THE REPUBLIC OF SLOVENIA

MINISTRY OF INFRASTRUCTURE

TECHNICAL SPECIFICATION TSG-211-XXX: 2025

Minister of Infrastructure on the basis of Article 13 of the Roads Act (Official Gazette of the Republic of Slovenia, No 132/2022 and 140/22 – ZSDH-1A) and Article 50(6) of the Railway Safety Act (Official Gazette of the Republic of Slovenia, No 30/18 and 54/21) issues the following technical specification

EARTHWORKS

SOIL TREATMENT WITH LIME AND/OR HYDRAULIC BINDERS IN ROAD CONSTRUCTION

TSPI – PG.05.300: 2025

Minister of Infrastructure

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Number:

Ljubljana,

This technical specification PGV.07.410: 2025 is issued having regard to the information procedure in accordance with Directive (EU) 2015/1535 of the European Parliament and of the Council of 9 September 2015 laying down a procedure for the provision of information in the field of technical regulations and of rules on Information Society services (OJ L 241, 17. 9. 2015, p. 1).

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SOIL TREATMENT WITH LIME AND/OR HYDRAULIC BINDERS IN ROAD CONSTRUCTION

1 Subject of the technical specification

The technical specification for transport infrastructure TSPI PG.05.300 sets out the technical conditions and method for carrying out the treatment of natural soils, processed or reused aggregates, rocks, recycled materials and artificial materials with lime and/or hydraulic binders in the construction of roads with the aim of improving unsuitable (inadequate) characteristics of materials for use in earthworks.

The use of excavated materials that are not usable in road construction without treatment can contribute to more environmentally and economically viable construction (shorter distances for material movements, transportation to landfills is not necessary or the need for landfilling is reduced).

Although various binders are introduced into the environment through treatment, when used appropriately, the positive impacts of such use are much greater than any undesirable effects, which are most often associated with the binder introduction phase. Weather conditions (particularly wind) can cause dusting and spreading of the binder to the wider surroundings, so it is necessary to foresee technological forms of introduction (closed mixing systems, suspensions instead of spreading, in-plant implementation) that do not have undesirable effects on the surrounding area, or to define in more detail in the design the weather conditions in which the treatment can be carried out.

Lime, hydraulic binders and binders with pozzolanic (latent hydraulic) properties are considered as binders in this technical specification. This technical specification does not address the use of other binders, such as products based on synthetic polymers, enzyme-based products, ionic products, lignins, resin-based products and others.

In TSPI PG. 05.300 two treatment procedures are considered, namely:

- improvement and
- stabilization.

Both processes can be carried out in the plant (in-plant) or by mixing at the installation site (in-situ). Combining is also allowed.

In addition to improving mechanical properties and weather resistance (water and cold) of materials, treatment procedures can also reduce the negative impact on the environment, such as the leaching of potentially toxic components that may be present. In this way, potentially contaminated soils or recycled materials can also be used in earthworks, whereby the addition of suitable binders immobilizes environmentally harmful components and prevents their leaching into the environment. Treatment to reduce leaching of potentially toxic components shall be the subject of a special study. It shall define, on the basis of preliminary laboratory and field research, the type and quantity of suitable binder, the procedures for preparation, installation and control the treated materials, in such a way as to ensure both the mechanical properties and weather resistance envisaged by the design and the environmental acceptability of the treated materials in accordance with the applicable legislation. Treatment procedures to reduce leaching are not addressed in this technical specification.

The technical specification defines the following requirements and procedures:

- quality requirements for basic materials;
- quality requirements for treated materials;
- procedures for the installation and maintenance of treated materials or the built-in layer;

- quality requirements for the quality of the work performed or the quality of the built-in layer;
- procedures for acceptance of the treated layer and accounting of works.

The annexes provide procedures for preparing test specimens and performing certain tests.

The content of this TSPI cannot be interpreted and implemented in such a way that would prevent or condition the proper use of construction products placed on the market in accordance with the requirements of the Construction Products Act.

2 Definition of terms

Alternative binders: various fine-grained industrial by-products with pozzolanic or hydraulic properties.

Lime: calcium oxide and/or hydroxide and calcium-magnesium oxide and/or hydroxide obtained by calcination of limestone or dolomite. According to SIST EN 459-1, lime includes quicklime (calcium oxide), hydrated or slaked lime (quicklime after reaction with water – calcium hydroxide) and lime with hydraulic properties (predominantly composed of calcium hydroxide, calcium silicates and calcium aluminates).

Lime with hydraulic properties: see lime. Lime with hydraulic properties binds and hardens in the presence of water and carbon dioxide from the air (carbonation).

Cement: a hydraulic binder that hardens and binds when in contact with water, due to hydration reactions and processes that occur, and after hardening retains its strength and stability even under water.

Construction joint: a longitudinal or transverse contact of the same material (mixture) made due to working conditions.

Fines: designation of the fraction in a mixture of stone grains that passes through a 0.063 mm sieve.

Aggregate size: a designation of a mixture of grains based on the lower (d) and upper (D) side sizes of a square sieve opening, expressed as d/D; this designation includes the possibility that some grains may remain on the upper sieve (oversized grains) or pass through the lower sieve (undersized grains).

Frost depth: the maximum depth to which the 0°C isotherm reaches in long-lasting cold.

Density: the mass of material, including moisture and cavities, per unit volume (kg/m^3 or t/m^3).

Granulated blast furnace slag: a partially glassy by-product of the smelting of iron ore in blast furnaces, which has hydraulic properties when properly activated. In this technical specification, the term refers to granulated blast furnace slag in accordance with SIST EN 15167-1 or partially granulated blast furnace slag in accordance with SIST EN 14227-2.

Hydraulic binder: a binder that hardens under water and remains solid under water when in contact with water.

Hydrated lime: see lime. Mainly in the form of calcium or calcium-magnesium hydroxide, which is produced by controlled slaking (addition of water) of quicklime. Dolomitic hydrated lime is also produced as partially hydrated lime, which consists mainly of calcium hydroxide and magnesium oxide.

Plasticity index: the difference in water content at the yield limit and plasticity limit.

Improvement: a process by which a homogeneous mixture of soil and binder is obtained, whereby the properties of the soil are changed (short term), such as plasticity, viscosity, swelling, optimum moisture…, in such a way as to improve the compactibility and increase the stiffness of the built-in layer.

Cohesion: the interaction of material particles that affects consistency, viscosity, elasticity and stiffness; the portion of the shear strength of the soil that is independent of the effective normal tension.

Boiler slag: a by-product formed after the combustion of coal or other fuels, when light particles, ash and gases are removed.

Fly ash: dust obtained by cleaning flue gases with mechanical or electrostatic filters (electrofilter ash) when burning pulverised coal or lignin, with or without the co-incineration of other materials in power plants (thermal power plants). It can be siliceous, the main components of which are silicates, aluminates and iron oxides, or calcium, the main components of which are silicates, aluminates, calcium oxide/hydroxide and sulphates. Silica fly ash is a pozzolanic material and requires a source of calcium oxide (e.g. lime or cement) for the hydration reaction to take place.

Grading curve limit: a curve limiting the range of grain composition.

Mixture: a compactible composition of a mixture of soil, binder and water and any other additives.

Metallurgical slag: a by-product of melting ore, remelting or further alloying, by which the desired metal fractions are separated from the unwanted ones. The composition depends on the type of process and input materials.

Modification: a process by which the properties of a material are changed/improved.

Natural soil: soil formed from natural processes classified in accordance with SIST EN 16907-2 and TSPI PG 05.201.

Processed aggregate: crushed or uncrushed granular material of natural mineral origin obtained by mechanical processing (crushing, sieving).

Optimum moisture content: the water content of the material at the maximum dry density of the mixture, determined by the Proctor test.

Layer: represents one or more beds of material with similar characteristics.

Subgrade: the area below the first layer intended to be treated.

Mellowing: the time period between the preparation of the binder and soil mixture (mixing) and the installation (compaction) of the treated material (mixture).

Proctor compaction test: a compaction test of soils or stone aggregates under certain conditions to determine the relationship between the moisture content and the density of the dry material.

Pozzolanic material: a material that reacts with water in the presence of an activator (usually $CaO/Ca(OH)_2$) to form hydration products and can also harden under water.

Recycler: a machine for crushing and mixing layers and adding different binders and water.

Recycled materials: materials that are produced during the processing of already used construction materials or come from excavations.

Retardant: a substance that slows down, inhibits a chemical reaction or process, for example the speed of binding of a binder.

Soil stabilizer: a mobile device – a machine for in-situ stabilization or improvement of the soil, which, with the help of a drum for crushing and mixing soil layers, with the addition of various binders, prepares a homogeneous layer of soil and binder mixture. Basically, the operation is the same as that of a recycler.

Stabilization: a process by which a homogeneous mixture of soil and binder is obtained, which, when properly built-in, significantly improves (in the medium or long term) the properties of the base soil, in particular in terms of increasing stiffness, improving weather resistance and increasing frost resistance.

Treatment: a process to obtain a homogeneous mixture of soil and binder, the properties of which meet the requirements for the intended purpose of use.

Artificial materials/aggregates: materials derived from industrial processes (e.g. steel slag).

Binder: a product or combination of products that provide (short-term or long-term) improvement in the properties of the base material to which they are added.

Hydraulic road binder: a commercial hydraulic binder, prepared for use, with properties suitable primarily for the treatment of materials in earthworks, road construction, the construction of railway infrastructure, airports and other infrastructure.

Compactibility: the ability of soil, spread out in a layer, to gain dry density and stiffness of the built-in layer when using mechanical energy of compaction with static and vibratory rollers.

Weather resistance: the effects of wetting and drying on the mechanical properties of the material.

Sample: representative quantity of material to be investigated to determine the average quality or to determine deviations from it.

Soil: the upper part of the Earth's crust consisting of products of weathering of rocks and/or sediments of different sizes of mineral and organic particles and colloids, that are not bound/cemented to each other. In earthworks, soil is the material on which structures are built (foundation soil for buildings, bridges), in which structures are built (e.g. tunnels, underground garages, buried reservoirs), with which structures are built (e.g. embankments, hydrotechnical ground barriers) or is located in the hinterland of supporting structures. For the purposes of this technical specification, the term soil includes the following materials for earthworks: natural soils, stone aggregates, crushed rocks, recycled materials, artificial aggregates.

Degree of compaction: the ratio between the dry density of the built-in material and the maximum dry density of this material determined by the Proctor method (%).

Grading/particle size distribution: grain size distribution expressed as a percentage by weight of the material passing through a given sieve.

Quicklime: see lime. Predominantly in the form of calcium and/or magnesium oxide, which reacts exothermically with water.

