Some Aspects of Grouting Dam Foundations with Cement and Importance of Geological Appraisal on Grouting Operations

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Foundations of dams can be rock or soil, as the sites dictate. This talk confines itself to only rock foundations of dams, and only grouting with cement. We resort to grouting the foundations of a dam generally for two purposes – One, for consolidating the rock immediately under the dam to some metres below the foundation grade; two, to install a grouted impervious curtain to a depth depending on the foundation geology and the depth of water behind the dam. Whether it is consolidation grouting or whether it is curtain grouting, geological appraisal and close and continuous co-ordinated effort between the engineer in-charge and the geologist at site is absolutely essential, for the grouting effort to be dependable.

In my experience and in my opinion, consolidation grouting of the rock under the dam is not optional, but essential, as despite all requirements in the specifications about careful controlled excavation procedures as we get close to the foundation grade, the requirements of the specifications almost always get overlooked, leaving the engineer uncomfortable, if consolidation grouting gets omitted altogether.

There is a practice prevalent, to do consolidation grouting only for part of a dam foundation (generally upstream part) deriving from the idea that this consolidation grouting is part of the subsequent curtain grouting. For a high dam particularly, and generally for all dams, consolidation grouting is required all over the foundation area and specially in the downstream part, where the stresses from the dam are highest. There is a view, justifiable under certain circumstances, that the drainage of the rock mass in the downstream part should not be interfered with; in such special conditions, the solution can be installation of drainage holes, draining into a downstream gallery in a masonry dam, or into a drainage tunnel in the rock below a fill dam; in the latter case, far away from the curtain. In any case, under a masonry dam, drainage holes are invariably provided behind the grout curtain.

In consolidation grouting, there is necessity to be cautious about the pressures to use. Too low a pressure will be ineffective and too high a pressure may cause hydraulic fracturing. For this purpose, it is advisable, even necessary, to load the foundation with a few-meter high construction (of the dam), prior to consolidation grouting. In the case of curtain grouting, since this is done practically after the entire structure has come up, there should be no fear of hydraulic fracturing, with the use of high enough pressures as needed.

There is then the question of consistency of the grout to be used. The usual practice, in our country, has been to start with a very thin grout (5:1 or even thinner) and progressively thicken the grout, depending upon the grout intake. There is need for reviewing this practice, in respect of the consistency of the grout. The thin grout can travel a grater distance, in any given situation than a thick grout; but, with a thin grout, in a very short distance, decantation takes place; cement in suspension separates out and settles, giving an impression of apparent grout refusal. A thick grout, on the other hand, has cohesion and therefore has much less tendency to bleed or cause premature sedimentation; it also has greater stability during the grouting process. In the post-grouting period, it has superior bond with the rock faces and less tendency to shrink. The thick grout is also superior in respect of permeability. Hence, many grouting engineers abroad prefer grouting, from beginning to end, with a grout mix of water – cement ratio, by weight, of 0.70 to 0.80. It is likely that a thick grout may need to have its flow improved. This can be done with the use of a super-piasticizer, some 0.25 to 0.50 percent, by weight, of the cement. Many grouting engineers abroad seem to prefer, in the case of curtain grouting, one single pre-determined thick grout (based on test grouting) and alter only the grouting pressure to control the grout intake. The limit for determining the refusal stage is generally of the order of 40 kg/m of the hole in the stage; likewise, the upper limit for the pressure is also fixed in the beginning itself. In certain grouting, high pressures can be used, as there is no apprehension about hydraulic fracturing. This, in essence, is the basis for grouting procedures, using the 'GIN' principle. (GIN is the grouting index number). For detail on GIN, I would refer you to the paper Grouting design and control using the GIN principle, Lombardi and Deere, Water Power and Dam construction, June, 1993.

Geology determines grouting procedures and success. Let us consider some live examples.

