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OPTIMIZATION ON FOOTING LAYOUT DESIGN FOR RESIDENTIAL HOUSE WITH PILES FOUNDATION

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ABSTRACT

In design practice, positioning piles foundation on footing layout of a residential house is usually based on empirical judgments and long working experiences of a designer. Heuristically, the pile positions are decided at locations such as/either: a corner; an intersection; endways of footing layout and/or under columns of the house. These empirical judgments in positioning of piles are necessary to avoid excessive bending moments acting on the footing layout from vertical loads of the house. Besides, the coincidence of both the centre of weight and shear centre of the foundation is necessary in order to eliminate the horizontal torsional effects under horizontal loadings during earthquakes. The present study is aimed at eliminating the horizontal torsional effects during the earthquakes occurrences by reducing the eccentricity distance between the centre of weight and shear centre, while satisfying the heuristically habit of the designer in designing pile foundations on the footing layout of residential houses. In this study, a genetic algorithm (GA) is proposed as a design tool for piles placing on the footing of residential housing. The layout of footing is encoded into an individual population, which contains genetic information of pile positions. The best goodness of the total fitness function will result in a layout design of a footing layout of residential housing. An example of footing layout design is demonstrated to show the effectiveness of the present study as a decision making tool in design practice.

Keywords: Pile Foundation, Layout Design, Genetic Algorithm, Optimization.

1. INTRODUCTION

It is the nature of design works that repetitive efforts of structural analyses are required to obtain optimal solutions of design. During designing a continuous footing layout of pile foundation, it is cumbersome to do structural analyses repetitively for all different possible arrangements of piles on the footing layout. A similar kind of study on placing of piles optimization is hardly found in the publications. The least weight design of pile foundation (Hoback and Truman 1993) and differential settlement of raft foundation (Kim et al. 2001) are two kinds of different optimizations which can be found in the publications. In both studies, the optimality and nonlinear criteria

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approaches were used as the basis criteria for placing pile design based on the least weight of piles and against the settlement problems. In this study, a simple method by means of GA is introduced to mimic the heuristic judgments of practitioners for solving the pile foundation layout design problem.

2. GENERAL ASSUMPTION

Assumptions considered in current study are: a. Structural and design analyses to assure the safety of the house have been evaluated beforehand; b. Pile foundations have been evaluated to be adequate to support the house within soil bearing capacities; c. Flat depth of soil bearing bed which supports the piles.

Therefore, the present study only focus on the optimization of designing the layout of pile under the house to eliminate the horizontal torsional effects during the occurrences of earthquakes while replacing the designers' empirical judgments in placing the piles.

3. GENETIC ALGORITHM

GA is one among the trendy computation algorithms for searching problems based on the mechanics of natural selection and genetics of living organism (Goldberg 1999). The essential effort in developing a layout design method for pile foundation is how to define the input parameters which have to be encoded into genes to form a chromosome of an individual population.

3.1. Encoding Scheme

An example of continuous footing layout is used to illustrate an encoding scheme proposed in present study. Figure 1 shows an encoding scheme of an irregular continuous footing layout as an individual population which is presented by a chromosome string consists of binary filled cells as genetics information. If the value of the gene is one, it means that there is a pile inside the cell. Obviously, if the value of the gene is zero, there is no pile exist in the cell.

3.2. Fitness Functions

In this study, three constraints which are converted into penalty functions (Michalewicz 1994) to evaluate the total fitness of each individual in the population are adopted.

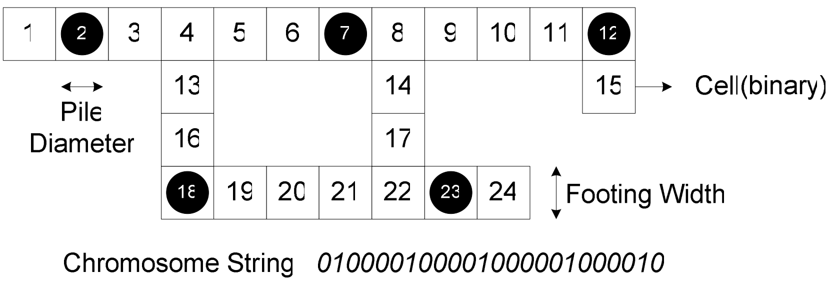

Figure 1: Schematic encoding of a chromosome of footing layout with piles

3.3. Total Fitness Functions

The total fitness evaluation, *FT*, for an individual population is defined from a multiplication of four predefined fitness functions.

$$FT = F1 \times F2 \times F3 \times F4 \tag{1}$$

The total fitness evaluation considered herein is to facilitate the main fitness function, *F1*, which is aimed to eliminate the torsional effects by positioning both the center of gravity and shear center as close as possible with the penalty functions, *F2-F4* which can mimic the heuristic judgments of designers in arranging the piles on the footing layout.

