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Travelling wave effects on a tall and narrow shape building based on observed data

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ABSTRUCT: The dynamic response of tall and narrow shape buildings is complicated, since the response of those buildings is affected by the spatial variance of seismic ground motions and by the torsional modes often stimulated in them. The purpose of this paper is to investigate the dynamic response of a tall and narrow shape building due to the traveling shear waves. Based on both the results of earthquake observations and the analyses, it was comfirmed that the traveling wave effects varies depending on the frequency characteristics of seismic wave, the epicentral distance and the incident direction.

1 INTRODUCTION

Turbine buildings of thermal power plants, recently constructed in Japan have generally two or four turbine units jointed together. Since each turbine unit has the length of about 80 meters, the building shape usually becomes long and narrow in the long direction about 160 or 320 meters, and in the short direction about 40 meters.

We have studied the vibrational characteristics of such a long and narrow turbine building, from a viewpoint of traveling wave effects, based on earthquake observations and analyses. One of the traveling wave effects is to cause the building a torsional motion (REF 2). The others are to cause the foundation an elastic deformation, and a self-cancelling effect(REF 3).

In this paper, we put a focus on the combined effects between the traveling wave effects and the earthquake properties, featured by the magnitude, epicentral distance and the incident direction.

2 TURBINE BUILDING AND SITE CONDITION

The turbine building is a four-story steel structure. Its plan dimension is 40m by 343m with the height of 30m. The whole plan and typical section of the turbine building are shown in Figs. 1 and 2. Fig. 3 shows the properties of subsurface soil layers. The layer below GL-80m is regarded as a bedrock, because it is so stiff with the velocity of shear wave Vs=2km/sec. The layers above the bedrock have shear wave velocities of about 300m/sec on the average. A transfer function from the bedrock to the ground surface shows the peaks at 1.1, 2.9, 5.1 and 7.0 Hz.

3 EARTHQUAKE OBSERVATION

3.1 Outline of earthquake observation

Four earthquake motions were recorded from 1988 to 1990, and the locations and magnitudes are shown in Fig. 4 and Table 1. The setup of the accelerometers is shown in Fig. 2.

On Point B, accelerometers were installed in

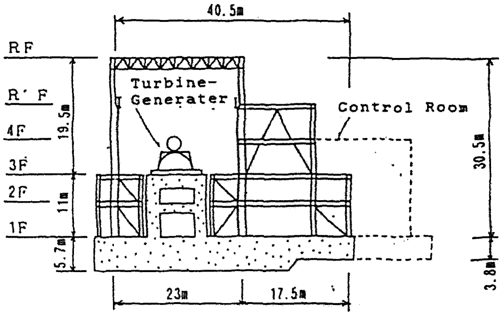


Fig. 1. Typical section of turbine building

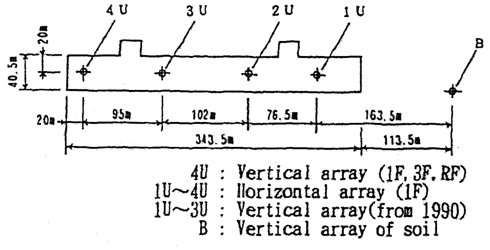


Fig. 2. Plan of turbine building and setup of accelerometers

the subsurface soil layers as a vertical array. On Points 1U to 4U, accelerometers were installed in the building as a horizontal array, and as a vertical array(from 1990).

In this paper , we restrict a discussion to the vibrational components in the short direction of the turbine building.

3.2 Characteristics of input waves

Those four earthquakes caused obviously different influences to the responces of structure regarding the traveling wave effects.

Firstly, as shown in Fig. 6, the waves of EQ-1 and 2 have relatively higher frequency components than other two waves, because of their short epicentral distances or small magnitude.

Secondly, as shown in Fig. 7 , angles of epicenter directions from turbine house axis are different from one another. The angle for EQ-1 is much smaller than others. And the one for EQ-2 is almost right angled.

