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# INNOTRACK

Integrated Project (IP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems

# D2.2.1 State of the art report on soil improvement methods and experience

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| **Dissemination Level** | | |
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| **PP** | Restricted to other programme participants (including the Commission Services) | |
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| **CO** | Confidential, only for members of the consortium (including the Commission Services) | |

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# Glossary

| | |
|---|---|
| ADIF | Administrador de Infraestructuras Ferroviarias (Spain) |
| BV | Banverket (Sweden) |
| CD | Ceske drahy,a.s. (Czech Republic) |
| CSN | Czech national standard |
| DB | Deutsche Bahn AG (Germany) |
| EN | European standard |
| HSL | High speed line |
| NRV | Standard RENFE (ADIF) Track |
| ÖBB | Österreichische Bundesbahn (Austria) |
| PG | Generals Specifications (ADIF) |
| SNCF | Société Nationale des Chemins de Fer Français (France) |
| UIC | Union Internationale des Chemins de Fer |

# 1. Executive summary

This report presents the state of the art of soil improvement methods with knowledge and practical experience to solve problems of insufficient subgrade and railway embankment conditions at the railway networks of the INNOTRACK consortium members, representatives of 6 European railway companies (ADIF, BV, CD, DB, ÖBB, SNCF).

The range of methods introduced in the chapter 3 “Summary of investigated methods” is wide and they were used at a very different volume, from several metres up to tens of kilometres, with experience from test sites up to routine use. Application of particular methods depends on geotechnical conditions, economic possibilities, tradition and experience of every railway company too. The range of methods, their volume and experience with them is presented at the chapter 4 “Conclusion” at its particular sections:

4.1 “Overview of methods by routine use”,

4.2 “Overview of methods by standard covering”,

4.3 “Overview of methods by range of application.

These overviews are completed by the section 4.4 “Examples of practical application of some investigated methods”, where several realisations of a subgrade improvement are introduced by photos or charts and basic information. Some of the railway consortium members sent specific documents from practical realizations of particular methods for this section.

For the elaboration of this report, a questionnaire was made, where experts from railway companies filled in information about their experience with each improving method which was used in their railway network. Filled questionnaires can be found in annex to this report (see chapter 6).

This document will be used as a basis for coming work of WP2.2 - Track subgrade improvement.

# 2. Introduction

The elaboration procedure was based on information and data collecting from railway company representatives. As members of sub-project 2, ADIF, BV, CD, DB, ÖBB and SNCF were questioned,

As was suggested in a meeting in Paris in October 2006, a questionnaire was prepared for that purpose by CD. The form of the questionnaire was introduced at the following meeting in Germany (Munich, November 2006).

Other material used was “Procedure for Transition Zone Improvement in Railway Lines, while maintaining commercial speed in daily traffic using the hydraulic fracture” (see Annex 6.2) from ADIF (Supertrack project) and “Strengthening Methods for the Subsoil in Transition Zones at existing Railway Bridges” delivered by BV from the Sustainable Bridges project (see Bibliography).

# 3. Background and objectives

Development of methods for improvement of soils in subgrade and railway embankment has a long history, which has been united with railway engineering. Progress in railway traffic lays stress on bearing capacity and embankment stability improvement.

Depending on local geotechnical, traffic and climate conditions, it is possible to apply effective methods for traffic requests accomplishment.

This report presents an overview of methods currently used by railway companies from the INNOTRACK consortium (ADIF, BV, CD, DB, ÖBB, SNCF).

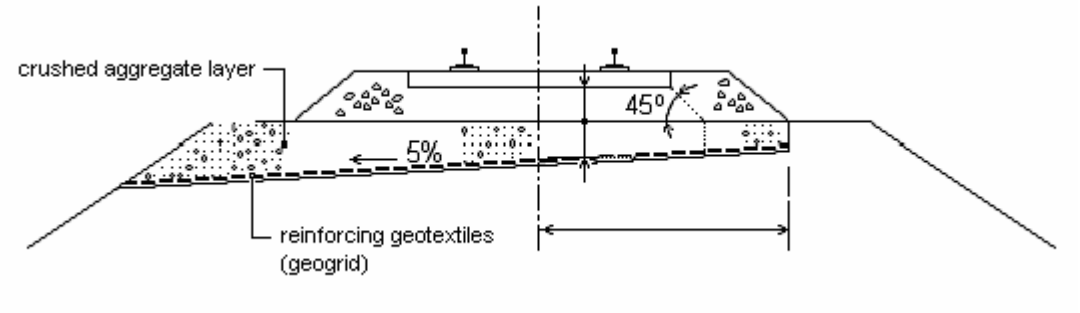
Data from the report will be used in the frame of the INNOTRACK project as basic information for SP2 activity and the knowledge will be exploited in other projects of European Commission as well.

# 4. Investigated methods

## 4.1 Summary of methods

### 4.1.1 Geosynthetics in subgrade construction

A / Reinforcing geotextiles




***Purpose of application:***

- Enhancement of bearing capacity of subgrade construction
- Soil reinforcement and separation subgrade layer materials

***Area of application:***

- Subgrade layers - for their separation and reinforcement
- Improvement of embankment stability in problematic places
- Embankment foundation with low bearing capacity of subsoil
- Enlargement of railway embankment

***General and internal standards:***

- EN 13250 Geotextiles and geotextile-related products - Characteristics required for use in the construction of railways
- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)
- General Technical Conditions “Geotextiles in Railway Embankment” (CD)

***Specification for application:***

- The minimal layer thickness 0,15 m for case of construct layer reinforcing of embankment (CD)
- The minimal anchor length is 5 times of layer thickness (CD)

***Application by Innotrack member consortium:***

- BV, CD, DB, ÖBB – routine; ADIF, SNCF – for selected projects

B / Geogrids

***Purpose of application:***

- Enhancement of bearing capacity of subgrade construction

- Soil reinforcement

***Area of application:***

- Subgrade layers – for bearing capacity improvement
- Slopes of embankment – for their stability; strength protection against climatic factors

***General and internal standards:***

- EN 13250 Geotextiles and geotextile-related products - Characteristics required for use in the construction of railways
- EN 14475 Execution of special geotechnical works - Reinforced fill
- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)
- General Technical Conditions “Geogrids and Geomembranes in Railway Embankment” (CD)

***Specification for application:***

- Minimal tension strength 30kN/m, maximal extension in rupture 15% (CD)
- UV rays resistance is requested in case of slopes protection

***Application by Innotrack member consortium:***

- BV, CD, DB, ÖBB – routine; ADIF, SNCF – for selected projects
- Example of application, Chapter 4.2 – No.1

## C / Geomembranes

***Purpose of application:***

- Hydroisolation
- Groundwater protection

***Area of application:***

- Subgrade layers of embankment – hydroinsulative and separative function
- Platform ground surface – protection against weathering of rock surface platform ground

***General and internal standards:***

- EN 13361 Geosynthetic barriers - Characteristics required for use in the construction of reservoirs and dams
- EN 13491 Geosynthetic barriers - Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures
- EN 13492 Geosynthetic barriers - Characteristics required for use in the construction of liquid waste disposal sites, transfer stations or secondary containment
- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)
- General Technical Conditions “Geogrids and Geomembranes in Railway Embankment” (CD)

***Specification for application:***

- Use when the water table is lower than 2,0 m bellow the ballast (SNCF)
- Minimal thickness of protection layer with planed surface and laying geomembrane is 0,15 m (CD)

***Application by Innotrack member consortium:***

- BV, CD, DB – routine; ADIF, SNCF – for selected projects; ÖBB – no
- Example of application, Chapter 4.2 – No.2

### D / Geocells

***Purpose of application:***

- Enhancement of bearing capacity of subgrade construction,
- Drainage layer

***Area of application:***

- Embankment foundation together with permeable aggregate as a filler
- Embankment layer with drainage function

***General and internal standards:***

- EN 13250 Geotextiles and geotextile-related products - Characteristics required for use in the construction of railways
- UIC CODE 719 Earthworks and track bed for railway lines
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

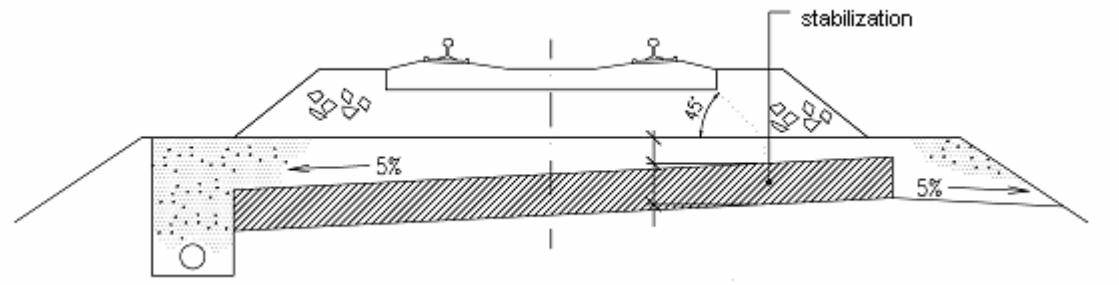
***Specification for application***:

- Details of application depend on the project

***Application by Innotrack member consortium:***

- BV – routine; CD – sporadically; ADIF, DB, ÖBB, SNCF – no
- Example of application, Chapter 4.2 – No.3

## 4.1.2 Stabilization of soils




### A / Cement stabilization

***Purpose of application:***

- Achievement of required compactness in pressure and endurance of stabilized material

***Area of application:***

- Transition zones between bridge and embankment
- Railway level crossing area
- Embankment and cutting with stability problems

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines

- NRV 2.1 – 2.0 Regulation (ADIF)
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Preparing in mixing centre and overspreading by finisher is recommended
- For new constructed lines mostly
- Minimal thickness of stabilization layer is 0,15 m after compaction (CD)

***Application by Innotrack member consortium:***

- ADIF, CD, DB – for selected projects; SNCF, ÖBB – sporadically; BV – no
- Example of application, Chapter 4.2 – No.4

## B / Lime stabilization

***Purpose of application:***

- Achievement of required compactness in pressure and endurance of stabilized material

