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ON A COMPLETELY ASSOCIATED RESPONSE SYSTEM OF THE UPPER STRUCTURE·BASEMENT·SOIL STRATA BELOW

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ABSTRACT

This paper treats the extensive contents in relaion to the paper published by the author at the 10-WCEE Madrid 1992. The same response theme of the former was concerned with the analytical model (named as M-1) on the consistent structural system related to the upper-structure·basement-box·supporting-subsoils, of which vibratory condition had an incomplete analytical connection between the basement and its lower soil-strata. In this paper its situation has been improved fully so as as to be completely consistent (named as M-2). The main points of this paper are shortened : (1) the model of earthquake response-system is aimed to be completely consistent concerning the related three parts of a upper-structure·basement·subsoils, (2)the rocking theory on the basement cylinder is adopted for its theoretical development after Dr.H.Tajimi's, which includes the interactive effect of the damping between the body and its surrounding surface-soil, (3) the solving method for the constituted dynamic equations on multi-masses response motion is relied firstly upon gaining respective values of the transfer function for the serial angular velocity of ω by the simultaneously developed equations of the first order on moving masses, (4) the resultant response acceleration and wave of each mass are acquired through the method of inverse Fourier transformation, and on the other side (5) a real structural model of 19 storeyed steel structure with two storeyed basement-box has been chosen for a test model for the verification of the suitableness comparing both cases of analyses and measured. Finally the author reaches the conclusion the analyses by the M-2 have given much more better approaches on the overall wave shape to the real measured ones compared with the results by the M-1, though max-accelerations are almost same.

KEYWORDS

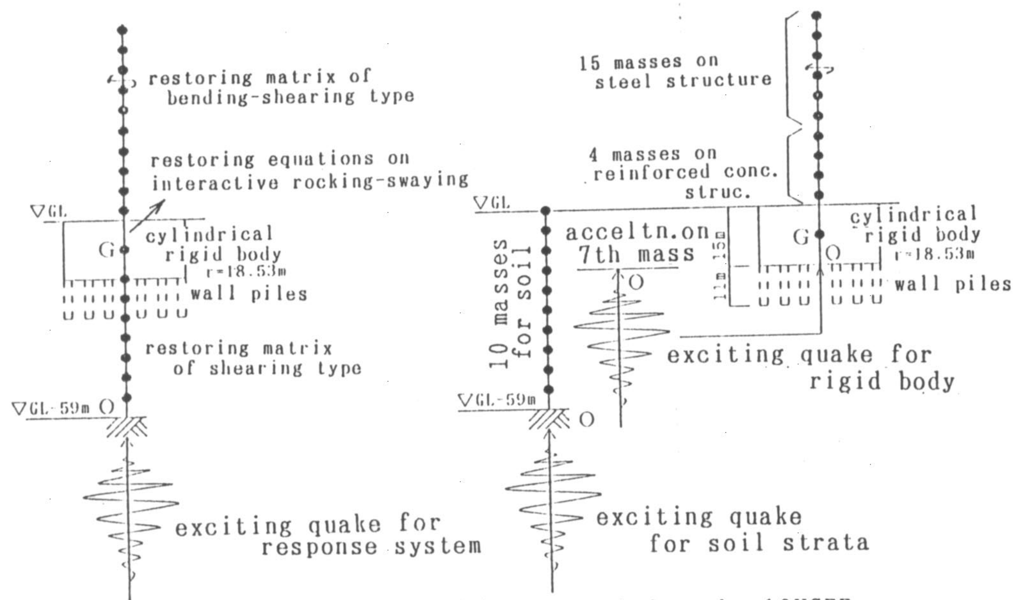
Earthquake response; upper-stru.·basement·subsoil; basement-soil interaction; multi-masses resp.system; transfer function; inverse Fourier transformation; actual build.system measurement; comparison between analysed and measured; verification of suitableness; computational mechanics

COMPLETELY CONSISTENT RESPONSE SYSTEM ON UPPER.ST·BASEMENT·SUBSOIL:

The Japanese paper on the theme was first published by Dr.H.Tajimi at the 4-WCEE (Hajime Tajimi,1969) and rcently two papers on it were made public by the author at the chances of the 10-WCEE and the V-ICCCBE (F.Suto,1992, F.Suto,1993).

