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Determination of the ultimate limit states of shallow foundations using gene expression programming (GEP) approach

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Abstract

In this study, a gene expression programming (GEP) approach was employed to develop modified expressions for predicting the bearing capacity of shallow foundations founded on granular material. The model was validated against the results of load tests on full-scale and model footings obtained from the literature. Two models were developed employing different input variables in the GEP approach. The results achieved using the proposed formulae were compared with those obtained from the Meyerhof and Vesic theories. Statistical analysis was used to demonstrate that the GEP models yielded more accurate results than the traditional solutions.

Keywords: Shallow foundations; Bearing capacity; Gene expression programming; Granular soil

1. Introduction

Shallow foundations are becoming increasingly viable alternatives to pile foundations for fixed platforms, particularly in the development of marginal fields. While procedures for pile design evolved smoothly from onshore experience and theory, the design of shallow foundation systems has been frequently re-examined in light of the extreme conditions often present in offshore environments (Barari and Ibsen, 2012). An example of an alternative foundation solution is for offshore wind energy schemes in deep water, as monopile structures have started to become uneconomical, owing to the size of the piles required for these structures (Barari and Ibsen, 2012; Ibsen et al., 2014).

The design guidelines established by DNV (1992), and the API (2000) for calculating the bearing capacity of shallow foundations, are ultimately based on classical bearing capacity equations for the failure of a vertically loaded strip foundation on a uniform Tresca soil with correction factors for the geometrical properties, load eccentricity, and embedment (Barari and Ibsen, 2012). It is becoming increasingly well known that, in many situations, the interaction of the loads acting on a foundation is often more complex than that represented by the traditional bearing capacity theory (Randolph and Gourvenec, 2011; Ibsen et al., 2014).

However, classical formulations are subject to restrictions and assumptions, and they do not always provide reasonable results when compared to the available experimental data. Due to the uncertain nature of soils and the difficulties inherent in

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Nomenclature

γ	effective unit weight of the soil (kN/m^3)
D	depth of the footing (m)
B	width of the footing (or diameter of the circular foundation) (m)
L/B	ratio of the length to width of the footing
L	length
c	cohesion of the soil
ϕ	friction angle
N_q, N_γ	Meyerhof's and Vesic's bearing capacity factors for surcharge and density
N_C	Meyerhof's and Vesic's bearing capacity factors for cohesion
F_s	Meyerhof's shape factor
F_d	Meyerhof's depth factor
S_c	Meyerhof's footing shape factors for cohesion
d_c	Meyerhof's footing depth factors for cohesion
S_q	Vesic's shape factor for surcharge
K_p	Rankin passive pressure coefficient
d_γ	Vesic's depth factor for density
S_γ	Vesic's shape factor for density
d_q	Vesic's depth factor for surcharge

laboratory and in situ testing, there has been an increasing trend toward the development of bearing capacity prediction methods using non-traditional computing techniques to improve accuracy. The great complexities encountered in geotechnical engineering, such as slope stability, liquefaction, and shallow foundation and pile capacity predictions, have motivated researchers to employ powerful new optimization algorithms and methods.

GEP is a promising new soft computing optimization technique that is being increasingly utilized for function generation in geomechanical problems. The technique is capable of identifying key variables and functions with a genetic approach (Goldberg, 1989); it enables the development of models for solving complex problems, such as strong ground motion, soil deformation properties, and soil liquefaction (Gullu, 2012; Kayadelen, 2011).

This paper presents a new GEP-based approach for predicting the ultimate bearing capacity of shallow foundations on cohesionless soil. A training and testing database, containing the results of load tests on full-scale and model footings, was used to develop and verify the GEP model. The performance of these models was compared against two commonly used bearing capacity theories.

2. Background

Every foundation design must satisfy two major criteria: ultimate bearing capacity and limited foundation settlement

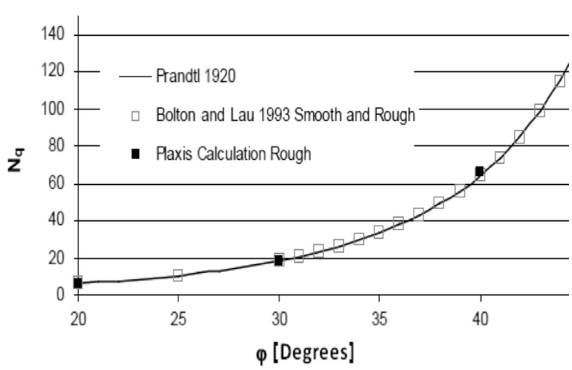

Fig. 1. Variation in N_q with friction angle (Ibsen et al., 2012).

(De Beer, 1965). The bearing capacity of soil may be defined as the maximum resistance to pressure applied through the foundation to the soil without inducing shear failure in the soil.

Terzaghi (1943) was the first to present a theory for evaluating the ultimate bearing capacity of rough shallow foundations. He expressed the ultimate bearing capacity of a

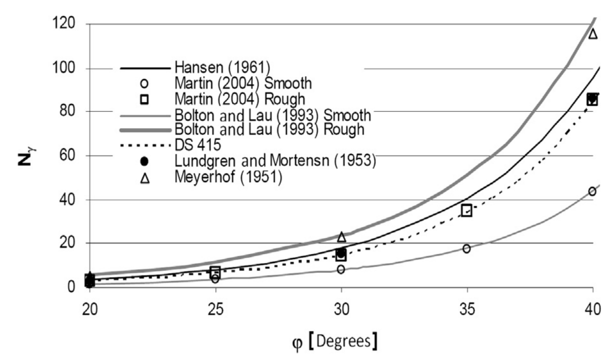

Fig. 2. Variation in published values of N_γ with friction angle.

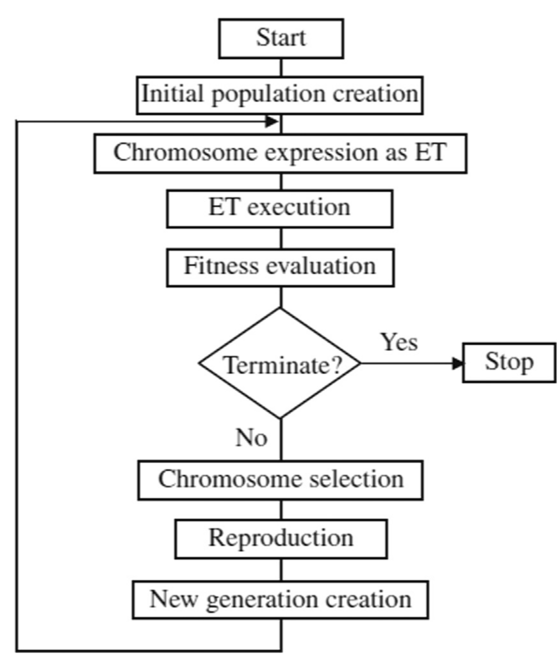

Fig. 3. GEP algorithm.