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TABU SEARCH ALGORITHM FOR OPTIMIZING PILE FOUNDATION LAYOUT ON FOOTING OF RESIDENTIAL HOUSE

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In practice, positioning pile foundation on footing layout of a residential house is often based on empirical judgment and long working experiences of a designer. After the pile requirements calculated, some conditions like number of piles, spacing placement of all piles on the footing, and locations such as under columns, corner, or intersection have to be determined. Besides, the coincidence of shear and gravity centers is also another essential design consideration, which is often ignored in design practice. The present study is aimed at eliminating the horizontal torsion effects during the earthquakes occurrences by reducing the eccentricity distance between the centers of gravity and shear. The scope of present study excludes any foundation or structural related design and analysis. Recent advancement of computing capabilities of computers has made the structural analysis become a convenient tool at hand for designers. In this study, the Tabu Search algorithm was adopted as an optimization tool for pile placing on the footing of residential houses. Tabu Search algorithm was known as an efficient method for solving combinatorial optimization problems where it can find some quality solutions in relatively short running time without getting stuck in local optima. An example of footing layout design was demonstrated to show the effectiveness of the present study as a decision-making tool in design practice.

Keywords: Optimization, Pile layout, Heuristics, Tabu search.

1 INTRODUCTION

In recent decades, the optimization problem has received many attentions in the engineering field. Because many engineering problems include complex combinatorial optimization problems, the number of combinations will be increased exponentially in a very large problem size. Thus, a huge amount of computational time is required to obtain the most optimum solutions for large problems (Korte and Vygen 2012). Therefore, some method that can solve a global optimum solution in a reasonable time has been sought.

A strategy for positioning pile foundation on footing layout of a residential house is often based on empirical judgment and long working experiences of a designer. Eventually, planning for the pile position is based on the number of piles and particular locations such as corner, endways of layout, intersections of footing or under columns of the house. In addition, the coincidence of both the centers of gravity and center of the foundation is required to eliminate the horizontal torsion effects during the earthquakes.

2 METHOD OF OPTIMIZATION

2.1 Tabu Search Algorithm

Tabu Search algorithm (TS) was proposed by Glover (1989, 1990), Glover *et al.* (1993), Glover and Laguna (1997). TS algorithm was known as an efficient method for solving the large combinatorial optimization problems where it finds quality solutions in relatively short running time without getting stuck in locally optimal solutions. One of the main components of TS is its use of memory, which plays an essential role in the search process. TS discovers more refined ways to exploit this memory and more efficient means to treat combinatorial optimization problems. TS is one of the heuristics like Genetic Algorithm (GA) and Simulated Annealing (SA) optimization methods.

2.2 Samples for Pile Positions

The positioning pile is expressed in a sample array with an arrangement consisted of elements of "0" or "1". If the element in the array is "1", a pile is existed on the footing. Otherwise, a pile does not exist. Figure 1 shows an example of a sample array of pile positions on the footing.

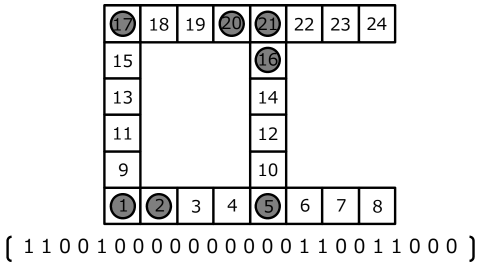

Figure 1. Example of an expression method of positioning pile.

2.3 Problem Formulation

The TS can be formulated by initially choose a solution and then generating a sample of solutions iteratively to find the best "moves" with highest evaluation. The moves of the optimum solution are restricted to narrowing the search and selecting the choice of samples. A set of attributes is identified to prevent from occurring in a future move and assure the present move cannot be reversed. The attributes which are classified as forbidden (tabu) are recorded in a "tabu" list, where they reside for a specified number of iterations and then are removed, freeing them from their "tabu" status. The evaluation of the solution is accomplished by examining the objective function and introducing "tabu" restrictions (or penalties) functions. Their functions are defined as follow.