All the functions are converted into a non-dimensional and non-zero shifted linear equation with the best fitness value of *1.0* and the worst fitness value of *2.0*. The non-zero shifted functions are necessary in order to use the equation (1).

3.3.1. Center to center distance, *F1* function

Assuming constant lateral stiffness for all piles on the footing in the x and y directions, the shear center can be calculated from static moment equations as follow,

$$X_S = \frac{\sum_{i=1}^{np} k_{yi} \cdot x_i}{\sum_{i=1}^{np} k_{yi}} \quad , \quad Y_S = \frac{\sum_{i=1}^{np} k_{xi} \cdot y_i}{\sum_{i=1}^{np} k_{xi}} \tag{2}$$

where, np is the total number of piles on the footing layout and, k_{xi} and k_{yi} are the lateral stiffness of i pile in the x and y directions, respectively. The center of gravity, (X_G,Y_G) is obtained from the vertical loadings which are transferred through the columns and/or walls to the footing. The center of gravity is given as an initial condition.

Thus, the distance between both center of gravity and shear center can be calculated from,

$$D = \sqrt{\left(X_G - X_S\right)^2 + \left(Y_G - Y_S\right)^2} \; . \tag{3}$$

The best fitness evaluation of each individual population is obtained when the value of D is approaching or closes to zero. Hence, the torsional effects due to horizontal seismic loadings during the earthquakes can be eliminated. A non-dimensional and non-zero shifted of the fitness function *F1* is defined as follow,

$$F1 = 2.0 - \left(1.0 - \frac{D}{D_W}\right)^{1/NF1} \tag{4}$$

where, D_W is the distance which gives the worst fitness value where the shear center is defined at the outermost cell distance from the center of gravity. This farthest distance is traced at each cell of the footing layout at the very beginning step before applying the GA. An integer fraction constant value of the exponential term *NF* is used to accelerate the process of finding the best fitness individual population at each fitness function stated hereafter.

3.3.2. Objective number of piles, *F2* function

In order to constraint an objective number of piles on the footing layout, a non-dimensional and non-zero shifted of the fitness function *F2* is defined as follow,

$$F2 = 2.0 - \left(1.0 - \frac{np - N_B}{N_B}\right)^{1/NF} \tag{5}$$

where, *np* is the counted total number of piles on the footing layout of one individual population. N_B is the objective number of piles on the footing layout which is obtained from the structural analyses of the upper structure of the footing.

3.3.3. Minimum separation distance, *F3* function

During the GA process, there are possibilities where two piles become too close by each other. These occurrences will be avoided by using a kind of constraint which can repel the surrounding piles whenever entering a predefined radius of influence. This function is a kind of penalty mechanism which can be defined in a fitness function.

$$F3 = 2.0 - \left(1.0 - \frac{R}{R_W}\right)^{1/NF} \tag{6}$$

where, *R* is total amount of pile(s) within the radius of influence of a pile of concern and R_W is the possible maximum number of piles accumulated inside the radius of influence. This possible maximum number of piles is searched at each cell of the footing layout in the very beginning step before applying the GA.

3.3.4. Pile at particular location, *F4* function

In practice, a designer tends to place piles based on their heuristic judgments at intersection, corner or end-way of a footing layout. The following fitness function is formulated to give a best fitness value of *1.0* if the objective numbers of piles are filling all intersection, corner and end-way of the footing layout. A non-dimensional and non-zero shifted of the fitness function *F4* is defined as follow,

$$F4 = 2.0 - \left(1.0 - \frac{I_B - I}{I_B}\right)^{1/NF} \tag{7}$$

where, I is total amount of cell weighted values and I_B is the best fitness value of total cell weighted values of the footing layout for objective numbers of piles, *NB*.

The cell weighted valuation scheme at designated locations where a pile is placed is shown in Figure 2. These maximum cell weighted values at designated locations are searched from the footing layout in the beginning before applying the GA.

