Dams in Europe & USSR
a geographical approach

ICOLD 1990

EUROPEAN GROUTING TECHNIQUES
FOR ROCK FOUNDATIONS

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European grouting techniques
for rock foundations

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Rock grouting is a method of treating rock in situ. After reviewing general
principles and practice, the author discusses the European approach.

The pioneers of dam construction always
looked for deep, narrow gorges in sound
rock. They considered this offered a
completely stiff, very (or even infinitely)
strong abutment and they never sus-
pected any problems could occur with
seepage through the foundation or even from the
reservoir.

After the best sites had been developed and
larger dams started to be built, questions began to
be raised as to the mechanical and hydraulic
characteristics of rock abutments.

Doubts were fostered by experience with
unsuccessful dams and even accidents, but
progress was very slow. Many decades passed
before concerns arose about the watertightness of
the abutments and reservoir area, because leakage
is more easily detected than other mechanical
flaws, and then attention turned to the potential
deformation of the rock abutments. It was only
after serious accidents had occurred that it was
realised that rock abutments did not possess the
infinite strength believed in by earlier generations
of engineers.

A desire gradually developed to improve the
mechanical and hydraulic properties of the rock
abutments of dams by artificial means, and the
technique of rock grouting began to emerge.

ROCK GROUTING BASICS

Rock grouting is a method of treating the rock in
situ. There are now many techniques available,
such as diaphragm walls, rock anchors of various
types, and drainage. But grouting is still the most
widely used method in the field of water-retaining
dams.

Grouting in civil engineering practice consists of
forcing into the ground, under appropriate
pressure, products which initially behave as a
liquid or near-liquid, but which, through complex
physical and chemical reactions, change to a solid
or pseudo-solid body after a suitable lapse of time,
thus improving the mechanical and hydraulic
properties of the surrounding rock mass.

The rock must be regarded as consisting of
blocks separated by joints or discontinuities.
Rock can also contain various sorts of voids such
as karsts (where the matrix has been dissolved by
water flowing during geological periods) or
cavities formed by entrapped pockets of gas and
vapour during volcanic eruptions.

Grouting always aims to fill voids along the
discontinuities. This reduces the overall permea-
bility of the formation, sometimes by an enor-
mous amount. As the discontinuities act as pre-
existing planes of weakness, it is arguable that
filling them will increase to some extent the
cohesion and strength of the rock mass, as well as
its stiffness. Since isolated voids are not directly
accessible for filling with grout, multiple holes are
drilled, intended to be within a short reach, and
the grout is injected at sufficient pressure to treat a
volume of rock around them.

CEMENT, THE PRIME CHOICE

Many products have been used in grouting since
the technique was developed more than a century
ago, such as bitumen, which is injected hot, so that
it hardens on cooling, chemicals such as silicates,
the stiffness of which increases as they gel, and
synthetic resins with two or more components
which polymerise in the ground and change the
viscous body into a very strong solid. But cement
is still the most widely used material in civil
engineering grouting. It hardens by hydration.

The cement is injected in the form of a slurry
mix with water, which is not a true liquid, but an
aqueous suspension. It is readily understood that
the size of the cement grains is very important for penetration of the slurry into the sometimes very fine fissures of the rock mass. Various admixtures are usually added to the main mix to control bleeding, cohesion, viscosity, final strength and setting time.

The next section will be concerned with cement grouts, although synthetic resins will probably gain ground in the near future.

PRACTICES
Practical experience and an empirical approach preceded any research into the theory of grouting. Satisfactory and sometimes excellent results were often achieved on the basis of explanations and interpretations that were not always logical, and sometimes even quite wrong.

This is an important aspect of rock grouting, since the rock is not directly accessible for inspection and the effects of grouting are not always directly visible. It must also be recognized that any laboratory simulation is extremely difficult, if not impossible, to devise successfully. Grouting effects can only be observed in ways that are sometimes hard to interpret. In addition, the treatment must remain effective for many years (comparable with the expected lifespan of the dam) so that the true effects can only really be judged by the next generation of engineers.

So it is hardly surprising that various "explanations" have been offered for the same event observed at one or more construction sites. It is inevitable that different schools of thought have emerged and offered sometimes contradictory prescriptions for the same objectives. So European grouting philosophy is radically different from its transatlantic counterpart, and there may be many reasons. The preponderance of concrete dams applying much higher stresses to their foundations than embankment dams, which are much more accommodating in many respects, the particular morphology and geology of the Alps and other mountain chains, the natural desire of older nations for durability, and, experience of failure have all meant that the countries of Europe, especially in mountainous areas, have developed a special technique which will be described next.

EUROPEAN TECHNIQUE
Grouting inherently requires pressure to be exerted inside the voids and discontinuities to be filled. Any pressure inside a void will inevitably tend to cause it to expand. Thus, in these circumstances, grouting will tend to open discontinuities, forcing the walls apart. But if the void is then completely filled with a properly designed product, there is no reason to consider expansion to be harmful. All other things being equal, high pressure increases the extent of the zone accessible to grouting treatment.

The need to fill all voids completely is of no concern during the grouting process, since this is inevitable with a liquid. The problem arises later, once the slurry has set and solidified. This dictates, or at least should encourage, the use of what are known as "stable" grout mixes, in which the cement grains will not settle out, and there is minimal risk of water in excess of the strict hydration requirement, bleeding out, so that there will be no water-filled pockets on completion.

Because of their higher viscosity and cohesion, dense, stable grouts require higher grouting pressures to penetrate the same distance from the borehole. Such mixes reduce the risk of elastic instability leading to pressure-induced splitting of the rock, known as hydraulic fracturing.

In summary therefore, the European grouting technique consists chiefly of the application of high to very high pressures in conjunction with stable grouts which develop high strength when they harden and also offer very high resistance to leaching over the years.

The excellent results reported from numerous dam construction sites are confirmation of the validity of this approach. Yet it is not impossible, and even quite likely, that further progress could be made possible, which will extend its applications to other seepage and consolidation problems.