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A study on the effect of nearby footing on surface vibration

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ABSTRACT: The study presents a numerical investigation of the response of footing under the influence of dynamic load placed on an elastic half-space. The geometrical features of the footing and its distance from the source of vibration are normalized in terms of Rayleigh wavelength. The objective is to study the effect of nearby footing on the propagation of surface waves for different footing dimensions. The study mainly focuses on the maximum displacement amplitude with and without footing, and the vibrational amplitude for varying dimensions of footing. The soil and the footing are assumed to be linear-elastic, isotropic, and homogeneous. The effect of dynamic response on a neighbouring footing is obtained in terms of amplitude ratio (A_R), which is the ratio of peak displacement amplitude with footing to the peak displacement amplitude without footing. In this study, it is observed that the amplitude ratio decreases with an increase in the width of the footing. However, the decreasing trend is not the same in all the cases. The amplitude ratio marginally decreases with an increase in thickness and depth of footing. However, a reverse trend is observed for a higher thickness and depth. Therefore, no generalized conclusion can be made on the effect of footing thickness and depth on amplitude ratio. It is observed that for all the cases, the percentage reduction ranges between 57% and 28% for different dimensions of footing. Observations from the study imply that vibrational amplitude significantly reduces due to the footing.

Keywords: Dynamic load, Vibration, Finite element method, Amplitude ratio, Rayleigh wavelength.

1. INTRODUCTION

1.1 OVERVIEW

Vibration caused by vehicular movement, vibrating machines, construction activity such as pile driving, deep dynamic compaction, blasting, and other sources has a significant impact on the long-term viability of adjacent structures and may damage the superstructure or substructure or foundation beneath it, which is difficult to repair later. We need to adopt the finite element approach to build the structure in such a way that it can survive the vibrations induced by natural and man-made causes. The footing in this study acts as a barrier in the route of wave propagation, causing a discontinuity in the wave field and half-space disruption. This study includes numerical solutions utilizing the finite element technique for various dimensions of footing and variations in amplitudes due to footing that may be encountered by engineers in the field, and where the offered solutions for homogeneous soil profiles are rendered inaccurate.

Ground Vibration occurs due to the propagation of seismic waves from the source of its generation. There are primarily two types of surface waves. There are other types of surface waves such as Rayleigh waves generated due to compressional and shear body waves which are transverse and travel faster than Rayleigh waves.

The need of studying elastic half-space medium subjected to dynamic loading to determine the two important elastic properties of shear and Poisson ratio of the medium. The determination of resonant amplitude of footing resting on the surface of an elastic half-space is the essence of a 2D wave propagation problem. Many researchers have been studied to obtain a solution for the dynamics of a rigid foundation with different geometries. The response of isotropic, homogeneous, elastic half-space to vibratory load and stabilization of models for 2D and 3D wave propagation have been investigated by Lamb [13].

1.2 NEED FOR PRESENT STUDY

A review of the literature shows that the investigation of vibrational behaviour on the footing has received little attention in prior studies. The researchers largely examined and worked on the influence of vibration on multi-layered soil and square footing in most of the literature. The influence of neighbouring footing for changing footing size on surface wave propagation on an elastic half-space, however, has not been addressed in the previous works, which pinpoints the necessity of such a study.

Many researchers have been performed on the effects of vibration caused by a vibratory load on nearby footing half-space elastic soil. Researchers like Zakaria and Al-Ezzi [2] presents an experimental study on the dynamic response of the rectangular foundation, under effect of dynamic load which results from an adjacent footing called (the source of vibration), having square shape and excited by a source of vibration. It was found that when the distance between the foundations increases, the amplitude and the acceleration for the second foundation decreased. Furthermore, the value of these parameters at dry state is higher than their value at soaked state.

Ladhane and Sawant [18], Mehndiratta [14] studied the analysis of laterally dynamic loaded vertical pile group considering the three-dimensional nature of the soil-pile system in which piles and soil are modelled using three-dimensional finite element techniques treating them as linear elastic. They found that frequency is decreasing with increase in the spacing of piles in series arrangement and maximum amplitude depends on stiffness of pile soil system, the external and natural frequency.

Sbartai [19], Rao [17], Han et al. [20] explored the dynamic interaction among two adjoining foundations on a viscoelastic soil surface. FEM technique has been utilized to define the arrangement at that point to decide the consistence elements of the two adjoining establishments concerning their dispersing, substratum profundity, masses, shapes, installing, load force, and frequencies of excitation. The results showed that the impact of a few parameters on the dynamic communication reaction of two nearby establishments is no immaterial. Although most of the approaches were carried out using the Finite element method (FEM) or Boundary element method (BEM) models, by carrying out modelling in PLAXIS software. Some researchers carried out both analytical and experimental approaches to compare the results of their studies.

Keawsawasvong et al. [12] and Chen [8] calculated the dynamic behaviour through numerical approach between rigid surface foundations on multi-layered half-space soil. The algebraic calculations are completely stable and simple and do not impose any limitations on footing form, segmentation, layered medium thickness, and frequency magnitude.

Pradhan et al. [16] examined the experimental validation of analytical solution using cone model for machine foundation vibration analysis on layered soil. In the paper comparison between frequency-amplitude response calculated by cone model and results of experimental investigation is thoroughly done.

Andersen [4], Narayan et al. [11] examined the significance of dynamic structure–soil–structure association (SSSI) for structures with at least two establishments, it led the investigation of such establishments in recurrence space, thinking about the range (0 – 50) Hz and utilizing Green's function for wave engendering in layered soil. The standardized powerful solidness identified with individual establishments and cross-coupling between two establishments are introduced.

Kim et al. [15] carried out brief review on the mechanism of earth-borne vibrations and studied the current practice of vibration control and mitigation. It was stated that the seismic waves or stress waves which travel through the layers of earth get superimposed with other types of stresses like static stresses or residual stresses due to the building loads, which causes severe damage to the structures. The study observed that high frequency (shorter wavelength) waves penetrate to a much deeper level and vice-versa. It has been observed that small frequencies of 2-5 Hz causes minor damage and high frequencies of 60-450 Hz causes major damages of structures. To effectively isolate the structures against vibrations, the amount of ground vibrations is estimated by several methods available in this literature.

Celebi and Schmid [7], Yang et al. [10] conducted a 2.5D finite/infinite element approach which depicts the three-dimensional results from the two-dimensional elements. In most studies, the depth, width and length of the trench were normalized with respect to Rayleigh wavelength (L_R) as Rayleigh waves are the surface waves caused by moving loads which mostly damage the structures. Some other mitigation measures like group of pile rows, wave impeding blocks are also studied in the literature. Most of the models were created in plane strain condition for two-dimensional wave propagation neglecting the transverse component of vibration.
Agarwal and Shrikhande [1] present the structural dynamics to application of seismic evaluation and retrofitting of reinforced concrete and masonry buildings. In the paper modeling and analysis has been done using laminated lead rubber bearing, and response of base isolated building has been compared with conventionally design earthquake resistance building using SAP 2000. It has been observed that base isolated building requires 30% less steel than a conventionally designed building for the same level of seismic protection. Further, nonlinear static pushover analysis was performed to compare the nonlinear response of base isolated building and conventionally designed building.