Thirdly, as shown in Table 2, the time-lags of input waves of the foundations are different from one another. The time-lags of EQ-1 show that the wave traveled along the reverse direction to the others(Fig. 7). Using the relation between the time-lag and the incident angle(Fig. 5) , other incident angles of the earthquakes are calculated as in Table 3. The small angle of EQ-1 suggests a very short epicentral distance. On the contrary , the small angle of EQ-2 shows that the traveling wave effects were not likely to occcur, because the angles of epicentral directions from the turbine house axis is almost right angle.

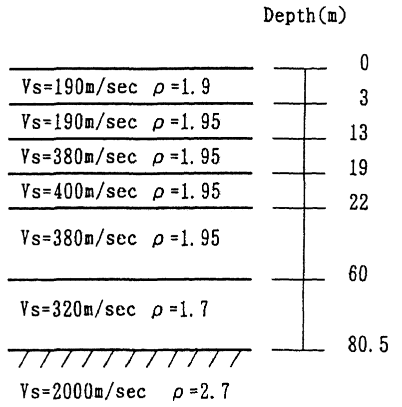


Fig. 3. Physical constants of soil layers

Table 2. Time-lag observed (Unit:sec)

	4U→3U	3U→2U	2U→1U	4U→1U	3U→1U
EQ-1		-0.02	0.00		-0.02
EQ-2		0.01	0.02		0.02
EQ-3	0.02	0.02	0.03	0.07	
EQ-4	0.01	0.01	0.03	0.05	

3.3 Observed traveling wave effects

An analysis of the maximum accelerations at the foundation , which were recorded in the four earthquakes(Table 4) , reveals the traveling wave effects.

Firstly , in all cases , the input loss of earthquake motion at the foundation exists. Especilly , the input loss of EQ-1 is larger than others , because of its high frequency components in input , as alredy described in section 3.2.

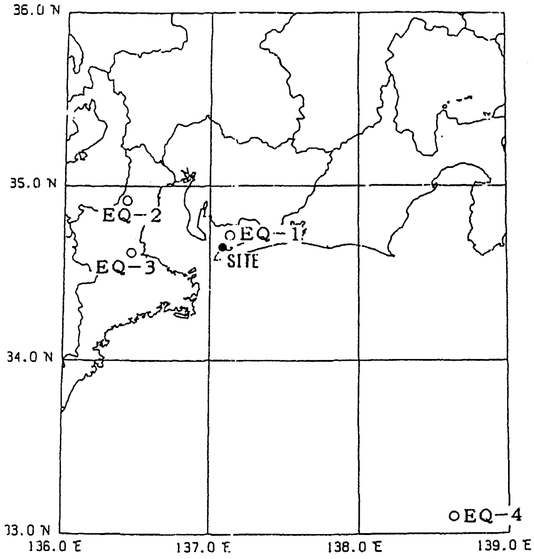
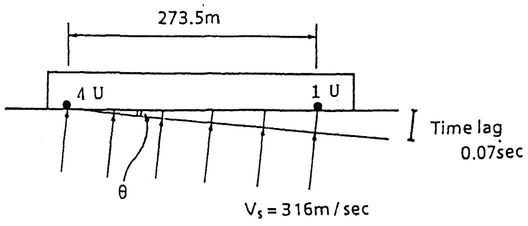


Fig. 4. Locations of recording point and epicenters

Table 1. Observed earthquakes

NO.	Date	Magnitude	Forcal Depth	Epicentral Distance
EQ-1	1988. 9. 20	3. 1	3 km	9 km
EQ-2	1989. 1. 30	3. 9	16 km	67 km
EQ-3	1988. 2. 19	5. 3	52 km	56 km
EQ-4	1990. 9. 24	6. 6	60 km	224 km



$$273.5\ \mathrm{m} \times \sin\theta = 316\ \mathrm{m/sec} \times 0.07\ \mathrm{sec}$$
$$\theta = 4.6^\circ$$
$$\approx 5.0^\circ$$

Fig. 5. Relation between time-lag and incident angle (EQ-3)

Secondly, as the wave of EQ-1 propagated from 1U side(Fig. 7), so the response of another side (4U) was larger than 1U side. In the same way, as the waves of EQ-3 and EQ-4 propagated from 4U side, so the responses of another side(1U) were larger. However, since the epicenter of EQ-2 lies at a right angle to the turbine axis, the difference between the responses at both ends are relatively small.

