal section 1:1000/100, cross sections)
- Archive geological – geotechnical data (where available)
- Stages and methods of investigations
- Selection of cabinet work methods (see 2.3.1)
- Geological mapping (see 2.3.2)
- [Selection of other field research work and laboratory tests][1]

2.4.2.4 Final document

In relation to the subject of preliminary investigations, the document may be:

- Report on preliminary geotechnical investigations for the route and the structures
- Comparative geotechnical study of the route's layout

2.4.2.5 Review

- Carried out in line with the assessment of the expert service of the Client

2.4.3 MAIN INVESTIGATIONS

2.4.3.1 Objective

- Obtaining all required data on composition and properties of the soil (see Table I)

2.4.3.2 Implementer

- Research institution having all references required by the tender

Required bases and the existing documentation

- The most current version of the design (layout, longitudinal section, cross sections, design of the facility)
- Report on preliminary geotechnical investigations
- Other data, which can influence the programme of investigations and conditions of the construction / foundations of the structures, such as:
  - *As regards structures: loading of foundations*
  - *As regards embankments: data, which can influence the selection of the filling material (floods in the area, availability of material from cuts, priority of selection of side excavations...), available consolidation time*
  - *Special requirements by the responsible project manager and designer*

2.4.3.3 Stages and methods of investigations

The main investigations generally include extremely varied activities, which are interdependent in terms of time, and current results can have an impact on corrections in details of the testing programme.

Three clearly distinguished stages are envisaged, with milestones being separate final documents. Tests can be performed in a single stage in case of simple facilities or for geotechnically simple locations, which has to be specifically mentioned in the tender for investigations.

- o *First stage:*
  - – *Objective: Getting the information on geological structure of the area and geotechnical properties of soil to the extent enabling preparation of the detailed programme of field and laboratory testing and calculative analyses.*
  - – *Methods:*

[1] Indents in angular brackets mean non-obligatory however often required work. Option.

    - *Cabinet work methods (see 1.1.2.1.1)*
    - *Detailed geological mapping (see 1.1.2.1.2)*
    - *[Selection of other field research work]*
    - *[Selection of laboratory tests (see 1.1.2.1.3)]*
    - *[Selection of calculative analyses (see 1.1.2.1.4)]*
  - *Final document: A design draft of the main geotechnical investigations*
  - *Review: A design draft is submitted for review and approval to the expert service of the Client.*

- *Second stage:*
  - *Objective: Getting information on the detailed structure of the area and physical properties of all characteristic materials on the basis of implementation of all research work envisaged in the approved programme. The results of this and the preceding stages shall enable an adequate preparation of the project for the planned facility.*
  - *Methods):*
    - *Selection of field research work with regard to the type of facility and the type of soil (see 1.1.2.1.2)*
    - *Selection of laboratory tests with regard to the type of facility and the type of soil (see 1.1.2.1.3)*
    - *[Selection of calculative analyses with regard to the nature of the project (see 1.1.2.1.4)]*
  - *Final document: Report on results of the main geotechnical investigations*
  - *Review: The programme is submitted for review and approval to the expert service of the Client.*

- *Third stage :*
  - *Objective: Analysing the results of all performed investigations and determining the conditions for implementation of the geotechnical facility and conditions for foundations of the facility. The final document is a link between the test results and the designer.*
  - *Methods:*

    Selection of calculative analyses or empiric methods with regard to the nature of the project (see 1.1.2.1.4)
  - *Final document: Report on conditions of the construction and conditions of foundations of the facility*
  - *Review: Carried out in line with the assessment of the expert service of the Client*

- *Final document*

  The final report consists of two parts: As regards the route:
  - *Report on results of the main geotechnical investigations for the route*
  - *Report on conditions for the motorway construction*

  The final report for the structure consists of:
  - *Report on results of the main geotechnical investigations for the structure*
  - *Report on conditions for foundations of the facility*

- *Review*

  The final report is subject to review by the expert service of the Client and/or external audit.

2.4.4 SUPPLEMENTARY INVESTIGATIONS

2.4.4.1 Objective

- *Supplementing the data obtained at previous stages (see Table I)*

2.4.4.2 Implementer

- *Research institution with appropriate references (if possible the one performing main investigations)*

Required bases and the existing documentation

- *The most current version of the design (layout, longitudinal section, cross sections)*
- *Report on preliminary and main geotechnical investigations*
- *Data on changes of the structure and other reasons for supplementary investigations*
- *Special requirements by the responsible project manager and designer*

2.4.4.3 Stages and methods of investigations

- *[Selection of cabinet work methods (see 1.1.2.1.1)]*
- *[Detailed geological mapping (see 1.1.2.1.2)]*
- *[Selection of other field research work]*
- *[Selection of laboratory testing (see 1.1.2.1.3)]*
- *[Selection of calculative analyses (see 1.1.2.1.4)]*

2.4.4.4 Final document

In relation to the subject of supplementary investigations, the document may be:

- *Report on results of the supplementary geotechnical investigations for the route*
- *Report on results of the supplementary geotechnical investigations for the structure*

2.4.4.5 Review

Geotechnical reports shall be reviewed by experts. The review method shall be determined by the expert services of the Client.

2.4.5 GEOTECHNICAL MONITORING OF CONDITION OF FACILITIES AFTER CONSTRUCTION

2.4.5.1 Objective

The term geotechnical monitoring of condition of facilities include earth structures, such as cuts and embankments, as well as any retaining structures (gravity walls, anchored walls, sheet pile walls, various types of composite retaining structures), and foundations of bridging and other complex structures.

The basic objective of geotechnical monitoring is to check the functional abilities of a facility. In case of any changes of conditions, prompt measures are required with additional geotechnical interventions in terms of due diligence and providing for traffic safety.

2.4.5.2 Implementer

- *The implementer can be a company having positive references to prove its ability to implement and interpret the appropriate geotechnical, geodetic and/or other required types of measurements and prepare, on the basis of measurement results, the appropriate analyses and geotechnical reports on condition of the facility.*

2.4.5.3 Required bases

- *The works implementation design and the as-built design*
- *Report on main geotechnical investigations*
- *Geotechnical report for the structure (the works implementation design level)*

- o *Terms of reference for implementing geotechnical monitoring*

2.4.5.4 Stages and methods of investigations

- o *Review of the existing design-technical documentation*
- o *Performing the required measurements on the facility*
- o *Interpretation of the measurement results*
- o *Preparing* the report with proposed measures and/or further monitoring

2.4.5.5 Final document

- o *The final report on geotechnical monitoring of the facility in the period with the proposed measures and further measurements*

2.4.5.6 Review

The final report on geotechnical monitoring of the facility after construction shall be reviewed by experts. The review method shall be determined by the expert services of the Client.

2.5 CONTENTS OF GEOTECHNICAL REPORTS

Given the fact that the geological geotechnical report is the final act of the entire research work, its full and integrated contents is important for all subsequent users of the report (designers, clients, supervising engineers and contractors). For that purpose, recommendations for contents of the geological geotechnical report are specified below:

2.5.1 CONTENTS OF REPORTS – GENERAL

Generally, a geotechnical report shall include at least three volumes: for the road route, for bridges, and, if any, for tunnels. In specific cases, separate volumes containing reports dealing with obtaining local materials, with road route sections in deep cuts, on high fills, on landslides and similar shall be prepared.

