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RESEARCH NOTE

Behavioral Interference of Vibrating Machines Foundations Constructed on Sandy Soils

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ABSTRACT

In this study, dynamic bearing capacity of adjacent shallow strip foundations located on sandy soil was examined using a numerical finite difference modeling, FLAC. The behavioral interference of shallow strip foundations under different conditions was investigated. The effect of soil strength parameters, geometric characteristics of shallow foundations and cyclic loads at different distance ratios on the bearing capacity of foundations were evaluated. The results indicated the noticeable effect of behavioral interference on the performance of shallow foundations under cyclic loading. As the distance ratio between the foundations increases, the interference effect increased and then decreased. The greatest influence of behavioral interference on the dynamic bearing capacity of foundations was obtained at distance ratio of 2. The interference effect canceled out at the distance ratio of larger than 5. Furthermore, the effect of behavioral interference on the bearing capacity of shallow foundations increased with increasing internal friction angle, soil elasticity modulus, and foundation depth. An increase in the foundation width and loading frequency led to lower interference coefficient. In general, the results demonstrate the necessity of considering the interference effect in the assessment of the bearing capacity of shallow foundations under cyclic loading such as vibrating machines foundation.

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1. INTRODUCTION

Accurate assessment of the behavior of foundations has a substantial role in the appropriate performance of structures and the mounted equipment [1-4]. In the meantime, the machine foundations require in-depth and precise examination. In addition to the static loads arising from the weight of foundations and machines, the soil is affected by the dynamic loads caused by vibrating machines [5-8]. Researchers have studied the behavior of foundations under dynamic loads [9, 10].

Gazetas [11] proposed a chart-based method to assess the behavior of foundations under vibrations. Anteneh [12] examined the effect of soil properties on the behavior of foundations under dynamic loading. Prakash and Puri [13] investigated the response of machines foundation to dynamic loading using spring-mass system. Chandrakaran et al. [14] proposed a simple approach to design of machines foundation under vertical vibration. The results of analytical and laboratory studies indicated the effect of soil layering on the performance of vibrating foundations [15].

Since most foundations are adjacent with each other, their behavioral interference can significantly affect the bearing capacity of foundations. In this case, adjacent foundations demonstrate a behavior different from individual foundations [16]. Therefore, some researchers focused on the behavior of adjacent foundations [17, 18]. Adopting the limit equilibrium method, Stuart [19] investigated the effect of interference on the bearing capacity of adjacent foundations under static loads. Das and Larbi-Cherif [20] experimentally investigated the effect of behavioral interference coefficient on the bearing capacity of shallow foundations. The interference coefficient (IC) was defined as follows:

$$IC = \frac{q_{u-\mathrm{interfering}}}{q_{u-\mathrm{single}}} \tag{1}$$

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where $q_{u\text{-}interfering}$ is the ultimate bearing capacity of interfering (adjacent) foundations and $q_{u\text{-}single}$is the ultimate bearing capacity of the single foundation.

The interference effect on the bearing capacity of adjacent strip foundations was examined through stress characteristics method [21] and upper boundary limit analysis [22]. The results showed that the ultimate bearing capacity reaches its maximum at distance ratio about 2. The results of laboratory studies on the behavior of interfering strip foundations located on sandy soil suggested that interference effect intensified as the soil density increased [23]. Javdanian and co-workers [24, 25] investigated the behavior of interfering shallow strip foundations on reinforced sandy soils through laboratory studies and numerical modeling. Their results indicated that the interference effect should be included in the behavioral analysis of foundations.

Review of the previous research reveals that the behavioral interference of foundations under vibrating loads has less frequently been examined. In the current study, the behavioral interference of vibrating machines foundations was investigated using numerical modeling. The adjacent strip foundations under cyclic loading and rested on sandy soil were modeled under different conditions. The effects of strength parameters of sandy soil [26] (i.e. elasticity modulus and internal friction angle), frequency and amplitude of cyclic load, and the geometric characteristics of shallow strip foundations on the bearing capacity of foundations were examined at various distance ratios.

2. NUMERICAL MODELING

A finite difference program, FLAC, was employed to evaluate the bearing capacity of shallow strip foundations rested on sandy soil under cyclic loads [27]. The FLAC program is widely used in deformation analysis and stabilities in geotechnical engineering problems [28, 29]. The Mohr–Coulomb's criterion was utilized for behavioral modeling of sandy soil. The geometry of the model has been displayed in Figure 1. In this figure, B is the strip foundation width and S is the center-to-center distance between shallow foundations.

