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STUDY ON DYNAMIC CHARACTERISTICS OF EMBEDDED MASS AND ITS SURROUNDING GROUD

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SUMMARY

Vibration tests of an embedded footing making use of a mechanical oscillator have been conducted in the field in order to examine the effects of backfill around the exciting footing on its vibration characteristics, on the equivalent stiffness and viscous constant of a soil-footing system, and on the behavior of its surrounding ground concerned with wave propagation. Moreover, the response of a viscoelastic half space due to the horizontal excitation applied at a point on its surface has been analyzed theoretically, and has been compared with the experimental one.

INTRODUCTION

To analyze interaction between a soil ground and building structures, it is necessary to understand the dynamic properties of a soil-footing system, which can be represented as the equivalent stiffness and damping constant of a soil ground to its footing. These analytical studies have been treated by a number of investigators making use of wave propagation theory, the finite element method, the thin layered element technique and so on. And also, the vibration tests of footing using a mechanical oscillator have been carried out. By the way, as the basements or foundations of the building structures are usually embedded in a soil medium, it is important to study the embedded effects on vibration characteristics or earthquake response of the building structures. Authors have conducted the vibration tests for three kinds of footings in the field. One of them rests on a ground surface and the others rest on or in a depression in the different depth. The complex stiffnesses of a soil ground to the embedded footing, which consist of spring and damping coefficient, can be calculated from its amplitude and phase characteristics, and they can be separated those at the bottom and those at the side. In this paper, the vibration characteristics of ground surface by means of the horizontal excitation of the embedded footing and the effects of embedment or backfill around the footing on the vibration characteristics are discussed in detail.

OUTLINE OF VIBRATION TEST

Vibration tests on three kinds on reinforced concrete footings due to the harmonic excitation by means of a mechanical oscillator were carried out in the reclaimed field on the coast of Osaka bay. These footings were equal each other, and their geometries were all 2m x 2m in plan and 1m in height, but these conditions were different from another. A-footing was rest on a ground surface, B-footing was rest on the depression dug a ground 50cm deep, and C-footing was rest on the depression dug a ground 100cm deep. And then, B-footing and C-footing were half and all embedded, respectively, and the vibration tests were conducted both the state of backfill and the state of an airgap shown in Fig.1. The soil properties in the experimental site are shown in Fig.2, and in the layer from surface to 3m in depth, S-wave velocity Vs=140 m/sec, P-wave velocity Vp=400 m/sec and density of soil medium ρ=1.70 t/m^3, moreover, in the layer from 3m to 10m in depth, Vs=220 m/sec, Vp=1480 m/sec and ρ=1.77 t/m^3. The horizontal and vertical velocity transducers were mounted on the edges of the footing and on several ground surface points to measure the horizontal and vertical motion, then the rotational motion of the footing can be obtained from its vertical motion and its width. The location of these transducers is shown in Fig.3.

EXPERIMENTAL RESULTS

Response of Footing Responses of the edges of the footing due to the harmonic horizontal excitation were measured with velocity transducers. The horizontal and rotational components of velocity amplitude and phase characteristics are shown in Figs.4 and 5, respectively, in which the eccentric moment is 12 kg.cm.

