

## USING GENETIC ALGORITHMS TO ESTIMATE THE SCOUR DEPTH AROUND THE BRIDGE PIER

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**ABSTRACT:** Scouring around bridge piers is the important safety issue of bridge management since it could lead to bridge slanting and collapsing. Since the mechanism of water flow around the pier structure is so complicated, which makes it is very difficult to develop a generic model to determine the scour depth. Many researchers have tried to estimate the scour depths around bridge piers by simulating the bridge model with the consideration of various factors such as the depth of water, average velocity of flow, and diameter of sand. However most of models require predefined conditions and can only be applied to certain types of bridges.

In this study, an integrated model that combines genetic algorithms and simulation technology is developed to estimate the scour depth around bridge piers by using the natural frequency of the bridge structure. A series of simulations are first performed on a concrete bridge by setting different scour depths and environmental conditions to determine the possible values of the natural frequency. Since simulations generate a huge amount of data, which makes it hard to analyze and find the relation between the scour depth and the natural frequency. Then, genetic algorithms are used to find the fitted generic formula that defines the relationship between the scour depth and the natural frequency.

The result of this study provides the bridge management authority an efficient and effective method to determine the scour depths around bridge piers and so forth to evaluate the bridge status when the flood strikes

**Keywords:** *Genetic Algorithm, Scouring around Bridge Piers, Natural Frequency*

### 1. INTRODUCTION

Bridges are the crucial components of traffic system. To ensure the bridge safety is an important task to the government since bridge failure may not only terminate the traffic system but also cause people death and property loss. The most common reasons for bridge failures include structural and design deficiencies, corrosion, construction and supervision mistakes, accidental overload and impact, lack of maintenance and inspection, and scour. However, Shirole and Holt who observed over 1,000 failed bridges in United State between 1960 to 1990 recognize that 60% of these failures are due to scour [1]. And from literatures [2] [3], these papers investigated recent bridge failures in

United State, and obtained the conclusion that scour is one of the major reasons for bridge failures.

Considering the scour as the critical cause of bridge failure, to know the depth of pile exposure is the major topic to estimate the state of bridge. However, the pile exposure can not be always observed directly, because piles are often under water, especially at the condition of flood. And the detection devices installed under water are often unstable after flood invading. To measure the scour depth around bridge piers and provide prior warning of bridge failure are hard tasks. For this reason, to develop a method as well as tools to detect the scour depths is useful.

In this study, an integrated model that combines

genetic algorithms and simulation technology is developed to estimate the scour depth around bridge piers by using the natural frequency. And finite element analysis is used to calculate the natural frequency of the scoured bridge in the model. A series of simulations are first performed on a concrete bridge by setting different scour depths and environmental conditions such as soil distribution, foundation dimensions, and pier condition to determine the possible values of the natural frequency. Since simulations generate a huge amount of data, genetic algorithms are applied to find the fitted generic formula that defines the relationship between the scour depth and the natural frequency. Therefore, the conduct formula can be easily performed in field by locating the initial point in the approximate relationship and estimates the scour depth. Thus, the manager can predict the scour depth immediately and evaluate the bridge safety especially in flood.

## 2. Literature review

For bridge safety issue, the mechanics of bridge scour are well discussed. About the mechanics of bridge scour, Dargahi presented the scour mechanism which is coupled to the three-dimensional separation of the upstream boundary layer and the periodic vortex shedding in the wake of the cylinder [4]. Melville and Raudkivi presented data that quantify the effects of pier non-uniformity for cylindrical piers. The concept of an equivalent size of uniform pier was introduced [5]. Melville et al. published the book “bridge scour”. The book covers the description, analysis and design for scour at bridge foundations. The central focus is the combination of old and new design methods into a complete methodology for bridge-scour design. The book is based upon an extensive summary of existing research results and design experience [6]. The mechanics of bridge scour are still complicated on various conditions and need more investigation.

