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Research on the Bionic Non-Smooth Nozzle for High-Pressure Jet Grouting Based on Computational Fluid Dynamics

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***Abstract*—In the practical engineering, high-pressure jet grouting (HPJG) has been widely used for reinforcing the soil mass and preventing seepage in the many different fields. Nozzle is the crucial component for HPJG, its hydraulic characteristics determine the working efficiency of HPJG directly. The bionic non-smooth technology is applied to design the nozzle's internal structure. According to the computational fluid dynamics (CFD) to compare the hydraulic characteristics of the normal nozzle and the bionic non-smooth nozzle, comparing the values of impact forces of high-pressure cement-slurry jets impact on the soil mass surfaces ejected by them, the value of bionic non-smooth nozzle is 17.05 N bigger than the normal nozzle. The relevant results show that the bionic non-smooth nozzle has better hydraulic characteristics. In addition, the grooves with equal intervals on the inner walls make the nozzle with a non-smooth surface. Moreover, the opposite rotational vortexes in the grooves on the inner walls of the bionic non-smooth nozzle are the main reason for increasing efficiency and reducing energy consumption.**

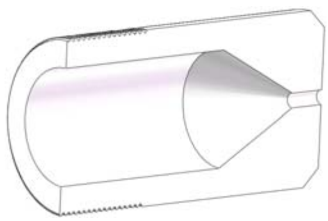
Keywords—High-pressure jet grouting; bionic non-smooth; nozzle; CFD

I. INTRODUCTION

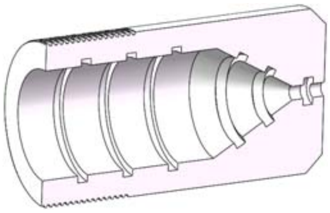
High-pressure jet grouting (HPJG) is an effective method to reinforce soil mass and to prevent seepage which has been widely used in the different practical projects for many years. Such as civil engineering, hydraulic and hydro-power engineering, railway transit engineering, geohazard prevention and control engineering, etc. These all achieved the significant social and economic benefits by using HPJG [1-7]. It is necessary to note that the high-pressure cement-slurry jet to impact and cut the soil mass is the crucial step in the whole process of HPJG. Its efficiency directly determines the overall efficiency of HPJG. Thus, it is an effective way to maximize the efficiency of high-pressure cement-slurry jet which is to increase the working efficiency of HPGJ effectively. However, the nozzle is the crucial component for producing high-pressure cement-slurry jet. The better the nozzle's internal structure, the higher the efficiency of high-pressure cement-slurry jet. In this study, the bionic non-smooth technology is applied to design the nozzle's internal structure. According to many practices show that this technology can effectively reduce the fluid resistance and increase the efficiency [8-9]. Computational fluid dynamics (CFD) is an effective method to study the problems about fluid which has been accepted by all over the world for many years, it has been widely used for aerospace, warship, missile, civil engineering, oil and gas engineering, etc. for many years [10]. The normal nozzle and the bionic non-smooth nozzle with the same structures under the same experimental conditions are compared researches based on CFD.

II. STRUCTURES OF NOZZLES FOR HPJG

In the practice, the straight cone nozzle is the most commonly used for HPJG, as shown in Figure 1 and Figure 2. The straight cone nozzle mainly consists of three parts: connection section, contraction section, outlet section [11-12]. For the normal nozzle, the all of the internal surfaces are smooth. The structure parameters mainly include the inlet diameter (D=32 mm), outlet diameter (d=4 mm), contraction angle (θ=60°), length of connection section (l_1=54 mm), length of contraction section (L=24.25 mm) and length of outlet section (l_2=10 mm). But for the bionic non-smooth nozzle, the grooves are arranged at equal intervals on the all of the internal surfaces. Its internal surfaces show the bionic non-smooth morphological characteristics. Its structural parameters are in addition to the structural parameters in the normal nozzle mentioned above, also including width of groove, height of groove.