In order to achieve appropriate quality of geotechnical investigations and their presentation in the "Geological Geotechnical Report (Study) on Soil Composition and Conditions of the Construction..." the following instructions should be taken into account:

- o The reports shall strictly separate data obtained by investigations and interpretation thereof. Test results shall be given in separate chapters in the first part of the report and interpretation in the final chapters. The same facts may result in different interpretations of conditions, and these are what the proposal for construction of the underlying facility depends upon.
- o Reliability of findings shall be given for findings based on test results. In general, the reliability of forecasts depends on complexity of the ground composition, and the number and quality of investigations. Individual conclusions may be based on hard facts or only on hypotheses. Each stage of investigations requires a certain degree of reliability of forecasts. In the main stage of investigations the reliability shall suffice for the integrated planning of motorway construction and foundations of structures.
- o New testing methods, statistical methods for data processing and interpretation, and new software for calculations and graphic presentation shall be introduced and regulations (notably the EUROCODE) as well as standards for particular tests (CEN, ISO) followed.
- o Solutions, proposals, and forecasts included in the report shall be given in the form, which the designer can understand, if possible in graphic form to the greatest extent possible. Thus, for example, in the selection of the most appropriate route for the motorway, the ground shall be classified by suitability for construction (from highly suitable to unsuitable). Expert data of narrower fields of expertise understandable

only to corresponding experts shall be given only as background and should not be in the focus of the final forecast.

More detailed specification of contents is not desirable as this would take away the necessary freedom from the reporter, i.e. certain points of the report would be emphasised too much and others too little with regard to the varying geological geomechanical field conditions Specifying the appropriate contents with emphasis on the most significant determined properties of the ground is an important component of the report, which defines the quality of the approach to investigations, their interpretation and conclusions.

In general, each report shall include the following chapters:

- o *INTRODUCTION:* (the Client, contract no., contract/order date, general data on the facility, stage of investigations, objective of the report)
- o *DATA ON PREVIOUS TESTS AND LITERATURE DATA ON THE UNDERLYING GROUND AND FACILITY* (give findings of previous investigations and their interpretation with regard to the previous investigations and previous experience with construction of similar facilities in the area or on identical rock)
- o *DATA ON PERFORMED FIELD AND LABORATORY TESTS:* (data shall be presented in the most understandable manner possible, notably in tables, charts and maps, and laboratory tests in enclosures)
- o *INTERPRETATION OF TESTS:* (includes the preparation of the geotechnical model of the ground and the assessment of its reliability)
- o *GEOTECHNICAL CONDITIONS FOR IMPLEMENTATION:* (specifies in detail the geotechnical conditions for implementing the route or structures)
- o *CONCLUSION:* (summary of main findings of the report and proposals for further investigations and measures)

The annex includes the sample contents of the geotechnical report. It specifies the individual chapters and enclosures generally included in the report. With regard to the stage and objective of investigations as well as the complexity of geological composition and complexity of the facility, the geotechnical report shall include those chapters by which conditions of the construction can be satisfactorily specified

2.6 TYPES AND DESCRIPTIONS OF TESTS

In order to facilitate understanding, planning, and management of the programme of geological geotechnical investigations, individual types of geotechnical investigations with a short description are specified below:

2.6.1 ENVISAGED SCOPE OF THE MAIN GEOTECHNICAL INVESTIGATIONS

2.6.1.1 Field Testing

The programme of main investigations shall be prepared on the basis of findings of preliminary investigations. The scope of the tests depends on the following:

- o The level of previous research of the ground
- o Type of soil
- o Design, size and significance of the facility
- o Envisaged loading of soil

Planning of tests shall take into account the applicable technical standards and one's own expert assessment and experience.

The scope of tests shall be adjusted to current findings.

The minimum requirements for the scope of Field testing in line with EC-7 for the geotechnical category 2 (the most common category) are as follows:

- o A network of tests is envisaged for large facilities, usually at the distance between 20 – 40 m. Thereby a part of boreholes and test pits can be replaced by penetration tests and geophysical measurements.
- o As regards pad and strip foundations, the soil shall be tested at least to the depth equalling 1 to 3 times the width of the foundations under the foundation level. At least a portion of tests shall be carried out in greater depth in order to enable exact calculation of settlement and prediction of eventual ground water-related problems.
- o As regards rafts, the depth of tests shall at least equal the width of the raft, unless the bedrock is encountered first.
- o As regards foundations on piles, soil shall be tested at least to the depth equalling five diameters of the pile under the position of the pile, however this does not suffice in all cases.
- o As regards a group of piles, soil shall be tested under the position of foundations at least to the depth smaller than both dimensions of a rectangle made from piles in the group.
- o As regards embankments and deposit sites, soil shall be tested at least to the depth, which still significantly contributes to settlement (up to the depth where less than 10% of the entire expected settlement is obtained). The typical distance between testing points as regards embankments is 100 to 200 m.
- o As regards cuts, soil shall be tested at least to the 40% of depth of the cut under its bottom or minimally 2 m under the bottom of the cut.

Minimum requirements regarding tests of the ground water in line with EC-7 are as follows:

Monitoring of ground water levels in wells and piezometers in regular time intervals

Determining any artesian pressures of ground water and any peculiarities such as closed aquifers and tidal oscillations.

As regards planning of deep cuts (construction pits), soil shall be in case of danger of hydraulic breaking of soil tested at least to the depth of two times the cut, and as regards soil with small volume weight, the depth should be even bigger.

2.6.1.2 Laboratory Testing

The planning of laboratory tests shall take into account the type of the structure, stratigraphy of the bedrock, and properties of soil and rocks.

The type and scope of tests shall be in any case adjusted to the findings of Field testing and shall merely upgrade and supplement them. Prior to the beginning of laboratory tests, the knowledge of the characteristic profile of the base – stratigraphy of the ground and of the layers relevant to the underlying structure is required.

The planned scope of tests shall be such that properties of all characteristic layers present in the ground can be specified.

Laboratory tests shall be in terms of contents and quantity promptly adjusted to the results of Preliminary investigations. Tests shall be supplemented or upgraded by more detailed methods with regard to the preceding results.

2.6.1.3 Geological investigations

Structural Geological Investigations

The purpose of structural geological investigations is to specify and explain the geological composition of the ground, which the motorway and its appertaining facilities cross. For that purpose the established lithological units shall be classified into groups by basic characteristic and relations between various lithological units / groups (normal, tectonic...)

established. These data shall be used for hydrogeological and engineering geological interpretation of the studied ground.

The final objective of structural geological investigations is to point to potential impacts of structural conditions and processes to the complexity or endangerment of construction (e.g. the possibility for global instability after a tectonic contact).

Engineering Geological (EG) Investigations

A primary purpose of EG investigation is:

- o Interpretation of the established geological composition (soil composition) and specifying the conditions for implementing facilities in various stages of investigations
- o Interpretation (in laboratory or IN SITU) of the established geomechanical properties and geophysical and other data from local point values in the entire studied area / individual lithological units.

The basic approach to work:

- o The established expert geological data shall be presented in a way making them directly usable and clearly understandable to the geomechanic, designer, investor... i.e. without any excessive geological, structural, EG, and HG expert data.

Data to be included in EG investigations:

EG properties:

- o Form of the ground
- o Morphological properties of the landscape
- o Inclination of natural slopes
- o Flora (plant density of the ground)
- o Sensitivity to exogenic phenomena
    - Desintegration
    - Average cracking
    - Characteristics of discontinuities
    - Erosion
    - Predisposition to sliding
- o Character of joints
- o Average thickness of weathering cover
- o Types of weathering cover
- o Methods of decay and weathering
- o Assessment of the ground' stability
- o Types of phenomena of destroying the natural balance
- o Hydrogeological conditions (more details in the next chapter)
- o Water permeability (more details in the next chapter)
- o Environmental aspects (the impact of surface drainage of roads on the quality of ground water)

Assessment of geotechnical properties of engineering geological units:

- o Classification of rock mass (descriptive, also in one of numeric forms, e.g. RMR, GSI,...)
- o Classification of soils
- o Strength (uniaxial compressive strength)
- o Moisture content (humidity)

- o Elasticity
- o Plasticity
- o Shear strength

Conditions for construction and other interventions in rocks: (Assessment of conditions for construction of individual road structures)

- o Excavation category (for the weathered mass and mass in the base)
- o Bearing capacity of the base
- o Sensitivity to settlement
- o Conditions of execution of deep cuts
- o Conditions of execution of high embankments
- o Usability of excavated materials for embankments

Seismic properties:

- o Classification of the base in line with the BiH regulations
- o Classification of the base in line with Eurocode 8

2.6.1.4 Hydrogeological Investigations

The objective of hydrogeological investigations is to deal with two areas, namely:

Protection of the road against ground water

Timely and quality forecast of hydrogeological conditions is required for accurate design technical solutions in construction under conditions of impact of ground water on the road structure.

