SEISMIC ANALYSIS AND DESIGN OF HUGE BLAST FURNACES

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SUMMARY

This study aims at revealing the seismic behavior of huge blast furnace structures and developing their rational aseismic design consideration. The investigations are based on the earthquake observation data at the existing structures as well as on the theoretical simulation. The substructure method of analysis is used to advantage for the effective three dimensional analysis with emphasis on the soil structure interaction. The concluding remarks are derived regarding the horizontal seismic force distribution between furnace and its supporting structure, and the plastic effect on top structural behavior.

INTRODUCTION

The furnace structures to be dealt with are illustrated in Fig.1. More specifically, they comprise the furnace, the supporting structure, the top structure and the pipings. The bracket-supporting type furnaces are the most common in Japan, which has three partionings in order to avoid an excessive thermal stresses; namely, the upper and mid parts supported by the brackets from the supporting structure and the self-supporting bottom part.

The two structural models for the present analysis are located at the Ogishima reclaimed island in Tokyo Bay. Both furnace structures have almost the same superstructures in size but are different at the foundation types. One is on a large caisson foundation (31.5m x 31.5m x 55.6m), which is denoted by the No.1 furnace herein; the other is on a grouped piles (361 piles of 914.4ϕ x 16t x 66m), which is denoted by the No.2 furnace.

In the previous paper(Refs.1,2), the authors have reported some on the dynamic characteristics of such structures based on the earthquake observation data as well as on the computer simulation. The present paper constitutes the succeeding one so that the interest of investigation is placed on the followings from their aseismic design point of view.

(1) The seismic wave characteristics at the site
(2) The dynamic interaction between the soil, the foundation and the superstructure
(3) The dynamic interaction between the furnace and the supporting structure
(4) The effect of the plastic behavior on response at the superstructure

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EARTHQUAKE OBSERVATION

In order to reveal the seismic behavior of blast furnace structures and get the useful knowledge for their aseismic design, the earthquake observation has been performed since 1976 at the aforementioned structures with 19 measurement points (48 channels for recordings) as indicated in Fig.1. The measurement system is set to start recording once the soil acceleration exceeds the trigger level of 1 gal at the pick up 2P9Z. Table 1 summerizes the earthquake records obtained so far. Fig.2 shows their time histories.

Through the analysis of maximum distribution and spectral densities of the accelerograms, the following remarks result:

(1) Long period waves more than 5 seconds are detected at the latter phase of Kawanazaki-oki earthquake record of oscillational type with far epicenter. On the other hand, at the initial phase of Chibaken Chubu earthquake record, which is rather classified as an impulsive type, predominant frequency contents are narrowed at 1.5Hz ∿ 4Hz range. (see Figs.2,5)

(2) The soil response beneath the caisson foundation has a tendency of being less pronounced than that beneath the pile foundation due to the relevant kinematic interaction (see Fig.3)

(3) The pile foundation of No.2 furnace tends to indicate the greater response than the caisson foundation of No.1 furnace (see Fig.3).

(4) The caisson foundation, being rather rigid for the superstructure, gives rise to this more whipping effect, while the pile foundation, being flexible, does less (see Fig.3).

(5) A relatively wider range frequency contents are noted in the response of the No.2 furnace, which means the more higher vibration modes are contributing to the response; however, rather narrow frequency contents are dominant at the No.1 furnace response (see Fig.4).

(6) Both the No.1 and No.2 furnaces indicate almost identical predominant frequencies; 1.3 Hz in the x-direction (in-plane) and 0.8 Hz in the y-direction (out-of-plane). Since these vibration modes are reflected on the response of top structure, the coupling of sway and torsional modes becomes important (see Fig.4).

DYNAMIC SUBSTRUCTURE METHOD

An efficient three dimensional finite element method of analysis is developed by applying the substructure technique (Ref.3). Namely, the soil-foundation part is formulated as an axisymmetric body and the superstructural part as a general three dimensional lumped mass system. Integrating those parts into a coupled system is made through the compatibility and equilibrium at their interface. The flow of earthquake response simulation is given in a block diagram in Fig.6.