Finally, the responses at the 3rd and the roof floor of EQ-3 and 4 were more enlarged than compared with those at the foundation.

These phenomena seem to have reflected the vibrational characteristics of long and narrow buildings by the traveling wave effects.

4 TRAVELING WAVE ANALYSES

4.1 Analytical model

The turbine building is modeled into a set of lumped-mass model as shown in Fig. 8. Each mass of the upper building is connected with the equivalent shear springs, featuring three dimensional behaviors, and the foundation slab is assumed to be a beam, being 43m deep by 343m long with a thickness of 4m. The supporting ground, shown in Fig. 3, is modeled by shear springs. Details of the analysis have been already reported in Ref. 2.

4.2 Response analyses

In order to examine the dynamic characteristics of the turbine building due to the traveling seismic waves, numerical analyses were conducted using observed waves. The response analyses were carried out using a numerical integration method in time-domain. The equation of motion is expressed as follows.

$$Mo \cdot \ddot{U}_{oD} + Co \cdot \dot{U}_{oD} + Ko \cdot U_{oD} = -Mo \cdot \ddot{U}_{oS} \qquad (1)$$

here Mo, Co, and Ko are the mass, damping and stiffness matrices respectively, relating to the nodes other than input points. The pseudo-static displacement U_{oS} and the dynamic displacement U_{oD} are parts of the displacement vector Uo, relating to the nodes other than input points, as expressed in following Eq. (2), and Uos is defined as following Eq(3).

$$Uo = U_{oS} + U_{oD} \qquad (2)$$

$$Ko \cdot U_{oS} = -Kb \cdot Ub \qquad (3)$$

where Kb and Ub are the stiffness matrix and the displacement vector for the input points, respectively.

Table 3. Incident angles of observed earthquakes (Unit:degree)

	4U→3U	3U→2U	2U→1U	4U→1U	3U→1U
EQ-1		-3.6	0.0		-2.0
EQ-2		1.8	4.7		2.0
EQ-3	3.8	3.6	7.1	4.6	
EQ-4	1.9	1.8	7.1	3.3	

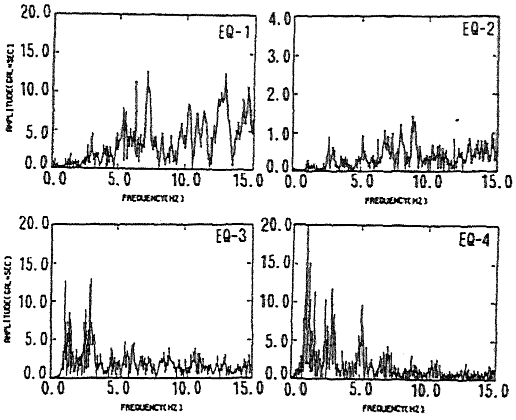


Fig. 6. Fourier spectra at free surface

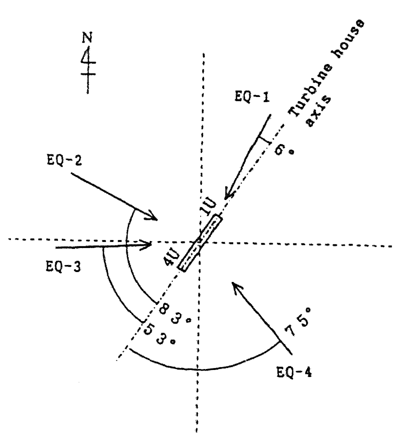


Fig. 7. Angles of epicenter direction from turbine house axis

Table 4. Maximum accelerations of observed earthquakes

(unit:Gal)

NO	4U			3U		2U		1U		GL
	1F	3F	RF	1F	RF	1F	RF	1F	RF	
EQ-1	4.0	7.5	1.9	2.1		1.6		2.4		11.1
EQ-2	1.0	2.7	1.9	0.8		1.0		1.0		5.1
EQ-3	13.0	24.3	50.2	12.6		13.7		14.4		19.8
EQ-4	6.1	11.4	35.2	6.4	38.6	7.6	43.1	8.7	49.7	9.9