The scour depth around bridge piers represents an important index of the bridge safety. There are many studies focus on how to estimate the scour depth. Yanmaz et al. developed of time-dependent local scour and

estimation of maximum possible scour depth around bridge piers [7]. Melville presented an integrated approach to the estimation of local scour depth at bridge piers and abutments [8]. Richardson et al. presented a fully three-dimensional hydrodynamic model which simulated the flow occurring at the base of a cylindrical bridge pier within a scour hole. The simulations could be supplemented by Lagrangian particle-tracking to estimate the depth of the equilibrium scour condition [9]. Johnson et al. investigated a probabilistic framework for estimation scour using deterministic methods given in the Hydraulic Engineering Circular (HEC-18) [10]. Different from physics analysis method, Batenia and Jengb [11], Mahmut Firat and Mahmud Gungor [12] use artificial neural networks method to estimate the scour depth.

And for the bridge safety of scouring there are also some studies presented with different concepts. Johnson presented reliability-based pier scour engineering which discussed a method of incorporation uncertainty into bridge pier design using a risk based design method and the probability of failure [13]. Johnson et al. simulated pier scour for a period of time and determined the probability that the bridge failed at various points in time during that period. Johnson et al. investigated about the actual cases of bridge damage [14]. If bridges are in the design procedures, Johnson et al. presented a risk-based method for ranking, comparing and choosing the most appropriate scour countermeasures using failure modes and effects analysis (FMEA) and risk priority numbers (RPNs) [15]. If bridges which are in design procedures scour, Chen et al. presented that a method to analysis time-variant bridge durability and service life. Therefore, to develop bridge scour analytic program is useful. It not only can match bridge condition of supervision to assess the bridge health, but also can be more grips on bridge structure [16].

Since the scour mechanics of bridge are complicated, most of the scouring models which are developed for estimating the scour depth are require predefined conditions and can only be applied to certain types of bridges. Thus, the model in this study which could generate a general formula will be useful.

### 3. Methodology

In this chapter, using finite element analysis to simulate and calculate the bridge natural frequency is introduced in first part. And adopting genetic algorithms to find the fitted generic formula between the bridge natural frequency and exposure depth are then introduced in the second section.

#### 3.1 Simulation of bridge natural frequency

Structure natural frequency calculation is a motion of a dynamic problem. For the problem the equation is:

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{C}\dot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{F} \quad (3.1)$$

where  $M$ ,  $C$ , and  $K$  are mass, damping, and stiffness matrices, respectively,  $X$  is the displacement vector, and  $F$  is the external force vector. If the damping and external force are neglected, one obtains:

$$\mathbf{M}\ddot{\mathbf{X}} + \mathbf{K}\mathbf{X} = \mathbf{0} \quad (3.2)$$

The displacement vector is assume to be  $\mathbf{X} = \Phi e^{i\omega t}$ , and equation (3.2) changes to

$$(\mathbf{K} - \omega^2 \mathbf{M})\Phi = \mathbf{0} \quad (3.3)$$

Equation (2.3) is a standard eigenproblem, where  $\omega$  is a natural frequency and  $\Phi$  is a modal shape.

To simulate the eigenproblem of bridges accurately, the foundation and soil cannot be ignored, since the bridge foundation often contains a large portion of the total structure. Especially for the scoured bridge, its natural frequency should be sensitive to the exposure of the bridge foundation. Figure 1 and 2 show the finite element mesh of the bridge with and without the exposure of the foundation. The bridge is the multi-span simply supported beams of Taiwan high-speed rail in Tainan, Taiwan.

