Case Study

Dynamic response of a footing adjacent to dynamically loaded footing on gypseous soil

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Abstract

This paper presents an experimental study on the dynamic response of a circular foundation, underneath the have an impact on of a dynamic load that outcomes from the placement of a neighbouring footing said as (vibration source), having square-shaped and excited by way of a known source of vibration placed on top of it. The cause is to evaluate the effect of dynamic motion closely by group called the second foundation. Both foundations were founded on collapsible soil (gypseous soil) with a content of gypsum 65%. The research is conducted in dry and soaked conditions with an oversized experimental programme. The first base (source vibration) and also the second base are made of steel, with the size of $80 \times 80 \times 40$ and the circular shape of 80 mm diameter. Subsequently, the soil had been prepared in layers in steel containers with $1000 \times 500 \times 500$ mm, then the two foundations positioned centrally over the underside. The first footing excited by the rotating mass type mechanical oscillator to come back up with vertical harmonic loading, produces a related have an impact on of dynamic loads and also the 2nd base is loaded with only static weight under dynamic excitement. The checks are conducted beneath dynamic response for 3 frequencies (12, 18, 24) Hz, Displacement amplitude and acceleration of the 2nd foundation are examined, at a special distance between the inspiration (2B, 4B, 6B). The results have shown that when the space between the inspiration increases, the amplitude and also the acceleration for the second foundation decreases. Furthermore, the value of these parameters at dry condition is larger than their value at soaked states.

Keywords Dynamic load · Machine foundation · Model test · Circular foundation · Vibration

1 Introduction

Dynamic loads can be generated from moving vehicles or heavy machinery or by moving the train, etc., which under these loads causes the foundations to be in a different position. The problem of interaction between nearby institutions is of great practical importance; in fact, many state institutions are not isolated and often interact with each other depending on the distance between them, often resulting in strong and dynamic damage to the structures, especially in serviceability. This means that a simplified technique must be developed to study the impact of

dynamic institutions at risk on neighbouring institutions. Many researchers have conducted several studies on a single isolated basis, ranging from a spring-plate mass system (simple) to a half-elastic area model (rigid) proposed by many researchers such as Gazetas [1]; Rao [2]; Rao [3]. An analytical and numerical research was conducted to understand the dynamic relationship of the group with the reactive behaviours of the soil structure, such as Tham et al. [4]; Priyanka [5]; Priyanka and Kumari [6].

One form of soil breakdown is gypsum soil. Its surroundings are wide in Iraq. This soil has a high drying capacity, but falls after saturation due to the disintegration

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of cement and binding of molecules. Supported structures on unstable soils should protect against this danger and therefore must be protected from this risk. These problems usually caused the erosion of the associated structure, tilt and fragmentation, Razouki et al. [7]. This type of land in Iraq comprises about 31.7% with gypsum levels between 10 and 70 %, Nashat [8].

Chen [9] examines the matter of mutual cooperation during a very straight sticky medium in small shear strains between multiple institutions. The basics are divided into different subcomponents of the examination. Dynamic response within each infrastructure is shown by the flexibility of green. Dynamic impedance and consistency are integrated into the fundamentals by the limit of movement and also the balance of power of institutions. Broad results are implemented for unidentified circular founders placed in several sectors. Dynamic cooperation between neighbouring institutions and also the results on small number of institutions are firmly scattered.

The dynamic interaction of squared institutions under tight machine shaking was experimentally explored by Abhijeet and Priyanka in [10]. A series of thorough model tests during this field were conducted in dynamic conditions including an outsized range of isolated study and basic reactive response to local soil in Kanpur, India. The dynamic interaction of distinct groups (size) of two-legged clusters was examined by causing the vertical harmonic load to be continued one in each of the bases (active base), where the other footing (inert footing) had only a collection of weight. Dynamic interaction between active and passive bases was observed by investigating the transmission ratio variation ($T+$) with the frequency ratio (fr). The passive base is resonant due to its vibrant excitement on the active base, which nevertheless occurs during a very phased delay of the resonant frequency of the active base. In determining the dynamic interaction of the baseline group, phase delay could also be a dynamic parameter. Phase delay is observed to be delayed when the spacing between surfaces decreases.

Chen [11] calculated the dynamic reaction by the numerical approach technique for a bunch of solid surface foundations. The formulation is completely stable and computationally simple with algebraic calculations. It does not impose any limitations on footing form, footing segmentation, layered medium thickness and frequency magnitude. Within the assessment, it is separated in several sub-square-regions from the foundation–base interface. By using the Green feature acquired through the transform and accurate Fourier–Bessel integration method, the dynamic reaction of each sub-region is calculated.

