Performance-based Type of Provisions in Building Standard Law of Japan
-Introduction of Soil Structure Interaction in Calculation of Response and Limit Strength-

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ABSTRACT : In order to incorporate a performance-based design, the Building Standard Law of Japan was revised and contained a calculation method of response and limit strength. Accordingly, in case that ground conditions will affect the performance of building during earthquakes, effects of soil structure interaction (SSI) will be considered in the calculation of a predominant period and a damping factor of buildings based on sway and rocking displacements. Outlines of the revised Building Standard Law of Japan related to the calculation method of The SSI effect are shown. A simplified calculation procedure of the predominant period and the damping factor based on SSI and an example to obtain a spring constant and an equivalent viscous damping factor are explained.

Keywords : Simplified method, Building Standard Law, seismic design, Period and damping factor, Cone model, effect of embedment,

INTRODUCTION

The Building Standard Law and its related enforcement and notices was revised for the direction to the performance-based design. The calculation method of response and limit strength was provided for checking serviceability and safety of buildings. In the calculation, soil and structure interaction (SSI) effects should be considered when the interaction effects will be negligible. As the interaction effects, an elongation of building period, a change of damping factor and an input earthquake motion to building, etc. are included. Especially, buildings with a high stiffness, a little numbers of spans on soft grounds are remarkably influenced.
A simplified method was introduced in the calculation. The concept of incorporation of SSI effects and the evaluation of impedance (spring constant and damping factor) are explained.

SSI PHENOMENA, AND PERIOD AND DAMPING OF BUILDING

SSI Phenomena Through Observation

Based on several materials related to observed data of soil structure interaction through analyzing mictrotremors and earthquake motions SSI phenomena are introduced.

1)Predominant period and damping factor
Ohba et al. summarized a relationship between predominant periods and soil conditions based on a microtremor measurement of reinfoeced concrete and steel reinforced concrete buildings whose heights are less than 40m, as shown in Fig. 1[1,2]. The relationship between predominant periods of buildings and the average N-values with two kinds of building heights is drawn. The predominant periods of buildings are dependent on soil conditions. With the N-values less, the predominant periods are longer. A regression formula was proposed as follows;

$$T=0.01H+0.2-0.08\log_{10}N$$

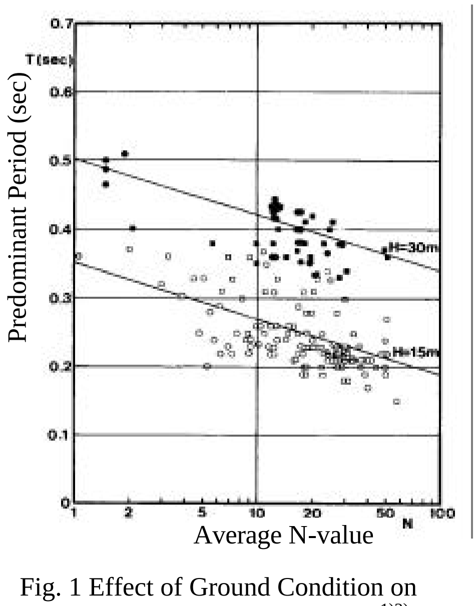


Fig. 1 Effect of Ground Condition on Predominant Period of Buildings[1)2)]

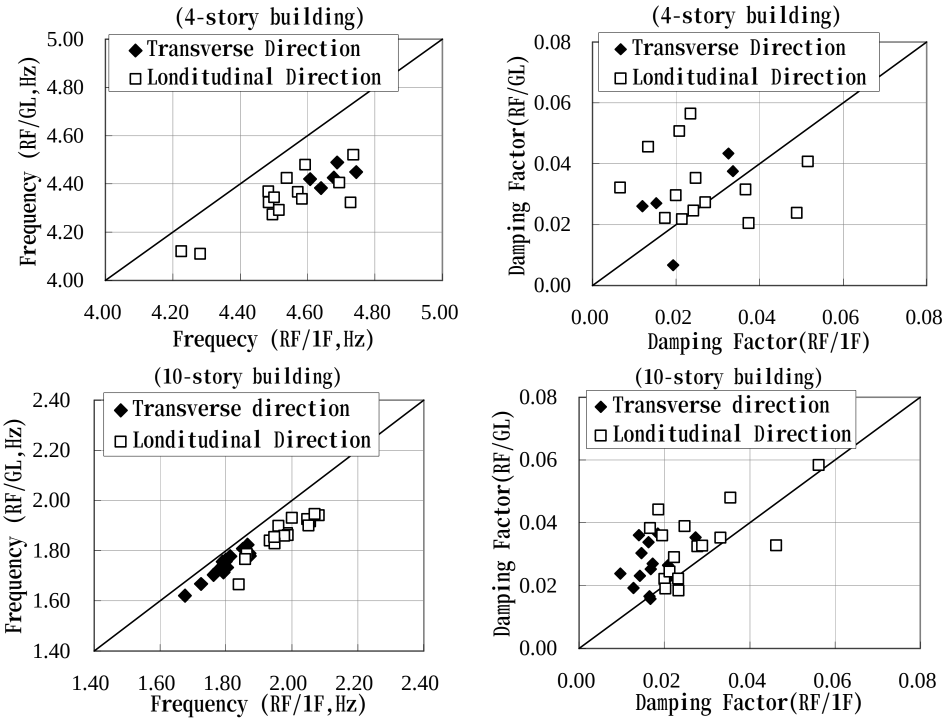


Fig. 2 Predominant Frequency and Damping Factor of Buildings by Transfer Function of RF/1F and RF/GL[6)]

