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Study on Effectiveness of Barrier Grouting at Transitional Area of Pressurized Tunnel: A Case Study in Upper Tamakoshi Hydro Electric Project-456MW

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Abstract

Regarding pressurized tunnel, if there are any crack/void/rock fissures inside rock mass then it may cause high seepage, permeability, erosion, weaken rock mass which eventually might lead to the failure of structure, delay of project, increase in cost and other risks. In pressurized tunnel, if rock mass is very week, concrete lining can be done instead of unlined tunnel(shot-creting). But in-case of penetration of water into weak rock mass from the transtion section (lined-unlined) of tunnel, concreted portion of tunnel might be weak in future. In order to fill the void and make barrier in between lined and unlined tunnel, grouting could become effective which is termed as barrier grouting. But barrier grouting might be useless if method of grouting is not suitable. Considering aforementioned facts, this research including case study regarding barrier grouting at transition section of pressured tunnel in "UTKHEP-456MW" is done. Based on Lugeon test, grouting data, site observation, data analysis is done to find the result of currently practiced method of barrier grouting. Drawbacks of accepted method are listed out. Based on result, modification of method of barrier grouting is given as a suitable method of barrier grouting for pressurized tunnel construction project. This research recommends to avoid Lugeon test prior to doing barrier grouting. Since water is incompressible, if grouting is done immediately after Lugeon test, grout injection might be less than actual void percentage due to injection of high volume of water during Lugeon test. Due to which, void might not be filled with grout. Based on this research, identification and verification of filling such void with grout can be done as reconfirmation test regarding completion of barrier grouting for respective work front.

Keywords

Barrier Grouting, Identification and Verification of Filling Void with Grout, Lugeon Test, Stopping Criteria

1. Introduction

Many pressurized tunnel projects are under construction in Nepal. Considering the priority of irrigation, hydro energy generation, many pressurized tunnels are expected to be constructed in future. Considering the rock mass condition in tunnel, different type of support and geotechnical activities should be done. Normally rock bolt installation, application of wiremess, lattice girder, shotcreting are the commonly adopted method of rock support in tunnel based on classification of rockmass. In case of very weak rock, in pressurized tunnel, there is high possibility of penetration of water to surrounding rock. If rockmass is very weak, due to high permeability of rockmass, water can penetrate to surrounding rock mass which eventually might lead to reduction of strength, erosion, increase the deformation of rock and other geotechnical issues in tunnel. To solve these types of geotechnical problem at very weak rock mass area of pressurized tunnel, concrete lining can be done instead of applying shotcrete. However, since permeability of shotcrete is high in comparison to concrete [1], in case of penetration of water into surrounding rockmass of concrete lining portion from the transition section of lined-unlined tunnel, aforementioned problems might not be solved permanently. In order to solve these problems, barrier grouting could be the best way to solve problem due to which void (crack/primary void/cavity/rock fissures/ rock discontinuities) will be filled with grout which will help to reduce rockmass permeability, erosion, deformation, seepage and increase the strength of rockmass by creating barrier at transition section between lined and unlined tunnel. However, if method of barrier grouting is not suitable, aforementioned geotechnical problems might not be solved permanently. On the other hand, procedure of grouting should be optimized one to achieve the goal of grouting at required location technically as well as economically. Considering these facts, this research is done to study the way of increasing effectiveness of barrier grouting in tunnel construction project. The main objectives of this research are to document a suitable method of barrier grouting, identification of crack/void/cavity/rock fissures/discontinuities and verification of filling such crack/void/cavity/rock fissures/discontinuities to solve the possible geotechnical problems as mentioned above in pressurized tunnel construction project.

Grouting operation was developed at first on early of 19th century (1802) by French Beringny who had invented for sealing of subsoil of weir. From 1802 to 1809, grouting was employed by French Beringny in construction field at first time to reduce to inflow of water [2] L. Ch. Mary grouted in Quentin canal with hydraulic mortar on 1820. In 1831, Charrie developed a method of grouting in construction of lock of canal. In 1837, Raynal described the application of grouting in repair activities of masonry [2]. In 1919, G.W Christian used asphalt as a grout material at Hales Bar dam to stop the leakage of water. After grouting with asphalt, leakage was decreased effectively.