Sbartai [12] explored the dynamic interaction for two adjoining rigid foundations during a very viscoelastic layer. The vibrations come from one in each of the rigid

soil layer foundations which have a harmonic load of translation, rocking and torsion. By taking into consideration their interaction, the dynamic responses to the rigid surface foundations are solved by the wave equations. The solution has been developed using the BEM (Bound Element) Frequency Domain technique. The evaluation of this research shows that the dynamic interactions between the two adjoining foundations have not had a negligible impact on multiple parameters. Particularly in respect to the other parameters, the dominant influence is clear just like the heterogeneity of the soil, the shape of the inspiration and also the load intensity.

Suraparb and Senjuntichai [13] investigated the dynamic response of two rigid foundations resting on a poroelastic medium with multilayered time-harmonic load. This research assumes soft, fully permeable contact surface between foundations and also the layered medium. A discretization method and an explicit stiffness matrix system are used to examine this dynamic interaction issue. They noted that the current solution's precision was checked for which numerical results were also presented for two square foundations impedance. They found that frequency of excitation and also the gap between the two bases were obviously tormented by the impedance features.

Han et al. [14] explored the dynamic interaction among two or more adjoining foundations on a laminated soil surface. Type of parametric studies was performed to clarify the implications of depth layer, soil dampening, spacing between adjacent foundation and support structural mass and moment of inertia and wave propagation velocity on the dynamic behaviour of the three-dimensional. Also the study provides numerical examples to assess the accuracy and computational stability of the proposed approach.

Ali et al. [15] determined the dynamic compressor foundation evaluation by using the ANSYS commercial finite-element software. The model used a three-dimensional finite-element model. The impact of the underside foundation interaction during this study was taken into consideration within the model, which modelled soil as vertical and lateral spring and damper components. The soil foundation scheme determined basic natural frequencies and also the respective mode shapes and mass involvement ratios. The soil foundation reaction under forced excitation was calculated and displayed by the machine uneven load at distinct spanning frequencies.

In 2018, Vicencio and Nicholas [16] identified the effects of the structure–structure interaction (SSSI) between two buildings, with differing construction standards, distance and soil type. Using a nonlinear model (a simple two-dimensional discrete), a set of nonlinear differential equations was defined. The results showed that both unfavourable and beneficial settings of the two structures generate

a significant distinction between nonlinear SSSI and nonlinear SSI (non-separated construction state) of the soil just below the foundations. Linear rotational interaction is assumed between structures and linear behaviour of structures. The adverse effects of SSSI appear to be more pronounced when the behaviour of nonlinear soils is taken for granted.

Andersen [17] examined two polypod foundations dynamically interacted on the surface of the soil and two flexible embedded piles. In both cases, a layered ground with a soft top soil was considered over a rigid half-space. A Fortran effective implementation of a semi-analytical approach was analysed in the frequency field by a soil foundation interaction using Green for a distributed load acting on a surface or an interface of a linear viscoelastic half-area with horizontal layers. The piles were modelled on the beams by finites and the soil at structure–soil–structure nodes, assuming the cross sections of the piles were rigid.

Keawsawasvong et al. [18] explored the dynamic response of rigid footing having arbitrary shapes on multilayer poroelastic half-space under time—harmonic moment loading by employing a way of discretionary process and a stiffness matrix approach. They founded when the gap from the neighbouring footing is twice greater than the width; rocking vibration is examined jointly footing. Rather, while the gap between these two footing increases, an unloaded foundation would still have radiated energy dissipated from a loaded foundation.

Therefore, the absence of empirical studies on the behaviour of the underside adjacent to the foundations of the machine encourages the study, explaining how two closely spaced institutions located on gypsum soil interfere dynamically with small models.

The urgent need for machinery and equipment within the event of cities is the main source of vibration that

transports the soil and affects its engineering properties. The objectives of this work are to test the dynamic response of the muse to a sandy plaster soil under the influence of the combined dynamic load in both the states (dry and full) on the adjacent foundation. Dynamic answer includes displacement, vibration speed and acceleration.

This text provides an analysis of the dynamic response of one base with a tough and fast load near another base with a dynamic load, like (vibration source), in each of the foundations of a square shape, and thus, the opposite includes a circular shape, on gypsum soil. The study discusses the effect of the first foundation vibrations on the near foundation. On the soil surface, both institutions settle.

