Numerical Experimental Study on Influence of Jet Diameter on Rock Breaking by High Pressure Water Jet

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Abstract

Water jet rock breaking technology has been widely used in many engineering fields, but its rock breaking efficiency has many influencing factors and complex mechanism. Based on numerical experiments, a numerical model of water jet is established. The dynamic nonlinear finite element method is used to study the effect of jet diameter on rock failure efficiency under different well depth conditions based on ANSYS/LS-DYNA. The results show that under different jet diameters, with the increase of jet diameter under the same time, the influence range of stress wave increases and the amount increases continuously. The effective plastic strain law does not change but the magnitude increases continuously, and the rock breaking depth increases, but It is not obvious under the influence of gravity stress and confining pressure of rock.

Keywords

Water jet; rock damage; Water jet diameter; Numerical test.

1. Introduction

With the continuous development of social economy, traditional methods of oil and gas resource exploitation can no longer meet the increasing energy demand. More and more oil and gas production technologies have emerged, which play an important role in the exploitation of oil and gas. Among them, high pressure water jet Rock breaking technology is a widely used technology. Sandstone is a common rock in nature and is widely used in our daily life, especially for the petroleum industry. More than 60% of the world's oil and gas is stored in sandstone, which is the focus of petroleum geologists.

A lot of theoretical derivation and physical experiments have been carried out on the study of water jet rock breaking, and some achievements have been made. However, due to the numerous factors affecting rock breaking and the complicated rock breaking mechanism, there are still many problems that need further research[1-3]. With the development of computer technology, the use of numerical techniques to simulate water jet breaking rock has become an important means of studying water jets, and has made some progress. Cao, et al. established a finite element model of pulsed water jet rock breaking, simulated the rock breaking process at different incident velocities, analyzed the influence of jet velocity on rock breaking efficiency, and obtained the optimal incident velocity of the corresponding model[4]. Song and other applications use ANSYS/LS-DYNA software to simulate the three-dimensional nonlinear impact dynamics of high-pressure water jet rock breaking, and obtain the energy conversion relationship and jet impact time-history curve during rock breaking process, which better reflects the water. The real physical process of jet breaking rock [5]. Lei, et al. used the dynamic nonlinear finite element method to study the control parameters such as jet velocity, diameter and incident angle during high-pressure water jet rock breaking process. The dynamic finite element analysis of rock failure under different well depth conditions was found. The jet efficiencies achieved by different jet control parameters are significantly different [6].

Most of the above studies have carried out research on the mechanism of water jet rock breaking. In this paper, the numerical model of water jet is established by numerical test method. The dynamic nonlinear finite element method is used to simulate the jet diameter under different well depth conditions based on ANSYS/LS-DYNA. The study on the influence of rock failure efficiency is to provide the most efficient rock breaking parameters for water jet rock breaking.

2. Model establishment

2.1 Calculation model

For the consideration of computing resources, efficiency and other aspects, a two-dimensional numerical model as shown in Fig. 1 is established to consider the high-pressure water flow as a bundle of water flow. Considering the damage failure of the rock, the model boundary is set to a semi-infinite surface, and the jet is set. The injection surface is a free surface. Under the action of high pressure water jet, the rock adopts Lagrange method[7].

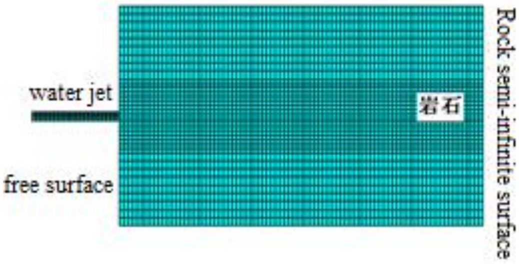


Fig. 1 Impacting rock model by pressure water jet

2.2 Material parameters

In the simulation of this paper, the high pressure water flow is considered as a completely plastic material, that is, the yield stress is zero. The mechanical parameters of sandstone are taken from the rock mechanics parameters. The specific material mechanical parameters are shown in Table 1.

