DYNAMIC BEHAVIOR OF A LARGE-SCALE BLAST FURNACE DURING EARTHQUAKES

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SUMMARY

Dynamic behavior of a large-scale blast furnace was investigated through earthquake observations and forced vibration tests. As the results the distribution of maximum acceleration in each level, natural periods, mode shapes, and damping ratios were obtained. The space structure model which approximately explains the observed dynamic properties was introduced, and the share ratio of lateral force between the supporting structure and the furnace was theoretically calculated.

INTRODUCTION

At the new steel-works in Ohgishima which is man-made island located in Tokyo Bay, No.1 and No.2 blast furnaces were constructed in 1976 and 1979 respectively with a caisson(No.1) or piles(No.2) as foundation. Their height is up to 100 m and the weight of upper structure is over 20,000 tons.

The main problems on aseismic design of such large-scale blast furnace are as followings:

1) Dynamic properties of a huge foundation which supports a heavy structure.
2) Dynamic interaction between the square tower and the furnace, for example the share ratio of lateral force caused during earthquakes.

STRUCTURE

Outline of No.1 blast furnace in Ohgishima is shown in "Fig.1". It is composed of furnace, supporting structure called square tower, top structure , and pipings. The furnace is partitioned into three parts and connected with expansion joints in order to avoid excessive thermal stresses. The lower part is self-standing and the mid and the upper parts are supported by brackets from the square tower as shown in "Fig.1". These structures are constructed on a caisson of 31.5 x 31.5 x 55.6 m. While in No.2 blast furnace, almost the same structures are supported by 361 piles of 914.4 ϕ x 16 t x 66 m.

EARTHQUAKE OBSERVATION

In order to clarify above mentioned problems, the earthquake observation on No.1 blast furnace has been continued since November 1976. The servo-type seismographs with 24 channels were installed in the structures as shown in "Fig.1". And up to now, the response waves during several earthquakes features of which were tabulated in "Table 1" were successfully recorded, and following significant results were obtained.

1) With respect to the distribution of maximum acceleration in each level, little magnification is recognized between below and on the

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caisson. While the magnification factor of upper structure becomes large up to over 10 showing whipping behavior.(Fig.2)

2) From power spectra shown in "Fig.3", the natural periods of No.1 blast furnace are estimated to be 1.25 and 0.78 sec. and so on.

3) For long-period (5-7 sec.) ground motion observed during Izu-oshima -kinkai Earthquake, the blast furnace moves swaying almost uniformly from the caisson to the top of the structure.(Fig.4)

4) For short-period (0.5-2 sec.) ground motion observed during Miyagi-ken-oki Earthquake, natural vibration are apt to be excited especially on the top portion of the structure.(Fig.5)

THEORETICAL ANALYSIS

To study theoretically the above mentioned results, the blast furnace was substituted to the space structure model considering the dynamic interaction among the furnace, surrounding soil, caisson or piles, square tower, and pipings. Results of free vibration analysis were shown in "Fig.6" and tabulated in "Table 2" together with the results of earthquake observation and of forced vibration tests which were performed by using unbalanced mass type vibrator. Coupling motion of sway and torsion should be emphasized in the 1-st and 3-rd normal modes, which is also implied from the power spectra of the observed response waves.

In simulation analysis, the damping ratios of 5 % in furnace and 2 % in structural element was assumed and the stiffness was made high up considering the effects of secondary members. The calculated waves of upper structure to the inputs of caisson waves which were determined by least-square error method using 11 waves of below and on the caisson, were compared with observed waves as shown in "Fig.7". Generally a good agreement was obtained, and using this model the share ratio of lateral force between the square tower and the furnace was theoretically calculated.

CONCLUSIONS

1) Because the top structure is more flexible compared with the square tower, the magnification factor of the top structure becomes large showing whipping behavior.

2) In the dynamic behavior of the blast furnace, coupling motion of sway and torsion was significant, therefore space structure model analysis should be required.