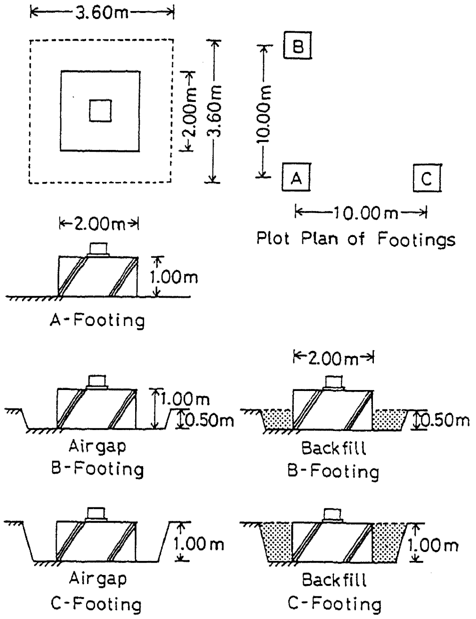


Fig.1 Outline of Footings

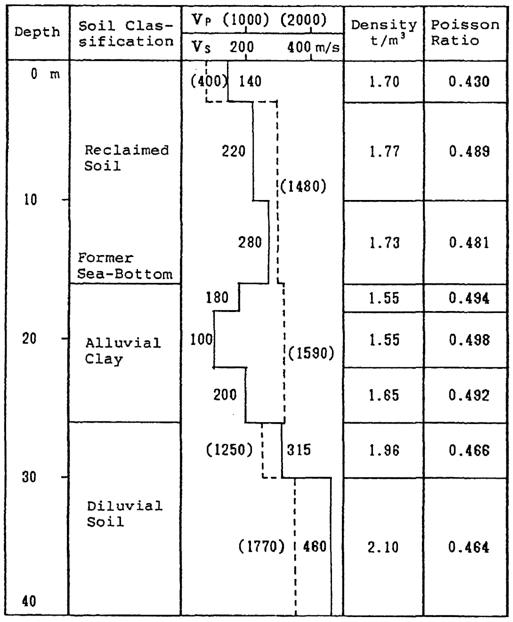


Fig.2 Properties of soil Medium

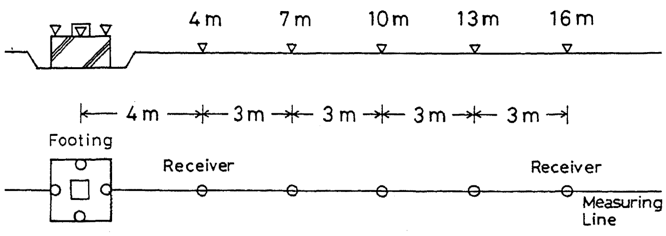
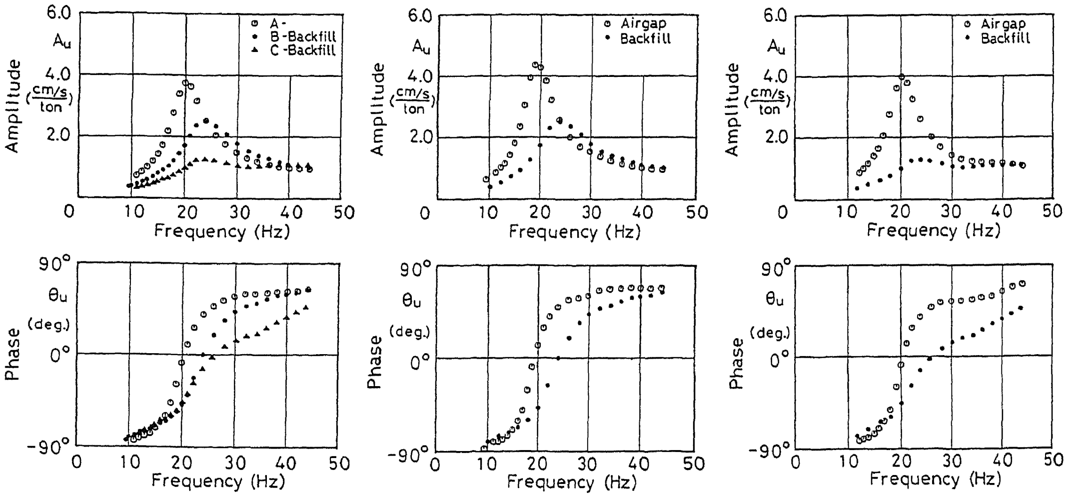


Fig.3 Location of Footing and Receivers

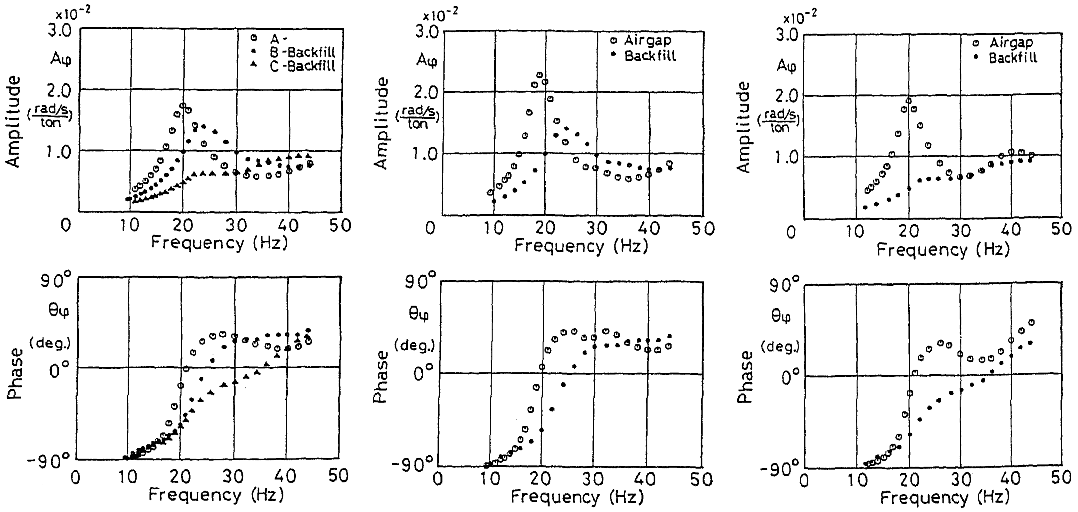
The amplitude is denoted as the absolute value of velocity response for unit exciting force, and phase is denoted the time lag of velocity response to the exciting force. From these figures, the deeper the embedded footing, the higher the resonant frequency and the smaller the resonant amplitude. And also, backfill at the side of footing effects on resonant amplitude and resonant frequency, and in the case of C-footing, amplitude characteristics of the footing with backfill does not show clearly peak.