Abbreviations and symbols		
Symbol / abbreviation	Unit	Meaning/description
CBR_{2w}	%	California bearing ratio of the built-in material at material moisture content w,

		subjected to water saturation, determined in accordance with SIST EN 13286-47 with a load of 4.5 kg.
CBR_2	%	California bearing ratio of the built-in material at optimum material moisture content wopt according to the Proctor method, subjected to water saturation, determined in accordance with SIST EN 13286-47 with a load of 4.5 kg.
CCC		Continuous dynamic measurements of the compaction of the built-in material on the surface of the layer with equipment mounted on a measuring roller (Continuous Compaction Control) in accordance with TSC 06.713: 2005.
C_{OM}	%	Organic matter content based on determination by the loss on ignition method in accordance with SIST EN 1744-1, item 17.
C_U		Coefficient of grain uniformity, expressed as the ratio of grain size at 60 % to 10 % screening, given as dimensionless parameter.
DMV		Dynamic measurement value for continuous surface dynamic measurement procedures (see also CCC).
D_{pr}	%	Density, also degree of densification. The ratio between the achieved dry density of the material after installation and the maximum dry density of the material determined according to the Proctor method (SIST EN 13286-2).
□$_{nab}$	%	Linear swelling, expressed as the ratio between the change in height of the test specimen after saturation with water and the height of the test specimen before exposure to water, determined within the framework of determining the California Bearing Ratio according to SIST EN 13286-47.
E_{vd}	MPa	Dynamic deformation modulus determined according to TSC 06.720.
FA		Fly ash.
IBI	%	Immediate bearing index of the built-in material at optimum moisture content w_{opt} according to the Proctor method, determined in accordance with SIST EN 13286-47 (without load).
IBI_w	%	Immediate bearing index of the built-in material at material moisture content w, determined in accordance with SIST EN 13286-47 (without load).
I_C		A dimensionless value expressing the consistency of the soil – consistency index.
I_P	%	Difference between the limit of viscosity and the limit of plasticity.
K_v	%	Weather resistance coefficient determined according to the procedure in Annex 2 of this technical specification.
C_f	%	Frost resistance coefficient, determined according to the procedure in Annex 3 of this technical specification.
MPT		Modified Proctor test with compaction energy 2.7 MJ/m^3, according to the procedure in SIST EN 13286-2.
q_u	kPa	Uniaxial compressive strength of soils, determined according to SIST EN ISO 17892-7.
Rc		Uniaxial compressive strength of bound mixtures, determined in accordance with SIST EN 13286- 41.
□$_d$	Mg/m^3	Dry density of the built-in material.
□$_{d\ max}$	Mg/m^3	Maximum dry density of the material determined according to the Proctor method (SIST EN 13286-2).
SPT		Standard Proctor test with a compaction energy of 0.6 MJ/m^3, according to the procedure in SIST EN 13286-2.
w	%	Material moisture (also natural moisture) determined by drying, defined as the

		mass of water relative to the mass of dry material.
w_A	%	Water adsorption according to the Enslin-Neff method (DIN 18132).
w_L	%	Viscosity limit, i.e. the moisture content of the soil at which it passes from a liquid (fluid) to a kneadable state.
w_{opt}	%	The moisture content of the material at which the maximum dry density of the material is achieved,

		determined according to the Proctor method (SIST EN 13286-2).
w_P	%	Plasticity limit, i.e. the moisture content of the soil at which it passes from a kneadable to a semi-solid state.

3 Purpose of soil treatment

3.1 General

In the context of road construction, materials that do not meet the minimum technical requirements for foundation soils or for use in embankments or backfills are often encountered, and as such, they cannot be used with high quality in geotechnical works with only mechanical processing. These are mainly materials:

- with high moisture ($w/w_{opt} > 1.2$ and $I_C < 0.8$);
- with a viscosity limit $w_L > 65$ % and a plasticity index $I_p > 12$ %;
- materials exhibiting high swelling potentials (linear swelling $\square_{nab} > 4$ % by volume);
- materials with natural moisture higher than optimum moisture and which cannot be appropriately compacted at this moisture ($D_{pr} < 92$ %);
- poorly compactible materials ($IBI_w < 3$ % and/or $CBR_{2w} < 3$ %, $C_u < 6$, $\square_{d\ max} \leq 1.45$ Mg/m^3 or ≤ 1.65 Mg/m^3 for the finishing layers of embankments, uniaxial compressive strength at natural moisture $q_u < 50$ kPa for fine-grained materials);
- susceptible to frost (category F3 – Table 1 and Figure 1);
- weather-sensitive soils (non-plastic, low, medium and high plastic silts and compound soils in which fine grains are from low plastic silt and the proportion of fine grains with a size below 0.063 mm > 35 %; very high plastic clays with $w_L > 70$ % and water adsorption according to Enslin-Neff $w_A > 85$ %; intermediate soils in which fine grains are from very high plastic clay) and
- soils in which mechanical compaction alone cannot ensure compliance with the minimum mechanical characteristics of the design or technical specifications (stiffness, shear strength, deformability – compressibility, etc.) for the intended purpose or they prove to be non-compactible during installation.

Nevertheless, such materials can mostly be used in road construction if they are appropriately treated with lime and/or hydraulic binders. In this way, the properties of soils are improved to the extent that they can be used with high quality in construction (short-term effects) or to ensure appropriate durability and mechanical properties of the built-in material (long-term effects).

In soil treatment procedures, the following is distinguished:

- Soil improvement:
  Soil improvement is a procedure for improving the compactibility of soils and for easier execution of construction work (short-term effects). Soil improvement can be achieved by adding binders or a combination of binders and/or additives, introducing other suitable construction materials or by other measures. This specification only addresses soil improvements with binders listed in items 1, 4.1 and 4.3.
- Soil stabilization:
  Soil stabilization is a process in which, by adding a suitable binder or combination of binders and/or additives, the properties of the soil are changed in such a way as to increase its resistance to loads (climatic, traffic, etc.) to the extent that it becomes permanently stable and resistant to climatic influences and the effects of surface and groundwater (medium-term and long-term effects). This specification only addresses soil stabilization with binders listed in items 1, 4.1 and 4.3.

Soil treatment procedures can be defined already within the design (geotechnical design, earthworks design, road construction design, etc.) or based on previous surveys of materials in the area ofthe envisaged construction, or materials intended for construction. However, they can be defined subsequently during construction, within the framework of a special study or technological study based on additional research of available materials.

4 Basic materials (and their quality)

4.1 General

Soils, binders, additives and water are used in soil treatment procedures.

Within the framework of this technical specification, the following earthworks (soils) materials are considered for treatment with binders:

- natural soils;
- natural stone aggregates;
- crushed rocks (categories 4, 5a, 5b and 6 according to TSPI PG.05.100);
- recycled materials;
- artificial materials and
- a mixture of the above materials,

wherein the maximum grain size shall be suitable for the intended installation machinery and the thickness of the built-in layers, and the treated soil shall not contain impurities that could negatively affect the binding, mechanical properties, environmental acceptability and volume stability of the treated soils.

Within the framework of this technical specification, lime, hydraulic binders and pozzolanic material and their mixtures are considered as binders. Within the scope of hydraulic binders, this technical specification addresses cement, hydraulic road binders (HRB), fly ash (silica or calcium) and granulated blast furnace slag, for which harmonised technical regulations (harmonised standards) already exist at the time of preparation of this technical specification. Within the scope of alternative binders, this technical specification addresses other binders with pozzolanic (latent hydraulic) properties, with which the characteristics of treated soils prescribed by this specification can be achieved. Lime is defined as all types of lime that are covered in the SIST EN 459-1 standard and include quicklime, hydrated lime and lime with hydraulic properties.

4.2 Soil identification and preliminary surveys

Within the scope of preliminary surveys, it is necessary to define the type and properties of existing soils for an individual design based on exploratory wells or test excavations and, if necessary, to envisage additional measures for the possibilities of using these materials in further construction works. The need for soil treatment may also arise later during construction or as part of ongoing or control tests, whereby the requirements and instructions of this technical specification shall be taken into account for use and follow-up procedures.

The identification or classification of the soil in question is the basis for defining the type and method of soil treatment, as well as the selection of a suitable binder.

The treated soil shall be classified in accordance with SIST EN ISO 14688-2 and TSPI PG.05.201 and, for the purpose of selecting possible treatment procedures, at least the following shall be determined:

- natural moisture content w (SIST EN 1097-5 or SIST EN ISO 17892-1);
- particle size composition (SIST EN 933-1 or SIST EN ISO 17892-4);
- consistency limits (SIST EN ISO 17892-12, only for fine-grained soils);
- maximum dry density and optimum moisture content according to the relevant Proctor test (SPT or MPT) (SIST EN 13286-2);
- Proctor compaction (D_{pr}) at natural moisture content (SIST EN 13286-2);

- IBI_w (SIST EN 13286-47);
- CBR_{2w} (SIST EN 13286-47);
- vertical swelling $\Box_{nab}$ (SIST EN 13286-47);
- compressive strength for fine-grained and mixed soils according to SIST EN ISO 17892-7 (test specimen prepared by compaction in a mould according to standard Proctor method in accordance with SIST EN 13286-2 at w).

For the planning of soil treatment with binders, measurements of E_{vd} and field CBR in research shafts are not relevant or sufficient, but they shall be planned based on at least the above-mentioned laboratory tests.

The possibility of treatment or the level of effectiveness of binders can also be greatly influenced by the presence of sulphates and sulphides in the soil, as well as the presence of organic matter or chlorides.
Due to chemical reactions of sulphates and sulphides in the soil with matrix components of lime, cement or mixed binder, destructive effects can occur in such treated soil, such as swelling and even collapse of the structure. The addition of a binder can thus cause the formation of secondary ettringite and thaumazite, which can cause up to 30 % volume swelling and swelling pressures of up to 5 MPa. The formation of these mineral phases is mainly stimulated by:

- an increased content of soluble sulphates;
- an alkaline environment (especially at pH > 10.5);
- the presence of reaction partners such as clays and carbonates, and
- high moisture.

In principle, all soils containing sulphides (e.g. pyrite) and sulphates (e.g. gypsum and anhydrite) are potentially hazardous. The potential presence of sulphates and sulphides should be identified already in the design phase on the basis of geological maps, mineralogical surveys and/or sulphate content surveys as part of preliminary research.
If higher concentrations of sulphates or sulphides are suspected in the soil to be treated, which may also occur during construction, their content shall be checked in accordance with the gravimetric method according to SIST EN 196-2 (expressed as % SO_3), or with a comparably validated method (e.g. SIST EN 1744-1), and as a risk assessment, the following approximate reference valuescan be adopted (*Merkblatt uber Bodenbehandlungen mit Blndemitteln, MBmB, B18740, 2021*):

- very low risk: sulphate content < 0.3 %;
- low risk: sulphate content 0.3–0.5 %;
- medium to high risk: sulphate content 0.5–0.8 %;
- very high risk – soil unsuitable for treatment: sulphate content > 0.8 %.