<u>Far Field Modeling</u>: The layered soils are assumed whose properties are determined based on the field boring test data. Further subdividing of the layers is made for the finite element modeling as to satisfy the shear wave propagation in the frequency range of interest that results in 12 layers above the rigid base at which the input earthquake motions are assigned. The internal soil damping is presumed as hysteretic type which gives 0.1

for the upper 5 layers and 0.05 for the lower 7 layers.

Far Field Elements: In order to represent the semi-infinite soil region in the horizontal direction, the so-called transmitting boundary (Ref.4) is introduced at the side boundary of the finite element near field region.

Sub-system Modeling: The near field that surrounds the foundation is bounded by the far field elements at side and underlain by the rigid base at bottom. Axisymmetric modeling for the above region allows the Fourier series expansion for the original three dimensional motion in the circumferential direction. Since each Fourier harmonic represents the respective vibration mode, the appropriate term or terms are adopted depending on the motion considered.

The isoparametric finite element formulation is taken for discretizing the near field. The interface substructuring approach is used for the analysis of the caisson foundation as a rigid body (see Fig.7). The pile foundation is dealt with from the interbody substructuring concept with relaxed compatibility condition between solid and beam elements. The original 361 piles arrangement is replaced by an equivalent 49 piles on the concentric rings from the computational convenience (see Fig.7). For both types of foundations, the sub-system (soil-foundation system) impedances are evaluated at the foundation gravity center and also the corresponding driving seismic force at the same point (the effective seismic input). The condensation process is carried out for this purpose from the Gauss elimination operation. Fig. 8 shows thus obtained impedance functions.

Super-system Modeling: The superstructure is partitioned into the several units. Both the stiffness matrix and the constraint force matrix for each unit are computed through the conventional three dimensional matrix method. All the units are joined by releasing the constraint forces at their junction points, and condensed from the Guyan reduction method to obtain the stiffness matrix for the lumped mass system modeling. The total degrees of freedom thus result in 105 (Ref.5).

The normal modes decomposition is made for the fixed base condition. Among them only the significant lower modes are used by truncating less significant higher ones, together with the displacement influence functions to evaluate the superstructural response when it is coupled with the subsystem impedance for the effective seismic input. Herein, the first 20 normal modes are selected for the interaction analysis with damping factor 0.02 of the respective critical value.

Numerical Results: Fig.9 shows the transfer functions of the interaction system for the rigid base motion. The No.1 furnace gives the greater amplification at the top structure than the No.2 furnace, while that at the foundation is in reverse. In Fig.10 the response Fourier spectral densities are compared between the observed and the computed accelerations. The Fast Fourier algorithm converts these into the time histories as shown in Fig.11 in which a good agreement is attained between them.

ASEISMIC DESIGN METHOD

For the design of present two furnace structures, the so-called seismic coefficient method was taken such that the seismic coefficient is

0.2 for the elevation up to 16m high for the lateral seismic force distribution and is increased by 0.01 at every 4m up. The seismic forces acting at the upper and mid parts of the furnace are presumed to be resisted by the supporting structure in turn. Note from Fig.3 that the more rational seismic force distribution may be determined against the above conventional one. The present analysis is suggesting that the 35∿50 percent of the total seismic force is distributed to the furnace and the remaining to the supporting structure (see Table 2).

Furthermore, the effect of the plastic behavior of the top structure is investigated by using the equivalent stiffness and damping ratio for the concerned structural part. The results from the parametric study are shown in Fig.12. Note that when the top structure deforms up to 1.5 times the ductility factor, the response is reduced to 1/3 of the elastic deformation, dimishing the whipping effect.

CONCLUSIONS

Concerning the huge blast furnaces, the seismic analyses have been carried out from both the earthquake observation and the computer simulation. The findings are summerized as below:

(1)The seismic wave characteristics at the site are greatly reflected by the distance from the epicenter. Accordingly, the structural response features are different depending on the earthquakes whether they are oscillational type or impulsive type.

(2)The spectral analysis of the observed responses indicates that the coupling of the sway and the torsional motions is substantial which makes it imperative to carry out the three dimensional analysis.

