THE MPSP SYSTEM:

A NEW METHOD OF GROUTING

DIFFICULT ROCK FORMATIONS

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Presented at

1988 ASCE Conference

May, 1988

Nashville, TN

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THE MPSP SYSTEM: A NEW METHOD OF GROUTING DIFFICULT ROCK FORMATIONS

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In unstable rock masses the traditional stage grouting methods may prove impractical or ineffective. A recent innovation has been the Multiple Packer Sleeved Pipe (MPSP) System. Akin to the well known sleeved pipe (Tube`a Manchette) System for grouting soils, this new method has had remarkable success in a number of major dam foundations. The paper describes the principles of the system, and illustrates the application and potential with respect to three major case histories.

1. INTRODUCTION

The fissure grouting of rock masses is typically conducted by some type of stage grouting procedure (Figure 1). In "downstage grouting," grout holes are advanced by drilling a certain length, usually 3-5m, grouting it, and then repeating the process after the grout has set, until final depth is reached. The packer may be kept at the top of the hole, or moved successively downwards to the top of each new stage in turn. In "upstage grouting," the hole is drilled to full depth in one pass and injected progressively in successive stages from the bottom upwards through a down-the-hole packer. Houlsby (1982) also describes "circuit grouting, downstage," which is not dissimilar to downstage without packer. This system has proponents in the U.S.A. (e.g., Burwell, 1958) although Ewart (1985) views the method's effectiveness "with some skepticism," being concerned about hydraulic fracturing "somewhere in the upper stages." Houlsby (1987) also describes it as "difficult, prone to blockages and very expensive." The major advantages and disadvantages of the two basic approaches--upstage and downstage--are summarized in Table 1. Their technical or financial balance on any particular site should logically dictate the final choice of method, but it would seem that tradition and bias often prove at least as decisive.

There are often conditions in which neither stage grouting method can be relied upon to provide an effective and reliable treatment. For example, in downstage schemes, the presence of very fissured, granular or fragmented rock (e.g., "sugary limestone") may result in caving of the stage after drilling, and before grouting can be executed. Thus in the worst case only the uppermost part of that stage will be treated, and the lower section will remain ungrouted, and most probably cause similar problems during later redrilling operations. Likewise, the presence of such strata, voids and/or soft infill zones, such as are found in karstic terrains, will prevent upstage grouting being practical: packers will be very difficult to "seat" efficiently, and may permit grout to bypass upwards, leading to ineffective treatment or trapped packers.

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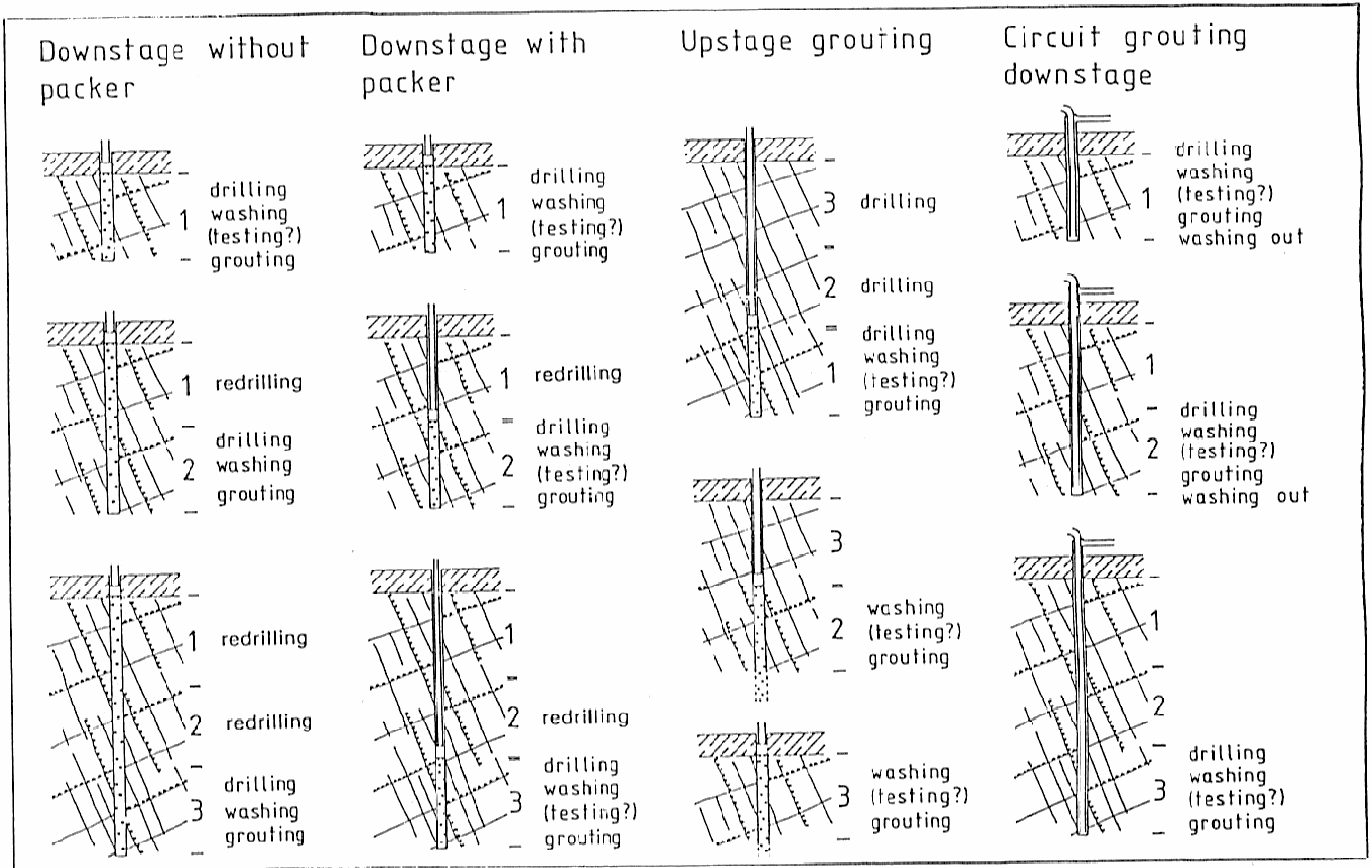


Figure 1. Conventional stage grouting methods for rock fissure grouting (Ewart, 1985 after Houlsby, 1982)

	DOWNSTAGE	UPSTAGE
ADVANTAGES	1. Ground is consolidated from top down, aiding hole stability, packer seating and allowing successively higher pressures to be used with depth without fear of surface leakage. 2. Depth of hole need not be predetermined: grout take analyses may dictate changes from foreseen, and shortening or lengthening of hole can be easily accommodated. 3. Stage length can be adapted to conditions as encountered to allow "special" treatment.	1. Drilling in one pass. 2. Grouting in one repetitive operation without significant delays. 3. Less wasteful of materials. 4. Permits materials to be varied readily. 5. Easier to control and program. 6. Stage length can be varied to treat "special" zones. 7. Often cheaper since net drilling output rate is higher.
DISADVANTAGES	1. Requires repeated moving of drilling rig and redrilling of set grout: therefore process is discontinuous and may be more time consuming. 2. Relatively wasteful of materials and so generally restricted to cement-based grouts. 3. May lead to significant hole deviation. 4. Collapsing strata will prevent effective grouting of whole stage, unless circuit grouting method can be deployed. 5. Weathered and/or highly variable strata problemmatical. 6. Packer may be difficult to seat in such conditions.	1. Grouted depth predetermined. 2. Hole may collapse before packer introduced or after grouting starts leading to stuck packers, and incomplete treatment. 3. Grout may escape upwards into (non-grouted) upper layers or the overlying dam, either by hydrofracture or bypassing packer. Smaller fissures may not then be treated efficiently at depth. 4. Artesian conditions may pose problems. 5. Weathered and/or highly variable strata problemmatical.