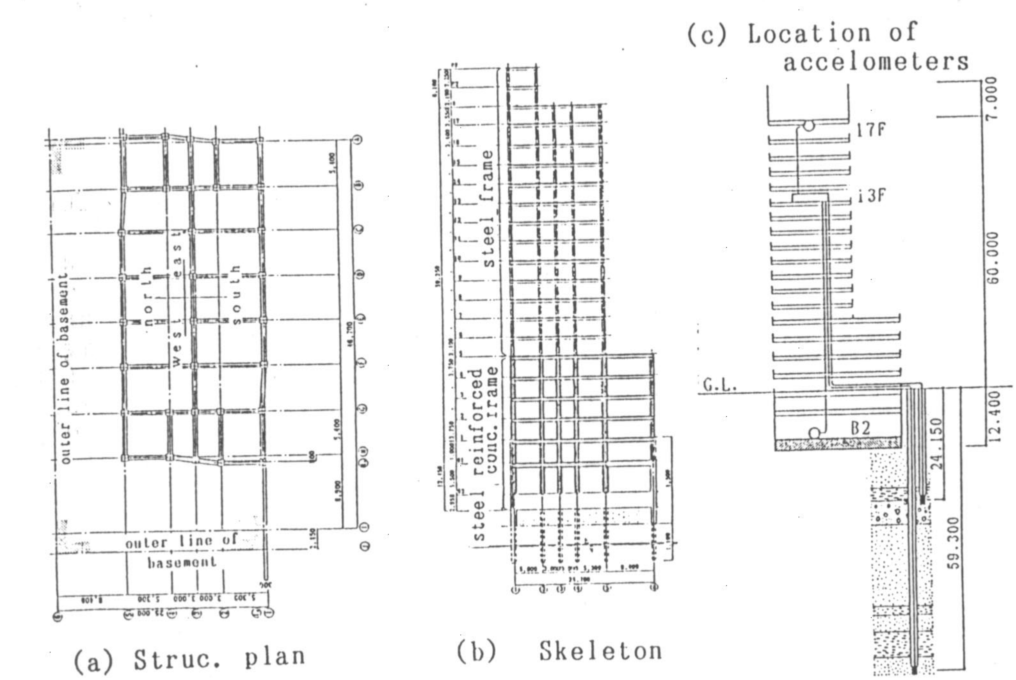
OUTLINE OF THE NECESSARY PRELIMINARIES

This paper treats the extensive contents in relaion to the paper published by the author at the 10-WCEE Madrid 1992 (Ref.1). The preceeding paper on the same response theme was concerned with the analytical model (named as M-1) regarding incomplete analytical connection between the basement-box (replaced to a rigid cylindrical body) and its lower soil-strata. In this place the mechanicl situation has been improved fully as a consistent model (named as M-2). The necessary matters are described firstly to write later main points of this paper.



(a) M2 model for this thesis (b) M1 model for the 10WCEE paper

Fig.1 Associated response-models on three structural parts by M2 & M1



(a) Struc. plan (b) Skeleton

Fig.2 Data on the Building, the soil state and the measuring

The object of this paper exists in the identification of theoretical suitableness on M-2 model extended from M-1 concerning the dynamical system of the above entitled theme. Namely the significance of the analytical method following M-2 shown in Fig.1-a is to be clarified reviewing over the exemplary results solved by M-2 and M-1 (Fig.1-b) which show some distinctive difference. The key'difference lies in the point whether the mechanical connection between the base of basement-box and its sopport soil-strata below is completely sufficient or not. In this paper this important difference is considered to characterize results analysed by M-2 comparing with those by M-1 and measured values carried out for an actual building of 19 storied steel frame with 2 storied basement box settled on about 45m-depth of supporting sandy soil-strata shown in Fig.2-a,b,c.

The methods adopted for this study are constituted by two phases as follows : (i) Attainment of theoretical integrity of the system has been aimed in computational mechanical process. The mechanical system is composed like the former M-1 by the three sturctural parts (Ref.1). The whole restoring matrix is made up as follows ; (a) the upper-frame's matrix of bending and shearing type with the basement's rocking, b) the columns and rows of stiffnesses on sway- and rocking of the basement-box including interactive effect of radiation damping after Dr.Tajimi's formula (Ref.2), and c) the matrix of shearing type on the subsoils. The modal response-method by Fourier Transformation is applied for the solution of this response system (Ref.3). (ii) On the other hand measuring work on an actual 19 storied frame has been carried out for the verification of the above theory's suitableness (Fig.2). For the background analyses the S-wave velocity of the surface soil layer is adopted as 375m/sec or so following the M-1 parametric study comparing the measured(Table 1). From among several earthquake response-data acquired till now,four quakes on accelaration under 40 gals listed in Table 2 are shown of their response-results and their mutual comparison. For analyses enforcing earthquakes to the system are given to the base-rock at GL-59m.

Physical properties on the measured object are briefly mentioned here. The upper 19 storeyed steel structure with 4 lower stories of steel reinforced concrete has its natural periods for E-W and N-S directions shown in Table 3, among which the 1st periods are compared with measured. For the lower supporting soilstrata of about 60 m thickness its predominant period around the site is known to be of about 0.5 sec or so by references.

Table 1 Basic matters on wave-propagation of soil medium and cylindrical rigid body

	C_T m/s	C_L m/s	C_{TB} m/s	C_{LB} m/s	ρ t/ms²/cm	ρ_b t/ms²/cm	h_s	ν_b	h_u
NS	350	700	1150	2400	0.168E-3	0.180E-3	0.10	0.37	0.013
EW	375	750	1150	2400	0.168E-3	0.180E-3	0.10	0.37	0.013

	H m	RAD m	HS m	FMAS ts²/cm	FIM tms²/cm	×Stiff. ξ_{st}
NS	15	18.53	5.574	20.57	0.277E+4	2.10
EW	15	18.53	5.574	20.57	0.486E+4	1.00

FIM :Mass moment
RAD :Replaced radius of body
FMAS:Mass of basement-body
H :Height of body
H_S :Gravity-center height
C_T :P-vel.of surface
C_L :S-vel.of surface
C_{TB}:P-vel.of b.rock
C_{LB}:S-vel.of b.rock
ρ :mass-density of surf.
ρ_B:mass-density of rock
ν_B:Poiss.'ratio of rock
h_S:Damp.const of surface
h_u:Damp.const of up.stru.
ξ_{st} :Magnif. to up.struct.

