**Contents**

The method on the market ..... 3  
Process description ..................... 4  
Soil improvement ..................... 6  
Foundation rehabilitation .......... 8  
Cavity grouting .......................... 10
Development
The compaction grouting process, which was first applied in the USA during the 1950ies and further developed, mainly by engineers of Hayward Baker Inc., is gaining more and more acceptance in Europe since the beginning of the 1990ies. When Keller first applied this technique in Europe, we were able to build upon the rich experience gained by our American sister company and since then have been continuously developing this process.

Fields of application / Position on the market
While compaction grouting had originally been used only for the foundation rehabilitation of settlement sensitive structures, the field of application in the meantime has been extended. Nowadays this technique is used in various fields of application – which frequently can be combined in a single project.

• Soil improvement
  Improvement of soils with insufficient bearing capacity, respectively with an increase in relative density, e.g. as an alternative or supplement to pile foundations or stone columns.

• Stabilisation and rehabilitation of foundations
  Increase or restoration of the bearing capacity of the soil under an existing foundation, e.g. in cases of increase in load or settlement damages. This process is an alternative to Soilcrete® or mini piles and/or serves as pre-treatment when applying the Soilcrete® and Soilfrac® process.

• Cavity Grouting
  Force locking backfill of very porous soils, erosions or cavities, e.g. in backfilled areas which have not sufficiently been compacted, in karst, in case of damages caused by water pipes or below carriageway slabs.

This process constitutes a multi-purpose supplement to existing specialised ground engineering techniques and, in addition, can be combined with almost all known procedures.
The Compaction Grouting Process

When applying the compaction grouting process usually a stiff to plastic grout is injected into the soil under pressure. It expands in the soil as a relatively homogeneous mass and at the same time is forming almost ball-shaped grout bulbs. The soil surrounding the grouted area is displaced and at the same time compacted. Compared to other grouting techniques, the grout material neither penetrates into the pores of the in-situ soil (as is the case with the classical injection) nor are local cracks formed (as is the case with the Soilfrac® technique).

During the compaction grouting process pressure and grout quantity as well as possible deformations at ground surface, respectively at structures are monitored. Depending on the design requirements, the compaction grouting process will be terminated either when reaching a maximum pressure, a maximum grout volume, when achieving the desired uplift of the structure or in case of grout material flowing out on the site surface. The execution method of the compaction grouting process is laid down in the European Standard EN 12 715.

Range of Application

The compaction grouting method may be used for the improvement of non-cohesive soils, especially in cases, where soils of loose to medium density are encountered. This method is also used in fine-grained soils* in order to install elements of higher strength and bearing capacity in soils of low bearing capacity, thus improving the load bearing behaviour of the soil.

When using this technique in saturated clayey soil, a temporary increase of the pore water pressure can be observed.

* Due to the fact that fine-grained soils cannot be compacted from the soil mechanics’ point of view – by applying the same technique – strictly speaking, consolidation grouting is carried out.
1 Installation of the Grout Pipe
The grout pipe is either installed by means of a drill rig or a vibro hammer, depending on the soil and on the treatment requirements.

2 Compaction Grouting
The grout paste is prepared in the mixing plant and pressed into the soil by means of a custom-built grout pump. While gradually pulling or penetrating the grout pipes, individual intersecting grout bulbs are consecutively formed, thus creating column shaped structural elements.

3 Staged Compaction
In order to achieve a uniform compaction of the soil, the injections are at first executed in a large primary grid, and may be compacted further by means of a secondary grid.

Quality Assurance

Quality as well as suitability of the fresh grout is constantly assured by measuring its slump.

The degree of compaction can be controlled by the following parameters, depending on the requirements:

- evaluation of the automatically recorded process parameters by means of a Keller in-house software
- deformation measurements at site surface or structures
- soundings (CPT, SPT) before and after the compaction grouting process

Evaluation

M4-print out: depth, pressure and grout volume are continuously recorded and shown on a time axis. Alternatively, recordings can be drawn on a depth axis.

Diagram of a penetrometer test (pre/post)
Ground Improvement

Frequently, soil improvement is necessary to increase the bearing capacity of poor soils, in case of a structure which has been proposed to be founded on this soil. In addition to the deep vibro techniques (such as vibro compaction and vibro replacement) which have been applied by Keller for decades, the compaction grouting technique has proven to be a suitable alternative in many cases. For the execution of compaction grouting works a number of different drill rigs and vibro hammers can be used. The execution method can therefore be easily adapted to the prevailing local conditions.

In principle, the compaction grouting technique can achieve a similar degree of improvement as by the deep vibro techniques.

The compaction grouting method is particularly well suited as an alternative or supplement to deep vibro techniques in the following cases:

• confined working space
• limited working height
• vibration-free technique required (e.g. because of a highly sensitive structure in the vicinity)
• compaction at very large depths
• for intermittent strong soil layers, which cannot be penetrated by a depth vibrator, thus making its use inefficient.

Visualisation

Each working level is shown separately

A Working level / grid
B Pressure distribution
C Quantity distribution
D Injections

1 Exposed section of a compaction grout column
2 Exposed compaction area
3 Soil improvement for the construction of a new power plant in Indonesia
4 Modern software is used for simulation and visualisation
**Foundation Rehabilitation**

Subsoil and footing together form the foundation system. Detrimental external influences and long-term processes which affect the subsoil conditions, are known to lead occasionally to a reduction in the bearing capacity of a foundation. Structural modifications of existing buildings often require an increase of the bearing capacity of the foundation.

In all these cases, the compaction grouting process can be sensibly applied for target-oriented rehabilitation of existing footings, in order to stop incompatible settlements and deformations and to reverse them, if necessary, or to increase the bearing capacity of an existing foundation in a controlled manner.

The compaction grouting process also has proven to be an excellent technique for underpinnings, in case of sensitive or non-homogeneous soil conditions are encountered or if the causes of the settlements could not exhaustively be determined.

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1 **Rehabilitation of a road bridge after flood damage**
2 **Rehabilitation of the footings under a residential building**
3 **Improvement of the stability of a church**
4 **Rehabilitation of a footing underneath a historical building**
**Cavity Grouting**

With resources becoming more and more scarce and prices for land increasing, it becomes increasingly necessary to build structures in areas, which were previously considered to be unsuitable for construction due to their poor soil properties.

In former mining regions, mining tailing backfills were for example sold as cheap construction lots after a certain rest period and are frequently used for the construction of industrial and commercial buildings.

Due to the direct interaction between soil and grout material the compaction grouting process is a particularly suitable technique to avoid or compensate nasty surprises as a result of unforeseen non-homogeneities or cavities occurring during the construction phase when building on poor soils of this kind.