4. EXAMPLE

Figure 3 shows an example of a real layout designed pile foundation of continuous footing problem. The objective number of piles from the real structural calculation design is *29*. The number of piles is a result from the structural calculation in real design work.

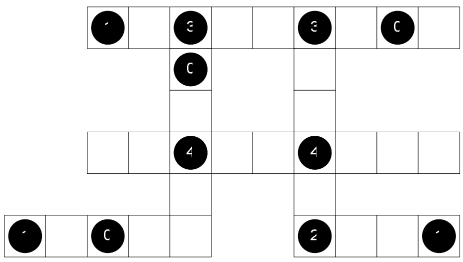

Figure 2: Cell weighted values of piles on footing layout.

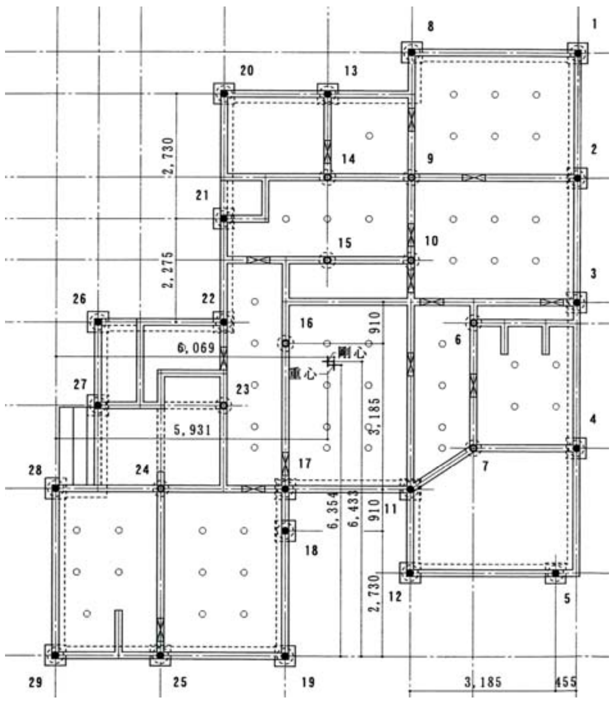

Figure 3: Real drawing plan of a pile foundation layout example.

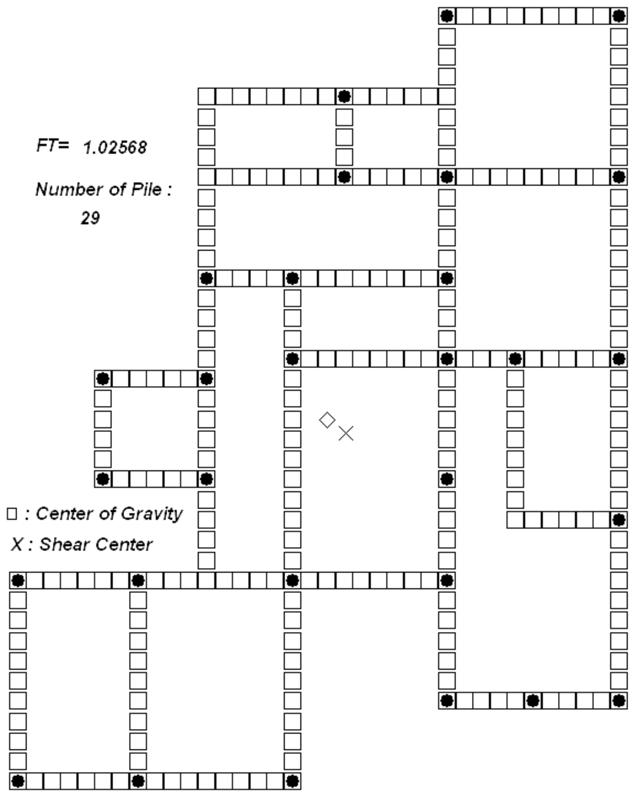

Figure 4: Result of pile placing on continuous footing layout using GA at 500 generation.

Two elites are selected from the population at each generation. The optimal result was obtained after the *500* generations of GA process. The nearly coincidence of the center of gravity and the shear center result is depicted in Figure 7.

Figure 5 shows the total fitness values which vary with the generation produced by the GA process.

