# The Development of Particle Swarm Optimization (PSO) for Boundary Element Inverse Analysis to Identify Rebar Corrosion

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## ABSTRACT

*The Particle Swarm Optimization (PSO) method has been used as optimization tool in many engineering problems. One of potential application of PSO method is in inverse analysis. The purposed of this research is to study the behavior of PSO application in boundary element inverse analysis for detecting rebar corrosion. The model of experimental rebar corrosion in concrete was used. The PSO was used to minimize the cost function. Variation in its inertia weight was applied to analyze its influence. The results showed that PSO can be used for the inverse analysis for detecting rebar corrosion by combining with Boundary Element Method (BEM), and depending on W, it will show different behavior in minimizing cost function.*

*Keywords: Particle Swarm Optimization, Boundary Element Method, Inverse Analysis, Optimization*

## 1. Introduction

There are many heuristic search algorithm based on nature. One of them is the the Particle Swarm Optimization (PSO). The use of PSO has increased in popularity recently (Figure 1) [1]. Its advantages include simple algorithm and easy to program, yet proven efficient [1].

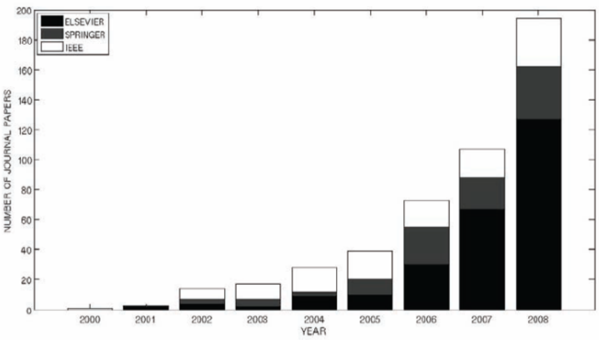


Figure 1. Use of PSO between 2000 and 2008

These characteristics have attracted many researchers to apply PSO to various problems. One of them is inverse analysis [2], [3]. GA has been used for rebar corrosion inverse problem in the past [3]. In this research, the use of PSO in rebar corrosion inverse analysis was studied. Important parameters such as random number generator used, velocity formula constant, and topology parameter was studied. However, this paper only focused inertia weight parameter in order to study optimization behavior.

## 2. Modeling of Steel Corrosion in Concrete

Concrete is referred to as homogeneous domain. There is no accumulation or loss of ions in the bulk of the domain. Thus, the potential field in the concrete domain ($\Omega$) can be modeled mathematically by the Laplace's equation [4-7]:

$$\nabla^2\phi = 0 \quad \text{in } \Omega \tag{1}$$

Eq. 1 shows the basic equation and boundary conditions used in the study. The density of current across the boundaries, which will be denoted by *i*, is given by:

$$i = -\kappa \frac{\partial \phi}{\partial n} \tag{2}$$

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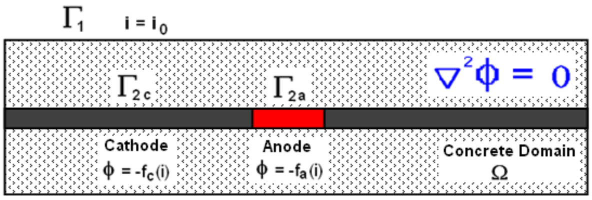


Figure 2. Boundary condition.

The boundary conditions (Figure 2) associated with Eq. 1 are written as:

$$i = i_o \qquad \text{on } \Gamma_1 \tag{3}$$

$$\phi = -f_a(i) \qquad \text{on } \Gamma_{2a} \tag{4}$$

$$\phi = -f_c(i) \qquad \text{on } \Gamma_{2c} \tag{5}$$

where $\phi$ is potential at any point, $i$ is current density, and $f_a(i)$ and $f_c(i)$ are the non-linear functions representing the experimentally determined polarization curves for corroded and non-corroded areas on the steel in concrete, respectively.

If the boundary conditions in Eq. 3 to 5 are known, boundary element method can be used to solve the Laplace's equation in Eq. 1. Hence, the potential, $\phi$ and current density, $i$ on the whole domain can be determined.

## 2. Inverse Analysis for Corrosion Detection

Inverse analysis is used to find the exact location of corroded area of rebar by comparing measured and calculated (by BEM) potential data on the top of concrete [3]. In carrying inverse analysis, the error of cost function, Eq. (6) must be minimized.

$$\varepsilon(C) = \sum_{j=1}^{N}\left(\left|\frac{\phi(j) - \bar{\phi}(j)}{\bar{\phi}_{\max}}\right|\right)^2 \tag{6}$$

Where:

- $\varepsilon$ = error
- $\phi$ = measured potential on concrete surface
- $\bar{\phi}$= calculated potential on concrete surface
- $\bar{\phi}_{max}$= maximal value of measured potential

## 3. The Particle Swarm Optimization (PSO)

To minimize the inverse equation, the PSO was used. PSO is population-based search algorithm. It was inspired by flocking behavior of birds [1]. Among the advantages of PSO are easy to implement and requires only few parameters.

