General

In foundation engineering, grouting refers to injecting fluid substances into hollow spaces and pores in the foundation soil. After injection, the substances should harden or set, depending on the construction work to be completed.

There are various hollow structures in the foundation soil:

- In rock and heavy clay soils, there are fissures, crevices, cracks, pores and cavities.
- In loose soil, such as gravel and sand, there are pores.
- In building structures, there are crevices, joints, cracks and pores.

In order to reach the cavities, holes are made in the ground by pile driving, vibration drilling or drilling. Injection pipes or injection lances are installed in these holes and are then used to inject the substances.

Grouting is one way of improving the foundation soil. It allows the soil to be compacted in order to increase the load bearing capacity of the subsoil or to reduce its deformability and/or allows the subsoil to be sealed.
The grout can be injected into the foundation soil either with or without displacement of the foundation soil.

**Non-displacement procedures** include the following:

- **Permeation grouting**
  The objective here is to fill all accessible spaces between the grains in permeable loose soil with grout without disturbing the original position of the foundation soil. The permeability of the foundation soil is reduced while the compactness and density are increased.

- **Fissure and contact grouting**
  Fissure grouting is used to fill open fissures, cracks and crevices in rock with grout without generating new cracks or expanding existing cracks, in order to reduce the permeability of the foundation soil treated and/or to increase its compactness.

- **Bulk filling**
  Bulk filling is used to fill large natural or man-made cavities. Large amounts of grout are injected in a non-pressurized procedure or at low pressures.
Displacement procedures (displacement grouting)

- **Hydraulic fracturing**
  Hydraulic fracturing grouting is used to stabilize or compact the foundation soil (loose soil or rock), to achieve controlled lifting of building structures (compensation grouting) and to achieve a sealing-off effect by creating compartments using bulkheads in the foundation soil. Details on compensation grouting (elevation grouting) are covered in a separate brochure.

- **Compaction grouting**
  In compaction grouting, comparatively thick (viscous) grout is injected into the subsoil in order to cause displacement and deformations in the soil. The grout is usually injected into the soil via injection pipes open at the bottom. The consistency of the grout is selected so that it remains homogeneous and the foundation soil is neither permeated nor hydraulically fractured. Compaction grouting is most commonly used to compact loose foundation soil and to secure building structures that have settled.

- **Jet grouting** (high pressure grouting)
  Jet grouting is not a grouting procedure in the conventional sense. In this procedure, the in-situ soil structure is broken up using a high-pressure jet and mixed or replaced with a cement suspension. Details on this procedure are given in a separate "jet grouting" brochure.
**Grouts**

<table>
<thead>
<tr>
<th>Type</th>
<th>Mortars and pastes</th>
<th>Suspensions</th>
<th>Solutions</th>
<th>Emulsions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Definition</strong></td>
<td>Suspensions with very high solid content</td>
<td>Fine dispersion of non-dissolved material in a carrier fluid.</td>
<td>Solid materials dissolved in a solvent.</td>
<td>Liquid mixture of two different liquids, usually with stabilizing agents.</td>
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<tr>
<td><strong>Composition</strong></td>
<td>Mixture of: water, cement, sand and possibly special additives, water/cement ratio generally less than 1</td>
<td>Mixture of: water, cement or fine binding agents and possibly bentonite, flue ash or similar substances, water/cement ratio generally greater than 1</td>
<td>Mixtures of: water, water glass, hardeners, synthetic resins, plastics</td>
<td>Mixtures of: water, bitumen, emulsifiers, water-insoluble water glass hardeners</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Filling of cavities and crevices. Manufacture of grouted-aggregate concrete, compaction of foundation soil</td>
<td>Sealing and stabilizing gravelly and sandy soils, fissures and cracks in rock, cracks in walls</td>
<td>Sealing and stabilizing sandy and fine gravelly soils, hairline cracks in walls</td>
<td>Sealing fine sandy soils</td>
</tr>
</tbody>
</table>

Grouts are classified according to the materials used to make them and their formulations: (see above)

- Mortars and pastes
- Suspensions
- Solutions
- Emulsions

Grouts are used successfully when the constitution of the grout and the injection method are adapted to the subsoil conditions. The structure of the subsoil in particular determines the limits of the grout injection capability.

**Application limitations**

Limitations to grout injection capability result amongst others from the fineness of the grains of soil to be treated (see figure 2 on the following page). For this reason, pure cement suspensions are not applicable in sandy soils.

Special cement suspensions (fine binding agents, solid injections) are used in combination with clay, bentonite or other additives in coarse sands. Chemical silicate-based (water glass based) grouts are primarily used for sandy soils. In this procedure, a silicon gel is precipitated via an organic reaction from the water glass solution, which leads to a cementing together of the grains of soil. Finally, in even finer-grain or silty soils, plastic solutions, e.g. epoxy resins and emulsions are used. Because of the risk of ground water contamination with organic substances, this procedure is only used in exceptional cases.
Jet grouting procedures, which cover the entire spectrum from clay to stone are covered in a separate "jet grouting procedures" brochure.

Grouting methods

Various methods can be used to inject the grout into the soil:

- In the case of fissure grouting in resistant rock, uncased bore holes 80 to 150 mm in diameter are made, into which an injection tube with packer is inserted. After the packer has closed off the bore hole at a particular depth, the grout is injected through the injection tube into the bore hole below until the required pressure is reached and maintained. The packer is then pulled up in steps and the process repeated.