***Area of application:***

- Embankment foundation with low bearing capacity of subsoil
- Construction of embankment, construct layers of subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- NRV 2.1 – 2.0 Regulation (ADIF)
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Preparing in mixing centre and overspreading by finisher is recommended
- Suitable for fine soils
- For new constructed lines mostly
- Minimal thickness of stabilization layer is 0,15 m after compaction (CD)

***Application by Innotrack member consortium:***

- ADIF, CD, DB, SNCF – for selected projects; ÖBB – sporadically, BV - no

## C / Cement – lime stabilization

***Purpose of application:***

- Achievement of required compactness in pressure and endurance of stabilized material

***Area of application:***

- Embankment foundation with low bearing capacity of subsoil
- Construction of embankment, construct layers of subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)

- ZTVE-StB Standard of earthworks for railroads (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Preparing in mixing centre and overspreading by finisher is recommended
- For new constructed lines mostly For new constructed lines mostly
- Suitable for sandy and fine soils
- Minimal thickness of stabilization layer is 0,15 m after compaction (CD)

***Application by Innotrack member consortium:***

- CD, DB – for selected projects; ÖBB, SNCF– sporadically; ADIF, BV - no

## D / Chemical stabilization

***Purpose of application:***

- Achievement of required compactness in pressure and endurance of stabilized material

***Area of application:***

- Embankment foundation with low bearing capacity of subsoil
- Construction of embankment, construct layers of subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Preparing in mixing centre and overspreading by finisher is recommended
- For new constructed lines mostly
- Suitable for sandy and fine soils (on CD were successfully used products on the base cement, lime and chemical ingredients)
- Minimal thickness of stabilization layer is 0,15 m after compaction (CD)

***Application by Innotrack member consortium:***

- CD – for selected projects; ÖBB, SNCF – sporadically; ADIF, BV, DB - no

## E / Mechanical stabilization

***Purpose of application:***

- Achievement of required compactness in pressure by mixing of original soil and soil of suitable quality

***Area of application:***

- Embankment foundation with low bearing capacity of subsoil
- Construction of embankment, construct layers of subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Swedish rules for soil compaction (BV)
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)
- Regulation CD S4 “Railway substructure” (CD)

- Sample Designs of Railway Substructure (CD)

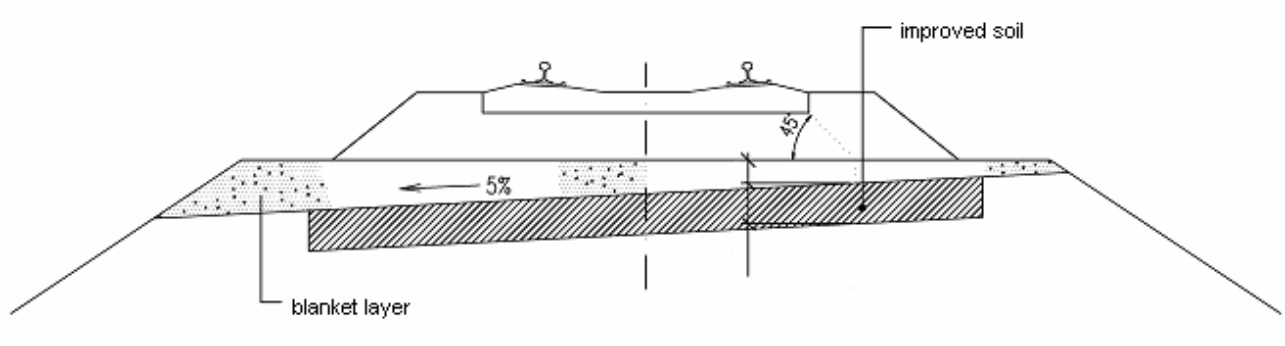
***Specification for application:***

- Preparing in mixing centre and overspreading by finisher is recommended
- For new constructed lines with unsuitable grain size curve of soil
- Minima thickness of stabilization layer is 0,15 m after compaction (CD)

***Application by Innotrack member consortium:***

- BV, DB, SNCF – routine; CD, ÖBB – for selected projects; ADIF - no

### 4.1.3 Soil improvement




#### A / Cement soil improvement

***Purpose of application:***

- Soil modification for its application to the subgrade construction
- Increasing and regulating the modulus of deformation of the embankment

***Area of application:***

- Construct layer under level-crossing area
- Embankment a cutting with stability problems

***General and internal standards:***

- EN 13242 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
- UIC CODE 719 Earthworks and track bed for railway lines
- PG – 3. Article 6 Regulation (ADIF)
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Usually realised in-situ by groundcutter machines
- Mostly used for exposed aggregate soils

***Application by Innotrack member consortium:***

- ADIF, CD – routine; DB – for selected projects; ÖBB, SNCF – sporadically; BV - no

#### B / Lime soil improvement

***Purpose of application:***

- Soil modification for its application in substructure construction

- Exploitation of subgrade soil and enhancement of bearing capacity of subgrade construction

***Area of application:***

- Embankment foundation, improvement of subgrade soil layer

***General and internal standards:***

- EN 13242 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Suitable for fine soil
- Lime (usually 2-3%) is put to the subgrade surface and by groundcutter machine is mixed with subgrade soil (CD)
- Thickness of improved layer is usually 0,40 – 0,50 m (CD)

***Application by Innotrack member consortium:***

- CD – routine; DB – for selected projects; ÖBB, SNCF – sporadically; ADIF, BV- no

## C / Cement - lime soil improvement

***Purpose of application:***

- Exploitation of subgrade soil and enhancement of bearing capacity of subgrade construction,
- Soil modification for its application in substructure construction

***Area of application:***

- Embankment foundation, improvement of subgrade soil layer

***General and internal standards:***

- EN 13242 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Suitable for sandy and fine soil
- As a first is in-situ mixed lime and as the second is mixed cement

***Application by Innotrack member consortium:***

- CD, DB – for selected projects; ÖBB, SNCF – sporadically; ADIF, BV- no

## D / Chemical soil improvement

***Purpose of application:***

- Exploitation of subgrade soil and enhancement of bearing capacity of subgrade construction
- Soil modification for its application in substructure construction

***Area of application:***

- Embankment foundation, improvement of subgrade soil layer

***General and internal standards:***

- EN 13242 Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction
- UIC CODE 719 Earthworks and track bed for railway lines
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- Suitable for sandy soils (CD successfully tested products on the base of cement, lime and chemical ingredients)

***Application by Innotrack member consortium:***

- CD - for selected projects; ÖBB, SNCF – sporadically; ADIF, BV, DB - no

## E / Mechanical soil improvement

***Purpose of application:***

- Exploitation of present soils, in case of loosing any size grain in their size grain curve and achievement of requested qualities
- Achievement of requested compaction
- Mitigation of settlement, vibration and improvement of total stability

***Area of application:***

- Embankment foundation, improvement of subgrade soil layer

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Swedish rules for soil compaction (BV)
- Ril 836 Code of practise for earthworks (DB)
- General Technical Conditions “Crushed aggregate in Railway Embankment” (CD)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

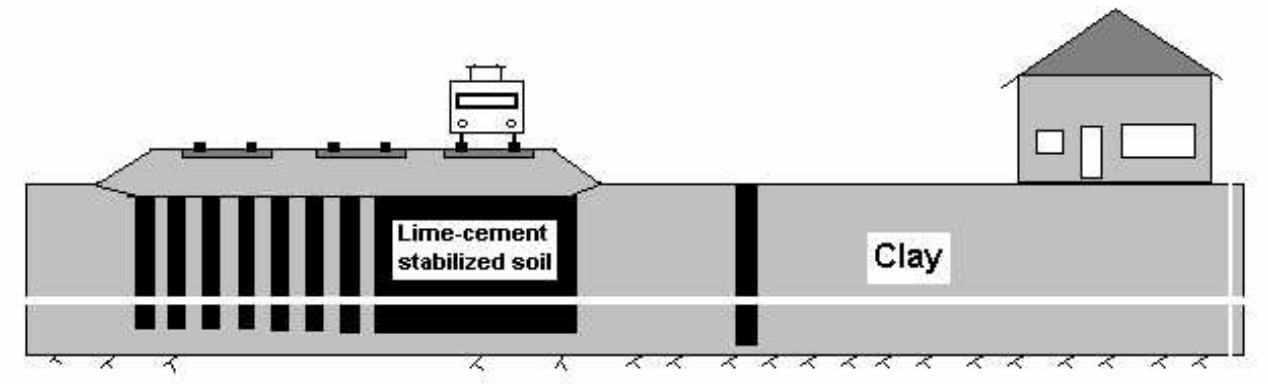
***Specification for application:***

- Make a grain size test of existing soil and fill loosing size grain in for fluently size grain curve
- Dynamic compaction only for new railways for loose soil (DB)

***Application by Innotrack member consortium:***

- BV, SNCF – routine; CD, ÖBB – for selected projects; DB – sporadically; ADIF – no

## F/ Deep mixing methods



***Purpose of application:***

- Soil improvement / strengthening of subsoil
- Mitigation of settlement, vibration
- Improvement of total stability embankment

***Area of application:***

- Areas with soft subsoil with low bearing capacity

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- EN 14679:2005 Execution of special geotechnical works – Deep mixing
- Ril 836 Code of practise for earthworks (DB)

***Specification for application***:

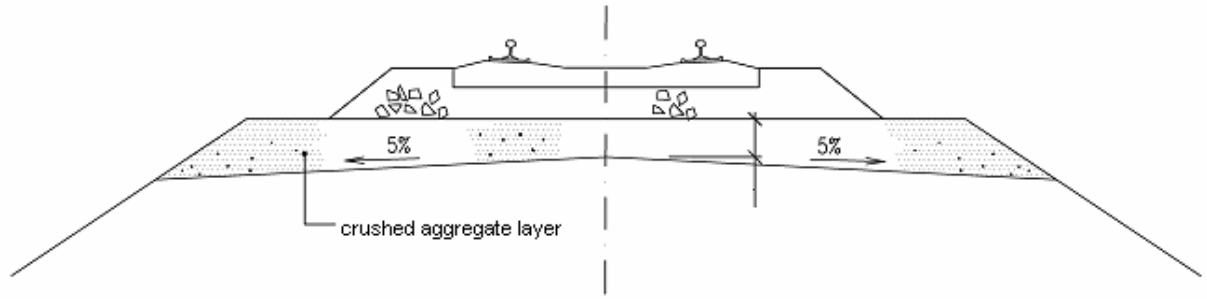
- Used for stabilization of soft soils, mainly clays and also organic soils as peat
- Stabilization of peat or soft soils, depth up to 10 m (DB)