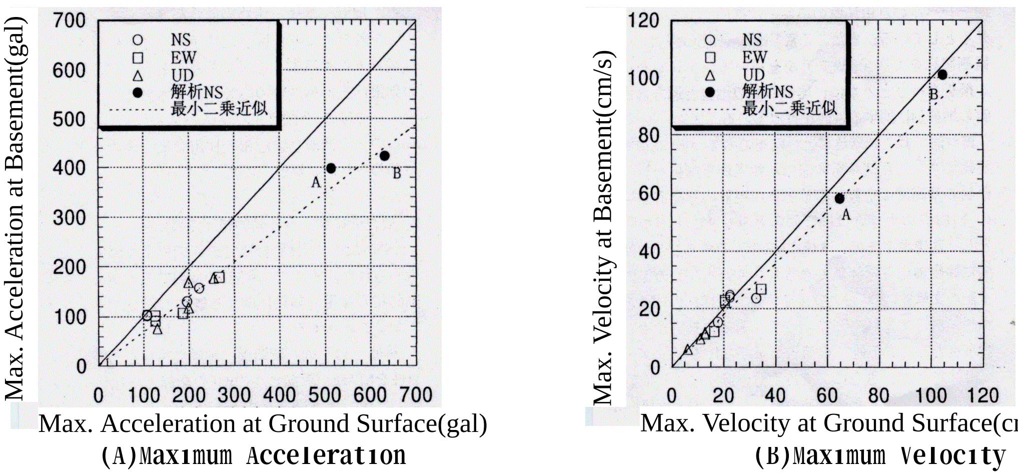


Fig. 3 Comparison of Max. Acceleration and Velocity between at Basement and at Ground Surface (1995.1.17 Hyogoken Nanbu Earthquake)[7)]

Where T, H are a predominant period and a height of building, respectively. And N is an average N-value of the ground beneath the building.

Fukuwa and Tobita et al. showed the SSI effect on building properties where heights of buildings are relatively small, based on data of the mictrotremor and earthquake motion observation measurements[3,4,5]. Some comparisons of the building frequncies and damping factors between with fixed base and with interaction are drawn in Fig. 2. The predominant frequncy and damping factor of building with fixed base are obtained through transfer functions of acceleration records at roof to those at 1st floor (RF/1F). The predominant frequency and damping factor of building with interaction are obtained through transfer functions of acceleration records at roof to those at ground surface (RF/GL). The predominant frequencies are always longer due to SSI effect. On the other hand, the damping factors considering SSI effect tend to be larger.

2)Maximum Acceleration Response at Basement and Ground Surface

Maximum acceleration and integrated velocity and a representative of acceleration response spectrum observed at basements and ground surfaces during 1995 Hyogoken Nanbu Earthquake are presented in Figs. 3 and 4, respectively. The max. accelerations at basement are about 70% of those at ground surface. In case of max. velocity, the ratios are 90% based on the regression of the data. With comparison of acceleration response spectrums, the value at 1st floor is less than that at ground surface with frequency higher. The difference of the ratio of maximum at basement to at ground surface between the acceleration and velocity is due to component of high frequency.

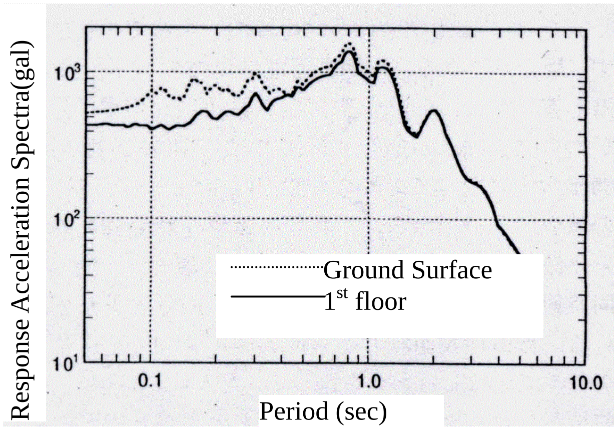


Fig. 4 Acceleration Response Spectrum at 1st floor and at Ground Surface [7)]

Effect of SSI on Period and Damping Factor

Inertial forces of superstructures, that is, base shears and inertial forces of embedment will be transferred to supported grounds (through piles when pile foundations). When the supported grounds are considerably hard, displacements of embedment or foundation due to the forces are negligibly small. The base fixed condition is satisfied and characteristics of superstructure will be obtained by superstructure itself. With less ground stiffness, the displacements become large and characteristics of superstructure are influenced by the displacements.

The phenomena that the displacement of embedment due to the inertial force of superstructure occurs are called "soil structure interaction". Especially these phenomena are the "inertial soil structure interaction". On the other hand, the effect of SSI to seismic input motions to the buildings is called the "kinematic soil structure interaction".

As a result of the displacement of embedment due to the inertial force of superstructure, characteristics of superstructure are changed as follows;

a) elongation of natural period (compared with base fixed condition)
b) change of damping factor (compared with base fixed condition)