TABLE 1

MAJOR ADVANTAGES AND DISADVANTAGES OF DOWNSTAGE AND UPSTAGE GROUTING OF ROCK MASSES

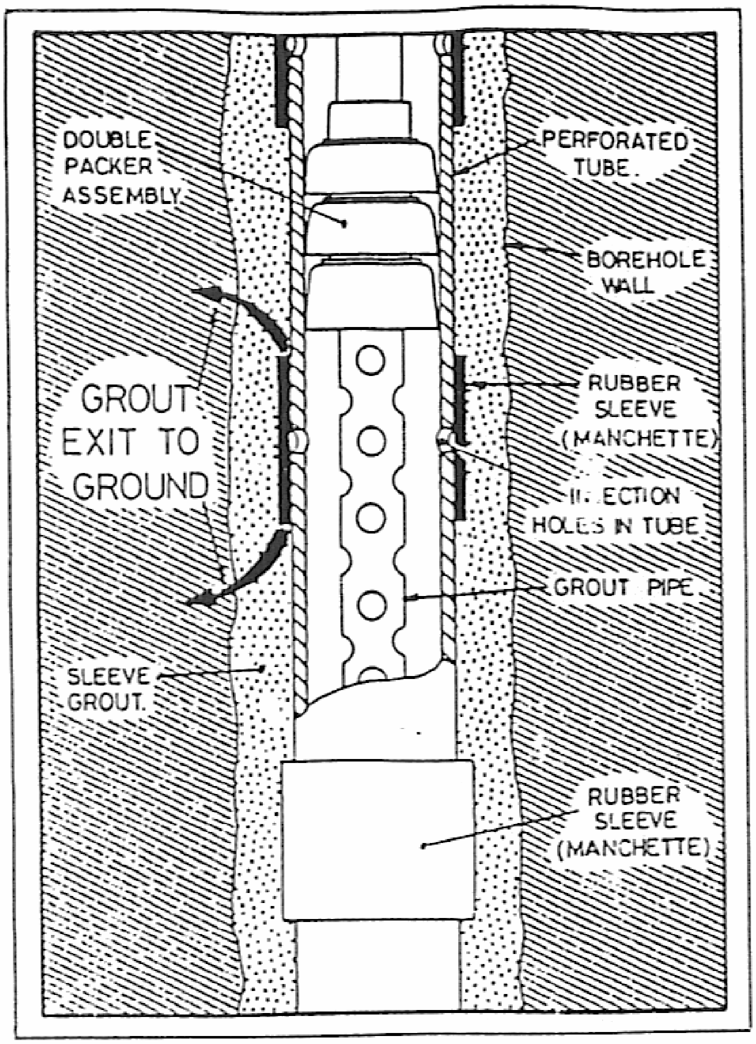


Figure 2. Operating principle of tube`a manchette (sleeved pipe) system.

Such geological conditions reflect more typically the problems associated with soil grouting, for which the standard "high tech" approach is the tube`a manchette (sleeved pipe), shown in Figure 2. A fundamental feature of the tube`a manchette operation is the necessity to rupture the "sleeve" grout, thus permitting egress of grout into the surrounding soil. However, in all but the softest rocks, the lateral restraint afforded by a rock mass is sufficient to prevent the sleeves opening (to allow the flow of grout into surrounding fissures). In addition, the nature of the system--involving the use of a stable cement-bentonite sleeve grout--essentially plugs off, for a short but critical distance, those fissures which are intersected by the borehole, thus further circumscribing the possible effectiveness of the system. In this regard, the finely fissured soft shales very successfully treated at Grimwith Dam, Yorkshire (Bruce, 1982) could well be regarded as an upper limit for rock mass quality in terms of effective tube`a manchette grouting.

In recent years, this dilemma of guaranteeing high quality treatment of ground which cannot be injected by traditional rock or soil grouting methods has been faced by Ing. Giovanni RODIO and Co., on a number of dam sites in Europe and Asia. The technique which has been developed--the Multiple Packer Sleeved Pipe (MPSP) System--clearly responds to the requirements of seepage control, and indeed the major applications reviewed below cite experience only in grout curtains. However, grouting of difficult rock masses is required on occasions to improve strength parameters. The MPSP System is equally valid for these applications also and so may be regarded as a technique of wider application than only a method of curtain grouting. .

2. THE MULTIPLE PACKER SLEEVED PIPE SYSTEM (MPSP)

MPSP owes much to the principle of the tube`a manchette system in that grouting of the surrounding rock is effected through the ports of a plastic or steel grout tube placed in a predrilled hole. However, unlike tube`a manchette, and in order to avoid the premature plugging of intersected fissures, no sleeve grout is used. Instead, the grouting tube is retained and centralized in each borehole by collars--fabric bags inflated insitu with cement grout. These collars are positioned along the length of each grout pipe either at regular intervals (say 3 to 6m) to isolate standard "stages," or may be placed at intermediate or closer centers to ensure intensive treatment of special or particular zones. As is described below, the MPSP System permits the use of all grout types, depending on the characteristics of the rock mass and the target and purpose of the ground treatment.

The typical construction sequence is as follows (Figure 3):

Step 1 - The borehole is drilled by fastest available method (usually rotary percussive) with water flush to full depth. Temporary casing may be necessary to full depth also, as dictated by the instability of the rock mass. Typically borehole diameters are about 100mm.

Step 2 - The MPSP is installed. The standard type consists of a steel pipe, 50mm o.d. with each length being screwed and socketted. Each 5m length has three 80mm long, 4mm thick rubber sleeves: 1, 2.75, and 4.5m from the bottom and protecting groups of 4mm diameter holes drilled in the pipe. A concentric polypropylene fabric bag is sealed by clips above and below the uppermost sleeve in each length and is 400 to 600mm long. For short holes, plastic pipes of 38 to 50mm diameter are used. The temporary drill casing is then extracted, and simultaneously the bags are inflated in turn (i.e., Step 3 below). Any collapsing material simply falls against the outside wall of the MPSP tube.

Step 3 - Starting from the lowermost pipe length, each fabric bag is inflated via a double packer positioned at the sleeved port covered by the bag (Figure 4). A neat cement grout of water content ratio, w = 0.5 (by weight) is used at excess pressures of up to 2 bar, to ensure intimate contact with the borehole wall. The material of the bag permits seepage of water out of the grout, thus promoting high early strength and no possibility of shrinkage (Unconfined Compressive Strength =100 bar at 24 hours, residual w = 0.28). In order to accommodate irregularities in the borehole wall--either natural or resulting from the drilling operation--each bag can inflate to 125mm o.d., if required to do so. Clearly the choice of the bag material is crucial to the efficient operation of the system: the fabric must have strength, a certain elasticity, and a carefully prescribed permeability.

Step 4 - Water testing may be conducted if required, through either of the two "free" sleeves per length, again through a double packer. Tests show that a properly seated fabric collar will permit effective "stage" water testing at up to 4 bar excess pressure.

Step 5 - Grouting is executed in standard tube`a manchette fashion, from bottom up via the double packer (usually of the inflatable type). The grouting parameters are chosen to respect target volumes (to prevent potentially wasteful long distance travel of the grout) and/or target pressures (to prevent potentially dangerous structural unheavals).