- In compaction grouting, grout can be injected through the bore pipe itself. To do this, a small cased bore hole 80 to 150 mm in diameter is drilled to the required depth using pile driving, rotary or hammer drilling, vibratory drilling or flushing; the bore pipe is then pulled up in steps while the grout is injected.

- To make gel injection slabs in drivable soils, a permanent driver and injection head (vibratory valve) with an attached injection tube in the driving pipe is vibrated down into the soil to the required depth. The vibrating driving pipe is then pulled up, while the annular space around the injection tube is filled with soil and compacted. The grout is then injected into the soil through the injection tube via the foot valve.
• For non-drivable soils, small cased bore holes 80 to 150 mm are first made to the required depth. The bore pipe is then filled with what is known as a sheathing compound made, for example, from water, cement and bentonite and the bore pipe is pulled up.

For a gel injection slab, the grouting pipe with the adjustment section attached at the end (see figure 2) is then installed into the sheathing compound supporting the soil.

When making grout bodies where a single foot valve is not sufficient, sleeve pipes are installed into the sheathing compound. Sleeve pipes are injection pipes made from hard PVC or steel, normally with diameters of 1” to 1.5”, which are perforated at intervals of 33 or 50 cm. The perforation is covered with a rubber sleeve, which expands in the form of a valve under the injection pressure, allowing the grout to pass out through the perforation into the surrounding area.

After the sheathing compound has hardened, it forms a sheathing around the pipe. This fixes the sleeve pipe in its position and prevents the grout from rising into the annular space during injection. During injection, the sheath (sheathing compound) at the perforated areas of the sleeve pipe is broken up by the grout. Injection through the holes in the sleeve pipe is carried out by double packers (see figure 1 on the following page). The double packers consist of 2 expandable sealing sleeves (sealing components) with an outlet pipe between them. Attached to the double packer is the injection and expansion tube.
After the double packer in the sleeve pipe has been brought to the correct height in front of a perforation in the sleeve pipe, the packer's sealing sleeves are expanded through the introduction of pressurized gas or liquid and press from the inside onto the sleeve pipe wall. The gas or liquid is fed through the expansion tube. The sleeve pipe in the packer area is thus sealed above and below and via the outlet pipe between the sealing sleeves, the grout is injected through the perforation in the sleeve pipe and the broken up sheathing compound into the subsoil.

After the injection, the expansion of the double packer's sealing sleeves can be reversed by reducing the pressure. The packer can be moved within the sleeve pipe so that the injection can be controlled and repeated as many times as required at every sleeve.

The layout of the injection tubes in the ground plan is adjusted to the dimensions of the injection body required. The distance between the injection lances depends on the compactness and permeability of the soil to be grouted, the type and characteristics of grout and the dimensions of the injection body. The distance is generally between 0.5 and 2.0 m.

The injection amount for the individual stages is determined based on the pore volume and the layout of the lances. The pressure that builds up during the injection process is an important indicator for the dispersion of the grout in the soil. When the required injection pressure has been reached and/or the amount of grout calculated for the cavity has been used, the next level is grouted.
The grout mixtures are usually prepared in a central mixing station. This consists of a dosing unit, mixer, storage containers with stirring units, pumps and silos or tanks and a control unit. Every pump unit has a measuring unit in the form of a pressure and flow recorder. The devices are often installed together in grouting containers, in order to be able to control the dosage, the charging of the pumps and the injection process completely automatically. Due to the large number of application areas and types of grout, a great variety of machines and equipment is used for storage, dosage, preparation and injection in practice.

**Traditional applications for grouting**

**Bulk filling**
- In mountains (karst caves, fissures, etc.)
- Mining remediation (protecting against risk of cave-ins in areas with former near-surface mining, old galleries, old shafts)

**Sealing grouting**
- Grout curtains under dams or in mountain sides at dams
- Grout curtains at locks between upstream and downstream water
- Base grouting for "water-impermeable" excavation pits to avoid lowering of the ground water level (soft gel, cement)
- Sealing during tunneling in rock
- Umbrella grouting to help drive a tunnel under compressed air in non-cohesive soil in order to reduce compressed air consumption.
- In building structures (sealing construction joints using injection tubes)
Compaction grouting

- Underpinning buildings next to excavation pits as gravity wall or anchored injection wall
- Improving foundations (foundation widening or lengthening or load transfer in lower-lying load-bearing areas when adding storeys to buildings and changing use of buildings or to limit settlement)
- Embankment stabilization
- Blanket grouting during tunnel construction to distribute high foundation unit loads through the tunnel
- Compensation grouting to lift foundations and "straighten" buildings

Grouting in combination with other procedures

- Shaft and pile base grouting using piles to increase load-bearing capacity
- Injection anchors as temporary or permanent anchors
- Subsequent grouting of anchors
- Injection piles
- Soil improvement underneath piles
- Vibratory injection piles
- Shield fissure grouting in tunnel construction during shield tunneling
- Grouting to strengthen the working face during tunnel construction
- Horizontal umbrella grouting in tunnel and gallery construction to secure tunnel driving (pipe screen cover)

Grouting in cases of damage

- Sealing leakages in underwater concrete beds
- Sealing defects in slot and bored pile walls as well as leaks in sheet pile walls