Table 2 Data on observed quake-waves and their max-acceleations

(a) Quake-data adopted for response-simulation

	Date	Magtd. (M)	Epi.-depth (km)	Epi.-distc. (km)	Max-accel.(GL-59M,unit:gal) NS	EW	UD	Epi.-loctn. N-latit.	E-longi.
*	'92.2.2	5.9	92	49	6.97	9.34	4.23	35° 14'	139° 14'
*	'93.9.18	5.0	35	112	0.67	1.01	0.56	36° 11'	140° 53'
*	'94.5.27	4.8	62	735	2.90	2.64	1.36	42° 3'	142° 35'
	'94.7.22	6.5	563	870	1.33	0.85	0.66	41° 17'	132° 49'
	'94.9.6	4.3	83	24	0.66	0.72	0.38	35° 35'	140° 08'
*	'94.10.4	8.1	30	1103	1.74	2.03	1.30	43° 22'	147° 40'

note; results of quakes with * are taken up for later explanation.

(b) Comparison of max-accel.s among data at 18 FL by M-2,M-1 and measured

Date	EW-direct. measured	M-1	M-2	NS-direct. measured	M-1	M-2
'92,2/2	33.9	39.20	29.02	36.96	30.23	19.37
'93,9/18	3.24	4.223	2.341	4.87	2.661	1.902
'94,5/27	5.95	5.438	6.767	6.71	10.42	5.363
'94,7/22	7.48	5.464	4.474	15.53	6.853	7.876
'94,9/6	2.04	1.986	1.072	1.77	3.716	0.799
'94,10/4	17.5	8.733	8.735	24.51	12.90	8.442

unit:gal

Table 3 Vibratory data on the upper frame and subsoils

(a) Natural periods of frame by analyses and measumt.

方向	Natural periods of upper structure (natural periods without rocking) (sec) 1st ord.	2nd ord.	3rd ord.	4th ord.	5th ord.	measured 1st ord.
N S	1.3166 0.8790	0.4434 0.2966	0.2697 0.1731	0.1880 0.12530	0.1638 0.1016	1.130
E W	1.1941 0.7940	0.3148 0.2114	0.2302 0.1635	0.1873 0.1248	0.1421 0.0850	1.000

(Values; upper row--fram.-stiff.x1.00, lower row---·x1.25)

(b) Searing-type of multi-masses sys. on subsoils

Mass-point (Depth)	Soil	N-val.	Mass (t.s/cm)	k (t/cm)
0m – 3.40m	surface	6	0.0027755	1.9169
3.40m – 7.45m	sandy silt	18	0.0060816	4.8274
7.45m – 15.00m	fine sand	44	0.0094693	6.3503
15.00m – 20.70m	fine sand	36	0.0108162	6.8926
20.70m – 23.65m	clay&silt	11	0.0070611	4.3241
23.65m – 30.55m	gravel	463	0.0087632	107.4579
30.55m – 38.65m	fine sand	301	0.0129673	40.3009
38.65m – 46.75m	fine sand	124	0.0132240	16.6739
46.75m – 52.40m	fine sand	143	0.0112244	27.5512
52.40m – 60.10m	fine sand	136	0.0108979	17.5011

note; values are of a square pillar of soils with unit sectional area.

FOCUSSED THEORETICAL POINT FROM M-1 TO M-2 MODEL

The computational theory of the M-1 model is based upon Dr.H.Tajimi' thesis(Ref. 2) which treats mainly the dynamically intearctive effect of radiation damping by 3-D Elasticity (Fig.3-a,b). The author's model M-1 aimed at the systematic connection of three structural parts as a unified system.However in the model it was not attained to connect completely between the base of the embedded body and its subsoil (Fig.3-c). At first essential parts of Dr.Tajimi's are shortened.

The vibration of a cyrindrical body in a surface soil is expressed by the following two elasticity-equations in the 3-D polar coordinates using unknown displacements of u_r, u_θ (Fig.3-a,b,c). The solution of the above unknown is gained introducing two approximate potential functions satisfied by a series of modified Bessel functions K_0 & K_1 on r under displacement condition to be equal of both the cylinder and soil at r=a. From the solved u_r and u_θ,dependent variables of σ_r and $\tau_{r\theta}$ are derived. Using these the resisting moment M against rocking by interactive effect between the cylinder and soil is formulated. According to the above, in the case of the model M-2 the equations of the horizontal response motion on the completely associated multi-masses constituted by three parts including the interactive rocking of the body are described in the following forms. Herein coefficients A_n, B_n, χ_n and Ω_n related to serial odd number n derived on the theoretical process are abridged (refer to Ref.2 for details).

Fundamental equations on vibration of a cylinder embedded in a soil layer.

