Applied Mechanics and Materials
ISSN: 1662-7482, Vols. 55-57, pp 945-949
doi:10.4028/www.scientific.net/AMM.55-57.945

Online: 2011-05-03

The Improved PSO Arithmetic for Identifying Ground Stress Based on Rock Core Discing Observation

Annan Jiang [1, a], Zhengwen Zeng [2,b], Junxiang WANG [1,c]

[1]Institute of Highway and Bridge, Dalian Maritime University,Dalian,Liaoning 116026,China

[2] Department of Geology and Geological Engineering, University of North Dakota,Grand Forks,North Dakota,58202–8358,USA

[a]jiangannan@163.com, [b]zane@und.edu, [c]Junxiang_W@163.com

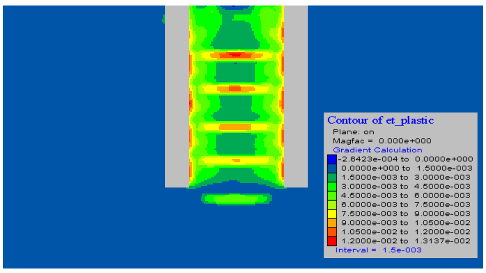
Keywords: Rock core discing, Ground stress identification, Fracture criteria, Particle swarm optimization.

Abstract. Identifying ground stress based on rock core discing can save a lot of surveying cost, so studying "rock core disicing" has great meaning. Aiming at the limitation of conventional methods, the particle swarm optimization (PSO) arithmetic is introduced to be combined with numerical simulation, so as to identify the ground stress based on rock core disicing observation. The objective function of optimization is constructed by combing Mohr-Coulomb criterion and tension criterion. Adopts dynamically adjusting momentum term method and steric compression method so as to improve the PSO in convergence velocity and globally searching property. The proposed method is mentioned and used to identify the ground stress of Bakken formation in USA. The arithmetic has good convergence speed and the identified results are coincident with the former reported results.

Introduction

The practice states rock coring in deep or high stress environment generally companying with "rock core disicing" phenomena, just as Fig.1.[1].Such as there are "rock core disicing" in Ertan power station, Yingxiu power station, bam region of Sanxia and Laxiwa power station in China. As well as nuclear power station of Sweden. These years the "rock core disicing" attracts the scholars' research in world[2-3], including libratory tests, field observing and numerical simulations.

a) Rock core discing in field[1]



b) Rock core disicing of numerical test

Fig.1 The observing and simulation of rock core discing

While drilling in deep or high stress environment, rock core will be cracked to disciform lentils, this is the "rock core disicing", the phenomena is typic reflection of high stress ground. Because the stress is difficult to be measured in these regions, Identify ground stress based on rock core discing can save a lot of surveying cost, so it has great meaning in researching the relation between ground stress and rock core discing. The paper introduced improved PSO arithmetic to be combined with numerical simulation, so as to identify ground stress.

The Improved PSO Ground Stress Identification Method Based on Rock Disicing

Improved PSO Arithmetic. Particle swarm optimization is an evolutionary computing technology simulating the birds flying and preying food. Supposing there are m particles in a population, one of the particles is denoted with $x_i=[x_{i1}, x_{i2},\cdots\cdots x_{il}]$, ($i\leq$m) in l-dimension space, judged by fitting function, then the particles are iterated as following formulas :

$$v_{id}^{k} = w_i v_{id}^{k-1} + c_1 * rand_1 * (pbest_i - x_{id}^{k-1}) + c_2 * rand_2 * (gbest - x_{id}^{k-1}). \quad (1)$$

$$x_{id}^{k} = x_{id}^{k-1} + v_{id}^{k}. \quad (2)$$

In above equations, i=1,2……,m; d=1,2……,l. where k is current iteration step, c_1 and c_2 denote two different positive constants, $rand_1$ and $rand_2$ are two independent random between 0 and 1, $pbest_i$ is local optimal solution of the i^{th} particle in current iteration, $gbest$ is global optimal solution of current iteration, w_i is momentum item coefficient, which may change search ability by adjusting its value. In searching process, each particle approaches to the optimal solution according to flying experience of itself and others. In order to guarantee the convergence velocity of particles, avoid early mature and improve algorithm accuracy, dynamically adjusting momentum term coefficient and compressing searching space[2], the dynamic adjusting formula of momentum term coefficient is as follows.