2.3.1 *Objective function*

The main objective of this study is to obtain the pile layout which reduces the eccentricity distance between the centers of gravity and shear. The lateral stiffness's of piles on the footing in the x and y direction are assumed to be constant. Hence, the center of shear can be calculated from static moment equations as follow,

$$Sx = \frac{\sum_{i=1}^{NPILE} X_i \times Kx_i}{\sum_{i=1}^{NPILE} Kx_i}, Sy = \frac{\sum_{i=1}^{NPILE} Y_i \times Ky_i}{\sum_{i=1}^{NPILE} Ky_i} \tag{1}$$

where, *Sx* and *Sy* are the centers of shear; *NPILE* is the total number of piles on the footing; Kx_i and Ky_i are the lateral stiffness of i^{th} pile in the x and y direction, respectively. The center of gravity (*Gx*,*Gy*) can be calculated from vertical loadings from the superstructure. Assuming the center of gravity is given as an initial condition.

Thus, the eccentricity distance between the centers of gravity and shear can be calculated from,

$$DS = \sqrt{(Gx - Sx)^2 + (Gy - Sy)^2} \tag{2}$$

where, DS is the eccentricity distance between the centers of gravity and shear. The object function can be formulated as follow using by the value obtained from Eq. (2).

$$\text{minimize } FPD = 1.0 + \left| \frac{DS}{DSw} \right| \tag{3}$$

where, *FPD* is the object function, and *DSw* is the specified "worst" maximum distance which can be obtained from the shape of the footing foundation. Figure 2 shows an illustration for measuring *DS* and *DSw*.

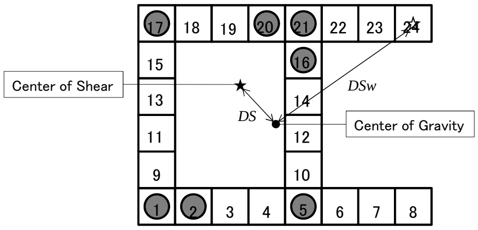

Figure 2. Illustration for measuring *DS* and *DSw*.

2.3.2 *Tabu restrictions*

In order to evaluate the solution of the sample, some restrictions are considered when pile positions are defined at a certain location. Therefore, it is necessary to express the restrictions by predefined evaluation functions.

(1) Restriction-I: Number of Piles

It is necessary to restrict the number of piles appear in the footing layout to meet the designed number of pile which was calculated from the structural analysis in advance. This restriction will result in the value of one as the best solution. A linear evaluation function is defined as follow,

$$FFP = 1.0 + \left| \frac{NPILE - NPILEDESIGN}{NPILEDESIGN} \right| \tag{4}$$

where, *FFP* is the evaluation of the number of pile on the footing; *NPILE* is number of piles appear on the footing layouts, and *NPILEDESIGN* is the number of piles obtained from structural analysis in advance. The evaluation of number of piles on the footing layout is "best" when the Eq. (4) approach to a value of one.

(2) Restriction-II: Interval Distance Between Piles

To adjust the interval between two piles not too dense and not too broaden, it is necessary to control the distance between two piles. Therefore, a restriction on the interval distance between two piles need to be imposed.

The designed number pile is used to determine the average of influence per single pile which is defined as,

$$AI = \frac{L}{NPILEDESIGN - 1} \tag{5}$$

where, *AI* is area of influence per single pile, and *L* is the total length of the stretched footing layout. The total of interval distances between piles can be calculated as,

$$AL = \sum_{i=1}^{NPILE} Distance\, of\, Pile_i \tag{6}$$

where, *AL* is the total interval distance between piles and $Distance\ of\ Pile_i$ is the distance between two piles inside the area of influence.

By using Eq. (6), a linear evaluation function representing the interval distance restriction can be defined as follow,

$$BB = 1.0 + \left| \frac{AL}{worstAL} \right| \tag{7}$$

where, *BB* is the evaluation of interval distance restriction; *AL* is the total of interval distance between piles and *worstAL* is the possible "worst" maximum interval which is initially calculated from a "dense" condition. The evaluation of interval distance is "best" when the Eq. (7) approach to a value of one.

(3) Restriction-III: Position of Piles

From a designer point of view, when designing a layout of piles on footings, there are several positions which often receiving priority to be placed such as under columns; corner; T connection; cross-section and endways of footing layout. To evaluate this restriction, a linear evaluation function is defined as,

$$FPC = 1.0 + \left| \frac{bestPiP - PiP}{bestPiP} \right| \tag{8}$$

where, *FPC* is the evaluation of positioning of pile restriction; *PiP* is the sample solution of positioning on footing layout during the search process and *bestPiP* is the values which are predefined at the priority places (under columns = 5+; T connection = 4; corner = 3; endways = 2; cross-section = 1; others = 0). The evaluation of positioning of a pile on the footing layout is "best" when Eq. (8) approach to a value of one.