***Application by Innotrack member consortium:***

- BV – routine; DB – for selected projects; ADIF, CD, ÖBB, SNCF, - no

### 4.1.4 Other methods

#### A / Crushed aggregate layer




***Purpose of application:***

- Achievement of track formation bearing capacity
- Achievement of subgrade soil frost protection

***Area of application:***

- Construct layers of subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Swedish rules for soil compaction (BV)
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)

- General Technical Conditions “Crushed aggregate in Railway Embankment” (CD)
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

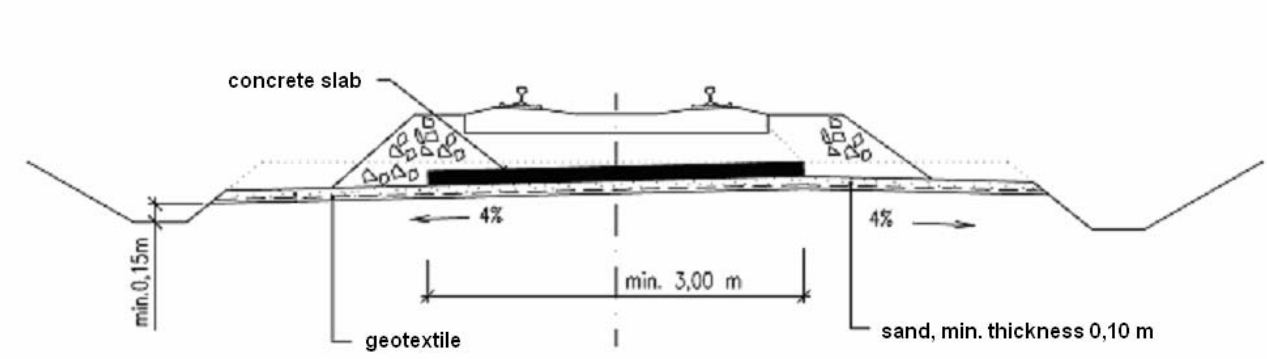
***Specification for application:***

- Used as soft soil replacement to the limited depth (BV, DB), the kind of redemption of unbearable soil method
- Used for sub-ballast layer I construction and renewal
- Construction with crush aggregate layer is taken as a one of substructure construction type (CD)
- Usually is 0/32 crushed aggregate used and minimal thickness of layer is 0,15 m

***Application by Innotrack member consortium:***

- BV, CD, ÖBB, SNCF – routine; DB – for selected projects; ADIF – no
- Example of application, Chapter 4.2 – No.5

## B / Concrete slabs




***Purpose of application:***

- Achievement of track formation bearing capacity
- Ballastless track construction (ÖBB)

***Area of application:***

- Usually in limited cases, with some special problems (cavities)
- Railway level-crossing area (CD)
- Transition zones of bridges close to the abutment (BV)
- On concrete piles (BV)

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

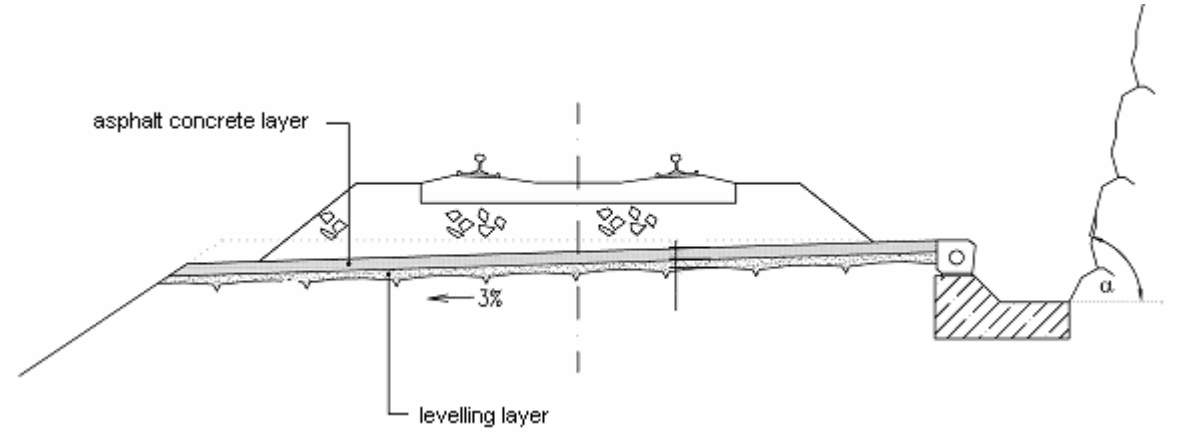
***Specification for application:***

- Construction with concrete slabs is taken as a one of substructure construction type (CD)
- Problems with moving and instability of slabs in subgrade

***Application by Innotrack member consortium:***

- ÖBB, SNCF – for selected projects; CD, BV – sporadically; ADIF, DB - no

## C / Asphalt concrete layer




***Purpose of application:***

- Protection of rock foundation against weathering

***Area of application:***

- Test site (3 km) on East-European HSL (SNCF)
- Type of substructure construction (CD)
- Used in areas with disintegrating rock in subgrade foundation (CD)

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Regulation CD S4 “Railway substructure” (CD)
- Sample Designs of Railway Substructure (CD)

***Specification for application:***

- There is possible to create precise cross and longitudinal slope of layer
- Spreader finisher is exploited for asphalt layer lying

***Application by Innotrack member consortium:***

- CD, SNCF – for selected projects; ADIF, BV, DB, ÖBB – no
- Example of application, Chapter 4.2 – No.6

## D / Replacement of unbearable soil

***Purpose of application:***

- Achievement of bearing capacity
- Mitigation of settlement, vibration
- Improvement of total stability

***Area of application:***

- Areas with extremely low bearing capacity
- Replacement soft soil (peat, clay)

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)

- Regulation CD S4 “Railway substructure” (CD)

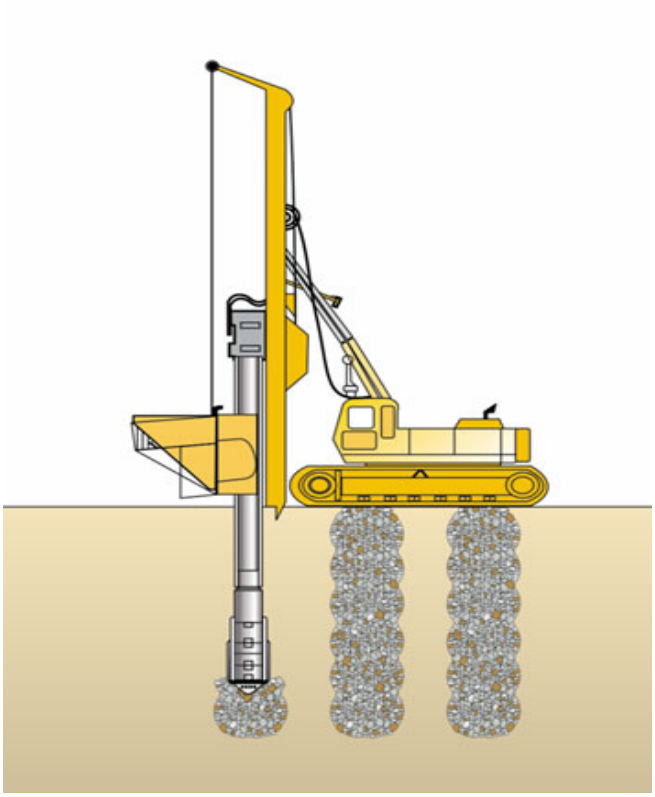
***Specification for application:***

- Application in cases when it is economical effective than use another improvement method
- Replacement of soft soil like peat or clay to the limited depth (DB)

***Application by Innotrack member consortium:***

- BV, DB – routine; CD, ÖBB – for selected projects; ADIF, SNCF – no

## E / Crushed aggregate piles



***Purpose of application:***

- Enhancement of minimal modulus of deformation on blanket layer
- Achievement of bearing capacity
- Mitigation of settlement, vibration and improvement of total stability

***Area of application:***

- Embankment with very low bearing capacity on blanket layer

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)
- ZTVE-StB Standard of earthworks for railroads (DB)

***Specification for application:***

- Piles are realized in the form of regular net, created on blanket layer surface, by special machine
- Used for stabilization of soft soil

***Application by Innotrack member consortium:***

- CD, DB – for selected projects; ADIF, BV, ÖBB SNCF – no
- Example of application, Chapter 4.2 – No.7

## F / Piles

***Purpose of application:***

- Achievement of bearing capacity
- Mitigation of settlement, vibration
- Improvement of total stability

***Area of application:***

- Under embankment and cutting with stability problems (ADIF, BV)
- Transition zones of bridges close to the abutment (BV)

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- NRV 2.1 – 2.0 Regulation (ADIF)

***Specification for application:***

- Sometimes is recommended to bore holes beforehand to reduce vibration effects
- In the case of soil settlement under embankment, inclined piles can be more effective

***Application by Innotrack member consortium:***

- ADIF, BV – routine; ÖBB – for selected projects; CD, DB, SNCF - no

## G / Lime-cement columns

***Purpose of application:***

- Mitigation of settlement, vibration
- Improvement of total stability

***Area of application:***

- Areas with low bearing capacity

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Swedish Geotechnical Society – report 2:2000 (BV)
- Ril 836 Code of practise for earthworks (DB)

***Specification for application:***

- Dry deep mixing method used in form of columns
- Method of dry lime columns (DB)

***Application by Innotrack member consortium:***

- BV – routine; DB – for selected projects; CD – sporadically; ADIF, ÖBB, SNCF, - no
- Example of application, Chapter 4.2 – No.8

## H / Station-type ash mixture

***Purpose of application:***

- Protection of rock foundation against weathering (CD)

***Area of application:***

- Disintegrating rock in subgrade

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- CSN 72 2071 Fly ash for building industry purposes - Common provisions, requirements and test methods (CD)

- CSN 72 2072-3 Fly ash for building industry purposes - Part 3: Fly ash for the fly ash mixtures (CD)
- CSN 72 2072-7 Fly ash for building industry purposes - Part 7: Fly ash for building of roadways

