CONVENTIONAL METHOD FOR ESTIMATING THE FLOOR RESPONSE PROPERTIES OF ELASTIC- AND ELASTO-PLASTIC SUB-STRUCTURE SYSTEMS

by

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SYNOPSIS

A practical,conventional method whereby earthquake response in sub-structure systems — pipings,tanks,electrical and mechanical equipments and other component systems — of industrial facilities such as nuclear and petro-chemical plants can be approximately estimated is presented and discussed.Results through this method are given by tabular forms and conventional smoothed curves for practical convenience.

INTRODUCTION

The importance of the appropriate aseismic design of various types of sub-structure systems,in particular,those in nuclear power facilities has been increasingly pointed out.Since the natural period and damping ratio for these sub-structure are variously distributed depending on the respective dynamic characteristics,the appearance of the overall convenient technique by which response properties can be approximately estimated is strongly requested.

This paper provides a conventional estimating method of the appendage sub-system response by using a simple coupled model.The results evaluated through the proposed technique are tabulated in a realistic fashion for practical convenience.It has been confirmed that this method can be applied not only for elastic structures but for some typical non-elastic sub-structure systems.

THE WORST FLOOR RESPONSE AMPLIFICATION FACTOR

First,maximum floor response in the "worst" or "least feasible" condition under which the first natural period of the appendage sub-system T_a coincides with that of the supporting structure T_s was calculated through response analysis technique by introducing a simple lumped mass model shown in Fig.1 in which the coupling effects between the main- and sub-system are actually considered

The floor response properties for the appendage sub-systems can be represented by proposed "WFRAF(worst floor response amplification factor)" taking mass ratio $\gamma = m_a/m_s$ and damping ratio for the appendage sub-system h_a parameter,

$$\mathrm{WFRAF}(\gamma, h_a) = \frac{\text{Envelope Response Spectrum}(\gamma\ ,\ h_a)}{\text{Appropriate Design Spectrum for Supporting Structure}(h_s)}$$

where envelope response spectrum means the spectrum which depicts the sub-system maximum response taking the first natural period under the condition $T_a = T_s$ as abscissa.In Fig.2 typical WFRAF curves with respect to acceleration response for 3 components of El Centro are shown.In these analyses h_s is fixed to 0.05.

Then,from a statistical investigation using 20 typical strong earthquake records as input,it could be found that these WFRAF values remain almost constant irrespective of variation of the natural period between 0.1s and 5.0s. The expected values and coefficient of variation(C.O.V.) for the WFRAF with respect to acceleration,velocity and displacement are regulated in Table 1.

Thus evaluated analytical results were compared with those through a statistical approach and fairly good agreement could be obtained.From this comparison the following conventional formula for estimating the WFRAF was presented;

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\left.\begin{array}{ll}
WFRAF_{Acc}(\gamma, h_a) = f_1(h_a)\exp\{-g_1(h_a)\cdot\sqrt{\gamma}\} & ;\ 0 \leqq \gamma \leqq 0.04 \\
\quad \begin{cases} f_1(h_a)=16.12\exp(-5.225\sqrt{h_a}),\ g_1(h_a)=10.30\exp(-9.59\sqrt{h_a}) & ;\ 0.01 \leqq h_a \leqq 0.09 \\ f_1(h_a)\ \ 4.33-11.2h_a,\ g_1(h_a)\ \ 0.90-3.52h_a & ;\ 0.09 < h_a \leqq 0.2 \end{cases} & \\
WFRAF_{Acc}(\gamma, h_a) = f_2(h_a) - g_2(h_a)\cdot\gamma & ;\ 0.04 < \gamma \leqq 0.1 \\
\quad f_2(h_a) = 62.23h_a^2 - 27.97h_a + 5.15,\ g_2(h_a) = 516.7h_a^2 - 197.0h_a + 20.53 &
\end{array}\right\} \quad (1)
$$

Fig.3 shows comparison of the expected WFRAF between the results through above mentioned analysis and those calculated from equations (1).Both results seem to quite agree with each other.

GENERALIZATION OF THE METHOD TO MORE ACTUAL CASES

From an aseismic viewpoint the natural periods of the actual sub-systems should be practically designed not to coincide with that of the supporting structure.Therefore it would be necessary to make this method applicable to more actual cases.For this general cases the authors propose to introduce generalized "floor response amplification factor(FRAF)" determined by relation

$$FRAF(\gamma, h_a, T_a/T_s) = C\cdot WFRAF(\gamma, h_a) \quad (2)$$

where coefficient C indicates the modification factor which involves the effect of γ , h_a and T_a/T_s .Then it has become very important to investigate the statistical characteristics with respect to the coefficient C .As a result of the response analysis using 20 earthquake inputs the expected values of these coefficients were obtained.In Table 2 thus evaluated C with respect to acceleration and displacement are regulated for fixed γ ,taking h_a as parameter.