Equivalent Stiffness and Viscous Constant It is possible to calculate the equivalent stiffness and viscous constant of soil ground to the embedded footing from the above amplitude and phase characteristics. The method to calculate them is as follows ; First, if mass m, inertia moment I, height of gravity center a, height of footing h, height of exciting level l, and the horizontal component and



(a) A-, B-, C-Footings (b) B-Footing (c) C-Footing

Fig.4 Horizontal Component of Velocity Amplitude and Phase Characteristics

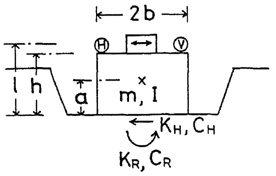


(a) A-, B-, C-Footings (b) B-Footing (c) C-Footing

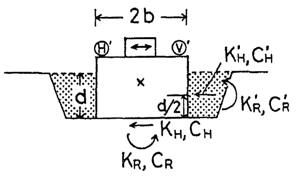
Fig.5 Rotational Component of Velocity Amplitude and Phase Characteristics the rotational component of velocity amplitude and phase at the top of footing Au, θu, A_ϕ, θ_ϕ are known, then one can calculate equivalent stiffness and viscous constant at the bottom of the footing without backfill (see Fig.6(a)), and then if the above equivalent quantities at the bottom of the footing are added as known parameters, then the equivalent side stiffnesses K_H', K_R' and side viscous constants C_H', C_R' can be calculated from the amplitude and phase characteristics of the footing with backfill (see Fig.6(b)). The horizontal component and rotational component of equivalent stiffness and viscous constant versus frequency are shown Figs.7(a) and 7(b), respectively. In these figures, symbol ○ shows the equivalent quantities at the bottom and symbol ● shows those at the side.

Response of Ground Surface If the footing is excited in the horizontal direction, then stress wave will propagate into its surrounding ground, but the response of the point along parallel line to the exciting direction will be different from that along perpendicular line to the exciting direction. Figs.8(a), 8(b) and 8(c) show the tangential component of velocity amplitude on the ground surface along perpendicular measuring line due to the horizontal excitation of A-footing, B-footing and C-footing, respectively. And Figs.9(a), 9(b) and 9(c) show the radial component of velocity amplitude on ground surface along the parallel measuring line. Symbols ○, △ and □ represent the responses of the ground surface at distance 4m, 10m and 16m, respectively, due to the horizontal excitation of the footing with an airgap, and symbols ●, ▲ and ■ show the responses due to the excitation of the backfilled footing. At the vicinity of 20 Hz, the response of ground surface for the airgap footing is greater than that for the backfill footing, because, the resonant frequency of the airgap footing is near 20 Hz and the response of the footing is very large. (see Figs.4,5).