$$w = w_0\left(1-\left(\frac{k-1}{k}\right)^n \right). \quad (3)$$

Compressing the searching space will accelerate the algorithm convergence, the space compress formulas are as follows.

$$Up'_{\max d} = \beta_0 (Up'_{\max d} - G_{cd}) + G_{cd}. \quad (4)$$

$$Down'_{\min d} = \beta_0 \ (Down'_{\min d} - G_{cd}) + G_{cd}. \quad (5)$$

In the formula, $0 < \beta_0 < 1$,Up'_{maxd}, $Down'_{mind}$ and G_{cd} are respectively the upper and lower boundary of d dimension compress space and geometry barycenter. G_{cd} is calculated by formula (6).

$$G_{cd} = \frac{\sum_{i=1}^{Npop} x_{id}}{N_{pop}}. \quad (6)$$

In above formula, N_{pop} is the population scale of the particles. The velocity of each dimensional particle will be limited by maximal velocity V_{max},if the velocity of one dimension of particle after iteration exceeds the maximal value V_{max}, let it equates to V_{max}.

The Objective Function of Ground Identification. The main cause of distability of rock soil body is the destroy force being much larger than resisting force, the former depends on stress enviroment, the latter depends on strenth parameters of material, rock discing as a destroy phenomena is in this way also.Generally, the stress field changing and stress concentration under core bottom in drilling process induce the core failure. According to classic analysis principle of rock soil engineerings(such as slope stability), the safety degree index should be gotten so as to analyze if the core discing occurs.

The principle of ground stress identification basic thinking is: firstly, According to observed rock disc thickness constructing numerical model, supposing a group of original stresses as initial values, calculates the stress distribution below rock core bench and the safety degree of potential destroy surface, decide if meet to the failure criterion, until the boundary stresses inducing the most critical damage of the potential surface, the corresponding stresses are the ground stresses to be gotten. According to the engineering state, the upper and lower bounds can be set, based on observing rock disc thickness, the ground stress identification objective function ie the fitness functions of particle swarm optimization are as follows:

$$\min E(s_1, s_2, s_3, \cdots, s_n) = \min\{(\sum_{i=1}^{k} abs(1-F_i))\}. \quad (7)$$

$$\min E(s_1, s_2, s_3, \cdots, s_n) = \min\{(\sum_{i=1}^{k} abs(1-F_{\max}))\}. \quad (8)$$

$$s_i^a \leq s_i \leq s_i^b (i = 1,2,\cdots,n).$$

In above formulas, S_i is a variable of field ground stress, n is the number of stresses（is less than or equates 6）, s_i^a and s_i^b are respectively the upper and lower bounds. F_i is the safety degree of each element on cracking surface, i is $1,2,\cdots,m$, is the index of monitoring elements in the cracking surface. F_{max} is the maximal value of F_i. There are two criterions to be used to decide if the rock cracked. Formula (7) means the average of all the elements in crack surface mostly approaching critical state, Formula (8) means the most safe element mostly approaching critical state.

The PSO Calculation Flow of Ground Stress Identification. The ground stress identification progress is an optimal problem in essence. F_i is a nonlinear implicit function of ground stresses, which should be solved by numerical simulation, so the conventional methods are limited. Therefore, the paper introduced a robust computing intelligent optimization arithmetic, PSO to identify ground stresses, the steps are follows:

Step1: Predict the ground scope and select ground variables to be identified according to engineering geologic investigation.

Step2: Observe rock core discing pattern, generalize numerical model and simulation.

Step3: Set initial parameters of PSO, including population scale, particle dimension and learning factor, the scope of variables, iteration number and momentum term. Randomly produced a group of particles, which are correspond to the potential solutions of variables.

Step4: Based on the variables corresponding to particles, carry on numerical simulation, compute the fitness values according to formula (7) or (8).

Step5: Update the position and the velocity of particles according to formula (1),(2), decrease weight w according to formula (3), re-construct searching space according to formula (4)-(6).

Step6: Decide if the ending criterion of minimal fitness value or iteration number is reached. If it is, the iteration is ended, output the ground stress result. Else, turn to Step 4 and continue to iterate. The calculation flow is shown as Fig.2.