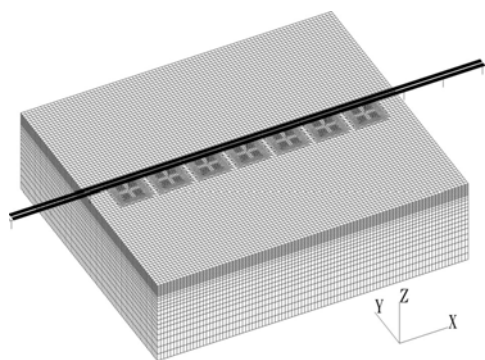


Fig. 1 3D finite element mesh without the exposure of the foundation

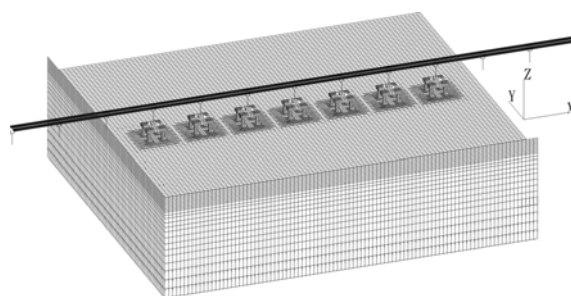


Fig. 2 3D finite element mesh with the exposure of the foundation

The total number of natural frequencies and modal shapes is the same as the total number of degrees of freedom (NDF) of the finite element mesh. The subspace iteration method was used to solve the eigenproblem of equation (3.2). The major advantage of this method is that first  $N$  eigenvalues and eigenvectors can be obtained, where  $N$  can be decided by users. For a finite element problem with large degrees of freedom, such as million or over, the subspace iteration method is efficient, since it is often required only first several modes, such as 40 to 60 modes. Since the mode shapes of soil, foundations, and superstructures may be coupled together, but the measurement devices installed on the superstructures can only obtain the natural frequencies of the superstructures. In this study, the effective mass above the soil surface is used to determine the natural frequencies of the superstructures. And the effective mass ratio can be used to represent the importance of this mode under the seismic load. If this value is large, such as 30%, this mode can be categorized as a mode shape in that direction. Figure 3 and 4 show the natural frequencies of the bridge after the finite element calculation. The results are verified by field experiment. Errors in the x direction and y direction are about 2.64%~4.58% and 1.42%~4.99%. The finite element results are in acceptable accuracy

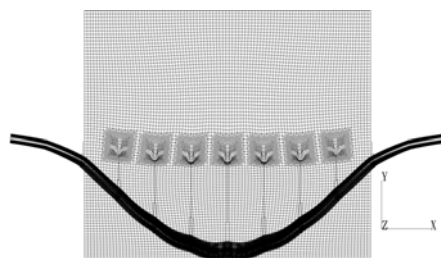


Fig. 3 Mode 12 in eigen-analysis (2.077 Hz, x-direction effective mass ratio =29.7%)

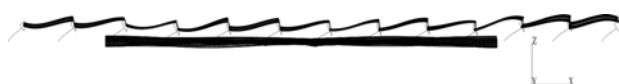


Fig. 4 Mode 60 in eigen-analysis (2.99 Hz, x-direction effective mass ratio=21.6%)

### 3.2 Genetic algorithms for fitting formula

From the above simulation method, one can change the parameters, such as soil distribution, foundation dimensions, and pier condition, to perform numerous finite element analyses and get bridge natural frequencies. However a huge numbers of data will be generated and make it difficult to generate a universal formulation to predict the scour depth. Genetic algorithms (GA) are then applied to find an approximate relationship between the bridge natural frequency and the scour depth. GAs are search algorithms developed by Holland [17] which are based on the mechanics of natural selection and genetics to search through decision space for optimal solutions [18]. In GAs, a string (chromosome combination) represents a potential solution to a problem. Each string is evaluated on its performance with respect to the fitness function (objective function). The crossover and mutation schemes will exchange the information (gene) between strings to produce various solutions. And a selection scheme such as roulette selects the strings (solutions). That string with higher performance will be selected with higher probability. The brief GA process is shown in Fig.5

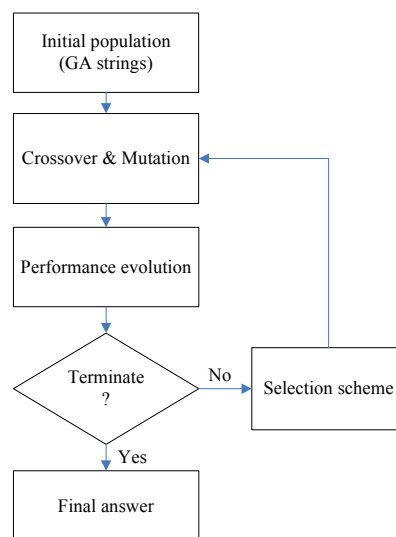


Fig. 5 Flowchart of GA

In this problem, the general form of equation can be written as:

$$Y = f(X, \theta) + \varepsilon \quad (3.4)$$

where  $Y$  is the dependent variable,  $X$  is an vector of independent variables,  $\theta$  is a parameter vector, and  $\varepsilon$  is a random error.