$$\begin{cases} (\lambda+2\mu)\frac{\partial}{\partial r}\left[\frac{1}{r}\frac{\partial}{\partial r}(ru_r)+\frac{1}{r}\frac{\partial u_\theta}{\partial\theta}\right]-\mu\frac{1}{r}\frac{\partial}{\partial\theta}\left[\frac{1}{r}\frac{\partial}{\partial r}(ru_\theta)-\frac{1}{r}\frac{\partial u_r}{\partial\theta}\right] \\ \quad =\left(\rho\frac{\partial^2}{\partial t^2}-\mu\frac{\partial^2}{\partial z^2}-\mu'\frac{\partial^3}{\partial t\,\partial z^2}\right)u_r-\rho u_g\cos\omega^2 e^{i\omega t} \\ (\lambda+2\mu)\frac{1}{r}\frac{\partial}{\partial\theta}\left[\frac{1}{r}\frac{\partial}{\partial r}(ru_r)+\frac{1}{r}\frac{\partial u_\theta}{\partial\theta}\right]+\mu\frac{\partial}{\partial r}\left[\frac{1}{r}\frac{\partial}{\partial r}(ru_\theta)-\frac{1}{r}\frac{\partial u_r}{\partial\theta}\right] \\ \quad =\left(\rho\frac{\partial^2}{\partial t^2}-\mu\frac{\partial^2}{\partial z^2}-\mu'\frac{\partial^3}{\partial t\,\partial z^2}\right)u_\theta+\rho u_g\sin\theta\,\omega^2 e^{i\omega t} \end{cases} \quad \cdots\cdots(a)$$

Solved variables of displacements u_r and u_θ.

$$\begin{cases} u_r=\sum_{n=1,3,5\cdots}^{\infty}\left\{-A_n\left[\frac{1}{r}K_1\left(\frac{\xi_n\omega_g r}{C_L}\right)+\frac{\xi_n\omega_g}{C_L}K_0\left(\frac{\xi_n\omega_g r}{C_L}\right)\right]+\frac{B_n}{r}K_1\left(\frac{\xi_n\omega_g r}{C_T}\right)\right. \\ \quad \left.+\frac{4}{n\pi}\frac{u_g}{\xi_n^2}\left(\frac{\omega}{\omega_g}\right)^2\right\}\cos\theta\sin\frac{n\pi z}{2H}e^{i\omega t} \\ u_\theta=\sum_{n=1,3,5\cdots}^{\infty}\left\{-\frac{A_n}{r}K_1\left(\frac{\xi_n\omega_g r}{C_T}\right)+B_n\left[\frac{1}{r}K_1\left(\frac{\xi_n\omega_g r}{C_T}\right)+\frac{\xi_n\omega_g}{C_T}K_0\left(\frac{\xi_n\omega_g r}{C_T}\right)\right]\right. \\ \quad \left.-\frac{4}{n\pi}\frac{u_g}{\xi_n^2}\left(\frac{\omega}{\omega_g}\right)^2\right\}\sin\theta\sin\frac{n\pi z}{2H}e^{i\omega t} \end{cases} \quad \cdots\cdots(b)$$

Basic matters on wave-propagation of soil medium.

$$\begin{cases} \frac{\lambda+2\mu}{\rho}=C_L^2 \quad \frac{\mu}{\rho}=C_T^2 \quad C_T\frac{\pi}{2H}=\omega_g \\ \sqrt{n^2\left(1+i\frac{\mu'}{\mu}\omega\right)-\left(\frac{\omega}{\omega_g}\right)^2}=\xi_n^2 \\ \frac{\mu+i\mu'\omega}{\rho}=C_T^2\left(1+i\frac{\mu'}{\mu}\omega\right) \quad \frac{\mu'}{\mu}=\frac{2h_g}{\omega^g} \\ k_R=\frac{\pi}{2(1-\nu_b)}\mu_b a^3 \end{cases}$$

Formula to get stresses of σ_r and $\tau_{\theta r}$.

$$\sigma_r=\lambda\left[\frac{1}{r}\frac{\partial}{\partial r}(ru_r)+\frac{1}{r}\frac{\partial u_\theta}{\partial\theta}\right]+2\mu\frac{\partial u_r}{\partial r} \qquad \tau_{r\theta}=\mu\left(\frac{\partial u_\theta}{\partial r}-\frac{u_\theta}{r}+\frac{1}{r}\frac{\partial u_r}{\partial\theta}\right) \quad \cdots\cdots(c)$$

Resisting rotational moment by vibratory interaction between the body and soil.

$$M=\int_0^H\left[\int_0^{2\pi}(\sigma_r|_{r=a}\cos\theta-\tau_{r\theta}|_{r=a}\sin\theta)a\,d\theta\right]z\,dz$$

$$=-\sum_{n=1,3,5\cdots}^{\infty}a^2\rho\pi\left(\frac{2H}{n\pi}\right)^2(-1)^{\frac{n-1}{2}}\xi_n^2\omega_g^2\Omega_n\left[\frac{8\varphi_0 H}{\pi^2}\frac{(-1)^{\frac{n-1}{2}}}{n^2}-\frac{4}{n\pi}\frac{u_g}{\xi_n^2}\left(\frac{\omega}{\omega_g}\right)^2\right]e^{i\omega t}(3) \quad \cdots\cdots(d)$$

From this after the description constitutes the main points on the association. The matrix equation (1) shows the total horizontal equations on multi-masses vibration for the three parts (Fig.3-c) and the equation (2) expresses the rocking motion of the basement. In this place considering the solution by Fourier transformation the respective unknowns are expressed by the following, defining several fundamental displplacement variables as below ;

$$X_{0i}(t)=x_{0i}(\omega)e^{i\omega t},\quad X_i(t)=x_i(\omega)e^{i\omega t},\quad \Phi_0(t)=\phi_0(\omega)e^{i\omega t},\quad U_g(t)=u_g(\omega)e^{i\omega t} \cdots(1)$$