In the case of treating soils with medium to high risk, additional surveys shall be planned and carried out on the basis of which it will be possible to ensure the appropriate properties of the treated soil and its long-term stability. Since in these cases the development of volume changes is usually slow (which can be more than half a year), it is necessary to plan the research accordingly.
The presence of organic substances in soils can inhibit the function of binders, which shall be taken into account when planning and carrying out research for the needs of soil treatment, as well as when preparing and installing treated soils. It is necessary to check in particular the influence of the presence of organic substances on the binding time of binders, as well as the influence on the final properties of the treated soil. If the organic substance content is below 2 % (C_{OM} < 2, loss after ignition method according to SIST EN 1744-1, item 17) or in the case of the Abrams-Harde colorimetric method, a lighter solution than the reference one (SIST EN 1744-1, item 15.1), no special measures or research are required. For soils with an organic matter content C_{OM} 2–20 % or if the solution according to SIST EN 1744-1 is darker than the reference solution (up to dark yellow),

additional tests are required to check the effect on the function of the binders and suitability for treatment. If the C_{OM} value is > 20, the soil is unsuitable for treatment.

As part of the preliminary surveys, it is also necessary to check the homogeneity of the soils in the area under consideration or to determine homogeneous sections that will be treated separately. For each homogeneous section, it is necessary to define the need for treatment and, in the case of treatment, prepare a separate recipe.

Very coarse-grained soils (Co, Bo), uniformly grained gravels (GrU) and, depending on operational experience, organic soils are not suitable for treatment with binders. Fine-grained soils, whose grain size composition lies entirely in area A on the diagram (Figure 2), are also unsuitable for treatment with binders, because they usually cannot be properly homogenized in treatment procedures. In cases of very high plastic soils, e.g. soil with a viscosity limit $w_L > 85$ %, careful consideration should be given to the feasibility of improving the use of binders due to technological constraints linked to the homogeneity of the mixture.
In cases where large excess quantities of organic soils appear in mass balances, the assessment of the treatment of these soils with binders should also include research to assess the long-term durability of these soils. The presence of organic components can slow down and/or reduce the function of binders, which shall be taken into account when planning the binder content. By adding 1–3 % lime, acidic organic components can be neutralized in the previous work step and thus prepare the soil for further treatment procedures. The amount of the necessary addition depends on the type of lime used and the acidity (pH value) of the soil and shall be determined by laboratory tests. Coarse organic impurities in the soil may swell upon contact with water and negatively affect the durability of such treated soils, which requires special attention in the planning and implementation of the treatment. If technically feasible, coarse organic impurities shall be removed before the treatment procedures.
It should be noted that coal particles from separations in the Zasavje coal mines are often present in flood sediments of Quaternary age, especially along the middle and lower Sava River. Colorimetric and analytical methods will recognize the organic character of such soil, but the presence of coal fragments will generally not harm the function of binders in soil treatment.

4.2.1 Criteria for selecting the treatment method:

The soil treatment method is selected based on the properties of the soil and the required characteristics of the soil for the intended purpose. Soil treatment with lime and/or hydraulic binders is divided into improvement and stabilization, and the two processes can also be intertwined or upgraded.

- Improvement:
  Improvement primarily covers soils that cannot be properly compacted under given conditions, which is most often a result of the very high moisture of the available soil or its characteristics (consistency limits or grain size), so that it cannot be properly installed and provide immediate suitable load-bearing capacity under given conditions.
  Soil improvement is required if at least one of the following criteria is met:
  - $w/w_{opt} > 1.2$;
  - $I_C < 0.8$;
  - Proctor compaction $D_{PR} < 92\ \%\ \rho_{d\,max}$ (SIST EN 13286-2 for SPT or MPT cylinders) at a natural moisture higher than the optimum moisture;
  - $CBR_{2w} < 3$ %;
  - $IBI_w < 3$ %;
  - viscosity limit $w_L > 65$ % (for fine-grained soils);
  - plasticity index $I_P > 40$ % (for fine-grained soils);
  - compressive strength for fine-grained and mixed soils $q_u < 50$ kPa at w;

- grain size $C_U < 6$.

If the material in question is suitable for improvement, but is frost-sensitive and will be built-in to the frost depth, regardless of the fulfilment of any of the above the stated criteria, stabilization or other measures (e.g. replacement) are necessary.

If, after improving the characteristics of the treated soil, despite adequate compactibility, it does not meet the minimum requirements of this technical specification or project requirements, stabilization is required.

- Stabilization:

  Stabilization primarily covers soils that, due to their properties, do not provide suitable mechanical properties or properties suitable for the intended purpose or exhibit high sensitivity to frost and weathering.

  Soil stabilization is required if at least one of the following criteria is met:

  - frost sensitive material (Category F3 materials – Table 1 and Figure 1), if built-in to frost depth;
  - □$_{dmax}$ < 1.45 Mg/m^3 or < 1.65 Mg/m^3 for the embankment finishing layers;
  - IBI_w > 3 % in CBR_{2w} < 3 %;
  - IBI_w or CBR_{2w} does not meet the design requirement;
  - vertical swelling □$_{nab}$ > 4 %;
  - viscosity limit w_L > 65 %;
  - Enslin-Neff w_A > 85 % (DIN 18132);
  - grain size C_U < 6;
  - non-plastic, low, medium and high plastic silts and compound soils containing fine grains of low plastic silt and a proportion of fine grains of > 35 %;
  - very high plastic clays, w_L > 70 %, Enslin Neff w_A > 85 %; intermediate soils in which the fine grains are from very high plastic clay;
  - compressive strength q_u > 50 kPa, but does not meet the design requirements (only for fine-grained and mixed soils, test specimen prepared according to SPT at natural moisture).

Table 1: Sensitivity of materials to freezing

Class	Sensitivity	Classification[1]
F1	insensitive	GrW, GrM, GrG SaW, SaM, SaG
F2	slightly to moderately sensitive	clGr[2], siGr[2] clSa[2], siSa[2] ClH
F3	very sensitive	clGr[3], siGr[3] clSa[3], siSa[3] ClL, ClM SiL, SiM, SiH

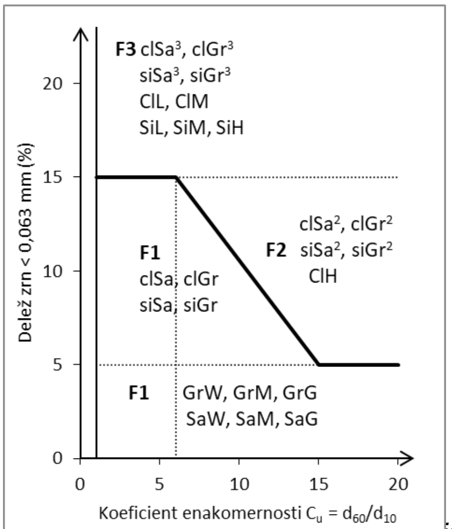


Figure 1: Sensitivity of materials to freezing

Note:
[1] Classification according to the principles of EN ISO 14688-2 or the main groups according to TSPI PG.05.201.
[2] Classified in F1, if they meet the condition in diagram 1.

[3] classified in F1 or F2, if they meet the condition according to diagram

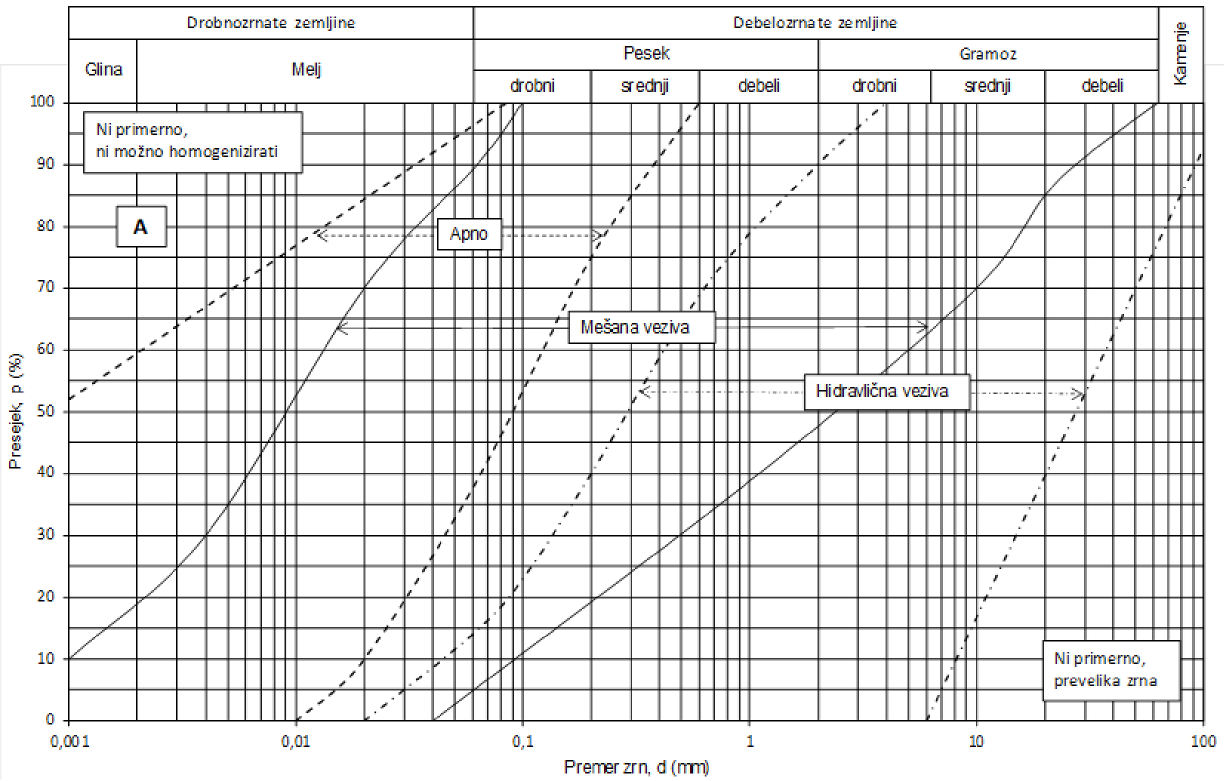
4.3 Binders

Binders are used in earthworks to improve and stabilize soils. According to current practice in Slovenia, binders are used primarily for soil improvement, and less often for soil stabilization. The most commonly used binders are lime and/or hydraulic binders. In general, lime or alternative binders with high lime content (CaO, $Ca(OH)_2$) are used to dry out wet materials and/or to improve the properties of cohesive materials. Hydraulic binders are mainly used to quickly and significantly increase the mechanical characteristics of non-cohesive materials that do not provide a stable layer structure in the compacted state. In the presence of cohesive materials and depending on the application, lime and hydraulic binders can be used together, either in a two-step process, or by using a pre-prepared binder mixture.

The properties of soils that influence the choice of type and efficiency of binder use are primarily:

- granular composition;
- plasticity of fine grains in connection with other property indicators related to soil-water interaction, e.g. Enslin Neff test;
- presence of sulphates and/or sulphides, chlorides;
- content of organic matter;
- soil condition parameters such as moisture, consistency index etc.