Regarding tunnel construction project, till date, different types of cement-based grouting, methods and application are developed [3]. Currently barrier grouting is the commonly used technique of grouting in tunnel. Method of barrier grouting is defined based on different criteria, in-situ test, observation, material property, objective of grouting at site, level of effectiveness of barrier grouting. Traditionally, grouting used to be done using hit and trial method. In 1993, G. Lombardi, D. Deere developed the grouting method using GIN principle[4]. Specially, GIN principle controls the grouting based on limit of maximum applied pressure as well as maximum grout volume injection. In 1996, Professor Friedrich Karl Ewert ran GIN principle for grouting in rock mechanics and tunnel projects [5]. After finding some wrong interpretation of GIN principle, Giovanni Lombardi clarified and enlarged certain issues concerning to GIN principle[6]. In 2008, Massimo Marotta described the grouting and its application in tunneling [3]. Massimo Marotta has developed the one of the methods of cement grouting in tunnel. Specially, he had developed the method for grouting in concrete lined tunnel in which PVC pipe should be preinstalled for grouting in futures if there is any seepage. In 2014, research done by Hamid Reza Rostami Barani, Gholamreza Lashkaripour and Mohammad Ghafoori gave a proposal for Geological Groutability Index (GGI) of Cement Grouting [7]. Now a days, different type of cement grouting such as consolidation grouting, backfill grouting, contact grouting and barrier grouting etc. are commonly used technic of cement grouting. In Nepal also, many tunnel projects are under construction. barrier grouting is considered to be conducted according to site condition.

However, none of research are discussing regarding negative impact of Lugeon on effectiveness of barrier grouting. In order to do Lugeon test, high volume of water should be injected. Due to injection of high volume of water in rock mas, volume of void which should be filled with grout might be filled with water. In order to find the advantage as well as disadvantage of Lugeon test prior to barrier grouting, so that effectiveness of barrier grouting can be increased, this research is done. After doing literature review, this research is focused to increase effectiveness of barrier grouting at transition section of pressurized tunnel. In this research, barrier grouting performed in UTHP-456MW is taken as a case study. Site observation, data for Lugeon test, grouting, hole inter connection, seepage during grouting as well as Lugeon test etc. are studied at site as a case study. After getting data, data analysis is done to find out the drawbacks of applied method of barrier grouting. Limitation of applied method of barrier grouting are listed. A method of barrier grouting is recommended including to solution regarding limitation of latest method of barrier grouting which will lead to increase the effectiveness of barrier grouting, reduce the cost of the grouting, reduce the project completion period etc. At the end, this research is succeeded to recommend the modified method of barrier grouting for transition section of pressurized tunnel to increase the effectiveness of barrier grouting technically as well as economically.

2. Methodology

This research is based on analytical method, i.e., based on case study, data analysis is done to get the result. All the data are taken from site as a primary resource during case study period. After getting result, drawbacks of applied method are found and solved respectively. After getting solution, a suitable method of barrier grouting is recommended for barrier grouting at transition section of tunnel construction project

After literature review, latest method of barrier grouting is studied. Then one case study for barrier grouting at "Upper Tamakoshi Hydro Electric Project-456MW (UTKHEP-456MW)" is done. Lugeon test, grouting, hole inter connection, grout injection behavior, site conditions, leakage of grout, tests related to grouting as well as grout and other parameters are observed. In UTKHEP-456MW, barrier grouting was done at nine work fronts. However, case study for this research was done at two work fronts: one at headrace tunnel near to intake (Ch0+015 to Ch0+020) another at adit gate which is connected with unlined section of headrace tunnel.