Using these C values the fundamental response properties of the appendage sub-system can easily calculated.Fig.4 shows a tripartite response diagram from which the FRAF w.r.t. the acceleration,velocity and displacement can be immediately available.

APPLICATION TO NON-ELASTIC SUB-STRUCTURE

If the structure is subjected to destructive earthquake motions,its response would frequently behave nonelastically.From this viewpoint it might be requested that the method could be used for a nonlinear sub-systems. Then the method was applied for the perfectly-elasto-plastic model.In this model the yielding force f has to be also taken as parameter which is given by

$$f = \alpha\cdot\omega_a^2 |z_a|_{max} \ ; \ z_a = \{x_a - x_s\}_{elastic} \quad (3)$$

where α is a parameter which represents the yielding effect.As shown in Fig.5, $\alpha = 0.7$ and $\alpha = 0.3$ are selected as typical values corresponding to the second and third yield levels of the sub-system while $\alpha = 1.0$ is the first level to linear elastic system.In these cases analysis was performed by using 20 artificial earthquake motions which were generated by Tajimi's idea mainly based on stationary random process theory.

Results are shown in Table 3 where β means the ratio of the elasto-plastic sub-system response to the elastic one.It is seen from this table that the expected values of β w.r.t. acceleration seem to be credible for use since C.O.V. values are quite small. However,for velocity and displacement response applicability was restricted because β fluctuates considerably depending on input characteristics,in particular,for the model of $\alpha = 0.3$. Similar results were obtained through the analysis with real earthquake motions as shown in Table 4.

ACKNOWLEDGEMENTS

The authors would like to express their sincere thanks to Professor H.Sato at the University of Tokyo for his fruitful suggestions and advices.

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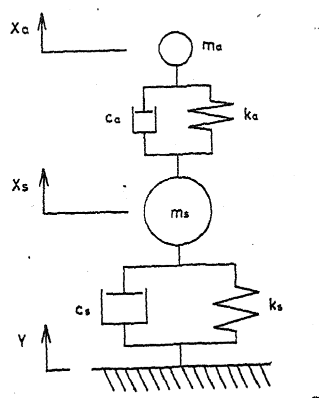

Fig 1 Simple Coupled Model

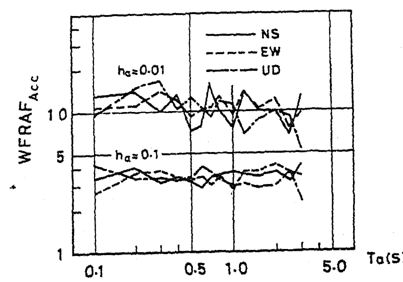

Fig.2 WFRAF w.r.t.Acceleration
(El Centro ,γ = 0)

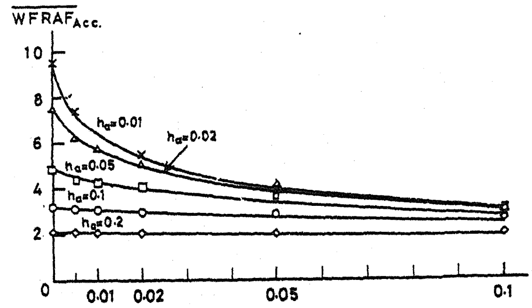

Fig.3 Expected WFRAF compared with Eqs.(1)

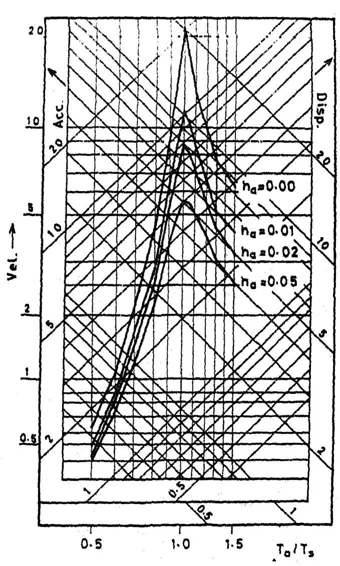

Fig.4 Tripartite Diagram for
Estimating FRAF (γ = 0)

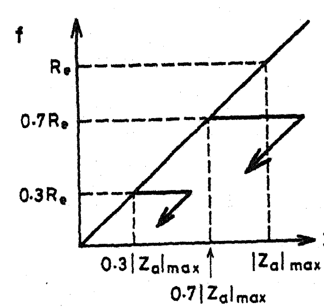

Fig.5 Yield Level for P.E.P.
Model (R_e= Max.Elast.Rest.Force)