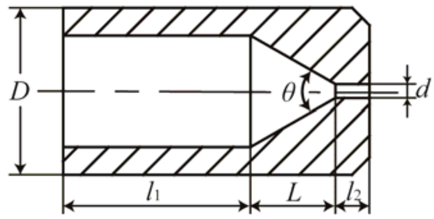


(a) Normal nozzle

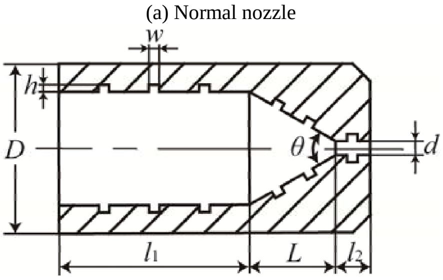


(b) Bionic non-smooth nozzle

FIGURE I. THE CUTAWAY VIEW OF THREE-DIMENSIONAL MODEL OF THE STRAIGHT CONE NOZZLES



(a) Normal nozzle

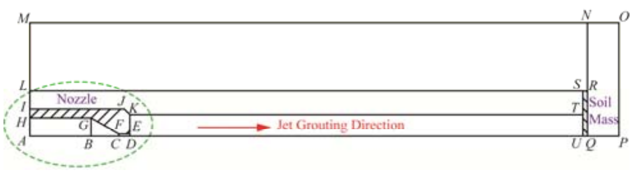


(b) Bionic non-smooth nozzle

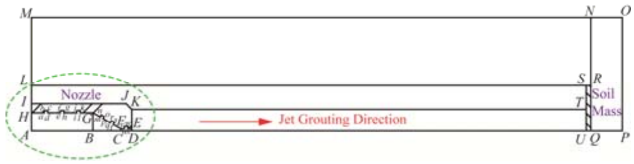
FIGURE II. THE DIAGRAM OF THE CONCRETE STRUCTURES OF THE STRAIGHT CONE NOZZLES

III. MODELING

In this study, the aim is to compare the two kinds of nozzles' hydraulic characteristics under the same conditions for HPJG based on CFD. Due to the entire models are axisymmetry, the half models just need to be created. Figure 3 shows the two kinds of nozzles' models. The zone of *ABCDEKJI* means nozzle. In which, the zone of *ABCDEFGH* means internal structure of nozzle, the zone of *EFGHIJK* means nozzle's external wall. The zone of *abcd-efgh-ijkl-mnop-qrst-uvwx* means six grooves on the internal surfaces of the bionic non-smooth nozzle at the same intervals. The zone of *QRSTU* means soil mass. The jet distance is the length of *DU*, it means the high-pressure cement-slurry ejected from the nozzle's outlet to the soil mass surface. These two models show the process of high-pressure cement-slurry jet ejected from the two kinds of nozzles to the surface of soil mass, the ambient medium is air. In order to simplify the simulation, the groundwater and the cement slurry remaining in the borehole are ignored. Thus, it belongs to the non-submerged jet.



(a) Normal nozzle

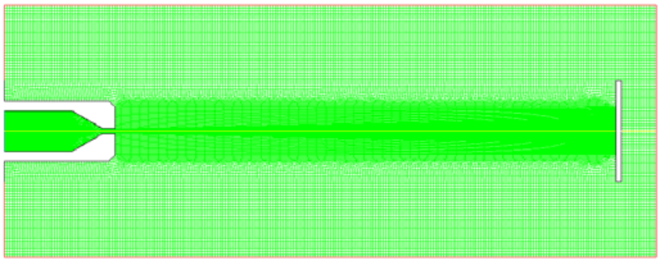


(b) Bionic non-smooth nozzle

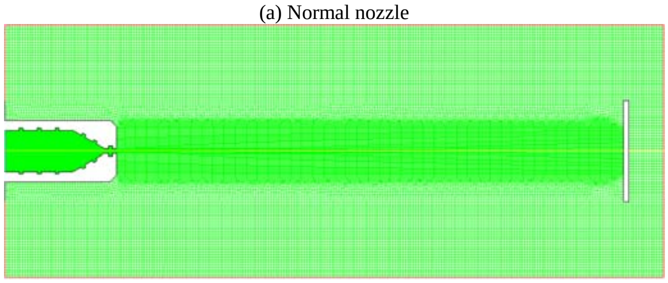
FIGURE III. THE ENTIRE MODEL FOR HPJG BASED ON CFD

