PROFESSIONAL STATEMENT

Description and methodology – Bases for planning and implementation

In cooperation with Geotechnik Dr. Nottrodt Weimar GmbH
Professional statement
DESOI Ram Injection Lances

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1. Chronology

The first mineral injection into the foundation soil took place over 200 years ago:

- In 1802 the Frenchman Charles Bérigny injected a suspension of water and cement in order to fill scouring (washout) in the subsoil of a sluice, to solidify and seal it. The „injection method“ originates with him.
- See also the annex: DESOI chronology, „Over 200 years of the injection method“
- In the US mineral injection into the foundation soil has been used since the 40s (compaction grouting), in Russia since the 50s...
- Loosely positioned soil materials are displaced and compacted around the injection site.
- The injection lance/ram injection lance is gradually pulled up
- A spherical body of up to 1 m forms

Specialist literature in Germany has documented practical knowledge and experience for more than 70/50 years as „injections in foundation soil“ (e.g. Jähde / Kutzner):

- Many processes in the subsoil remain unknown during injection
- The theoretical considerations are limited
- The „right solution“ therefore is:
  - If the purpose of the injection operation is achieved with acceptable technical and economic expenditure
2. The foundation soil consists of two basic types of rock

- Loose rock
- Hard rock

- The foundation soil is a system made up of three substances:
  - Solids (mineral grains / rock)
  - Liquid (usually water)
  - Gas (usually air)
- Liquid and gas fill the fissures (rock) or the pore space (soil)
- If fissures or pores are expanded due to processes (e.g. leaching out, rinsing...) or are unnaturally enlarged, we are dealing with cavities in the ground
- The formation or presence of cavities can usually only be seen due to effects on the earth’s surface (sinkholes, depressions...) or altered groundwater conditions (higher groundwater levels, greater groundwater flow etc.)

2.1 What do we mean by injection into the foundation soil?

- Injecting a grout for the purpose of sealing or tightening in cavities, fissures, pores
- The permeability and firmness of the injected solid and loose rocks are crucial
- All injection grouts are fluid and penetrate into fissures and pores

The first successful method for sealing and consolidating the foundation soil is the Joosten method, patented August 15, 1926 in Germany
- Water glass and calcium chloride successively pressed together (gelling)
- The reaction occurs abruptly

2.2 Types of injection

Filling injection
- Injection for filling existing fissure and pore systems
  - Sealing
  - Consolidation of solid and loose rock
(Formation of connected injection objects)

Important: Continuous flow of grout, at a pressure of 5 – 10 bar

Compaction grouting
- Injection to fill an artificially created cavity
- The cavity is filled with grout and compacted

Objective:
- Increasing the load capacity of loose rock
- No connected injection objects
Pressure: up to 2 MN / m² – 20 bar

2.3 Using the method that involves ram injection lances:

- Soils consisting of fine sands and silty fine sands
- Grout: cement suspension, acrylic gel
- With compaction grouting, the cement objects do not need to touch
- Ram lance clearance: 0.5 – 1 m
- The method involves compression zones
  - Pressure: approx. 0.5 MN/m – 5 bar
  - Injection rate: 2 – 3 l / min at the beginning
  - 1 – 1.5 l / min at the end

Note:
- Too high pressure splits the environment (the granular structure of the soil)
- Material exits from the annular gap with excessive pressure

3. Theory of injection into the foundation soil

Prerequisites
- Cavities are filled with grout
- Complete filling is possible if the cavities are interconnected
- Grout penetrates from the drill holes into the fissure and pore system
- The grout keeps flowing due to the injection pressure.
  „Range“ → Distance between the injection source and the point toward which the grout is advancing.

Note:
The injection pressure and the range must always be limited
 excess pressure = elevations on the surface or shifts. The material exits the annular gap.