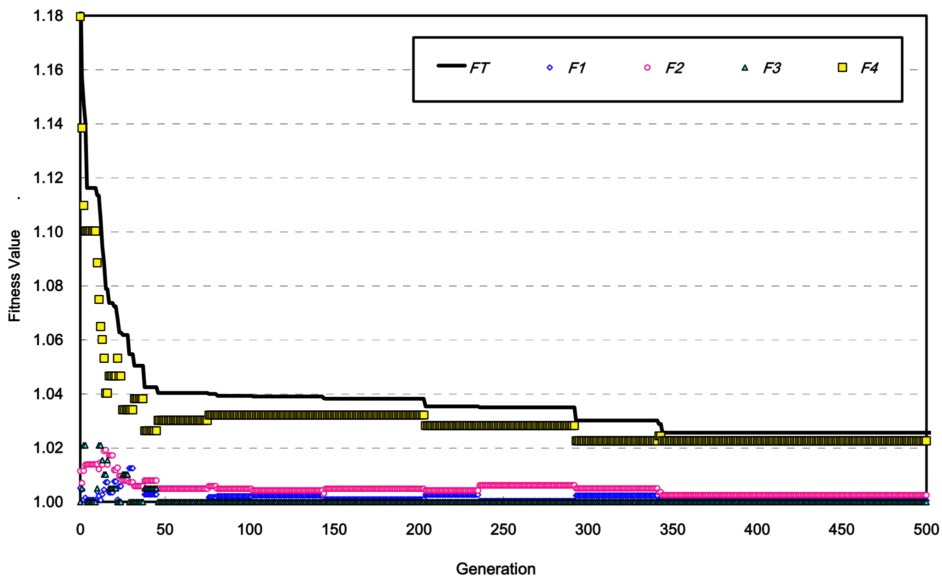

Figure 5: Result of the total fitness values of the first elite generations with *NF=7*.

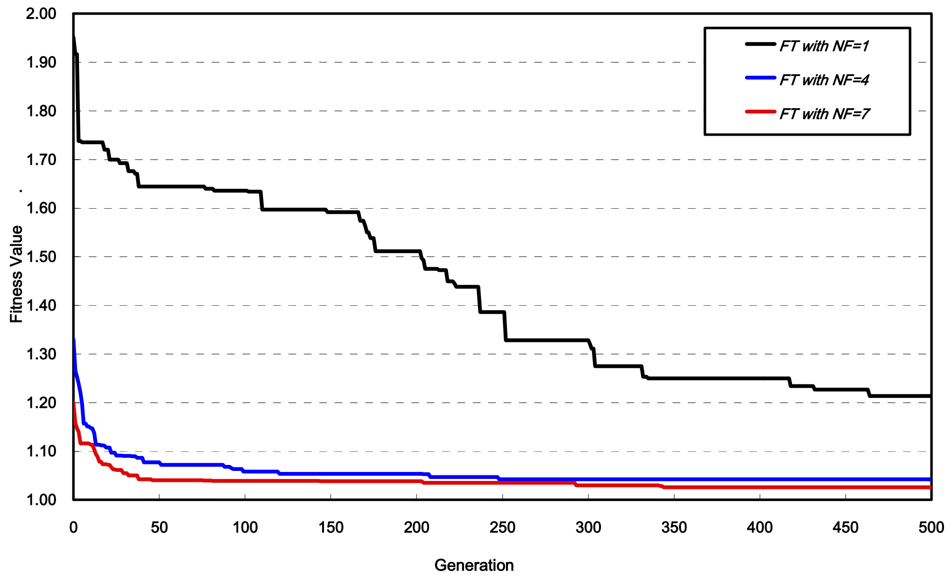

Figure 6: Result of the total fitness values with different values of *NF*s.

Figure 6 shows the total fitness values which converged rapidly with less generation by using higher value of *NF=4* and *NF=7* compared to the result of *NF=1*. The results show that the usage of exponential term *NF* to accelerate the process of finding the best fitness individual population can provide better performance to the GA process.

5. CONCLUSIONS

In this study, one fitness function combined with three constraints which are converted into penalty functions to evaluate the total fitness of each individual of footing layout by using GA is proposed. With the help of the GA proposed, the present study has succeeded to mimic the designer heuristic judgments in designing a footing layout of pile foundation. A real example of footing layout design works has been shown to demonstrate the efficiency of the present proposed method.

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