Protection of ground water against impacts from the road

Ground water is an element of the environment, which should be protected in a quality manner notably in areas where the motorway directly or indirectly affects the quality of ground water. These areas are protection areas as well as potential water sources specified in regulations.

The basic approach to work

Hydrogeological investigations shall be carried out and interpreted in such a manner that they, for the needs of the responsible designer and/or geotechnician, clearly, understandably and unambiguously present the quality conditions of the aquifer, levels of ground water in a longer hydrogeological period, direction and speed of the ground waster flow, vulnerability, sensitivity and exposure of the aquifer and other hydrogeological properties influencing the relationship between the ground water and the motorway as a civil engineering development and as a permanent source of pollution.

The proposed course of hydrogeological investigations and the contents of the study on HG investigations:

- o *Regional overview of geological conditions*

  A short overview of geological conditions shall be performed, relating foremost to the hydrogeological issues.

- o *Regional hydrogeological overview*

  This stage of investigations shall examine the regional hydrogeological conditions, i.e. the direction of flow of ground water, and the depth of wetted and non-wetted layer in the area. The spread of hydrogeological properties shall be examined (permeability coefficient, transmissivity, and the basic balance characteristics of aquifers shall also be given.

- *Hydrogeological measurements*

  Hydrogeological measurements shall be carried out in line with the provisions of the project task and in relation to the hydrogeological properties (permeability, transmissivity). The measurements shall foremost include the following:

  - *Pumping tests*
  - *Pouring tests*
  - *Measurements of ground water levels in piezometers*

- *Overview of protection areas and other water supply from ground water*

  This stage of investigations shall include the overview of all protection areas specified in regulations and other unprotected water sources. Additionally, hydrogeological characteristics defining the individual water source (abundance of wells, stock of ground water, etc.) shall also be given. The issue of protection as required by individual regulations shall also be given from the hydrogeological point of view.

- *Brief description / Forecast of hydrogeological conditions on the route*

  The study on hydrogeological investigations shall also present future hydrogeological conditions applying along the route. The overview shall be given together with the appertaining road position intervals.

- *Classification of hydrogeological conditions on the road's layout*

  An overview of hydrogeological conditions is important for planning of technical measures for protection of ground water and other technical solutions for protection against ground water. The classification shall be made on the basis of guidelines and instructions used for that purpose.

  Ground

2.6.1.5 Geophysical Investigations

The purpose of geophysical investigations

The basic purpose of geophysical investigations required for geophysical studies and other project documentation among other things includes the following:

- Obtaining basic information on the geological composition of the area of motorway construction
- Checking the appropriateness of geological profiles obtained on the basis of surface and/or local data from boreholes/excavations
- Obtain quantitative data on physical properties of rocks and soils
- Determining the optimal points for boreholes used for obtaining other representative data (engineering geological, geomechanical, etc.)
- Determine the points for boreholes used for checking certain anomalies
- Obtain basic data for adoption of expert and/or economic decisions

The approach to geophysical investigations

The approach to geophysical investigations should in any case follow the order specified below:

- Defining of the problem by the Client (designer, engineer, geotechnician, hydrogeologist, engineering geologist, etc.)
- Review of the existing documentation on the studied location (location, topography of the ground, field conditions, data from boreholes, geological profile, etc.)
- Specifying the requirements of the Client (the best if the optimal and minimal scope are specified)

- A framework agreement on the possibilities for implementation of geophysical investigations and solvability of the problem (which data are to be surely provided by geophysical investigations, which data can be provided conditionally, which are unobtainable, the envisaged quality of geophysical data, etc.)

Co-operation between the Client/user(s) and the implementer of geophysical investigations is obligatory in this part.

Selection of geophysical methods

- Geoelectrical methods
- Seismic methods
- Electromagnetic methods
- Borehole-logging measurements
- Establishing the technical condition of boreholes

2.6.2 Geomechanical investigations

2.6.2.1 Field Testing

This chapter gives an overview and characteristics of field Geotechnical investigations. The specified tests present a selection of widely used tests; however this presentation does not include all methods known. Other methods can be used with regard to the characteristics of the project and equipment of the researcher as well as the agreement with the Client.

For each test the following is given: purpose, equipment, implementation (with the reference to the appropriate standard) evaluation of results, reporting method for results, type of soil for which the test is suitable, examples of typical projects for which the method is used and any comments.

Sampling

Purpose:	Performing laboratory tests
Equipment:	Appropriate tube core barrel (see Annex 6.1), cylinder for storage and transport of the sample, equipment for tight sealing of the cylinder
Implementation:	Eurocode 7-3 (Sections 12 and 13)
Type of soil:	All types of soil
Project type:	All types of projects
Evaluation of results:	(laboratory)
Report on the test:	List of samples with basic data (see Annex 6.1), marking in the list of boreholes
Standard:	EC 7-3, EC 7-2
Notes:	The procedures of sampling, transport and storage shall comply with the applicable standards related to the sample category / type of tests to be performed on the sample

Field Vane Test

Purpose:	Determining the undrained shear strength and sensitivity of cohesive original subgrade
Equipment:	Vane, extension rods, rotation equipment and lever measuring device
Implementation:	Eurocode 7-3 (Section 8), JUS?
Type of soil:	Cohesive soils in very soft to very firm consistency

Project type:	Bearing capacity of soil in undrained conditions (stability of embankments, bearing capacity of base) Safety of temporary cuts
Results:	Undrained shear strength, sensitivity
Evaluation of results:	Eurocode 7-3 (Section 8, Annex G)
Report on the test:	
Standard:	EC 7-3 (Section 8), BS 1377: Part 9
Notes:	Results depend on the type of soil It is recommended that a series of measurements are performed in different depths in order to obtain the profile of undrained shear strength with depth

Standard Penetration Test (SPT)

Purpose:	Determining the relative density, shear strength and deformability, notably for noncohesive foundation base, and conditionally also the assessment of undrained shear strength and compressibility of cohesive soil, assessment of quality of rocks
Equipment:	Drilling equipment, sampler, drive rods, standard weight on a guide
Implementati on:	Eurocode 7-3 (Section 5), BS 1377: Part 9
Type of soil:	Noncohesive soils (conditionally cohesive soils and soft rocks)
Project type:	Bearing capacity and settlement of shallow foundations on noncohesive base, construction of cuts and embankments on noncohesive base, liquefaction potential
Results:	Relative density, shear angle, settlement of foundations (assessment of undrained shear strength, elastic modulus)
Evaluation of results:	Eurocode 7-3 (Section 5, Annexes D)
Report on the test:	See Annex 7.3.3
Standard:	EC 7-3 (Section 5), BS 1377: Part 9
Notes:	The equipment shall be calibrated with regard to transmission of energy to the drive rods The equipment shall provide for identical height of fall of the driving device at all times (automatic trigger) The use of cone is not standard and no reliable correction exists The use on the bottom of an excavation for the piles (diameter >15 cm) is not standard

Cone (static) Penetration Test (CPT)

Purpose:	Classification of soils, determining of relative density, shear strength and deformability of cohesive and noncohesive soils
Equipment:	Instrumented cone, push rods, a trust machine and a measuring/recording equipment In addition to resistance under the cone and resistance along the friction sleeve, the pore pressure (the CPTU test) is often measured; there are also cones with measuring devices for seismic waves, environmental parameters (temperature, pH...)
Implementati on:	Eurocode 7-3 (Section 3), BS 1377: Part 9
Type of soil:	Cohesive and noncohesive soils