(3)The effective dynamic substructure method is devopled which is based on the axisymmetric modeling for the soil and foundation part, and the general three dimensional formulation for the superstructure. The advantage of this approach lies in that either the computed results for sub-system or superstructure are ready to be used for the analysis of the modified system at the either part.

(4)The rational seismic force distribution is such determined that the 35∿50 percent of the total forces goes to the furnace and the remaining to the supporting structure.

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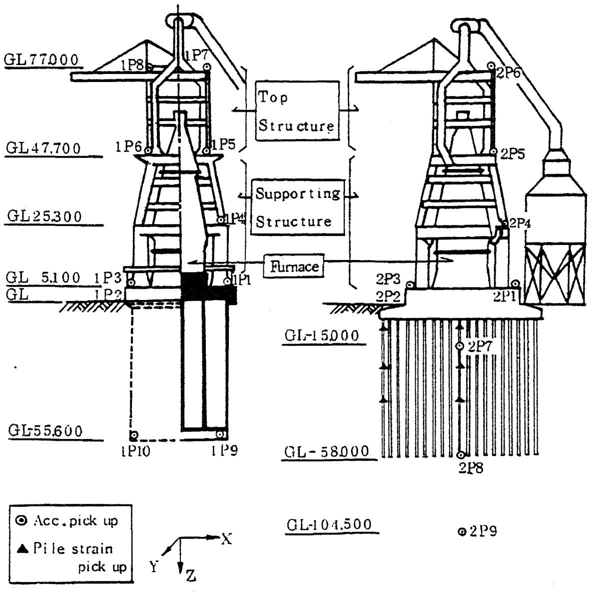


(a) No.1 Blast Furnace (b) No.2 Blast Furnace

Fig.1 General View of Structures.

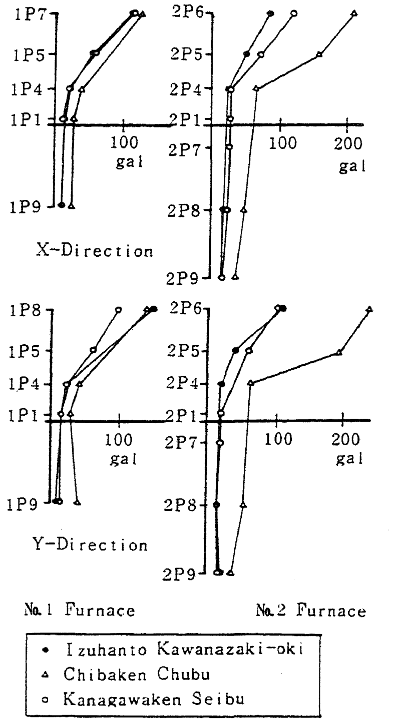


Fig.3 Maximum Response Accelerations.

