GROUTING AROUND POWER TUNNEL LINING

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ABSTRACT. The usefulness of any hydroelectric power project is that what percent of intended electricity it is generating. Electricity generation is directly proportional to the net head. Thus, the most sensitive part in hydroelectric project are power tunnels. This fact become more relevant where there are long power tunnels where maximum head loss is in head race tunnels (HRT'S) only. The head loss is sometimes as high as more than 90%. In most of the hydroelectric projects, HRT'S pass through rock masses which contains discontinuities such as folds, faults, joints, minor shear planes, fissures etc. These discontinuities further deteriorate during excavation by blasting and drilling techniques. Due to the presence of these continuities the rock mass does not behave monolithically. Proper grouting of the surrounding rock mass around the opening ensures the monolithic behaviour of the rock mass. Grouting is primarily carried out to: Strengthen the surrounding rock mass around openings by filling shattered rock mass, joints etc. Fill voids and cavities between rock mass and concrete lining. To ensure no permeability in surrounding of the power tunnels. To reduce the drainage problem during tunnel driving. To reduce leakage of water from lining.

Keywords. Grouting, Permeability, Usefulness, Tunnel.

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INTRODUCTION

Grouting is primarily carried out for the purpose of improving impermeability of the rock-mass otherwise shattered due to bad rock quality and blasting during excavation. It also improves the rock strength by way of solidifying seamy but otherwise good rock (consolidation grouting) and to control leakage by way of introducing an impervious stratum and suitable drainage system (curtain grouting).

Grouting is also used to bring about, as nearly as possible a fully bonded contact between any concrete structure and adjacent rock by way of filling the gaps between structural surface and surrounding rock body by shear presence of shrinkage and/or construction defects otherwise. In Headrace Tunnel of Hydro electric Project, in addition to contact grouting, consolidation grouting is carried out to improve the surrounding rock-mass and to provide pre-stressing at initial stages, to the concrete lining against internal hydrostatic pressure. This is considered to be a step forward in achieving economical solution for un-cracked, un-reinforced concrete lining in power tunnels. Power tunnels in hydroelectric projects are considered to be most sensitive part in determining the net head for available quantity of water thus, power to be generated. This is more relevant to projects containing long power tunnels, where maximum head loss (some times as high as 90%) is in headrace tunnels only. In case of power tunnels, grouting is required over various portions in following ways:

Contact Grouting: To fill large voids behind the steel and concrete liners which occur due to inadequate concreting, or due to air trapped during the concreting operation.

Embedment Grouting: To seal the gap between the steel liner and concrete which forms due to concrete shrinkage, due to plastic set in the rock during loading/unloading, and due to the temperature differential between the liner and the mass rock.

Consolidation Grouting: To consolidate blast damaged or relaxed rock and to reduce leakage. Consolidation grouting is the last step, and is done by the ring method, moving upstream and grouting through the same holes as the embedment grouting. With the packer attached to the steel liner, a second grouting of the gap as well as the fractured rock is done. It is advantageous to grout at the highest pressure possible, but without buckling the liner. Consolidation and contact grouting of tunnel lined only

in concrete, is done to the same general criteria as a steel/concrete section. Thus, well-planned and staged consolidation grouting could result in a desired pre-stressing in concrete lining, at initial level, against internal hydrostatic pressure. This will reduce cracks in concrete lining due to internal hydrostatic pressure resulting lesser head loss and loss of water.

GROUTING AS LEAKAGE CONTROL MEASURE

Excessive leakage can occur from pressure tunnels in two ways. Firstly, by hydraulic jacking, and secondly if the rock is pervious and the internal pressure exceeds the external groundwater pressure. Some seepage loss may be allowed depending upon the quantity and value of available water and the probable effect of seepage on the stability of the terrain and its effect on the environment. Grouting to reduce permeability around a concrete lining can be successful provided carefully controlled techniques and pressures are used.

Grouting Methods

Grouting technology is vast expanding and integral part of rock science. Depending upon state of the art and experience gained in a particular field different technique are adopted for grouting. The best known and widely used grouting methods are as following;

- Stage Grouting,
- Stop Grouting,
- Series Grouting,
- Circuit Grouting,
- Ring grouting etc.