Project type:	Bearing capacity and settlement of shallow foundations on noncohesive base Bearing capacity of shallow foundations on cohesive base (undrained condition) Bearing capacity of piles Construction of cuts and embankments Time development of settlement (consolidation) – CPTU test Liquefaction potential
Results:	Classification of soils, relative density, shear angle, undrained shear strength, sensitivity, elastic modulus, consolidation / permeability coefficient, settlement of foundations, bearing capacity of piles
Evaluation of results:	Eurocode 7-3 (Section 3, Annexes B)
Report on the test:	
Standard:	Eurocode 7-3 (Section 4), BS 1377: Part 9
Notes:	The equipment (cone) shall be properly calibrated The advantage of the test is continuous profile of measured quantities with depth

Dynamic Probing

Purpose:	Continuous profile of resistance of soil against dynamic penetration of the cone
Equipment:	Cone, drive rods, driving device (weight on a guide)
Implementation:	Eurocode 7-3 (Section 6), BS 1377: Part 9
Type of soil:	Noncohesive soils (conditionally cohesive soils and soft rocks)
Project type:	Bearing capacity and settlement of shallow foundations on noncohesive base assessment of bearing capacity of piles on noncohesive base, construction of cuts and embankments on noncohesive base liquefaction potential
Results:	Relative density, shear angle, module elasticity (all one the basis of locally determined correlations)
Evaluation of results:	Eurocode 7-3 (Section 6, Annexes E)
Report on the test:	See Annex
Standard:	EC 7-3 (Section 6), BS 1377: Part 9
Notes:	There are numerous variations of the equipment (shape and size of the cone, mass and height of the weight's fall) The equipment shall be calibrated with regard to transmission of energy to drive rods The equipment shall provide for identical height of fall of the driving device at all times (automatic trigger)

Pressuremeter Test

Purpose:	Field measurement of the relation between tensions and deformations, dimensioning of shallow and deep foundations
Equipment:	Pressuremeter probe, push rods, cables, control and measuring unit, pressure source
Implementation:	Eurocode 7-3 (Section 4), NF P 94-110-1-N
Type of soil:	Cohesive and noncohesive soils, soft to medium hard rocks
Project type:	Bearing capacity and settlement of shallow foundations Bearing capacity and settlement of piles

	Tunnel construction
Results:	Limit pressure, loading and unloading pressuremeter modulus, bearing capacity and settlement of shallow foundations, bearing capacity and settlement of piles
Evaluation of results:	Eurocode 7-3 (Section 4, Annexes C)
Report on the test:	
Standard:	Eurocode 7-3 (Section 4), NF P 94-110-1-N
Notes:	The measured pressuremeter modulus is not an elastic (Young) module due to the complex tension condition in the surroundings of the probe (radial pressure, tangent tension) The number and distribution of tests with regard to depth shall be such so that it corresponds with the methodology for analysis of the envisaged method of foundations

Dilatometer Test

Purpose:	Field measurement of strength and deformability of clay, silt and sand soils and measurement of stress conditions in the ground
Equipment:	Flat dilatometer probe, push rods, a thrust machine, control and measuring unit, pressure source
Implementation:	Eurocode 7-3 (section 9)
Type of soil:	Cohesive and sandy soils (there is also a cylindrical dilatometer for rocks)
Project type:	Bearing capacity and settlement of shallow foundations Bearing capacity and settlement of piles Tunnel construction
Results:	Stratigraphy of soils, undrained shear strength, edometer modulus
Evaluation of results:	Eurocode 7-3 (Section 9, Annex H)
Report on the test:	
Standard:	Eurocode 7-3 (section 9)
Notes:	

2.6.1.1 Laboratory Investigations

Details regarding the methods and procedures are specified in Annex 2.7.2. The results of geotechnical laboratory tests shall be specified in the "Report on Laboratory Tests", which shall include detailed description of the principle of tests, the procedure of implementation of individual tests, specification of any sources used for the test and correlation comparison of values with other, classical methods.

2.6.3 PROVIDING FOR THE QUALITY OF IMPLEMENTATION OF GEOLOGICAL GEOTECHNICAL INVESTIGATIONS

The implementation of field and laboratory investigations shall comply with the basic requirements regarding the providing and controlling of quality and traceability of implementation. The basic criteria in the system of quality to be fulfilled by the implementer of field and laboratory tests are as follows:

1. The management line of the geotechnical test project and responsibilities of all individual implementers in the programme of tests shall be clearly defined.
2. Tests can only be performed by suitably qualified staff.

3. Only equipment in perfect technical condition, complying with the requirements of reference standards and regulations, can be used for testing.
4. All measuring equipment shall be calibrated and regularly controlled by an authorised institution.
5. Data on the equipment, technical characteristics thereof, certificates of calibration and instructions for use of the equipment shall be available for viewing by the Client, upon request.
6. The Records of Tests shall be kept for all tests, be it field or laboratory. The obligatory contents of these records are generally specified by the relevant standards and/or instructions for work. All records shall be promptly filed and kept as originals as a part of the documentation on tests.
7. All records shall be kept in such a manner that it is possible to unambiguously see from them data on implementer of the test, the entire course of the test, any disturbances and external influences, which could affect the results, and data on whether the test was performed in line with the standards.
8. The tests can only be performed in weather or laboratory conditions not affecting the tests results. The work records shall clearly indicate data on weather conditions and temperature as regards Field testing and data on the microclimate in the laboratory as regards laboratory tests.
9. Each field or laboratory test shall have a unique identification number enabling follow-up of the entire work procedure from the beginning to the end.
10. Samples shall be coded if so required by the Client.

2.7 Appendixes

2.7.1 DRILLING FOR TESTING OF SOIL

2.7.1.1 The tasks of drilling for testing of soil

The tasks of drilling for testing of soil are as follows:

- o Obtaining samples of soils and the rocks for visual (geological and geotechnical) recording and classification and laboratory tests required for identification and classification
- o Obtaining samples for laboratory tests of geotechnical characteristics
- o Determining the ground water level
- o Preparation of boreholes for measurements in boreholes and
- o Preparation of boreholes for installation of monitoring equipment

2.7.1.2 Drilling technology

The most frequent method of drilling in the geotechnical invstigations is the rotation drilling by means of tools for taking samples of different lengths. Such a drilling method is relatively rapid and widely applicable.

Less frequently, drilling by means of ramming is used in geotechnical investigations. Such drilling is only applicable to shallow boreholes and in case of cohesive soils. Winning samples is quick and simple.

In geotechnical investigations where solid rock mass is in question, as well as in cases where an intact sampling is required (tunnels, cut-and-fills, cuts), »structural drilling« is recommended. In the technological point of view this is a rotation drilling using a wire-line or multiple-wall tools for taking samples accompanied by simultaneous flushing. A sample won in this way is of topmost quality. A weak point of the structural drilling is the time consumption, which affects the cost amounting to twice the price of the classic rotation drilling.

In addition to the abovementioned methods, systems without winning the core by means of rotation and impact-rotation chisels are used in the geotechnical investigations as well. Such a method is applicable in case of known geological composition and serves for inserting the pipes of inclinometers and piezometers. The mentioned drilling method is advantageous for its rapidity, thus for a low cost. It also allows an approximate determination of geological composition of the soil.

2.7.1.3 Sampling equipment

Samples can be obtained from each drilling; the quality of samples and their usability depend on the drilling technology and the sampling equipment. Samples obtained by cylinders or tube core barrels are generally used for testing the soil.

Thin-walled cylinders

Thin-walled cylinders consist of thin tubes with smooth (treated) inner surface. At the bottom there is a shoe with a blade and they are divided into open cylinders and cylinders with a mallet. They are designed so that the damage to rock in sampling is minimal.

The dimensions are standardised and it is most appropriate to use the same standards as those used for laboratory tests.