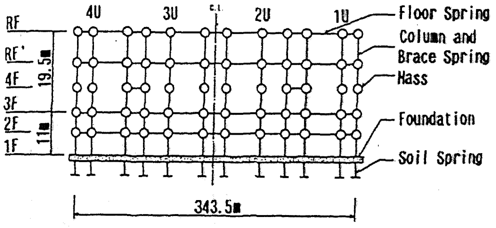


Fig. 8. Vibration model for analysis

4.3 Response of foundation and structure

The analyses were carried out , using the observed records of EQ-1 and 4 (TABLE 1) at free surface(point B). EQ-1 represents a very short epicentral distance , and EQ-4, a relatively long epicentral distance. Figs. 10 and 11 show the maximum accelaration responces coresponding to lumped-masses. In addition to the analyzed data, observed records at the turbine house are indicated.

The tendency of the observed records is in good agreement with the results of analysis, as seen in the effects of propagating and self-canceling effects.

From more deep analyses of the results, further interesting results are recognized.

Firstly, the results of EQ-1, which represent the earthquake of short epicentral distance or small magnitude , shows a large amount of input-loss and self-canceling effect. And the amplitude of vibration at the roof is very small , because high frequency components of seismic wave do not coincide with the first natural frequency of tubrine building.

Secondly, the results of EQ-4, which represent the earthquakes of long epicentral distance or relatively large magnitude , shows a smaller input-loss and self-canceling effect. However , the amplitude of vibration at the roof is large, and the torsional mode is found, depending on the travering waves.

5 CONCLUSIONS

From the results of earthquake observation and numerical analyses , several important relationships between the traveling wave effects and the earthquake properties are derived, for the tall and narrow shapr buildings.

1. Earthquakes of short epicenter distance or small magnitude give a large input loss to the response of the foundation and the structure.
2. Earthquakes of long epicenter distance, or big magnitude give a relatively small input loss to that of the foundation, aber large torsional response to the structure.
3. Angles of epicentral directions from the turbin house axis give the significant influence to the traveling wave effects.

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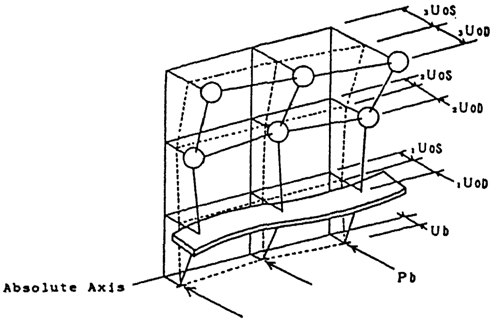

Fig. 9. Static and dynamic displacement vector

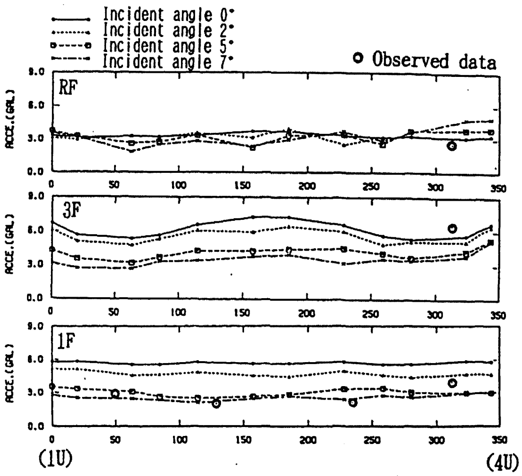

Fig. 10. Results of analysis (EQ-1)

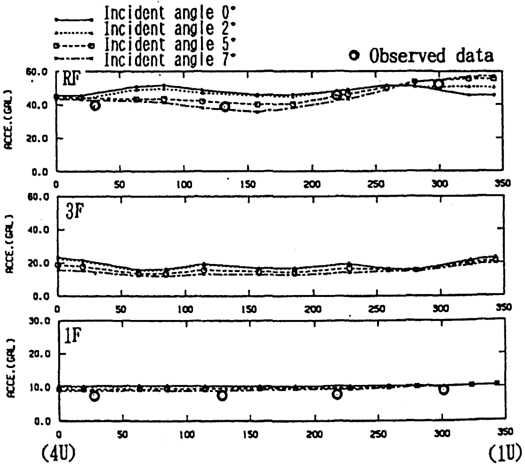

Fig. 11. Results of analysis (EQ-4)