In all of these, the "split spacing" procedure of determining final hole spacing is followed, that is, the spacing of each succeeding set of holes is determined by splitting the interval between the holes of the previously completed sets. Holes for the initial or primary set are drilled at the maximum spacing (commonly 6.0 meters) and grouted, and the spacing of holes is reduced with each succeeding set until it becomes such that no appreciable quantity of grout can be injected at the maximum permissible pressure.

Stage grouting

Stage grouting, as the name implies, is a method of grouting whereby the work is accomplished in stages from top to down. Grouting in the upper part of the holes is accomplished before the lower parts are drilled. Its primary purpose is to give separate grouting treatment to cracks and other openings encountered in grout hole drilling that are of such size that separate treatment is desirable.

Some advantages of stage grouting are as following

i. It excels all other methods for flexibility in meeting local conditions. It allows for separate treatment of each imperfection as encountered and, thus, permits the use of the grout mixes and the pressures that best meet each condition.

ii. It minimizes the problem of premature stoppage in the smaller seams or fractures because each seam encountered in drilling is subjected to additional grouting with each successive grouting stage.

iii. The first grouted upper sections of the holes are subjected to successively higher pressures as the holes are deepened and higher pressures are applied.

iv. The use of packers or expansion plugs is unnecessary in as much as washing, pressure washing, pressure testing, and grouting for all stages are accomplished from the top of hole.

A **disadvantage** of stage grouting is that the holes must be cleaned out after each stage. The cost of doing this is low, however, if it is done before the grout takes a hard set.

Stop Grouting

Stop grouting is a method whereby packers or expansion plugs are used to block off pre-selected portions of the holes, while those portions are being grouted. Under this method the holes are drilled to their full depth and grouted in successive zones from the bottom up. Packers or expansion plugs are set in the holes at the top of the zone to be grouted, blocking off the higher portions of the holes, and the zone then pressure tested and grouted. The lower most zone is grouted first. Grouting in any particular zone is completed in all holes drilled through that zone before proceeding to the next higher zone. The packers are then raised to the top of the next higher zone and pressure-testing and grouting repeated.

Some advantages of stop grouting are as following

i. Imperfections disclosed by drilling operations, if so, desired may be isolated by means of the expansion plug and given special treatment.

ii. Grout mixes can be varied so that mixes can be employed that are best suited for the conditions of each zone,

iii. Pressure washing and testing may be concentrated, if desired, to small segments of the holes by means of double expansion plugs, thereby improving the efficiency of these operations.

iv. Cleaning or drilling out holes after grouting is unnecessary.

Some disadvantages of stop grouting are as following

i. Grout often bypasses the grout stops, or expansion plugs, through vertical or near vertical fractures or joints.

ii. A tight seal is difficult to obtain with expansion plugs in fractured or broken rock, and in cavernous or solution honey-combed rock.

iii. Leaks into nearby holes often cause difficulties and may plug fractures and seams and other imperfections in those holes above the zone being grouted.

iv. Sizes of holes that can be used for grouting are limited to the sizes of packers or expansion plugs obtainable.

Series Grouting

Series grouting involves the drilling of a separate series of holes for each zone of grouting. Grouting of holes in all series is performed from top of hole. The series for the uppermost zone are drilled, pressure-tested, and grouted first starting with a primary set of holes on a wide spacing and reducing the hole spacing with succeeding sets by split-spacing method until the zone has been grouted to the satisfaction of the person in charge.

Some of the advantages of series grouting are as following

i. Holes for the uppermost zone and possibly those for the next deeper zone may be drilled with percussion drills, which is less expensive than drilling with rotary drills.

ii. Cleaning of grout from the holes after grouting is not required.

iii. The use of packers or expansion plugs with their attendant problems is unnecessary, in as much as all washing, pressure-washing, pressure testing, and grouting are performed from the tops of the holes.

The series grouting method has two major disadvantages

i. It requires an excessive amount of grout hole drilling.

ii. It lacks flexibility in meeting localized conditions.

