Optimization Study on Grouting Method Based on the Grouting Intensity Number

Jingya Li[1,*], Lisheng Xu, Meng Xu

School of Geosciences and Info-Physics Central South University
Central South University
Changsha City 410083, China

***Abstract* — Conventional grouting methods that are widely used in the foundation treatment is analyzed and compared with the grouting intensity number method. It is obtained that conventional grouting has a disadvantage of rock lift-movement and seepage flow, which brings about serious surface crack and body damage for the dam foundation. The grouting intensity number method can achieve fracture plugging effectively so as to decrease the rate of permeable rock mass, which makes it have strong resistance for erosion and piping damage. By comparison with the two grouting methods, analysis results showed that the grouting intensity number method overcame the shortages of conventional grouting and had an advantage of high stability and safety. This study has a great significance for the development of effective foundation treatment method in hydraulic construction projects.**

Keywords-Conventional grouting; Optimization study; Osmotic pressure; Grouting intensity number.

I. INTRODUCTION

In the field of hydraulic engineering construction, foundation treatment has a critical role to the project quality. Through the base treatment, improve the integrity and foundation bearing capacity and the permeability resistance. Hydraulic structures, especially the dam foundation engineering, osmotic pressure is the most important factor affecting the engineering operation and safety [1-10]. If the osmotic pressure goes out of reasonable rang, it would bring about serious consequences as follows: (1) large number of economic losses caused by leakage; (2) wash damage of dam foundation and dam body caused by concentrated seepage flow; (3) high dam foundation uplift pressure on the dam body and dam foundation stability. Foundation treatment is the most effective solution to the above issues, and in the construction of hydraulic project, grouting is one of the important measures to foundation treatment. So finding out the main factors to grouting effect and grouting method optimization have great instructive significance to the safety and quality of hydraulic construction engineering.

The paper is organized as follows. In section 2 and 3, conventional grouting and GIN grouting was analyzed respectively. In Section 4, the two methods were compared and obtained the advantages and disadvantages. At last, some conclusions are given in section 5.

II. CONVENTIONAL GROUTING

In addition to special grouting situation, conventional grouting usually adopts full-hole-one or more commonly segmented grouting which includes top-down segmentation method, bottom-up segmentation method and comprehensive section three forms. The grouting pressure is determined according to the depth and geological conditions. Besides extremely obvious fissure, grouting slurry concentration (water-cement ratio) generally begins with thin slurry and changes to thick slurry gradually. In the filling period, the grouting hole often contains all kinds of width of crack. In order to make the fissure be grouted sufficiently, it is better to use low viscosity thin slurry firstly so as to meet the needs of small crack. After completion of the basic grouting, thick grout is grouted into large crack, which is widely used in our country. The current specification provides that concentration of the filling slurry should follow the principle of thin to thick and being thick step by step. Grouting can use the water cement ratio of 8:1, 5:1, 3:1, 2:1, 1.5:1, 1:1,0.8:1,0.6:1,0.5:1, and the beginning water cement ratio generally goes to 8:1.

During the conventional process of grouting method, slurry concentration is changed from thin to thick, which makes it a complex, time-consuming and high demanding work. What is more, in the process of filling, it is hard to control when and which kind of slurry concentration need to be grouted, which always results in unnecessary slurry consumption. In addition, when it comes to the use of unstable slurry grouting, water is separated into small cracks and cement particle is left behind, which would increase the mass lift force on the rock. If the slurry is too thin, holes and leakage passage would appear after grouting and groundwater flows along these holes and channel, which makes the cement in the loose stones be gradual corroded, affecting the durability of the curtain. After the grouting, it is need to drainage with closed pore which extends the grouting time again. Obviously, conventional grouting method has the following disadvantages: (1) the failure in the process of grouting; (2) multifarious process of changing slurry grouting with low efficiency and high cost; (3) slurry separation in the low irrigation period, low mechanical strength of cement stone, and poor corrosion resistance, thus the grouting quality is difficult to guarantee; (4) grouting simulation of thin to thick applies to small cracks and when it comes to wide crack, slurry may be filled far more than the design requirements, causing grout waste; (5) grouting simulation of thin to thick would increase the cohesive force which hinder the slurry flow and penetration in the rock mass, and even make the grouting process is terminated.

III. GIN GROUTING

In order to overcome the shortage of conventional grouting and improve grouting quality and efficiency, Lombardi and Deere proposed "Dam batholith GIN grouting method" [11]. GIN grouting intensity values were defined as the product of the final grouting pressure and absorption per meter for a given single borehole, within a certain period at the end of grouting the result is a constant value.

$$GIN = PV \quad (1)$$

where P is the final grouting pressure and V is the ultimate grout take which means the energy consumption per unit grouting period.

