DYNAMIC RESPONSE OF BUILDINGS SUPPORTED ON PILES EXTENDING THROUGH SOFT ALLUVIAL SUBSOIL LAYERS

by

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INTRODUCTION

The soil-structure interaction has been studied with non-linear vibration characteristics for the buildings supported on piles extending through soft alluvial subsoil layers.

In this analysis, as shown in Fig. 1, the shearing and bending deformations as well as the rotation due to rocking have been taken into consideration for the vibration system of the superstructure and the piles. The lumped mass system of soils consists of two soil columns connected with foundation of building and piles.

The shearing moduli and equivalent damping of soils have been determined from the results of the laboratory tests and in-situ measurements, then the non-linear stress-strain relationships of soils have been used.

In order to evaluate the fitness of this method, several analytical studies on the results of the vibration tests and of the earthquake observations on actual buildings have been performed by the authors.

ANALYTICAL METHOD

The vibration system and the explanation of notations are shown in Fig. 1. The stiffness of soil-foundation interaction, shown in note d of Fig. 1, is based on Penzien's method which estimates the stiffness between pile and its surrounding soil using Mindlin's solution (*1).

The stiffness of two soil columns have been calculated, assuming that the shearing deformations would develop. The horizontal spring constants between the two soil columns have been considered, assuming that the axial deformation of soil between concentrated masses would develop.

The mechanic of damping has been assumed as a different internal viscouse damping that is divided into soil and structure (*2). The damping coefficient of superstructure and piles are taken as 0.0032(sec). The equivalent damping coefficient and the hysteretic damping of soils have been evaluated for convenience' sake as shown in the next chapter.

DYNAMIC CHARACTERISTICS OF SOILS

The shearing moduli have been decided from the following two kinds of data. One is obtained from two methods which are the dynamic tri-axial compression tests of alluvial clays and in-situ shear wave velocity measurements at the same sites. Both of these test results are shown in Fig. 2. The other data are the statistical results of the relation between number of blows in standard penetration tests and the shearing moduli obtained at many sites. From Fig. 3, it is noticed that number of blows are almost in proportional to shearing modulus.

The hysteretic damping and elasto-plastic properties of the soils have been determined from the hysteretic loops of the dynamic tri-axial compression tests, and idealized hysteretic loops have been assumed as degrading bi-linear.

The damping coefficient of soils is taken as 0.0191(sec).

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VIBRATION TEST AND ITS ANALYSIS ON A 7 STORIED BUILDING

The vibration test has been performed on a 7 storied reinforced concrete building supported on piles extending through soft alluvial sand layers 18 meters below ground. The resonance curves obtained from the test and its corresponding analysis are shown in Fig.4-(1). In this case, the stress-strain relationships of soils are treated as linear. The peak at 0.44 seconds as the 1st natural period whose mode shape is shown in Fig.4-(2), and the peak at 0.33 seconds indicates the period of the 2nd natural vibration whose mode shape is shown in Fig.4-(3). In the 1st mode, both phases of superstructure and surrounding soil column are in the same directions, and in the 2nd mode, the phases are in opposite directions. In the 3rd mode, the remarkable rocking motion of the superstructure appears as shown in Fig.4-(4).

EARTHQUAKE RECORDS AND THEIR ANALYSES ON A 5 STORIED BUILDING

The proposed method has also been applied to the analysis on a 5 storied reinforced concrete building during the "Higashi-Matsuyama Earthquake", near Tokyo, on July 1, 1968. This building is also supported on piles extending through saturated silt layers 30 meters below ground. The recorded accelerations in this building were about 40 to 60 gals, but no record was obtained at the foundation layer.

To evaluate the input acceleration of foundation layer, the records obtained on the basement floors of eleven other buildings were selected. These buildings including Kasumigaseki Building were constructed directly on the same foundation layer continued from the subject building. Since the acceleration spectra of these records have the properties similar to each other, the record obtained at the Kasumigaseki Building has been chosen as the input acceleration to this building.