1. In a very competent and tight rock formation, like the one on which most of the 120-m + high Nagarjunasagar dam sits, except in the case of a very narrow shear zone in the deepest part, one should consider whether a conventional deep grouted curtain is necessary. No doubt, in the top most 10 m – 15 m portion where consolidation grouting is necessary, an effective grouted curtain is also called for. Below this depth, we could install piezometers at locations and depths as advised from the geology and if, and only if, excessive pressures are indicated by the piezometers, localized grouted curtain can be installed, after the reservoir has built up. The competency of the rock is such that this procedure should be perfectly acceptable. If we now analyze data from the curtain grouting actually carried out in Nagarjunasagar, it is quite likely that this view and approach will be seen as fully justified.

2. We have a different situation in formations like the blocky quartzite's under a 100 m high concrete gravity dam in the south of the country. For various reasons, the curtain grouting effort got postponed till after the reservoir fully built up. The Result: It became very difficult, almost impossible, to grout effectively, as the flow through the rock joints, under reservoir pressure, just carried most of the grout down the river. The grout curtain here is not effective.

3. In another case , in the case of a 150 m + high rock fill dam, in the north of the country, on a formation of alternating bands of shale and sandstone with near vertical dip, for reasons, which are not quite clear, curtain grouting as carried out consisted of a single row of holes, holes 13 (thirteen) m apart. This is certainly not adequate and it shows up. Piezometers in the downstream part of the dam foundation show the same pressure as the reservoir, closely following the reservoir level fluctuations. Also, behind this 'curtain' , drainage holes have been drilled from the grouting gallery; there is copious flow into the gallery through the drainage holes; the pressure, as measured, in some of the drainage holes, is of the order of 7 – 8 bars. In the opinion of many engineers, the drilling of the drainage holes (remember the dam is a fill dam) was undesirable, as it shortens the flow length for the leakage and consequently increases the exit gradient.

The Exit gradient

In the case of the last two dams, remedial measures will be unconventional, unless the reservoirs can be lowered for grouting, which is just unthinkable, with the reservoir high and high flows through the joints, large diameter holes (75 mm -125 mm) at close intervals may be necessary to enable sending down large size material (like 75 mm aggregate), followed successively by smaller size material, till a blockage has been affected and grouting with sanded cement, may become effective. Similar procedures have been reported as successful, in the case of a foundation of a 225 mt high arch dam (limestone formation) in Honduras; here, they sent down, first 70 mm diameter wooden balls, followed successively by smaller and smaller sized material, prior to grouting.

One Other case

A 100 m high concrete gravity dam in Himalayan terrain sits on highly-jointed formation, phyllitic quartzites and quartzitic phyllites. Initial water-loss tests showed marginally groutable conditions. Consolidation grouting, 10 m – 15 m depth, was necessary for the full block width. (The blasting for excavation was nowhere near ideal and there was considerable time lapse between completion of excavation and placement of concrete). Initial grouting effort, apparently, had been with a single hole drilled (not several holes in a pattern, to enable washing of holes and establishing inter-connection). The grout was seen to have traveled just down the hole to the bottom and shown itself some 100 m away in an adjacent lower-down excavation. Core holes drilled in the vicinity of the grouted hole, close to it, did not show any trace of grout in the joints in the core. Grouting operation, much later for consolidation grouting, with holes drilled in a pattern and washed prior to grouting, still showed that grout traveled with ease down the hole and did not travel laterally. In this situation, with a considerable depth of concrete of the dam already in place, the indications were that the bottom of the hole, in each stage, should be sealed first (with some 50 cm sanded grout allowed to harden for a day or two) prior to grouting the stage; and a sufficiently thick grout should be used, with a high pressure (no fear of any hydraulic fracturing). This was advised. This advice will apply equally in the case of curtain grouting, here.

The examples and the discussions preceding them show the great necessity for informed and experienced grouting engineers, with very close and continuous input from experienced geologists. There is thus a case for such expertise to be built up, in the engineering and geology disciplines. This build-up of expertise will be greatly facilitated if, from time to time, there are seminars or workshops organized, with experts, including from abroad, participating.