Sampling is performed at the bottom of the borehole by threading the cylinder in the rock with static force, i.e. with no vibrations. Sampling by a cylinder is possible in combination with any drilling method. Prior to sampling the bottom must be cleaned, and any unstable walls protected. Protection of the walls of the borehole (protective column or wastewater) depends on the drilling technology and the rock in the unstable part.

Thick-walled cylinders

Thick-walled cylinders consist of tubes without any special treatment of the inner surface. A shoe with a blade is at the bottom end. Sampling is performed at the bottom of the borehole by driving the cylinder in the rock. The borehole must be prepared identically as in case of sampling with thin-walled cylinders. The structure of the rock usually changes in sampling with thick-walled cylinders.

Single-walled tube core barrels

A single-wall tube core barrel is a tube with core trap, a crown and the head. The drilling liquid passes between the core and the inner wall of the tube core barrel and exits along the inter wall of the crown. The core is exposed to erosion caused by drilling liquid and mechanical impacts of the tube core barrel's rotation.

Double-wall tube core barrels

A double-wall tube core barrel has two concentric tubes, core trap, a crown and the head. Double-wall tube core barrels are divided as follows:

– Tube core barrels with a rotating inner tube; and

– Tube core barrels with a non-rotating inner tube.

In the former, the inner tube rotates together with the outer tube and in the later it does not rotate. The drilling liquid flows between the both tubes and exits through channels in the crown. In tube core barrels with a rotating inner tube the core is protected from erosion caused by drilling liquid, and in non-rotating inner tube also against mechanical impacts of the tube core barrel's rotation. Tube core barrels with non-rotating inner tube are generally used for testing of soil.

Triple-wall tube core barrels

Triple-wall tube core barrels are similar to double-wall tube core barrels except that they have an insert (cylinder) in the inner tube for the core i.e. a third tube. The insert protects the core and is used as packaging in storage and transport. Inserts are generally made from transparent plastic so that they enable inspection of the core, and prevent any changes.

Tube core barrels with rubber tube

Tube core barrels with rubber tube are similar to double-wall tube core barrels except that they have a soft and elastic tube on a special sheath. The tube braces the core immediately after it enters the tube core barrel. The tube is prolonged by means of unwinding the sheath. The elastic tube wrapped around the core ensures that parts of the core are in identical mutual position as they were upon entering the tube core barrel.

Denison tube core barrels

A Denison tube core barrel is a triple-wall tube core barrel with a shoe (extension) on the inner tube and an insert (cylinder) for the core. The shoe has a blade being in front of the crown. The inner tube is threaded in rock before the crown and drilling liquid have an impact on it. The obtained core is similar to samples obtained by thin-wall cylinders. In case the section of coring has inserts from hard rock, coring must be suspended and hard parts drilled by another tube core barrel.

Tube core barrels with elastic inner tube

Tube core barrels with elastic inner tube have similarly to the Denison tube core barrel a shoe (extension) with a blade and an insert (cylinder) for the core on the inner side. The head of the tube core barrel has a spring, which enables setting the force to the inner side and thus the pressure of the knife to the rock. When the resistance (hardness) exceeds the selected value, the inner tube retracts to the tube core barrel and comes out again after softer rock is encountered. In these tube core barrels no stopping of drilling because of changed hardness of rock is required. The obtained core is similar to samples obtained by thin-wall cylinders. Known tube core barrels with elastic inner tube are: Mazier and Triefus.

Laskay tube core barrel

Laskay tube core barrel is a tube core barrel for an auger on hollow bars. The core tube with the shoe and insert for the core is on bars in hollow auger and is threaded to rock by rotation of the auger. Blade of the core tube is in front of the auger, similarly as in case of the Denison tube core barrel. The obtained core is similar to samples obtained by thin-wall cylinders.

Wire-line tube core barrel

Wire-line tube core barrel is a double-wall tube core barrel with the outer tube being at the same time drilling bars and the inner (core) tube having a thorn and breech. The breech is used to connect the core tube with the bars and the thorn for connection with the steel rope and closing of the breech. The drilling crown is on drilling bars. The core tube descends and ascends by steel rope so that it is not necessary to take out the entire tool in order to empty the tube core barrel. Wire-line tube core barrels are suitable for coring longer sections as the time for manoeuvring shortens significantly.

Tube core barrels for oriented coring

Oriented core can be obtained by using tube core barrels for oriented coring. Tube core barrel for oriented coring have a "multi-shot" device for measuring the direction. Two systems of such tube core barrels are known, namely:

– with knives; and
– with rubber tube.

As regards tube core barrels with knives, they scratch (mark) the sample by length, which, in connection to data on direction of the sample and position of the borehole, enables orientation of each piece of the core.

As regards tube core barrels with rubber tube there is a connection with the device for measuring the direction. The rubber tube is wrapped around the core immediately after it enters the tube core barrel and the core and individual parts in the tube cannot change their position. By knowing the direction of the rubber tube the direction of the core is also known when it enters the tube core barrel and by taking into account the position of the borehole the position in the layer prior to sampling is known as well

2.7.1.4 Samples of soils

Samples of soils are divided in: undisturbed, disturbed and mixed. The basis of the division is parameters of the soil in the sample compared to parameters at the sampling point.

Undisturbed samples

The soil in undisturbed sample has identical composition, structure, porosity, and moisture content as the soil at the sampling point. A sample is "undisturbed" until one of these parameters changes. Undisturbed samples of soil are identical to the samples of class A by Eurocode 7.

Undisturbed samples are taken from cohesive soils and exceptionally from sands. Sampling from sands often requires special technology and equipment. Undisturbed samples can be obtained by:

- Thin-wall cylinders
- Denison tube core barrel
- Tube core barrel with elastic inner tube, and
- Laskay tube core barrel

The cylinder or insert with the sample shall be immediately tightly sealed and appropriately stored. The sample shall be handled so that damage to rock is prevented, i.e. with no vibrations and no significant temperature changes.

Disturbed samples

The soil in disturbed sample has identical composition, layer order and moisture content as the soil on the sampling point, and the structure and porosity are changed. The layer order or composition of the soil can be identified in disturbed samples "in situ". A sample is "disturbed" until one of these parameters changes. Disturbed samples of soil are identical to the samples of class B by Eurocode 7.

Dimensions of disturbed samples depend on the purpose of the test and the required quantity of the sample. Generally, the diameter of the sample shall be 5 to 10 times bigger than the diameter of the maximum grain in the soil from which the sample is taken. Disturbed samples of soil can be obtained by:

- Thick-wall cylinders (driving)
- Double- and triple-wall tube core barrels
- Tube core barrels with rubber tube
- Wire-line tube core barrel and
- Tubes (driving drilling)

In cohesive soils and foremost in clays disturbed samples can also be obtained by single-wall tube core barrel and by "dry" drilling, i.e. without drilling liquid. In such samples the outer part of the core is strongly damaged, and may also be dried.

When emptying the equipment with samples it should be provided that no additional disturbing of rock, mixing of the sample or change of length occurs. Parts of the sample envisaged for tests in which the moisture content is important shall be tightly sealed, the most suitable by using paraffin.

When drilling with tube core barrels the required quantity of the core is generally 100% (volume) and minimally 80% in each manoeuvre.

Mixed samples

The soil in a mixed sample has a totally changed composition and a different distribution of layers and components as the soil at the sampling point. The moisture content can also be changed. The order of layers cannot be reliably determined "in situ" from mixed samples. Mixed samples of soil are identical to the samples of class C by Eurocode 7.

Dimensions of the borehole for mixed samples depend on the purpose of the test and the required quantity of the sample. Mixed samples can be obtained by:

- Single-wall tube core barrels and dry drilling i.e. without drilling liquid
- Auger (short or long) and
- Impact drilling

2.7.1.5 Rock samples

Important geotechnical properties of certain rock are: condition (cracking or crushing and weathering), composition (texture), hardness, and deformation properties. These characteristics can be determined by examination and laboratory tests of the appropriate samples.