The following additional points are especially noteworthy regarding the MPSP System. Firstly, it is clear that once a hole has been grouted once, it generally cannot be regrouted: some of the pressure grout will remain in the annulus outside the tube and so form a strong "sleeve grout" preventing the opening of sleeves in contact,

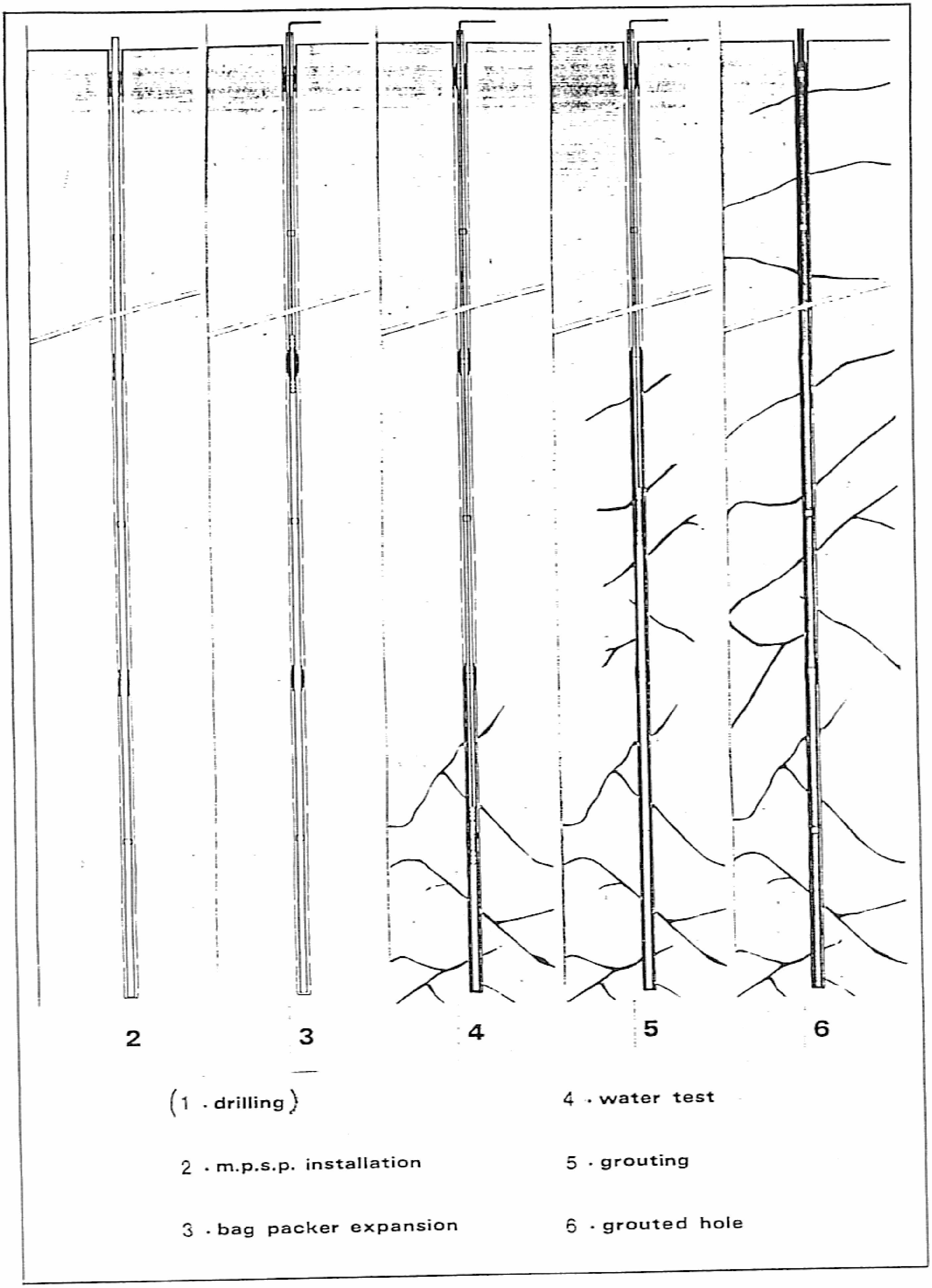


Figure 3. Installation sequence for MPSP.

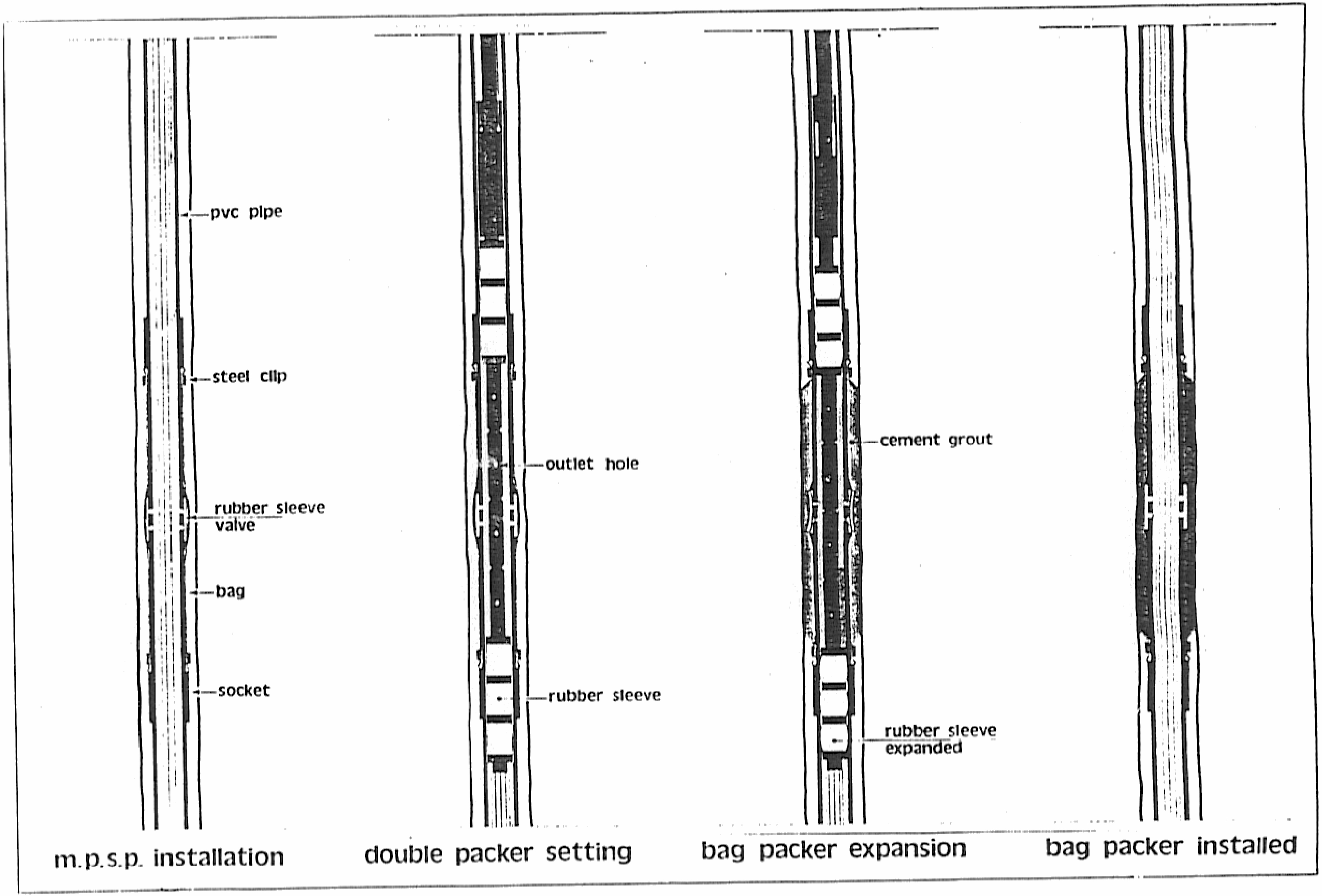
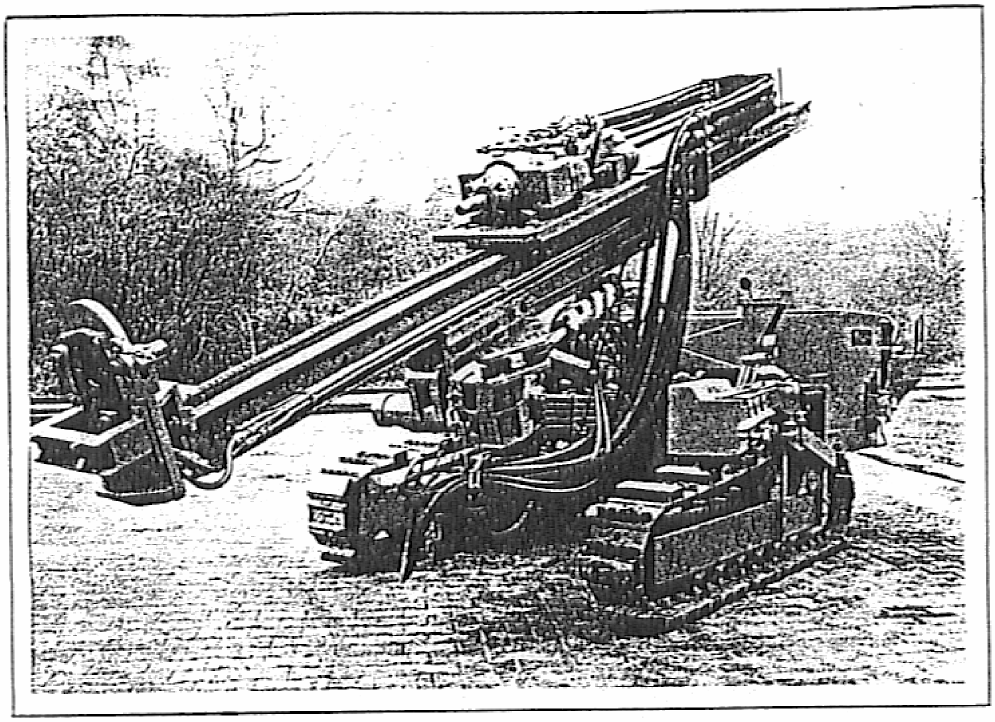