Total displacement and transfer function vectors are defined as follows ;

$$\{\Delta_s(\omega,t)\}=\{(x_{0i}(\omega)+u_g(\omega)),\ \phi_0(\omega),\ (x_i(\omega)+h_i\phi_0(\omega)+x_{0n}(\omega)+u_g(\omega))\}^T e^{i\omega t} \cdots(2)$$

$$\frac{\{\ddot{\Delta}_s(\omega)\}}{\ddot{u}_g(\omega)}=\frac{\{\dot{\Delta}_s(\omega)\}}{\dot{u}_g(\omega)}=\frac{\{\Delta_s(\omega)\}}{u_g(\omega)}=H_s(\omega) \quad (0i=01\cdots0n,\ 0,\ i=1\cdots N) \cdots(3)$$

$$H_s(\omega)=-\omega^2\{(x_{0i}(\omega)-\omega^{-2}),\ \phi_0(\omega),\ (x_i(\omega)+h_i\phi_0(\omega)+x_{on}(\omega)-\omega^{-2})\}^T \quad s=(0i=01\cdots 0n,\ 0,\ i=1\cdots N) \quad \cdots(4)$$

where $x_{0i}(\omega), x_i(\omega), \phi_0(\omega)$ and $H_s(\omega)$ are unknown transfer functions of ω solved from the equations (7) & (8) and $u_g(\omega), u_g(\dot{\omega})$ & $u_g(\ddot{\omega})$ are known transfer function calculated from earthquake data given.

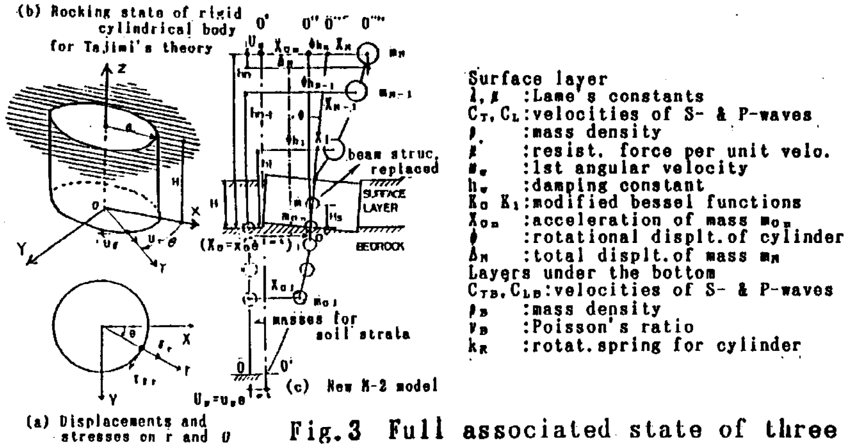


Fig.3 Full associated state of three parts in M-2

Equations on the response-vibrations are described as follows :

- Equations on the subsoil-part beneath the basement

for $m_{01}\cdots m_{0N-1}$, $\quad [m]\{\ddot{X}_{0i}\}+[c]\{\dot{X}_{0i}\}+[k]\{X_{0i}\}=-[m]\{\ddot{U}_g\}$, $\quad 0i=01\cdots 0n$

for m_{0N}, $\quad m_{0N}\ddot{X}_{0N}+[c]\{\dot{X}_{0i}\}+[k]\{X_{0i}\}+(\Sigma\Sigma k_{ij})(X_{0N}-X_i)+(\Sigma m_j h_j)\ddot{\Phi}_0=-m_{0N}\ddot{U}_g$,

- Equations on the part over the basement-base $\quad i=1,\cdots N$

for m_1, $\quad m_1(\ddot{X}_1+h_1\ddot{\Phi}_0+\ddot{X}_{0N})+[c]\{\dot{X}_i+h_i\dot{\Phi}_0\}+[k]\{X_i\}-(\Sigma\Sigma k_{ij})X_{0N}=-m_1\ddot{U}_g$,

for $m_2\cdots m_N$, $\quad [m]\{\ddot{X}_i+h_i\ddot{\Phi}_0+\ddot{X}_{0N}\}+[c]\{\dot{X}_i+h_i\dot{\Phi}_0\}+[k]\{X_i\}=-[m]\{\ddot{U}_g\}$, $\quad \cdots(5)$

- Equations on the part of rocking of body $\quad i=1,\cdots N$

$$I_R\ddot{\Phi}_0+k_R\Phi_0+(\Sigma m_i h_i(\ddot{X}_i+h_i\ddot{\Phi}_0+\ddot{X}_{0N}+\ddot{U}_g))+(\Sigma h_i\Sigma c_{ij}(\dot{X}_j+h_j\dot{\Phi}_0))+M=0 \quad \cdots(6)$$

Further to make rearrangement for gaining respective transfer functions on horizontal displacements of constituent masses, equations of (5) and (6) are changed using expression of (1) so as to deduce a matrix equation of variable ω. In this place items concerning the rotational displacement is treated carefully.