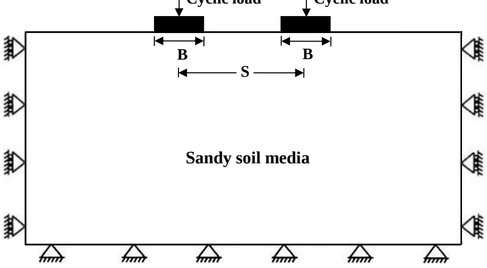

Figure 1. Geometrical properties of model of adjacent shallow strip foundations

The deformations were fixed in the horizontal direction for side boundaries and both directions for the lower boundary of the model. Absorbed boundaries were used to prevent wave reflection. Table 1 presents the characteristics of sandy soil and shallow strip foundations in the numerical modeling. The effect of each parameter on the behavioral interference of shallow strip foundations was evaluated while the values of other parameters were fixed and equal to those provided in Table 1.

In the numerical modeling, the loading on foundations involved two static and harmonic loads. The static load, including the weight of foundation and machines, was considered to be 8 kN/m^2 [30]. The harmonic loading from the operation of machines mounted on the foundation includes two important components namely load amplitude and loading frequency defined as Equations (2) and (3), respectively:

$$Q = Q_0 \exp(i\omega t) \tag{2}$$

$$\omega = 2\pi f \tag{3}$$

where, Q_0 is loading amplitude, ω is angular frequency, and f is ordinary frequency.

The Rayleigh damping coefficients (i.e., β and α) utilized in the dynamic analysis of the present study were calculated according to Equation (4):

$$C = \beta K + \alpha M \tag{4}$$

where, C, M, and K, are damping, mass matrices, and stiffness, respectively [27].

In the FLAC program, the values of β and α computes based on the Equations (5) and (6):

$$\beta = \frac{\xi_{\min}}{\omega_{\min}} \tag{5}$$

$$\alpha = \xi_{\min}\omega_{\min} \tag{6}$$

TABLE 1. Properties of sandy soil and shallow foundations used in numerical modeling

Sandy soil	
Unit weight, γ (kN/m^3)	17
Elasticity modulus, E (MPa)	13
Cohesion, c (kPa)	1
Friction angle, φ (deg.)	30
Dilation angle, ψ (deg.)	1
Poisson’s ratio, ν	0.30
Shallow strip foundation	
Depth, D_f (m)	0
Width, B (m)	1

where, ξ_{min} is minimum damping ratio that is selected equal to 0.05 [27].

Bearing capacity of shallow foundations under cyclic loading was obtained according to ACI recommendation [31]. Based on this method, the bearing capacity of machine foundations under vibrating is determined on the basis of loading frequency and recorded settlement.

3. RESULTS AND DISCUSIONS

Figure 2 illustrates the variations of interference coefficient (*IC*) of foundations versus the distance ratios (*S/B*) of foundations. The soil properties and the position of foundations are equal to values given in Table 1.

As shown in Figure 2, an increase in *S/B* led to increase and then decrease of interference coefficient, *IC*. The value of interference coefficient at distance ratio of about S/B=2 is maximum (Figure 2). As the distance ratio of foundations widens over 2, the value of *IC* decreases and the interference effect canceled out at distance ratio of *S/B*>5 (Figure 2). In fact, the foundations behave independently at distance ratios larger than 5.

3.1. The Effect of Soil Strength Properties

3.1.1. Elasticity Modulus The behavioral interference coefficient of shallow strip foundations under cyclic loading was determined for different values of elasticity modulus (*E*=13, 20, 30, 40 and 50 MPa) of sandy soil at distance ratios (*S/B*) of 1, 2 and 5 (Figure 3). As shown in Figure 3, the interference coefficient (*IC*) increased with increasing soil elasticity modulus (*E*).

3.1.2. Friction Angle The effect of soil friction angle (φ) on the bearing capacity of adjacent shallow foundations under cyclic loading was presented in Figure 4. The internal friction angle of sandy soil was changed from 30 to 45 degrees to examine its effect on the interference coefficient (*IC*).

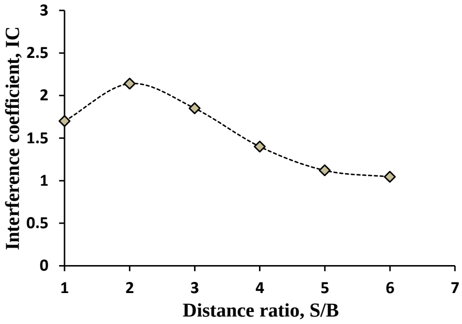

Figure 2. Variation of interference coefficient against distance ratio of foundations