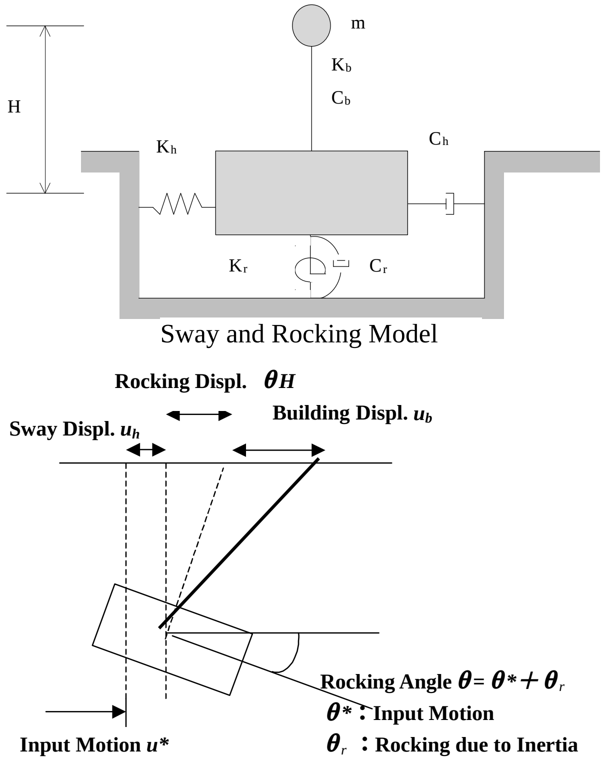


Fig. 5 Sway-Rocking Model and Displacement

Figure 5 shows a model and a displacement distribution for the SSI model. In case of SSI model, a horizontal displacement and a rotational angle at base occur in addition to building itself (u_b) displacement. The horizontal displacement due to horizontal force and the rocking angle due to overturning moment are called sway displacement (u_h) and rocking angle(θ_r), respectively. The horizontal displacement at top of building due to the rocking is expressed by the rocking displacement($\theta_r H$) and is proportional to the height of the building (including the depth of embedment). A effective input motion to the building is expressed by u^* for horizontal component and θ^* for rotational angle. The predominant period is corresponding to the displacement of building (u_b). In case of the SSI system, the predominant period is elongated due to the sway and rocking displacements.

A radiation energy is dependent on the displacement distribution of SSI system. A damping factor of building is one of superstructure itself at fixed base. For the SSI system, the damping factor of the ground layer and radiation damping are included. In case that SSI effect is large, the damping factor of the building is dependent on the characteristics of soil nonlinearity and wave radiation. It is important to evaluate the mode (displacement distribution) and the contribution of each damping for the mode. Recent knowledge and results of the damping characteristics of buildings are summarized in ref.[8].

INCORPORATION OF SSI EFFECT IN SEISMIC DESIGN

Evaluation of Predominant Period and Equivalent Damping Factor

It is assumed that the influence of embedment mass and the moment of inertia at each floor on response of SSI system is negligible [9]. A external force acting to springs of superstructure, sway and rocking is only the inertial force of superstructure, as shown in Fig.6. In this case, the springs are arranged in a series. An equivalent spring constant for SSI system is able to be calculated as series springs and a circular frequency for SSI system is expressed as follows [2];

$$\omega_e^{\ 2} = \left(\frac{1}{\omega_b^{\ 2}} + \frac{1}{\omega_{sw}^{\ 2}} + \frac{1}{\omega_{ro}^{\ 2}} \right)^{-1} \qquad (1)$$

where ω_b, ω_{sw} and ω_{ro} are circular frequencies corresponding to displacements of superstructure, sway and rocking, respectively.

$$\omega_b^{\ 2} = \frac{K_b}{m}, \quad \omega_{sw}^{\ 2} = \frac{K_h}{m}, \quad \omega_{ro}^{\ 2} = \frac{K_r}{mH^2} \qquad (2)$$

Where m is a mass of superstructure, and K_b, K_h, and K_r are spring constants for superstructure, sway and rocking, respectively.

Based on the relationship of $T_e = 2p/w_e$, $T_b = 2\pi/\omega_b$, $T_{sw} = 2\pi/\omega_{sw}$ and $T_{ro} = 2\pi/\omega_{ro}$, the predominant of building for SSI system is obtained as follows [2];

$$T_e = \sqrt{T_b^{\ 2} + T_{sw}^{\ 2} + T_{ro}^{\ 2}} \qquad (3)$$

Compared with the natural frequency of superstructure, the predominant period is shown as a ratio of period.

$$r = \frac{T_e}{T_b} = \sqrt{1 + \left(\frac{T_{sw}}{T_b}\right)^2 + \left(\frac{T_{ro}}{T_b}\right)^2} \qquad (4)$$

In the same manner, an equivalent damping factor of building is estimated following the next equation.

$$h_e = h_b \left(\frac{T_b}{T_e}\right)^3 + h_{sw}\left(\frac{T_{sw}}{T_e}\right)^3 + h_{ro}\left(\frac{T_{ro}}{T_e}\right)^3 \qquad (5)$$

or

$$h_e = \frac{1}{r^3}\left[h_b + h_{sw}\left(\frac{T_{sw}}{T_b}\right)^3 + h_{ro}\left(\frac{T_{ro}}{T_b}\right)^3 \right] \qquad (6)$$

Where h_b, h_{sw} and h_{ro} are the equivalent damping factors for superstructure at circular frequency of ω_b, for sway at circular frequency of ω_{sw} and for rocking at circular frequency of ω_{ro}, respectively, and are obtained by following equations;

$$h_b = \frac{1}{2\omega_b}\frac{c_b}{m} \qquad h_{sw} = \frac{1}{2\omega_{sw}}\frac{c_h}{m}$$

$$h_{ro} = \frac{1}{2\omega_{ro}}\frac{c_r}{mH^2} \qquad (7)$$

Where c_b, c_h, c_r are equivalent viscous damping coefficients for superstructure, sway and rocking at the predominant frequency of SSI system (ω_e), respectively.

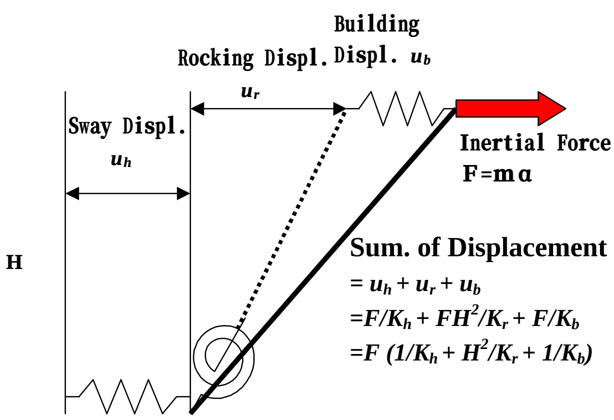


Fig. 6 Force vs. Displacement in SSI System

Reduction of Input Motion due to Embedment

In case of building with embedment which is a part of building under the ground surface, the input motion to buildings is not the same as the seismic motion at ground surface. The embedment restricts the deformation of surrounding ground because of higher stiffness of embedment. The foundation input motion is obtained as a seismic response at the embedment assuming that the embedment is rigid and massless, as drawn in Fig. 7. The foundation input motion is usually compared with the response at ground surface. The foundation input motion is less than the response at ground surface. The tendency is remarkable in high frequency regions. [2]