2 Definition of problem

There are two very far apart foundations, as shown in Fig. 1, on the gypsum soil. The load density belonging to the first base (vibration source) was maintained as 6 kN/m^2 , while the second foundations were placed during a load range of 30 kN/m^2 and thus the gap between the two establishments (S). The goal is to determine the dynamic responses of the second rule (acceleration of displacement amplitude) due to the dynamic excitement of application to the first rule both dry state and water.

3 The material and method

3.1 Apparatuses of model

Figure 2 shows the apparatuses of model; it includes the followings:

Fig. 1 Layout of experimental model

Fig. 2 The model with apparatuses

- Steel box with dimension $1000 \times 500 \times 500$ mm.
- Two foundations with dimension $80 \times 80 \times 40$ mm, for first foundation as a machine foundation, 80 mm in diameter, for second foundation which manufactured from steel
- Mechanical oscillator.
- Piezoelectric accelerometer.
- Two dial gauge.
- Variable frequency drive.
- Vibration meter.
- Digital tachometer.
- Computer device.
- Steel mould.
- Water tank.
- Static weight.
- Ac automatic voltage regulator.
- Camera

3.2 Test Setup

After examining previous studies by different researchers, like [19–24], a preliminary concept was developed; then, the experimental model group was designed. The primary concept could be a machine-based foundation with dimensions $80 \times 80 \times 40$ mm (vibration source), and also the second base with 80 mm diameter is subject only to fixed load. Circular weights 20 kg with a diameter of 25 cm are accustomed steadily load the second footing, a mechanical oscillator of the rotating mass rather than the primary footing comes up with a varying dynamic load. The mechanical oscillator consists of steel turntables, with a diameter of 60 mm and a thickness of 13 mm. With a tiny low eccentric block (l) instead of the turntable within

the eccentric (e) of 15 mm from the axis of rotation. During this study, just one style of eccentric settings worth 50 g is employed. The DC motor is employed to convert the mechanical oscillator with a special frequency starting from 100 rpm to 12,000 rpm. The controller is positioned outside the model to regulate the speed of the DC motor.

Before proving a dynamic response as displacement, speed or acceleration, the piezoelectric accelerometer is directly connected to the computerized model of digital vibration measurement (6063), which was previously defined by the computer. See Fig. 3.

The DT-2234A+ (digital tachometer) model was applied to guarantee that frequencies are not altered. See Fig. 4.

3.3 Preparation and test procedure

The soil for this study has been derived from the northern Iraqi Governorate, namely Tikrit, for the test programme; see Fig. 5. The physical properties of the soil can be found in Table 1, and the chemical properties are shown

Fig. 3 Devices used for measuring vibration response

Fig. 4 Digital tachometer

Fig. 5 The location of the soil sample (google earth image)

Table 1 Physical property of gypseous soil which is used for testing

Test	Properties	Value	Specification
Atterberg's limits	Specific gravity (Gs)	2.41	ASTM D 854 (2006)
	Liquid limit (LL) %	21	ASTM D4316-84
	Plastic limit (PL) %	N.P	
	Plasticity Index (PI)	N.P	
Compaction characteristics	Compaction characteristics:		ASTM 698-00
	Max. dry unit weight (KN/m ³)	16.23	
	Optimum moisture content %	12.33	
	Water content %	2.8	ASTM D2216-02
Grain size analysis	D10 (mm)	0.07	ASTM D422-02
	D30 (mm)	0.14	
	D60 (mm)	0.35	
	Coefficient of uniformity, Cu	5	
	Coefficient of curvature, Cc	0.8	
	Passing sieve No. 200 (%) (using kerosene)	24	
	Classification of soil based on USCS	SM	
	The collapse potential	7.9	ASTM D5533-2003
Direct shear test	Angle of internal friction (ϕ) in dry	38	ASTM D 3080-98
	Soil cohesion (C) (KN/mm ²) in dry	14	
	Angle of internal friction (ϕ) in soaked condition	34	
	Soil cohesion (C) (KN/mm ²) in soaked condition	5	
	Test unit weight (kN/m ³), γ_d test	15	
	Field unit weight ((kN/m ³), field	14.6	ASTM D1556-07

in Table 2. The results of a laboratory test performed on the sample soil used in the present research are shown in Figs. 6 and 7. Test water content at kept at (45) °C to

prevent loss of gypsum–soil crystal. The 65 per cent sample of gypsum soil is classified as (moderately severe) (ASTM D5533-2003). The gypsum soil (Sieve No. 4) has

Table 2 Results of chemical properties of gypseous soil used for testing (BS 1377: 1990, Part 3)

Composition	Value %
Total soluble salts (TSS) %	67.2
Gypsum content %	65
Sulphate content (SO ₃) %	30.5
Organic matters (OM) %	0.22
Chloride content (CL) %	0.062
pH value	8.1

Fig. 6 Grain size distribution for gypseous soil **Fig. 7** Results of single oedometer

been put in six layers of (steel container); with a uniform field density and by means of a hummer. A bubble ruler (equilibrium) system checks the surface and levels them. Both bases are centrally positioned over the prepared soil.