IV. MESHING AND BOUNDARY CONDITIONS SETTING

Because the quality of meshing directly determines the result of simulation, it is very important to take a suitable scheme for meshing. Considering the shape of models, the hybrid grids are taken in this study. The zones of *ABGH*, *CDEF*, *DEKTU*, *LMNS*, *NOPQR*, *abcd*, *efgh*, *ijkl*, *mnop*, *qrst* and *uvwx* are all taken the structured grids for meshing. Others are taken the unstructured grids. Figure 4 shows the situations of meshing for CFD. In addition, the boundary conditions mainly include the Pressure Inlet (*AH*=30 MPa), the Pressure Outlet (*IL*, *LM*, *MN*, *NO*, *OP*=101325 Pa), the Axis (*AB*, *BC*, *CD*, *DU*, *UQ*, *QP*=101325 Pa) and the wall (the zones of the external wall of nozzle and the zone of soil mass).



(a) Normal nozzle



(b) Bionic non-smooth nozzle

FIGURE IV. THE SITUATIONS OF MESHING FOR CFD

V. POST-PROCESSING AND RESULTS ANALYSIS

The velocity contours of cement-slurry jet ejected by the two kinds of nozzles for HPJG based on CFD as shown in Figure 5. Comparing the area where the high-pressure cement-slurry jets impact on the surfaces of soil mass in the following two pictures, the bionic non-smooth nozzle is larger than the normal nozzle. In addition, comparing the values of impact forces of high-pressure cement-slurry jets impact on the surfaces of soil mass ejected by the two kinds of nozzles, the bionic non-smooth nozzle is 17.05 N bigger than the normal nozzle.