After case study, based on site observation, Lugeon data, grouting data, hole inter connections, grout mix design, in-situ test and other records, interpretation, data analysis and studies is done. Based on obtained results, drawbacks of latest method of barrier grouting are listed. Drawbacks of latest method of barrier grouting are addressed based on data interpretation and possible solution. Eventually, modified method barrier grouting is recommended. Latest method of barrier grouting which is also adopted in UTHEP-456MW is shown in figure 1

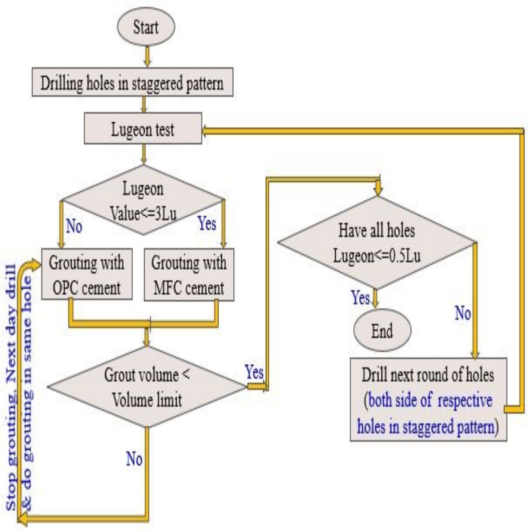

Figure 1: Latest method of barrier grouting (adopted at UTHEP-456MW)

3. Results and Discussion

After getting data for Lugeon and grout injection volume, Lugeon Vs grout injection volume relation is interpretated. Theoretically, if lugeon is high, grout injection should be also high and vice versa [8]. But from case study in some cases, Lugeon is high but grout injection is very low. this case might be due to two reasons.

Case-1: because of inter connection of two holes with same void, void might be filled with grout during grouting from first hole due to which while doing grouting from second hole having high lugeon, grout injection might be low.

Case-2: second reason might be because of filling of void with water during Lugeon test. If water don't leak out after Lugeon test and grouting is done immediately after Lugeon test, grout injection might be less than volume of void due to filling of void with water since water is in-compressible.

Lugeon Vs grout injection is shown in figure 2 to 5 for different location and different stage.