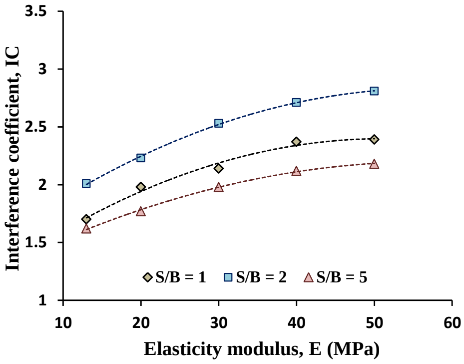

Figure 3. Variation of interference coefficient against soil elasticity modulus

Figure 4 indicates the variation of interference coefficient versus distance ratios of foundations for friction angles of 30, 37 and 45 degrees. As seen in this figure, an increase in the soil friction angle led to higher interference coefficient. This finding is in good agreement with experimental studies of Kumar and Bhoi [23]. In fact, Kumar and Bhoi [23] investigated the influence of soil density on the bearing capacity of interfering foundations rested on sandy soil under static loads. They concluded that an increase in soil density and subsequently the soil internal friction angle led to higher behavioral interference.

3.2. The Effect of Loading Characteristics

3.2.1. Loading Frequency Loading frequency is one of the most important factors that affect the performance of a vibrational system. Therefore, it is essential to examine the effect of harmonic load frequency on the bearing capacity of adjacent shallow foundations.

Figure 5 demonstrates the effect of loading frequency (*f*=10, 50 and 250 Hz) on the interference coefficient at distance ratios of 1, 2 and 5. Interference coefficient decreases with increasing loading frequency. The decreasing rate of interference coefficient tends to be higher at smaller frequencies (Figure 5).

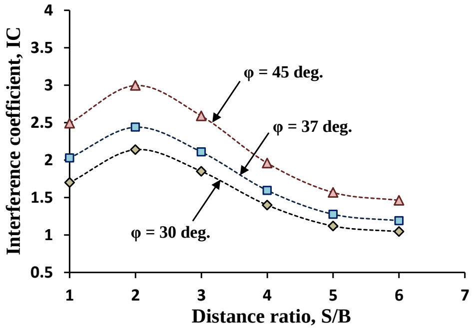

Figure 4. Variation of interference coefficient against soil friction angle

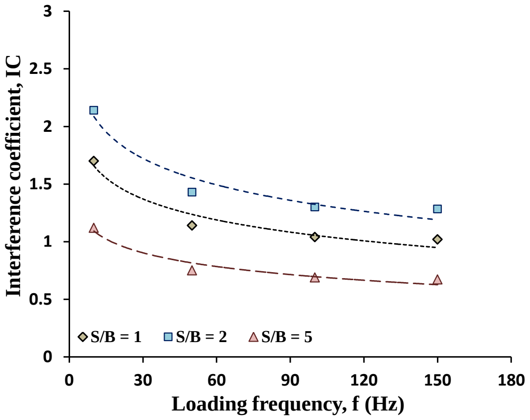

Figure 5. The effect of loading frequency on the interference coefficient

As depicted in Figure 5, at frequencies larger than 50 Hz, the variations rate of *IC* significantly decreases.

3.2.2. Loading Amplitude

In this section, the effect of loading amplitude on the behavioral interference of strip foundations was modeled under cyclic loads. The behavior of foundations at amplitudes of 50, 100 and 150 kN was investigated at distance ratios of 1, 2 and 5. As shown in Figure 6, the interference coefficient increased as loading amplitude increases. For different loading amplitudes, the highest interference coefficient was obtained at a distance ratio of about *S/B*=2 (Figure 6).

3.3. The Effect of Geometrical Characteristics of Foundations

3.3.1. Foundation Width

The bearing capacity of strip foundations with the widths of 0.5, 1, 1.5 and 2 m and at distance ratios of 1, 2 and 5 was investigated through numerical modeling. Figure 7 illustrates the effect of variations in foundation width (*B*) on the interference coefficient (*IC*). An increase in strip foundation width led to lower interference coefficient (Figure 7).

3.3.2. Foundation Depth

In this section, the effect of embedded depth on the bearing capacity of adjacent strip foundations was examined. For this purpose, the interference coefficients were evaluated for different embedded depth ratios (D_f/B). The numerical modeling involved D_f/B ratios of 0, 0.2, 0.5, 0.8 and 1. Figure 8 illustrates the effect of embedded depth on the interference coefficient at the various distance ratios. The results indicated that an increase in foundation depth led to greater behavioral interference coefficient (Figure 8).