In general, the type of binder can be selected based on the grain composition of the soil. The application areas
of individual types of binders according to the grain composition of the soil are given in the diagram (Figure 2).



Note:

- The alternative binders referred to in item 4.3.3 are used appropriately according to their composition and mode of function. They are generally applicable in the area for mixed binders.
- For a viscosity limit w_L between 35 and 40 % and I_p between 12 and 15 % and the grading area shown in the diagram indicating mixed binders, the most appropriate treatment procedure is lime and hydraulic binders.

Figure 2: Applicability of treatment binders according to soil grading areas

If it is not possible to achieve the required properties of the treated soil with the selected type of binder based on the given usability ranges, a different type of binder may also be selected depending on the grading composition, regardless of the proposed binder type.

The choice of binder depends on the properties and type of soil. The suitability of binders for soil improvement according to soil type is given in *Table 5*, and for stabilization in *Table 7*.

4.3.1 Lime

Lime and alternative binders with an appropriate lime content (CaO, $Ca(OH)_2$) are suitable for the improvement of fine-grained, plastic soils of types ClL, ClM, ClH and compound soils of types clGr, clSa.

In the case of using quicklime, special measures are required to ensure the homogeneity of lime mixing, safety at work and prevention of negative impacts on the surroundings (also outside the construction site area). In general, the use of quicklime in-situ is not recommended.

Lime may be used for soil treatment in accordance with SIST EN 459-1. Hydrated lime listed in *Table 2*, quicklime listed in *Table 3*, as well as lime with hydraulic properties listed in *Table 4* may be used.

Lime milk of categories CL 90 S ML, CL 80 S ML, DL 85-30 S ML and DL 85-5 S ML may also be used for in-situ application, primarily in cases where work would also need to be carried out in windy weather, but it is not possible to perform dosing using a dust-free procedure (on a mobile mixing device – recycler or soil stabilizer with an integrated binder dosing module just before the crushing – mixing rotor), which could cause a significant negative impact on the environment and the health of workers due to dust and make it impossible to ensure an appropriate proportion of lime in the treated soil. When using lime milk (S ML), it is necessary to precisely define the implementation procedures and demonstrate the suitability of the properties of the treated soil as part of preliminary research.

In the design and implementation processes, it is necessary to adapt the technology of the work to the setting time.

Table 2: Hydrated lime suitable for soil treatment

Calcium lime	Dolomite lime
CL 90-S	DL 90-30-S
	DL 90-30-S1
	DL 90-5-S
	DL 90-5-S1
CL 80-S	DL 85-30-S
	DL 85-30-S1
	DL 85-5-S
	DL 85-5-S1

Table 3: Quicklime suitable for soil treatment

Type of quicklime	Category	Reactivity
CL 90 Q	R4, R5	$T_{60\,°C} \leq 25$ min
CL 80 Q	R3, R4	$T_{50\,°C} \leq 25$ min
DL 85-30 Q	R2	$T_{40\,°C} \leq 25$ min
DL 80-5 Q	R1	$T_{35\,°C} \leq 25$ min

Note: The grading categories may be P1–P4.

Table 4: Lime with hydraulic properties suitable for soil treatment

Type of lime with hydraulic properties	Compressive strength (28 d) MPa	Setting time (h) (start/end)
NHL 5	5–15	1–15
FL (A;B;C) 5	5–15	1–15
HL 2	2–7	1–15
HL 3.5	3.5–10	1–15
HL 5	5–15	1–15

4.3.2 Hydraulic binders

Within the scope of hydraulic binders, this technical specification addresses cement, hydraulic road binders (HRB), fly ash (silica or calcium) and granulated blast furnace slag, for which harmonised technical regulations (standards) exist at the time of preparation of this technical specification.

Cements and hydraulic road binders are particularly suitable for the improvement of non-plastic fine-grained soils (SiL, SiM), compound and composite soils in which the fine grains are not plastic (siGr, siSa). Fly ash, particularly of the calcium type, is widely used alone or in combination with lime or cement to improve damp, clayey gravels and sands (clGr, siSa). Silica fly ash is also useful, but it must be activated, which requires the presence of sufficient lime ($CaO/Ca(OH)_2$). The possibility of using such binders shall be checked by planning additives or as part of preliminary research, which shall also include the mineralogical composition of the soil intended for treatment.

4.3.2.1 Cement

For soil treatment, cements in accordance with SIST EN 197-1 are used, namely cements of strength class 32.5 L, 32.5 N or 32.5 N – LH.

4.3.2.2 Hydraulic road binders (HRB)

For soil treatment, hydraulic road binders are used:

- in accordance with SIST EN 13282-1, namely binders of strength class E2, E3 or E4; and
- in accordance with SIST EN 13282-2, namely binders of strength class N1, N2 and N3.

4.3.2.3 Fly ash

For soil treatment, coal fly ash (FA) is used as a binder, which is formed by the combustion of coal dust with or without co-combustion of other materials and is removed from the smoke by mechanical or electrostatic precipitators – filters.
For soil treatment, fly ash in accordance with SIST EN 450-1 or fly ash in accordance with SIST EN 14227-4 is used.
When using silica ash, a sufficiently high pH in the system shall be ensured to activate the pozzolanic reaction, which requires careful planning of the combination of such ash with a reaction activator (presence of CaO and/or $Ca(OH)_2$, lime or cement).

4.3.2.4 Slag

Slag that can be used as a binder in soil treatment is suitably activated granulated blast furnace slag in accordance with SIST EN 15167-1 or partially granulated blast furnace slag in accordance with SIST EN 14227-2.

4.3.3 Alternative binder for soil treatment

Alternative binders include various fine-grained industrial by-products with pozzolanic or hydraulic properties, which can be used to achieve the appropriate or desired properties of the treated soil. These are various ashes, residues from gas cleaning in high-temperature processes in industry and energy sector, such as wood ashes, paper ashes, biomass ashes and others (except fly ashes defined in item 4.3.2.3); slags (except granulated blast furnace slag defined in item 4.3.2.4) and other powders (e.g. microsilica). Some untreated natural materials (e.g. tuffs, diatomaceous soil, etc.) and treated natural materials (calcined clay – metakaolin, fired shale, fired clay – ceramics) also have pozzolanic properties.
Alternative binders may be used if they can achieve the minimum required characteristics for the treated soil, long-term stability and environmental acceptability of the treated soil (the quality of the treated soil leachate shall meet the criteria of the relevant applicable environmental legislation). They may be used alone or as one of the components of mixed binders. Long-term stability and environmental acceptability shall be demonstrated based on the results of preliminary surveys. Alternative binders shall be characterised before use and at least their mineralogical composition, the time required for their function (setting speed) and the chemical composition of the leachate shall be determined for parameters in accordance with applicable environmental legislation. When using alternative binders, the mineralogical composition of the soil intended for treatment shall also be determined to facilitate the planning of treatment procedures.

4.3.4 Mixed binders

Mixed or complex binders, which are mixtures of the above-mentioned binders in different proportions, or as pre-prepared mixtures or they can be used individually in successive working steps, may also be used for soil treatment. Regardless of the method of using mixed binders, it is necessary to check the compatibility of individual components of mixed binders in preliminary surveys, prove their usability and clearly define the method of their use.

4.4 Other materials

In soil treatment procedures, other materials may also be used, such as additives of various aggregates, additives of other soils or various chemical additives, such as retardants, or others that may be necessary to activate or improve the hydraulic reaction, improve machinability, compactibility or mechanical properties of the treated soil.
The type, quantity, purpose and method of use of other materials shall be described in detail in the laboratory composition and technological study, whereby it is necessary to prove on the final product (treated soil) through laboratory tests that the treated soil meets the minimum requirements of this technical specification or the minimum requirements for the intended purpose of use and is environmentally acceptable, which shall be proven in advance by the quality of the leachate in accordance with applicable environmental legislation.

4.5 Water

Any natural or process water that meets the criteria of SIST EN 1008 is suitable for soil treatment, whereby the pH value of the water used shall not be lower than 6 (pH ≥ 6), and its composition does not negatively affect the binding and properties of the treated soil. Drinking water can be used without verification.

5 Soil treatment

In soil treatment procedures, the following is distinguished:

- soil improvement and
- soil stabilization.

SOIL TREATMENT WITH LIME AND/OR HYDRAULIC BINDERS IN ROAD

5.1 General

The suitability of the soil for improvement or stabilization shall be verified through preliminary surveys, according to the properties listed in item 4.2.1, whereby the maximum grain size of the soil shall be suitable for the intended installation machinery and the thickness of the built-in layers. As a rule, all soils with a maximum grain size of 125 mm are suitable, but in the presence of larger grains, it is necessary to verify the feasibility of improvement or stabilization or to provide measures that will make implementation possible (e.g. removal of excessive grains). The treated soil shall not contain impurities that could adversely affect the binding, mechanical properties, environmental acceptability and volume stability of the treated soil. Other basic materials that can be used in the soil treatment process are listed in items 1–4.5.

5.2 Soil improvement

Soil improvement processes primarily change the properties of the material in such a way as to improve the compactibility and increase the stiffness of the built-in layer.
The properties of the improved soil shall meet the requirements set out in item 5.2.3 of this technical specification.

5.2.1 Binder selection

The selection of the type of binder for soil improvement depends on the properties of the soil. The suitability of binders for soil improvement with respect to the grading composition of the soil is given as a basic guideline in the diagram (Figure 2), and with respect to the type of soil (classification) in *Table 5*.

Table 5: Binder suitability for the improvement of individual soil groups

Soil description	**Classification**[1)]	**Binder type**		
		Lime[2)]	**Hydraulic binders**[3)]	**Mixed and alternative binders**
Coarse-grained soils	GrW, GrM, GrG	—	X	—
	SaW, SaM, SaG	—	X	—
Mixed soils	siGr, clGr	(X)	X	(X)
	siSa, clSa	(X)	X	(X)
Fine-grained soils	SiL	X	X	(X)
	SiM	X	(X)	(X)
	SiH	X	—	(X)
	ClL	X	(X)	(X)
	ClM	X	(X)	(X)
	ClH	(X)	—	(X)
Organic soils		(X)	(X)	(X)
Very coarse-grained soils	Lbo, Bo, Co	(X)	(X)	(X)

Note: X – suitable, (X) – conditionally suitable, — – unsuitable
1) SIST EN ISO 14688-2
2) SIST EN 459-1
3) SIST EN 197-1, SIST EN 13282-1, SIST EN 13282-2, SIST EN 450-1, SIST EN 14227-4, SIST EN 15167-1

If the required characteristics for the improved soil cannot be achieved with just one type of binder, a mixture of several binders (mixed binders) and/or additives can also be used, whereby the laboratory composition shall clearly state which binders are used and in what proportion, whether it is a previously prepared mixture of binders and/or additives or sequential additions, time intervals of addition (if relevant), methods and procedures of homogenization, reaction time of the binder used, etc.