In the revised seismic design code in Japan, a response spectrum method is applied. The seismic response of buildings is expressed in acceleration response spectrum at ground surface. To get the acceleration response spectrum at ground surface, an amplification characteristics of surface ground on the engineering bedrocks (Vs is equal to and larger than 400 m/s) is taken into consideration. The effect of embedment on foundation input motion is treated as a reduction of the acceleration response spectrum at ground surface. The amplification factor, which is a amplitude ratio of the acceleration response spectrum at ground surface to that at exposed engineering bedrock, is expressed to be Gs at the ground surface. The amplification factor at the engineering bedrock is equal to 1. As shown in Fig. 8, the amplification factor of surface ground through depth is proportional to depth and becomes the value between Gs and 1. For simplicity, the foundation input motion at the bottom of embedment is assumed to be equivalent to the response of soil deposit at the same depth as bottom of embedment (G(De) in Fig. 8).

In addition to the horizontal input motion to the bottom of embedment, an earth pressure acts on the embedment. The earth pressure has an influenced to not only increase of horizontal motion but also occurrence of rotational motion. With depth of embedment, the influence of rotational motion is remarkable. To consider effect of input motion from side and bottom, the input motion to buildings is evaluated through weighted way of spring constants for side and bottom parts (K_{hb} and K_{he}) as follows;.

$$b' = \frac{K_{hb}\left\{1-\left(1-\frac{1}{Gs}\right)\frac{D_e}{\sum H_i}\right\}+K_{he}}{K_{hb}+K_{he}} \qquad (8)$$

Fig.9 presents results of acceleration response spectra at bottom of embedment by the proposed methods compared with that by more rigorous method (the thin layer method). The proposed results have a good agreement with the more rigorous solution.

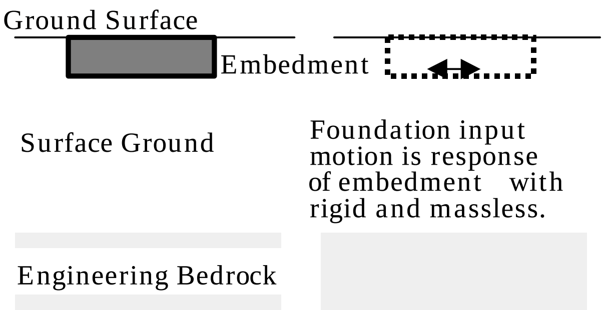


Fig. 7 Foundation Input Motion

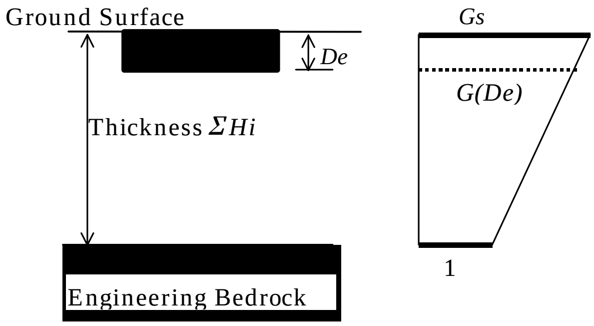


Fig.8 Distribution of Input Motion through Depth

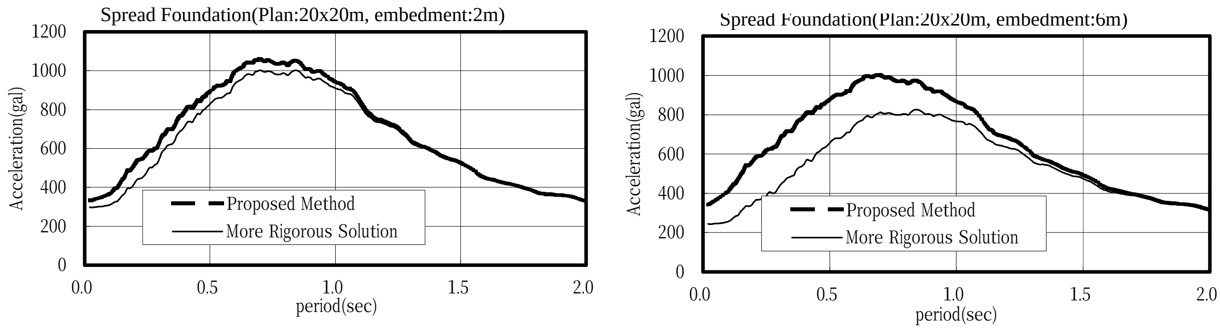


Fig. 9 Comparison of Horizontal Foundation Motion at Base between Proposed Results and More Rigorous One

EXAMPLE OF CALCULATION OF SPRING CONSTANT AND DAMPING FACTOR

Definition of Spring Constant and Equivalent Viscous Damping Factor

The features of sway and rocking motions for foundation or embedment of building are expressed as follows. A sinusoidal force is exerted to the massless foundation.

$$\overline{F} = Fe^{i\omega t} \qquad (9)$$

Where $\overline{F}$:dynamic force, *F*: amplitude of force, ω:circular frequency($2\pi f$, *f*: frequency)、*t*, *i*: time and unit of imaginary. The corresponding displacement is as follows;

$$\overline{u} = ue^{i(\omega t-\psi)} \qquad (10)$$

Where $\overline{u}$: response of displacement, *u*: amplitude, ψ: phase of displacement to force. From the relationship between force and displacement, a following relation is obtained.

$$\overline{K} = \frac{\overline{F}}{\overline{u}} = \frac{F}{u}e^{i\psi} = \frac{F}{u}\left(\cos\psi + i\sin\psi\right) \qquad (11)$$

Where $\overline{K}$ is a dynamic impedance and is defined to be complex. Dividing into real and imaginary parts provides a following relation.