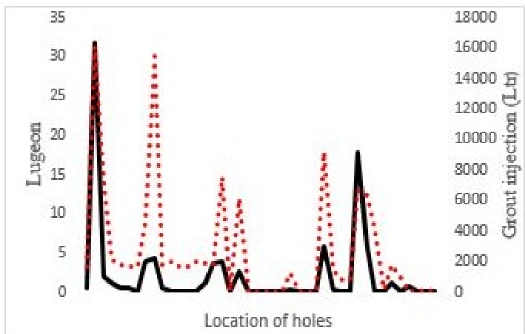

Figure 2: Lugeon Vs grout volume for packer setting at 5m @HT1

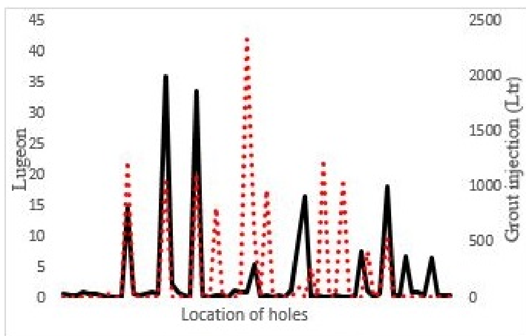

Figure 3: Lugeon Vs grout volume for packer setting at 0.5m @HT1

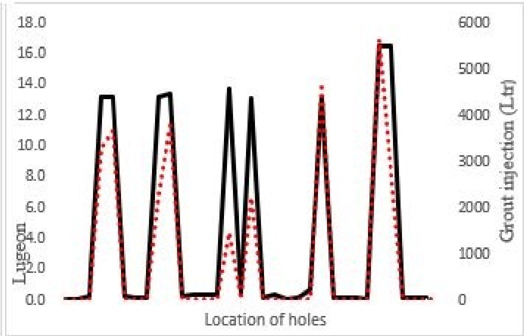

Figure 4: Lugeon Vs grout volume for packer setting at 5m @Bhaise adit gate

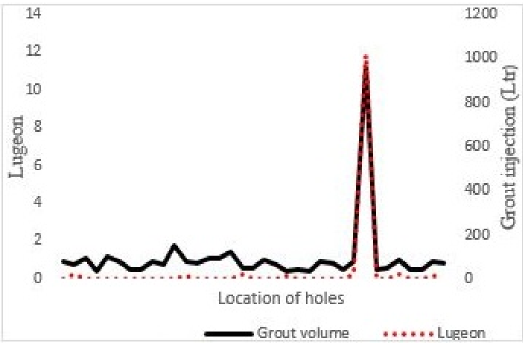

Figure 5: Lugeon Vs grout volume for packer setting at 0.5m @Bhaise adit gate

Percentage of void in surrounding rockmass is shown in figure 6 and figure 7. Since, grouting holes are drilled up to 12m, grout injection is also assumed up to 12m from rock line. Similarly, grout is assumed to be injected within transition section. Accordingly, volume of rockmass is taken for transition section only up to 12m from rock line.

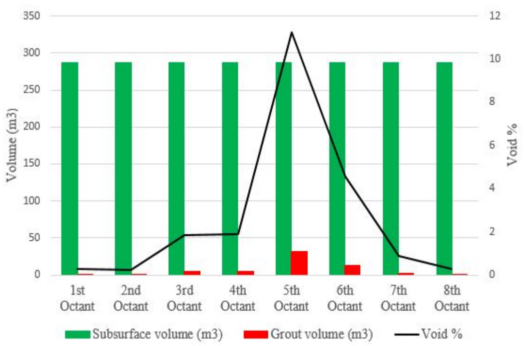

Figure 6: Interpretation of void percentage octant wise for HT1

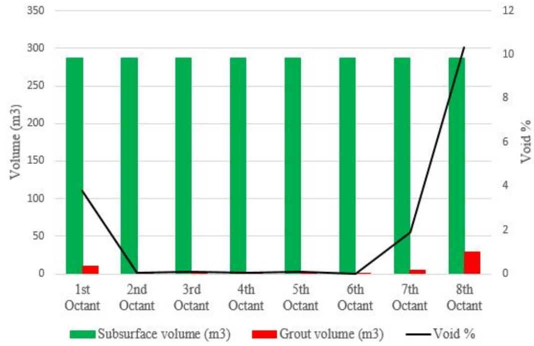

Figure 7: Interpretation of void percentage octant wise for Bhaise adit gate

Similarly, location of possible void /crack/ cavity/ rock fissures are analyzed by plotting rose-diagram regarding injected volume. See figure 8 and figure 9.

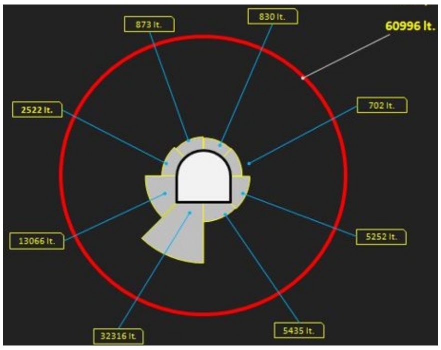

Figure 8: Comparison of volume of grout injection around tunnel profile at HT1 looking D/S

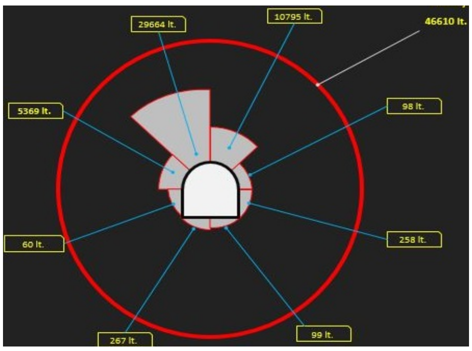

Figure 9: Comparison of volume of grout injection around tunnel profile at Bhaise adit gate looking D/S

From figure 8, regarding HT1, it is clear that surrounding rockmass above spring line is very strong and surrounding rockmass at invert near to left side of tunnel while looking D/S is very weak which is the possible location of major void/crack/cavity. From figure 9, regarding Bhaise adit gate, it is clear that surrounding rockmass below spring line is very strong and surrounding rockmass at crown near to left side of tunnel while looking D/S is very weak which is the possible location of major void/crack/cavity.