SOIL TREATMENT WITH LIME AND/OR HYDRAULIC BINDERS IN ROAD

5.2.2 Binder and/or additives proportion

Binder and/or additives proportion is determined based on the required properties of the improved soil. The optimum proportion of binder for the preparation of improved soil is the lowest proportion that ensures the minimum required characteristics of the improved soil listed in item 5.2.3 or the project requirements. The proportion of binder for the preparation of improved soil shall not be lower than:

- 2.5 % when using lime;
- 3 % when using hydraulic binders; and
- 3 % when using mixed or alternative binders.

In the case that only lime is used as a binder, the optimum proportion of lime can be estimated based on the pH test in accordance with SIST-TS CEN/TS 17693-1, on at least three different lime additions. The optimum proportion of lime is the smallest proportion with which the pH of the improved soil is higher than 12.4. If the pH value determined with all lime additions is higher than 12.4, at least one more test with the addition of lime shall be prepared, in which the pH value will be lower than 12.4. The properties of the mixture with the estimated optimum proportion of lime shall be checked. If the properties of the improved soil prepared with the estimated lime proportion meet the requirements specified in item 5.2.3 and the design requirements, the preparation and verification of the properties of other mixtures with different lime proportions, within the framework of the laboratory composition, is not required.

The assessment of the optimum binder proportion based on pH can also be useful as a guide in the case of using binders with a high content of free lime (some alternative and/or mixed), but it is nevertheless necessary to prepare and determine the properties of all three series of mixtures with different binder proportions. The optimum binder proportion for the preparation of improved soil is the lowest proportion that ensures the minimum required characteristics of the improved soil specified in item 5.2.3 or in the design.

5.2.3 Properties of improved soil

The properties of improved soil, regardless of the type of binder used and any additives, shall comply with the requirements set out in *Table 6*.
If the improved soil is to be built-in to the frost depth, the frost resistance of the mixture shall also be checked according to the procedure in Annex 3. The frost resistance coefficient (C_f) shall be ≥ 0.7.

Table 6: Required properties of improved soil

Property	**Method of determination**	**Requirement**
w of the improved soil	SIST EN 1097-5, SIST EN ISO 17892-1	$w_{opt} \leq w_{\text{of the improved soil}} \leq w_{\text{at 95 \% Dpr}}$
D_{pr} of the improved soil ($\square_d$ at w)	SIST EN 13286-2 (calculation of $\square_d/\square_{d\,max}$)	≥ 95 %
IBI_w	SIST EN 13286-47	≥ 5 %[2)]
CBR_{2w}	SIST EN 13286-47	≥ 4 %
Vertical swelling $\square_{nab}$	SIST EN 13286-47	< 2 % (single up to 4 %)
Weather resistance coefficient K_V	Annex 2	≥ 0.7[1)]

Note:
[1)] Mandatory for the finishing layer and in the area ofgroundwater fluctuation.
[2)] Suitability can also be demonstrated by the result of testing on test specimens that have been maintained for up to 4 days (protected from moisture loss after preparation).

5.3 Soil stabilization

Soil stabilization procedures primarily ensure the volumetric stability of the material, long-term improvement of mechanical properties (compressive, shear and tensile strength), increase in load-bearing capacity, decrease in water sensitivity and increase in frost resistance.
The properties of the stabilized soil shall meet the requirements set out in item 5.3.3 of this technical specification and the requirements of the design.

5.3.1 Binder selection

The selection of the type of binder for soil stabilization depends on the properties of the soil. The suitability of binders for soil treatment with respect to the grading composition of the soil is given as a basic guideline in the diagram (Figure 2), and with respect to the type of soil (classification) in *Table 7*.

If the required characteristics for the stabilized soil cannot be achieved with just one type of binder, a mixture of several binders (mixed binders) and/or additives can also be used, whereby the laboratory composition shall clearly state which binders are used and in what proportion, whether it is a previously prepared mixture of binders and/or additives or sequential additions, time intervals of addition (if relevant), methods and procedures of homogenization, reaction time of the binder used.

Table 7: Binder suitability for the stabilizing of individual soil groups

Soil description	**Classification**[1]	**Binder type**		
		Lime[2]	**Hydraulic binders**[3]	**Mixed and alternative binders**
Coarse-grained soils	GrW, GrM, GrG	—	X	—
	SaW, SaM, SaG	—	X	—
Mixed soils	siGr, clGr	—	X	(X)
	siSa, clSa	—	X	(X)
Fine-grained soils	SiL	X	X	(X)
	SiM	X	(X)	(X)
	SiH	X	—	(X)
	ClL	X	(X)	(X)
	ClM	X	(X)	(X)
	ClH	(X)	—	—
Organic soils		(X)	(X)	—
Very coarse-grained soils	Lbo, Bo, Co	—	—	—

Note: X – suitable, (X) – conditionally suitable, — – unsuitable
1) SIST EN ISO 14688-2
2) SIST EN 459-1
3) SIST EN 197-1, SIST EN 13282-1, SIST EN 13282-2, SIST EN 450-1, SIST EN 14227-4, SIST EN 15167-1

5.3.2 Binder and/or additives proportion

Binder and/or additives proportion is determined based on the properties of the stabilized soil. The optimum proportion of binder for the preparation of stabilized soil is the lowest proportion that ensures the minimum required characteristics of the stabilized soil listed in item 5.3.3 or the project requirements. Binder proportion for the preparation of stabilized soil shall not be lower than:

- 4 % when using lime;
- 4 % when using mixed or alternative binders in the stabilization of coarse-grained soils;
- 3 % when using hydraulic binders in the stabilization of coarse-grained soils; and

- 6 % when using hydraulic, mixed or alternative binders in the stabilization of fine-grained and mixed soils.

In the case that only lime is used as a binder, the optimum proportion of lime can be estimated based on the pH test in accordance with SIST-TS CEN/TS 17693-1, on at least three different lime additions. The optimum proportion of lime is the smallest proportion with which the pH of the stabilized soil is higher than 12.4. If the pH value determined with all lime additions is higher than 12.4, at least one more test with the addition of lime shall be prepared, in which the pH value will be lower than 12.4. The properties of the mixture with the estimated optimum proportion of lime shall be checked. If the properties of the stabilized soil prepared with the estimated lime content meet the requirements specified in item 5.3.3 and the design requirements, the preparation and verification of the properties of other mixtures with different lime proportion, within the framework of the laboratory composition, is not required.

The assessment of the optimum binder proportion based on pH can also be useful as a guide in the case of using binders with a high content of free lime (some alternative and/or mixed), but it is nevertheless necessary to prepare and determine the properties of all three series of mixtures with different binder proportions. The optimum proportion of binder for the preparation of stabilized soil is the lowest proportion that ensures the minimum required characteristics of the stabilized soil listed in item 5.3.3 or in the design.

5.3.3 Properties of stabilized soil

The properties of stabilized soil, regardless of the type of binder used and any additives, shall comply with the requirements set out in *Table 8*.
If the stabilized soil is to be built-in to the frost depth, the frost resistance of the mixture shall also be checked according to the procedure in Annex 3. The frost resistance coefficient (C_f) shall be ≥ 0.7 and the difference in height after the first and twelfth freezing and thawing cycles may not exceed 0.1 %.

Table 8: Required properties of stabilized soil

Property	**Method of determination**	**Requirement**
$w_{\text{of the stabilized soil}}$	SIST EN 1097-5, SIST EN ISO 17892-1	$w_{opt} \leq w_{\text{of the stabilized soil}} \leq w_{\text{at 95 \% Dpr}}$
D_{pr} of the stabilized soils (ratio between $\square_d$ at w and $\square_{d\,max}$)	SIST EN 13286-2 (calculation of $\square_d/\square_{d\,max}$)	≥ 95 %
IBI	SIST EN 13286-47	≥ 10 %[1)]
CBR_2	SIST EN 13286-47	≥ 7 %[1)]
Vertical swelling $\square_{nab}$	SIST EN 13286-47	< 2 % (single up to 4 %)
Uniaxial compressive strength R_c at w_{opt}: • Fine-grained and mixed soils o after 7 days of curing o after 28 days of curing	SIST EN 13286-41 (preparation of SIST EN 13286-50, Curing, Annex 1)	0.40–2.5 MPa[1)] 0.50–3.5 MPa[1)]
• Coarse-grained soils		

o after 7 days of curing o after 28 days of curing		1.5–3.0 MPa[1)] 2.0–4.5 MPa[1)]

Weather resistance coefficient K_V	Annex 2	≥ 0.7

Note:

1) For stabilized soils, compliance with the requirements may be demonstrated by IBI and CBR_2 or with compressive strengths.

5.4 Laboratory composition (recipe)

5.4.1 Preparation of laboratory composition (recipe)

For the laboratory (preliminary) composition of the treated soil mixture, at least five batches of soil mixtures with natural moisture, binder and possible other ingredients shall be prepared and, in the case of moisture that is too low for installation, the necessary (optimum) amount of water. The mixture shall be homogenized in the laboratory using an appropriate procedure (usually in a mixing device), so that a homogeneous composition of the mixture is ensured.

If lime or an alternative binder or a mixed binder with a high content of free lime is used as a binder, after homogenizing the soil with the binder and before preparing the test specimens, the mixture shall be stored protected from moisture loss (in sealed bags or containers) for at least 1 hour (mellowing time) to allow the reaction to take place. The mellowing time of the mixture may vary depending on the type of lime or binder with a content of free lime used. Foreign experience provides a basic guideline for the mellowing time of 6 hours for quicklime and 2 hours for hydrated lime. After mellowing, the mixture shall be stirred and homogenized again, usually by mixing for at least 2 minutes in a mixing device. After preparing the mixture, the test specimen shall be prepared (thickened) within 30 minutes.

When using hydraulic binders, the preparation of the test specimens is carried out without mellowing the mixture, and the preparation of the test specimen shall be completed no later than 90 minutes after mixing.

If the treatment of the soil is carried out in two steps, first with lime or an alternative binder with high free lime content and then with a hydraulic binder, it is necessary to ensure at least 2 hours of mellowing before adding the hydraulic binder. The preparation of test specimens from such a mixture shall be completed no later than 90 minutes after adding the hydraulic binder.
The mellowing time of the mixture and the time intervals between individual additives in the preparation of the mixture, if it is carried out in two or more steps, shall be clearly defined and stated in the laboratory composition.
The properties of binders, other materials and water shall meet the requirements of items 1, 4.4 and 4.5.

For each mixture, it is necessary to determine:

- binder proportion;
- mixture moisture content at the time of preparation (SIST EN 1097-5, SIST EN ISO 17892-1);
- dry density of the mixture at the moisture content in the time of preparation according to the relevant Proctor method (SPT or MPT) (SIST EN 13286-2);
- optimum moisture content and maximum dry density (SIST EN 13286-2);
- IBI (SIST EN 13286-47);
- CBR_2 (SIST EN 13286-47);
- vertical swelling $\square_{nab}$ (SIST EN 13286-47);
- compressive strength after 7 and 28 days (SIST EN 13286-41), only for stabilized soils;
- weather resistance (procedure in Annex 2);
- pH of the mixture (SIST ISO 10390, procedure with water).