***Specification for application:***

- Protecting layer of ash mixture from power station with very good bearing capacity and very low water penetration
- Very short time between ash mixing and application to the embankment (cca 4 hours)

***Application by Innotrack member consortium:***

- CD – sporadically; ADIF, BV, DB, ÖBB, SNCF – no
- Example of application, Chapter 4.2 – No.9

## I / Soil nailing

***Purpose of application:***

- Improvement of slope stability

***Area of application:***

- Slopes of embankment and cuttings, natural slopes

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- Ril 836 Code of practise for earthworks (DB)

***Specification for application:***

- Suitable length and spacing of nails for stability holding

***Application by Innotrack member consortium:***

- BV, DB – routine; CD – for selected projects; ADIF, ÖBB, SNCF – no
- Example of application, Chapter 4.2 – No.10

## J / Grouting

***Purpose of application:***

- Enhancement of embankment stability
- Transition zones improvement
- Mitigation of settlement, vibration and improvement of total stability

***Area of application:***

- Embankment and cutting with stability problems

***General and internal standards:***

- UIC CODE 719 Earthworks and track bed for railway lines
- EN 12716 Execution of special geotechnical works – Jet grouting
- PG – 3. Article 6 Regulation (ADIF)
- Ril 836 Code of practise for earthworks (DB)

***Specification for application:***

- Used as a grouting of resin or cement
- Method of grouted stone columns (DB)

***Application by Innotrack member consortium:***

- ADIF– routine; DB – for selected projects; CD, BV, ÖBB, SNCF – no

## 4.2 Practical applications – some examples

### Example 1 / Geogrids

CD, line Ceska Trebova – Prerov, connection between two Trans-European Corridors (Corridor IV and Corridor VI).

Geogrid application for bearing capacity enhancement on line relocation cutting section near Rudoltice v Cechach; In this section is located an area of clays with low bearing capacity on platform. It was used with geotextile combination.

### Example 2 / Geomembrane

CD, line Praha – Decin, track relocation, cutting near Mlcechvosty, near by new tunnel construction.

Application of geomembrane is as a protection of rock foundation against weathering. Parameters of geomembrane have to accomplish CD technical conditions for that component.

## Example 3 / Geocells

CD, line Brno – Ceska Trebova, station Rajec-Jestrebi.

Geocells were used in blanket layer for bearing capacity improvement. It was the first experience with geocells in substructure on CD.

## Example 4 / Cement stabilization

CD, line Praha, hlavni nadrazi – Praha-Liben, in the “Nove spojeni (New connection) building site.

Cement stabilization of track No. 2 near Praha-Liben railway station.

## Example 5 / Crushed aggregate layer

CD, line Praha, hlavni nadrazi – Praha-Liben, in the “Nove spojeni (New connection) building site.

This kind of subgrade construction is taken as a type 2 (in accordance with CD S4 Regulation) and this layer was realised for bearing capacity achievement. CD used aggregate 0/32 mm with given grading size curve.

## Example 6 / Asphalt concrete layer

CD, line Ceska Trebova – Prerov, connection between two Trans-European Corridors (Corridor IV and Corridor VI), cutting near Trebovice v Cechach railway station.

It was realised as a protection of rock foundation, type 5 of track support (CD S4 regulation). The spreader finisher was used here for creating of compact asphalt concrete layer with required parameters (thickness, width, inclination).

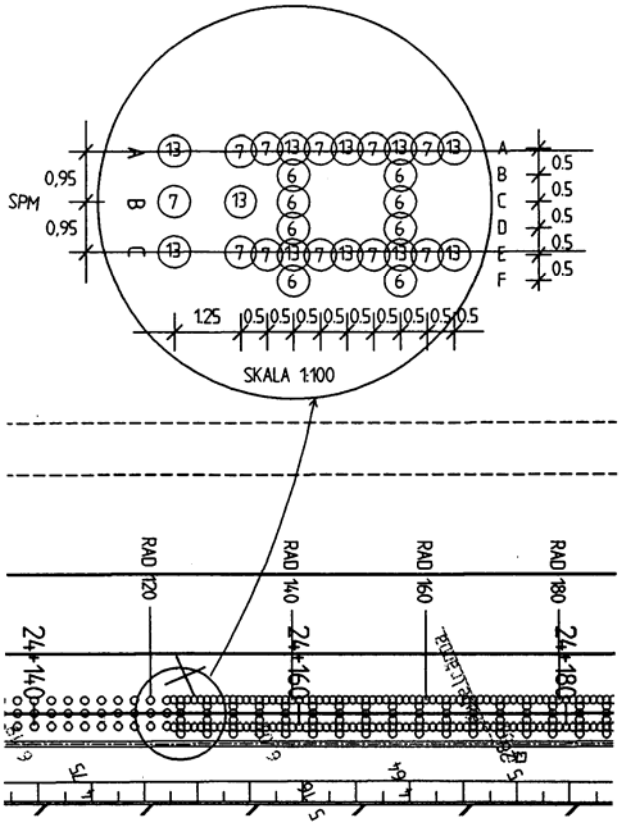
## Example 7 / Crushed aggregate piles

CD, line Olomouc – Ceska Trebova, cutting in front of new tunnel near Trebovice v Cechach railway station.

Piles were applied in the form of regular net on embankment for bearing capacity improvement. This method was several times successful used on CD lines on embankments with low bearing capacity.

## Example 8 / Lime - cement columns (DMM Deep Mixing Method) - BV

One of a good example of application of Deep Mixing Method is soil improvement under railway structure. Stiffness of subsoil has been increased with application of lime-cement columns and in this way train speed related vibrations have been mitigated.




Layout of soil improvement with lime-cement columns, column length below the rail level is given by figures within circles.

Installation of lime-cement columns (Ledsgård /Sweden July 2000)

## Example 9 / Station-type ash mixture

CD, line Hradec Kralove – Liberec, railway station Smirice, track No.3, test section

Station-type ash mixture layer is realised as a protection of disintegrating halfrocky embankment foundation. Station-type ash mixture from Chvaletice power station was used with technological condition of processing till 4 hours after mixing. This condition determines the area around power station for possible exploitation.

## Example 10 / Soil nailing

CD, line Praha, hlavni nadrazi – Praha-Liben, in the “Nove spojeni (New connection) building site.

Soil nailing was used for track embankment reinforcement.

# 5. Overview of methods by utilisation

## 5.1 Geosynthetics in subgrade construction

| Method | | Routine | Selected projects | Sporadically | No |
|---|---|---|---|---|---|
| A | Reinforcing geotextiles | BV, CD, DB, ÖBB | ADIF, SNCF | | |
| B | Geogrids | BV, CD, DB, ÖBB | ADIF, SNCF | | |
| C | Geomembranes | BV, CD, DB | ADIF, SNCF | | ÖBB |
| D | Geocells | BV | | CD | ADIF, DB ÖBB, SNCF |

## 5.2 Stabilization of soil

| Method | | Routine | Selected projects | Sporadically | No |
|---|---|---|---|---|---|
| A | Cement stabilization | | ADIF, CD, DB | ÖBB, SNCF | BV |
| B | Lime stabilization | | ADIF, CD, DB, SNCF | ÖBB | BV |
| C | Cement – lime stabilization | | CD, DB | ÖBB, SNCF | ADIF, BV |
| D | Chemical stabilization | | CD | ÖBB, SNCF | ADIF, BV, DB |
| E | Mechanical stabilization | BV, DB, SNCF | CD, ÖBB | | ADIF |

## 5.3 Soil improvement

| Method | | Routine | Selected projects | Sporadically | No |
|---|---|---|---|---|---|
| A | Cement soil improvement | ADIF, CD | DB | ÖBB, SNCF | BV |
| B | Lime soil improvement | CD | DB | ÖBB, SNCF | ADIF, BV |
| C | Cement- lime soil improvement | | CD, DB | ÖBB, SNCF | ADIF, BV |
| D | Chemical soil improvement | | CD | ÖBB, SNCF | ADIF, BV, DB |
| E | Mechanical soil improvement | BV, SNCF | CD, ÖBB | DB | ADIF |
| F | Deep mixing methods | BV | DB | | ADIF, CD, ÖBB, SNCF |

## 5.4 Other methods

| Method | | Routine | Selected projects | Sporadically | No |
|---|---|---|---|---|---|
| A | Crushed aggregate layer | BV, CD, ÖBB, SNCF | DB | | ADIF |
| B | Concrete slabs | | ÖBB, SNCF | BV, CD | ADIF, DB |
| C | Asphalt concrete layer | | CD, SNCF | | ADIF, BV, DB, ÖBB |
| D | Replacement of unbearable soil | BV, DB | CD, ÖBB | | ADIF, SNCF |
| E | Crushed aggregate piles | | CD, DB | | ADIF, BV, ÖBB, SNCF |
| F | Piles | ADIF, BV | ÖBB | | CD, DB, SNCF |
| G | Lime - cement columns | BV | DB | CD | ADIF, ÖBB, SNCF |
| H | Station-type ash mixture | | | CD | ADIF, BV, DB, ÖBB, SNCF |
| I | Soil nailing | BV, DB | CD | | ADIF, ÖBB, SNCF |
| J | Grouting | ADIF | DB | | BV, CD, ÖBB, SNCF |

# 6. Overview of methods by standard covering

## 6.1 Geosynthetics in subgrade construction

| Method | | EN - No | UIC - No | National | | No standards or regulations |
|---|---|---|---|---|---|---|
| | | | | ***Standards*** | ***Regulations*** | |
| A | Reinforcing geotextiles | 13250 | 719 | | CD, DB, ÖBB | SNCF |
| B | Geogrids | 13250, 14475 | 719 | | CD, DB, ÖBB, SNCF | |
| C | Geomembranes | 13361, 13491, 13492 | 719 | | CD, DB, SNCF | ADIF, ÖBB |
| D | Geocells | 13250 | 719 | | CD | ADIF, DB, ÖBB, SNCF |