Chourasia et al. [9] studied the influence of a deep foundation (single under-reamed pile) with or without square footing on the displacement behaviour of a four-story, one-bay frame resting on distinct types of soil under dynamic loading was investigated using the finite element analysis software ANSYS WORKBENCH (18.0). The results show that adding footing to a single under-reamed friction pile has a considerable impact on the structure's dynamic response when compared to a pile without footing. The overall displacement for a foundation with a single under-reamed friction pile with footing is also lower than for a foundation with a single under-reamed friction pile without footing.

In many of the literatures Das & Ramana and Verruijit [5] found that it is convenient to use such systems to represent the response of the soil to a footing subjected to periodic loading. It can also be used for single piles in a homogenous elastic half space. While the finite element method and the boundary element method can be used in engineering practices, it is easier and faster to deal with the reduced system. It also allows the engineers to focus on the problem at hand not on the complexity that is associated with using the numerical methods. This method also allows making changes on the problem parameters and decision making becomes much faster and easier. In this paper the developments of the soil dynamics field with a focus on the response of the soil supporting shallow foundation subjected to a harmonic load shall be presented.

1.3 SUMMARY
Review of literature on dynamic analysis elaborated the governing factors like geometric features and elastic properties of the backfill material. The effects of dynamic load (source of vibration) on a multi-layered soil and square footing are appropriately

studied in all aspects in most of the literature. In all the literature demonstrating the frequency of vibratory load and a static footing were mostly considered for study by the researchers. However, the effect of a nearby footing of different dimensions on surface vibration and the amplitude ratio (A_R) were not studied in the previous works which identifies the need for further study in this domain.

2. SIGNIFICANCE OF VIBRATION

Vibration is a natural or mechanically occurrence of motion in the form of oscillation about a fixed or stationary point. The oscillations are represented as waves. The wave that causes volumetric change is called compression or primary waves (P-waves) and the wave that causes distort of the material is called shear waves or secondary waves (S-wave). These waves are called seismic waves. These are divided into longitudinal and transverse waves depending on the direction of propagation.

2.1 SEISMIC WAVES AND ITS TYPES

There are generally two types of seismic waves: Body waves and Surface waves. The first type of body wave (P-wave) is the fastest kind of seismic wave that travels through solids and liquids, causing momentary volume change. These are longitudinal in nature which implies that the particle displacement is parallel to the direction of propagation of these waves. The other type of body wave is S-waves which are much slower than the P-waves. These are transverse waves, whose particle displacement is perpendicular to the direction of propagation. Shear waves lead to shape changes in the material they pass through. Thus, these waves cannot travel through liquids. Surface waves originate at the surface of the earth. The propagation of surface waves is limited to some depth of earth's surface. The decay of surface waves take place at a much lower rate than the body waves as the latter travels through the interior of the earth and interacts with its various layers (Agarwal and Shrikhande [1]).

In body waves, amplitude varies inversely with the radial distance from the source of vibration (1/r), except along the surface as its amplitude decreases in a rate of ($1/r^2$), where r is the radial distance (Woods, [21]).

Surface waves are generally classified as Rayleigh waves (R-waves) and Love waves. Surface waves travels slower than P-waves and S-waves which decay through its propagation. R-waves is called ground roll, travel as ripples of motion in elliptical paths and is slower than body waves. R-waves are longitudinal as well as transverse in nature whereas Love waves are transverse in nature. In the recording station, it is found that the P-waves arrive first, followed by S-waves, which is further followed by R-waves. Hence, the velocity of P-waves is more than S-waves and the velocity of S-waves is more than Rayleigh waves. The equations of velocity of P-waves, S-waves and R-waves (Das and Ramana [5]) are as follows:

$$V_P = \sqrt{\frac{(1-\nu)}{\rho(1+\nu)(1-2\nu)}} \qquad (2.1)$$

$$V_S = \sqrt{\frac{E}{2\rho(1+\nu)}} \qquad (2.2)$$

$$V_R = \frac{(0.87+1.12\nu)V_S}{(1+\nu)} \qquad (2.3)$$

Where V_P, V_S, V_R are the velocity of P-wave, S-wave and R-wave respectively and E, ν and ρ denotes the elastic modulus, Poisson's ratio and mass density of the material respectively.

2.2 MATERIAL DAMPING

In the case of real earth materials, some of its energy is lost per deformation cycle which is called material damping. Material damping is generally denoted by β, which is also termed as absorption co-efficient. The value of absorption co-efficient depends on the frequency of excitation in a linear manner as follows:

$$\beta_2 = \beta_1 \frac{f_2}{f_1} \qquad (2.4)$$

Where β_1 is the known value of absorption coefficient at frequency f_1 and β_2 is the unknown value at frequency f_2.

2.3 REDUCTION OF SEISMIC WAVES WITH DISTANCE

The reduction of seismic waves with distance from source is governed by both radiation damping and material damping. The total damping effect on wave amplitude taking both forms of damping into account can be expressed in the following (Woods [21]):

$$A_2 = A_1(\frac{r_1}{r_2})^n \, exp \, exp \, [-\beta(r_2 - r_1)] \qquad (2.5)$$

Where,
A_1 = Amplitude at distance r_1 from source
A_2 = Amplitude at distance r_2 from source
β = Absorption coefficient
n = 1/2 (for Rayleigh waves)

= 1 (for body waves)
= 2 (for body waves along the surface)

2.3 OBJECTIVES OF THE STUDY

The detailed objectives of this study can be summarized as follows:

- Numerical analysis of a footing's dynamic reaction in an elastic half-space soil.
- Obtain average displacement amplitude at equally spaced nodes at the base of the footing.
- To calculate the ratio of displacement amplitude with footing to displacement amplitude without footing (termed as amplitude ratio).
- To investigate the variation of amplitude ratio for different footing sizes (width and thickness) and depths.
- To draw conclusions on the effect of footing on surface vibration.

3. METHODOLOGY

The study on dynamic vibration on an elastic half-space is investigated using a finite element software, PLAXIS 2D. It is two-dimensional finite element software used for performing deformation and stability analyses of several geotechnical problems more quickly and simply. Here, the methodology involved in the study is mostly discussed. In light of the current study's requirements, the units and sign conventions, elements, geometry, boundary conditions, mesh creation, material qualities, etc are briefly discussed.

3.1 FINITE ELEMENT MODELLING IN PLAXIS

3.1.1 Units and Sign Convention

The standard units chosen for the study are metre for length, kilo-Newton for force, and seconds for time. The geometry is generated in the X-Y plane of the global coordinate system and the Z-axis is out of the plane direction.

3.1.2 Model

PLAXIS 2D contains the two basic options for the type of models, plane-strain and axisymmetric. The present work is carried out using the plane-strain model for uniform cross-sectional geometries and the strains and displacements in Z-direction are considered zero.

3.1.3 Elements

The software provides two choices for the user to model either using 6-node or 15-node triangular elements. The 15-node triangular element is the default element that is chosen for this study which is proven to be more accurate and provides accurate results of stresses.