Tab.1 Mechanical parameters

	Elastic Modulus（MPa）	Poisson's ratio	Density（kg/m3）	Friction angle（°）	Cohesion（MPa）	Compressive strength（MPa）	Tensile strength（MPa）
Sandstone	3.55×103	0.16	2.4×103	45	2.6	73.5	9.2
Water flow		0.45	1.05×103				

2.3 Test plan

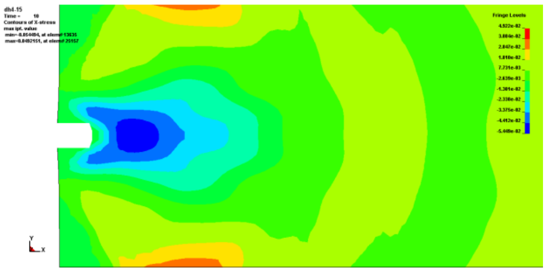
In the simulation of the effect of perforation diameter on the rock breaking effect of high-pressure water jet impact, the fixed jet velocity is 200m/s, and the perforation diameters are selected as 5mm, 5mm, 6mm, 7mm and 8mm, respectively. For the three boundary conditions of 1000m, 1500m and 2000m, the specific simulation conditions are set as shown in Table 2.

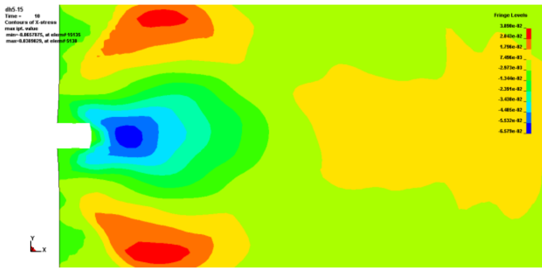
Tab.2 Jet diameter study simulation conditions

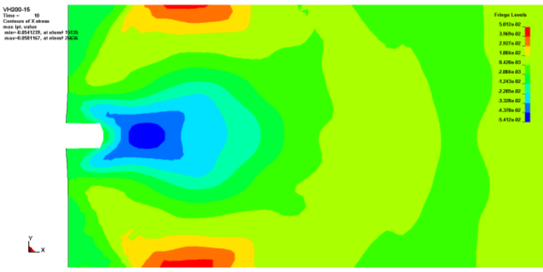
Working condition number	Perforation diameter（mm）	Vertical stress（MPa）	Confining pressure（MPa）	Deep well（m）
DH4-10	4	24	10	1000
DH4-15		36	15	1500
DH4-20		48	20	2000
DH5-10	5	24	10	1000
DH5-15		36	15	1500

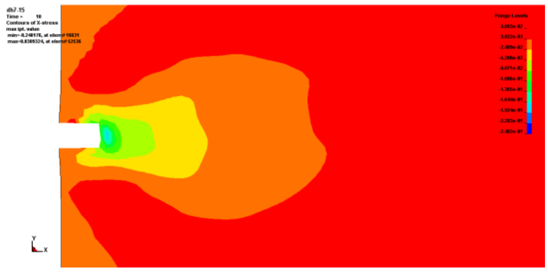
DH5-20		48	20	2000
DH6-10	6	24	10	1000
DH6-15		36	15	1500
DH6-20		48	20	2000
DH7-10	7	24	10	1000
DH7-15		36	15	1500
DH7-20		48	20	2000
DH8-10	8	24	10	1000
DH8-15		36	15	1500
DH8-20		48	20	2000

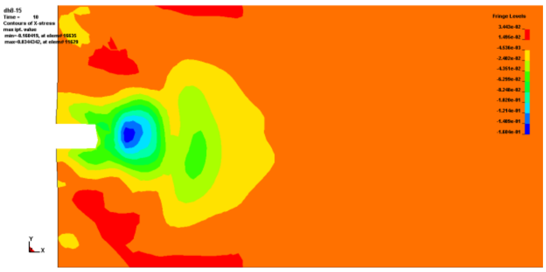
3. Analysis of rock breaking efficiency of jet diameter