## 6.2 Stabilization of soil

| Method | | EN - No | UIC - No | National | | No standards or regulations |
|---|---|---|---|---|---|---|
| | | | | ***Standards*** | ***Regulations*** | |
| A | Cement stabilization | | 719 | DB | ADIF, CD, DB | BV, ÖBB, SNCF |
| B | Lime stabilization | | 719 | DB | ADIF, CD, DB, SNCF | BV, ÖBB |
| C | Cement – lime stabilization | | 719 | DB | CD, DB | ADIF, BV, ÖBB, SNCF |
| D | Chemical stabilization | | 719 | | CD | ADIF, BV, DB, ÖBB, SNCF |
| E | Mechanical stabilization | | 719 | DB | CD, DB, SNCF | ADIF, BV, ÖBB |

## 6.3 Soil improvement

| Method | | EN - No | UIC - No | National | | No standards or regulations |
|---|---|---|---|---|---|---|
| | | | | ***Standards*** | ***Regulations*** | |
| A | Cement soil improvement | | 719 | | ADIF, CD, DB | BV, ÖBB, SNCF |
| B | Lime soil improvement | | 719 | | CD, DB | ADIF, BV, ÖBB, SNCF |
| C | Cement- lime soil | | 719 | | CD, DB | ADIF, BV, ÖBB, SNCF |

| | | | | | | |
|---|---|---|---|---|---|---|
| | improvement | | | | | |
| D | Chemical soil improvement | | 719 | | CD | ADIF, BV, DB, ÖBB, SNCF |
| E | Mechanical soil improvement | | 719 | BV | CD, DB, ÖBB, SNCF | ADIF |
| F | Deep mixing methods | 14679 | 719 | | DB | ADIF, BV, CD, ÖBB, SNCF |

## 6.4 Other methods

| **Method** | | **EN - No** | **UIC - No** | **National** | | **No standards or regulations** |
|---|---|---|---|---|---|---|
| | | | | ***Standards*** | ***Regulations*** | |
| A | Crushed aggregate layer | | 719 | BV, DB | CD, DB, ÖBB, SNCF | ADIF |
| B | Concrete slabs | | 719 | | CD | ADIF, BV, DB, ÖBB, SNCF |
| C | Asphalt concrete layer | | 719 | | CD | ADIF, BV, DB, ÖBB, SNCF |
| D | Replacement of unbearable soil | | 719 | | CD, DB | ADIF, BV, ÖBB, SNCF |
| E | Crushed aggregate piles | | 719 | | DB | ADIF, BV, CD, ÖBB, SNCF |
| F | Piles | | 719 | | ADIF | BV, CD, DB, ÖBB, SNCF |
| G | Lime- cement columns | | 719 | BV | DB | ADIF, CD, ÖBB, SNCF |
| H | Station-type ash mixture | | 719 | CD | | ADIF, BV, DB, ÖBB, SNCF |
| I | Soil nailing | | 719 | | CD, DB | ADIF, BV, ÖBB, SNCF |
| J | Grouting | 12716 | 719 | | ADIF, DB | BV, CD, ÖBB, SNCF |

# 7. Overview of methods by magnitude of use

| No. | Soil improvement method | Magnitude in unit value of application by Innotrack members railway companies |
|---|---|---|
| 1 | Reinforcing geotextiles | Tens of kilometres |
| 2 | Geogrids | Tens of kilometres |
| 3 | Geomembranes | Tens of kilometres |
| 4 | Lime stabilization | Tens of kilometres |
| 5 | Lime soil improvement | Tens of kilometres |
| 6 | Deep mixing methods | Tens of kilometres |
| 7 | Crushed aggregate layer | Tens of kilometres |
| 8 | Lime – cement columns | Tens of kilometres |
| 9 | Geocells | Kilometres |
| 10 | Cement stabilization | Kilometres |
| 11 | Cement – lime stabilization | Kilometres |
| 12 | Mechanical stabilization | Kilometres |
| 13 | Cement soil improvement | Kilometres |
| 14 | Cement - lime soil improvement | Kilometres |
| 15 | Mechanical soil improvement | Kilometres |
| 16 | Replacement of unbearable soil | Kilometres |
| 17 | Soil nailing | Kilometres |
| 18 | Asphalt concrete layer | Kilometres |
| 19 | Crushed aggregate piles | Kilometres |
| 20 | Piles | Kilometres |
| 21 | Chemical stabilization | Hundreds of metres |
| 22 | Chemical soil improvement | Hundreds of metres |
| 23 | Concrete slabs | Hundreds of metres |
| 24 | Station-type ash mixture | Hundreds of metres |
| 25 | Grouting | Hundreds of metres |

SP 2 should validate some of the methods in-situ, in conditions of railways companies.

# 8. Conclusions

In the beginning of the project lime-cement mixing columns, geogrids and deep inclined cement columns were chosen. As data from the report show, the range of described methods is relative wide and from results of this report, it is possible to discuss next suitable methods for validation.

Their practical exploitation depends of course on many factors and conditions.

From a technical point of view, geotechnical conditions play an important role in the decision about their applicability. Members of the INNOTRACK consortium are from all over Europe with mostly different conditions on their railway nets and participating in projects give them opportunity to discuss and exchange experiences.

A very important aspect, associated presently with method application, is the question of costs. This is important to evaluate together with other influences and main focus concentrates to the future of the railway operation.

The INNOTRACK project has for objective to find ways for LCC costs reduction with contemporary railway traffic development. The question of quality railway substructure is one of the key success factors.

# 9. Bibliography


| | |
|---|---|
| EN 12716 | Execution of special geotechnical works – Jet grouting |
| EN 13242 | Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction |
| EN 13250 in the | Geotextiles and geotextile-related products - Characteristics required for use construction of railways |
| EN 13361 | Geosynthetic barriers - Characteristics required for use in the construction of reservoirs and dams |
| EN 13491 | Geosynthetic barriers - Characteristics required for use as a fluid barrier in the construction of tunnels and underground structures |
| EN 13492 liquid | Geosynthetic barriers - Characteristics required for use in the construction of waste disposal sites, transfer stations or secondary containment |
| EN 14475 | Execution of special geotechnical works - Reinforced fill |
| EN 14769 | Execution of special geotechnical works – Deep mixing |
| UIC CODE 719 | Earthworks and track bed for railway lines |
| CSN 72 2071 | Fly ash for building industry purposes - Common provisions, requirements and test methods |
| CSN 72 2072-3 | Fly ash for building industry purposes - Part 3: Fly ash for the fly ash mixtures |
| CSN 72 2072-7 roadways | Fly ash for building industry purposes - Part 7: Fly ash for building of |

Kempfert, H.-G. Groung improvement methods with special emphasis on column-type techniques
(Int. Workshop of Geotechnics of Soft Soils-Theory and Practice, 2003 VGE)

SUSTAINABLE BRIDGES (FP6 – Project Reference: 1653), Deliverable 6.2.1, Appendix A
“WP 6-13-T-060707-F-STRENGTHENING METHODS FOR THE SUBSOIL IN TRANSITION ZONES AT EXISTING RAILWAY BRIDGES”

# 10. Annexes

## 10.1 Questionnaires

### 10.1.1 Partner: ADIF

| No. | Method Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications, …) | Conditions for method application, application experiences, comments | Quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation | Exploited method for substructure improvement. | $m^2$ |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials | yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation | Used for embankment improvement with stability problems | $m^2$ |
| | Geogrids | Enhancement of bearing capacity | yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation | Used for embankment improvement with stability problems | $m^2$ |
| | Geomembranes | Hydroisolation; protection of platform grounds | yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation | Used as a hydroizolating of the embankments. | $m^2$ |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Geocells | Enhancement of bearing capacity | NO | – | – | |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | NO | – | – | |
| | Cement stabilization | -do- | yes | Used to improvements the subgrade<br>NRV 2.1-2.0 Regulation | Use is not generalized | Kg |
| | Lime stabilization | -do- | yes | Used to improvements the subgrade<br>NRV 2.1-2.0 Regulation | Use is not generalized | Kg |
| | Cement-lime stabilization | -do- | NO | | | |
| | Chemical stabilization | -do- | yes | It is used as grouting of resin or cement in order to improvement embankment and subgrade.<br>PG-3 Article 6 Regulation | It is used in embankment and cutting with stability problems | Kg |
| | Mechanical stabilization | -do- | NO | – | – | |
| 3. | Subgrade soil improvement | Soil modification for its application to the subgrade construction | NO | – | – | |
| | Cement soil improvement | -do- | yes | PG – 3. Article 6 Regulation | Increasing and regulating the modulus of deformation of the embankment, in the zones where it appeared less compact<br>It is used in embankment and cutting with stability problems | Kg or meters |
| | Lime soil improvement | -do- | NO | – | – | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cement-lime soil improvement | -do- | NO | – | – | |
| | Chemical soil improvement | -do- | NO | – | – | |
| | Mechanical soil improvement | -do- | NO | – | – | |
| 4. | Crushed aggregate layer | Achievement of track formation bearing capacity | NO | – | – | |
| 5. | Concrete slabs | Enhancement of bearing capacity | NO | – | – | |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | NO | – | – | |
| 7. | Redemption of unbearable soil | Achievement of bearing capacity | NO | – | – | |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity | NO | – | – | |
| 9. | Piles | Enhancement of bearing capacity | yes | NRV 2.1-2.0 Regulation | It is used in embankment and cutting with stability problems.<br>Driven rail is used often.<br>In order to generate a new structure pile supported instead the embankment. | Kg of rail<br>ml cement |
| 10. | Lime- cement columns | Enhancement of bearing capacity | NO | – | – | |
| 11. | Station-type ash mixture | Protection of rock foundation against weathering and rainfall water influence; | NO | – | – | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | enhancement of bearing capacity | | | | |
| 12. | Next one | | | | | |