The recorded accelerogram and its spectrum have been compared with the computed values using the proposed method as shown in Fig.5, and 6. In this analysis, the non-linear stress-strain relationships of soils have been used. In Fig.6, the resonated 1st natural period is 1 second. This is longer than that of other buildings of the similar height, because of saturated silt subsoil layers. From other results, it has been found that the shearing modulus declined to 80% from the initial value even at a small strain of about 0.03% which is the maximum response value of soil.

CONCLUSION AND ACKNOWLEDGMENT

In this paper, the simplified evaluation method for the soil-structure interaction during earthquakes has been proposed, and the results of simulation analyses proved to be in good agreement with the records observed in actual buildings.

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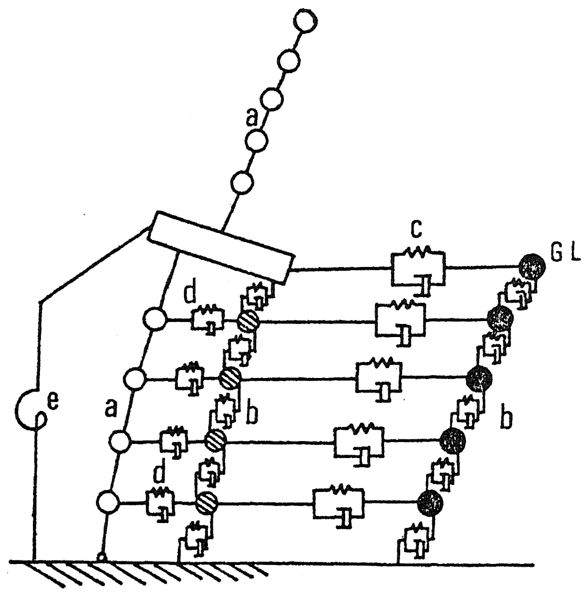
REFERENCE

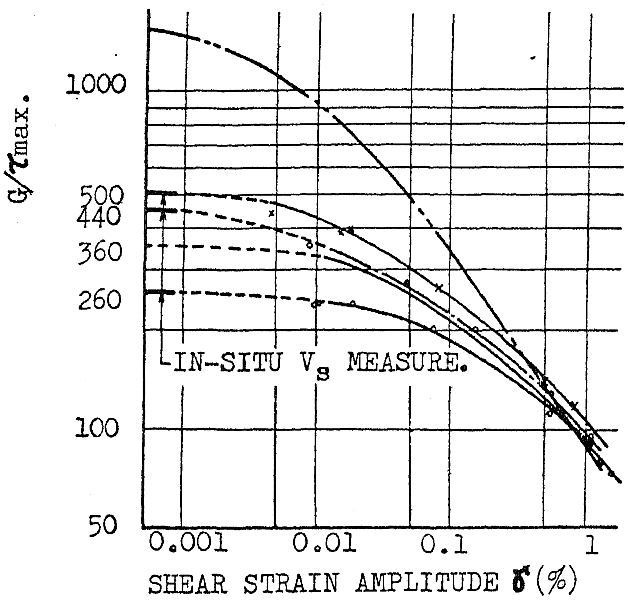
(*1) J. Penzien et al ; "Seismic Effect on Structure Supported on Piles Extending through Deep Sensitive Clays", Univ. of Calif., Aug., 1964.

(*2) K. Muto et al ; "The Earthquake Response Analysis for a BWR Nuclear Power Plant Using Recorded Data". The First International Conference on Structural Mechanics in Reactor Technology, Berlin, 1971.



Mathematical model :
Lumped mass system composed of Voigt model
Mass estimation :
⊘ ; neighboring soil, soil column under foundation
● ; surrounding soil, twice neighboring soil mass
Stiffness estimation :
a ; bending & shearing deformation
b ; shearing deformation
c ; axial deformation
d ; soil-pile interraction
e ; rotation of foundation

Fig. 1 ANALYTICAL MODEL



Saturated Clay
; at NAGOYA (N=7)
; HAYABUSACHO (N=4)
; OHJI (N=1)
; OHKURAYAMA (N=0)
(N; No. of blows)
SEED & IDRISS (1970)