γ \ h_a		WFRAF				C.O.V. of WFRAF			
		0.01	0.02	0.1	0.2	0.01	0.02	0.1	0.2
Acceleration	0	9.56	7.48	3.21	2.09	0.169	0.137	0.089	0.045
	0.005	7.37	6.31	3.12	2.07	0.132	0.126	0.102	0.078
	0.01	6.44	5.73	3.04	2.05	0.134	0.131	0.102	0.077
	0.02	5.35	4.94	2.94	2.03	0.132	0.132	0.104	0.078
	0.05	3.93	3.78	2.68	1.96	0.115	0.115	0.109	0.082
	0.1	3.00	2.94	2.38	1.87	0.115	0.116	0.099	0.077
Velocity	0	10.16	7.94	3.44	2.26	0.191	0.163	0.104	0.088
	0.005	7.80	6.71	3.35	2.25	0.147	0.140	0.106	0.089
	0.01	6.79	6.04	3.26	2.23	0.134	0.132	0.104	0.088
	0.02	5.69	5.25	3.16	2.21	0.123	0.124	0.107	0.090
	0.05	4.14	4.00	2.88	2.15	0.100	0.104	0.102	0.090
	0.1	3.21	3.14	2.58	2.07	0.084	0.088	0.100	0.092
Displacement	0	9.83	7.75	3.53	2.41	0.195	0.132	0.083	0.073
	0.005	7.63	6.60	3.45	2.41	0.121	0.114	0.080	0.052
	0.01	6.72	6.03	3.39	2.40	0.120	0.116	0.094	0.051
	0.02	5.63	5.25	3.29	2.38	0.118	0.116	0.080	0.052
	0.05	4.20	4.07	3.05	2.35	0.093	0.094	0.083	0.054
	0.1	3.28	3.23	2.76	2.28	0.088	0.087	0.072	0.053

Table 1 Expected Values and Coefficients of Variance of the WFRAF

T_a/T_s \ γ	Acceleration			Displacement		
	0.0	0.005	0.01	0.0	0.005	0.01
0.50	0.142	0.195	0.228	0.038	0.049	0.058
0.60	0.182	0.248	0.288	0.065	0.089	0.105
0.70	0.247	0.332	0.385	0.121	0.163	0.189
0.80	0.356	0.467	0.527	0.228	0.297	0.335
0.85	0.456	0.578	0.646	0.329	0.417	0.463
0.90	0.613	0.773	0.784	0.497	0.594	0.635
0.95	0.770	0.869	0.898	0.703	0.783	0.813
1.00	1.000	1.000	1.000	1.000	1.000	1.000
1.05	0.853	0.959	1.012	0.940	1.072	0.126
1.10	0.681	0.830	0.904	0.812	1.016	1.111
1.20	0.462	0.613	0.700	0.666	0.895	1.030
1.30	0.339	0.461	0.536	0.573	0.790	0.993
1.50	0.249	0.339	0.398	0.553	0.769	0.914
1.70	0.200	0.276	0.325	0.559	0.807	0.958
1.80	0.184	0.252	0.297	0.595	0.827	0.981
2.00	0.152	0.210	0.248	0.608	0.846	1.001

Table 2 Estimated Values of Modification Factor C (h_a = 0.01)

	T_a/T_s	E[β]		C.O.V.	
		α=0.7	α=0.3	α=0.7	α=0.3
Acc.	0.5	0.79	0.41	0.047	0.033
	1.0	0.72	0.32	0.004	0.007
	2.0	0.72	0.32	0.009	0.018
Vel.	0.5	1.60	2.70	0.177	0.138
	1.0	0.74	0.36	0.017	0.042
	2.0	0.83	0.53	0.099	0.109
Disp.	0.5	2.51	8.02	0.276	0.359
	1.0	0.75	0.41	0.013	0.122
	2.0	1.03	1.05	0.097	0.266

Table 3 Expected Value and C.O.V. of β for Nonelastic Model

	T_a/T_s	(a)		(b)	
		α=0.7	α=0.3	α=0.7	α=0.3
Acc.	0.5	0.76	0.40	0.80	0.39
	1.0	0.71	0.31	0.71	0.32
	2.0	0.73	0.32	0.74	0.34
Vel.	0.5	2.11	3.71	1.07	2.33
	1.0	0.75	0.36	0.73	0.37
	2.0	0.95	0.53	1.00	0.77
Disp.	0.5	3.22	9.97	1.71	5.20
	1.0	0.75	0.40	0.76	0.44
	2.0	0.91	0.93	1.11	1.26

Table 4 Expected values by Earthquake Records
(a); Tokachi-oki,1968
(b); El Centro,1940