Figure 4. MPSP : detail of inflatable fabric grout bag.

unless a very weak mix was used. (The system does, however, allow different stages in the same hole to be treated at different times.) Thus, the MPSP System adopts the principles of stage grouting, where "split spacing" methods are used: the intermediate Secondary holes both demonstrate the effectiveness of the Primaries and intensify the treatment by intersecting incompletely grouted zones. Analyses of water test records, grout injection parameters, "reduction ratios" and so on will dictate the need for further intermediate grouting phases.

Secondly, in addition to the technical advantages of the system, there are significant logistical and work scheduling attractions. For example, the drilling and installation work can proceed regularly at well known rates of production, without requiring an integrated effort from the grouting crews (as in downstage grouting). In addition, the "secure" nature of the grout tube prevents the possibility of stuck packers, which is an unpleasant but unavoidable fact of life in upstage grouting in boreholes in most rock types. Grouting progress is therefore also more predictable and smoother, to the operational, technical and financial advantage of all parties concerned. With respect to output, the use of powerful hydraulically powered rotary percussive drill rigs (Photograph 1) will allow over 100 m of MPSP to be installed per shift. Grouting productions up to 500 liters per hour per pump can be anticipated, depending always on the rock mass characteristics, the type of grout, and the quality of the equipment and operators.



Photograph 1. Typical diesel hydraulic track rig.

A third point relates to the straightness of the borehole and thus the integrity and continuity of the ground treatment. The temporary drill casings used in the hole drilling operations (Step 1) are typically thickwalled and robust. They, therefore promote hole straightness whereas the uncased boreholes common in stage grouting in rock, and drilled by relatively flexible small diameter rods, are known to deviate substantially, especially in cases where fissures and/or softish zones in the rock mass are unfavorably located or oriented. By way of illustration, at Metramo Dam, Italy (described below), the maximum deviation recorded in a test block of 150 holes each 120 m long was 1.5% with the great majority being less than 1%.

3. CASE HISTORIES

The earliest field studies were carried out at Oymapinar Dam, on the Manavgat River, Turkey, in 1982, and were in response to problems incurred in trying to grout unstable limestone formations. The quantities of MPSP actually installed (several hundred meters) were insignificant per se, given the mature stage of the contract at the time of the system development. Illustrative details of works executed are, therefore, limited to three major dam projects in which RODIO was involved either alone, or in Joint Venture: Tarbela Dam, Pakistan; Metramo Dam, Italy; and a large dam being built in Asia which cannot be named for political reasons, and which is referred to as Dam C.

3.1 Tarbela Dam (River Indus, Pakistan) - Many authors have described different aspects of the long program of development and remedial works undertaken at this site (e.g., Lowe et al., 1979; Lowe and Sandford, 1982; Bruce and Joyce, 1983). It will be recalled that most of the effort was concentrated on spillway and tunnel protection by various means, including rock anchorages and roller compacted concrete.

In early 1983, however, an intensive chemical grouting program was carried out in the Right Abutment of the Main Embankment Dam (Figure 5). The purpose was to verify a practical method to reduce seepage mainly through the notorious "sugary limestone" present between Right Grouting Adit 4 (RGA-4) and Tunnel 1 (Figure 6), a zone otherwise comprising fissured limestone with phyllitic and carbonaceous schist interbeds. Two test panels were selected, as shown in Figures 6 and 7. Four different grout mixes were considered (based on hydrocycloned bentonite, cement-bentonite, sodium silicate, and resin, respectively) while all but six of the holes were equipped with plastic MPSP pipes. The other six holes (Panel 2, downstream row) were formed by the downstage method and cement-bentonite injection, as a comparison only. Frequent major caveins of holes attempted in this way had already confirmed the unsuitability of that method in these ground conditions.

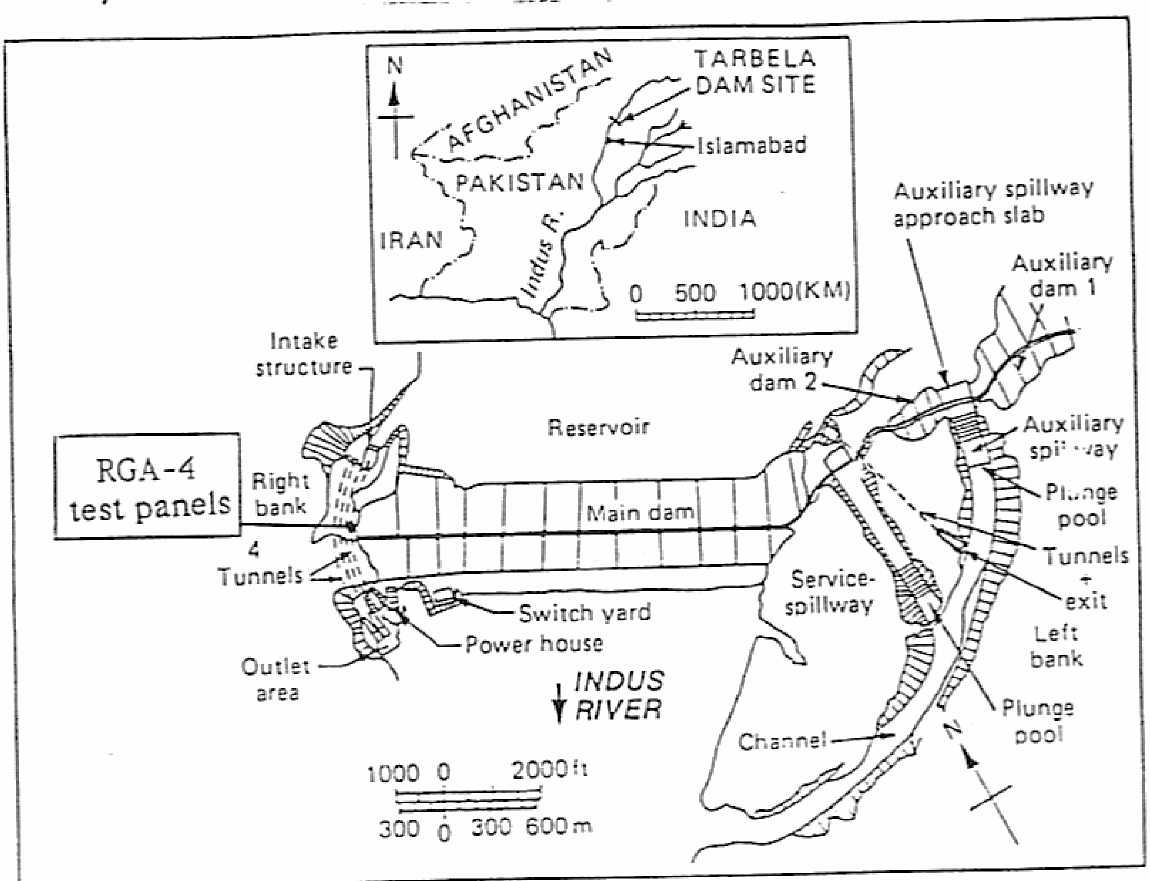


Figure 5. General layout, Tarbela Dam, Pakistan.