* delete as appropriate

## 10.1.2 Partner : BANVERKET

| No. | Method Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications,…) | Conditions for method application, application experiences, comments | Skeleton quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | yes | SS-EN 13250 | Function as a separation and drainage layer | |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials + soil reinforcement | yes | SS-EN 13250 | Function as a separation and reinforcement layer | |
| | Geogrids | Enhancement of bearing capacity + soil reinforcement | | SS-EN 13250 and SS-EN 14475 | Function as a soil reinforcement | |
| | Geomembranes | Hydroisolation; protection of platform grounds | yes | SS-EN 13361 and SS-EN 13491 and SS-EN 13492 | Groundwater protection | |
| | Geocells | Enhancement of bearing capacity, drainage | yes | SS-EN 13250 | Function as a drainage layer | |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | no | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cement stabilization | -do- | no | | | |
| | Lime stabilization | -do- | no | | | |
| | Cement-lime stabilization | -do- | no | | | |
| | Chemical stabilization | -do- | no | | | |
| | Mechanical stabilization | -do- | yes | Swedish rules for soil compaction | | |
| 3. | Deep soil improvement – mass stabilisation | Soil modification for its application to the subgrade construction. Mitigation of settlement, vibration and improvement of total stability | yes | no | Mostly used for stabilisation of peat to the limited depth | |
| | Deep soil improvement – columns<br>Lime soil improvement<br>Cement soil improvement<br>Lime - Cement soil improvement | Mitigation of settlement, vibration and improvement of total stability | yes | Swedish Geotechnical Society – Report 2:2000 | Dry deep mixing method used in form of columns | |
| | Chemical soil improvement | -do- | no | | | |
| | Mechanical soil improvement | -do- | yes | Swedish rules for soil compaction | Just compaction is used | |
| 4. | Crushed aggregate layer | Achievement of track formation bearing capacity. Mitigation of settlement, vibration and improvement of total stability | yes | Swedish rules for soil compaction | Often used as soft soil replacement to the limited depth | |
| | | | | | | |
| 5. | Concrete slabs | Enhancement of bearing capacity. Mitigation of settlement, vibration and improvement of total | yes | no | Used in limited cases normally on concrete piles mostly in transition zones of bridges close to the | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | stability | | | abutment | |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | no | | | |
| 7. | Replacement of unbearable soil | Achievement of bearing capacity. Mitigation of settlement, vibration and improvement of total stability | yes | no | Replacement of soft soil like peat or clay to the limited depth | |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity. Mitigation of settlement, vibration and improvement of total stability | no | | | |
| 9. | Piles – concrete and wooden piles | Enhancement of bearing capacity, mitigation of settlement, vibration and improvement of total stability | yes | no | Normally used under embankment often in transition zones of bridges close to the abutment | |
| 10. | Soil nailing | Improvement of slope stability | yes | no | Applied in embankments and natural slopes | |

* delete as appropriate

## 10.1.3 Partner: CESKE DRAHY

| No. | Method Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications,…) | Conditions for method application, application experiences, comments | Quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | yes | CD S4 Regulation „Railway substructure“,<br>GTC „General technical conditions“<br>SDRS „Sample Designs of Railway Substructure“ | Very exploited method for substructure improvement. | |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials | yes | CD S4 Regulation; GTC for geotextiles; SDRS | Used for embankment foundation with low bearing capacity of subsoil; construction of embankment or its enlargement for stability enhancement (min. anchor length is 5 times thickness of layer); reinforcing of construct layers of embankment (min. layer thickness 0,15m) | Km |
| | Geogrids | Enhancement of bearing capacity | yes | CD S4 Regulation; GTC for geogrids and geomembranes; SDRS | -do-<br>Min. tension strength 30 kN/m; max. extension in rupture 15% | Km |
| | Geomembranes | Hydroisolation; protection of platform grounds | yes | CD S4 Regulation; GTC for geogrids and geomembranes; SDRS | Used as a hydroizolating, separative or reinforcing component.<br>Laying on planed surface and protection layer realisation with min. thickness 0,15m | Km |
| | Geocells | Enhancement of bearing capacity | yes | CD S4 Regulation; SDRS | Embankment foundation; filled in permeable aggregate | Tens of metres |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | yes | CD S4 Regulation; SDRS | Prepared in mixcentrum and it is overspread by finisher mostly.<br>Kind of stabilization is chosen on the geotechnical research base. | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | Min. thickness of stabilization layer is 0,15m after compaction. | |
| | Cement stabilization | -do- | yes | CD S4 Regulation; SDRS | Mostly used with exposed aggregate soils; used in railway level-crossings area, in transition zones | Hundreds of metres |
| | Lime stabilization | -do- | yes | CD S4 Regulation; SDRS | Realised in lines with fine soils in subsoil | Km |
| | Cement-lime stabilization | -do- | yes | CD S4 Regulation; SDRS | Suitable for sandy and fine soils | Tens of metres |
| | Chemical stabilization | -do- | yes | CD S4 Regulation; SDRS | There was utilized system CONSOLID in several cases, but now systems of preparations from cement production on the base of cement, lime and other chemical ingredients are preferred. It is successfully used in sandy soils. | Km |
| | Mechanical stabilization | -do- | yes | CD S4 Regulation; SDRS | Combination of original soil and other soils with suitable quality | Hundreds of metres |
| 3. | Subgrade soil improvement | Soil modification for its application to the subgrade construction | yes | CD S4 Regulation; SDRS | Realised in situ. Binding material is put to the subgrade and mixtured in through the groundcutter. | |
| | Cement soil improvement | -do- | yes | CD S4 Regulation; SDRS | Used often in railway level-crossings area and in transition zones | Hundreds of metres |
| | Lime soil improvement | -do- | yes | CD S4 Regulation; SDRS | The most used kind of soil improvement: Mostly in fine soil with 2-3% of lime. The thickness of improvement layer is from 0,40 to 0,50m. | Km |
| | Cement-lime soil improvement | -do- | yes | CD S4 Regulation; SDRS | The first is mixed lime and secondary is mixed cement. | Km |
| | Chemical soil improvement | -do- | | CD S4 Regulation; SDRS | Systems of preparations from cement production on the base of cement, lime and other chemical ingredients. It is successfully used in sandy soils. | Hundreds of metres |
| | Mechanical soil improvement | -do- | yes | CD S4 Regulation; SDRS | It is used when any size fraction in original soil is needs to fill in. | Hundreds of metres |
| 4. | Crushed aggregate layer | Achievement of track formation | yes | CD S4 Regulation; GTC for crushed aggregate; | It is taken as a type of substructure construction. There is usually used crushed aggregate 0/32 fraction. Min. | Km |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | bearing capacity | | SDRS | layer thickness is 0,15m. | |
| 5. | Concrete slabs | Enhancement of bearing capacity | yes | CD S4 Regulation; SDRS | It is taken as a type of substructure construction. It is not very much used, it is recommended to use them in railway level-crossings area only. We had several problems with their moving in ordinary construction of track. | Hundreds of metres |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | yes | CD S4 Regulation; SDRS | It is taken as a type of substructure construction.<br>It is used in areas with disintegrating rock in subgrade and it is possible to do perfect slope of track formation. | Hundreds of metres |
| 7. | Redemption of unbearable soil | Achievement of bearing capacity | yes | CD S4 Regulation; SDRS | It was done in several cases in areas with extremely low bearing capacity. | About 5 km |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity | yes | - | It was used on two sections of main lines with very low bearing capacity. From piles were done a net for achievement of minimal modulus on track formation. | Tens of km |
| 9. | Piles | Enhancement of bearing capacity | no | - | - | |
| 10. | Lime- cement columns | Enhancement of bearing capacity | yes | - | SOLMIX system was used on one construction at CD only | 150 m |
| 11. | Station-type ash mixture | Protection of rock foundation against weathering and rainfall water influence; enhancement of bearing capacity | yes | - | It is taken as a test section in railway station track.<br>There are disintegrating rock in subgrade, a layer of ash mixture is the protection again water influence and it is the layer with very good bearing capacity. | 300 m |
| 12. | Next one | | | | | |

* delete as appropriate

## 10.1.4 Partner: ÖBB

| No. | Method<br>Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications,…) | Conditions for method application, application experiences, comments | Skeleton quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | yes | yes | | **~562000m²** |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials | yes | yes | | **~90.000m²** |
| | Geogrids | Enhancement of bearing capacity | yes | yes | | |
| | Geomembranes | Hydroisolation; protection of platform grounds | no | no | | |
| | Geocells | Enhancement of bearing capacity | no | no | | |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | yes | yes | | **50-80km/year** |
| | Cement stabilization | -do- | yes | | sporadically | |
| | Lime stabilization | -do- | yes | | sporadically | |
| | Cement-lime stabilization | -do- | yes | | sporadically | |
| | Chemical stabilization | -do- | yes | | sporadically | |
| | Mechanical stabilization | -do- | yes | | | |
| 3. | Subgrade soil improvement | Soil modification for its application to the subgrade | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | construction | | | | |
| | Cement soil improvement | -do- | yes | | sporadically | |
| | Lime soil improvement | -do- | yes | | sporadically | |
| | Cement-lime soil improvement | -do- | yes | | sporadically | |
| | Chemical soil improvement | -do- | yes | | sporadically | |
| | Mechanical soil improvement | -do- | yes | yes | | |
| 4. | Crushed aggregate layer | Achievement of track formation bearing capacity | yes | yes | | |
| | | | | | | |
| 5. | Concrete slabs | Enhancement of bearing capacity | yes | | only at ballastless track or due to special problems | |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | no | | | |
| 7. | Redemption of unbearable soil | Achievement of bearing capacity | yes | | | |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity | yes | | | |
| 9. | Piles | Enhancement of bearing capacity | yes | | | |
| 10. | Lime- cement columns | Enhancement of bearing capacity | no | | | |
| 11. | Next one | | | | | |