- Equations on the subsoil-part beneath the basement $\quad 0i=01\cdots 0n$

for m_{01} -- m_{0N-1}, $\quad [[-\omega^2 m]+[i\omega c]+[k]]\{x_{0i}\}=\omega^2[m]\{u_g\}$, $\quad i=\sqrt{-1}$,

for m_{0N}, $\quad -\omega^2 m_{0N}x_{0N}+[[i\omega c]+[k]]\{x_{0i}\}+(\Sigma\Sigma k_{ij})(x_{0N}-x_1)+(-\omega^2\Sigma m_j h_j)\phi_0=\omega^2 m_{0N}u_g$,

- Equations on the part over the basement-base $\quad i=1,\cdots N$

for m_1, $\quad -\omega^2 m_1 x_1+[[i\omega c]+[k]]\{x_i\}+[h_i][[-\omega^2 m]+[i\omega c]]\{\phi_0\}-(\Sigma\Sigma k_{ij})x_{0N}=\omega^2 m_1 u_g$,

for m_2 -- m_N, $\quad [[-\omega^2 m]+[i\omega c]+[k]]\{x_i\}+[h_i][[-\omega^2 m]+[i\omega c]]\{\phi_0\}=\omega^2[m]\{u_g\}$ $\quad \cdots\cdots(7)$

- Equation on the part of rocking of body $\quad i=1,\cdots N$

$$((-\omega^2 I_R+k_R-\omega^2(\Sigma m_i h^2)+i\omega(\Sigma h_i\Sigma c_{ij}h_j))\phi_0+\{-\omega^2\Sigma m_j h_j x_j+i\omega\Sigma h_i\Sigma c_{ij}x_j+(-\omega^2\Sigma m_j h_j)x_{0N}\}=\omega^2(\Sigma m_j h_j)u_g-M \quad \cdots\cdots(8)$$

where M in (6) & (8) of Tajimi's (d) is divided into two items like $[E(func.(f_n(\omega))\phi_0(\omega)+F(func.(f_n(\omega))u_g(\omega)]e^{i\omega t}$, and these are built in matrix formation.

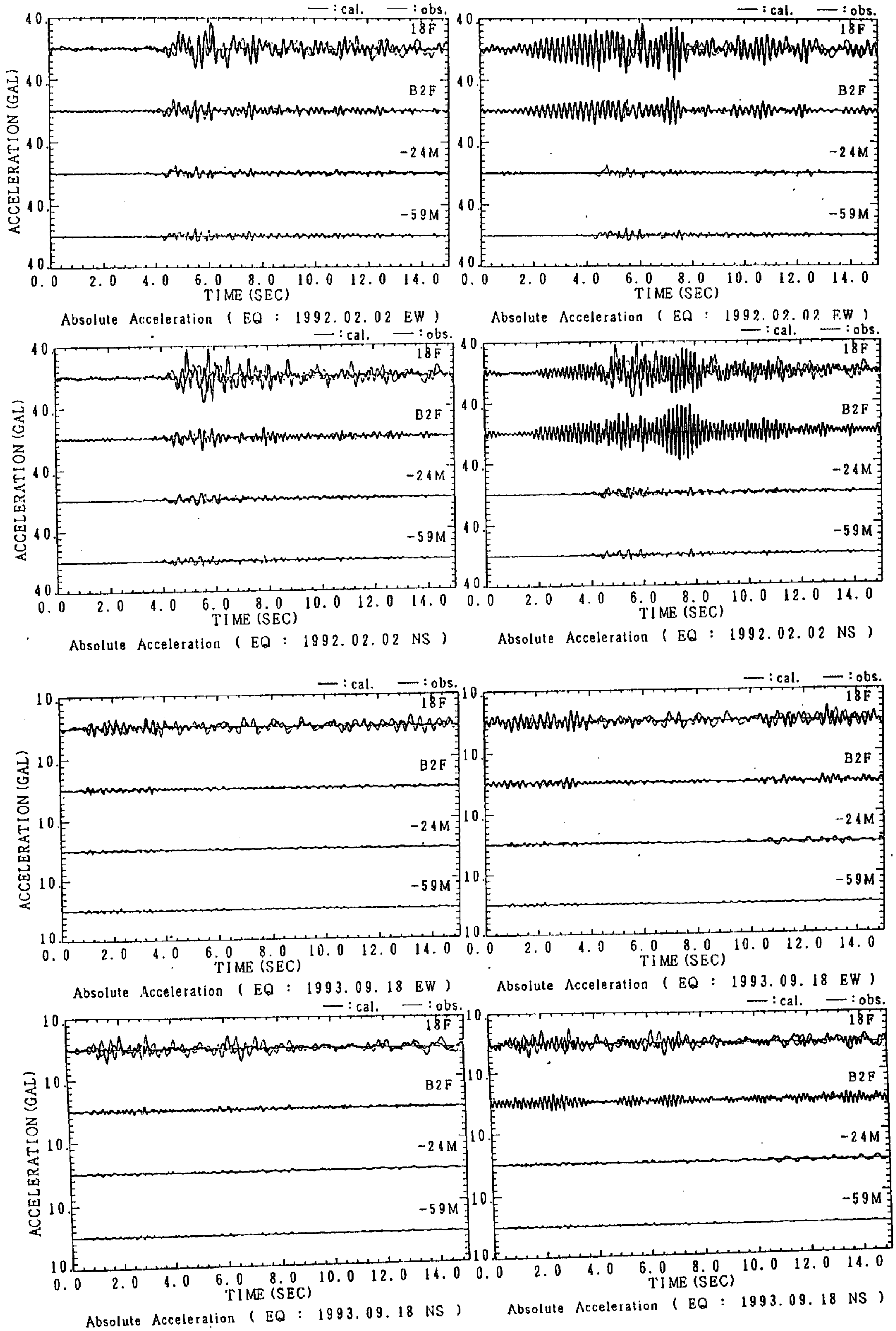
These matrix equations are expressd in an algebraic form in relation to the unknown transfer function vector $\{x_{01}, x_{02}, \cdots\cdots x_{0n}, \phi_0, x_1, x_2, \cdots\cdots x_N\}^T$ on displacements and these unkown elements are solved of the simultaneous equations on (7) & (8) as the function of angular velocity ω given sequentially. Three sorts of response results on each mass to the absolute vertical axis of o-o are gained using $H_s(\omega)$ constituted by elements of the above transfer function vector solved and the final response function by t, i.e. $\{\Delta_s(t)\}$ are calculated by the following Fourier inverse transformation ;