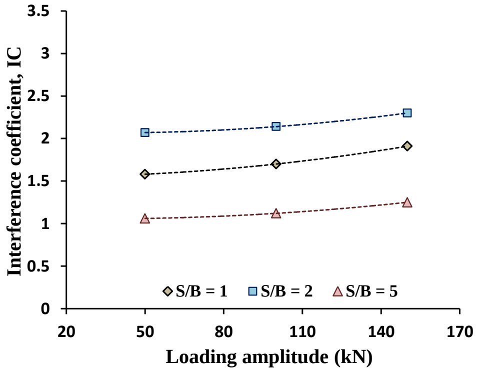

Figure 6. The effect of loading amplitude on the interference coefficient

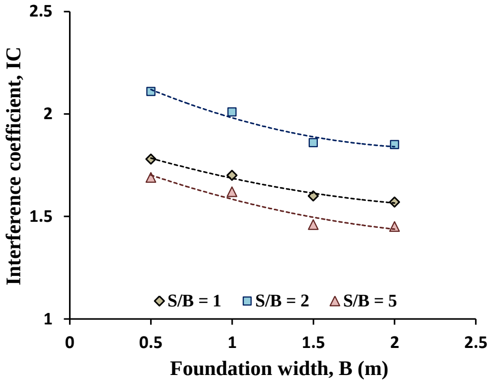

Figure 7. Variation of interference coefficient against foundation width

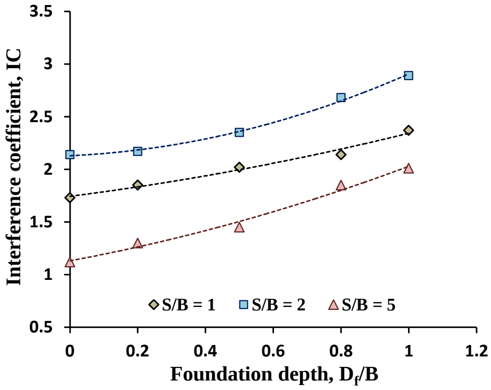

Figure 8. The effect of foundation depth on the interference coefficient

4. CONCLUSIONS

In this study, the dynamic bearing capacity of interfering shallow foundations was explored. The strip foundations of vibrating machines were numerically modeled using finite difference program of FLAC. The Mohr-Coulomb criterion was adopted to control the failure stage of sandy soil beneath the foundations. The effect of soil strength properties, geometric characteristics of foundations, loading frequency and loading amplitude on the behavioral interference of foundations were investigated. Based on the numerical analyses conducted in this study, the following results were obtained:

- The variation in distance ratio between foundations changes their bearing capacities. This is due to the impact of failure wedges on each other.
- The highest interference coefficient was observed at distance ratio about $S/B=2$. At distance ratios above 5 (i.e., $S/B>5$), the amount of interference coefficient reached $IC=1$, where foundations behave independently.
- As the soil elasticity modulus (E) increased, the interference coefficient increased. Moreover, increasing rate of IC decreases with increasing E.
- An increase in internal friction angle of sandy soil beneath foundations led to greater dynamic bearing capacity of interfering foundations.
- An increase in loading frequency was accompanied by a reduction in behavioral interference coefficient in adjacent strip foundations.
- The interference coefficient increased with increasing loading amplitude.
- As the foundation width increased, the interference coefficient decreased even though it was insignificant.
- An increase in foundation depth led to higher interference coefficient. This indicated an acceptable confidence factor for the interference coefficient values calculated at zero embedded depth.

5. ACKNOWLEDGEMENT

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چکیده

در این مطالعه با استفاده از مدلسازی عددی تفاضل محدود با برنامه‌ی FLAC به بررسی ظرفیت باربری دینامیکی پی‌های سطحی نواری مجاور هم مستقر بر خاک ماسه‌ای پرداخته شد. اثر تداخل رفتاری این پی‌ها تحت شرایط مختلف بررسی شد. اثر پارامترهای مقاومتی خاک، مشخصات هندسی پی‌های سطحی، و مشخصات بار سیکلی در نسبت فواصل مختلف بر ظرفیت باربری پی‌ها ارزیابی شد. نتایج حاصل بیانگر اثر تداخل رفتاری بر عملکرد پی‌های سطحی تحت بارهای سیکلی می‌باشد. با افزایش نسبت فاصله‌ی بین پی‌ها، اثر تداخل افزایش و سپس کاهش می‌یابد. بیشترین اثر تداخل رفتاری پی‌ها در نسبت فاصله‌ی 2 برابر عرض پی مشاهده شده است. در نسبت فواصل بزرگتر از 5 برابر عرض پی، اثر تداخل از بین میرود. همچنین با افزایش زاویه اصطکاک داخلی، مدول الاستیسیته خاک ماسه‌ای زیر پی، و همچنین عمق مدفون پی اثر تداخل بر ظرفیت باربری پی‌ها افزایش یافته است. افزایش عرض پی و فرکانس بارگذاری کاهش ضریب تداخل را به دنبال داشته است. بطور کلی نتایج حاصل بیانگر لزوم لحاظ اثر تداخل در ارزیابی ظرفیت باربری پی ماشین آلات مرتعش می باشد.

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