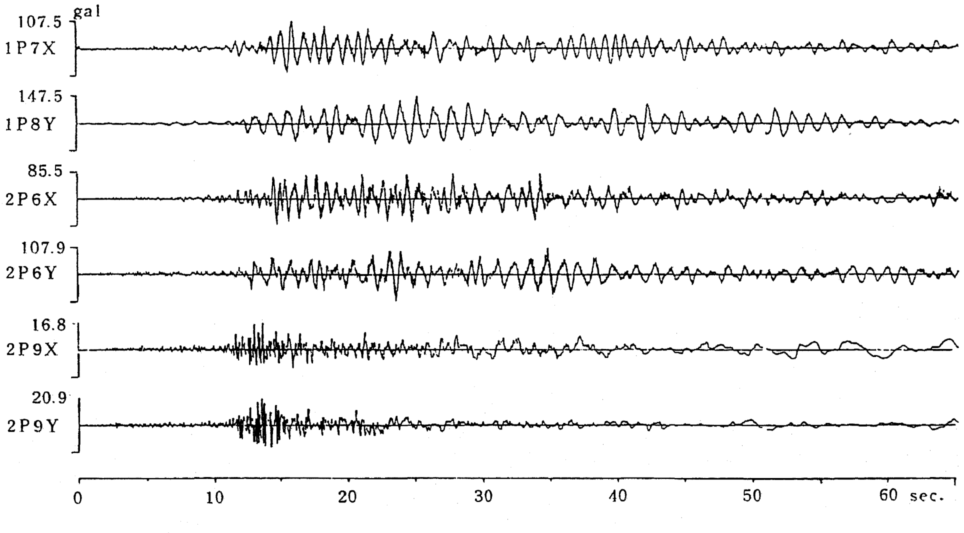


Fig.2 (a) Observed Accelerograms,
Izuhanto Kawanazaki-oki Earthquake, 1980. 6. 29.

Table 1. Features of Observed Earthquakes.

Earthquakes	Date	Intensity*		M	Epcientral distance	Depth
		Tokyo	Yokohama			
Izuhanto Kawanazaki-oki	1980. 6. 29	4	4	6. 7	80 Km	10 Km
Chibaken Chubu	1980. 9. 25	4	4	6. 1	40	80
Kanagawaken Seibu	1983. 8. 8	4	4	6. 0	60	20

*J.M.A. scale

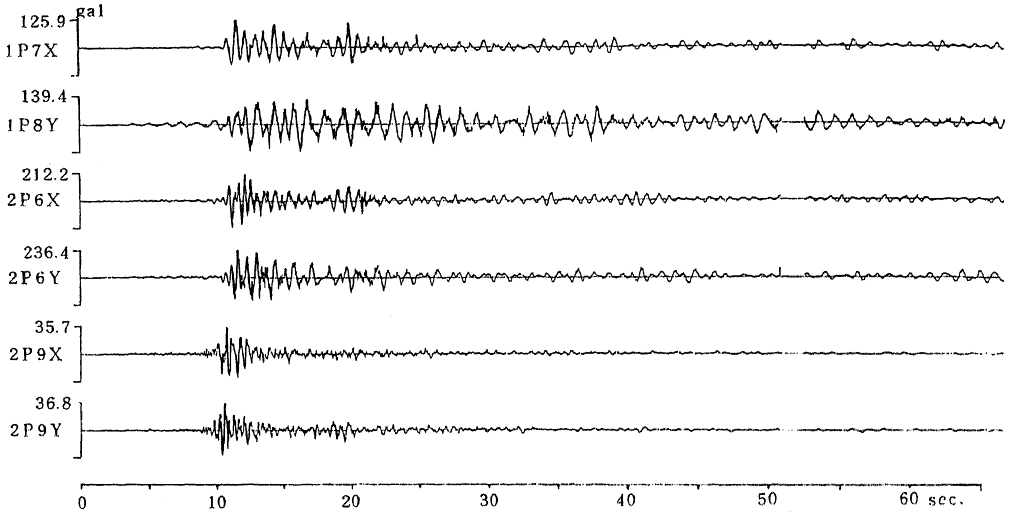


Fig.2(b) Observed Accelerograms, Chibaken Chubu Earthquake, 1980. 9. 25.

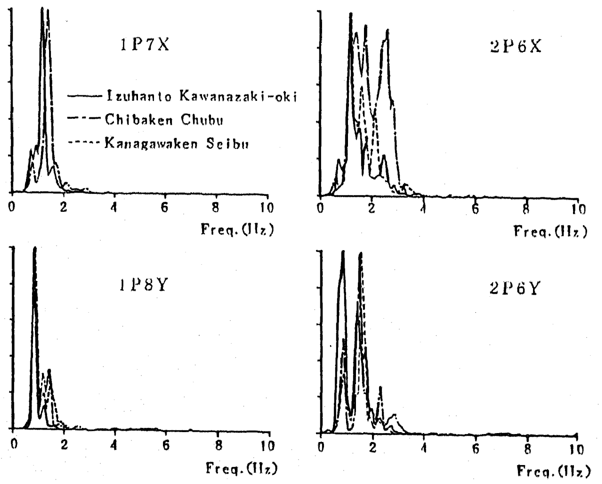


Fig.4 Normalized Power Spectral Densities.