The surface displacement divided by the product of the soil·reaction and frequency versus the product of distance from the footing to measuring point and frequency are shown in Figs.10 and 11, which are the tangential component and radial component, respectively. In these figures, the analytical solutions which are the responses at surface of viscoelastic half space due to the horizontal excitation of point source are shown with solid line, $\xi=0$ and dotted line, $\xi=0.1$, where $\xi = \omega\mu'/\mu$ is a damping ratio and these constants ω, μ and μ' are called circular frequency, modulus of rigidity and viscous constant, respectively. The soil properties are as follows ; S-wave velocity Vs=220 m/sec, P-wave velocity

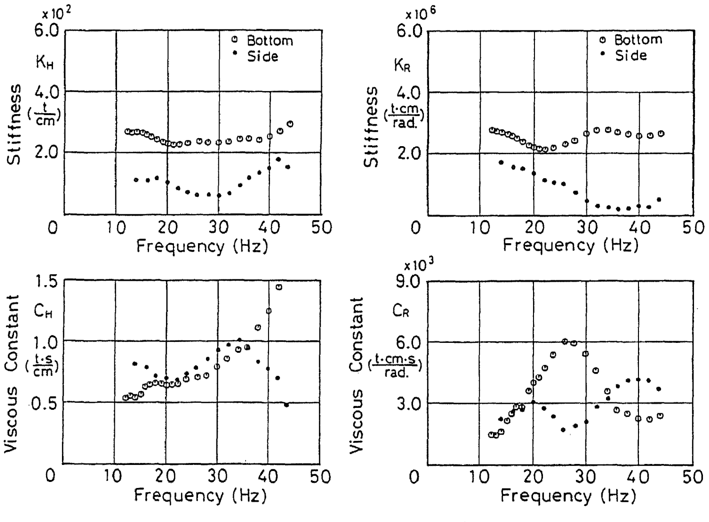


(a) Airgap Model



(b) Backfill Model

Fig.6 Model to Evaluate Equivalent Stiffness and Viscous Constant from Amplitude and Phase Characteristics



(a) Horizontal (b) Rotational

Fig.7 Equivalent Stiffness and Viscous Constant for C-Footing against Frequency

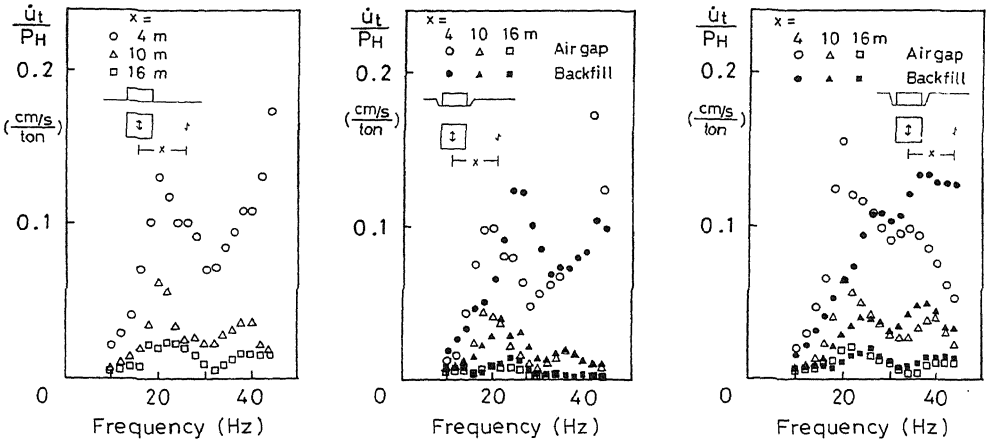
Vp=1480 m/sec, and density of soil ρ=1.77 t/m^3. It is pointed out from these figures that the displacement response at the surface divided by the soil reaction is independent on the embedment and backfill, and that, in the tangential *component, the analytical result is corresponded to the experimental one, when* damping ratio ξ is nearly equal to 10 %.

CONCLUSIONS

From the vibration test of the footings with an airgap or with backfill, the following results are obtained.

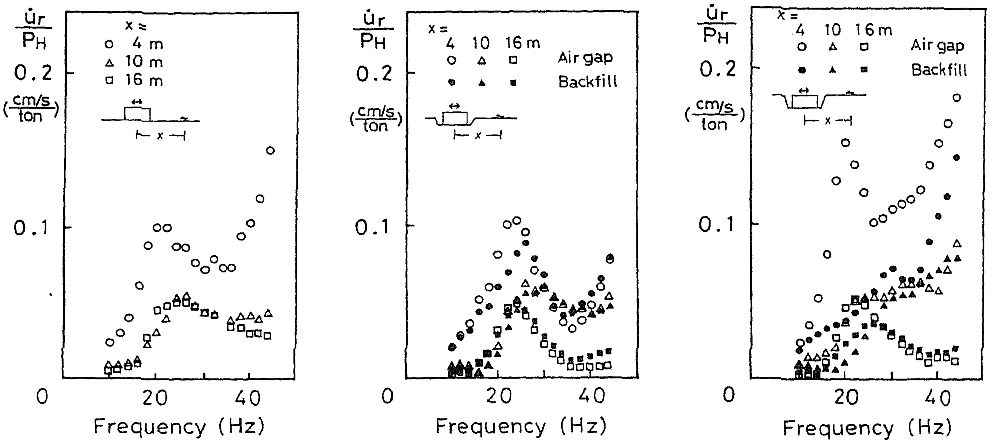
(1) The embedment or backfill of the footing influences on the response curve of the footing, and the deeper the embedment, the lower the resonant amplitude.