The proportion of binder ($p_{of\ binder}$) is given in percentage, as the mass of dry binder in kg per mass of dry soil in kg:

$$p_{of\ binder} = \frac{m_{of\ dry\ binder}}{m_{dry\ soil}} \times 100\ [\%]$$

The moisture content of the mixture ($w_{of\ mixture}$) during preparation is determined by drying in a ventilated dryer in accordance with SIST EN 1097-5 or SIST EN ISO 17892-1.

The dry density of the mixture (□$_{d\ of\ the\ mixture}$) during preparation is determined by compacting the prepared mixture into a cylinder according to the relevant Proctor method (SPT or MPT) in accordance with SIST EN 13286-2. The choice of the Proctor method is based on the size of the largest grain and the grain composition in the treated
material. For materials with 90–100 % of grains with a size below 16 mm, whereby all grains shall be smaller than 32 mm (up to 10 % of oversized grains of 16–32 mm are allowed), and the proportion of grains with a size above 4 mm < 25 %, the SPT should be used. For other materials, the MPT shall be used. The Proctor method used shall be stated in the laboratory composition.

The optimum moisture content (w_{opt}) and maximum dry density (□$_{d\ max}$) of the mixture are determined by the relevant Proctor method (SPT or MPT) in accordance with SIST EN 13286-2. The Proctor method used shall be stated in the laboratory composition.

Immediate Bearing Index (IBI), the California Bearing Ratio of the test specimen submerged in water (CBR_2) and the vertical swelling (□$_{nab}$) are determined in accordance with SIST EN 13286-47.

The procedure for preparing and curing the test specimens for determining the compressive strength is given in Annex 1.

The compressive strength of an individual mixture is determined after 7 and 28 days on at least three test specimens in accordance with SIST EN 13286-41. The test specimens for determining the compressive strength shall be prepared and cured in accordance with the requirements in Annex 1. Like the compressive strength of the mixture after 7 (Rc7) or 28 (Rc28) days is given as the average of the compressive strengths of at least three test specimens after 7 and 28 days of curing, respectively, whereby the compressive strengths of all test specimens shall comply with the requirements in *Table 8*, item 5.3.3, for stabilized soils. In addition to the results of the compressive strength of individual test specimens, the laboratory composition shall also include data on the applied loading rate and time to failure.

The coefficient of weather resistance of the mixture (K_v) is determined according to the procedure in Annex 2 on test specimens prepared and cured according to the procedures in Annexes 1 and 2.

The pH value of each mixture shall be determined in accordance with SIST ISO 10390 using the water procedure.

From the prepared batch of mixtures, the optimum mixture for implementation shall be selected based on the properties of each mixture and the requirements of this specification and the requirements for the intended purpose of use. The laboratory composition shall provide all data on the preparation and properties of each mixture, as well as all necessary data and information for the preparation of the optimum mixture (types of materials, quality of materials, proportion of individual components in percentages). In the case of in-situ implementation, the intended thickness of the applied layer and the proportion of individual components in kg/m^3 and kg/m^2 of the applied layer shall also be defined.

The laboratory composition shall also provide the properties of the soil intended for improvement or stabilization, the quantities and properties of the binders used, as well as any additives and, when required within the framework of this technical specification, also evidence of compliance with environmental requirements in accordance with applicable legislation.

The report on the laboratory composition of the treated soil shall contain at least:

- the results of all tests carried out;
- the type of binder(s) used;
- composition of the tested mixtures;
- demonstration of the dependence of the amount of binder and the achieved compressive strength or CBR_2 value;
- for the optimum mixture, the optimum moister and maximum dry density shall be given.

5.4.2 Preparation of preliminary laboratory composition

In preliminary research for an individual project, it is necessary to check the possibility of using the available material. In the event that the material does not meet the conditions for normal installation in embankments or backfills, it is necessary to check whether it can be used after the treatment. Preliminary surveys for treatment shall be carried out for each type of homogeneous material, the quantity of which is at least 5 000 m^3 and is located in layers with a thickness of at least 2 m.

Research for the preparation of a preliminary laboratory composition for the purpose of preparing a design or a geological-geomechanical report, due to the limited quantities of material obtained in the preliminary surveys phase, may be carried out on a smaller scale than that envisaged for the laboratory composition in item 5.4.1.

To determine the optimum preliminary laboratory composition, it is necessary to prepare at least two mixtures with different binder proportions, at least one of which meets the requirements of this specification and the requirements for the intended purpose of use.

For each mixture, it is necessary to determine:

- binder proportion;
- mixture moisture content at the time of preparation (SIST EN 1097-5, SIST EN ISO 17892-1);
- dry density of the mixture at the moisture content in the time of preparation according to the relevant Proctor method (SPT or MPT) (SIST EN 13286-2);
- IBI (SIST EN 13286-47);
- CBR_2 (SIST EN 13286-47);
- vertical swelling $\square_{nab}$ (SIST EN 13286-47);
- compressive strength after 7 and 28 days (SIST EN 13286-41) on at least two test specimens, only for stabilized soils;
- weather resistance (procedure in Annex 2).

The optimum mixture meeting the requirements of this specification and the requirements for the intended use shall be determined:

- optimum moisture content and maximum dry density (SIST EN 13286-2) and
- pH of the mixture (SIST ISO 10390, procedure with water).

When preparing the preliminary laboratory composition, all other requirements given in item 5.4.1 for the preparation of the laboratory composition shall be taken into account.
The report on the preliminary laboratory composition shall contain all relevant data, the same as required for the report on the laboratory composition in item 5.4.1.

The optimum preliminary laboratory composition shall be confirmed before carrying out the soil treatment by preparing the laboratory composition (recipe) in accordance with the requirements in item 5.4.1.

5.5 Performance of works

The performance generally includes the following works:

- preparation of the technological study;
- subgrade preparation;
- preparation and installation of the treated soil mixture;
- curing of the built-in mixture.

5.5.1 Technological study

The contractor shall submit to the supervisor for approval a technological study at least 15 days before the start of the work, which shall be prepared in accordance with the requirements specified in the currently valid technical regulations and as stated in the chapters below. The works may begin once the technological study has been approved.

5.5.1.1 Technological procedures for the performance of works

The following shall be provided:

- purpose of treatment, underlying soil, embankments, finishing layer;
- description of any preparatory works;
- composition and properties (recipe) of the intended treated soil;
- mixture preparation process (in-plant or in-situ, in-situ/in-plant);
- location and estimated time of transport to the installation site (in the case of in-plant and in-situ/in-plant preparation);
- installation implementation procedure:
  - in case of in-plant preparation:
    - spreading,
    - compacting,
  - in case of in-situ preparation:
    - binder dosing,
    - mixing method,
    - compacting;
- the sequence and length of the individual implementation fields;
- a sketch and procedure for implementing connections or switches between individual implementation fields and layers;
- a sketch of individual homogeneous fields for soil treatment with markings of the laboratory composition of the treated soils that will be used in these sections (if relevant);
- method and implementation of layer curing.

5.5.1.2 Information on mechanization

Mechanization shall be selected according to the type of material and the thickness of the built-in layer. The contractor shall provide basic information on the means of transport (in the case of in-plant preparation) and other necessary construction machinery (type, origin, capacity) intended for the execution of the works. Before the start of operation of machinery and devices on which the quality of the works depends, their suitability shall be checked to ensure uniform quality of the execution of the works. Equipment and machinery shall enable the execution of the works and comply with any requirements defined in the project documentation and/or in this specification.

5.5.1.3 Average control frequency programme

The contractor shall submit a program of average frequency of internal control examinations in the technological study, which shall be prepared on the basis of a certain minimum frequency of tests defined in this specification.

5.5.1.4 Information on the working personnel and responsible workers on the project

The contractor shall submit a list of responsible and professional workers on the construction site.

5.5.2 Subgrade preparation

In the case of in-plant preparation of treated soil, the subgrade (layers under the first layer of treated soil) shall meet the requirements for foundation soil and enable transport and execution of works with the intended construction machinery. The subgrade shall be arranged in accordance with the design requirements or profiled in such a way that the best possible drainage is ensured in the given conditions of terrain.

In the case of in situ preparation and execution of treated soil, there are no special requirements for the subgrade, except that their properties correspond to the intended purpose of use (foundation soil, embankment) and execution with the intended construction machinery is enabled.

5.5.3 Preparation and installation of the mixture

5.5.3.1 Preparation of the mixture

The preparation (production) of the treated soil may be carried out using the in-situ process (production on installation site) or by production at a mixing plant (in-plant).

- Production on installation site (in-situ):
  The mixture of treated soil is prepared using a mobile mixing device (usually a soil recycler or stabilizer), which is used to prepare a homogeneous mixture by processing the soil and binder (or binder mixture), other intended additional ingredients and any additional water required.
- Production at a mixing plant (in-plant):
  In the production process at a mixing plant, a homogeneous mixture of improved soil is prepared by mixing the soil with the intended amount of binder (or binder mixture), other intended additional ingredients and any additional water required. The process may be carried out on stationary or mobile devices.

In both technological processes, mixing shall be implemented mechanically. The capacity of the mixing equipment shall enable the uniform production of the required amount of homogeneous mixture, which will have the required properties after installation.

In the case of in-plant production, the quality of the production shall be checked beforehand by trial mixing at a mixing plant.

The mixture shall be prepared in accordance with the laboratory composition (recipe). The properties of the produced mixture and the built-in layer shall meet the requirements in *Table 9*.

For stabilized soils, compliance with the requirements may be demonstrated by IBI and CBR_2 or with compressive strengths.

5.5.3.2 Installation of the mixture

During installation, it is necessary to take into account the necessary reaction time of the binder used and the possible necessary mellowing time of the mixture before compaction.

The in-situ installation of treated soils is carried out in layers 15 to 30 cm thick, and in the case of in-plant production, it can be installed up to a thickness of 50 cm, using compaction devices that achieve the prescribed level of compaction.

The following shall also be taken into account in the in-situ execution:

- Before applying (spreading) the binder, it is necessary, in order to ensure a uniform thickness of the improved layer, the subgrade layers intended for improvement shall be levelled and arranged in the slopes provided for by the design.
- It is necessary to ensure a uniform application of the binder, in the amount provided for in the laboratory composition.
- If in-situ mixing is carried out in several passes on the same processing field, the spreading of the binder may be carried out alternately with the execution of the mixing transitions. In this way, a better homogeneity of the mixture can be achieved. The binder shall be mixed in as soon as possible after spreading.
- In the case of soils with a high content of stones, the binder may be mixed using disc harrows, cultivators or bulldozers or other suitable additional equipment. Special attention shall be paid to ensuring homogeneity. Excessive grains that prevent the work from being carried out
  shall be removed before applying the binder.
- The length of each mixing stroke shall be adjusted to the appropriate implementation of the joints or switches, which shall be defined in the technological study.