The PSO started with a population of particles that represent candidate solutions. These particles will be subjected to cost function, and classified according to its fitness. The particles then will move, using the local and global best particle as reference. Local best is the best particle, in terms of its fitness, relative to one individual particle. Global best is the best particle, in terms of its fitness, relative to whole population. The movement of the particles is described as velocity by following equation:

$$v_{i=1} = Wv_1 + a_1 r_1 (pbest - x_1) + a_2 r_2 (gbest - x_{1)} \tag{7}$$

where:

- $v_{i=1}$ = next velocity
- $v_1$ = current velocity
- $W$ = inertia weight
- $a_1$ and $a_2$ = constants
- $r_1$ and $r_2$ = random number
- *pbest* = local best particle
- *gbest* = global best particle

From the velocity formula Eq. (7), it can be seen that the inertia term, $Wv_1$, will greatly play role when the other two terms approaches zero. It will occur as the particles converge. Thus inertia weight, W, is an important factor that must be subject of study. The whole algorithm for PSO is shown in Figure 3.

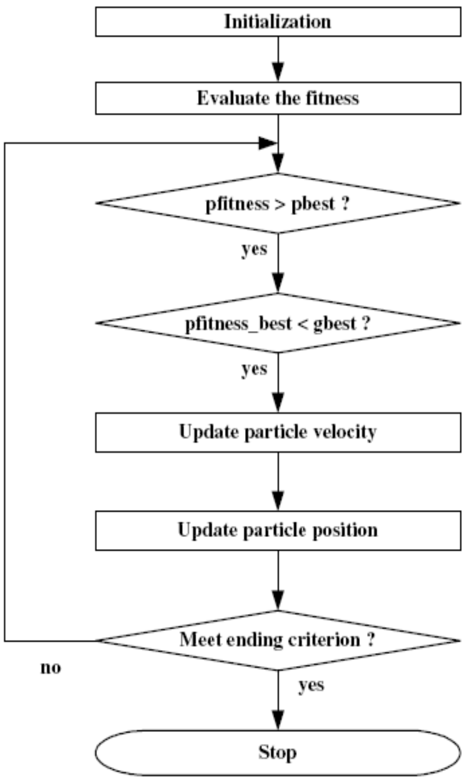


Figure 3. Procedures of PSO

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## 4. Case Study

An experimental model of rebar corrosion was used (Figure 4). The size of corroded area is assumed to be known.

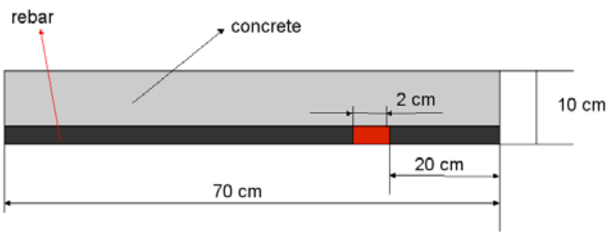


Figure 4. The experimental model of rebar corrosion

All the concrete surfaces assumed to have zero current density. The potential on the non-corroded area of rebar (shown ad a darker part in Figure 4) is 0.27 V, while the corroded area (shown as a lighter part in Figure 4) has 0.6 V potential on its surface.

By using BEM, the potential on the top of the concrete can be obtained. Then, this potential data is randomly selected in specified number, and used as model of measured potential data.

The exact position of corroded area is not known. To locate the corroded area, the inverse equation, Eq. (6), has to be minimized.

The corroded area was determined as particle. The particles then subjected to PSO procedures as shown in Figure 3.

## 5. Results and Discussion

Figure 5 and 6 show results of using W value of 0.5 and 0.1, respectively. Figure 5 shows the particles was spread around the solution (the corroded area) and seems unstable.

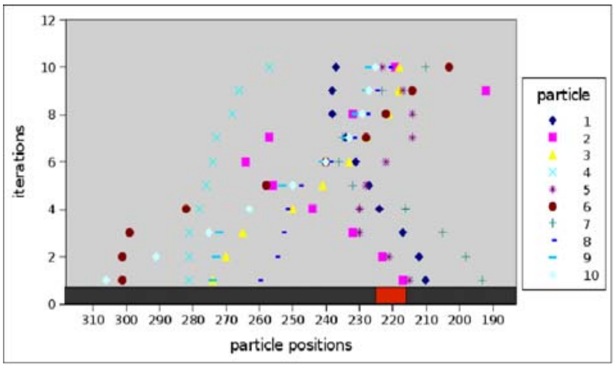


Figure 5. Result with W=0.5

Meanwhile in Figure 6, it is clear that the particles converged to the solution steadily. These results showed that W=0.5 will produce fluctuation in particle's movement in this inverse analysis case.