3) Using this model, the share ratio of lateral force caused during earthquake was calculated and resulted in about 40 % in the furnace and 60 % in the supporting structure.

Above conclusions are obtained from rather moderate earthquakes. The responses fcr strong earthquakes, particularly magnification of top structure , will be restricted due to the effects of the plastic deformation of steel structure, then the authors now continue further studies concerning to the plastic behaviors of the blast furnaces subjected to destructive earthquakes.

ACKNOWLEDGEMENTS

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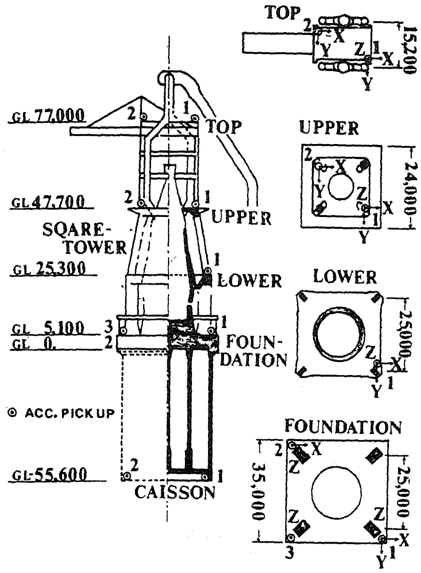


Fig.1 Outline of No.1 blast furnace

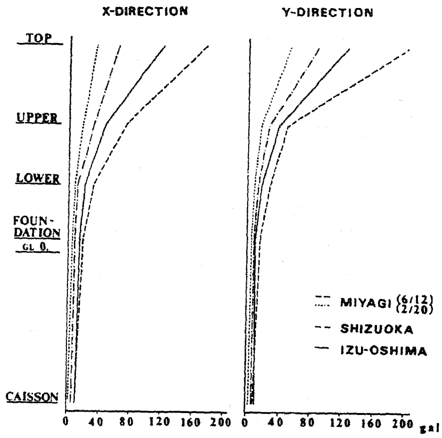
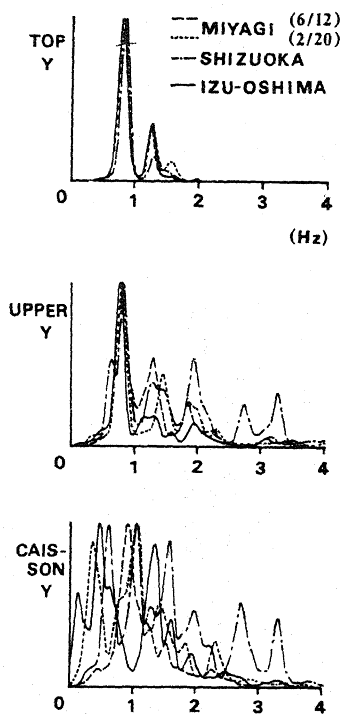


Fig.2 Distribution of maximum acceleration

Table 1 Features of the observed earthquakes

Earthquakes	date	M	Intensity scale		epicentral distance	depth (km)
			Tokyo	Yokohama		
Izu-oshima-kinkai	1978, 1, 14	7.0	4	5	90 km	0
Miyagi-ken-oki	1978, 2, 20	6.7	3	3	420	50
Shizuoka-ken-okiai	1978, 3, 7	(7.0)	3	3	450	440
Miyagi-ken-oki	1978, 6, 12	7.4	4	4	370	40