$f(X, \theta)$  could be displayed in various forms such as (3.5) to make the fitting function more suitable.

$$Y_i = \theta_0 \sin(X_i^{\theta_1}) + \varepsilon_i \quad (3.5)$$

As a result, a GA string which represents a potential solution for fitting formula should determine the variables including  $\theta$ , numerical parameters to adjust the dependent variable, and the transform functions such as trigonometric function.

The numerical parameter ( $\theta$ ) could be displayed as (3.6).

$$\theta = \alpha \times 10^\beta \quad (3.6)$$

Set  $\alpha$  is a number around -1 to 1 with acceptable precise such as 6 decimal places. And also set  $\beta$  within a acceptable range, such as 0 to 3 and accurate to 3 decimal places. As a result,  $\alpha$  and  $\beta$  could be coded in binary. Then, the GA strings of  $\theta$  are defined. For example, the bits (string length) required for  $\alpha$  in this case are 21, since  $\alpha$  equal size range is smaller than or equal to  $2^{21}$ . The calculation formulation is shown in (3.7)

$$2^{m-1} < (b-a) \times 10^d \leq 2^m \quad (3.7)$$

where  $m$  is the required bits,  $b$  and  $a$  are the upper and lower bound of the range, and  $d$  is the decimal places.

A GA string for  $a$  is like Fig. 6

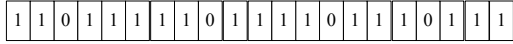


Fig. 6 GA string

For the selection of transform functions, a 100% percentage number is divided into equal parts to represent each transform functions. Then a random number between 0 to 1 is used to determine the selection of transform function by means of the location of the percentage. The random number is then coded in binary as the GA strings for transform functions selection. Fig. 7 illustrates an example with 2 transform functions.

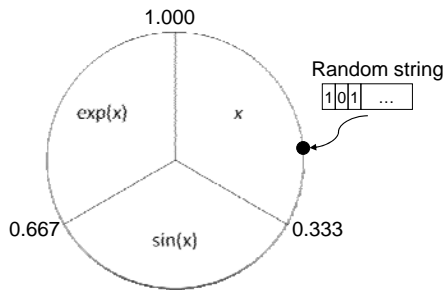


Fig. 7 Illustration of transform function selection

Root mean square error (RMSE) is finally used to measure the performance of the GA string (solution). Thus, the fitness function could be displayed as (3.8):

$$\gamma = \sqrt{\frac{\sum E_i^2}{n}} \tag{3.8}$$

where  $\gamma$  is RMSE,  $E_i = Y_i - Y_0$  ( $Y_i$  : estimate value,  $Y_0$  : real value), and  $n$  is the number of data.

The error means the different between the result of fitting formula and the scour depth which is simulated by finite element analysis. When the error is lower than an acceptable level, GA process finish and the formula is conducted.

**4. Conclusion**

In this study an integrated model that combines genetic algorithms and simulation technology to estimate the scour depth around bridge piers by using the natural frequency is

introduced. Since bridge failures are often caused by the foundation scour. The scour depth around bridge piers could be a warning index to the bridge safety. However it is unstable to measure the exposure depth of the bridge using contact measurement schemes since the water flow may destroy the device under water especially in the flood. Alternatively, using the natural frequency of bridge structure is an available way to measure the scour depth. In this study a finite element mesh of bridge is used. And through a series of computer simulation by setting different conditions of bridge, a large numbers of natural frequencies are generated. Genetic algorithms are then applied to find an approximate relationship between the bridge natural frequency and the scour depth base on simulation data and then conduct the formula. Thus, the scour depth of bridge could be easily computed in the field experiment by using natural frequency. The model provides an effective way to predict scour depth around bridge piers.

For the further research, to categorize different conditions such as the bridge forms, soil types, piers forms and...etc from various results will be benefit for bridge design on different environment. And a data auto feedback or machine learning scheme will be benefit to formula accuracy.

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