$$\{\ddot{\Delta}_s(t)\}=\frac{1}{2\pi}\int_{-\infty}^{\infty}\{H_s(\omega)\cdot\ddot{u}_g(\omega)e^{i\omega t}\}d\omega, \quad s=(0i=01\cdots 0n,\ 0,\ i=1\cdots N)$$
$$\{\dot{\Delta}_s(t)\}=\frac{1}{2\pi}\int_{-\infty}^{\infty}\{H_s(\omega)\cdot\dot{u}_g(\omega)e^{i\omega t}\}d\omega,$$
$$\{\Delta_s(t)\}=\frac{1}{2\pi}\int_{-\infty}^{\infty}\{H_s(\omega)\cdot u_g(\omega)e^{i\omega t}\}d\omega. \quad \cdots\cdots(9)$$

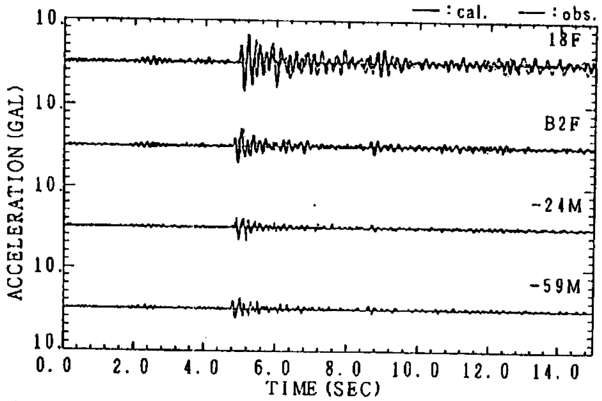
, where in the case $u_g(\omega), u_g(\dot{\omega})$ & $u_g(\ddot{\omega})$ are exciting earthquake data at GL-59m (base-rock level) transformed by the Fourier formula.

Fig. 4 Comparative expression on results by M2 & M1 for a response example

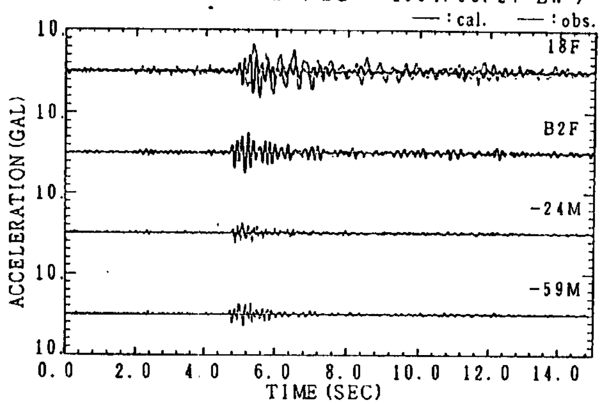
(a) Results by M2 model (b) Results by M1 model



(a) Results by M2 model



Absolute Acceleration (EQ : 1994. 05. 27 EW)



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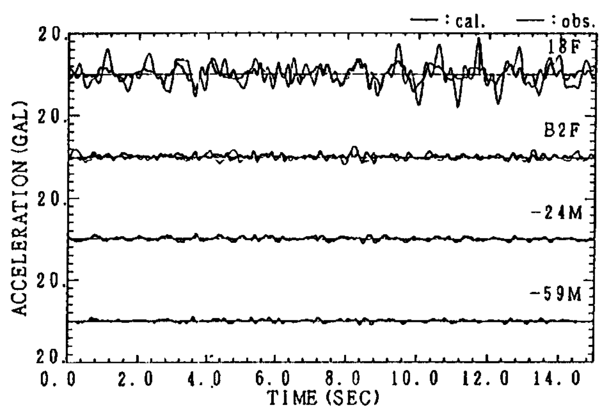