DH4-15


DH5-15

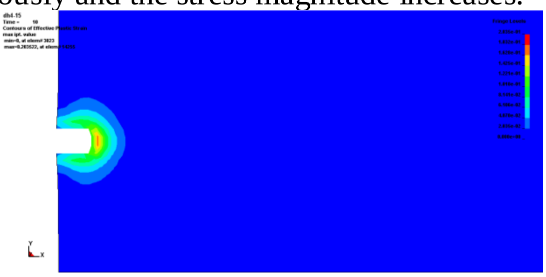

DH6-15


DH7-15


DH8-15

Fig,2 Stress model of rock mass under different jet diameters at the same well depth at 10ms

By comparing and analyzing the rock stress wave maps with different jet diameters at the same time, it can be clearly seen that as the jet diameter increases, the stress wave action area increases continuously and the stress magnitude increases.


DH4-15


DH5-15

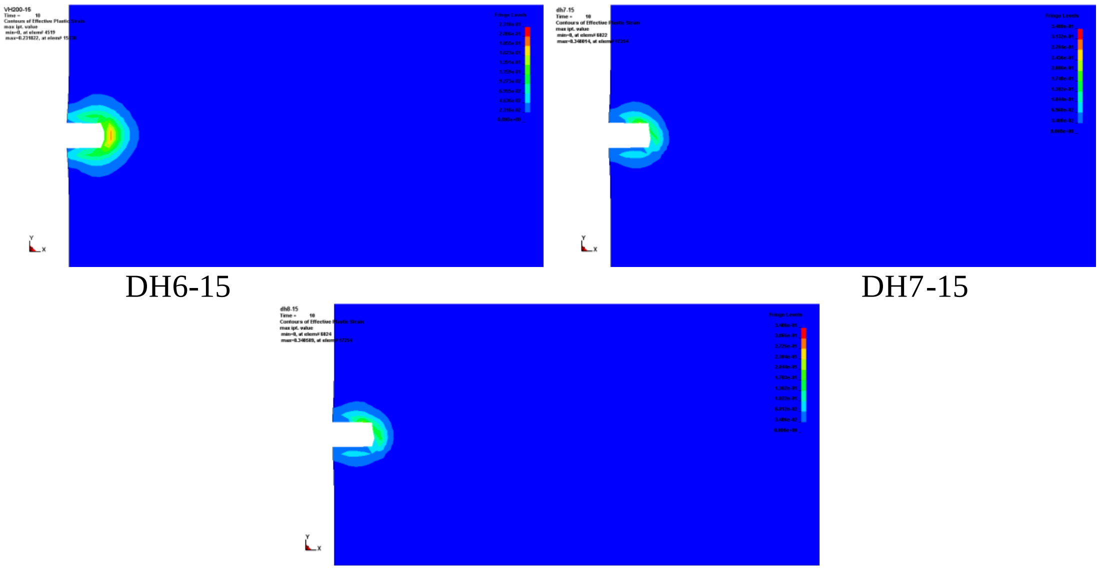
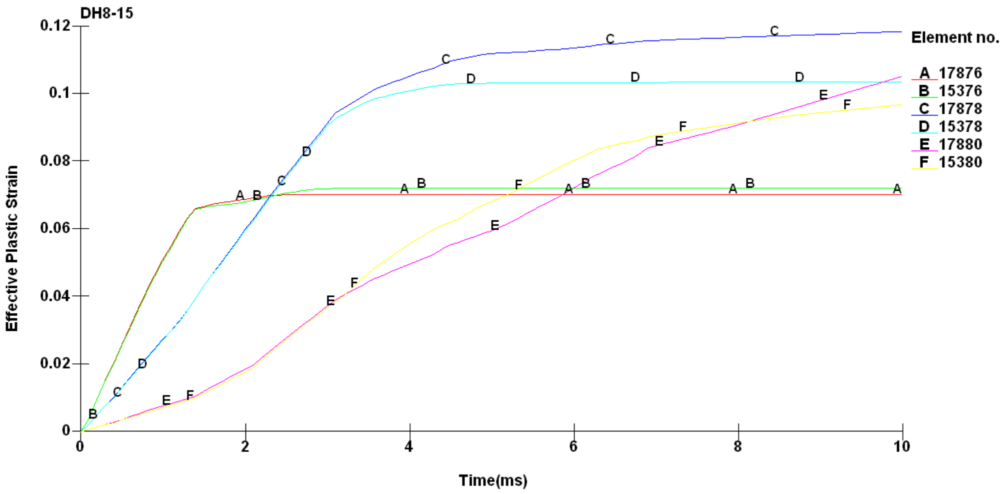