$$\overline{K} = K + iK' \qquad (12)$$

$$K = \frac{F}{u}\cos\psi \qquad (13)$$

$$K' = \frac{F}{u}\sin\psi \qquad (14)$$

Real and imaginary parts of the impedance are corresponding to the spring constant and damping property. The equivalent viscous damping factor is obtained in the following;

$$h' = \sin\left(0.5\tan^{-1}\left(\frac{K'}{K}\right)\right) \qquad (15)$$

When $\frac{K}{K'}$ is small, one uses next formula.

$$h' = \frac{K'}{2K} \qquad (16)$$

The equivalent viscous damping coefficient is obtained as follows;

$$c = K'/\omega \qquad (17)$$

For the sway and rocking motions, subscripts of *h* and *r* are added.

$$\overline{K}_h = K_h + iK_h' = K_h(1 + i2h_h') = K_h + ic_h\omega \qquad (18)$$

$$\overline{K}_r = K_r + iK_r' = K_r(1 + i2h_r') = K_r + ic_r\omega \qquad (19)$$

The dynamic impedance is dependent on a type of foundations, their shape and dimension and properties of soil. As to influence of nonlinearity of the soil, there are many unclear items. There are two kinds of nonlinearity. One is based on nonlinearity of soil when seismic wave comes up in the soil deposits. The shear stiffness and damping factor are dependent on the shear strain of the ground. The other is the nonlinearity related to contact face between foundation or pile and soil, so called, local nonlinearity. It will take times to summarize the local nonlinearity. In the calculation, only the former, that is, nonlinearity of the soil property is considered. When the degree of nonlinearity will be large, that is, soil liquefaction and wide change due to repetition, this method will not able to be applied.

The impedance has a frequency dependency. Considering the convenience to incorporating into design, the frequency dependence is treated to be simplified. As to the spring constant, the value at rest (frequency is zero) will be used. As to the damping factor, the value at frequency of *fe* (circular frequency : ω_e) will be applied because of not neglecting frequency dependence.

Spring constant : $K = K(\omega_e = 0)$ (20)

Equivalent viscous damping Factor : $h' = \sin\left(0.5\tan^{-1}\left(\frac{K'(w_e)}{K(w=0)}\right)\right)$ (21)

Equivalent viscous damping coefficient : $c = K'(w_e)/w_e$ (22)

Spring Constant for Spread Foundation

a)Spring Constant of Sway and Rocking at Bottom (K_{hb}、 K_{rb})

Considering the transform of solutions for an uniform layer to that for multiple layers, a cone model is applied, as drawn in Fig. 10[10,11]. The spring constant for sway motion is obtained as follows;

$$K_{hb} = b_h K_{1hb} \quad (23)$$

$$b_h = \frac{1}{\sum_{i=1}^{n} \frac{1}{a_{hi}}} \quad (24)$$

Where β_h, K_{1hb} are a modification factor and a spring constant for rigid foundation with semi-infinite uniform layer, respectively.

$$K_{1hb} = pG_1\left(\frac{r_{h0}^{\;2}}{Z_{h0}}\right) \quad (25)$$

$$a_{hi} = \left(\frac{G_i}{G_1}\right)\cdot\frac{Z_{hi}Z_{hi-1}}{Z_{h0}\left(Z_{hi}-Z_{hi-1}\right)}$$

$$i = 1,2,\cdots,n-1 \quad (26)$$

$$a_{hn} = \left(\frac{G_n}{G_1}\right)\cdot\frac{Z_{hn-1}}{Z_{h0}} \quad (27)$$

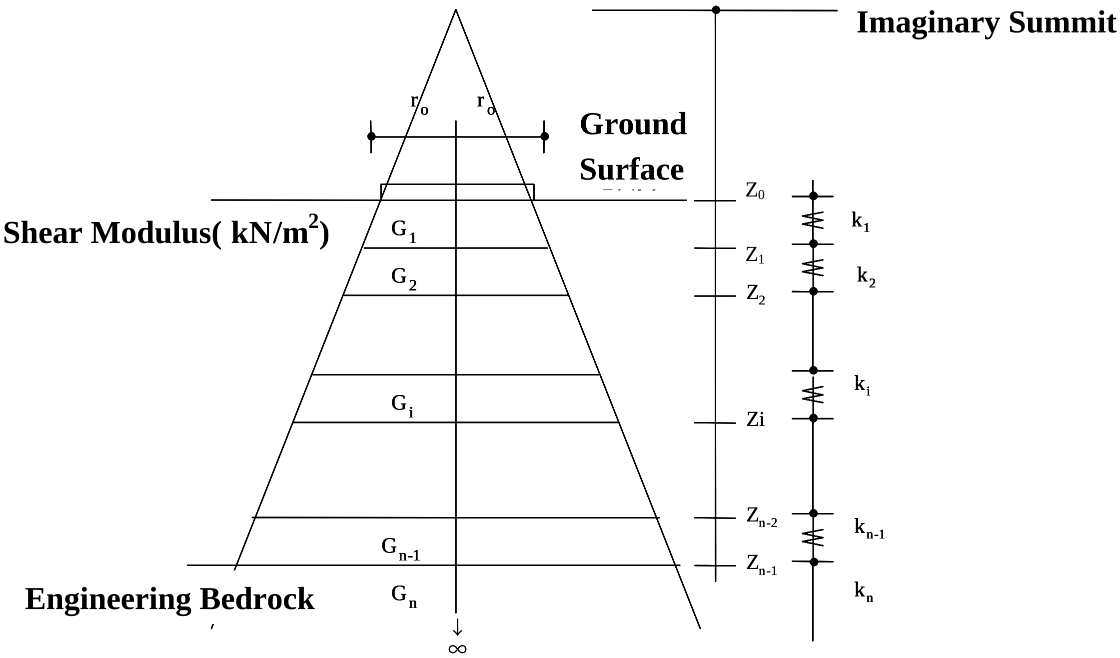


Fig. 10 Ground Layers and Setting of Cone

$$Z_{h0} = pr_{h0}\frac{2-u_1}{8} \qquad (28)$$

Where υ_1 is a Poisson's ratio of ground under the foundation. *Gi* and Z_{hi} are the shear stiffness of ith layer of ground and the distance of lower boundary from the cone summit of ith layer. r_{h0} is an equivalent radius for sway spring constant in the following;

$$r_{h0} = \sqrt{B \cdot D/p} \qquad (29)$$

Where *B* and *D* are a width and a depth of foundation, respectively.