J.M.A. scale



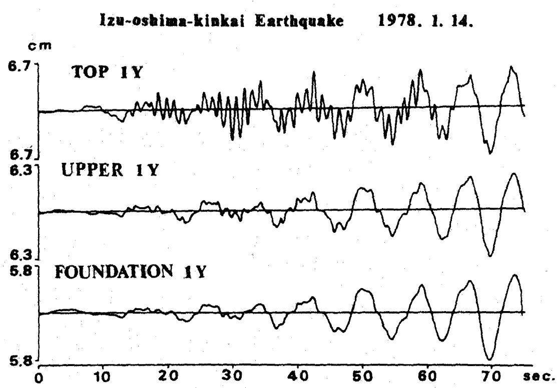


Fig.4 Observed displacement response waves

Fig.3 Power spectra

Table 2 Dynamic properties of the blast furnaces

BLAST FURNACE		1-st mode period (sec.)	1-st mode shape (damping)	2-nd mode period (sec.)	2-nd mode shape (damping)	3-rd mode period (sec.)	3-rd mode shape (damping)
NO.1	observed	1.25	sway in Y-direction + torsion (1.32%)	(0.92)	sway in X-direction (1.17%)	0.78	torsion (1.37%)
	calculated*	1.41		1.04		0.87	
NO.2	observed	1.14		0.74		0.63	
	tested	1.09		0.75		0.69	
	calculated*	1.41		1.05		0.87	

* fixed base

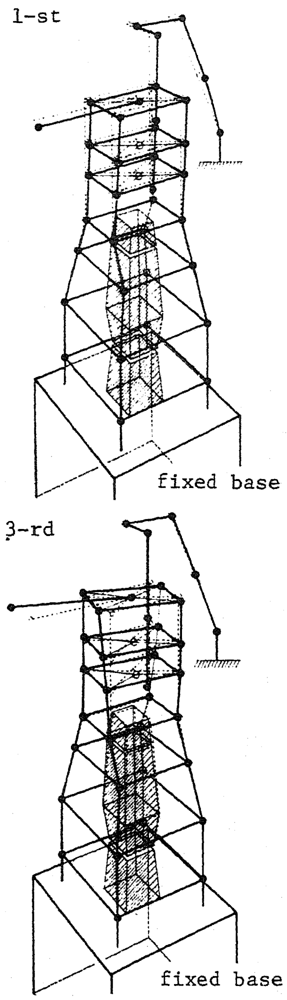


Fig.6 Normal modes of No.1 blast furnace

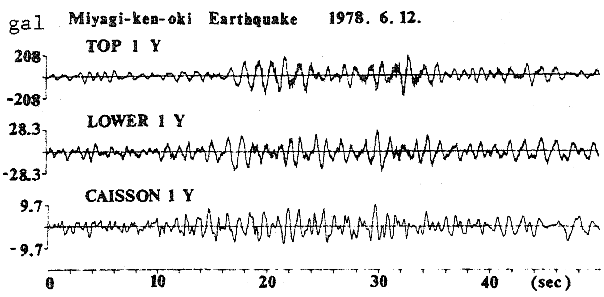


Fig.5 Observed acceleration response waves

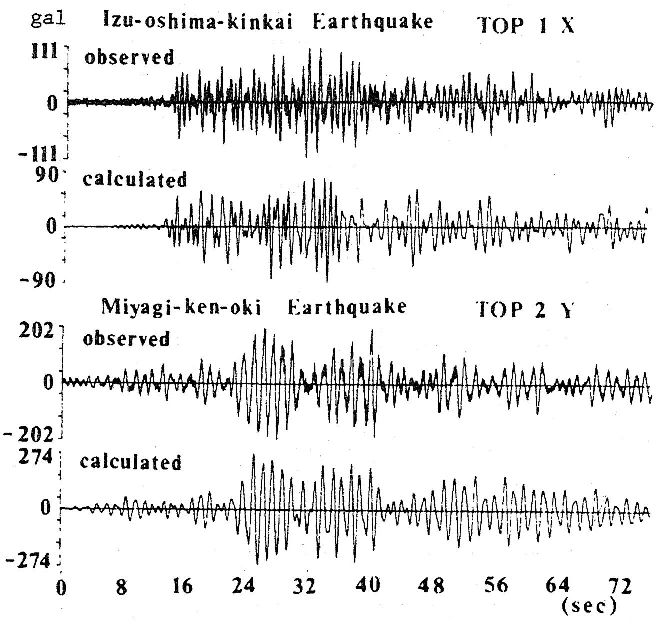


Fig.7 Comparison of observed and calculated acceleration waves