3.1.4 Loads and Boundary Conditions

The dynamic load system is chosen and the distributed load system B is applied. Along the boundaries, the standard fixity option is selected. The standard fixity condition imposes the following boundary conditions:

- In the model, vertical geometry lines obtain horizontal fixity ($u_x = 0$)
- In the model, horizontal geometry lines obtain full fixity ($u_x = u_y = 0$)

In addition, absorbent boundary conditions are used for the right, left and the bottom surface of the model to avoid any wave reflections at the model boundaries.

3.1.5 Material Properties

The constitutive model chosen for the present study is a linear-elastic model. The model involves the parameters; Young's modulus (E), Poisson's ratio (ν), and mass density of soil (ρ). The material type is selected as the drained type. For all the materials, some material damping value should be assigned as all the materials possess a certain damping property due to their viscous properties and internal friction. In PLAXIS, the material damping is assigned in terms of Rayleigh alpha (α_R) and Rayleigh beta (β_R). The relationship between α_R, β_R, ω, and ξ is represented as follows:

$$\alpha_R + \beta_R\omega^2 = 2\omega\xi \qquad (3.1)$$

Where, $\omega = 2\pi f$ is the angular frequency of excitation and ξ is the damping ratio (material damping).

3.1.6. Mesh generation

After defining the mesh of the entire geometry model and assigning the material properties, the model has to be divided into finite elements to carry out the finite element computations. The set of finite elements is called a mesh. In the present study, the mesh is discretized with a 'very fine' element option.

3.1.7 Dynamic Analysis

Dynamic analysis calculation is carried by out taking suitable values of amplitude, frequency, time period. Displacement vs. time plots is extracted for further calculation of displacement amplitudes. The total time interval, number of steps, etc. is to be specified for computing the desired results in dynamic analysis. The amplitude multiplier, frequency, and initial phase angle of the harmonic

motion are to be specified in the calculation phase. Before running the calculation, specific nodes are selected in the model and the displacement vs. time graphs are generated at the selected nodes.

4. AMPLITUDE RATIO

The effect of vibration caused by the vibratory load on a neighbouring footing is estimated in terms of amplitude ratio (A_R), which is the ratio of peak displacement amplitude with footing to the peak displacement amplitude without footing in the vertical direction.

$$A_R = \frac{Displacement\ amplitude\ of\ footing}{Maximum\ displacement\ amplitude} \quad (3.2)$$

To start with first, the displacement vs. time plot of the half-space with and without footing is obtained and subsequently, the average peak displacement amplitude of three equally spaced nodes for different footing dimensions is obtained. The amplitude ratio is thus calculated.

4.1 DEVELOPING CONSTITUTIVE MODEL

For developing constitutive models, the following elastic parameters are assumed for modelling the half-space soil and the footing. The half-space elastic parameters and frequency of the source of vibration (f) are assumed by Ahmad and Al-Hussaini [3]; Yang and Hung [10]. The material properties are listed in Table 4.1.

Table 4.1: Half-space material properties

Properties	Half-space soil	Footing
Type	Drained	Non-porous
Model	Linear elastic	Linear elastic
Elastic Modulus, E	4.6×10^4 kN/m^2	2.5×10^7 kN/m^2
Poisson's ratio, ν	0.25	0.2
Mass Density, ρ	1800 kg/m^3	2400 kg/m^3
Material Damping, ξ	5%	5%

For the selected half-space parameters and frequency of vibration, the Rayleigh wave velocity can be calculated as $V_R = 93\ m/s$. The Rayleigh wavelength (ratio of Rayleigh wave velocity and Frequency) will be $L_R = 3\ m$.

4.2 Model Description

The geometric features of the footing are normalized with respect to Rayleigh wavelength (L_R), i.e., depth of footing (D_f/B = 0, 0.5, and 1) width of footing ($B = 0.33L_R$, $0.66L_R$, and $1.0L_R$) and thickness ($T = 0.1L_R$, $0.2L_R$, and $0.3L_R$) and distance from source is assumed to be (l) = $2.L_R$. The dimensions of the half-space model adopted based on the previously published studies (Ahmad and Al-Hussaini [3]; Yang and Hung [10]) are $20L_R \times 5L_R$, i.e., 60 m × 15 m. The plane-strain models of 15-noded triangular elements are incorporated into the study for the analysis. The half-space material is assumed to be linear-elastic, homogeneous, and isotropic. The footing is also assumed to be linear-elastic. A vertical harmonic load assumed to be 1 kN/m with a frequency of 31 Hz is imposed over a half-space elastic soil with a footing nearby the load on the surface of soil shown in Figure 4.1. The wave relaxation coefficients C_1 and C_2 are assigned with 1 and 0.25 respectively (Brinkgreve *et al.* [6]).

The overall length of the zone of study is taken as $2L_R$ from the source of vibration. The node points to obtain the peak displacement at the ground as well as the footing are selected. The material damping value adopted in the study is 5%. Using Equation 4.1, the values of Rayleigh's mass (α_R) and stiffness (β_R) coefficients are estimated to be 0.90 and 0.4880E-3 respectively. Local line refinement and cluster refinement are carried out to get a reduced size of elements. The global coarseness type of mesh generation is assigned to be 'very fine' for determining the extent of deformation accurately. Dynamic analysis is carried out for different dimensions of footing on elastic soil to obtain the displacement vs. time plots for different dimensions of footing are determined. The time interval (Δt) for the analysis is taken to be 0.5 sec for the propagation of waves due to harmonic loading. The number of additional steps and the number of dynamic sub-steps are taken as 250 and 4 respectively.

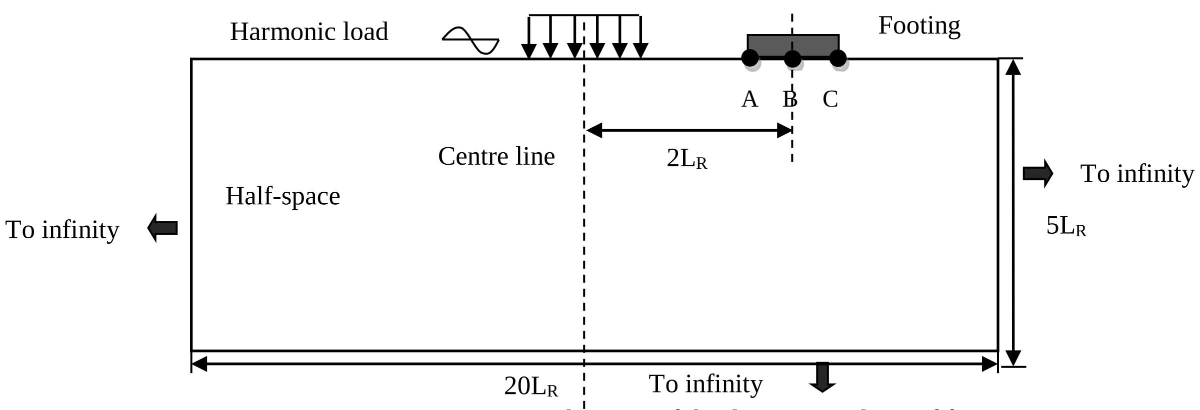

Figure 4.1: Schematic of the dynamic analysis of footing

4.3 Non-dimensional Approach

The study is carried out using a non-dimensional approach for the analysis. The design parameters of the footing are taken with respect to Rayleigh wavelength (L_R) as explained in Table 4.1, which results in a non-dimensional parametric research approach. In all circumstances, the geometric dimensions of the footing, such as width (B), depth (D_f/B), and thickness (T), will vary significantly. For the first case, the footing is considered on the ground ($D_f/B = 0L_R$) at a distance of $2L_R$ from the load as depicted in Figure 4.1.