Sampling of rocks depends on the purpose of tests and the type and condition of the rocks. Rock samples are divided into undisturbed, disturbed, mixed, and oriented. The basis of the division is parameters of the rock and the rock at the sampling point.

Undisturbed samples

The rock in undisturbed rock mass sample has identical composition, structure and moisture content as the rock at the sampling point so that hardness and deformation properties are also identical. A sample is "undisturbed" until one of these parameters changes. Undisturbed samples of rocks are identical to the samples of class A by Eurocode 7.

In sound and little weathered and cracked rock mass undisturbed samples can be obtained by:

- o Double- and triple-wall tube core barrels
- o Tube core barrels with rubber tube and
- o Wire-line tube core barrels

In strongly weathered and cracked rock mass undisturbed samples can, in addition to the above specified tube core barrels, be obtained by cylinders as well

Minimum diameter of the sample depends on the condition and composition of the rock and should not be less than 76 mm in rock with discontinuities.

Parts of the core for undisturbed samples shall be tightly sealed and so handled as to prevent changes in the sample.

Disturbed samples

Rock in the disturbed sample is divided into individual pieces, by main discontinuities, and proportions of components are identical to those in the rock mass at the sampling point. On disturbed samples it is impossible to determine parameters of the rock mass as whole but only parameters of individual pieces. Main distribution of discontinuities can be determined on disturbed samples. Disturbed samples of rock mass are identical to the samples of class D by Eurocode 7.

Disturbed samples can be obtained by using the same methods as for the undisturbed ones (Item 6.1). In sound rock mass they can also be obtained by single-wall tube core barrels, while in strongly weathered and crushed rock by impact drilling.

Samples envisaged for tests in which moisture content is important shall be tightly sealed.

Mixed samples

Rock in a mixed sample is crushed and has different structure as the rock at the sampling point. Mixed samples can be used for determining the type and texture of the rock mass but not the discontinuities or borders between the layers.

Mixed samples can be obtained by:

- o Single-wall tube core barrels
- o Percussion drilling by reverse circulation and
- o Impact drilling

Diameter of the borehole for mixed samples depends on the required quantity of the sample.

Oriented samples

Samples or the core shall be oriented if their position in the crust, as it was before sampling, can be determined. Direction and fall of the layer, sliding plates, discontinuities and similar can be determined from oriented samples. Oriented samples are important for specifying the geological composition (structure) on the studied area. Data on the direction and inclination of the borehole are also required for interpretation.

Oriented samples can be obtained by using tube core barrels for oriented coring.

2.7.1.6 Expert documentation on the borehole

Expert documentation on the borehole for tests of the soil includes documents on:

- o Drilling
- o Visual inspection
- o Tests in the borehole

- o Laboratory tests for identification and classification and
- o Geotechnical profile of the borehole

Documentation on drilling is kept by the implementer of drilling. Documentation must contain data on:

Location: facility, marking, coordinates of the borehole

- o Drilling machinery and tools
- o Drilling liquid: type, composition, density, and viscosity
- o Borehole: diameters, depths, protective tubes
- o Core: sampling interval, % of the core
- o Samples: marking, depth, sampling method
- o Measurements in the borehole: type and point of measurements
- o Drilling parameters
- o Findings during drilling: loss of drilling liquid, caverns, layer fluids occurrence and
- o Ground water level if the drilling technology enables it

Drilling parameters depend on the drilling method. In rotation drilling these is:

- o Weighing of the drilling tool
- o Rotation speed
- o Pressure and flow of drilling liquid and
- o Drilling advancement

Drilling parameters can only be obtained during drilling by recording the data from the instruments or by automatic registering devices (MWD – Measurement while drilling).

Visual examination of the core, fragments, and samples shall be performed by suitably trained workers having appropriate knowledge in geology.

When preparing the geological geotechnical profile of the borehole, data from all specified documents shall be taken into account.

2.7.2 METHODS AND PROCEDURES FOR GEOTECHNICAL LABORATORY INVESTIGATIONS

2.7.2.1 Introduction

Geomechanical laboratory tests are carried out for the purpose of supplementing and upgrading the data from field testing. The laboratory investigations programme is a plan of tests prepared jointly by the responsible person in charge of the tests and the engineer in the geomechanical laboratory by taking account of the characteristics of the soil and the facility, as well as the quality – class and suitability of the sample for individual tests.

2.7.2.2 Main Test Groups

Laboratory investigations are,with regard to the design and parameters to be determined, classified into the following main test groups:

Tests for classification and identification of soils and/or rocks

These tests determine the basic so called elementary or index properties of the material on the basis of which the soil or rock can be unambiguously described and made recognisable to the user. Determining of the following parameters is included:

- o Water content
- o Volume weight
- o Volume weight excluding pores and cavities
- o Grain size distribution
- o Atterberg’s plasticity limits
- o Other special tests, e.g. sensitivity to freezing, density index

Chemical tests of soil and ground water

These tests are within the group of the classification tests. They are used for determining the properties of soil, which could due to their chemical composition cause adverse effects on concrete, steel or the soil itself, only when it is the original subgrade of the facility or an earth structure has been implemented from it. The most common chemical tests performed in geomechanics in road construction include determining of the following parameters:

- o Content of organic substances, carbonates, and sulphates
- o pH value
- o Chloride content
- o Other special tests, e.g. cationic exchange, methylene blue test, etc.

Investigations of deformability and expandability of soil

These tests are intended for determining the deformability, expandability, and the danger of collapse in the soil in edometers, in which the sample is laterally limited, and the loading is vertical, by levels, whereby water leaking is enabled in the vertical direction. The purpose of the tests is to determine the behaviour of the soil in loading or unloading conditions thus providing prognosis of the expected volume changes in the ground.

The purpose of the test for determining the collapse is the assessment of compression parameters of unsaturated soil and assessment of additional volume changes occurring in flooding.

Tests for determining strength parameters of soil

These tests are intended for determining the undrained shear strength, effective strength parameters of the soil and pore pressures for the purpose of assessing bearing capacity and stability of the soil. The most common tests / methods for determining the strength parameters include:

- o Pocket penetrometer
- o Uniaxial compressive strength
- o Torvane testing
- o Laboratory cone
- o Unconsolidated undrained compression test
- o Direct and rotation shear test
- o Triaxial compression test

Permeability tests

These tests are used to determine the permeability coefficient or conductivity coefficient of soil for water for the purpose of assessing water flow in the ground, assessing inflows of water in construction pits or for calculating the time development of consolidation. The most common research methods include:

- permeameter with variable or constant hydraulic fall
- triaxial cell for water permeability tests
- edometer cell with capillaries

Compaction tests / suitability for construction of soil

These tests are used assess the ability of soil for mechanic hardening and condensing and properties of soil in the condensed state. When properties of the soil are such that mechanical condensing is not possible, the standard methods are joined by methods whereby the ability for improving the soil by additives – inorganic or organic binders is tested. The most common test methods include:

- o Determining optimal water content and maximum density by Proctor

- o Determining CBR index of bearing capacity
- o Determining optimal optimum water content of soils stabilised with cement or other binders
- o Determining compressive strength of soils stabilised with cement or other binders
- o Determining weather resistance of soil

Other geomechanical laboratory tests

Special geomechanical laboratory tests include tests not included in the description given above, used for describing the properties of soils with specific characteristics, e.g. light soil, single-grain sands, preconsolidated hard clays, diatom soils or properties and behaviour of soils in combination with other materials. In such cases the selection and implementation of the procedure is left to the decision of the geotechnical designer and the procedure itself shall be described and documented in detail.

Investigations for the identification and classification of rock

Purpose: Identification and description of rock material on the basis of the mineralogical composition, genesis, structure, proneness to wear and tear, and basic characteristics (moisture content, volume weight). The description can be carried out on samples of natural rock from cores won by means of drilling or by any other source, or on the rock mass in situ. Prior to sampling it is necessary to divide the rock mass (presented in a borehole or in situ) into individual »quasi-homogeneous« zones, and to specify the characteristic engineering-geological parameters for these zones, as it applies to RQD for example.