* delete as appropriate

## 10.1.5 Partner : SNCF

| No. | Method<br>Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications,…) | Conditions for method application, application experiences, comments | Skeleton quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | **yes** | **Yes, for separation of materials** | **Systematic use for separation of layers on tracks with no sub-ballast (conventional lines)** | **~100 km of track** |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials | **yes** | **no** | **experimental** | **A few km** |
| | Geogrids | Enhancement of bearing capacity | **yes** | **no** | **experimental** | **A few km** |
| | Geomembranes | Hydroisolation; protection of platform grounds | **Yes** | **yes** | **Use when the water table is lower than 2m below the ballast.** | **A few km** |
| | Geocells | Enhancement of bearing capacity | **no** | **no** | **Use in earthworks, but not for trackbed reinforcement** | |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | | | | |
| | Cement stabilization | -do- | **yes** | **no** | **sporadically** | |
| | Lime stabilization | -do- | **yes** | **yes** | **For new works** | |
| | Cement-lime stabilization | -do- | **yes** | **not yet** | **sporadically** | |
| | Chemical stabilization | -do- | **no** | | **sporadically** | |
| | Mechanical stabilization | -do- | **yes** | **yes** | **Compacting, new works** | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3. | Subgrade soil improvement | Soil modification for its application to the subgrade construction | | | | |
| | Cement soil improvement | -do- | **No** | **No** | **Sporadically (limited experience on HSL)** | |
| | Lime soil improvement | -do- | **No** | **No** | **sporadically** | |
| | Cement-lime soil improvement | -do- | **No** | **No** | **sporadically** | |
| | Chemical soil improvement | -do- | **No** | **No** | **sporadically** | |
| | Mechanical soil improvement | -do- | **Compacting** | **Yes** | | |
| 4. | Crushed aggregate layer | Achievement of track formation bearing capacity | **yes** | **Yes** | **Used for sub-ballast layer in construction and renewal** | |
| 5. | Concrete slabs | Enhancement of bearing capacity | **yes** | **No** | only at ballastless track (very limited) or due to special problems (cavities) | |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | **yes** | **No** | **3 km test site on East-European HSL** | |
| 7. | Redemption of unbearable soil | Achievement of bearing capacity | **?** | | | |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity | **No** | | **Under embankments, but not under subgrade** | |
| 9. | Piles | Enhancement of bearing capacity | **No** | | **Under embankments, but not under subgrade** | |
| 10. | Lime- cement columns | Enhancement of bearing capacity | **no** | | **To be tested in Innotrack** | |
| 11. | Next one | | | | | |

* delete as appropriate

## 10.1.6 Partner : DEUTSCHE BAHN AG

| No. | Method Term, description | Purpose of method application | Application of method yes*/no* | Standardization of method in the system of application (covering to internal standards, specifications,…) | Conditions for method application, application experiences, comments | Skeleton quantity of method exploitation (km, m2, units, …) |
|---|---|---|---|---|---|---|
| 1. | Geosynthetics in subgrade construction | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | yes | Ril 836 (DB code of practise for earthworks) | Function as a separation and drainage layer and for reinforcement | Very frequent application, standard construction |
| | Reinforcing geotextiles | Enhancement of bearing capacity; separation of layer materials + soil reinforcement | yes | Ril 836 (s.a.) | Function as a separation and reinforcement layer | Frequent application, standard construction |
| | Geogrids | Enhancement of bearing capacity + soil reinforcement | yes | Ril 836 (s.a.) | Function as a soil reinforcement | Frequent application, standard construction |
| | Geomembranes | Hydroisolation; protection of platform grounds | yes | Ril 836 (s.a.) | Groundwater protection | |
| | Geocells | Enhancement of bearing capacity, drainage | no | --- | --- | |
| 2. | Stabilization of soil | Achievement of required compactness in soil pressure | yes | Ril 836 (s.a.), ZTVE-StB (Standard of earthworks for railroads) | Stabilization of subgrade, stabilization of embankments for new railway lines | Frequent application for new and renewal lines, partly for improvement of existing lines |
| | Cement stabilization | -do- | yes | s.a. | Depends on soil | |
| | Lime stabilization | -do- | yes | s.a. | Depends on soil | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Cement-lime stabilization | -do- | yes | s.a. | | |
| | Chemical stabilization | -do- | no | --- | | |
| | Mechanical stabilization | -do- | yes | s.a. | | |
| 3. | Deep soil improvement – mass stabilisation | Soil modification for its application to the subgrade construction. Mitigation of settlement, vibration and improvement of total stability | yes | Ril 836 (s.a.) | Used for stabilization of peat or soft soil, depth up to 10 m: f.e. cut-mix-injection (FMI), vibration pressure columns | Frequent application in special cases |
| | Deep soil improvement – columns<br>Lime soil improvement<br>Cement soil improvement<br>Lime - Cement soil improvement | Mitigation of settlement, vibration and improvement of total stability | yes | s.a. | s.a., several methods: grouted stone columns, dry lime columns | application in special cases |
| | | | | | | |
| | | | | | | |
| | Chemical soil improvement | -do- | no | --- | | |
| | Mechanical soil improvement | -do- | yes | s.a. | Dynamic compaction only for new railways for loose soil | Rare application |
| 4. | Crushed aggregate layer | Achievement of track formation bearing capacity. Mitigation of settlement, vibration and improvement of total stability | yes | Ril 836, ZTVE-StB | Often used as soft soil replacement to the limited depth | application in special cases |
| | | | | | | |
| 5. | Concrete slabs | Enhancement of bearing capacity. Mitigation of settlement, vibration and | no | --- | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | improvement of total stability | | | | |
| 6. | Asphalt concrete layer | Protection of rock foundation against weathering and rainfall water influence | no | --- | | |
| 7. | Replacement of unbearable soil | Achievement of bearing capacity. Mitigation of settlement, vibration and improvement of total stability | yes | s.a. | Replacement of soft soil like peat or clay to the limited depth: deep soil replacement; | Frequent application, standard |
| 8. | Crushed aggregate piles | Enhancement of bearing capacity. Mitigation of settlement, vibration and improvement of total stability | yes | s.a. | See point 3 | |
| 9. | Piles – concrete and wooden piles | Enhancement of bearing capacity, mitigation of settlement, vibration and improvement of total stability | no | --- | | |
| | | | | | | |
| 10. | Soil nailing | Improvement of slope stability | yes | s.a. | Applied in embankments, cuttings and natural slopes | Frequent application |

* delete as appropriate

# 10.2 Grouting Improvement Technique

## CEDEX document on grouting

### PROCEDURE FOR TRANSITION ZONE IMPROVEMENT IN RAILWAY LINES, WHILE MAINTAINING COMERCIAL SPEED IN DAILY TRAFFIC USING THE HYDRAULIC FRACTURE GROUTING TECHNIQUE

**1.** Geotechnical characterization of the transition zone and its foundations ground. In addition to the field and laboratory techniques usually employed for that characterization, it is considered necessary to determine, for each identified level of fill or natural ground, the initial value of celerity $v_S$ of shear wave (S) propagation. This aims to overcome possible undesirable scale effects due to the presence of gravel, cobbles or boulders in the soil or to evitable the influence of groundwater in body wave (P) propagation if seismic refraction technique are used.

**2.** Definition of:

- Volume or volumes of subsoil to be treated (platform and foundation)
- Final mechanical conditions of strength and deformability to be obtained in those improved volumes
- Limiting acceptable rail deformations in the zone of improvement

**3.** Construction of a working platform, adjacent to the transition zone, that allows the desired improvement to be effected without any physical interference to the railway traffic and its zone of influence. Should this working platform be available since the very beginning of the transition zone study, the explorations to be carried out could be affected without unnecessary delays from the track side.

**4.** Having proved that grouting techniques through sleeve tubes (“tubes a machetes) are both flexible and susceptible of very rigorous control during applications, a restricted could be organised, where bidding societies would have to justify their previous involvement in soil improvement operations by that technique through impregnation and hydraulic fracture of ground, under very strict conditions of environmental deformations (less than 1/1000 relative movements). Each society would have to furnish a complete grouting design and operation prescriptions.

**5.** It is essential that each bidder will define through plan views and detailed cross-sections, the space configuration of the sleeve pipes and approaching pipes needed to carry out the treatment of the volumes defined in point 2, working from the platform established in point 3. In order to provide the treated soil with the final mechanical parameters defined in point 2, the operation prescriptions established by each bidder will clearly set forth the final grouting pressures needed at the sleeves, depending upon the location of each one, to achieve, in his own experience, the predefined mechanical parameters of the treated soil. Each bidder will have to come up with a program of daily control of movements of the track in order to respect the limiting acceptable deformations of rails in the zone of improvement defined in point 2.

**6.** The Railway Representative in charge of the Operation Direction will take care of controlling:

- By high precision levelling, at the beginning and at the end of each working day, that the deformations of the rails introduced by the grouting operations do not approach the limiting conditions established in point 2.

- The final grouting pressures achieved at the sleeves that should match the prescriptions self-established by the society in charge of the operation.

- Allowing an interval of at least 20 days after the completion of grouting at a section, the celerity of shear waves at the treated ground, that should match the mechanical conditions desired for that section.