For the examination of first the case, the model with width ($B = 0.33L_R$), depth ($D_f/B = 0L_R$), and thickness ($T = 0.1L_R$) of footing with global coarseness type of mesh to be 'very fine' generation, line, and cluster refinement is assigned locally. Similarly, the models with varying width ($B = 0.66L_R$ and $B = 1.0L_R$), depth ($D_f/B = 0.5L_R$ and $D_f/B = 1.0L_R$), and thickness ($T = 0.2L_R$ and $T = 0.2L_R$) of footing are created and the conclusions are analyzed for the other cases.

5. RESULTS AND DISCUSSION

This results obtained from the analyses performed with the finite element method, PLAXIS 2D. The results are presented and discussed in the subsequent sections.

5.1 DISPLACEMENT AMPLITUDE VS. TIME

The variation of displacement amplitude versus time has been studied at three equally spaced nodes on the base of the footing. The present study is carried out for different dimensions of footing at a distance assumed to be $2L_R$ from the source of vibration as mentioned in Section 4.3.1. Variation of displacement amplitude with and without footing to dynamic time for $D_f/B = 0$ has been depicted [Figure 5.1(a) to Figure 5.1(c)].

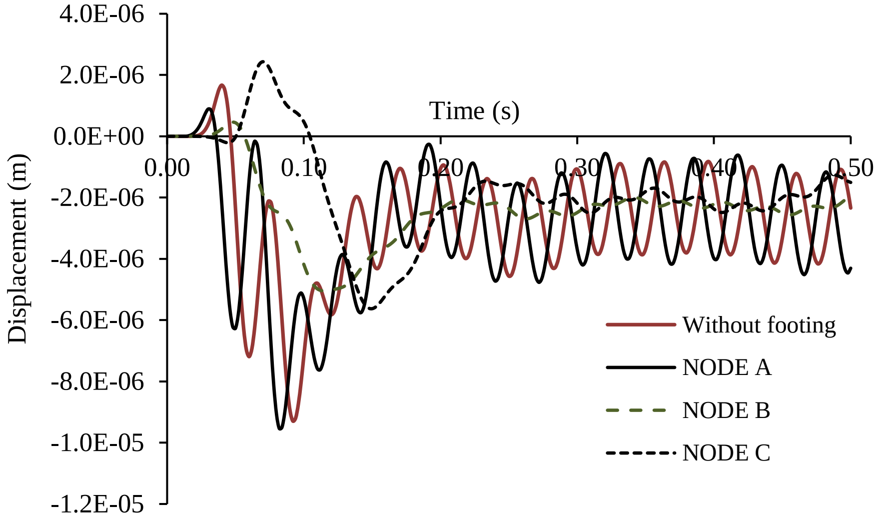

Figure 5.1(a): Displacement vs. time graph for $D_f/B = 0$ ($B = 0.33L_R$, and $T = 0.1L_R$)

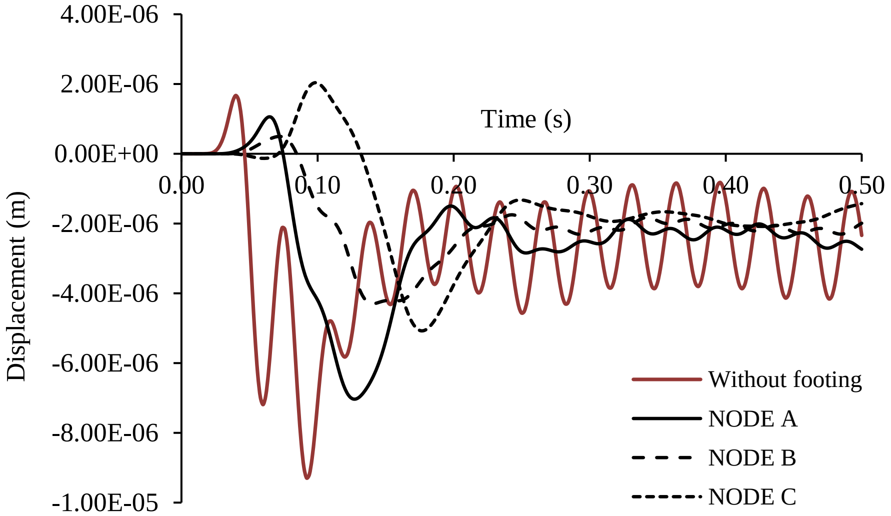

Figure 5.1(b): Displacement vs. time graph for $D_f/B = 0$ ($B = 0.33L_R$, and $T = 0.2 L_R$)

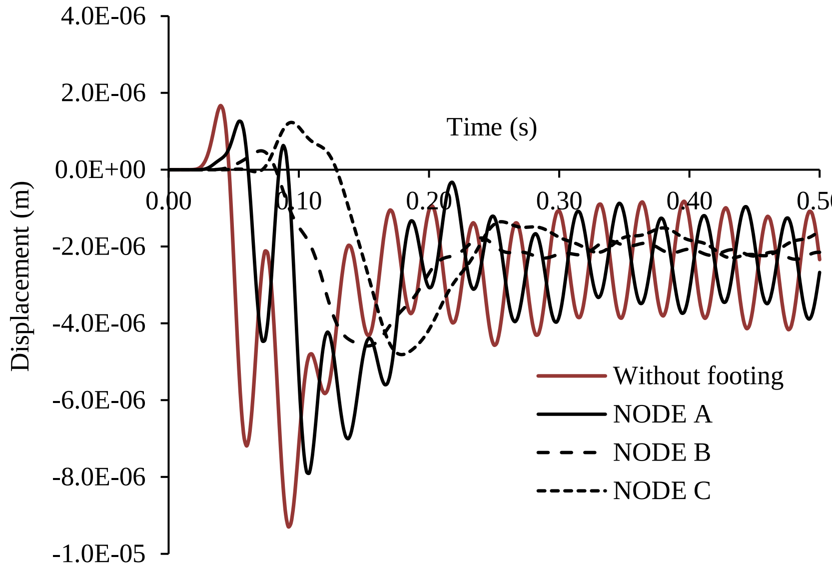

Figure 5.1(c): Displacement vs. time graph for $D_f/B = 0$ ($B = 0.33L_R$, and $T = 0.3L_R$)

However displacement vs. time graph has also been calculated for the other cases and it has been observed that the displacement amplitude with footing decreases for D_f/B = 0.5 and 1.0. After further analysing the displacement vs. time plots, it is evident that with the construction of footing, the displacement amplitude reduces. The vibration amplitude without footing and with footing for various cases has been explored further.