Fig. 2 RELATIONSHIP BETWEEN G/τmax AND γ%

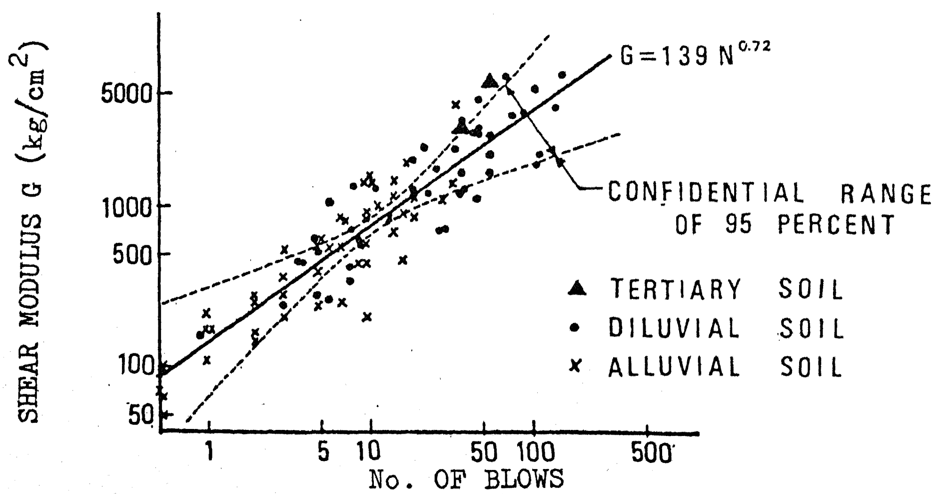


Fig. 3 RELATIONSHIP BETWEEN SHEAR MODULUS AND No. OF BLOWS

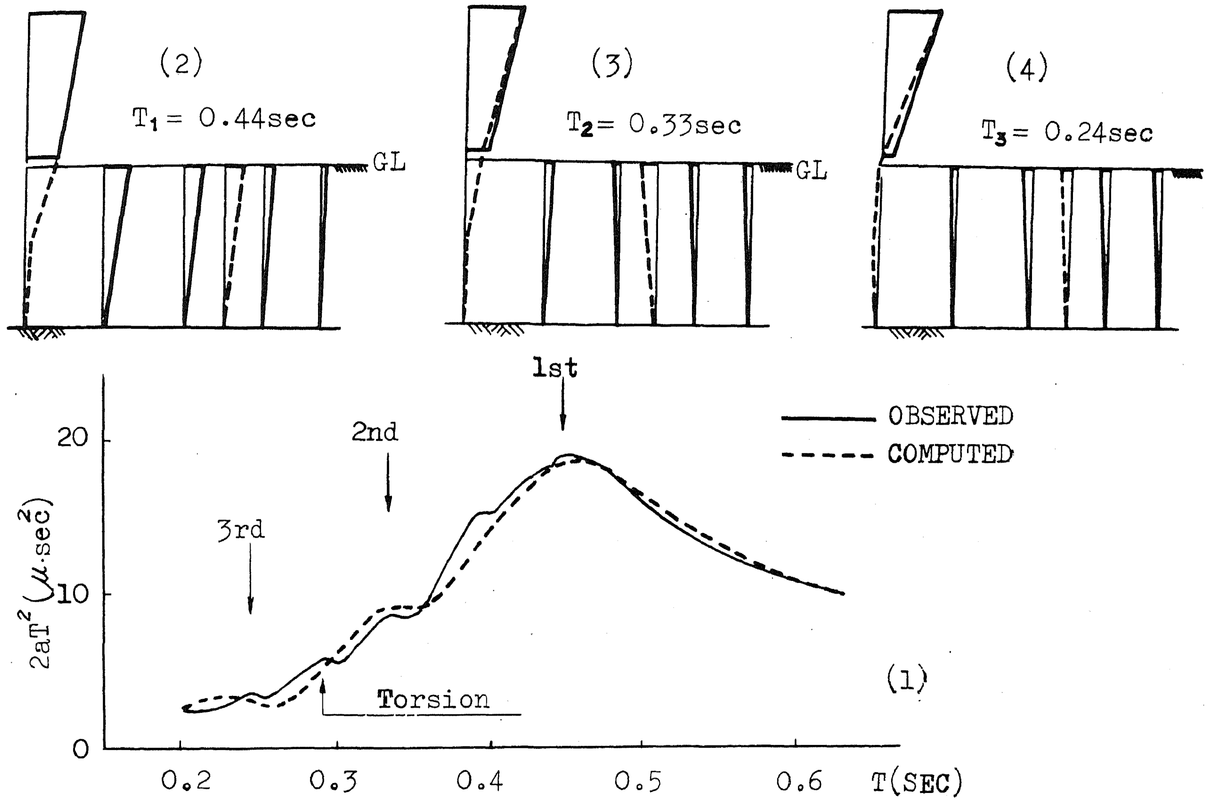


Fig. 4 RESONANCE CURVES AND VIBRATION MODE SHAPES OF A 7 STORIED BLDG.

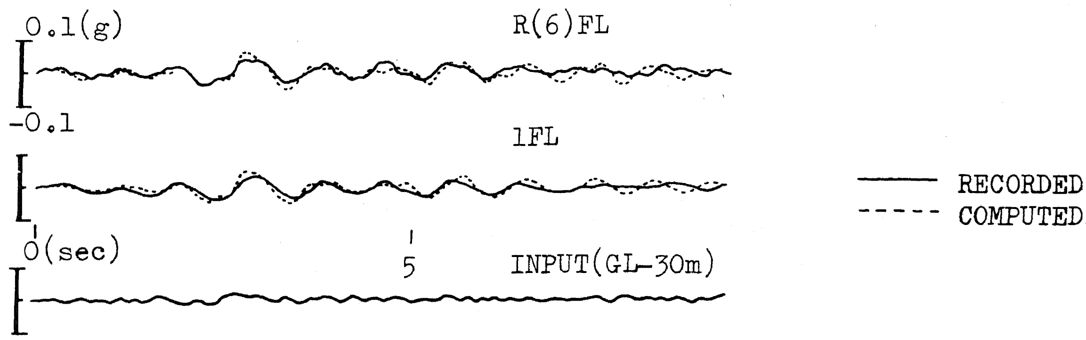


Fig. 5 TIME HISTORIES OF ACCEL. OF A 5 STORIED BLDG. DURING AN EARTHQUAKE

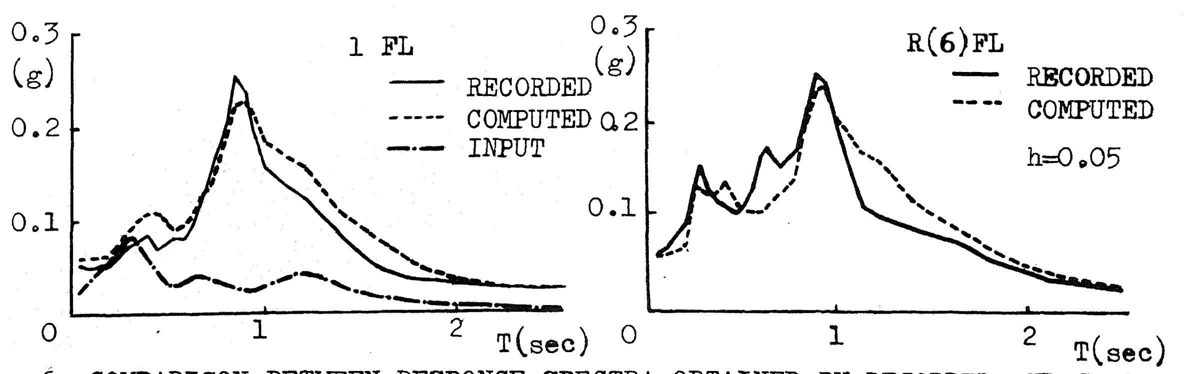


Fig. 6 COMPARISON BETWEEN RESPONCE SPECTRA OBTAINED BY RECORDED AND COMPUTED ACCELEROGRAMS