When the shear stiffness of soil is treated as a complex one as in the next expression, K_{hb} in equation(23) will be complex.

$$G_i' = G_i(1 + i2h_i) \qquad (30)$$

Where G_i、h_i is the shear modulus and damping factor of soul with soil nolinearity considered.

In the same way, the rocking spring is calculated as follows;

$$K_{rb} = b_r K_{1rb} \qquad (31)$$

$$b_r = \frac{1}{\sum_{i=1}^{n}\frac{1}{a_{ri}}} \qquad (32)$$

$$K_{1rb} = \frac{4}{3}\frac{E_1 r_{r0}^3}{1-u_1^2} \qquad (33)$$

$$a_{ri} = \left(\frac{E_i}{E_1}\right)\left(\frac{Z_{ri-1}}{Z_{r0}}\right)^4 \frac{Z_{r0}Z_{ri}^3}{Z_{ri-1}\left(Z_{ri}^3 - Z_{ri-1}^3\right)} \qquad i = 1,2,\cdots,n-1 \qquad (34)$$

$$a_{rn} = \left(\frac{E_n}{E_1}\right)\left(\frac{Z_{rn-1}}{Z_{r0}}\right)^3 \qquad (35)$$

$$Z_{r0} = \frac{9}{16}\pi\left(1-\upsilon_1^2\right)r_{r0} \qquad (36)$$

$$E_i = 2(1+u_i)G_i \qquad (37)$$

$$r_{r0} = \sqrt[4]{\frac{B^3 D}{3p}} \qquad (38)$$

Where β_r and K_{1rb} are the modified factor and rocking spring constant for rigid foundation with semi-infinite uniform layer, respectively. E_i, ν_i and Z_{ri} are the elastic stiffness and Poisson's ratio of i-th layer of ground and the distance of lower boundary from the cone summit of i-th layer. r_{h0} is a equivalent radius for rocking spring constant.

Figures 11 and 12 present the comparison of static sway and rocking springs between results by proposed method and static results by more rigorous method. There is a good agreement in the results and the proposed method provides good results for engineering use.

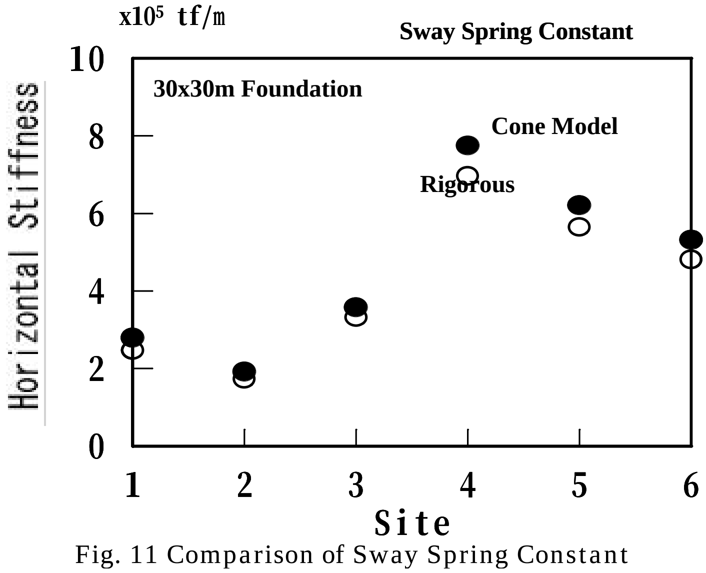


Fig. 11 Comparison of Sway Spring Constant (Dimension:30mx30m、No Embedment)

b)Effect of Embedment for Spring Constant of Sway and Rocking (K_{he} 、 K_{re})

The sway spring constant due to earth pressure of surrounding soils is evaluated as follows[10];

$$K_{he} = K_{hb} \frac{D_e}{r_{h0}} \frac{G_{he}}{G_{hb}} \qquad (39)$$

Where K_{he} and K_{hb} are the bottom and side of sway spring constants. And D_e, G_{he}, G_{hb} are the depth of embedment, equivalent shear module of soil for side and for bottom which are expressed in the next equations.

$$G_{he} = \frac{\sum_{i=1}^{m} G_i H_i}{\sum_{i=1}^{m} H_i} \qquad (40)$$

$$G_{hb} = \frac{(2-u)K_{hb}}{8r_{h0}} \qquad (41)$$

Where m is the number of soil layers of thickness of H_i in the depth of embedment and ν is the average Poisson's ratio.

The case of rocking is as follows;

$$K_{re} = 0.5K_{rb}\left(2.3\frac{D_e}{r_{r0}} + 0.58\left(\frac{D_e}{r_{ro}}\right)^3\right)\frac{G_{he}}{G_{hb}} \qquad (42)$$

Where K_{re} and K_{rb} are the bottom and side of rocking spring constants.

Figures 13 and 14 present the comparison of sway and rocking springs between results by proposed method and results by more rigorous method.