(2) For the backfilled footing of which the ratio of the height to the width is equal to 0.5, the equivalent stiffness at the side of footing is less than that at the bottom, but the equivalent viscous constant at the side is comparable to



(a) A-Footing (b) B-Footing (c) C-Footing

Fig.8 Tangential Component of Velocity Amplitude Characteristics at Ground Surface due to Horizontal Excitation



(a) A-Footing (b) B-Footing (c) C-Footing

Fig.9 Radial Component of Velocity Amplitude Characteristics at Ground Surface due to Horizontal Excitation that at the bottom.

(3) The experimental response at the ground surface around the footing for soil reaction is independent on the backfill and its tangential component corresponds to the analytical one, provided that the damping ratio ξ is equal to about 0.1.

ACKNOWLEDGMENTS

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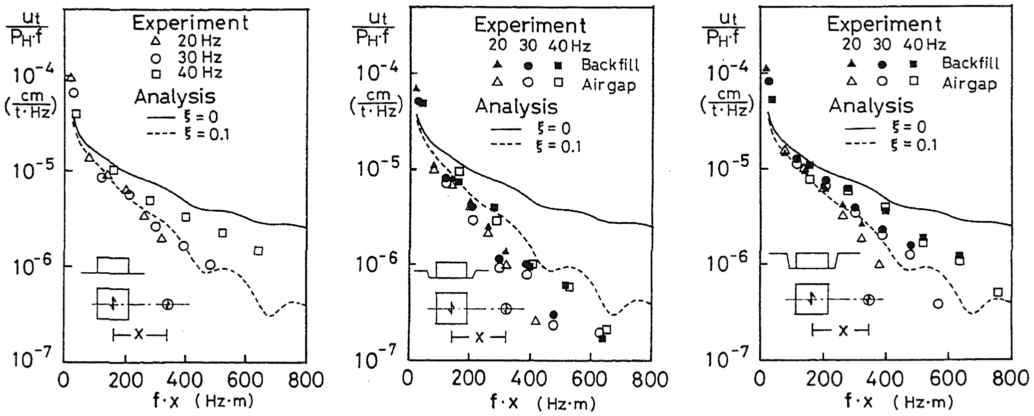
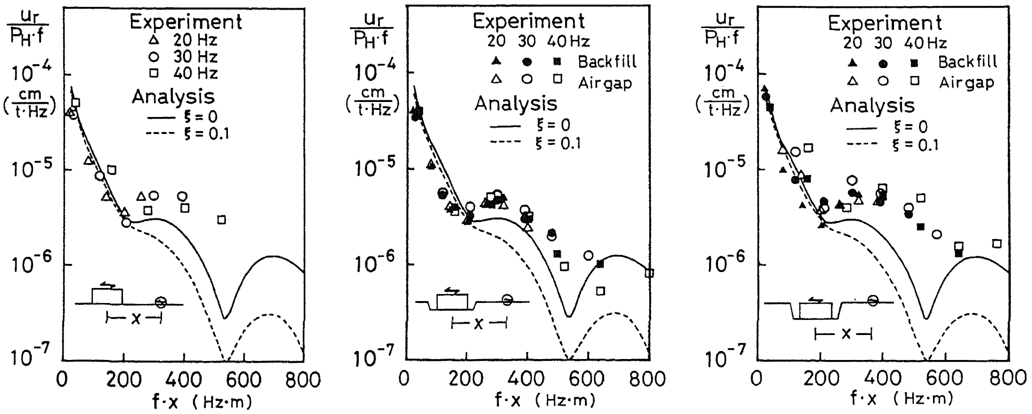


(a) A-Footing (b) B-Footing (c) C-Footing

Fig.10 Tangential Component at Ground Surface due to Horizontal Excitation against Product of Distance x and Frequency f



(a) A-Footing (b) B-Footing (c) C-Footing

Fig.11 Radial Component at Ground Surface due to Horizontal Excitation against Product of Distance x and Frequency f