Fig.3 Equivalent plastic strain cloud diagram of rock mass under different jet diameters at the same well depth at 10ms

By comparing and analyzing the equivalent plastic strain cloud images of different jet diameters at the same time, it can be clearly seen that as the jet diameter increases, the effective plastic strain region develops continuously.



Fig,4 Plastic strain time history curve of jet diameter 8mm

There is also a significant change in the plastic strain time-history curve above. As the diameter of the jet increases, the plastic strain value corresponding to the upper and lower positions of the perforation begins to separate. When the jet diameter varies between 4mm and 6mm, Almost completely overlapping, when the jet diameter varies between 7mm and 8mm, separation begins and the degree of opening increases.

It can be concluded from the above analysis that the jet diameter has little effect on the rock-breaking efficiency of the high-pressure water jet. As the jet diameter increases from 4 mm to 8 mm, the rock-breaking depth increases little, but the perforation increases due to the increase of the jet diameter. The effective plastic strain at the top and bottom begins to differ.

In the study of the effect of water jet diameter on impact rock, the final rock breaking depth of each simulated working condition in the calculation time is shown in Table 2.

Tab.2 Jet diameter affects rock breaking depth in simulated working conditions

Simulation condition	Rock breaking depth（mm）
DH4-10	17.42

DH4-15	17.42
DH4-20	17.42
DH5-10	17.05
DH5-15	17.00
DH5-20	17.00
DH6-10	17.51
DH6-15	17.49
DH6-20	17.47
DH7-10	16.77
DH7-15	16.77
DH7-20	16.77
DH8-10	21.21
DH8-15	21.21
DH8-20	20.90

The diameter of the jet and the depth of the rock are generally linear. Under the same time, the depth of the jet increases with the increase of the diameter of the jet. The solid rock can be used in the field, machinery and other conditions. If possible, increase the jet diameter to achieve rapid rock breaking, but the jet diameter cannot be increased without limit.

4. Conclusion

In this paper, the numerical simulation method is used to simulate the high-pressure water jet rock breaking. The effect of jet diameter on the rock-breaking efficiency of rock under different well depth conditions is studied. The results show that:

(1) The water jet impacts the rock first to form stress concentration near the contact part. As the impact process continues, the stress wave expands outward and the stress value increases continuously. During the whole impact process, the shape of the stress change region remains basically unchanged. The stress maximum region is symmetrically distributed. The maximum compressive stress occurs immediately in front of the hole, and the tensile stress zone continues to appear inward.

(2) The plastic strain of the rock is roughly symmetric around the jet aperture, and the change is mainly concentrated near the contact surface between the jet and the rock, and it is fan-shaped and continuously develops into the rock.

(3) The diameter of the jet and the depth of the rock are generally linear. Under the same time, the depth of the rock increases with the increase of the jet diameter, and the depth of the well has little effect on the rock breaking depth.

Acknowledgements

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