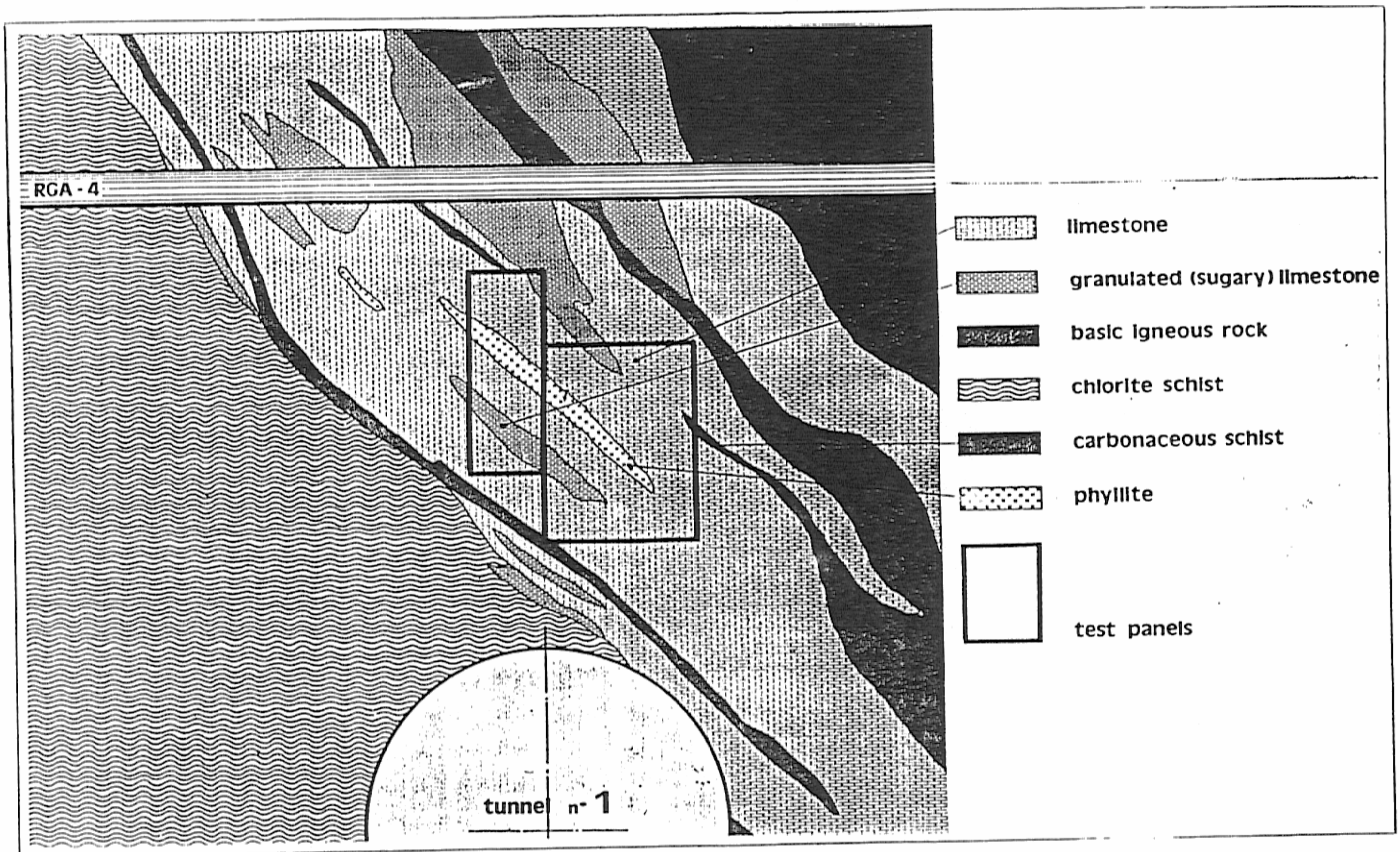


Figure 6. Location of test panels and details of geology. MPSP Trial, Tarbela Dam, Pakistan.

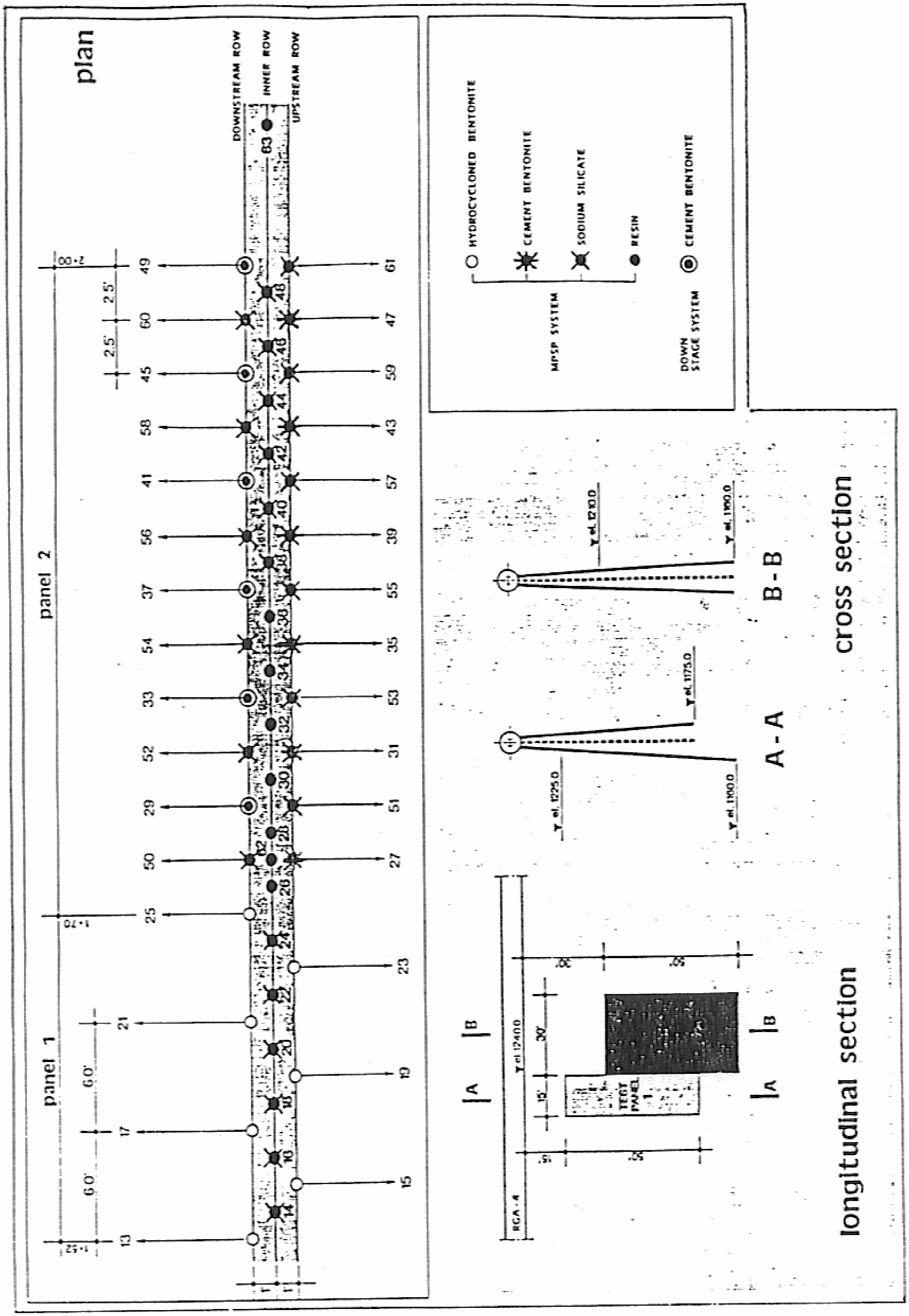


Figure 7. Details of grout hole arrangement. MPSP Trial, Tarbela Dam, Pakistan.