In the grouting construction, keep the grouting section of energy consumption to be consistent, which meant GIN was constant and formed a roughly uniform impervious curtain. By keeping the GIN to be constant, the grouting quantity can be automatically limited for wide crack and the grouting pressure can be improve for micro fractures, avoiding the ground lift movement and the high pressure of hydraulic fracturing and large grouting quantity, and the low pressure for micro fractures and small filling quantity. As shown in figure 1, the greater the grouting pressure was, the less the grouting quantity was and vice versa, eventually the two factors came into a hyperbolic relationship.

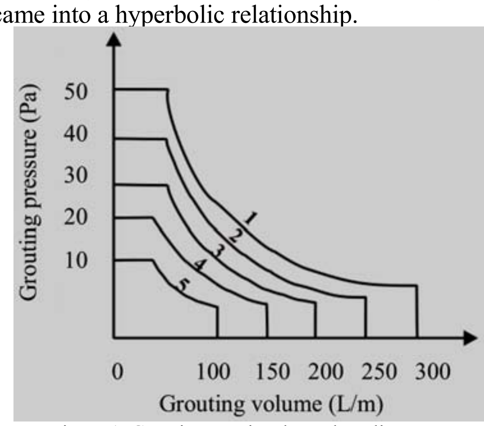

Figure 1. Grouting restricted envelope line.

TABLE I CORRESPONDING DATA TO THE ENVELOPE CURVE

Grouting intensity (bar •L/m)	>2500	2000	1500	1000	<500
Maximum pressure(Pa)	50	40	30	22.5	15
Maximum volume(L/m^{-1})	300	250	200	150	100

GIN value varies with different geological conditions, but GIN is constant under the similar condition. It needs to be noted that the GIN each envelope curve includes a maximum pressure and maximum absorption slurry in addition to a GIN value. When the injection rate reaches a predetermined limit, or pressure reaches the limit, or the product of the two factors achieve the selected GIN, the grouting can be ended.

GIN method needs to select the appropriate value of GIN and there are three kinds of methods: (1) Mathematical method which is established by accurate or simplified description of rock fracture situation and on this basis, simulate the grouting process so as to get a reasonable GIN value and this method is only applicable to simple situation; (2) Experiment method which is established by choosing the same or similar regional grouting area to perform grouting experiment to get reasonable values of GIN and this approach is necessary in all cases. (3) Observation method which is established by previous experience and literature (Lombardi suggestions of five kinds of GIN). Assume a temporary GIN value and revise the value according to the results in the process of grouting to get reasonable values of GIN. Generally, the above three methods are taken into comprehensive consideration, combining the natural conditions of the rock and the design requirements and economic factors in the process of grouting to choose one of the most effective GIN value. Single and stable slurry is an important factor for GIN and the grouting slurry must be stable and has high consistency and low adhesiveness and good penetrability of rock fracture to make the cement slurry filled in have stable performance, low drainage rate high strength and good anti-seepage after coagulation with the rock. The stable grout needs to be determined through indoor test and many large engineering projects. The grout is mixed with high plasticizer to reduce the size of the plasticizer and viscosity and the slurry water cement ratio is controlled of 0.66:1-0.8:1. It is known that grout used in GIN grouting method is thick grout, so before grouting, the rock above the underground water level need to be immersion saturated so as to avoid the water in the slurry absorbed by the dry rocks, leading to jams phenomenon because of high concentration. In the process of grouting, in order to minimize the negative impact of the hydraulic fracturing and reduce the grout consumption, grouting pressure should be kept below the critical level. A lot of engineering examples showed that the critical pressure did not depend on overburden pressure in most case, but depended on the strength of the rock. In soft rocks below the ground surface, intensity usually did not vary with depth and as well as the critical pressure.

IV. ADVANTAGES AND DISADVANTAGES OF ANALYSIS

Compared with the conventional grouting, GIN grouting used single water cement ratio, stability and thick slurry in the process of grouting. As a kind of predictable Bingham fluid, the cohesive force remains constant to ensure the flow characteristic of the slurry and penetration. Compared with the slurry used in conventional grouting, the GIN grouting slurry has a long distance migration stability, less precipitation under the slow flow state and low extrusion force and little filtered water when slurry flows through narrow thin cracks, so it has little damage of hydraulic fracturing forced on the rock. Due to using a single consistency of stable and uniform GIN value during the slurry grouting process, it is unnecessary to change the water cement ratio of slurry, which makes the working process simplified, saving the grouting time. At the same time, it is advantageous for the computer automatic to control the grouting factors and improve the work efficiently. Due to large slurry cement content and high density, after being grouted into rock, the hardening contractility is small, so the structural plane in combination with the rock has high strength which can achieve effective plugging fracture so as to decrease the rate of permeable rock mass, have stronger ability to resist erosion and piping and anti-seepage curtain. The grouting pressure is increased gradually in the process of GIN grouting, until pressure, volume and GIN reach the grouting ending standard. The ending standard of conventional method is few consumption under design pressure (grout absorption rate less than a design value) and continue to grout for 30~60 minutes. As shown in some GIN method grouting projects, another characteristic of conventional method compared with GIN method is material saving and the average unit injection quantity is 30% ~53.4% of conventional grouting method. Figure 2 is drawn from comparison of GIN method and conventional method by calculating unit consumption of the cement discharge (P, S, T, respectively first, second and third row) based on the Xiaolangdi project data. Two methods were applied in the left bank of the second and fourth grouting sections, unit cement consumption and the grouting time of each section were calculated and recoded. It can be known that the GIN grouting reduced the economy and time cost for a project.