5.2 AMPLITUDE RATIO FOR VARIOUS CASES

The vibration amplitude on a neighbouring footing is estimated in terms of amplitude ratio (A_R), which is the ratio of peak displacement amplitude with footing to the peak displacement amplitude without footing in the vertical direction. The amplitude ratio is thus calculated for varying dimensions and depth of footing that have been illustrated [Table 5.2(a) to Table 5.2(c)].

Table 5.2(a): Amplitude ratio for $D_f/B = 0$

Width of footing, B (m)	Thickness of footing, T (m)	Amplitude ratio, A_R
$0.33\ L_R$	$0.1\ L_R$	0.724
	$0.2\ L_R$	0.588
	$0.3\ L_R$	0.569
$0.66\ L_R$	$0.1\ L_R$	0.619
	$0.2\ L_R$	0.547
	$0.3\ L_R$	0.514
$1.0\ L_R$	$0.1\ L_R$	0.513
	$0.2\ L_R$	0.505
	$0.3\ L_R$	0.469

Table 5.2(b): Amplitude ratio for $D_f/B = 0.5$

Width of footing, B (m)	Thickness of footing, T (m)	Amplitude ratio, A_R
$0.33\ L_R$	$0.1\ L_R$	0.569
	$0.2\ L_R$	0.564
	$0.3\ L_R$	0.570
$0.66\ L_R$	$0.1\ L_R$	0.569
	$0.2\ L_R$	0.494
	$0.3\ L_R$	0.561
$1.0\ L_R$	$0.1\ L_R$	0.498
	$0.2\ L_R$	0.446
	$0.3\ L_R$	0.446

Table 5.2(c): Amplitude ratio for $D_f/B = 1$

Width of footing, B (m)	Thickness of footing, T (m)	Amplitude ratio, A_R
0.33 L_R	0.1 L_R	0.574
	0.2 L_R	0.567
	0.3 L_R	0.608
0.66 L_R	0.1 L_R	0.566
	0.2 L_R	0.499
	0.3 L_R	0.519
1.0 L_R	0.1 L_R	0.480
	0.2 L_R	0.497
	0.3 L_R	0.500

From Table 5.2(a) to Table 5.2(c), it is evident that the amplitude ratio (A_R) reduces with the increase of width (B) and thickness (T) for varying depths of footing. However, variations of amplitude ratio with different footing dimensions have been studied further.

5.3 VARIATION OF AMPLITUDE RATIO WITH FOOTING DIMENSION

The influence of depth (D_f/B = 0, 0.5 and 1.0), width ($B = 0.33L_R$, $0.66L_R$, and $1L_R$), and thickness ($T = 0.1L_R$, $0.2L_R$, and $0.3L_R$) of footing is investigated at a distance assumed to be $2L_R$ from the source of vibration. The vibration amplitude changes depending on the dimension of the footing, which is explored further.

5.3.1. Variation of Amplitude Ratio with Different Footing Width

The effect of vibration amplitude due to changes in footing width is briefly studied in this section. The variation of amplitude ratio with varied width ($B = 0.33L_R$, $0.66L_R$, and $1L_R$) for different depth (D_f/B = 0, 0.5 and 1.0) and thickness ($T = 0.1L_R$, $0.2L_R$, and $0.3L_R$) of footing has been examined thoroughly. The variation of amplitude ratio with different footing widths has been depicted [Figure 5.4(a) to Figure 5.4(c)].

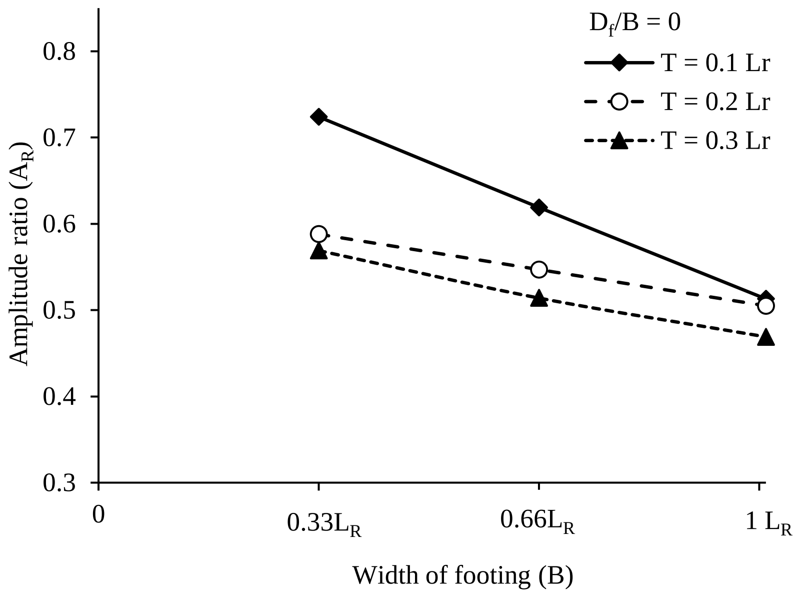

Figure 5.4(a): Amplitude ratio (A_R) vs. width (B) for varying thickness (T) at $D_f/B = 0$

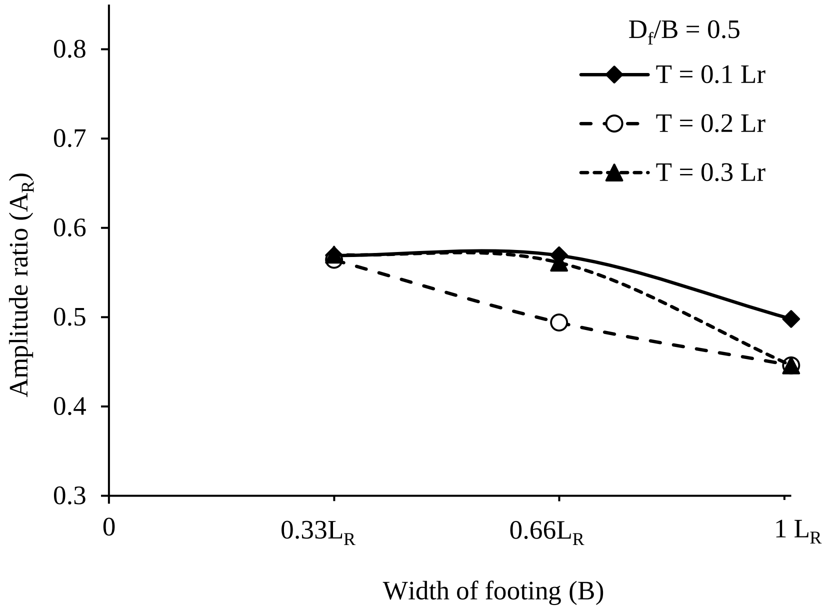

Figure 5.4(b): Amplitude ratio (A_R) vs. width (B) for varying thickness (T) at D_f/B = 0.5