The grouting station featured mixing plants located above the entrance to RGA-4, and pumping stations set up near the grout holes in the Adit. The mixing plant incorporated electronic volumetric batching, while the injection plant provided electronic pressure, volume and flow rate monitoring in real time, and hard copy records for later use.

The treatment was undertaken in strict sequence. The injection of the outer rows with hydrocycloned bentonite and sodium silicate mixes (Panels 1 and 2, respectively) was followed by sodium silicate and resin grouting in the middle row. Analysis of the grouting records indicated generally low takes of cement-based grouts, inconsistent with the high permeabilities, but consistent with the microfissured nature of the rock mass. Equally, the analyses indicated that these outer rows had limited the travel of the (expensive) chemical grouts of the center row. Of special interest was the very low takes in the six downstage holes (25 out of 34 stages, each typically 5m long, consumed less than 15 liters of grout) compared with adjacent holes in the same row injected via MPSP (19 out of 41 stages less than 15 liters, but many stages readily accepting full target volume).

As a final demonstration of the effectiveness of the grouting program, Figure 8 shows the Lugeon values obtained in water test holes drilled before and after grouting. In addition, hole stability was markedly improved and outflow of artesian water was greatly decreased in those test holes drilled after grouting.

3.2 Metramo Dam (River Metramo, Italy) - This 600m long earth and rock fill dam, almost 100m high (Figure 9) is currently under construction in western Calabria. Given the high resource value of the water to be impounded in this arid area, a deep multi-row grout curtain was designed with an average maximum target permeability of 10^{-5} cm/sec (about 1 Lugeon) compared to the virgin permeability of about 10^{-4} cm/sec.

The site is on the outcrop of the crystalline "Le Serre" formations, consisting of a number of largely grandioritic lithologies. They feature numerous major pegmatite veins and the whole mass is severely fissured and fractured in response to tectonic and cooling stresses. In addition, the bedrock is very deeply and heavily weathered by geothermal percolations. There are also substantial thicknesses of alluvial and colluvial materials increasing away from the river bed to over 50m. The site is in an active earthquake region, and the dam design allows for a maximum seismic acceleration of 0.33g.

Both blanket (consolidation) and curtain grouting are required. The former features holes at 0.5m centers, to 10 to 15m below the core trench. The curtain itself has three rows, the outer two being 50m (downstream) and over 100m deep (upstream) while the middle averages 25m. The curtain extends laterally for about 70m on the Left Bank and 120m on the Right Bank. Under the dam, 20-30m below the core trench, a system of galleries and shafts has been constructed, within the grouted zone. They will permit monitoring of the performance of the structure in service and allow additional regrouting, if deemed necessary.

An extensive phase of water testing and grouting involving 57 test holes was conducted in the early 1980's. This confirmed firstly that the ground would not permit efficient treatment by conventional stage grouting, due to its inherent instability and variability, and secondly that the following standard cement based mix would be suitable:

Clay	60kg
Bentonite	5kg
Cement	35kg
Water	220kg

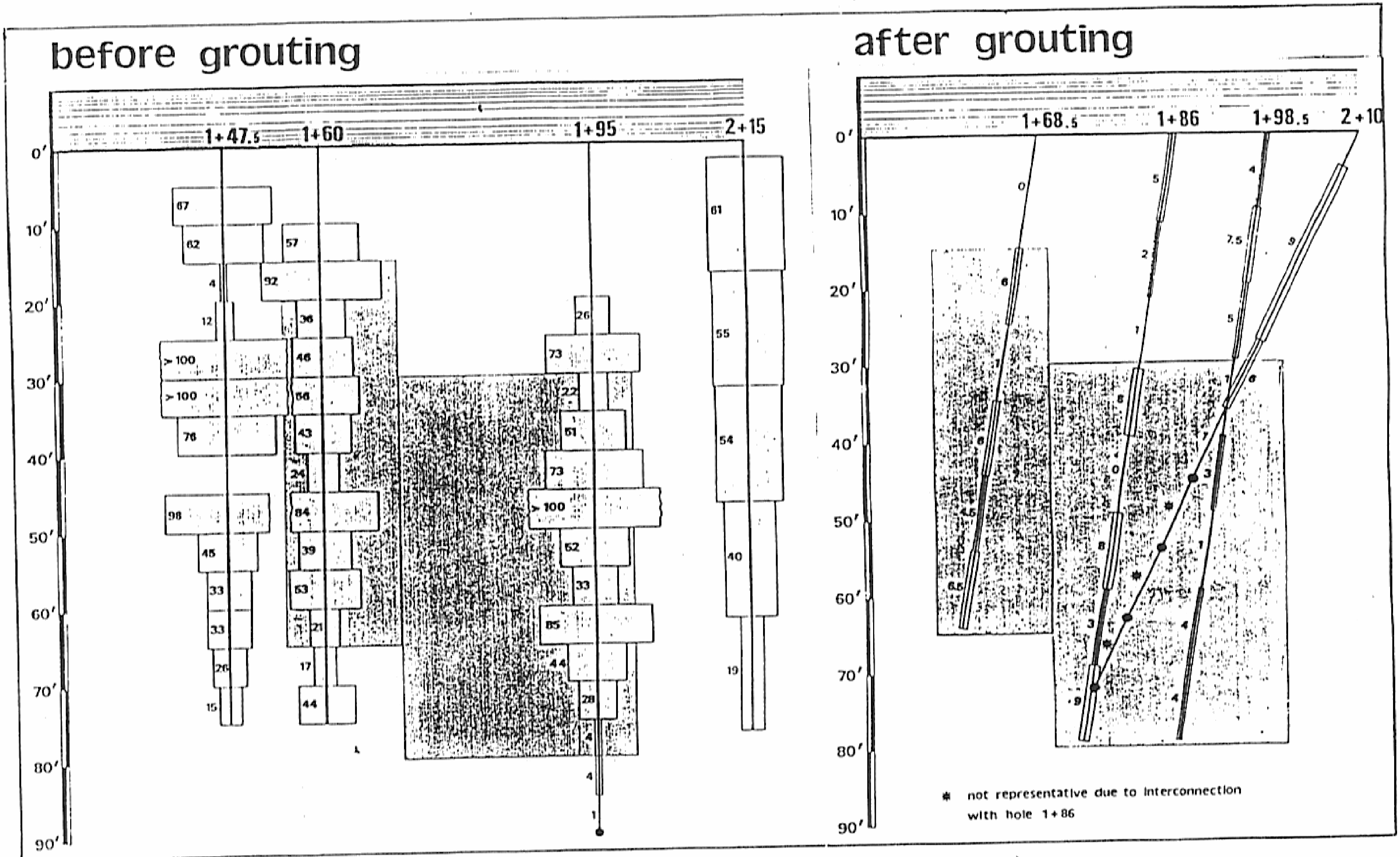


Figure 8. Comparison of water test results (in Lugeon units) before and after treatment. MPSP Trial, Tarbela Dam, Pakistan.