3.1 Flow and solidification behaviour of the grout

The flow and solidification behaviour of all grouts is characterised by viscosity and flow limit, e.g. Marsh funnel.
1 litre of cement suspension: approx. 25 – 30 seconds (water: 20 – 25 seconds) flow time

3.2 Recommendations regarding injection pressure

Objective:
Merging or overlap of adjacent injection regions

Recommended injection pressure and injection speed:
- Maximum allowable pressure which must not be exceeded
- Depends on the injection range
- Slowly increase pressure
- Maintain pressure for several minutes (absorption capacity of the fissures and pores)
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3.3 Trial injections
Ideally carried out before the tender
(trial injections are dependent on the building, but are always recommended)

Objective of the trial injection
• Investigating technical details
• Establishing pile driving procedures / piling engineering
• Determining and documenting the injectability of the foundation soil
• Recording the findings in the preliminary remarks of the service specifications / contract conditions

Arrangement of ram injection lances for trial injections

Fig.: As per Kutzner
- Possible water testing
- Then fill the ram injection lances with cement suspension
- Test with core drillings

Findings from the trial injection
• Basic suitability of the method
• Appropriate clearance for the ram injection lances
• Determine draw-up pressure and appropriate injection pressure
• Determine the injection material absorption and possible relation to the water absorption

3.4 Injection time
• Is linked to viscosity development of the grout,
• to injection pressure,
• to the desired or achievable range
Note: pumpability (tilting time) of the grout
→ it is pumpable as long as it still flows out as a fluid when a container is being tilted

4. Foundation soil investigations
4.1 The necessity of foundation soil investigations
The following general parameters of a foundation soil injection must be established in advance:
• Thickness of what is to be injected / of the foundation soil layer(s) to be improved
• Proportion of water or gas-filled pores and cavities
• Physical and chemical properties of the soil and groundwater
• Groundwater flow direction and – speed
• Driveability of the foundation soil – Is it „driveable“? Can ram injection lances be feasibly utilised?
4.2 Foundation soil investigation in loose rock
- Selective explorations in the form of core drillings, drill probes or excavations
- Ideally carry out supplementary field trials, particularly pumping and/or injection trials (and the assessment of trial injections)
- Pressure or driving probes for determining bulk density and driveability
- Removal of undisrupted and disrupted soil samples, environment and water samples
- Investigations in the soil laboratory for the following parameters at least:
  - usual local designation
  - particle size distribution
  - mass portion of rocks and blocks
  - water content
  - plasticity
  - consistency index
  - bulk density
  - soil group
  - pore volume and permeability as well if possible

→ Environmental chemistry investigation of the soil and water, depending on the intended grouting
→ If necessary also using geophysical methods for the spatial cavity search

„Savings“ in foundation soil investigations has quite often led to:
- construction complications
- cost overrun
- accidents
- abandonment of construction
(H. Jähde 1953).

Note:
Soil and rock classes as per VOB/contracting rules for award of public works (2012 and earlier) are invalid.

4.3 Notes on homogeneous areas (from ATV DIN 18304 - 2015)
„Soil and rock are to be classified into homogeneous areas in accordance with their state before the piling, vibrating, or pressing work. The homogeneous region is a limited area consisting of single or multiple soil or rock layers having comparable properties for piling, vibrating, or pressing work.
If environmental ingredients need to be taken into account, these must be considered in the classification into homogeneous areas.“

5. Planning of injection work (foundation soil injection)
Objective:
- Planning of filling injection involves arranging the ram injection lances such that they overlap the foundation soil zones
- An interconnected, closed injection object (soil grains and injection material) should be the result (DIN 4093)

• Compaction of loose rock
  - Producing a horizontal grouted bottom
  - Producing a grout curtain
  - Special solutions, such as the compaction of a trench bottom for laying pipelines
• Consolidation and improvement of loose rock
  - Underpinning of constructions or components
  - Foundation soil consolidation or improvement (increasing construction sustainability before the construction or in the context of renovation)
  - This calls for break-up injections due to the high pressures required (to offset subsidence)

5.1 Recommended arrangement of ram injection lances
- Arrange them in such a way that an interconnected, closed injection object is formed
- The clearance for the ram injection lances depends on the range of the injection substance

Typical clearances
- 0.25 – 0.5 m within a series
- 0.25 – 0.5 m for deep injections (grout curtain)
- 0.5 – 1 m for surface injection holes
- Adjacent series are to be staggered

Fig.: Suggested arrangement of ram injection lances

5.2 Notes on carrying out injection works
Basics
- Introducing the ram injection lances
- Producing the injection object

The advantage of ram injection lances:
Costs for driving are significantly lower than for the drilling. Ram injection lances can be used repeatedly (several times).
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5.3 Notes on the procedure for using ram injection lances

Ascending pressing „from the bottom up”
- Bore hole / advance the lance to the target depth
- Carry out injections from the bottom up for each section
- With lost tip
Selecting the method based on geological conditions.