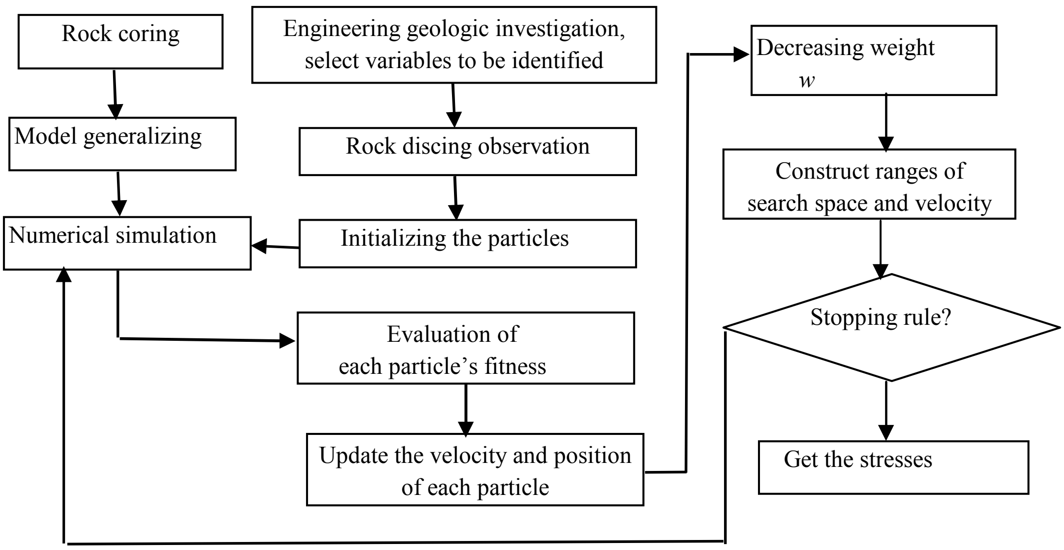
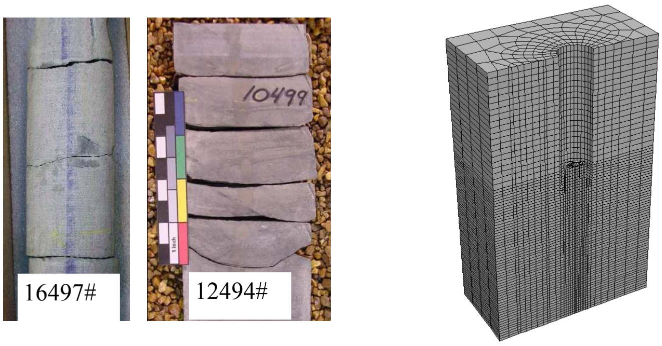


Fig.2 The particle arithmetic flow of ground identification

Engineering Application

Engineering and Parameters Introduction. The Williston Basin is a roughly oval-shaped structural down-warp with a surface area between 120,000 and 240,000 square miles. The Bakken Formation is a thin, naturally fractured Upper Devonian-Lower Mississippian sedimentary unit. It can be divided into three intervals: the upper shale, the lithologically variable middle member, and the lower shale. The rock property and ground stress of the field have been studied by Microfracture Stress Tests, Anelastic Strain Recovery, and Differential Strain Analysis etc[5]. Two groups of rock core of two wells are selected, one is located at the depth of 2907.5m of 16497# , the other is located at the depth of 3200.1m of 12494#. 16497# is horizontal rock core (the direction of rock coring is coincident with the direction of minimal stress), the ratio of thickness of rock disk and diameter of rock core is 2.11. 12494# is vertical rock core, the ratio of thickness of rock disk and diameter of rock core is 1.09. The rock cores and the corresponding numerical model are shown in Fig.3.

PSO arithmetic needs repeating the numerical simulation of rock core discing, according to former research results, the mechanical parameters are as follows: tension strength is 2.5 MPa, Poisson ratio is 0.2, elastic modulus is 20GPa,cohesion is 12.5MPa,inner friction angle is 27 ˚. The PSO initial parameters are set as follows: The dimension of particle is 2, corresponding to k_1 and k_2. The population scale is 14, iteration number is 20, learning factors C_1 and C_2 equates 2, initial momentum factor w_0 is 0.4, the n of adjusting formula(3) is 2, the β_0 of formula (4),(5) is 0.7. The variables (k_1, k_2) to be identified are between (0.25-1).



a) Rock cores b) Numerical model

Fig.3 The rock cores and the corresponding numerical model

Optimizing Results Analysis. Adopts the proposed PSO arithmetic optimized the ground stresses, the results are shown in Table1. According to formula (7),(8), the fitness values are different. And the k_1 are respectively 0.8639 and 0.9069, the k_2 are respectively 0.8833 and 0.7836.