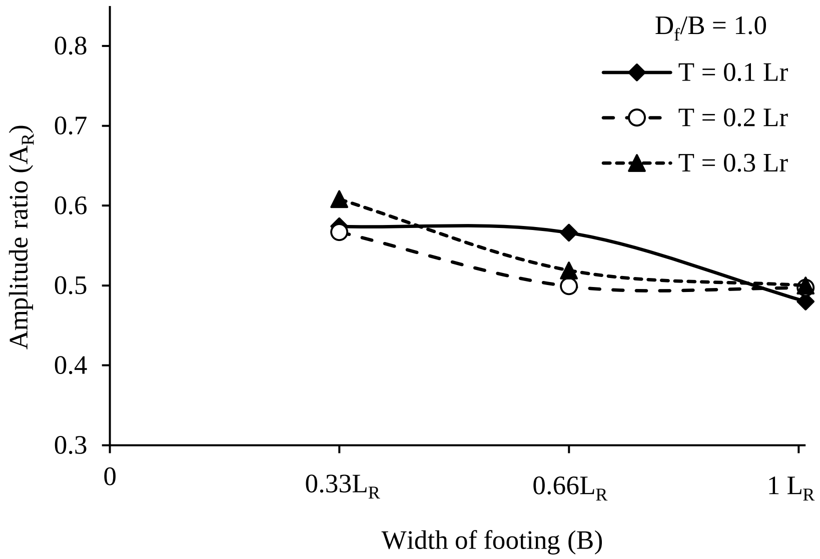

Figure 5.4(c): Amplitude ratio (A_R) vs. width (B) for varying thickness (T) at D_f/B = 1.0

From Figure 5.4(a) to Figure 5.4(c), it has been observed that with an increase in the width of footing, the amplitude ratio reduces. When the width of footing is considered to be 0.33L_R, it can be observed that the amplitude ratio is higher compared to 0.66L_R and 1.0L_R.

At D_f/B = 0, when the width of footing increases from 0.33L_R to 1.0L_R, the amplitude ratio (A_R) reduces as shown in Figure 5.4(a), which can be seen for all thicknesses values. However, the decreasing trend is not the same for the other cases. For D_f/B = 0.5 and D_f/B = 1.0, the amplitude ratio marginally reduces with an increase in the width of footing Therefore, the amplitude ratio decreases with an increase in footing width for varied thickness and depth of footing. When the variation of amplitude ratio with thickness and depth of the footing is examined, an irregularity in the variation of the amplitude ratio is found, which is explored further.

5.3.2. Variation of Amplitude Ratio with Different Footing Thickness

The vibration amplitude however reduces with the width of footing but it is contradictory in the other cases. In this section, the variation of amplitude ratio with the thickness (T = 0.1L_R, 0.2L_R, and 0.3L_R) of footing is investigated at varied depth (D_f/B = 0, 0.5 and 1.0) and width (B = 0.33L_R, 0.66L_R, and 1L_R) of footing. [Figure 5.5(a) to Figure 5.5(c)] shows the variation of amplitude ratio with varying footing thickness.

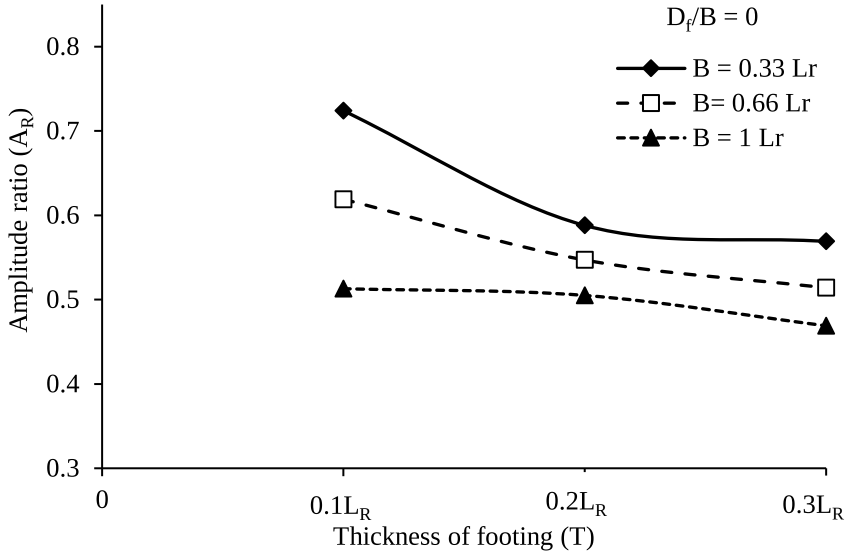

Figure 5.5(a): Amplitude ratio (A_R) vs. thickness (T) for varying width (B) at D_f/B = 0

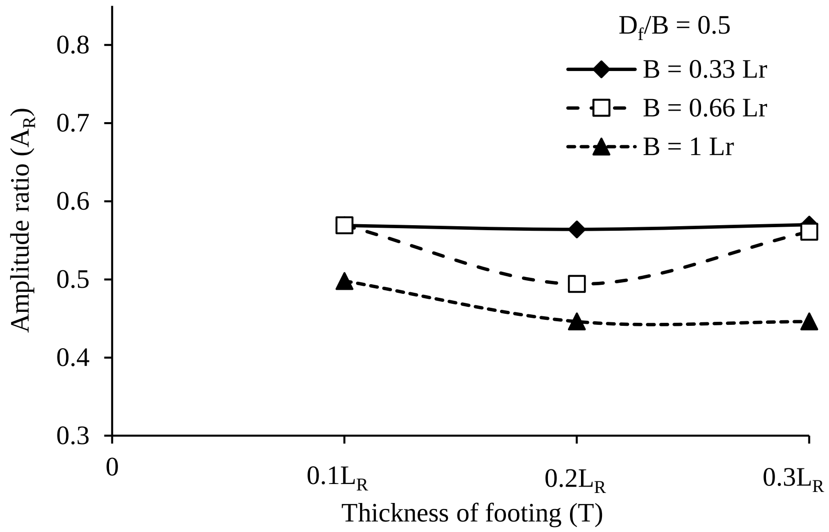

Figure 5.5(b): Amplitude ratio (A_R) vs. thickness (T) for varying width (B) at D_f/B = 0.5