5.4 Notes regarding grout / injection substances

The objective of foundation soil injections:
- Sealing
- Consolidation / improvement

Injection grout
- Solutions
- Chemical compounds of liquid, solid and gaseous substances
- Fully mixed – e. g. gels / fluid plastics / resins
- Suspensions
- Mixtures made of liquid and solids
- Diameter: 1 – 100 µm – e. g. suspensions made of water and cement/ aggregates such as binders
- Emulsions
- Mixtures of two or more liquids with different properties 1 – 10 µm – e.g. emulsions of bitumen and water / resin and rubber emulsions

Grout selection — depends on the size and volume of the pores and fissures.

Note:
Generally finer grouts that fit into the pores and fissures

Injection mortar:
Cement suspension plus sand additive for large cavities or fissures.

Suspensions based on cement
- Crucial:
  - High grinding fineness
  - Maximum particle size distribution 0.1 mm
    90 % of the cement grains smaller than 0.05 mm
- Squeeze out excess water
- Flow properties are crucial
- Take into account the sediment behaviour

Silicate gels
- Raw material: water glass mixed with inorganic or organic hardener
- This gel is injected into soils similar to sandstone
- A certain tensile strength
- Low compressive strength
Long-term tests have been positive since 1937 – No fatigue or solidification in a selected building in Nordhausen - checked again in 1956

5.5 Test the production of the injection object with DESOI Flow Control II

- The injection body is always below the ground surface
- Flow Control II
  - The injection substance amount data is continuously documented
  - Constant monitoring during production!

Advantages for designers and builders

DESOI Flow Control II devices guarantee that planned consumption rates and prescribed technical parameters are constantly monitored and maintained, e.g. mixing ratio and injection pressure. The machine technology designed for this purpose is reliable, robust, tried and tested, and enables high implementation safety. On request, the system can be customised for a project or application.

You can find the technical brochure at www.desoi.de or request it from us!

Fig.: Flow Control II - Display
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Experiences
- Constantly increasing pressure with an injection rate that is constantly falling at the same time indicates that there are no breakages in the injection site
- For pore injections into loose rock D monitor the injection rate for each injection lance / bore hole section. This is an indication that the grout has been produced as planned.
- Records also provide a calculation basis for the work being done
- The injection object’s environment is checked and documented

6. Notes on environmental compatibility
- Investigations since 1981 – pp. 272/273 with Kutzner
  - Structures investigated:
    - Berlin subway H 110
    - Mendelsohn Bau Berlin
    - Hamburg Allermöhe
    - Vienna subway 3/5

6.1. Current regulations in Germany

DIBt – Report II 6
Requirements for construction works with regard to the effects on soil and water (ABuG), version 16.12.15

Water Resources Act (WHG)
§ 9 (1) 4 Uses
- Introducing/discharging substances into bodies of water requires an official permit or license.

§ 49 Soil exploration
- The water authority or environment agency must be notified of planned foundation soil injection works a month before they begin.

§ 62 Principle of Prevention
- Equipment must be acquired, maintained and operated in a way that it does not cause any adverse changes to the water that require action

Construction contract and tendering
The tender is the foundation and eventually the main component of a construction contract.

7. Conditions for the Building Description / Tendering
- The prospective construction must be described in a way that the provider has a clear idea of the expected services and supplies
- What technical methods are to be used?
- Description of the individual construction services for a reliable calculation – including partial services
- Include all construction services, even those that are currently not sufficiently known

7.1 Tendering injection work
- Service and construction description
- General contractual conditions
- Technical implementation conditions
- Technical specifications

VOB standards that must be observed (amended version 2015) for injections with ram injection lances
- ATV DIN 18304: Piling, vibration, and pressing work
- ATV DIN 18309: Grouting

7.2 Service description recommendations
- Work to be carried out must be described in full
- Include results from completed foundation soil investigations
- Evaluate geological, rock, and soil-mechanical reports
- Results of field and laboratory tests and conclusions
- Climate, rainfall, temperatures in the construction area/construction time
- Identify access routes and their status
- Water and energy supply of the construction site
- Disposal conditions for all substances being used
- Groundwater conditions / measured water level
- Vegetation and provisions for its protection
  - regional characteristics, location and nature of the building
  - potentially record keeping and an audit
  - document instructions and agreements with the builders
  - removal of ram injection lances / hydraulic lance lifters

Recommendation:
Do a site inspection in advance with the builders / planners
Suggested priorities for the service description

Injection work in the foundation soil
1. Site equipment
   - Preparation of all drilling / injection sites
   - Office trailers, accommodation, toilet, Energy supply ...