Circuit Grouting

In circuit grouting, an injection pipe is extended through a packing gland to the bottom of each hole for each specific zone or stage being grouted, and the grout is pumped through a complete circuit from the grout mixer or the sump through the injection pipe to the bottom of the hole and, thence, up the hole and back to the sump.

Some advantages of circuit grouting are as following

i. Grout is circulated constantly through the system and even in the case of relatively tight holes, the entire depth of hole is exposed to the circulating grout fluid.

ii. Periodic washing of the holes is facilitated.

iii. It is adaptable to the grouting of caving or revealing holes in that the injection pipe can be jetted to the bottoms of the holes and accretion material is removed by the rising column of grout.

The principal disadvantages of circuit grouting are as following

i. More time is required to install and to remove the injection pipe than is required to make and to unmake hole connections by other grouting methods, especially if jointed pipe is used.

ii. The injection pipe may become grouted in holes that take grout so rapidly that no return flow is maintained in the circuit,

iii. The grout holes cannot be closed under pressure after completion of a grouting operation because of the removal of the injection pipe.

Ring Grouting

This type of treatment is akin to curtain grouting under a dam in that it forms a grout barrier intended to reduce the possibility of water percolating from the reservoir along the tunnel bore. Stage-grouting method usually will produce the best results.

GROUTING MATERIAL

Followings are the main constituent of grouting material;

i. **Portland Cement**: OPC without air entraining agent is best. Use of proper water cement ratio is most important factor.

ii. **Fillers**: To reduce the relatively high cost use of fillers like sand, rock flour, stabilized clay, bentonite, straw, sawdust, grains and mica flakes etc. is recommended. If available at near source fly ash is considered to be good filler.

iii. **Accelerators**: Used to limit the extent of grout travel. Calcium chloride, high alumina cement and sodium carbonate.

iv. **Retarders**: Used to increase the set time, if required. Common retarders used for concrete will work.

v. **Lubricants**: Used to increase the flowability of the grout to have penetration in finer cracks. Fly ash and rock flour is used for this purpose.

vi. **Non-shrinkage Agents**: Powdered Aluminium is the agent most commonly used.

BRIEF LITERATURE SURVEY

Grouting is a widely used method for strengthening and sealing rock, soil and concrete. The possibilities for sealing structures are of great importance from both an economic and environmental point of view. The cost of grouting has in certain projects been as high as the cost of blasting and excavating the tunnel. To improve the technique for grouting with cement-based material, it is necessary to examine the properties of the grout mixture used.
In planning a grouting program for particular conditions, the engineer needs knowledge of the various types of grouts and their properties. The basic types of grouts now in use and their properties are discussed below. Types of admixtures and fillers used and their effects on the grout are also discussed. The most common types of grouts are Portland-cement, clay, chemical, and asphaltic grouts. No one grout is suitable for every situation. The properties of each specific grout make it desirable under certain circumstances. An important requirement for the selection of a grout is that its particles be substantially smaller than the voids to be filled. Figure 1 shows limiting grain sizes of materials that can be grouted by various types of grout. These data are based on experience and testing and should be used only as a guide. Another relationship can be determined by the groutability ratio, N, expressed by the equation

$$N = D_{15}/D_{85}$$

where D_{15} is the 15 percent finer grain size of the medium to be grouted and D_{85} is the 85 percent finer grain size of the grout. N generally should be greater than 25 but, in some cases, may be as low as **Portland-cement grout.** Portland-cement grout is a mixture of Portland cement, water, and, frequently, chemical and mineral additives. The properties of materials generally used in Portland-cement grout are described below.

Portland-Cements

Five types of Portland-cement, produced to conform to the specifications of ASTM Designation C 150, are used in cement grouts.

Type I is a general-purpose cement suitable for most cement grout jobs. It is used where the special properties of the other four types are not needed to meet job requirements.

Type II cement has improved resistance to sulfate attack, and its heat of hydration is less and develops at a slower rate than that of type I. It is often used interchangeably with type I cement in grouting and is suggested for use where precautions against moderate concentration of sulfate in groundwater are important.

Type III cement is used where early strength gains are required in grout within a period of 10 days or less. It may also be used in lieu of type I or type II in injection work because of its finer grind, which improves its injectability.