**D2.2.1 - State of the art report on soil improvement methods and experience - Summary**

| No. | Method description | Purpose of method application | Application of method yes/no | | | | | | Standardization of method in the system of application (covering to internal standards, specifications,...) | | | | | | Conditions for method application, application experiences, comments | | | | | Quantity of method exploitation (km, m2, units, ...) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ADIF | BV | CD | DB | OEBB | SNCF | ADIF | BV | CD | DB | OEBB | SNCF | ADIF | BV | CD | DB | OEBB | SNCF | ADIF | BV | CD | DB | OEBB | SNCF |
| 1 | **Geosynthetics in subgrade construction** | Enhancement of subgrade bearing capacity; separation of layer materials; drain of rainfall water | Yes | Yes | Yes | Yes | Yes | Yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation. | SS-EN 13250 | CD S4 Regulation „Railway substructure"; GTC „General technical conditions"; SDRS „Sample Designs of Railway Substructure" | RII 836 (DB code of practise for earthworks) | Yes | Yes, for separation of materials | Exploited method for substructure improvement. | Function as a separation and drainage layer | Very exploited method for substructure improvement | Function as a separation and drainage layer and for reinforcement | | Systematic use for separation of layers on tracks with no sub-ballast (conventional lines) | $m^2$ | | | Very frequent application, standard construction | ~562000 $m^2$ | ~100 km of track |
| 1a | Reinforcing geotextiles | Enhancement of bearing capacity separation of layer materials<br>*DB completing: + soil reinforcement* | Yes | Yes | Yes | Yes | Yes | No | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation. | SS-EN 13250 | CD S4 Regulation; GTC for geotextiles; SDRS | RII 836 (s.a.) | Yes | No | Used for embankment improvement with stability problems | Function as a separation and reinforcement layer | Used for embankment foundation with low bearing capacity of subsoil; construction of embankment or its enlargement for stability enhancement (min. anchor length is 5 times thickness of layer); reinforcing of construct layers of embankment (min. layer thickness 0,15m) | Function as a separation and reinforcement layer | | Experimental | $m^2$ | | km | Frequent application, standard construction | ~90.000 $m^2$ | A few km |
| 1b | Geogrids | Enhancement of bearing capacity<br>*DB completing: + soil reinforcement* | Yes | Yes | Yes | Yes | Yes | Yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation. | SS-EN 13250 and SS-EN 14475 | CD S4 Regulation; GTC for geogrids and geomembranes; SDRS | RII 836 (s.a.) | Yes | No | Used for embankment improvement with stability problems | Function as a soil reinforcement | -do- as at reinforcing geotextile; min. tension strength 30 kN/m; max. extension in rupture 15% | Function as a soil reinforcement | | Experimental | $m^2$ | | km | Frequent application, standard construction | | A few km |
| 1c | Geomembranes | Hydroisolation; protection of platform grounds | Yes | Yes | Yes | Yes | No | Yes | Use is not generalized. The standardization of the methods depends of the project. With any specific regulation. | SS-EN 13361 and SS-EN 13491 and SS-EN 13492 | CD S4 Regulation; GTC for geogrids and geomembranes; SDRS | RII 836 (s.a.) | No | Yes | Used as a hydrozolating of the embankments | Groundwater protection | Used as a hydrozolating, separative or reinforcing component.Laying on planed surface and protection layer realisation with min. thickness 0,15m | Groundwater protection | | Use when the water table is lower than 2m below the ballast | $m^2$ | | km | | | A few km |
| 1d | Geocells | Enhancement of bearing capacity | No | Yes | Yes | No | No | No | - | SS-EN 13250 | CD S4 Regulation; SDRS | | No | | - | Function as a drainage layer | Embankment foundation; filled in permeable aggregate | | | Use in earthworks, but not for trackbed reinforcement | - | | Tens of metres | | | |
| 2 | **Stabilization of soil** | Achievement of required compactness in soil pressure | No | No | Yes | Yes | Yes | | - | | CD S4 Regulation; SDRS | RII 836 (s.a.), ZTVE StB (Standard of earthwork for railroads) | | | - | Mostly used for stabilisation of peat to the limited depth | Prepared in mixcentrum and it is overspread by finisher mostly.Kind of stabilization is chosen on the geotechnical research base. Min. thickness of stabilization layer is 0,15m after compaction. | Stabilization of subgrade, stabilization of embankments for new railway lines | | | | | Hundreds of meters | Frequent application for new and renewal lines, partly for improvement of existing lines | 50-80 km/year | |
| 2a | Cement stabilization | -do- | No | No | Yes | Yes | Yes | No | Used to improvements the subgrade; NRV 2.1-2.0 Regulation | | CD S4 Regulation; SDRS | | | No | Use is not generalized | Dry deep mixing method used in form of columns | Mostly used with exposed aggregate soils; used in railway level-crossings area, in transition zones | | Sporadically | Sporadically | kg | | | | | |
| 2b | Lime stabilization | -do- | Yes | No | Yes | Yes | Yes | Yes | Used to improvements the subgrade; NRV 2.1-2.0 Regulation | | CD S4 Regulation; SDRS | s.a. | | | Use is not generalized | Dry deep mixing method used in form of columns | Realised in lines with fine soils in subsoil | Depends on soil | Sporadically | Sporadically | kg | | km | | | |
| 2c | Cement-lime stabilization | -do- | No | No | Yes | Yes | Yes | Not yet | | | CD S4 Regulation; SDRS | s.a. | | | | | Suitable for sandy and fine soils | Depends on soil | Sporadically | For new works | | | Tens of metres | | | |
| 2d | Chemical stabilization | -do- | Yes | | Yes | No | Yes | | It is used as grouting of resin or cement in order to improvement embankment and subgrade. PG-3 Article 6 Regulation | | CD S4 Regulation; SDRS | | | | It is used in embankment and cutting with stability problems | Dry deep mixing method used in form of columns | There was utilized system CONSOLID in several cases, but now systems of preparations from cement production on the base of cement, lime and other chemical ingredients are preferred. It is successfully used in sandy soils. | | Sporadically | Sporadically | | | km | | | |
| 2e | Mechanical stabilization | -do- | No | | Yes | Yes | Yes | Yes | - | | CD S4 Regulation; SDRS | s.a. | | | - | | Combination of original soil and other soils with suitable quality | | | Compacting, new works | | | Hundreds of metres | | | |
| 3 | Subgrade soil improvement<br>*BV completing: Deep soil improvement – mass stabilisation* | Soil modification for its application in the subgrade construction<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | Yes | Yes | No | - | No | CD S4 Regulation; SDRS | s.a. | | | - | Mostly used for stabilisation of peat to the limited depth | Realised in situ. Binding material is put to the subgrade and mixtured in through the groundcutter | Used for stabilization of peat or soft soil, depth up to 10 m: f.e. cut-mix-injection (FMI), vibration pressure | Sporadically | | kg or metres | | | Frequent application in special cases | | |
| 3a | Cement soil improvement<br>*Bv completing: Deep soil improvement - columns* | -do-<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | Yes | Yes | Yes | Yes | Yes | No | PG – 3. Article 6 Regulation | Swedish Geotechnical Society – Report 2:2000 | CD S4 Regulation; SDRS | s.a. | | No | Increasing and regulating the modulus of deformation of the embankment, in the zones where it appeared less compact. It is used in embankment and cutting with stability problems | Dry deep mixing method used in form of column | Used often in railway level-crossings area and in transition zones | s.a., several methods: grouted stone columns, dry lime columns | Sporadically | Sporadically (limited experience on HSL) | kg or metres | | Hundreds of metres | Application in special cases | | |
| 3b | Lime soil improvement<br>*Bv completing: Deep soil improvement - columns* | -do-<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | Yes | Yes | No | - | Swedish Geotechnical Society – Report 2:2000 | CD S4 Regulation; SDRS | | | | | Dry deep mixing method used in form of column | The most used kind of soil improvement: Mostly in fine soil with 2-3% of lime. The thickness of improvement layer is from 0,40 to 0,50m. | | Sporadically | Sporadically | | | km | | | |
| 3c | Cement-lime soil improvement<br>*Bv completing: Deep soil improvement - columns* | -do-<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | Yes | Yes | No | | Swedish Geotechnical Society – Report 2:2000 | CD S4 Regulation; SDRS | | | | | | The first is mixed lime and secondary is mixed cement | | Sporadically | Sporadically | | | km | | | |
| 3d | Chemical soil improvement | -do- | No | No | Yes | No | Yes | No | | | CD S4 Regulation; SDRS | | | | | | Systems of preparations from cement production on the base of cement, lime and other chemical ingredients. It is successfully used in sandy soils. | | Sporadically | Sporadically | | | km | | | |
| 3e | Mechanical soil improvement | -do- | No | Yes | Yes | Yes | Yes | Compacting | | Swedish rules for soil compaction | | s.a. | Yes | Yes | | Just compaction is used | It is used when any size fraction in original soil is needs to fill in. | Dynamic compaction only for new railways for loose soil | | | | | Hundreds of metres | Rare application | | |
| 4 | **Crushed aggregate layer** | Achievement of track formation bearing capacity<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | Yes | Yes | Yes | | Swedish rules for soil compaction | CD S4 Regulation; GTC | RII 836, ZTVE-StB | Yes | Yes | | Often used as soft soil replacement to the limited depth | It is taken as a type of substructure construction. There is usually used crushed aggregate 0/32 fraction. Min. layer thickness is 0,15m. | Often used as soft soil replacement to the limited depth | | Used for sub-ballast layer in construction and renewal | | | km | Application in special cases | | |
| 5 | **Concrete slabs** | Enhancement of bearing capacity<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | No | Yes | Yes | | No | CD S4 Regulation; SDRS | | | | | | It is taken as a type of substructure construction. It is not very much used, it is recommended to use them in railway | | only at ballastless track or due to special | only at ballastless track (vert limited) or due to special problems (cavities) | | | Hundreds of metres | | | |
| 6 | **Asphalt concrete layer** | Protection of rock foundation against weathering and rainfall | No | No | Yes | No | No | Yes | | | CD S4 Regulation; SDRS | | | No | | | It is taken as a type of substructure construction. It is used in areas with disintegrating rock in subgrade and it is possible to do perfect slope of track formation. | | | 3 km test site on East-European HSL | | | Hundreds of metres | | | 3 km |
| 7 | **Redemption / replacement of unbearable soil** | Achievement of bearing capacity<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | No | Yes | Yes | Yes | Yes | ? | | No | CD S4 Regulation; SDRS | s.a. | | | | Replacement of soft soil like peat or clay to the limited depth | It was done in several cases in areas with extremely low bearing capacity. | Replacement of soft soil like peat or clay to the limited depth: deep soil | | | | | About 5 km | Frequent application, standard | | |
| 8 | **Crushed aggregate piles** | Enhancement of bearing capacity | No | No | Yes | Yes | Yes | No | | No | No | s.a. | | | | | It was used on two sections of main lines with very low bearing capacity. From piles were done a net for achievement of minimal modulus on track formation. | See point 3 | | Under embankments, but not under subgrade | | | Tens of km | | | |
| 9 | **Piles**<br>***BV Completing: Concrete and wooden piles*** | Enhancement of bearing capacity<br>*BV completing: Mitigation of settlement, vibration and improvement of total stability* | Yes | Yes | Yes | No | Yes | No | NRV 2.1-2.0 Regulation | No | No | | | | It is used in embankment and cutting with stability problems. | Normally used under embankment often in transition zones of bridges close to the abutment | | | | Under embankments, but no under subgrade | | | 150 m | | | |
| 10 | **Lime- cement** | Enhancement of bearing capacity | No | | Yes | | No | No | | | No | | | | | | SOLMIX system was used on one construction at CD only | | | To be tested in Innotrack | | | | | | |
| 11 | **Station-type ash mixture** | Protection of rock foundation against weathering and rainfall water influence; enhancement of bearing capacity | No | | Yes | | | | | | No | | | | | | It is taken as a test section in a railway station track. There are disintegrating rock in subgrade, a layer of ash mixture is the protection again water influence and it is the layer with very good bearing capacity. | | | | | | | | | |
| 12 | **Soil nailing** | Improvement of slope stability | | Yes | | Yes | | | | No | | s.a. | | | | Applied in embankments and natural slopes | | Applied in embankments, cuttings and natural slopes | | | | | | Frequent application | | |