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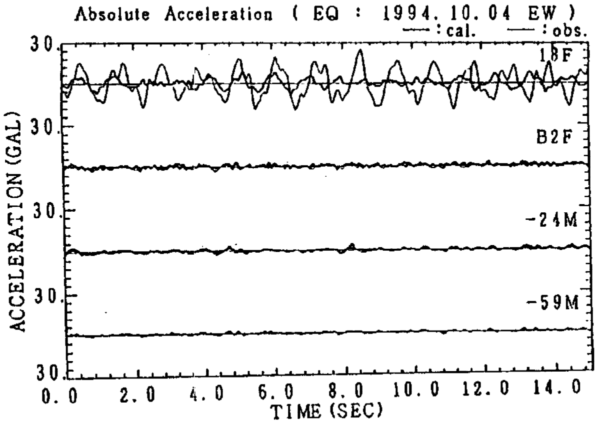
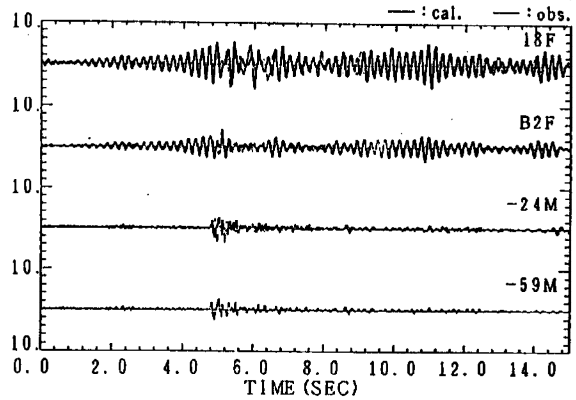
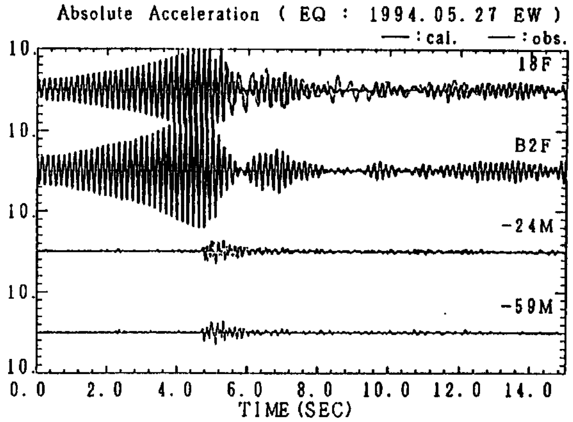


Absolute Acceleration (EQ : 1994. 10. 04 NS)

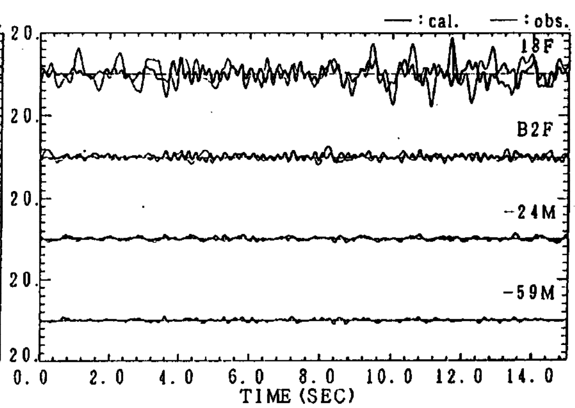
(b) Results by M1 model



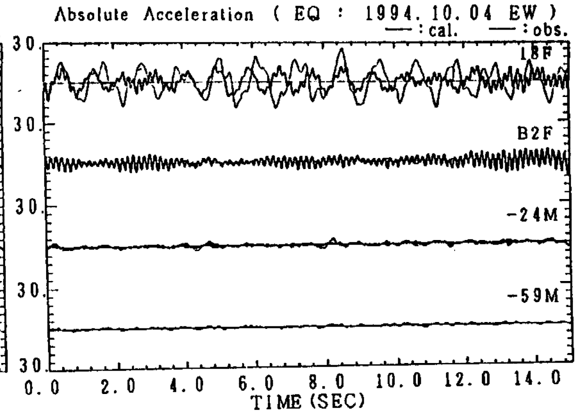
Absolute Acceleration (EQ : 1994. 05. 27 EW)



Absolute Acceleration (EQ : 1994. 05. 27 NS)



Absolute Acceleration (EQ : 1994. 10. 04 EW)



Absolute Acceleration (EQ : 1994. 10. 04 NS)

RESULTANT COMPARISON OF DATA WITH MEASURED

To find out the appropriateness of the computational analyses by the model M-2, comparative study on the same actual tall building as in the M-1 article by both analytical and experimental ways, and the effectiveness shown through results from M-2 is investigated in order to recognize the diferences clearly.

Exciting earthquake-waves given to the base-rock at GL-59m are listed in Table 2 , which were acquired during Feb.2 '92 to Oct.4 '94 by the measuring system installed as in Fig.2-c. These were seemingly rather small of their magnitude. Therefore the responding structural behaviours are thought to show the mechanical range from very incipient elastic stage including stiffness-effectiveness of all non-structural members to some elastic state without the above. Due to the elastic region mentioned above and the shape replacement of the basement to cylinder,results by M-2 seem to deviate somewhat from measured especially for N-S.

Their analytical maximum-values of the responded accelaration data concerning in both cases of M-2 and M-1 have been known not to show large differences. On one hand, when compared them with those measured, responded wave-shapes by the analytical two have generally shown some differences from the latter for the responses especially towards N-S direction rather than towards E-W. On the graphic detailed comparison of the wave-shapes observed between two analyses by both M-2 & M-1 and measured, those by M-2 and measured are tolerably alike in their general phase, meanwhile by M-1 have considerably different tendency as a whole, especially of beat waves in the responding part to P-waves till the main shock of S-waves which was improved in cases by M-2 (Fig.4).The reason of this is thought due to the condition with or without interactive reverberation of quake propagation between the rigid basement and the supporting soil-strata below.

CONCLUSION

The author emphsizes the degree of the consistent association, when made up of its model on this type of response-system consisted by three structural parts, governs the general phase on approximation of responded quake-data when compared with actual measurements. From this point of view, the results by the model M-2 described here is thought to be considerably satisfactory and appropriate,though there remain yet on the other side study-problems on the precise evaluation for the stiffnesses of the total structural system so as to cover responses to wide range of earthquake-level and on some proper modification method of the shape-replacement from the parallelepiped basement to circular cylinder.

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