Type IV cement generates less heat than type II cement and develops strength at a very slow rate. It is rarely used in grouting.

Type V cement has a high resistance to sulfates. It is not often used in grouts, but its use is desirable if either the soil to be grouted or the groundwater at the jobsite has a high sulfate content.

Mixing Water

Generally, water suitable for drinking may be regarded as suitable for use in grout. Ordinarily the presence of harmful impurities (e. g., alkalies, organic and mineral acids, deleterious salts, or large quantities of silt) is known in local water sources. If there is reason to suspect a water source, it should, be tested in accordance with CRD-C 400.

METHODOLOGY/ PLANNING OF WORK

The power tunnel is proposed to be grouted after laying the concrete lining, methodology and planning of both contact and consolidation grouting works is described as under

Contact grouting shall provide an interface between the final rock support and lining and shall be carried out to fill all the voids between concrete and rock.

Consolidation Grouting shall prestress and strength the rock mass and provide the desired water tightness to the structure.

QUANTITIES OF EXPECTED GROUTING WORKS

Contact grouting/ consolidation grouting

1. Nos. of Profiles
2. Nos. of Holes per Profiles
3. Depth of Drilling
4. Total Length of Drilling
5. Total No. of Holes
6. Expected intake of cement in average

Drilling for grouting

Drilling Equipment

Holes will be drilled using some standard drilling equipment.

GROUTING EQUIPMENT

Requirement to carry out work shall include Grout pump, grout mixer, agitator, packers, pipes and grout lines, fitting, pressure gauges, water meters, grout platforms and other miscellaneous Supplies. The equipment shall be capable of satisfactory mixing, stirring and supplying grout/mixes of various densities and viscosities at the required constant pressures provide a continuous circulation of grout and permit accurate volume and pressure control.

GROUTING MATERIAL

The water used of drilling, washing, water testing and as grout ingredient shall be fresh, clean and free from deleterious silt, oil, grease and other impurities.

The cement used in the grout shall conform to IS: 1489-1991. The fineness shall be greater than 350 m^2/kg.

TESTING OF GROUTMIXES AND QUALITY CONTROL

Before starting of grouting works, each kind of grout mix which will be used during the grouting works will be tested for sp. gravity, viscosity, compressive strength and initial & final settings.

During the execution of grouting works, samples of each grouting mix shall be taken daily/weekly for testing.

GROUT LEAKAGES

If during the process of grouting any leakage is observed from the concrete joints, the same shall be repaired with mortar before the grouting is resumed again.

In case a leakage is observed from a grout hole already drilled in the vicinity the same shall be sealed with packer before grouting is resumed. Such problematic holes shall be re-drilled before grouting of these holes.

WATER PRESSURE TESTING (WPT)

Before the start first stage consolidation grouting two holes one in the crown and the other in the left or right side wall alternatively shall be checked to assess the rock permeability values. The pressure for WPT will not be more than those laid down for the grouting of particular stage.

FACILITIES REQUIRED FOR THE PROPOSED WORK

Besides the team of leading grouting specialist, civil engineer, Electrical Engineer, Mechanical Engineer, Quality Control Engineers and maintenance team like air supply maintenance, Pipe line & water maintenance etc. the following equipment's are required at site:

1. Drilling Machine

2. Grouting pump
3. Agitator
4. Grouting Centrifugal pump
5. Packers
6. Pressure gauges
7. Water meters
8. Mixer & Recorder

CONCLUDING REMARKS

The paper finds its significance as the power tunnels of most of the Hydro Power Projects possess all or any few of the following properties along the entire length:

- Leakage of water causing loss of water.
- Formation of phreatic lines.
- Naturally fissured and cracked rocks.
- Damage to rocks (if any) caused by blasting carried out for construction activities.

FUTURE SCOPE

- Proves to be an essential tool for assessing the efficacy of grouting.
- It helps to take decision regarding whether the certain part of Head Race Tunnel needs to be re grouted.
- Sufficiently low permeability values in the grouted zones conclude that rock around power tunnels is sealed to a desired value.
- Overall improvement in permeability along the complete length of HRT surrounded by broken, jointed, faulted, fractured rocks improves the safety of tunnel and is extremely essential for bigger diameter tunnels in poor rock masses
- Closing of cracks, joints and other discontinuities helps in :

  a) Reducing the seepage of water from and to power tunnels.
  b) To help in behaving of rock mass as monolithic structure around the power tunnels.