2.3.3 *Total evaluation*

The total evaluation of the restrictions is defined as follow,

$$\text{minimize} \quad FF = FPD \times FFP \times BB \times FPC \tag{9}$$

where, *FF* is total evaluation of all the restrictions which is "best" when the Eq. (9) approach to a value of one.

3 EXAMPLE

Figure 3 shows an example of a real foundation of residential house and its initial condition.

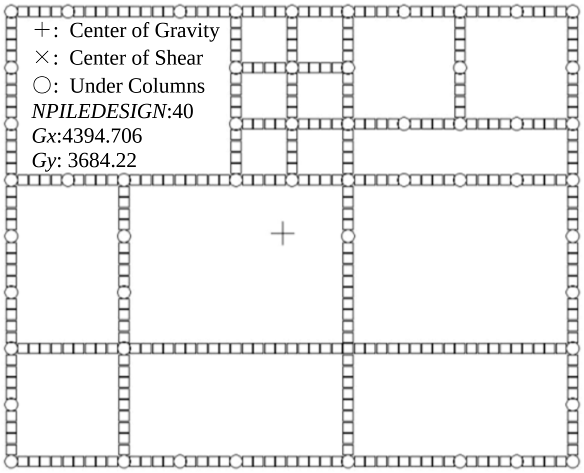

Figure 3. Example of real foundation of residential house and an initial condition.

Figure 4 shows a transition from value of the *FF* and *FPD* obtained by using TS. The optimal result was obtained after the 1000 generation doing TS. Figure 5 shows an optimal result and value of the object functions and their restrictions.

4 CONCLUSION

Designing pile foundation layout on footing of residential house was formulated, and the optimal pile layout was obtained by using the TS. From the result of the example, the center of gravity and the center of the shear of the optimal layout obtained by using

TS are close. Furthermore, values of all restriction function of the optimal layout are approach to a value of one.

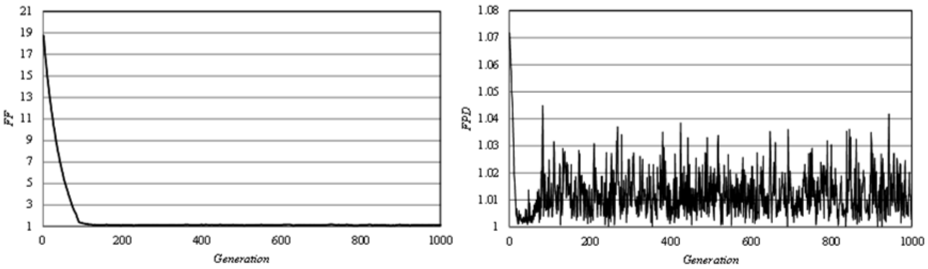

Figure 4. Transition of value of the *FF* and *FPD.*

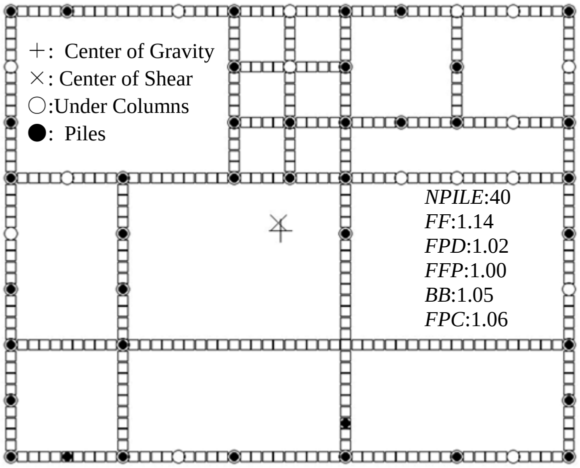

Figure 5. Optimal result and value of the object function and restrictions.

Thus, TS can be used as a decision-making tool in design practice since this algorithm can find optimal pile locations in a relatively short running time. Possibilities for merging with other optimization procedures offer stimulating likelihood for explorations.

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