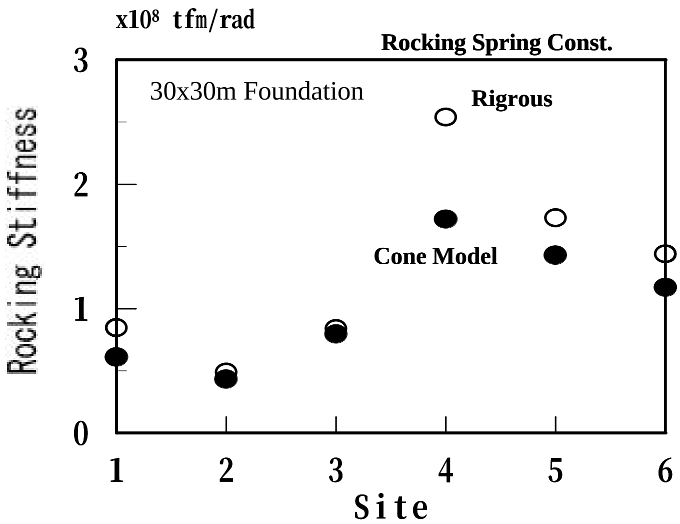
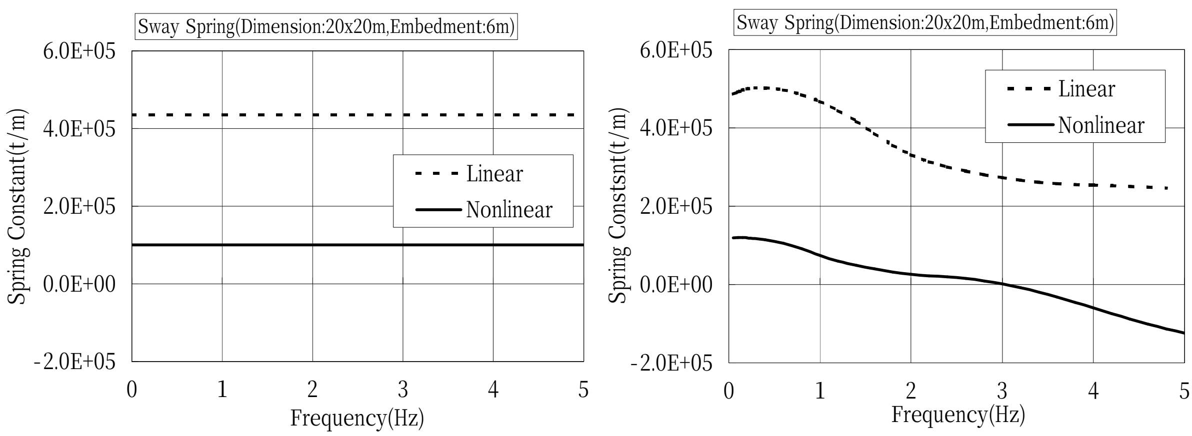


Fig. 12 Comparison of Rocking Spring Constant (Dimension:30mx30m、No Embedment)



a)Proposed result b) More rigorous result

Fig. 13 Comparison of Sway Spring Constant (Dimension:20mx20m、Embedment Depth 6m)

Equivalent Viscous Damping Factor for Spread Foundation

Imaginary Part of Sway and Rocking at Bottom(K_{hb}'、 K_{rb}')

The imaginary part of sway impedance is evaluated as in Fig. 15. In the range of the predominant frequency of building with SSI (*fe*) is less than the predominant frequency of soil deposit *(fg)*, the imaginary part is dependent on the damping characteristics due to soil nonlinearity. The impedance is obtained through the complex shear modulus of soil as equation (30) is expressed as follows;.

$$\overline{K}_{hb} = K_{hb} + iK_{hb}' = K_{hb}(1 + i2h_{hb}') \qquad (43)$$

Where K_{hb} , K_{hb}' and h_{hb}' are the real and imaginary parts of impedance and the equivalent viscous damping factor, respectively. K_{hb}' is constant and independent of frequency.

In case of the rocking impedance, the following solution will be got in the same manner. It will be changed that it is applicable for *fe* less than *2*fg*.

$$\overline{K}_{rb} = K_{rb} + iK_{rb}' = K_{rb}(1 + 2ih_{rb}') \qquad (44)$$

On the other hand, when the predominant frequency of building with SSI (*fe*) is equal and higher than the predominant frequency of soil deposit *(fg)*, the radiation effect is added to the damping characteristics due to soil Nonlinearity. the radiation effect is considered to be proportional to ω. Though the imaginary part is expressed to be $c\omega$, the following equation is adopted considering continuity ay frequency of *fg*.

$$K_{rad}' = c(\omega - \omega_g) \qquad (45)$$

Where c is the viscous damping coefficient.

In case of *fe* > *fg*, the imaginary part for sway and rocking modes is expresses as follows. In the case of rocking mode, it will changed that *fg* should be *2*fg*.

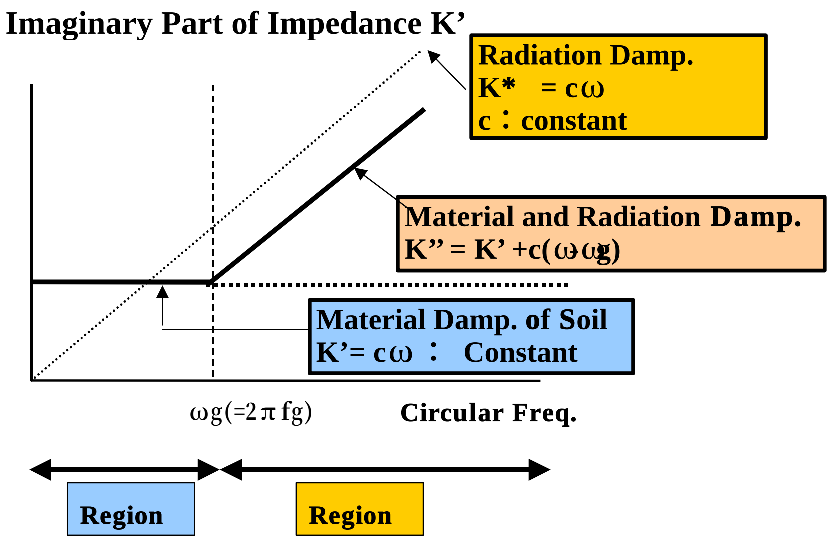


Fig. 15 Simplified Evaluation for Imaginary Part of Impedance

$$\overline{K}_{hb} = K_{hb} + iK_{hb}'' = K_{hb}(1 + 2ih_{hb}'') \tag{46}$$

$$K_{hb}'' = 2K_{hb}h_{hb}' + 2p^{2} r_{h0}^{2} \sqrt{r_e G_{hb}} \left(\frac{1}{T_e} - \frac{1}{T_g} \right) \tag{47}$$

$$h_{hb}'' = \sin\left(0.5 \tan^{-1}\left(\frac{K_{hb}''}{K_{hb}} \right) \right) \tag{48}$$