Investigations of rock compressibility and swelling

The goal of investigating the compressibility is to determine both deformation and consolidation characteristics of a rock mass, thus the behaviour of the soil in both loading and unloading conditions. For the needs of designing deep cuts or tunnels it is indispensable to carry out suitable tests for the identification, confirmation, and quantification of eventual swelling phenomena. Such testing shall be performed within the scope of standard or modified compressibility testing.

Tests to determine the rock strength parameters The following methods are most frequently used:

- o Monoaxial deformability test
- o Point load test
- o Direct shear test
- o Brazilian test
- o Triaxial test

2.7.2.3 Sample Quality Classes

Samples of soils intended for laboratory tests are divided into five (5) quality classes with regard to that which of their properties has remained unchanged. Sample quality classes and suitability of samples for laboratory tests are presented in the table below (according to Eurocode 7, Part 2):

Soil properties/Quality classes	**1**	**2**	**3**	**4**	**5**
Unchanged properties of soils:					
Particle-size	**+**	**+**	**+**	**+**	
Moisture content	**+**	**+**	**+**		
Density, relative density, permeability	**+**	**+**			
Deformability, shear strength	**+**				

Properties which can be determined:					
Order of layers	+	+	+	+	+
Borders between layers, rough	+	+	+	+	
Borders between layers, exact	+	+			
Plasticity limits, specific weight of particles, organic	+	+	+	+	
substances content	+	+	+		
Water content	+				
Deformability, shear strength					

2.7.2.4 Methods and Procedures for Laboratory Tests

Work procedures and equipment for geomechanical laboratory tests are prescribed by national standards and various recommendations and guidelines. Generally, various national standards slightly vary, which can affect the test results. Eurocode 7 is based on British Standards, however not entirely.

The table below gives an overview of standards prescribing procedures for geomechanical tests. The table presents as still applicable those JUS standards, which enable carrying out the tests, which are traceable and still comparable with the modern European standards. Where JUS standard do not exists or are totally inadequate, the table presents standards, recommended for laboratory tests.

The Laboratory Tests Report shall obligatory specify the method used for the test. When the test is performed in full compliance with the prescribed method, no description of the test is required. When deviations from the standard procedure in implementation of the test have occurred or where the test has been carried out by a procedure not generally recognised, an exact description of the test is required.

List of standard methods for implementation of main laboratory tests of soils:

	Standard marking (fully or a part, item or section) or marking of non-standard test methods	Title of the standard or non-standard test method and any relation to other standards and methods	Calibration of equipment	Notes
1	JUS U.B1.001/90	Classification of soils		
2	JUS U.B1.003/90	Field identification of soils		
3	JUS U.B1.010/79	Sampling of soils		
4	JUS U.B1.012/ 1980-02-21	Determining water content of soil samples	YES Scales, furnaces	
5	JUS U.B1.014/88	Determining volume mass of soil excluding pores	YES Scales, furnaces Pictometers	
6	JUS U.B1.016/ 1-VII-1968	Determining volume mass of soil	YES Scales, furnaces, cylinders	Isotope probe by ASTM
7	JUS U.B1.018 / 1980-07-30	Determining granulation composition - By aerometer - By Andreas pipette	YES Scales, furnaces, sieves	
8	JUS U.B1.020 / 1980-07-30	Determining soil consistence	YES Scales, furnaces,	

	Standard marking (fully or a part, item or section) or marking of non-standard test methods	Title of the standard or non-standard test method and any relation to other standards and methods	Calibration of equipment	Notes
			cup Penetrometer	
9	DIN 18132 / December 1995	Bestimmung des Wasseraufnahmevermögens (determination of the water absorption)	YES Scales, furnaces Temperature	
10	JUS B.B8.039 / 1982-08-07	Determination of organic impurities. Colorimetric method		
11	BS 1377 / 1990 Part 3 Item 3	Soils for civil engineering purposes Part 3. Chemical and electrochemical tests Determination of the organic matter content		
12	BS 1377 / 1990 Part 3 Item 9	Soils for civil engineering purposes Part 3. Chemical and electrochemical tests Determination of the pH value	Buffer solutions	
13	BS 1377 / 1990 Part 3 Item 6.3	Soils for civil engineering purposes Part 3. Chemical and electrochemical tests Determination of the carbonate content		
14	JUS U.B1.022/68	Determining changes in volume mass of soil		NOT IMPLEMENTED
15	JUS U.B1.024/68	Determining contents of combustible and organic substances in soil	YES Scales, furnaces	
16	JUS U.B1.026/68	Determining carbonate contents of soil		
17	JUS U.B1.028 / 1-I-1970	Examining direct shear of soil	**YES** Dynamometer Micrometer	BS standard does not know undrained testing BS standard prescribes the determining speed of shear on the basis of calculation of square root t_{100} during consolidation.
18	JUS U.B1.029/71	Examining shear in triaxial apparatus		**Not usable, BS is appropriate**
19	BS 1377 / 1990 Part 7	Soils for civil engineering purposes	**YES** Volumometers	

	Standard marking (fully or a part, item or section) or marking of non-standard test methods	Title of the standard or non-standard test method and any relation to other standards and methods	Calibration of equipment	Notes
	Item 7 Item 8 Part 8 Item 7 Item 8	Part 7. Shear strength tests (total stress) Determination of the unconfined compressive strength Determination of the undrained shear strength in triaxial compression without measurement of pore pressure (definitive method) Part 8. Shear strength tests (effective stress) Consolidated-undrained triaxial compression test with measurement of pore pressure Consolidated-drained triaxial compression test with measurement of volume change	Shift meters Pressure gauges	
20	BS 1377 / 1990 Part 7 Item 6	Soils for civil engineering purposes Part 7. Shear strength tests (total stress) Determination of residual strength using the small ring shear apparatus	**YES** Dynamometers Micrometers Transfer ratios	
21	JUS U.B1.030 / 1-VII-1968	Determination of compressive strength of a soil	**YES** Dynamometers Micrometers	**Go to BS as soon as possible**
22	JUS U.B1.032 / 1-I-1970	Determination of the one-dimensional consolidation properties	**YES** Transfer ratios Micrometers	**ATTENTION!** **Careful in tests of expansion. Go to BS as soon as possible**
23	**BS 1377, PART 5, PART 6**	**TESTS OF DEFORMABILITY AND EXPANDABILITY SHOULD BE ALIGNED WITH BS**	**YES**	
24	JUS U.B1.034 / 1-I-1970	Determining the coefficient of water permeability	**YES** Capillaries Volumometers	**ATTENTION!** **WATER PERMEABILITY IN EDOMETER IS NOT IN ACCORDANCE WITH THE STANDARD AND IS NO LONGER**

	Standard marking (fully or a part, item or section) or marking of non-standard test methods	Title of the standard or non-standard test method and any relation to other standards and methods	Calibration of equipment	Notes
				INCLUDED IN BS Go to BS as soon as possible
25	JUS U.B1.036/68	Determining capillary Expansion	YES Capillaries	
26	JUS U.B1.038/68	Determining optimal Water content by Proctor		**UNUSABLE, replaced by DIN**
27	DIN 18127 / February 1993	geräte (Proctorversuch) (Proctor test) (Determination of maximum dry density and optimum moisture content)		
28	JUS U.B1.042 / 1-I-1970	Determination of the California Bearing Ratio Determining CBR value in the laboratory Determining CBR value for bearing layers for roadway constructions for which density of 95% is prescribed of optimal density in line with the modified Proctor test	**YES** Dynamometers Micrometers	**ATTENTION!** **SEE** DIN 18127
29	JUS U.B1.044 / 69	Determining capillary permeability and capillary expansion		**NOT IMPLEMENTED**
32	JUS U.B1.048 / 1-VII-1969	Determination of optimal water content of a soil stabilized by cement		**ATTENTION! SEE DIN 18127**
33	JUS U.B1.050 / 69	Determining resistance of soil stabilised by cement to freezing		**INADEQUATE**

Calibration of equipment is obligatory. In addition to the initial calibration, period checkups and control of measurement units is required. The scope of control of measurement units and equipment specified in Eurocode is extensive and presents large financial burden for small laboratories.