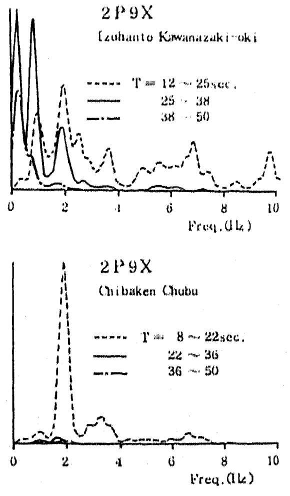


Fig.5 Normalized Running Spectral Densities.

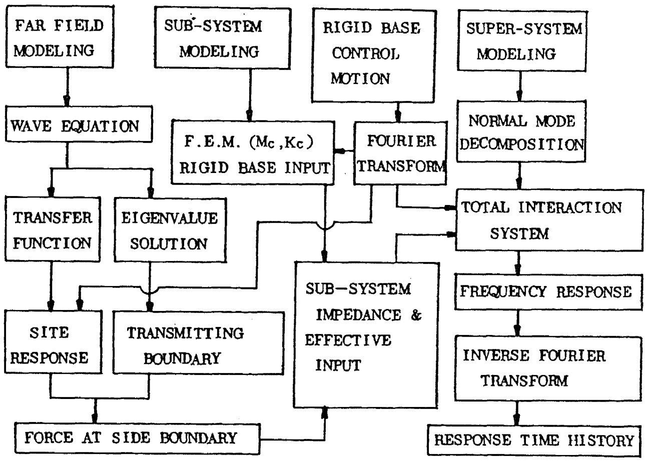


Fig.6 Flow for Simulation.

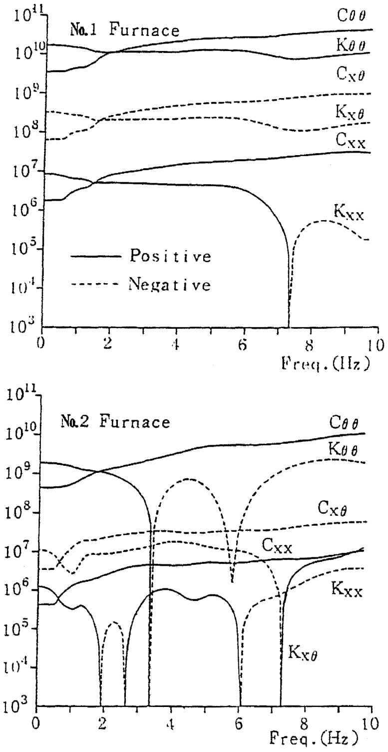


Fig.8 Calculated Sub-System Impedance.

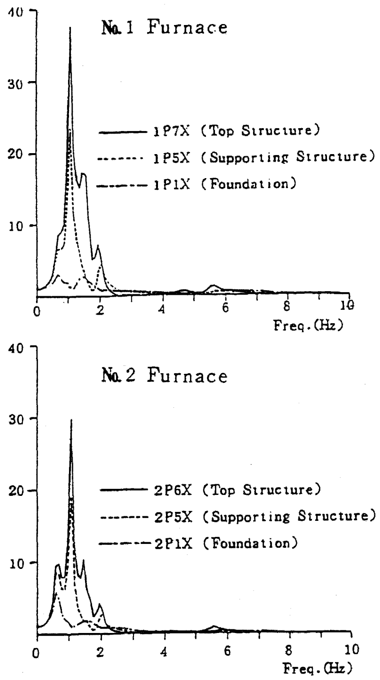
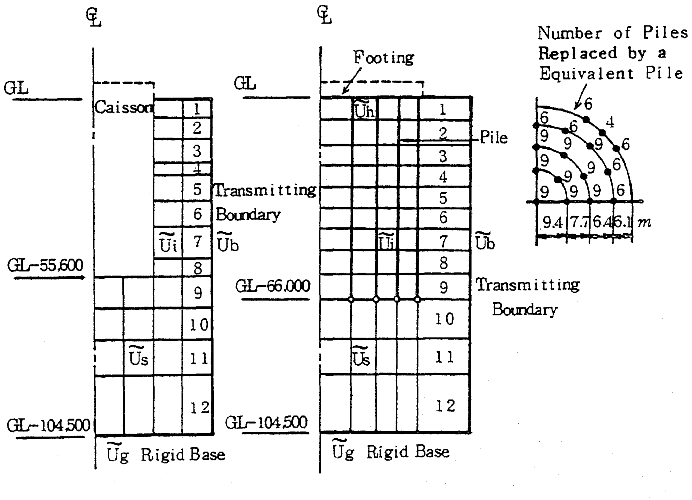


Fig.9 Calculated Transfer Functions.