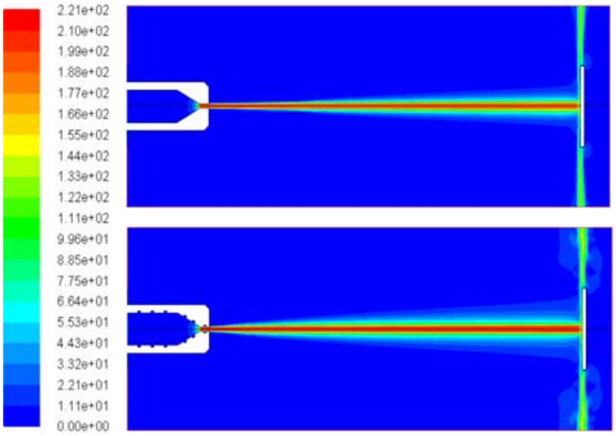


FIGURE V. VELOCITY CONTOURS OF CEMENT-SLURRY JET FOR HPJG BASED ON CFD

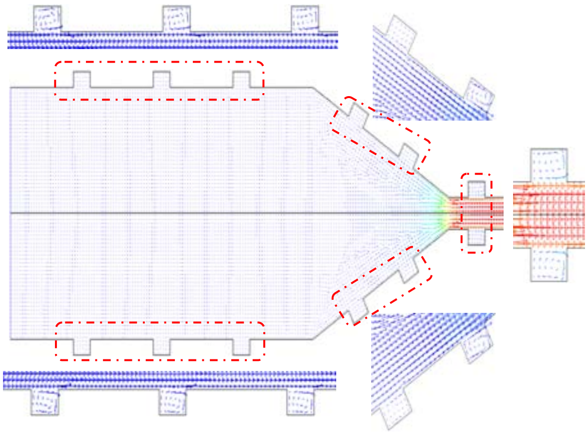


FIGURE VI. FLUID TRACE GRAPH OF THE BIONIC NON-SMOOTH NOZZLE FOR HPJG BASED ON CFD

In order to better reveal the mechanism of fluid flows in the bionic non-smooth nozzle, the fluid trace graph should be studied. Figure 6 shows the fluid trace graph of the bionic non-smooth nozzle for HPJG based on CFD. The vortexes are produced in the all grooves of the bionic non-smooth nozzle. Moreover, the rotational directions in all grooves are counterclockwise. In other word, the all vortexes rotate in the opposite direction of flow. Because of this, there are four beneficial effects for increasing efficiency and reducing energy consumption as follows: (1) Adding thrust. The opposite rotational vortexes can provide the additional thrust for high-pressure cement-slurry in the nozzle. (2) Hydraulic rolling bearing. The opposite rotational vortexes like several hydraulic rolling bearing on the internal surfaces of nozzle, they can reduce the friction between high-pressure cement-slurry and the nozzle's internal surfaces effectively. (3) hydraulic pads. The opposite rotational vortexes touch with the high-pressure cement-slurry directly in the nozzle, resulting in the liquid-liquid contact replaces the liquid-solid contact. Thus, the friction can be reduced to a certain extent. (4) Reducing erosion of solid particles. The solid particles in the cement-slurry erode the inner walls of nozzle directly, the non-smooth surface makes the inner walls of nozzle discontinuity, so as to reduce the area in which solid particles touch the inner walls, resulting in the erosion reduced. In the meantime, the opposite rotational vortexes can provide the lateral forces to avoid the solid particles directly impact on the inner walls to a certain extent. Therefore, the life of nozzle can be extended than before. This also means the comprehensive efficiency of nozzle for HPJG can be improved.

VI. CONCLUSIONS

According to the above discussion, the following conclusions can be obtained as follows: (1) It is a feasible approach to design the internal structures of nozzle with the bionic non-smooth technology. (2) The bionic non-smooth nozzle has the better hydraulic characteristics than the normal nozzle for high-pressure jet grouting. (3) The opposite rotational vortexes on the internal surfaces of nozzle are the main reason for increasing efficiency and reducing energy consumption.

ACKNOWLEDGEMENT

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REFERENCES

[1] PGA Njock, J Chen, G Modoni, et al., A review of jet grouting practice and development, Arabian Journal of Geosciences, 2018, 11(16): 1-31.

[2] PGA Njock, JS Shen, G Modoni, et al., Recent advances in horizontal jet grouting (HJG): An overview, Arabian Journal for Science and Engineering, 2018, 43(4): 1543-1560.

[3] Jiwei Wen, Xiangjun Pei, Wenchen Wang, et al., Discussion on several problems of high-pressure jet grouting in seepage prevention and reinforcement, Exploration Engineering (Rock & Soil Drilling and Tunneling), 2016, 43(10), 56-62.

[4] Mingsen Wang, Hongen Wang, Zhenheng Zha, et al., High-pressure jet grouting anti-seepage reinforcement technology, China Water & Power Press, Beijing, 2010.

[5] Yongcheng Zhang, Shuning Dong, Jianshen Su, et al., Grouting Technology, China Coal Industry Publishing House, Beijing, 2012.

[6] Xingwang Zhou, Gangrong Gao, Zhifeng Bo, et al., Grouting construction manual, China Coal Industry Publishing House, Beijing, 2013.

[7] Chunlei Peng, Xiaodong Yang, Dong Ma, et al., Anchorage and grouting equipment manual, China Electric Power Press, Beijing, 2013.

[8] Luquan Ren, Yunhong Liang, The introduction of bionics, Science Press, Beijing, 2016.

[9] Jiwei Wen, Chen Chen, Ziwei Qi, et al., Research to break oil shale with high pressure water jet based on bionic nozzle, Procedia Engineering, 2014, 73: 264-268.

[10] Fujun Wang, Computational fluid dynamics analysis-CFD software principles and applications, Tsinghua University Press, Beijing, 2005.

[11] Jiwei Wen, Chen Chen, Optimizing the structure of the straight cone nozzle and the parameters of borehole hydraulic mining for Huadian oil shale based on experimental research, Energies, 2017, 10(12): 1-14.

[12] Jiwei Wen, Chen Chen, Urso Campos, Experimental research on the performances of water jet devices and proposing the parameters of borehole hydraulic mining for oil shale, PLOS ONE, 2018, 13(6): 1-32.