2. Compliance with the requirements of environmental protection / WHG

3. Provision of all equipment, machinery, devices, material, ram injection lances

4. Trial drillings for injection purposes at an angle of degree - total depth
   Price per m

5. Insert the ram injection devices
   Depth:
   ___________ Piece  Price per piece ___________

6. Water testing (optional item)
   Number
   ___________ Price per test

7. Delivery, warehousing,
   injection substance
   ___________ kg/t  Price per kg

8. Preparing and injection
   ___________ kg/t  Price per kg

9. Waiting times due to:
   - Arrangement of ram injection lances, possible obstacles
   - Due to reaction / setting behaviour of the injection substance
   ___________ Hourly  Cost per hour

10. Hourly wage works:
    for especially arranged services
    time/hour

11. Quality control as proof of injected quantities,
    Injection pressure, time of injection

Information lifting measurement depending on the object

7.3. Invoicing basis
• Construction site equipment / flat-rate invoicing
• Clearing the site
• Provision of devices, technology in accordance with time/days
• Drilling and driving work by metres, pieces
• Possible packer placement, billing by piece
• Possibly necessary water testing, water pressure testing as per time expenditure/piece
• Injection, invoicing according to injection hours and by weight or volume of the injected materials
• Removal of the ram injection lances
• Records – Flow Control II - diagram

7.4. Recommendation for monitoring during construction
• In urban areas, ensure the neighbouring buildings are audited in advance (preferably by a publicly appointed and certified expert)
• Plan and implement a monitoring programme during the injection work; do this selectively on vulnerable parts of the structure (e.g. plug gauges, horizontal inclinometers) or continuously, e.g. in the injection area using fiber optic sensors, for instance; possibly measure at trial injections
8.1 Reference object: Drinking water reservoir
„Schwarze Pumpe Industrial“
Injection with ram injection lance

Drinking water reservoir 1 and 2 on the area of the „Schwarze Pumpe industrial area“ have a storage space of 2800 cubic metres each. They were built in the period from 1989 to 1991 as standardized projects (series „PROWA“).

Building construction
The overhead tanks are free-standing round containers with an outside diameter of 25.88 meters and a ceiling height of 6.00 meters. They were manufactured in a mixed structure, usually as a reinforced concrete structure.

Monolithic construction: ring container foundations, lower foundations, container floor with a berm formation in the wall area. Erection of buildings: container wall, supports and upper sealing construction. The container floors were constructed from in-situ concrete (B 20) with a soft steel reinforcement. The entire floor plate area was thus formed with both radial and diagonal joints (transverse joints). The container bottom is approx. 1.50 meters above ground level. This means that the plate surface was refilled during the construction phase.

Structural damage
After water leaked from the drinking water reservoir 1 to the outer area, an internal investigation was carried out following the emptying of the reservoir with the following results: leaking joints were found in parts of the container edge areas between the berm and the foundation ring. A ground subsidence was found in the berm plate area next to an obviously crumbling transverse joint, due to erosion / flushing in the floor area below the tank bottom as a result of leaking joints.

Restructuring plan
The required restructuring planning was implemented by Kiwa MPA Bautest GmbH, Lausitz Service Centre. Prior to the renovation of the crumbling joint, the lowered underground in the berm plate area needed to be solidified in order to avoid further sinking of the ground in this area. As mentioned previously, the foundation soil is, backfill or refill material (certainly gravel mixture). The following steps were planned for this process:
1. Drilling of injection channel for the intended ram injection lance at intervals of about 50 cm x 50 cm vertically through the concrete base plate.
2. Following the vacuuming of debris and dust from the injection channels - the injection lances are rammed into the ground.
3. Product: ram injection lance from DESOI GmbH, type: BP-complete, diameter 25 mm x 1200 mm.
4. Sealing and consolidation of ground injection by injecting a low viscosity polyurethane-based duromer resin manufactured by MC-Bauchemie with a 2-component injection pump over the previously introduced ram injection lance.
5. After the injection material has hardened, the steel packer is removed and the concrete surface is repaired.