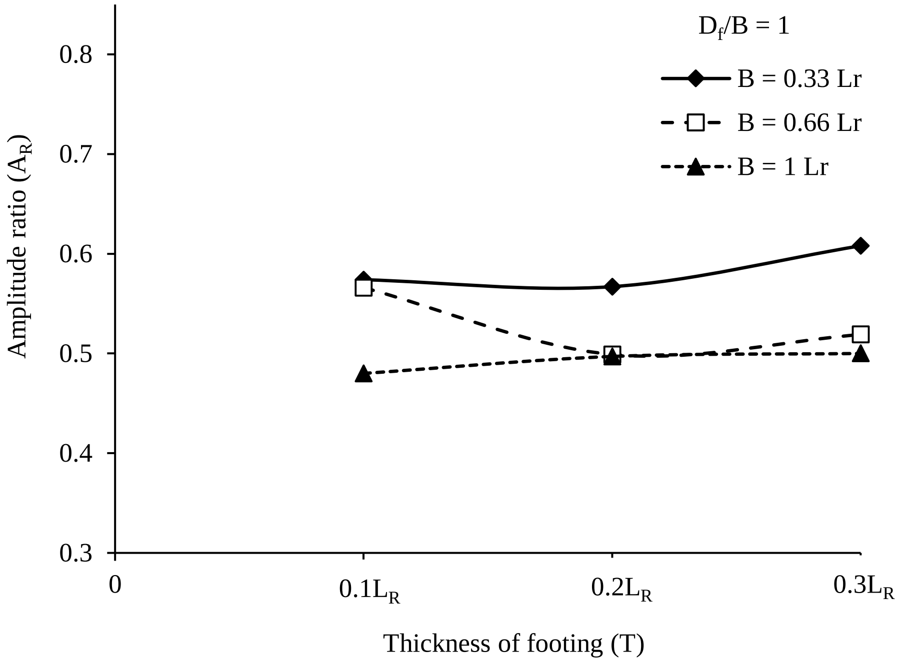

Figure 5.5(c): Amplitude ratio (A_R) vs. thickness (T) for varying width (B) at D_f/B = 1.0

From Figure 5.5(a) to Figure 5.5(c), it has been observed that in most cases, the value of amplitude ratio (A_R) is found to be reducing whereas in some cases, it increases. When thickness (T) is increased from $0.1L_R$ to $0.3L_R$, amplitude ratio (A_R) reduces gradually (for

D_f/B = 0). Whereas for D_f/B = 0.5 and D_f/B = 1.0, when thickness (T) is increased from 0.1L_R to 0.3L_R, the amplitude ratio (A_R) increases. Hence, in this case, the variation of amplitude ratio with the thickness of footing is not consistent for all the cases of study.

5.3.3. Variation of Amplitude Ratio with Different Footing Depth

In this section, the depths (D_f/B = 0, 0.5 and 1.0) of footing is investigated at varied thickness (T = 0.1L_R, 0.2L_R, and 0.3L_R) and widths (B = 0.33L_R, 0.66L_R, and 1L_R) of footing. The vibrational amplitude also varies inconsistently with different depths of footing. Variation of amplitude ratio with the depth for different widths and thicknesses of footing has been depicted [Figure 5.6(a) to Figure 5.6(c)].

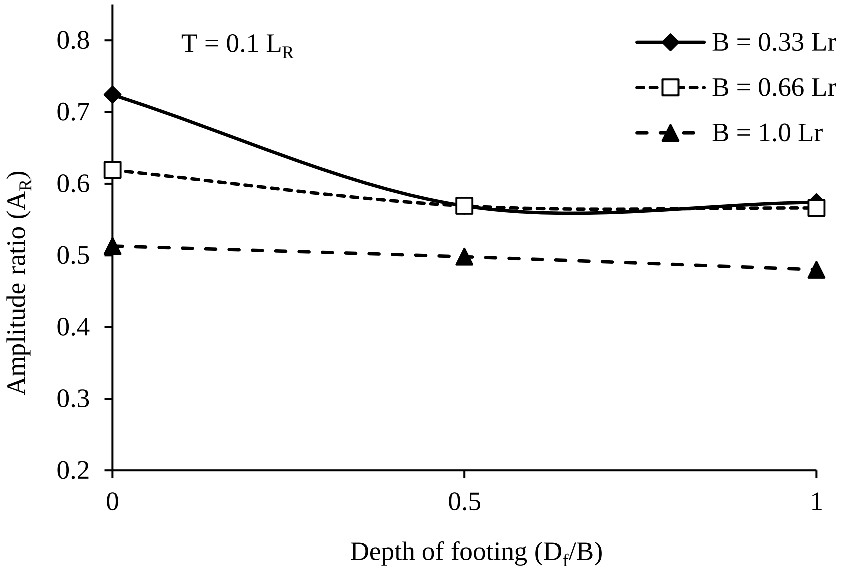

Figure 5.6(a): Amplitude ratio (A_R) vs. depth (D_f/B) for varying width (B) at T = 0.1L_R

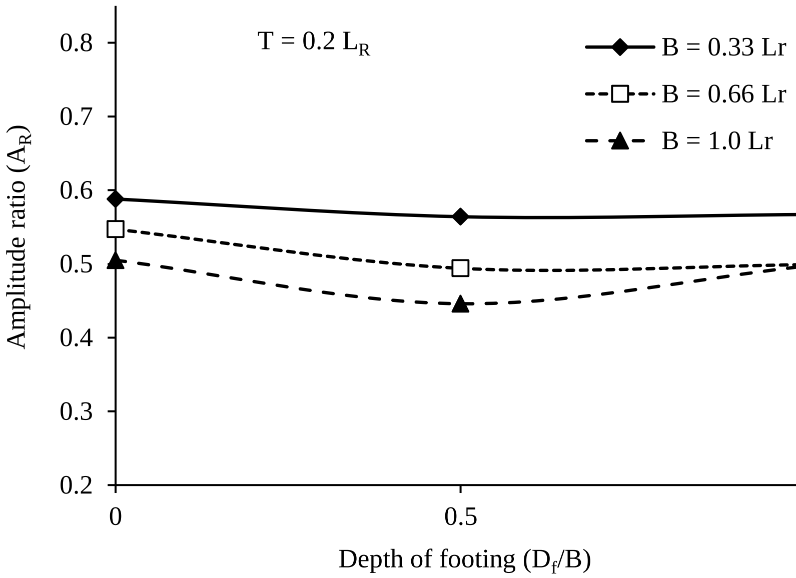

Figure 5.6(b): Amplitude ratio (A_R) vs. depth (D_f/B) for varying width (B) at T = 0.2L_R

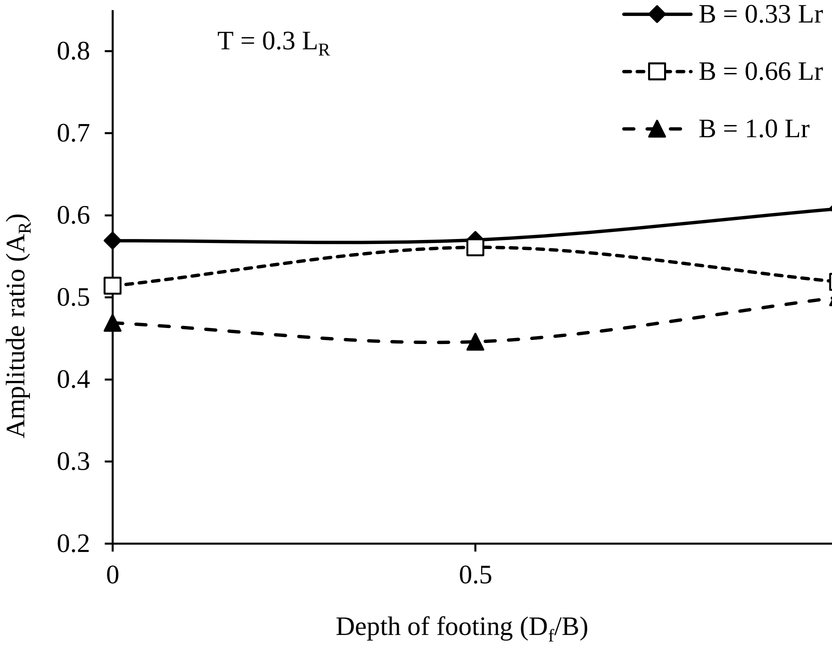

Figure 5.6(c): Amplitude ratio (A_R) vs. depth (D_f/B) for varying width (B) at T = 0.3L_R

From Figure 5.6(a) to Figure 5.6(c), it has been observed that for T = 0.1L_R and 0.2L_R, the amplitude ratio (A_R) values marginally reduce with depth. Whereas, in the case of T = 0.3L_R, a reverse trend is observed. Therefore, variation of amplitude ratio with the depth of footing is not consistent for all the cases. For lesser values of thickness, the amplitude ratio reduces, and a reverse trend is seen when thickness increases beyond a certain value. Thus, the variation of amplitude ratio with the depth of footing is not prominent for all the cases of study.