In the case of in-situ implementation, the binder is applied to the prepared surface for treatment in the intended amount with appropriate machinery (spreader, dredger, etc.)
before starting the mixing. The amount of added binder is controlled by measuring the amount of spreading on the surface of the layer to be treated. The amount of spreading is determined by placing a tray or canvas of known surface (the surface of the tray or canvas shall not be less than 2500 cm^2) on the surface of the layer to be treated before spreading. In the case of dosing the binder with an integrated module for direct dosing in front of the crushing/mixing rotor, the dosing is checked in the same way, whereby at the time of passing of the mixing device the crushing/mixing rotor shall be switched off. From the binder mass in the tray, the amount of added binder per m^2 or m^3 of the treated layer is determined. After the control determination of the amount of binder, it is necessary to sprinkle the place where the measurement was carried out with the intended amount of binder.
In the event that the implementation does not enable the described method of checking the amount of binder, another suitable method of checking the amount of added binder may be defined based on a prior agreement with the supervisor or client (e.g. proof of consumption with delivery notes, weighing, etc.).

Compaction and levelling of the prepared treated soil with hydraulic binder shall be completed at air temperatures below 20 °C no later than 3 hours after mixing at the plant (in-plant) or no later than 2 hours after spreading the binder at the installation site (in-situ).
At air temperatures above 20 °C, compaction and levelling shall be completed at the latest 2 hours after mixing at the plant (in-plant) or 1.5 hours after spreading the binder at the installation site (in-situ).

In the case of treatment with lime, alternative binders with a high lime content and/or mixed binders, at air temperatures below 20 °C, compaction and levelling shall be completed within 5 hours after mixing at the plant (in-plant) or 4 hours after spreading the binder at the installation site (in-situ).

When installing at temperatures above 20 °C, compaction and levelling shall be completed within 4 hours after mixing at the plant (in-plant) or 3 hours after spreading the binder at the installation site (in-situ).

The maximum permissible installation time may be extended by the mellowing time of the mixture when using lime, alternative binders with a high lime content and/or mixed binders, which shall be previously defined in the laboratory composition and technological study, and confirmed in the test field.

The layer of treated soil shall be compacted evenly over the entire thickness of the layer. It should be taken into account that in the case of in-situ implementation, pre-compaction has already been carried out in the area ofthe wheels of the binder spreader and the mixing device.

For the installation of improved fine-grained soils, it is necessary to use a roller with oscillating drums.

After the compaction is completed, the subgrade of the built-in layer shall be arranged at the intended slope, in accordance with the project requirements.

The contractor shall demonstrate the suitability of the installation by previously carrying out a test field. On the test field, it is necessary to check the suitability of the installation procedures, define the time course of the work, the number of passes of rollers to ensure adequate compaction, perform the jointing, and check the homogeneity and properties of the built-in layer. The test field shall be carried out in a length of at least 50 m and a width of at least two installation strokes (one longitudinal joint included).

5.5.3.3 Weather conditions for performing the work

Works shall not be carried out in the following unfavourable weather conditions:

- rain;
- wind (implementation is possible when using suspensions of binder and water, e.g. milk of lime, which shall be previously defined and described in detail in the laboratory composition and technological study);
- at air and/or subgrade temperatures below 3 °C.

5.5.4 Curing of the built-in mixture layer

In the case of treating soils with lime and/or alternative binders with a high lime content, curing of the layer is usually not necessary, it is only necessary to ensure that the layer is protected from excessive wetting or drying. Protection is necessary until the next layer is built up.

In the case of using hydraulic binders for soil treatment, the built-in layer shall be properly curing for at least three days or until the next layer is built up (whichever comes first) by wetting or by an appropriate process of protection against drying out (covering with a material that retains water, for example jute or felt, by covering with a foil that prevents water evaporation, etc.).

Construction site traffic and further construction work on the treated built-in layer may be carried out no earlier than 24 hours after the installation is completed.

6 Requirements for the quality of the produced and built-in mixture

Soil treatment shall be carried out in accordance with the previous composition (recipe). The properties of the produced mixture and the built-in layer of the treated mixture shall meet the requirements given in *Table 9*.

For stabilized soils, compliance with the requirements may be demonstrated by IBI and CBR_2 or with compressive strengths.

Table 9: Requirements for built-in mixture and built-in layer of treated soil

Property	Test procedure	Requirement (improved soils)	Requirement (stabilized soils)
Layer density	TSC 06.711 isotope probe (or other non-destructive method) or alternative method according to TSC 06.712 or TSC 06.713	≥ 95 % (limit value min. 92 %)	≥ 95 % (limit value min. 92 %)
Layer density – final layer	TSC 06.711 isotope probe (or other non-destructive method) or alternative method according to TSC 06.712 or TSC 06.713	≥ 98 % (limit value min. 95 %)	≥ 98 % (limit value min. 95 %)
IBI and CBR_2	SIST EN 13286-47	IBI ≥ 5 %[6)] CBR_2 ≥ 4 % (limit value for the individual test specimen 3.6 %)	IBI ≥ 10 %[5)] CBR_2 ≥ 7 %[5)] (limit value for the individual test specimen 6.3 %)
Compressive strength – Fine-grained and mixed soils - 7 days	SIST EN 13286-41 (preparation of SIST EN 13286-50, Curing, Annex 1)	—	0.4 MPa–2.5 MPa[5)] (limit value after 7 days for an individual test specimen 0.3 MPa–3.0 MPa)
Fine-grained soils - 7 days		—	1.5 MPa–3.0 MPa[5)] (limit value after 7 days for an individual test specimen 1.0 MPa–3.5 MPa)
Weather resistance - after 7 days (K_v)	Annex 2	≥ 0.7[1)]	≥ 0.7[1)]
Moisture w	SIST EN 1097-5	$w_{opt} \leq w \leq w_{\text{at 95 \% Dpr}}$	$w_{opt} \leq w \leq w_{\text{at 95 \% Dpr}}$
Stiffness E_{vd}	TSC 06.720	≥ 15 MPa[2)]	≥ 20 MPa[2)]
Stiffness E_{vd} – final layer (only in case of build up with road structure)	TSC 06.720	≥ 25 MPa[2)]	≥ 30 MPa[2)]
Binder proportion	Weighing Procedure item 5.5.3.2	max. ±10 % of the intended binder proportion or binder mixture[3)]	max. ±10 % of the intended binder proportion or binder mixture[3)]
Layer homogeneity	excavation, phenolphthalein method[4)]	completely coloured	completely coloured
Thickness	excavation	±15 %	±15 %

Notes:
1) Mandatory for stabilized soils, for improved soils only in the final layer.
2) E_{vd} measurement is carried out no later than 4 hours after installation, in case of using binders based on free lime, no later than 1 day after installation.
3) The intended binder proportion is determined within the framework of preliminary tests (laboratory composition).
4) Spraying of phenolphthalein solution on the excavation wall – procedure in Annex 4.
5) For stabilized soils, compliance with the requirements may be demonstrated with IBI and CBR_2 or with compressive strengths.

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[6)] Suitability may also be demonstrated with the result of the test on test specimens that have been cured for up to 4 days (protected against moisture loss after preparation).

6.1 Frequency of tests

6.1.1 Internal quality control – IQC

Internal (own) quality control shall be carried out by the contractor or an institution authorized by him to determine whether the quality of the basic materials used, the treated mixture produced and the treated built-in layer meets the requirements of the design or these technical specifications. The contractor of internal control shall have at his disposal all laboratory and field equipment that enables the performance of all field and laboratory tests and measurements specified in this specification. The minimum scope of tests for internal quality control is given in *Table 10*.

6.1.2 External quality control – EQC

External control is provided by the contracting authority and is carried out by an institution authorized by him to determine whether the quality of the basic materials used, the treated mixture produced and the treated built-in layer meets the requirements of the design or these technical specifications.

The type of external tests is the same as the tests that must be carried out by IQC, in a scope that is in a ratio of 1:4 with respect to the frequency of IQC (*Table 10*).

Table 10: Minimum test frequency for IQC and EQC

Quality control tests			**Frequency**	
Property	**Test procedure**	**Unit**	**IQC**	**EQC**
Soils				
Grain size, consistency (foundation soil)	SIST EN 933-1, SIST EN ISO 17892-1, SIST EN ISO 17892-12	m^2	4 000	16 000
Grain size, consistency (embankments)	SIST EN 933-1, SIST EN ISO 17892-1, SIST EN ISO 17892-12	m^3	4 000	16 000
Binder				
Proportion	weighing	m^2	4 000	16 000
Produced mixture				
Moisture	SIST EN 1097-5	m^2	4 000	16 000
Maximum dry density and optimum moisture content of the produced mixture according to Proctor (ρ_d at w)	SIST EN 13286-2	m^2	4 000	16 000

IBI and CBR_2 (3)	SIST EN 13286-47	m_2	4 000	16 000
Compressive strength (3) (3 test specimens after 7 days)	SIST EN 13286-41, SIST EN 13286-50, Annex 1	m_2	4 000	16 000
Weather resistance (C_f)	Procedure[1)]	m_2	8 000	32 000
Built-in layer of mixture				
Moisture content and density	TSC 06.711 (or other non-destructive method) or an alternative method according to TSC 06.712 or TSC 06.713	m_2	100[2)]	400
Dynamic deformation modulus (E_{vd})	TSC 06.720	m_2	200[2)]	800
Thickness	excavation	m_2	4 000	16 000
Layer homogeneity	excavation, Annex 4	m_2	4 000	16 000

1) The determination of weather resistance is carried out according to the procedure in Annex 2 (improved soils/final layer, stabilized soils/all).

2) If a roller with the CCC system (TSC 06.713, SIST EN 16907-5, SIST-TS CEN/TS 17006) is used to control compaction, the measurements of moisture content and compaction and dynamic deformation modulus may be omitted as part of the internal control.

3) For stabilized soils, compliance with the requirements may be demonstrated by IBI and CBR2 or with compressive strengths.

In the event that the treated surface area is less than the specified minimum frequency of tests for IQC and EQC, at least one test or measurement shall be performed.

6.1.3 Control tests

Control tests may be ordered by the contractor or the investor or by an approved institution if he considers that the results of the internal or external control do not reflect the actual state of the work carried out.

Control tests shall be carried out by an independent institution that was not involved in carrying out internal
or external control and is determined in agreement between the contractor and the investor or the institution authorised by the investor.

The costs of control tests are borne by the party who is harmed by the test result.

7 Measurement and acceptance of works

7.1 Measurement of works

The surface area of the treated layer is measured according to the actual scope of work performed within the project and evaluated in square meters.

Due to possible build-up with other planned layers of materials, the scope of the work performed shall be measured in a timely manner and documented in writing. The contractor shall not continue with the work until the measurement has been performed. If the work continues despite the fact that the measurement has not been performed, it bears all the consequences that would result from subsequent works in order to determine the actual scope of the work performed.