To save time and money decision about discarding of some holes can be taken

- Can prove best as base/ reference for research and designs, advance studies and practical training of students.

- During construction of civil structures on geologically poor grounds this can be effectively used as a reference tool.

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REFERENCES

1. Barton N., Lieu R and Lunde J. (1974)” Engineering classification of rock masses for design of tunnel support”, Rock Mechanics Vol.6 No. 4 pp. 189-236

2. Brantberger, M., Stille, H & Eriksson, M., (2000) “Controlling Grout Spreading in Tunnel Grouting Analysis and Development of the GIN-Method”, Tunneling and Underground Space Technology, 15(4), pp.343-352

3. Dalmalm, (2004)” Choice of Grouting Method for Jointed Hard Rock” based on Sealing Time Predictions, Ph.D. Thesis, Royal Institute of Technology.

4. Emil Mosonyi, (1991) “High- Head Power Plants”, volume Two/A and Two/B

5. Eriksson, M. & Stille, H., (2003) “A Method for measuring and evaluating the penetrability of grouts”, Neworleans, Proceeding of 3th International Conference on Grouting and Deep Mixing.

6. Ewert, F., (1996) “The GIN Principle-a helpful method for rock grouting”, pat 1 and 2, International Water Power and Dam Construction, February and April, 48(2), pp. part1: pp.17-19, part2: pp. 36-40.

7. Fransson, A., (2001) “Characterization of a fractured rock mass for a grouting field test”, Tunneling and Underground Space Technology, volume 16, pp.331-9

8. Gustafson G., & Stille, H., (1996) “Prediction of Groutability from Grout Properties and Hydrogeological Data”, Tunneling and Underground Space Technology, Volume II, pp.325-332.

9. Hast,N., (1958) “The measurement of of rock pressures in mines”, Sveriges Geol. Undersokn, 52(3)

10. Hoek, E. & Brown, E., (1980) “Underground Excavation in rock”, London: Institute of Mining and Metallurgy.

11. Houlsby, A., (1990) “Construction and Design of Cement Grouting”, A guide to grouting in rock foundations, Newyork: John Wiley and Sons.

12. Ivanitich, K., Bryant, K. & Gularte, F., (2012) “The use of Optical Televiewer in Geotechnical Construction”, Neworleens, Proceeding of 4th International conference on Grouting and Deep Mixing.

13. IS 516: (1999). “Methods of tests for strength of concrete”, Bureau of Indian Standard, New Delhi.

14. IS 5529 (Part-2):(1985). “Code of practice for in-situ permeability tests (Part VII – Grouting)”, Bureau of Indian Standard, New Delhi.

15. IS 5878 (Part VII): (1972). “Code of practice for construction of tunnels (Part VII – Grouting)”, Bureau of Indian Standard, New Delhi.

16. Kobayashi, S., Stille, H., Gustafson, G.& Stille, B., (2008)”Real Time Grouting Control Method”, Development and application using Aspo HRL data, Stockholm, Sweden; Swedish Nuclear Fuel and Waste Management Co. (SKB)

17. Lombardi, G.& Deere, D., (1993) “Grouting Design and Control using the GIN Principle”,International Water Power and Dam Construction ,45(6),pp. 15-22

18. Rafi, J.& Stille, H., (2013) “Controlling Jacking of Rock Considering Spread of Grout & Grouting Pressure”, Tunneling and Underground Space Technology.

19. Stille, B., Stille, H., Gustafson, G.& Kobayashi, S., (2009) “Experience with the real time grouting control method”, Geomechanics and Tunneling, 2(5), pp.447-459

20. Terzaghi, K. & Richart, F., (1952) “Stresses in rock about cavities”, Geotechnique Volume 3, pp. 57-90

21. Snow, D.,T., (1968) “ Rock Fracture Spacing, Openings and Porosities”, Journal of Soil Mechanics and Foundation Division, proceedings of the American Society of Civil Engineers, 94, pp. 73-91