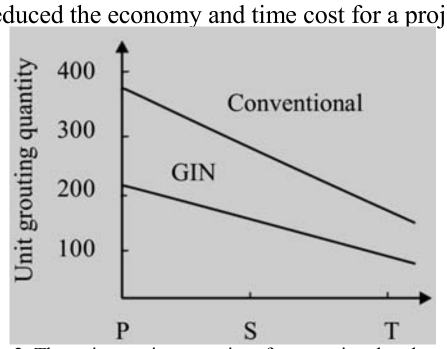

Figure 2. The unit grouting quantity of conventional and grouting intensity number methods.

TABLE I CORRESPONDING DATA TO THE UNIT GROUTING QUANTITY

Section position	1#	2#	3#	4#	5#
Conventional grouting	91.5	140	130	122.5	115
GIN grouting	137	250	280	248	210

V. CONCLUSION

GIN grouting overcomes many shortcomings of conventional grouting, improves the efficiency and quality of grouting and reduces the cost of grouting engineering. The critical disadvantages of conventional grouting are complex grouting process and operation, low grout take efficiency and slurry segregation and excessive grout loss, which cause frequent engineering accidents and damage to the dam foundation safety and high project cost. The essential advantages of GIN grouting are simplified high-efficiency grouting operation, constant cohesion and erosion and grouting piping resistance, which ensure the grout mobility and penetrability. In addition, GIN grouting shows excellent stability during long distance transportation, which applies well to large-scale high-depth hydraulic dam engineering.

However, GIN method overlooks the slurry rheological properties, hydrogeological characteristics and the sensitivity of the hydraulic fracturing, so GIN theory shows a limited applicability to slurry with complex characteristics. Most engineering grouting test results showed that it was difficult for GIN grouting to be carried out and the grouting effect is not obvious for rock formation with permeable rate below 1 L_u . It is recommended to subdivide GIN constants to obtain proper GIN value.

REFERENCES

[1] Lisheng Xu, Wei Chen, Huanyun Peng, Meng Xu, "Study on high accurate dynamically monitoring water cement ratio nuclear densimeter and its application", Journal of Central South University (science and technology), vol.4, pp.647-650, 2009.

[2] Ministry of Water Resources of the People's Republic of China, "SL223-2008", Acceptance code of practice on water resources and hydroelectric engineering, China Water Resources and Hydropower Press, Beijing, 2008.

[3] The state economic and trade commission of the People's Republic of China, "DL/T5148-2001". Technical Specification for Construction for cement grouting of the hydraulic structures. China Water Resources and Hydropower Press, 2012.

[4] Jingxiu Zhang, "Technology of base of dam permeate proof and grouting", Water Resources and Hydropower press, Beijing, 2008.

[5] Yuanfei Yang, "Study on Un-contacted Density and Level Measurement for the Flow System of Viscous Slurry", Sichuan University, Chengdu, 2005.

[6] ISSA RI, "Solution of implicitly discredited fluid flow equations by operator splitting", Journal of Computational Physics, vol.1, pp.40-65.

[7] Songling Wang, "Fluid mechanics", China Electric Power Press, Beijing, 2004.

[8] Shengjian Liu, Hongtao Leng, Aijun Zhao, "Application of modular formation tester on KD48 well", Well Testing, vol.1, pp.68-69, 2007.

[9] MIGUEL A, FARID B, "Numerical modelisation of the flow in centrifugal pump: volute influence in velocity and pressure fields", International Journal of Rotating Machinery, vol.3, pp.244-255, 2005.

[10] Lisheng Xu, Dingming Guo, Huanyun Peng, "Development and practice of LJ-Ⅱ grouting and pressing water monitoring system", Water Resources and Hydropower Engineering, vol.11,pp.68-69,2003.

[11] Zhao Sun. The dam bedrock grouting. China Water Power Press, Beijing, 2003.