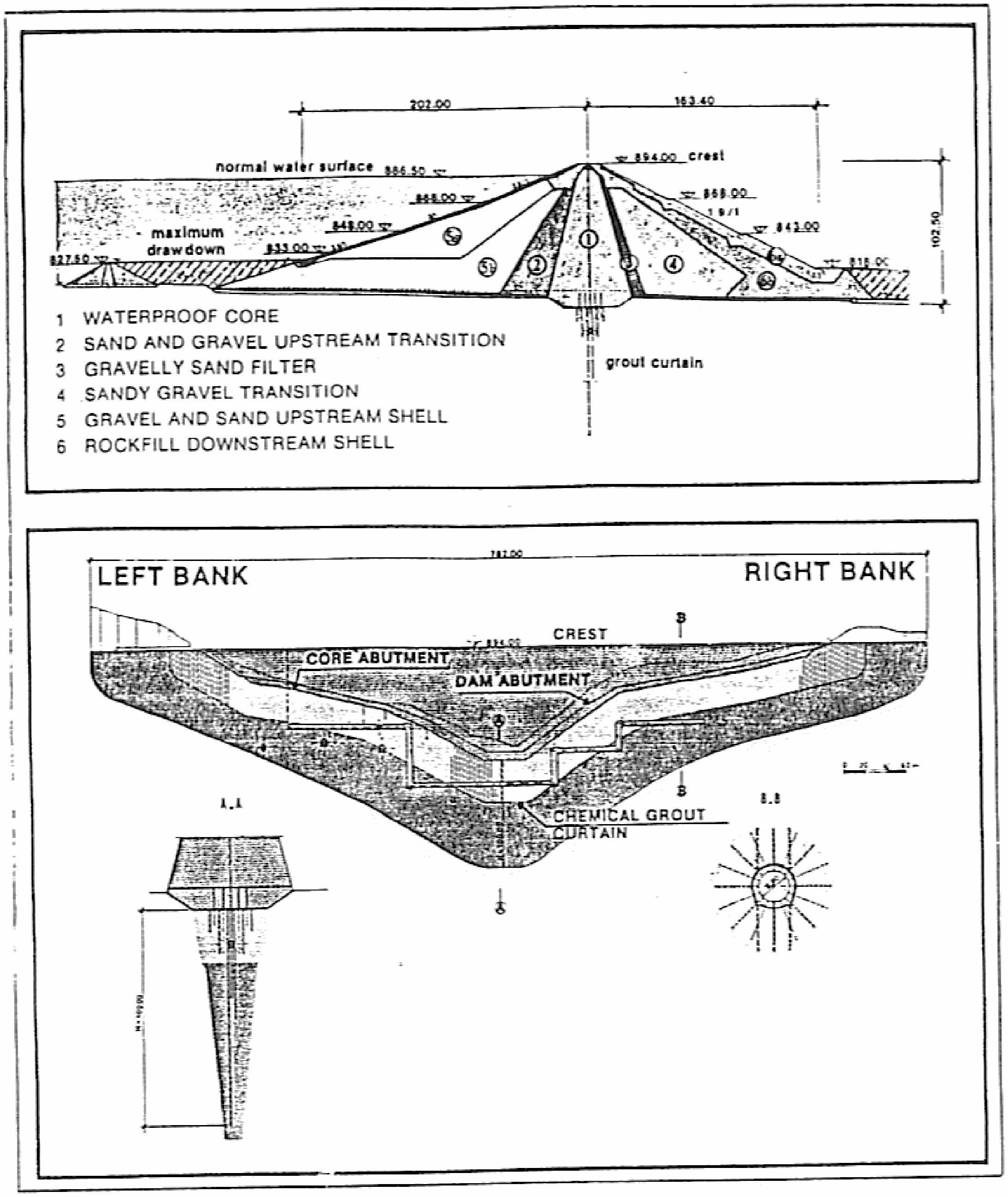


Figure 9. General arrangement, Metramo Dam, Italy.

This is stable, with a 45 second Marsh cone reading.

The MPSP System was proposed and accepted, and to date over 80,000m of grout holes have been installed and injected in this way. 105mm diameter holes are drilled and cased by diesel hydraulic rotary percussive duplex methods, with water flush. Steel pipes 50/44mm diameter have bags at 5m centers, while the interhole spacing in the curtain ranges from 1.5 to 3.0m. For the chemical grouting, a long chain compound diacid ester reagent is used to react with the sodium silicate solution, to enhance the long-term performance of the gel in place. Typically, cement grout injection rates vary from 150 to 450 liters/hour, while those for the chemical grout are somewhat higher, depending always on grout take characteristics. Maximum injection flow pressures range up to 15 bar. Average cement takes of around 300kg of mix on the Right Abutment are about three times those on the Left.

3.3 Dam C, Asia - The bedrock formations of marls, chalky limestone, and gypsum were found to render impracticable the upstage grouting system originally specified. Similar technical problems seriously compromised the efficiency of a downstage treatment while the very restrictive programming requirements further prevented its general usage. The MPSP System was, therefore, proposed and adopted.

Under the 3600m long, 100m high Main Dam, and in the Right Bank extension, the system was adapted in places to provide both a conventional sleeved pipe approach for up to 40m of very weathered rock (almost a loose, granular soil) lying above the fresher but mechanically unstable sediments (Figure 10).

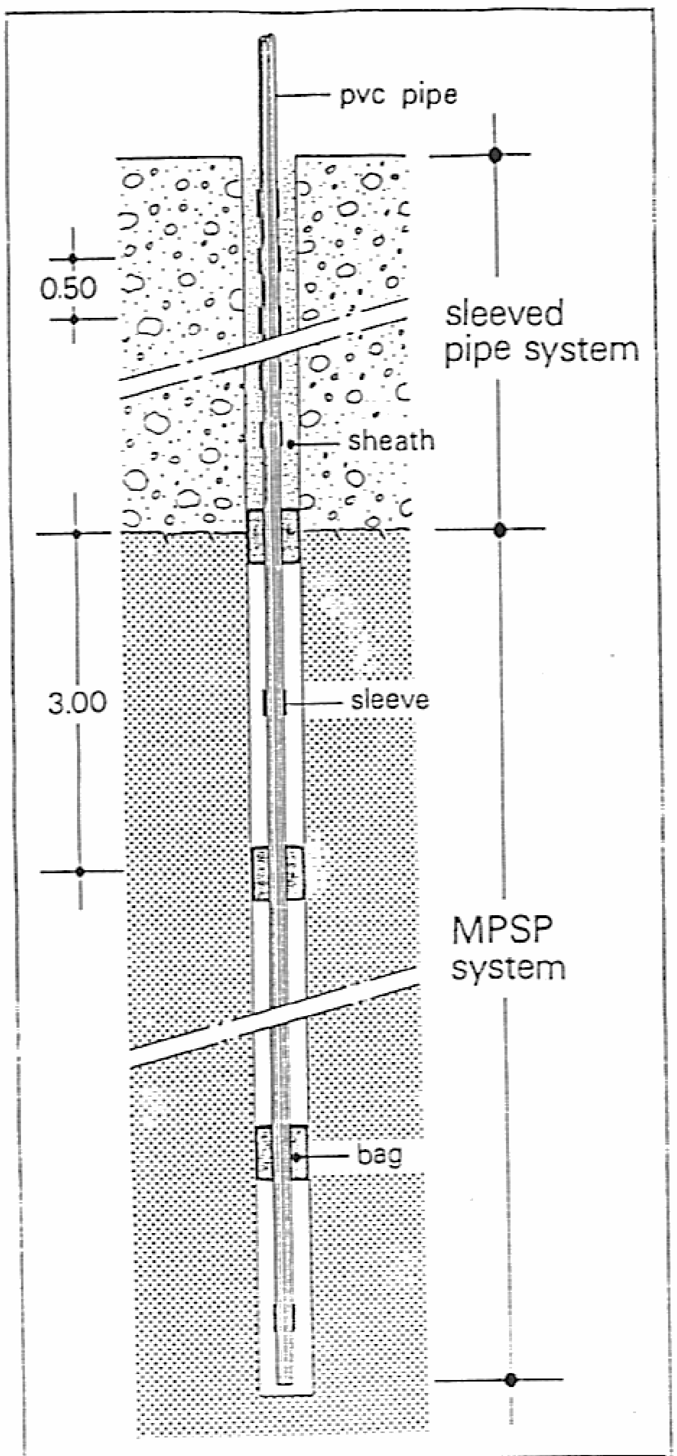


Figure 10. Combined use of tube`a manchette and MPSP for treatment of different ground conditions. Dam C, Asia.

Primary holes were located at 12m centers, but final interhole spacings were reduced to as low as 1.5m by Quaternaries in places where postgrouting water tests indicated residual permeabilities above the target: 2 Lugeons from 0 to 30m, 5 Lugeons below. Holes varied from 80 to 150m deep and were drilled (and cased where necessary) by rotary methods plus water flush to 105mm diameter. A total of 60,000m of drilling was conducted of which 10,000m was the combined sleeved pipe/MPSP adaption.

The inflatable bags were spaced to provide 3m stages along the tough plastic 38mm i.d. MPSP pipes. Grouting was conducted with stable cement-bentonite mixes, of water cement ratio (by weight) 4, 3, 2, or 1, as dictated by the recorded injection characteristics. Pressures of up to 35 bar were used. Where Quarternaries were necessary, the standard mix was preceded by the injection of a "supergel mix" (water, bentonite, and strength enhancing additives) to promote filling of the finest remnant fissures.