Similarly, based on data observed at site regarding Lugeon test, grouting, grout material test, grout mix design, hole inter connection, seepage of grout during grouting, leakage of water during Lugeon test, rock mass deformation etc. interpretation from different point of view such as possible area of void, possibility of crack or void or cavity or rock fissures, possible way to increase effectiveness of barrier grouting, alternative of Lugeon tests are studied.

4. Recommendation of Revised Method and Validation

Based on data analysis, interpretation of grouting and possible solution of drawback of latest method of barrier grouting, slightly modified method of barrier grouting is hereby recommended. See figure 10 for flow chart of steps of modified method of barrier grouting.

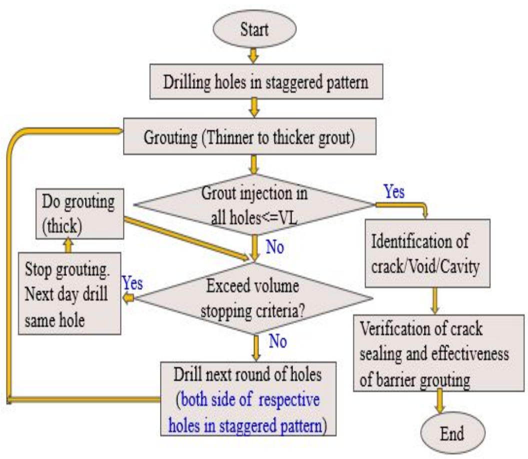

Figure 10: Recommended method of barrier grouting

This recommended method avoids Lugeon test. As discussed above, if Lugeon test is done prior to barrier grouting, grout injection might be less than volume of void due to which effectiveness of barrier grouting might not be achieved. Since injecting high volume of water into rock mass during Lugeon test might have negative effects, alternative of doing Lugeon test in order to confirm necessity of additional holes for barrier grouting to fill the void with grout, should be found. Since motto of barrier grouting at transitional section of pressurized tunnel, is to convert weak rock mass into strong rock mass by injecting grout at respective location, property of rock mass after completion of barrier grouting should be same like very strong rock mass. It means permeability, rock deformability should be very less after completion of barrier grouting. According to GIN principle regarding grouting,

$$GINValue = P_{max}(bar) * V_{Max}(Litre) \tag{1}$$

If GIN value corresponding to very tight rock mass is choosen, since PMax is constant for respective work front (three times the future water pressure [9]. VMax corresponding to very strong rock mass will be found out which will be volume limit (VL) to confirm whether additional holes are needed or not i.e., VL will work as threshold value of grout volume injection. If grout injection exceeds VL, it means surrounding rock mass has void in comparison to tight rock mass which refer grouting should be done in additional holes too. Based on necessity of effectiveness of barrier grouting, S factor can be introduced as ,

$$S * GINValue = P_{max}(bar) * V_{Max}(Litre) \tag{2}$$

where S=0.5 to 1 which was provided based on-site conditions and literature review [9]. If result obtained based on threshold value of Lugeon and threshold value of VL is compared regarding necessity of additional holes, it seems similar i.e., revised method of barrier grouting is valid. It means Lugeon test can be avoided prior to barrier grouting. Since volume of void, which can be filled with water during Lugeon test, will be filled with grout in case of accepting revised method instead of old method of barrier grouting, effectiveness of barrier grouting will be increased. Since cost as well as time period of doing Lugeon test is high, revised method of barrier grouting is valid technically as well as economically. Therefore, instead of threshold value of Lugeon 0.5, threshold value of volume of grout injection (VL) can be taken to confirm necessity of additional holes for grouting in order to confirm the completion of barrier grouting at respective work front.

Based on revised method of barrier grouting, if grout injection for respective hole for respective packer setting depth is more than VL, next round of holes should be drilled. If all holes of latest round have grout injection less than VL then grouting at that workfront will be assumed as completed. Similarly, in order to complete grouting for any work front, initial GIN value can be taken considering project economy, required effectiveness of barrier grouting, site conditions based on experience or literature review. Then grouting can be started. Based on observation of grouting at site, GIN value can be adjusted to meet final pressure of grouting and optimized volume of grout injection.

Note: Selection of GIN value to calculate VL and selection of GIN value to do grouting for any work fronts are two different cases. For same work fronts, GIN value can be adjusted based on grout injection pattern.