7.2 Acceptance of works

The basis for acceptance of treated layers are the established results of external and internal quality tests in relation to the requirements of these technical specifications and the established quantity of work performed.

Due to the possible build-up of treated layers with other planned layers of materials, the contractor is obliged to request and wait for temporary acceptance of the work in a timely manner. Otherwise, the contractor shall bear all the consequences that would arise from subsequent works for determining the quality of the work performed.

All identified deficiencies according to the requirements of these technical specifications shall be corrected by the contractor before continuing with the work, otherwise deductions for inadequate quality of the work performed will be charged to him.

All costs for eliminating deficiencies are borne by the contractor, including the costs for all measurements and tests that showed inadequate quality of the work performed and it was necessary to determine the quality of the work with repeated measurements and tests after the repair was performed.

8 Accounting of works

8.1 Deductions due to inadequate quality

The quality of the basic materials specified in these technical specifications shall be guaranteed.

8.2 Quality of the work performed

If the quality control determines:

- insufficient compaction of the built-in layer;
- inhomogeneous layer of treated soil;
- too low or too high uniaxial compressive strength of the mixture or too low CBR_2 value or
- too low binder proportion in the build-in layer;

the supervisory authority may apply deductions, which shall be evaluated according to the bases given for each case, where:

FO is the financial deduction (EUR)

p is the surplus of the stated limit values, up to the stated maximum limits (above or below the stated extreme values, the value of the performed work is zero) (%)

C is the price per unit of the quantity of the performed work (m^2)

d is the proportion of the unpainted surface of the excavation wall – visual assessment (%)

PD is the volume of the deficiently performed work (m^2)

8.2.1 Due to insufficient density of the built-in layer

Deductions are determined for density below 95 % of the density determined according to MPT in the preliminary test procedure (recipe) up to the extreme limit value – 3 % (92 % according to MPT) according to the following equation:

FO = 1/100 x (11p – 4.5) x C x PD,

whereas in the case of density below the extreme limit, the layer is worthless or further measures are decided by the supervisor.

8.2.2 Due to inhomogeneity of the built-in layer

When inhomogeneity of the treated built-in layer is determined (visual assessment; more than 10 % of the tested surface of the excavation wall is unpainted), the deductions are determined according to the following equation:

FO = d x C x PD.

8.2.3 Due to too low or too high uniaxial compressive strength or too low CBR_2

The deductions are calculated according to the deviation from the specified limit value of uniaxial compressive strength to the extreme limit value (0.3–3.0 MPa or 1.0–3.5 MPa for stabilized soils for an individual test specimen) after 7 days according to the following equation:

FO = p/100 x 2 x C x PD, where p is (absolute)

$$p = \frac{\sigma_z - \sigma_d}{\sigma_z} \times 100(\%)$$

The deduction may be calculated based on the average value of all achieved uniaxial compressive strengths or based on the sum of deductions for individual test specimens. The higher value of the deduction is decisive.

Deductions are calculated based on the deviation from the specified CBR_2 limit value to the extreme limit value (3.6 % for improved soils or 6.3 % for stabilized soils) for an individual test specimen according to the following equation:

FO = p/100 x 2 x C x PD, where p is (absolute)

$$p = \frac{\sigma_z - \sigma_d}{\sigma_z} \times 100(\%)$$

The deduction may be calculated based on the average value of all CBR_2 values achieved or based on the sum of deductions for individual test specimens. The higher value of the deduction is decisive.

8.2.4 Due to too low binder proportion in the mixture

When the determined amount of binder deviates by more than 0.5 % from the expected value, deductions are determined according to the following equation:

$FO = p^2 \times C \times PD \times f$ weighting factor $f = 3$

9 Specification of works

Code	Unit of measurement	Description of works
		Treatment of the foundation soil
0001	m^2	Preparation of the foundation soil subgrade
0002	m^2	Implementation (spreading of additives, mixing of additives, installation and hardening of layers) of treated fine-grained soil in-situ, in a thickness of up to 20 cm
0003	m^2	Implementation (spreading of additives, mixing of additives, installation and hardening of layers) of treated fine-grained soil in-situ, in a thickness of 21 cm to 30 cm
0004	m^2	Implementation (spreading of additives, mixing of additives, installation and hardening of layers) of treated coarse-grained soil in-situ, in a thickness of up to 20 cm
0005	m^2	Implementation (spreading of additives, mixing of additives, installation and hardening of layers) of treated coarse-grained soil in-situ, in a thickness of 21 cm to 30 cm
0006 hardening	m^2	Implementation (spreading of additives, mixing of additives, fitting and of layers) of treated coarse-grained soil in-situ, in a thickness of 31 cm to 40 cm
0007	t	Supply of binder for soil treatment – lime
0008	t	Supply of binder for soil treatment – hydraulic binders
0009	t	Supply of binder for soil treatment – other additives
0010	m^2	Supplement for work in closed mode (no dusting) Treatment of embankment
		(embankment layers, backfill layers, wedges and finishing layers)
0011	m^3	Implementation of treated fine-grained and mixed soil in-situ (supply and delivery of base material and additives, preparation of the subgrade, spreading of additives, mixing of additives, installation and hardening of the layer)
0012	m^3	Implementation of treated fine-grained and mixed soil in-plant (supply of mixture of base material and additives, preparation of the subgrade, spreading, installation and hardening of layers)
0013	m^3	Implementation of treated fine-grained and mixed soil in-situ/in-plant (supply of base material and additives, preparation of the mixture, preparation of the subgrade, loading and spreading of the mixture, installation and hardening of layers)
0014	m^3	Implementation of treated coarse-grained and mixed soil in-situ (supply and delivery of base material and additives, preparation of the subgrade, spreading of additives, mixing of additives, installation and hardening of the layer)
0015	m^3	Implementation of treated coarse-grained and mixed soil in-plant (supply of mixture of base material and additives, preparation of the subgrade, spreading, installation and hardening of layers)
0016 (supply	m^3	Implementation of treated coarse-grained and mixed soil in-situ/in-plant of base material and additives, preparation of mixture, preparation of subgrade, loading and spreading of the mixture, installation and hardening of

		layers)
0017	t	Supply of binder for soil treatment – lime
0018	t	Supply of binder for soil treatment – hydraulic binders
0019	t	Supply of binder for soil treatment – other additives
0020	m^3	Supplement for work in closed mode (no dusting)
0021	m^2	Arrangement of the subgrade of the final layer

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11 ANNEX 1: Preparation and curing of treated soil test specimens for determining uniaxial compressive strength

11.1 Preparation of test specimens

Test specimens for determining compressive strength shall be prepared in accordance with the SIST EN 13286-50 procedure at the moisture content of the mixture (natural moisture content w) or at the optimum moisture content (w_{opt}) with compaction energy according to the standard or modified Proctor procedure, depending on the type of soil (see item 5.4).

11.2 Curing of test specimens

Prepared test specimens for determining compressive strength shall be cured for 7 or 28 days in a humid chamber with at least 95 % humidity at a temperature of 20 °C ± 5 °C. Instead of a humid chamber, test specimens may also be stored in tightly closed plastic bags. Test specimens may be demoulded no earlier than 3 days after preparation.

12 ANNEX 2: Procedure for determining the weather resistance

To determine the weather resistance coefficient, two batches with at least three test specimens each are prepared for each mixture in accordance with Annex 1 (minimum six test specimens).
One batch of test specimens is cured for the intended curing time in accordance with the procedure in item 11.2. The uniaxial compressive strength of the test specimens thus cured shall be determined in accordance with SIST EN 13286-41.
The second batch of test specimens, after the 7-day curing procedure specified in item 11.2, is immersed in water at a temperature of 20 °C ± 5 °C for 24 hours. After soaking in water, the test specimens are drained on a grid, perforated sheet or porous plate (at least 1 hour) and their uniaxial compressive strength is determined according to SIST EN 13286-41.
The ratio of the average valuesof the uniaxial compressive strengths of the test specimens immersed in water and the test specimens after the same curing time according to the curing procedure in item 11.2 is designated as the weather resistance coefficient of the mixture (K_v).

13 ANNEX 3: Procedure for determining the frost resistance coefficient

To determine the frost resistance coefficient, two batches with at least three test specimens each are prepared for each mixture in accordance with Annex 1 (minimum six test specimens). It is necessary to determine the frost resistance coefficient (C_f).

One batch of test specimens is cured for 32 days in a humid chamber according to the procedure in item 11.2. After the end of the curing, the uniaxial compressive strength of the test specimens thus cured shall be determined in accordance with SIST EN 13286-41.

The second batch of test specimens, after 7 days of curing in a humid chamber (according to the procedure in item 11.2), is exposed to 12 cycles of freezing and thawing, i.e. alternating storage of the test specimens for 24 hours in a freezing chamber with a temperature of –23 °C ± 5 °C and for 24 hours in a humid chamber at a temperature of 20 °C

± 5 °C, where the test specimens shall be placed on a water-saturated subgrade that allows water absorption.

After the last 24-hour thawing (in a humid chamber) of the test specimens, their uniaxial compressive strength shall be determined according to SIST EN 13286-41.

After each freezing and thawing cycle, the height of the test specimens shall be measured. The difference in height after the first and twelfth freezing and thawing cycle may not exceed 0.1 %.

The ratio of the average valuesof the uniaxial compressive strengths of the test specimens exposed to 12 freezing and thawing cycles and the test specimens after 32 days of curing according to the procedure given in item 11.2 only in a humid chamber (Annex 1) is designated as the frost resistance coefficient of the mixture (C_f).

14 ANNEX 4: Checking the homogeneity of the layer using the phenolphthalein method

The homogeneity of the built-in layer of treated soil is checked based on a visual assessment using a phenolphthalein indicator solution. The method is based on a change in the colour of the indicator solution from colourless to purple at a soil pH value above 8.2. The homogeneity of the colour of the treated soil in the test excavation area indicates the homogeneity of the binder mixing in the layer of treated soil.

The phenolphthalein indicator solution is prepared according to the procedure (SIST EN 14630):
1 g of phenolphthalein is dissolved in 70 mL of ethanol (min. 95 %). When the phenolphthalein is completely dissolved, dilute the solution to 100 mL with distilled or deionized water.

After the treated soil layer built-in is completed, an excavation is carried out with a width of at least 30 cm along the entire depth of the tested layer to check its homogeneity. The entire wall of the excavation is sprayed with a phenolphthalein indicator solution. The layer is homogeneous if the entire wall of the excavation turns purple. Uncoloured areas indicate an inhomogeneous implementation of the layer.

If the treated soil does not turn purple, the binder proportion for treatment is too low or the binder is not present. In this case, a detailed review of the laboratory composition, installation procedures, compliance of the properties of the soil for treatment with the expected properties in the laboratory composition and re-treatment of the soil is required, if necessary with a previously prepared new laboratory composition.