The pretreatment of the sugary limestone necessary for the excavation of a tunnel (Figure 11) proved equally impractical with conventional methods. A program involving 20 overlapping "umbrellas" of subhorizontal steel MPSP pipes was therefore designed to provide stable and dry excavation conditions under 30m

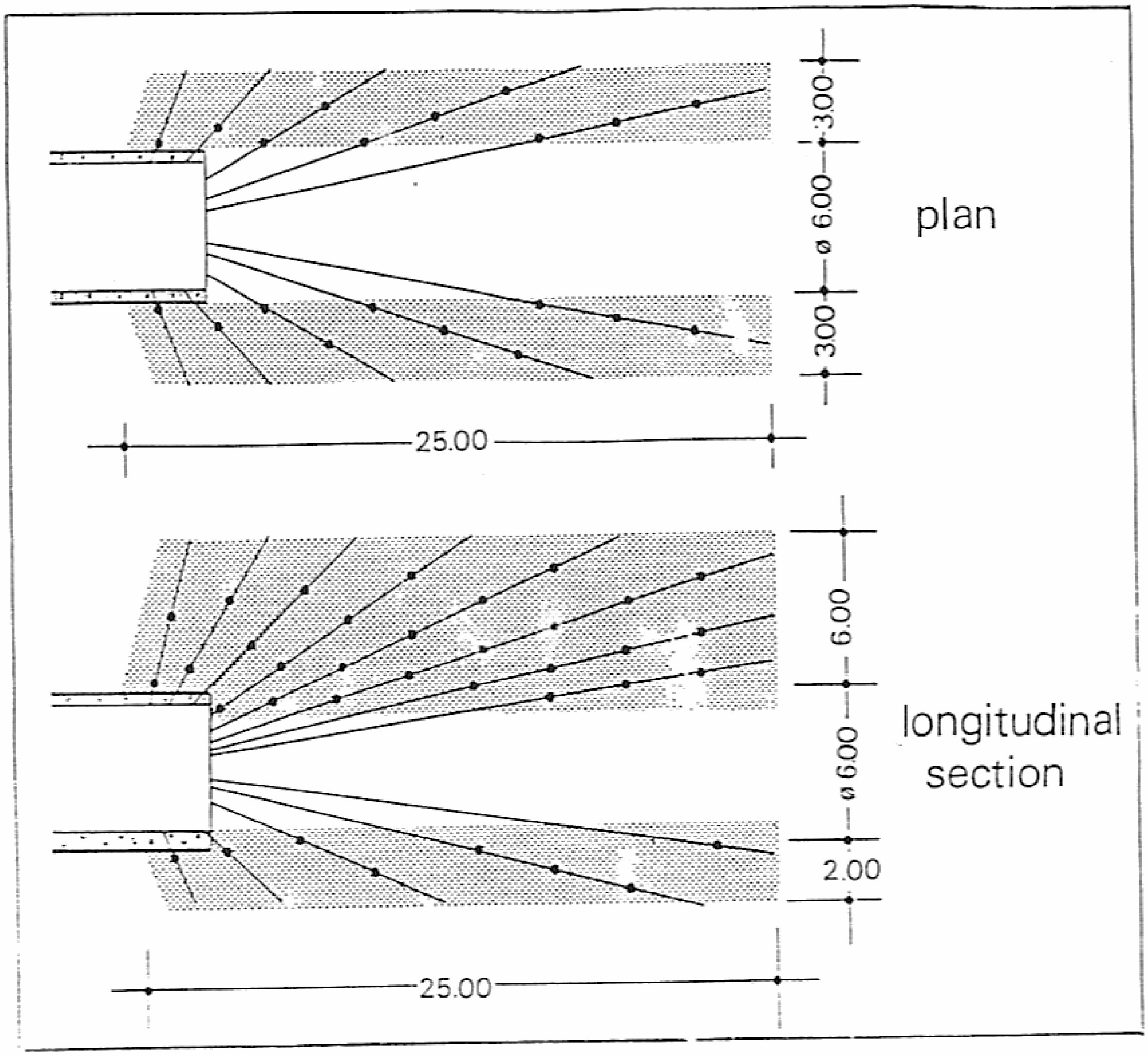


Figure 11. MPSP System for consolidation and reinforcement of microfissured rock above tunnel, Dam C, Asia.

hydraulic head otherwise giving a potential in flow of 60 liters/sec. The holes in each umbrella were 15m long, spaced at 1m centers around the ring and were drilled by water flushed rotary duplex methods involving full length casing. Steel MPSP pipes 38mm i.d. were used thereby providing a further insitu reinforcement benefit to the highly fissured rock mass being consolidated. Each pipe had bags at 3m intervals, and each umbrella allowed a 12m excavated length to be made in one pass. This application in tunnels is expanded upon further by Bruce and Gallavresi (1988).

4. FINAL REMARKS

The MPSP has been proved on a number of major projects to be a cost effective method of providing uniform and efficient treatment for rock masses which may be referred to as "difficult." It constitutes a r liable alternative to the conventional "downstage" or "upstage" methods which have hitherto been specified widely, but executed with demonstrably variable efficiency in certain cases.

MPSP is not limited to providing grout curtains for dams: its use in tunneling highlights its potential for increasing the mechanical performance of rock masses, when the grout pipes act simultaneously as insitu reinforcement. Equally, the MPSP System can be used to enhance the bearing resistance of poor rock masses under vertical loading: the grouting consolidates the mass, and the tubes act as micropiles.

Given its wide range of application in treating difficult rock masses to reduce seepage, provide insitu reinforcement or improve load bearing characteristics, the MPSP System is a significant addition to the armory of the geotechnical engineer.

ACKNOWLEDGEMENTS

The authors have the pleasure of acknowledging the assistance of their colleagues in the NiCON Corporation, Pittsburgh, Pennsylvania, and in Ing. Giovanni RODIO & Co., Milano, Italy. The work at Tarbela Dam was executed by RODIO in Joint Venture with GKN Keller GmbH and Colcrete Ltd.

REFERENCES

Bruce, D. A. (1982), Aspects of Rock Grouting Practice on British Dams, Proc. Conf. on Grouting in Geotechnical Engineering, New Orleans, Feb. 10-12, pp. 301-316.

Bruce, D. A. and Joyce, G. M. (1983), Slabjacking at Tarbela Dam, Pakistan. Ground Engineering, April. 5 pp.

Bruce, D. A. and Gallavresi, F. (1988), Special Tunneling Methods for Settlement Control: Infilaggi and Premilling. Proc. 2nd Int. Conf. Case Histories in Geotechnical Enginering, Rolla, MO, June 1-5, 6 pp.

Burwell, E. B. (1958), Practice of the Corps of Engineers, Jour. Soil Mech. and Founds. Div., ASCE, SM1, Feb., pp. 1551-1 to 22.

Ewart, F. K. (1985), Rock Grouting, With Emphasis on Dam Sites. Springer Verlag, ISBN 0-387-15252-0, New York, 428 pp.

Houlsby, A. C. (1982), Cement Grouting for Dams. Proc. Conf. in Grouting in Geotechnical Engineering, New Orleans, Feb. 10-12, pp. 1-34.

Houlsby, A. C. (1987), Stage Grouting Methods. In. 9th Annual Short Course on Fundamentals of Grouting, March 30-April 3, Univ. of Missouri, Rolla, St. Louis, MO. p. 23.

Lowe, J., Chao, P.C. and Luecker, A. R. (1979), Tarbela Service Spillway Plunge Pool Development. Water Power and Dam Construction, November, pp. 85-90.

Lowe, J. and Sandford, T. C. (1982), Special Grouting at Tarbela Dam Project. Proc. Conf. on Grouting in Geotechnical Engineering, New Orleans, Feb. 10-12, pp. 152-171.

Metramo Dam Handbook (1985), Edited by Geotecna Progetti S.p.A., via Salvio Giuliano 5, Milano 20146, 15. pp.