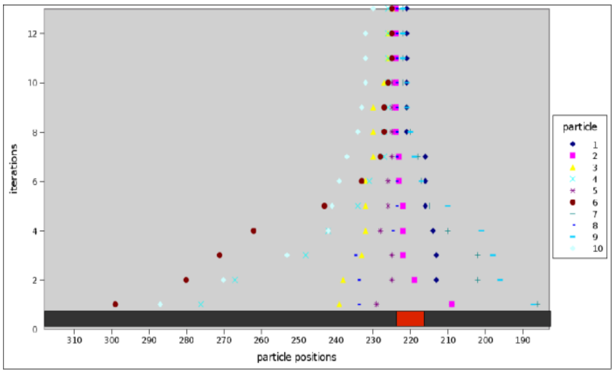


Figure 6. Result with W=0.1

Figure 7 shows error for each iteration for the PSO search with W=0.5. It is clear that the error for each iteration is very unstable, although the solution (i.e. the minimum value of error approaching zero) was found by the particles.

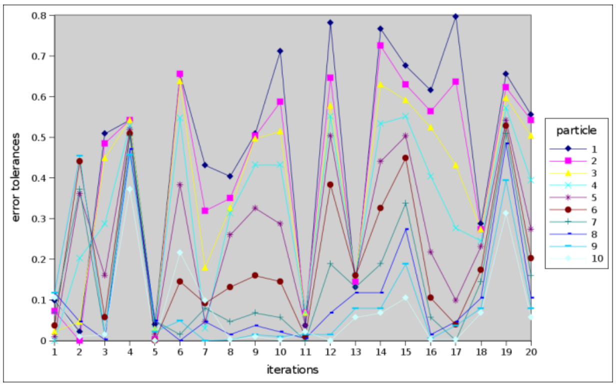


Figure 7. Error for each iteration with W=0.5

Meanwhile, the error for each iteration in PSO search with W=0.1 (Figure 8) converged smoothly to minimum, approaching zero (in this case 1e-14).

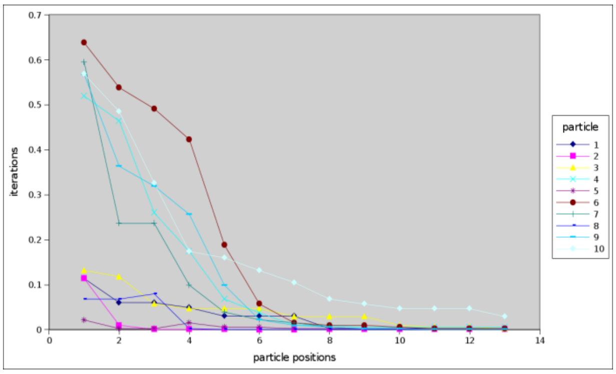


Figure 8. Error for each iteration with W=0.1

## Conclusion

The PSO has been applied for boundary element inverse analysis to predict the location of corrosion in rebar. The PSO successfully minimize the inverse

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equation in order ti determine the corroded area of rebar by using some given potential. Different value of W will affect the movement and path of the particles during optimization process.

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## References

[1] Konstantinos E. Parsopoulos and Michael N. Vrahatis, *Particle Swarm Optimization and Intelligence: Advances and Applications*, Information Science Reference, New York, 2010

[2] Kyun Ho Lee, Seung Wook Baek, Ki Wan Kim, *Inverse Radiation Analysis Using Repulsive Particle Swarm Optimization Algorithm*, International Journal of Heat and Mass Transfer (2008), 51: 2772-2783

[3] Ridha, M., K. Amaya, and S. Aoki, *Multistep Genetic Algorithm for Detecting Corrosion of Reinforcing Steels in Concrete*, Corrosion, Nace International September (2001) 794-801.

[4] Aoki, S., Amaya, K. and Miyasaka, M. *Boundary Element Analysis on Corrosion Problems*, Shokabo, Tokyo, 1998

[5] Telles, J.C.F., Mansur, W.J., Wrobel, L.C. and Azevedo, J.P.S., *Boundary Elements for Cathodic Protection Problems*, Proc. Int. Conf. Boundary Element VII. Editor: Brebbia, C.A. and Maier, G., Springer-Verlag, (1985) 73-83.

[6] Syarizal Fonna, Safuadi, M. Ridha and A. K. Ariffin., *Corrosion Detection in Concrete Structure by Using 3D Boundary Element Inverse Analysis*, Indonesia’s Anti-Corrosion Days 2008, INDOCOR, 4 December 2008, Jakarta, Indonesia, 2008

[7] Syarizal, F., Safuadi, A.K. Ariffin, M. Ridha, A.R. Daud and N.F.L. Ramli., *Boundary Element Method: an Application to Evaluate the Potential on Reinforced Concrete*, Seminar on Engineering Mathematics, UKM, 27-29 June 2008, Pahang (2008) 64-69