Where r_e, G_{hb}, T_e, and T_g are average Poisson's ratio, predominant Period of building with SSI and soil deposit, respectively.

$$r_e = \frac{\sum_{i=1}^{n} r_i H_i}{\sum_{i=1}^{n} H_i} \tag{49}$$

In case of the rocking motion, the relation for energy radiation is summarized as follows;

$$\overline{K}_{rb} = K_{rb} + iK_{rb}'' = K_{rb}(1 + 2ih_{rb}'') \tag{50}$$

$$K_{rb}'' = 2K_{rb}h_{rb}' + \frac{1.7\pi}{1-\upsilon} r_{r0}^{4} \sqrt{\rho_e G_{hb}} \left(\frac{1}{T_e} - \frac{2}{T_g} \right) \tag{51}$$

Figures 16 and 17 present the comparison of the equivalent viscous damping factors for sway and rocking motions between results by proposed method and results by more rigorous method. The proposed one provide a little under-estimated one a good agreement with the rigorous one.

CONCLUDING REMARKS

The appropriate method for introducing the performance-based design and checking the structural safety of buildings during severe wind and earthquake was showed in the Building Standard Law in Japan. In the method, it is included that the SSI effects should be considered in case that the SSI has influenced on the safety of buildings. The consideration of SSI effect into the design in the Law have just started. It remains many issues which should be solved. To incorporate SSI effects into the design procedures, the following general issues have yet to be solved.

(1) To clearly determine the SSI phenomenon during vibration caused by earthquakes and wind.
(2) To carry out research on understanding the inelastic and/or nonlinear behavior caused by SSI, particularly

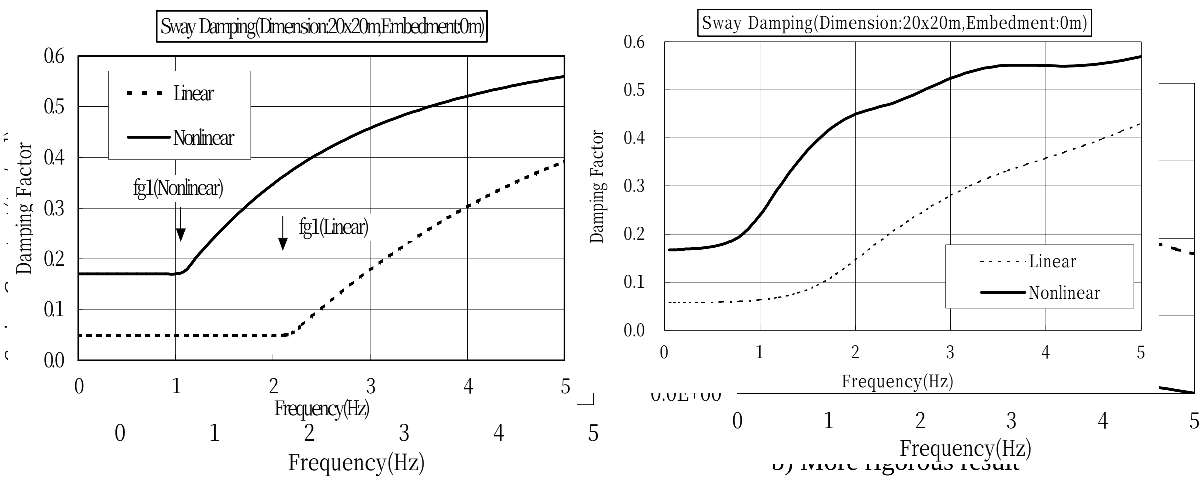
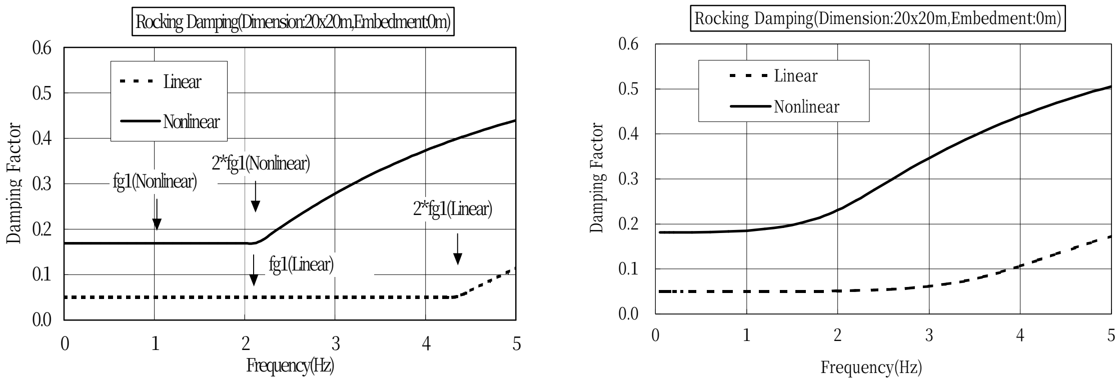


Fig. 16 Comparison of Damping Factor for Sway Motion (Dimension:20mx20m、No Embedment)

Fig. 14 Comparison of Rocking Spring Constant(Dimension:20mx20m、Embedment Depth 6m)



a)Proposed result b) More rigorous result

Fig. 17 Comparison of Damping Factor for Rocking Motion (Dimension:20mx20m、No Embedment)

during strong shaking.

(3) To clarify the external loads which are a combination of inertial force and ground displacements in case of pile foundations.

In future, the SSI research on detailed phenomena of SSI through observation during earthquake and experiments. And mutual relation between seismic response and structural modeling will be made clear.

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