Table1 The identified results corresponding to different evaluation criterias

Fitness function	Iteration number	K_1	K_2	Optimal fitness value	Average fitness value
Formula(7)	11	0.8639	0.8833	1.3763	2.1416
Formula(8)	9	0.9069	0.7836	0.00441	0.42642

Former study[5] adopted Microfracture tests and differential strain analysis(DSA) on the Upper and Lower Bakken to determine the magnitude of minimum principal in-situ stress. According to the researching results that the minimum principal stress is 7950 psi(54.82MPa) and the maximal principal stress 8933 psi(61.59MPa) while the vertical stress is 9945psi（68.57MPa）, the corresponding k_1 and k_2 are respectively 0.898 and 0.890. The paper identified results are coincident with them, which states the proposed method is feasible.

Fig.4 is the best fitness value and average fitness value changing following the iteration respectively of PSO and improved PSO(IPSO), the fitness value function is formula(7). The best fitness is the optimal solution corresponding fitness in current step, average fitness is the average value of the fitness values corresponding all particles of population in current step. It is shown in the figure, convergence velocity of general PSO is slow, and limited in a local optimal solution. However, IPSO has better convergence property, the values can more quickly get the optimal solution.

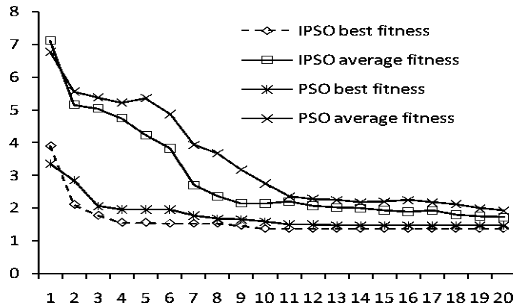


Fig.4 The convergence curve of the PSO and IPSO

Conclusion

Aiming at the limitation of conventional methods, the paper combines improved PSO with numerical simulation, proposed an ground stress identification method based rock core discing observation. The improved arithmetic adopts dynamic momentum factor and space compress method, which improving the convergence speed and globally optimization ability. The method can be automatically identify ground stresses by observing rock core discing, overcoming the blindness of human computing.

The proposed method is used in ground stress identification of Bakken formation in USA. According to the observation of horizontal rock core and vertical rock core, the horizontal stress coefficients k_1 and k_2 are identified as 0.8639 and 0.8833. Which is coincident with the former study of reported. Results stated that IPSO has better convergence property, the values can more quickly get the optimal solution. The proposed not supposing shear destroy or tension destroy, but automatically decided by the stress state of the model, which has the powerful flexibility for the complex condition of rock coring.

Acknowledgements

The authors deeply appreciate support from Fundamental Research Funds for the Central Universities(2009QN050), Liaoning Province Education Depertment Fund(L2010063) and the National Natural Science Foundation (51079010).

References

[1] S.H.TANG,Z.G.WU, X.H.CHEN. Approach to Occurrence and Mechanism of Rockburst in Deep Underground Mines. Chinese Journal of Rock Mechanics and Engineering, Vol22(8)(2003). pp.1250－1254.

[2] J.C.Jaeger, G.W.Cook,N. Pinching Off and Discing of Rocks.J. Geophys. Res., Vol68.(1963).pp. 1759-1765.

[3] L.Obert, D.E.Stephenson, , Stress Conditions under Which Core Discing Occurs. Trans Soc Min Eng AIME.Vol238(1965),pp.227-35.

[4]R.C .Eberhart, J.Kennedy. “A New Optimizer Using Particles Swarm Theory”, Sixth International Symposium on Micro Machine and Human Science (Nagoya, Japan),Piscataway, NJ:IEEE Service Center(1995), pp.39-43.

[5] R.D.Kuhlman, J.I.Perez and Claiborne, Microfracture Stress Tests, Anelastic Starin Recovery, and Differential Strain Analysis Assist in Bakken Shale Horizontal Drilling Program. Paper SPE 24379(1992). SPE Rocky Mountain Regional Meeting, Casper, Wyoming, May 18-21.