Figure 8 illustrates the test programme for this study.

The system's focus of gravity and the foundations must be kept vertically in line with the container's centre of gravity. After investigating results obtained by researchers and performing preliminary tests for 1-h testing time, 30-min dry-zone operation test and 30-min soaking testing time, it should be noted that the steel container left for (24) h for the soaking test to ensure that the soil was fully soaked, and in some cases soaked, and in the second day the test is continue.

In this study, the dynamic load is simulated with eccentric (me) setting 50 g. The oscillator is then slowly operated by means of a velocity control unit, to avoid elevated dynamic load from occurring suddenly. The first foundation was therefore subjected to vertical vibration.

The dynamic reaction (displacement amplitude and acceleration) of the second base is evaluated and registered simultaneously using a Piezoelectrical accelerometer. The functioning frequency (720, 1080, 1440) c.p.m. is regarded equal to (12, 18, 24) Hz; the dynamic response parameters were recorded every five minutes during operation test duration.

4 Results and discussion

The present research examines the dynamic response of the circular footing with exciting dynamic force coming from an adjacent base as the basis of the machine.

In the second rule, dynamic analysis is performed by the first sensational rule with a vertical load density generated by the vibratory device after checking the stability of the rules under a fixed load. The displacement amplitude and acceleration of the second baseline are measured at different distances ($S=B$, $S=4B$, $S=6B$), and for each state (dry and soaking), the two foundations are based on gypsum soil in the presence of the excitation dynamics applied at the first baseline. Figures 9, 10, 11 and 12 show the dynamic response of the second rule at separate distances to three frequencies (12, 18, 24) Hz.

4.1 Displacement capacity

In figs. 9 and 10, maximum and minimum displacement capacity were plotted versus frequency for both dry condition and condition, and displacement amplitude increases at ($S=2B$) when the frequency of operation increases for both cases (dry and soaking). This increase is small if it ranges from 12 to 18 Hz and high if it reaches 24 Hz for

Fig. 8 Test programme

optimum capacity just in case of drought and sunken. In contrast, when 12–18 Hz or 24 Hz during a dry state, the minimum capacity indicates a small increase, but in the case of soaking, the worth doubles.

In soaking conditions, the displacement amplitude value decreases compared to the dry state of the three frequencies, due to the presence of water that acts as a wave inhibitor. During soil transfer when soaking, the vibrations from the first foundation were less energy and the displacement capacity of the second basis was reduced.

When the spacing is 4B, the displacement amplitude decreases compared to ($S=2B$) in both cases. The reason for this may be that the vibrations travel a protracted distance from the source vibration (first base) to the adjacent footing (second base). In other words, increasing distance lands up in reduced amplitude; the spread of vibrations across the soil ends up in reduced energy of those vibrations.

At the spacing of 6B, the number increased by half from 12 to 18 Hz to induce the foremost displacement capacity at drought and increased by 2.5 times in value at 24 Hz. For the minimum displacement capacity, the price doubled from 12 to 18 Hz or 24 Hz.

In soaking, the displacement capacity is reduced compared to the dry state. The utmost capacity is slightly

higher when it ranges from 12 to 18 Hz but doubled when it rises to 24 Hz. The minimum displacement capacity is different. The amplitude is doubled when it rises from 12 to 18 Hz. But it increased by thrice the value of 24 Hz. Here the displacement amplitude value decreased when comparing the amplitude volume at ($S=2B$) and ($S=4B$) for each case (soaked and dry).

4.2 The acceleration

The maximum and minimum acceleration vs. frequency are shown in Figs. 11 and 12 and are registered in a dry and soaked state for three spacing ($S=2B$, $S=4B$, $S=6B$). The direction of behaviour is similar in the case of dehydration and sunken for minimal and minimum accelerations. Acceleration increases with increasing frequency in dry and sunken conditions. The effects resulting from the increased distance between the two shots on the accelerated volume are comparable with the effect of displacement and increased distance that causes acceleration to decrease, because the proliferation of vibrations across the soil leads to a decrease in energy and thus a decrease in acceleration. We also note that the volume of acceleration is higher in the case of drought than in the case of soaking.

