Vibrational Characteristics of the Structure
influenced by the Ground

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SYNOPSIS:

The study which will be reported here was made of the forced and free
vibrations of the models, 1) isolated foundation, 2) combined system of
foundation and single-story building, and 3) two isolated foundations joined
by connection-beam, for the purpose of evaluation of the spring constant and
the damping constant of the ground, and of finding out a convenient method of
this evaluation.

INTRODUCTION:

The model foundations were made of concrete and laid on the ground of
Kanto loam, Fig. 1. The tests were made on the following three types of
model by imparting them the forced vibration or by setting them on their
free vibrations, Fig. 2.

Model: 1) three types of foundation (FL, FM and FS); 2) combined system
(FL+Bn and FM+Bn) of isolated foundation (FL and FM) and single-story
building (Bn); 3) joined isolated foundation (2FL+BG and 2FL+B) of two
isolated foundations (FL) and connection beam (B)

EXPERIMENTS AND RESULTS:

1) FL and FL+Bn

The resonance frequency, mode of vibration and damping coefficient
obtained by the experiments of the combined system of a model-building and
an isolated foundation coincide well with those calculated by inserting the
spring constant and the damping coefficient determined experimentally by
using the isolated foundation only, or by using the model building only.
The influence of the ground on the building may be nearly evaluated by a
ratio of the amounts of rocking and swaying motions observed, Fig. 3.

In the case of a small resonance amplitude, the resonance frequency
of the isolated foundation approaches the theoretical value, if we ignore the
virtual earth-mass. This suggests that the pressure-distribution over the
area of the plate which is in contact with the ground surface becomes akin to
the distribution over a rigid base, if the type-FL (isolated foundation) is
used, Fig. 4. The distribution, however, approaches to the uniform
pressure distribution in the case of the type-FM (isolated foundation), while
it does so to the parabolic pressure distribution in the case of the type-FS
(isolated foundation). In other words, if we assume the pressure distribution
be that of the rigid base, it becomes necessary to take larger virtual earth-
mass as the contact area of the isolated foundation becomes smaller.

A specially different point in the results which were obtained
experimentally for the isolated foundation only and for the combined system
lies in a sudden increase in the spring constant which contributes to the
rotation (rocking) of the structure, even though the strain of the ground is

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fully taken into consideration when the load due to the building becomes large, Fig. 4.

The decrease in the resonance frequency due to increase in the resonance-amplitude may be explained by the decrease in the shearing modulus with increasing amplitude of displacement of the soil, i.e., the increase in the shearing strain in the soil. Because, the shearing modulus which is deduced from the spring constant increases as the amplitude decreases, and coincides with the value which is obtained from the shear wave-velocity in the region of a small amplitude, Fig. 5.

As for the damping percentages, h which were obtained for the isolated foundation and for the combined system, it may be said that approximately the theoretical values become twice as large as the experimental values. If the values of $C_H$ and $C_P$ are deduced from the experimental values of $h$ separately, the value of $C_H$ (for horizontal displacement) becomes about $\frac{1}{3}$ of the theoretical value, Fig. 6.

2) (2FL + BG) and (2FL + G)

The spring constants for model (2FL+BG) were calculated by the method of J. Elorduy$^4$, Fig. 7. For model (2FL+B), the constants were calculated by the following expressions, by using the spring constants which were determined for isolated foundation (FL), i.e., $K'_H$, $K'_R$ and $K'$.

$$K_H = 2 \cdot K'_H, \quad K_R = 2 \cdot (K'_v \cdot l_o^2 + K'_R)$$

$l_o$: See Fig. 7.

The theoretical values of spring constants determined for (2FL+BG) agree well with those for (2FL+G), suggesting that the influence of the connection beam which is in contact with the ground is slight, Table - 1.

The agreement of the values determined for these models can be seen also in their natural frequencies and modes of vibration, Table - 2.

In the case of model (2FL+BG), the natural frequencies and modes of vibration which were determined theoretically and shown in column A of Table-2 nearly agree with those experimentally determined, whereas in the case of (2FL+B), the theoretical values as shown in column B of Table-2 agree well with the experimental values rather than those which are shown in column A.

The value $h$ which is determined theoretically becomes generally greater than those determined experimentally, Table-2.

We can see a well correlation between the vertical displacement of the foundation and the accompanying earth-pressure. The distributions of this pressure which were determined by experiments showed an agreement with those theoretically determined in their tendency, Fig. 8.

BIBLIOGRAPHY:

1) M. Takeuchi and others "Vibrational Characteristics of the Structure influenced by Ground (1)" Bull. of Sc. and Eng. Res. Lab., Waseda Univ. No.57
Fig. 1 Boring log and N-value of standard penetration test

Fig. 2 Models of Building and Foundation

Fig. 3 Damping vs. resonance-frequency

Fig. 4 Spring constants for horizontal displacement and rotation (FL)

Building: Bn
Weight: n=2 (0.49 t)\n n=8 (1.30 t)

Foundation
Type-FL
Weight: 2.32 (t)
1250 x 1250 x 620

Type-FS: 850 x 850 x 400
Type-FM: 1000 x 1000 x 520
(a) Building and Foundation (FL, FM and FS)

Vibrator

Type-(2FL+BG)

Type-(2FL+B)

Loam:
S wave-velocity
Vs = 110 m/sec
P wave-velocity
Vp = 220 m/sec
Specific weight
= 1.16 kN/m3
Poisson Ratio
= 0.33

rocking+sway(%)\n n=2 (75.9%)
 n=4 (73.1)
 n=6 (65.8)
 n=8 (61.4)

Building: Bn

K_H (N/m*cm)
0 1 2 3 4
0 100 200 300
Horizontal displacement (μ)

(a) Spring constants for horizontal displacement

(b) Foundation (2FL+BG and 2FL+B)

n=8

n=2

FL+4

n=8

FL+4

(Rigid)

FL

(Rigid)

FL
Fig. 5 Shear modulus ($G$) vs. horizontal shear strain ($\varepsilon_H$)

Fig. 6 Correlation between damping coefficient ($C_m$) and ($C_H$)

Fig. 7 Method of calculation of spring constant.

Fig. 8 Correlation between vertical displacement and earth pressure.

Table 1: Spring constants (calculated)

<table>
<thead>
<tr>
<th>Spring constant</th>
<th>2FL+BG</th>
<th>2FL+B</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_h$ (kg/cm)</td>
<td>$10^4$</td>
<td>9.53</td>
</tr>
<tr>
<td>$K_r$ (kg/cm.rad.)</td>
<td>$10^5$</td>
<td>4.44</td>
</tr>
<tr>
<td>$K_v$ (kg/cm)</td>
<td>$10^9$</td>
<td>1.23</td>
</tr>
</tbody>
</table>

Table 2: Results of experiments and analyses.

<table>
<thead>
<tr>
<th>Model</th>
<th>2FL+BG</th>
<th>2FL+B</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vibrat. of model</strong></td>
<td>Exp.</td>
<td>A</td>
</tr>
<tr>
<td>1st. frequency (Hz)</td>
<td>17.64</td>
<td>17.70</td>
</tr>
<tr>
<td>1st. mode ($\nu$)$\times10^3$</td>
<td>2.15</td>
<td>2.15</td>
</tr>
<tr>
<td>Damping ($%$)</td>
<td>20.5</td>
<td>19.0</td>
</tr>
</tbody>
</table>

Experi: Experimental value  
A: Theoretical value ($C_H, C_r$: Yamahara)  
B: Theoretical value using experimental values obtained for Type-FL  
$c$ : Angle of rotation  
$u$ : Displacement of center of gravity

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