5. Voids Identification and Verification of Filling such Voids with Grout

After completion of grouting, transition section is assumed as three-dimensional plane. Drilled holes are shown in tunnel drawing. Then identification of crack/ void/ cavity/ fissures can be done based on nature of grout flow, hole inter connection, pressure development pattern etc. If grout injection volume is high in some holes and holes are inter connected, that holes lie in major cracks. If inter connected holes are not observed however grout injection is high and these holes are in a pattern, in this casealso, there might be major crack. In that case, crack might be extended far from rock line so that inter-connection might not be observed. Similarly, if grout injection is neither high nor low and holes are in a pattern, this is the case of minor crack. If volume of grout injection in any hole is high but there is neither inter-connection nor high grout injection in other holes nor high grout injection in next round of holes for respective holes, in this case, there might be void/cavity. Surrounding rockmass might be weak. If seepage from rock mass during grouting is observed continuously, rock mass might be highly permeable. I.e., rockmass might be very weak. If pressure is increasing rapidly during grouting in all holes, grout injection is very low, seepage is not observed, holes are not inter connected to each other then there is low possibility of crack, void, cavity, and discontinuities etc. See figure 11 and 12 for identified major crack and minor crack at HT1 and Bhaise adit gate respectively.

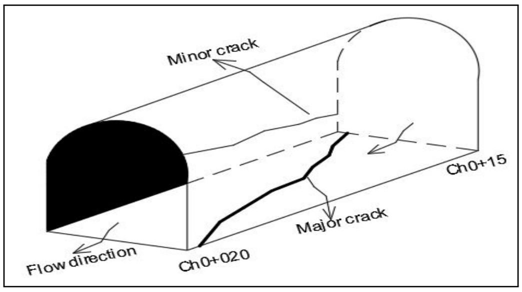

Figure 11: Identified crack at HT1

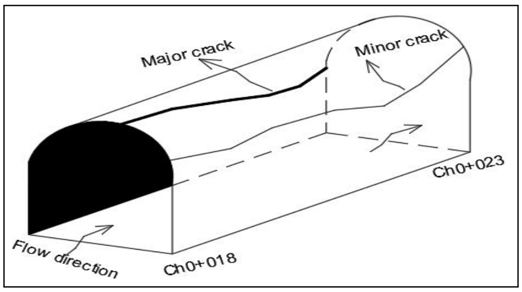

Figure 12: Identified crack at Bhaise adit gate

After completion of barrier grouting based on volume limit stopping criteria and identification of void/crack/cavity/rock fissures, some holes (let's say 2,3) can be drilled in such a way that hole will penetrate the identified area of void/crack. After doing grouting in these holes, reconfirmation of filling identified void with grout can be done. While doing reconfirmation test regarding filling voids with grout, if void filling with grout is not confirmed, grouting should be resumed again around identified crack/voids.

6. Conclusion

Based on site observation of barrier grouting during case study, data analysis, interpretation of different parameter, study of drawbacks of latest method of barrier grouting is done. After finding drawbacks of latest method of barrier grouting which was also applied in "Upper Tamakoshi Hydro Electric Project" and finding possible way of solution for such drawbacks following conclusions are made from the research.

1. Lugeon test prior to barrier grouting should be avoided so that grout injection volume can be increased due to which effectiveness of barrier grouting could be increased based on GIN principle.

2. Barrier grouting is effective techniques of improvement of surrounding rock mass which can fill the micro/macro crack/void/cavity/fissures, increase strength of surrounding rock mass, reduce the seepage, reduce rock mass deformability and reduce the permeability etc.

3. Barrier grouting at transition section of headrace tunnel and Bhaise adit gate in Upper Tamakoshi Hydro Electric Project-456MW seems effective.

4. Finally, this research is succeeded to recommend modified method of barrier grouting in order to increase the effectiveness of barrier grouting. According to recommended method, identification of void and filling such voids with grout can be also verified.

5. Since cost of Lugeon test is very high and it is time consuming, modified method of barrier grouting can reduce the cost of project as well as project construction duration.

7. Acknowledgement

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