Fig. 9 The displacement amplitude versus frequency for different spacing (s), **a** at $S=2B$, **b** at $S=4B$, **c** at $S=6B$ for dry condition

The acceleration volume within the dry state increases almost linearly when the frequency increases from 12 to 18 Hz or 24 Hz, at a distance (2B). The identical applies to (4B) and (6B) breaks. The gap between the utmost and also the minimum increases when the frequency rises and also the gap decreases when the gap between the two institutions increases as shown in Fig. 11.

In soaking condition, the acceleration rate increases only slightly for maximum and minimum accelerations when frequency increases from 12 to 18 Hz, but is about double in value for 24 Hz, which applies to the acceleration magnitude at a distance between the two footings as 4B, 4B and 6B. When the frequency increases, the gap between the maximum and the minimum acceleration increases and decreases with increasing the distance between the two foundations. In comparison with their values at dry level, the acceleration values at soaked state for three frequencies 12, 18, and 24 Hz, at a spacing of 2B, 4B and 6B, have fallen because of the presence of water, which

Fig. 10 The displacement amplitude versus frequency for different spacing (s), **a** at $S=2B$, **b** at $S=4B$, **c** at $S=6B$ for soaking state

acts as a wave inhibitor in soil (as already mentioned) and increases when the frequency increases, irrespective of whether its state is wet or dry. When the distance between the two foundations increases, the acceleration is reduced for both soaked and dry conditions, see Fig. 12.

5 Conclusions

5.1 Displacement amplitude

- The value of the displacement capacity of the footing under effects of dynamic loading comes from a close-by foundation (both footings are supported gypsum soil) with low operating frequency. The displacement in an undervalued state just in case of drought increases displacement capacity while reducing distance between feet. Reduction of displacement capacity when the space between the two foundations

Fig. 11 The acceleration versus frequency for different spacing (s), **a** at $S=2B$, **b** at $S=4B$, **c** at $S=6B$ for dry condition

increases from 2B to 4B at a frequency of 12 Hz is 14% in the dry state and 7 in the case of soaking. When the space increases from 2B to 6B, the reduction is 38.9% and 29% in the case of dehydration and soaking, respectively. At a frequency of 18 Hz, the displacement capacity (6.5% and 24.2%) decreased in dry and sunken conditions, respectively, when the space increased from 2B to 4B and decreased by 9.2% and 40.9% just in case of drought and soaking, respectively, when the space increased from 2B to 6B. For the frequency 24 Hz, the reduction is 5.01% in the case of drought and 13.88% in the case of soaking when the space increases from 2B to 4B. When the space increased from 2B to 6B, the displacement capacity decreased (11.96% and 25.1%) in dry and soaked conditions, respectively.

- There decrease in displacement capacity at dry condition when spacing increases from 2B to 4B or 6B less than the decrease in soaking displacement capacity for the same spacing.

5.2 Acceleration

- The acceleration of the footing under the influence of dynamic loading resulting from the near foundation (on gypsum soil) increases with increasing operating frequency. The magnitude of acceleration in the dry conditions is greater than its value in the case of soaking.
- Acceleration increases with reduced distance between feet. Reduced acceleration when the gap between the

Fig. 12 The acceleration versus frequency for different spacing (s), **a** at $S=2B$, **b** at $S=4B$, **c** at $S=6B$ for soaked condition

2 bases increases from 2B to 4B, at a frequency of 12 Hz, 23% in the case of dry, and 32.9% in the case of soaking. When the gap increases from 2B to 6B, the reduction is 47% and 65.8% in dry and soaking conditions, respectively. At a frequency of 18 Hz, the acceleration value decreased (9.1% and 10.91%) in dry and soaking conditions, respectively, when the gap increased from 2B to 6B, and decreased (28.1% and 23%) in the case of dry and soaking, respectively, when the gap increased from 2B to 6B. For a frequency of 24 Hz, the reduction is 11.16% in the case of dehydration and 13.94% in the case of soaking when the distances increase from 2B to 4B, and when the gap increases from 2B to 6B, the quantity of acceleration decreases by 37% and 43% within the case of dryness and soaking, respectively.

- Reduced acceleration in soaking when spacing increases from 2B to 4B or 6B greater than the decrease in dry volume acceleration for the same spacing.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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