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INFLUENCE OF SPATIALLY VARIANT GROUND MOTIONS ON RESPONSE OF A BUILDING WITH LONG CONFIGURATION

S. ASAYAMA and F. SUTO

Faculty of Architecture and Engineering, Tokyo Denki University,
Kanda-Nishikicho 2-2,Chiyoda-ku,Tokyo101, Japan

ABSTRACT

This paper reveals relation between structural responses of a building with long and large configuration and actual spatially variant ground motions based on earthquake observation and full-scale response analysis. Records of the structural responses and ground motions were acquired when Far Offshore Tokaido Earthquake of Oct. 12, 1993 and Kashimanada Earthquake of Sept. 18, 1993 occurred. They are compared with those calculated under the conditions of both uniform ground shaking and spatially variant ground motions using a discrete vibration model with flexible slab, static soil spring and virtual mass considering soil-structure interaction approximately. Remarkable response reduction at the top of the building in a certain time domain can be explained when the spatial variation of input motions produced by interpolating records of 3 seismographs horizontally arrayed 15 m under the ground is taken into consideration. However, the slab shear of the 1st floor increases remarkably in spite of that.

KEYWORDS

Spatially variant ground motion; time phase difference; seismograph array; earthquake observation; kinematic interaction; flexible slab; full-scale analysis; long building; earthquake response.

INTRODUCTION

Since the beginning of 1970's (Duke *et al*, 1970), several observational studies have been carried out concerning dynamic behavior of building with long and large configuration in plan. However, even in recent research works (Ohami and Murakami, 1984, 1992; Takita *et al*, 1988), none of them gives clear explanation on relationship between actual response and exciting ground motion. Authors described it under the condition of uniform ground shaking and spatially variant excitation, which can be thought traveling wave approximately, based on observational data and full-scale analysis (Suto and Asayama, 1988). In this paper, influence of irregular variation of the motions, which seems to be caused by wave propagation under non-homogeneous soil conditions and unpredictable factors, on response of a long building with flexible slabs is discussed.

OUTLINE OF EARTHQUAKE OBSERVATION

Seismographs are arrayed in a 4 story reinforced concrete building and in soil layer as shown in Figure 1. The building has dimensions of 116 m in length, 16 m in width and 16 m in height and its independent footings are sustained by sandy gravel with clay whose N-value is about 50. Components of the seismographs installed in the structure are represented by notations from 1ch to 12ch. Similarly notations from UG.1ch to UG.9ch show those embedded in 15 m under the ground. Table 1 shows magnitude, focal depth, epicentral distance and maximum acceleration at observation point #1 (O.P.1) in Figure 1 of observed earthquakes. Figure 2 is a map showing their epicenters and an observation site, Hatoyama Campus of Tokyo Denki University where the above building is located. In the following chapters, the dynamic behaviors under spatially variant ground motions are discussed by means of comparing these observational data with results of full-scale structural analysis.

TIME PHASE DIFFERENCE OF EARTHQUAKE RECORDS

Amplitudes and time phase differences of simultaneous earthquake records are examined by means of evaluation of the powers in time domain and their phase spectra (Miyamura et al., 1986) and basic characteristics of response and ground motion are discussed from an observatinal point of view.

First Figure 2 shows EW components of accelerograms acquired at the top when Far Offshore Tokaido Earthquake of Oct. 12, 1993 occurred. Transversal direction of the building coincides with them which are represented by notation 6ch, 10ch and 11ch in Figure 1. The amplitudes increase at the middle and southern parts of the structure in time domain 1 and decrease rapidly in time domain 2. Figure 3 shows enveloped curves of powers of the simultaneous records in the same direction acquired by 3 seismographs horizontally arrayed 15 m under the ground when the above earthquake occurred. A thick line shows power of the average of them. The difference between them is small in time domain 1 but they vary remarkably in time domain 2. Similarly Figure 4 and 5 show response accelerations at the top due to Kashimanada Earthquake of Sept.18,1993 and enveloped curves of powers of the underground records respectively. The amplitudes at the top decrease gradually in time domain from 1 to 4 seconds and the powers have roughly the same configurations.

Next phase delay in frequency domain of the accelerogram at observation point #3 (O.P.3) against #1 (O.P.1) is described. Figure 6 (a) and (b) show phase spectra of the records divided into time domain 1 and 2 respectively concerning Far Offshore Tokaido Earthquake of Oct. 12, 1993. Here the phase spectra $\theta_{xy}(\omega)$ is defined as follows:

$$S_{xy}(\omega) = \int_{-\infty}^{+\infty} R_{xy}(\tau)\exp(i\omega\tau)d\tau\,, \tag{1}$$

$$\theta_{xy}(\omega) = \tan^{-1}(Q_{xy}(\omega)/K_{xy}(\omega))\,, \tag{2}$$

where $R_{xy}(\tau)$ denotes correlation coefficients and $K_{xy}(\omega)$ and $Q_{xy}(\omega)$ denote real and imaginary parts of cross spectrum $S_{xy}(\omega)$ respectively. The phase delay of the record in time domain 2 varies in higher frequency region than 2Hz enveloping natural frequency of the structure 4.1 Hz as shown in Figure 6 (b). On the other hand the variation of the spectrumon time domain 1 is small (Figure 6 (a)). Judging from these observational facts, rapid reduction of amplitudes of responses at the top of the building with long and large configuration seems to arise from spatial variation of the ground shaking.

MODELING OF STRUCTURE AND SOIL

Since the modeling of this structure enveloping the sustaining soil layer was described precisely(Suto and Asayama, 1990), the outline is summarized here. Static soil springs are obtained by Tajimi's method (Kanai, Tajimi, Osawa and Kobayashi, 1968) modified for extended application. