DYNAMIC ANALYSIS OF GROUND-STRUCTURE SYSTEM, BASED ON ELASTIC WAVE THEORY

by

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SYNOPSIS

The development of computer programs for the dynamic analysis of ground-structure systems based on an elastic wave theory is outlined, and the accompanied results of the programs to various dynamic models are discussed, including ground-structure interaction.

Recommendations are made for the earthquake resistant design of foundation structures in the construction of important structures such as nuclear facilities on a soft ground.

INTRODUCTION

It is expected that large and heavy structures such as nuclear power plants and multi-story buildings will come to be constructed on a soft ground in Japan. The purpose of this research is to develop an analysing method of earthquake resistant composite elements, namely ground-structure system, taking account of interaction effects between the both elements.

At present, the finite element method and the lumped mass method are widely used for these dynamic problems, but as far as the soft ground is concerned, satisfactory results are not always obtained. For this reason this study is performed to examine a method based on a wave equation.

DEVELOPMENT OF COMPUTER PROGRAM

Firstly, three-dimensional linear wave equations including a viscous damping term proportional to velocity, are expanded to finite difference equations, having irregular meshes[1)]. In addition, by applying the linear acceleration method, a proposed program for the earthquake response analysis has been developed. However, there are some difficulties to use this program, as follows:

1. It is difficult to simulate correctly the geometrically complicated shapes of the structures, because of the use of rectangular

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meshes.

2. Computation errors will increase for the models where the elastic properties of each element in the whole system are largely different.

Secondly, in order to get rid of these difficulties, this program has been improved as follows:

The partial derivative terms at any points are represented by the displacements and distances of the adjacent points, applying non-equidistant finite difference method[2]. Thus, the above method has been proposed, because of the elimination of the uncertainty on the wave propagation during the each time interval in the dynamic computation.

Thirdly, that is a difficult problem how well the damping phenomenon in the system may be simulated. In this program, the damping forces have been quantitatively defined as the products of viscous coefficients and strain-velocity components. On the other hand, the stiffness matrices in the system often tend to be unsymmetric and very hard to treat compared with symmetric ones. Therefore there have been spent much efforts and time to develop this program for calculating dynamic responses economically and accurately, as well as eigenvalues and eigenvectors for analytical purposes. As the result, a considerably close agreement has been found between the computed and recorded response for some earthquake analyses.

DYNAMIC ANALYSIS OF GROUND-STRUCTURE SYSTEMS

As the results of the dynamic analyses by using three models of which their dimensions and elastic values are shown in Table 1, several interesting ones have been obtained as follows:

1. As shown in Fig.1, response amplitudes of Model 1-1-1 and Model 1-2-1 which have some kinds of under-ground structures become very large, when compared with that of Model 1-1-2 and Model 1-2-2 which have not any foundation works. This means that the foundation works have not any dynamic advantage in this particular case. Because the natural frequency of the upper structure approaches to that of the surface layers of a ground, due to the increased height and decreased frequency of the upper structure. Therefore, statically designed foundation works should also be investigated in view point of dynamic characteristics, including that of the surface layers.

2. Dynamic characteristics of Model 2 are shown in Fig.2. Model 2-3 (perfectly fixed structure) indicates the first mode peak (3) in this figure. When the structure is constructed on a soft ground, its natural frequency becomes small as shown in the peak (2) and (1), comparing with that of the peak (3).

In many cases, the frequency of Model 2-2(the frequency of the surface layers is larger than that of the structure, because the depth of the layers is small) becomes smaller than that of Model 2-1(the frequency of the surface layers is smaller than that of the structure, because the depth of the layers is large). This indicates the existence of coupling effects between the dynamic characteristics of the ground and structure.

Thus, in this earthquake resistant design for the important structure, it is necessary to investigate the interaction between dynamic characteristics of the surface layers and the upper structures. It will be disirable to design the upper structures that have higher natural frequency than that of the surface layers.

3. As the result of computation on Model 3, it is noticed that response amplitude of the structure is unexpectedly small. This shows that the thick and soft ground behaves like a shock absorber.

According to the wave theory, response amplitude of the surface layers is only twice of that at the base rock, and the amplitude beneath the foundation works is nearly the same as that at the base rock. This means that large and heavy structures on the soft ground do not respond sensitevely. This result will be applicable to the earthquake resistant design of structures.

As shown in Fig.3, however, large dynamic stresses in the ground are noticed in the deep outside part of the edge of the foundation works. To prevent the ground from failure, it is necessary to find some sort of foundation works. It is hoped to develop "A SOFT FOUNDATION STRUCTURE" like roots of trees in nature.

CONCLUDING REMARKS

The authers have atempted to present an approach for the dynamic analyses of ground-structure systems in this paper, under a computer program based on an elastic wave theory. It is summarized, as follows:

1. In cases where the natural frequency of a ground is close to and larger than that of the upper structure, the latter in the both combined system prominently decreases by the coupling effects and its magnification factor for acceleration increases.

2. In cases of a soft ground with large depth, the magnification of the acceleration of earthquake waves is rather small, because low frequency components of spectra are scarcely included at the base rock. The magnification at the surface does not exceed about twice of that at the base rock.

3. The above mentioned situation is very advantageous for earthquake resistant design of large and heavy upper structures on a soft ground, however, it is necessary to develop new foundation works in order to avoid large concentrated stresses approaching the ultimate strength of the soil.

Further study on these analyses will promise remarkable development in the design of earthquake resistant structures and their foundations.

REFERENCE

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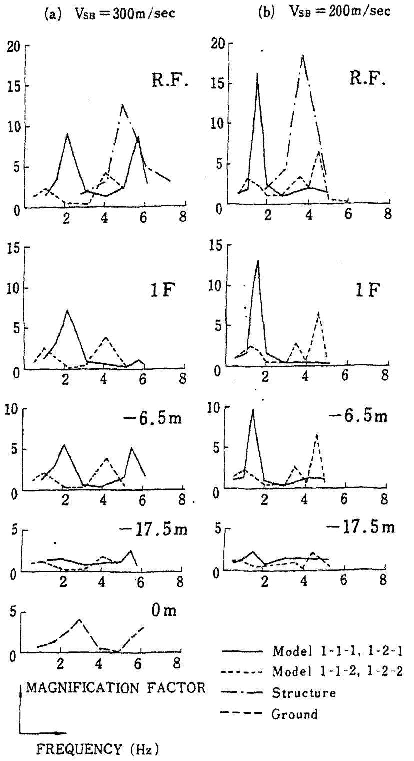


Model 1

Fig. 1 Effect of foundation works on amplitude magnifying factor

Model 2

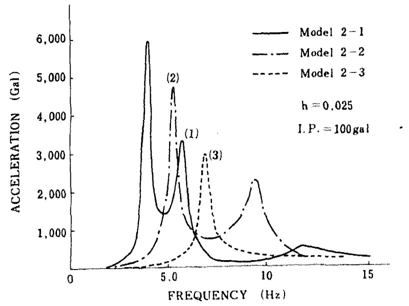
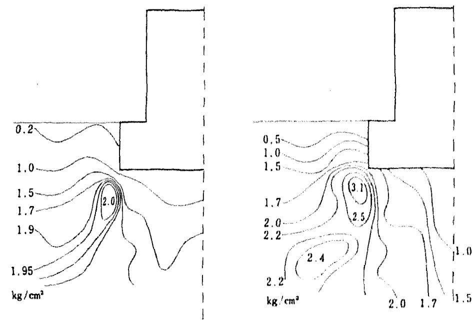


Fig. 2 Effect of ground depth on earthquake response acceleration

Model 3



(a) Max. comp. principal stresses (b) Max. shearing stresses

Fig. 3 Distribution of dynamic stresses in ground

Tab. 1 Approximate dimension and elastic values of three Models

Approximate Dimension & Elastic Value \ Model No.		1				2			3
		1 − 1		1 − 2		2 − 1	2 − 2	2 − 3	
		1−1−1	1−1−2	1−2−1	1−2−2				
Structure	Height (m)	14.4				8.0			45.0
	Base (m)	13.5×42.4				4.0×4.0			44.0×44.0
	Weight (ton)	3,400				80			100,000
	V_{SB}(m/sec)	200		300		360			1,100
	ρ (ton/m³)	0.41		0.41		0.63			1.2
Foundation	Depth (m)	10.0		10.0					19.0
	V_s (m/sec)	200		200					1,100
	ρ (ton/m³)	1.8		1.8					1.2
Ground	Depth (m)	20.0				27.0	12.0		150
	V_s (m/sec)	160				370	330		410
	ρ(ton/m³)	1.9				1.7	1.7		2.0

V: Shear wave velocity, ρ: Density