No.1 Furnace No.2 Furnace

Fig.7 Simulation Models of Sub-Systems.

Table 2. Distribution of Horizontal Seismic Force (No.2 Furnace).

		Supporting Structure		Furnace	
		Force(ton)	Ratio(%)	Force(ton)	Ratio(%)
Izuhanto Kawanazaki-oki	X	352.7	65	193.9	35
	Y	308.8	53	272.7	47
Chibaken Chubu	X	390.3	56	302.1	44
	Y	492.6	51	478.2	49
Average			56		44

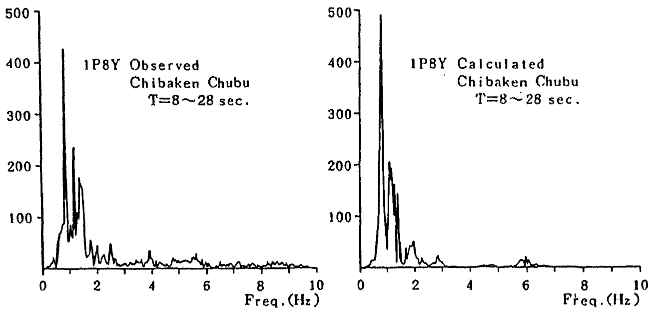


Fig.10 Fourier Spectral Densities.

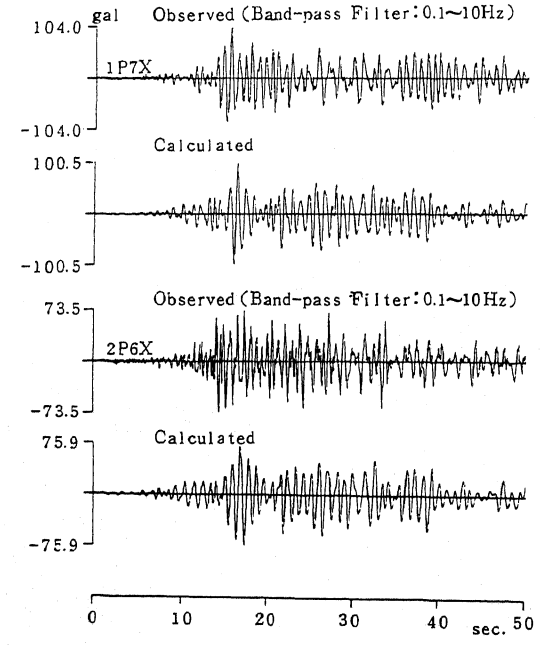


Fig.11 Response Time Histories, Acceleration, Izuhanto Kawanazaki-oki.

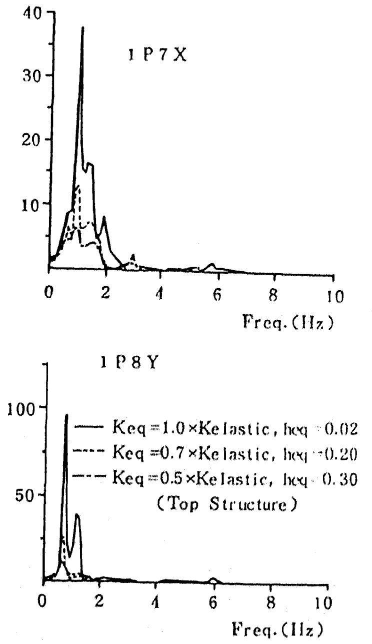


Fig.12 Transfer Functions, Top Structure/Rigid Base.