As a result of evaluating the variation of amplitude ratio with change in footing size, it has been discovered that the amplitude ratio steadily decreases for different widths of footing. The amplitude ratio, on the other hand, is inconsistent for different depths and thicknesses of footing. When the thickness of the footing is increased from 0.1L_R to 0.2L_R, the amplitude ratio decreases in most circumstances. However, when the thickness is increased to 0.3L_R, the amplitude ratio rises. Similarly, when the depth dimension of the footing is increased, the amplitude ratios are shown to be inconsistent.

6. CONCLUSIONS

A numerical investigation was conducted using PLAXIS 2D to study the effect of a nearby footing on surface vibration caused by a harmonic source of excitation. Following are the conclusions of the study.

- From Figures 5.4(a) to 5.4(c), it is evident that the amplitude ratio decreases with an increase in the width of the footing. It is true for all three thickness values. However, the decreasing trend is not the same for all cases. It can also be seen that the amplitude ratio further decreases with width as D_f/B increases.
- At D_f/B = 0, B = 0.33L_R, and T = 0.1L_R, the amplitude ratio (A_R) is found to be maximum which implies that when the footing is at the ground surface, the vibrational amplitude is higher than the footing at a certain depth.
- From Figure 5.5(a) to 5.5(c), it can be seen that amplitude ratio decreases to some extent with increase in thickness of footing (T = 0.1L_R, T = 0.2L_R, and T = 0.3L_R) for D_f/B = 0 case. However, the same trend is not observed for the other cases (D_f/B = 0.5, D_f/B = 1.0). So, no generalized conclusion can be made on the effect of footing thickness on amplitude ratio.
- In case of variation of amplitude ratio versus depth of footing, for T = 0.1L_R and 0.2L_R, the amplitude ratio (A_R) values marginally reduce with depth. Whereas, in the case of T = 0.3L_R, a reverse trend is observed. Therefore, variation of amplitude ratio with the depth of footing is not consistent for all the cases. For lesser values of thickness, the amplitude ratio reduces, and a reverse trend is seen when thickness increases beyond a certain value.
- The amplitude ratios for all cases are found to be less than unity. This implies that vibration amplitude reduces due to the construction of footing. For all the cases, the percentage reduction varies from 57% to 28% for varying dimensions of footing.

REFERENCES

[1] Agrawal, P., & Shrikhande, M. Earthquake resistant design of structures, PHI Learning Pvt. Ltd., 2007.
[2] Al-Ezzi, S. K., & Zakaria, W. A. Dynamic response of a footing adjacent to dynamically loaded footing on gypseous soil, *SN Applied Sciences*, 2(4), 1-11, 2020.
[3] Al-Hussaini, T.M. and Ahmad, S. Design of wave barriers for reduction of horizontal ground vibration, *Journal of Geotechnical Engineering*, Vol. 117, No. 4, pp. 616-636, 1991.
[4] Andersen, L. V. Dynamic soil–structure interaction of polypod foundations. Computers & Structures, 232, 105966, 2020.

[5] Braja, M., Das, G., & Ramana, V. *Principles of soil dynamics*, 2010.

[6] Brinkgreve, R.B.J. and Vermeer, P.A. Plaxis Users Manual. Balkema, Rotterdam (The Netherlands), 2002.

[7] Çelebi, E., & Schmid, G. J. E. S. Investigation of ground vibrations induced by moving loads. Engineering Structures, 27(14), 1981-1998, 2005.

[8] Chen, L. Dynamic interaction between rigid surface foundations on multi-layered half space, *International Journal of Structural Stability and Dynamics*, 16(05), 1550004, 2016.

[9] Chourasia, J., Pendharkar, U., & Singh, R. Dynamic analysis of pile foundation with footing in different foundation soils, *International Research Journal of Engineering and Technology (IRJET)*, 5(1), 2395-0072, 2018.

[10] Hsiao-Hui, H., & Yang, Y. B. Analysis of ground vibrations due to underground trains by 2.5 D finite/infinite element approach, *Earthquake Engineering and Engineering Vibration*, 9(3), 327-335, 2010.

[11] Kapil, N. Seismic response of vertically forces considering soil structure spectrum analysis, 2016.

[12] Keawsawasvong, S., Senjuntichai, T., Plangmal, R., & Kaewjuea, W. Rocking vibrations of rigid foundations on multi-layered poroelastic media, *Marine Georesources & Geotechnology*, 38(4), 480-492, 2020.

[13] Lamb, H. I. On the propagation of tremors over the surface of an elastic solid, Philosophical Transaction of the Royal Society of London, Series A, Containing papers of a mathematical or physical character, 203(359-371), 1-42, 1904.

[14] Mehndiratta, S., Sawant, V. A., & Samadhiya, N. K. Nonlinear dynamic analysis of laterally loaded pile, *Structural Engineering and Mechanics*, 49(4), 479-489, 2014.

[15] Nam, B. H., Kim, J., An, J., & Kim, B., A review on the effects of earthborne vibrations and the mitigation measures, *International Journal of Railway*, 6(3), 95-106, 2013.

[16] Pradhan, P. K., Mandal, A., Baidya, D. K., & Ghosh, D. P., Dynamic response of machine foundation on layered soil: cone model versus experiments, *Geotechnical and geological engineering*, 26(4), 453-468, 2008.

[17] Rao, N. K., Vibration analysis and foundation dynamics, Wheeler Publishing.

[18] Sawant, V. A., & Ladhane, K. B. (2016), Nonlinear FEA of Pile Group Subjected to Lateral Load, *Open Journal of Civil Engineering*, 6(01), 19, 1998.

[19] Sbartai, B., Dynamic interaction of two adjacent foundations embedded in a viscoelastic soil, *International Journal of Structural Stability and Dynamics*, 16(03), 1450110, 2016.

[20] Taddei, F., Mykoniou, K., & Zejun, H., Dynamic foundation-soil interaction: A comparative study. Bauingenieur, (87 DACH-Bulletin), 9-13, 2012.

[21] Woods, R. D., Screening of surface wave in soils. *Journal of the soil mechanics and foundations division*, 94(4), 951-979, 1968.