Construction
The construction work was carried out by the company MBS MAERTIN, Bausanierung Spremberg GmbH. The construction work was carried out professionally in accordance with the restructuring plan incl. specifications. In addition to the ground consolidation, the general restructuring / repair of all crumbling joints are included. The implementation of the construction was controlled on site by the planner and the client.

Result
After the acceptance of the construction work with a positive leaking test after having filled the reservoir, the reconstruction measures, incl. ground consolidation by the ram injection lance, were completed successfully.
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Reference object
„Schwarze Pumpe Industrial“
Injection with ram injection lance

Photo 1 + 2: Drinking water reservoir „Schwarze Pumpe Industrial“
Photo 3: Application - Ram injection lance (Photo: Desoi)
8.2 Reference object: Gas pipeline / Anklam

Nature reserve Anklam / Groß Polzin
Sealing by ram lances

Creating a micro tunnel for the gas pipeline
When creating a micro tunnel for the gas pipeline during the course of its construction, around 20 meters had to be created under the Peene using a tunnel procedure, near the nature reserve in Wismar. The geological structure included on one hand a sandy gravel floor and on the other hand a layer of solidified peat close to the surface. Despite the dry ground, water was found under the riverbed of the Peene. A slurry machine with a 3 m outside diameter was chosen to be appropriate for the cohesive ground.

Specifics during transit
After the first half of the tunneling route posed no problems, a boulder was identified in front of the machine. A plan was made to destroy the stone by driving through it. Since the cutting tool of the machine, however, was designed for soft floors, this could not be achieved despite several attempts. The strong forces placed on the stone during the attempts to destroy it resulted in cavities appearing around the boulder and the machine. This had to be balanced out by a greater amount of supporting fluid with higher pressure at the same time. The ground coverage over the microtunnelling machine could not, however, withstand the pressure of more than 2.5 bar of supporting pressure, therefore the stone had to be blown up. All attempts to fill the resulting crater by using liquid soil and then solidify it thus failed: the support pressure could not be started up again. The filled crater was neither pressure-tight nor was it able to hold the supporting slurry fluid. It had to be sealed and solidified using an additional measure on the ground in front of the tunnel face. A particular challenge in finding solutions was the lack of logistics and the requirement to use neither large appliances nor environmentally unfriendly injectables. The tight time frame for the completion of the work also had to be taken into account.

Sealing by ram lances
TPH, a company involved in the project, suggested stabilizing and sealing the backfill soil by injection. In addition, an injection by the tunneling machine should fill in and compress the blasted boulder which was checked previously. As no machine movement was allowed in this nature reserve, conventional methods such as cement injection or freezing were out of question. The injection by means of a Desoi ram lance was therefore selected. The ram lances are of modular design and can be adapted with different technical properties according to on-site conditions. In this case, at up to 17.5 m, they were rammed into the ground with a light pile hammer and could be placed very close over the machine.

Procedure of injection work
Over the lances acrylate gel had been injected by the DESOI pump PN-1412-3K and so the soil was consolidated. The whole equipment could be transported without machinery and the acrylate gel was approved for use by the local water authority on the basis of the DIBt certification. A total of 56 ram lances were used and approx. 2,400 l gel was introduced. The basically dense backfill soil was consistently permeated and solidified only by the use of very low viscose acrylate gels, where a combination of solidification and sealing had to be achieved. The ram lances enabled the required targeted injection.

The cavities which had been created in the ground by the boulder blast were filled with a silicate foam by a further injection device, PN-2036-2K, out of the tunneling machine. The benefit of silicate foam is that it provides a very good adhesion to siliceous substrates due to the high water glass content, but it also passes through easily from the machine.

Result:
Within 3 days the problem was solved. The slurry pressure could be increased once again and the machine could continue its work.
Reference object: Gas pipeline / Anklam
Nature reserve Anklam / Groß Polzin
Sealing by ram lances

Photo 1: Nature reserve Anklam / Groß Polzin
Photo 2: Mounting the injection lance
Photo 3: Ramming the injection lance with the pile hammer (Photo: Desoi)