The minimum frequency of control of measurement units is recommended until an appropriate standard is adopted:

- Scales: 2 years
- Dynamometers and el. measurements units of force 2 years
- Micrometers: initial, then own every 6 months with ethanol
- Electronic shift meters: 2 years

- Volumometers: own, 6 months
- Dryers: initial, then own every 6 months with calibrated thermometer

Classification and Description of Samples

Description of samples and classification of soil are the basic data of laboratory tests upgrading field recordings of cores of boreholes. Description of samples should take into account data from performed tests and findings of the macroscopic examination.

Main description of samples includes the following data:

Example:

Soil type:	Well graded gravel, rounded
Density or consistence:	Medium density
Colour:	Grey
Auxiliary description includes:	
Important observations:	Grains up to 30 mm
Grain composition:	Grains from flint sandstone
Other special features:	Grains visibly washed, smooth

The description can be supplemented by other data if they are important for the material in question. The description of soil should avoid special names otherwise familiar to other fields of geoscience, e.g. diluvial gravel, argillite clay, etc.

2.7.3 REPORTING ON GEOTECHNICAL INVESTIGATIONS

2.7.3.1 General

This annex gives requirements regarding reporting on individual Geotechnical investigations. It gives sample forms for entering important data during the test.

The basic data to be specified for each test are as follows:

- Name of the company performing the test
- Name of the location (construction site)
- Number of research work (work order, contract no...)
- Marking of borehole, probe
- Test type with reference to the standard used
- Date of testing
- Coordinates of borehole (probe)
- Ground position
- Drilling method and borehole diameter (for tests performed in boreholes)
- Calibration of equipment data (date and No. of certificate, calibration constants)
- Any deviations from the standard procedure, observations of the operator
- Name and signature of the operator and head of research work

2.7.3.2 Sampling

The form below has to be filled for each sample. One copy is enclosed with the sample and the other is kept for reference in case the original is damaged. Additionally, the sample is enclosed with one or two labels with sample number (depending on the storage, handling and transport method in order to preserve reliably at least one marking).

Companies can use the template below to make their own pads with numbered sheets (doubles with identical number). Doted line marks perforation.

No. 0001

DATA ON THE SAMPLE

Location (construction site)……………………………………………………………………………………

Date:………………………………………………………

Sample type:…………………………………

Borehole:…………………………………………………………

Depth:………………………………………

Sample no.:………………………………………………………

Note:

Name and signature:

2.7.4 CONTENTS OF GEOTECHNICAL REPORT

2.7.4.1 GEOTECHNICAL REPORT FOR THE ROAD PRELIMINARY (MAIN) DESIGN

VOLUME 1 – REPORT FOR THE ROUTE

1. **INTRODUCTION**

2. **TYPES AND SCOPE OF INVESTIGATIONS**

2.1. Review of previously executed investigations
2.2. Investigations for the road design
2.2.1. Field investigations
2.2.2. Laboratory investigations

3. **PRESENTATION OF BASIC RESULTS OF INVESTIGATIONS**

3.1. Geomorphological characteristics
3.2. Geological composition of ground
3.2.1. Lithostratigraphical composition
3.2.2. Tectonic units
3.3. Hydrogeological characteristics
3.4. Results of testing physical-mechanical characteristics of samples of soil and rock including prognosis of properties of rock mass
3.5. Up-to-date geological processes and phenomena (landslides, erosion, etc.)
3.6. Seismic activity of ground

4. **ANALYSIS OF GEOTECHNICAL CONDITIONS FOR THE ROUTE**

4.1.1. Description of the route including dividing into zones and geotechnical models for each zone
4.2. Selection of parameters for geotechnical calculations
4.3. Conditions of execution of cuts
4.4. Conditions of fill construction
4.5. Specific problems related to the route (protection from surface and ground water, sections on a ground of low bearing capacity or on a unstable ground)
4.6. Applicability of local materials

5. **CONCLUSIONS**

6. **INVESTIGATION PROGRAMME FOR THE SUBSEQUENT DESIGN STAGE**

7. **BASIC DRAWINGS**

- Geological and engineering-geological map
- Longitudinal engineering-geological profile along the route
- Characteristic cross-section (mandatory on locations of all cuts and fills, all landslides, and ground of low bearing capacity)
- Results of laboratory testing, of field measurements, drilling geophysical investigations, etc.

VOLUME 2 –BRIDGE (BRIDGES) REPORT

1. INTRODUCTION

2. TYPES AND SCOPE OF INVESTIGATIONS

3. PRESENTATION OF BASIC RESULTS OF INVESTIGATIONS AT THE BRIDGE LOCATION

3.1. Basic geological characteristics of the ground

3.2. Hydrogeological ground characteristics

3.3. Physical-mechanical properties of soil and rock, and selection of parameters for design calculations

3.4. Up-to-date geological processes (ground stability)

3.5. Seismic parameters at bridge location

4. ANALYSIS OF GEOTECHNICAL CONDITIONS OF BRIDGE CONSTRUCTION

4.1. Basic structural characteristics of the bridge

4.2. Geotechnical models of the ground at the bridge location – selection of the foundation type

4.3. Conditions of excavating the foundation pits

4.4. Structural stability

4.5. Specific problems related to the route (protection from surface and ground water, sections on a ground of low bearing capacity or on a unstable ground)

4.6. Calculation of settlement

4.7. Recommendations for protection and monitoring of the structure

5. CONCLUSIONS

6. PROGRAMME OF INVESTIGATIONS FOR THE SUBSEQUENT DESIGN STAGE

7. PROGRAMME OF MONITORING DURING CONSTRUCTION AND SERVICE

VOLUME 3 –TUNNEL (TUNNELS) REPORTS:

1. INTRODUCTION

2. TYPES AND SCOPE OF INVESTIGATIONS IN THE TUNNEL AREA

3. PRESENTATION OF BASIC RESULTS OF INVESTIGATIONS IN THE TUNNEL AREA

3.1. Basic geological characteristics of the ground

3.2. Tectonical units, discontinuities and characteristics of discontinuities

3.3. Hydrogeological ground characteristics

3.4. Physical-mechanical properties of the ground/rock masses, and selection of parameters for design calculations

3.5. Up-to-date geological processes – ground stability

3.6. Seismic parameters at the tunnel location

4. ANALYSIS OF BRIDGE CONSTRUCTION GEOTECHNICAL CONDITIONS

4.1. Predicted geological/geotechnical cross-section along the route including geotechnical dividing into zones

4.2. Geotechnical classification of rock masses

4.3. Analysis of construction conditions by geotechnical zones

4.3.1. Conditions of excavation

4.3.2. Elaboration of profiles – tunnel excavation in stages

4.3.3. Temporary stabiliy of excavation (analysis of cinematic possibilities of formation of local blocks, stress-strain analysis of excavation without support measures and with primary support

4.3.4. Permanent stability of tunnel

4.3.5. Prognosis of ground water inflow and proposal of protection

4.3.6. Prognosis of occurrence of harmful gases and proposal of protective measures

4.3.7. Analysis of conditions of portal and approach cut construction

4.4. Possibility of using the excavated material and applicability of local materials for the tunnel construction

4.5. Impact of construction on the surrounding ground and structures (vibrations due to blasting and operation of machinery, changes of ground water regime, settlement of ground surface, conditions of depositing the excavated material)

5. CONCLUSIONS

6. PROGRAMME OF INVESTIGATIONS FOR THE SUBSEQUENT DESIGN STAGE

7. PROGRAMME OF GEOLOGICAL MAPPING AND GEOTECHNICAL MEASUREMENTS DURING CONSTRUCTION AND SERVICE LIFE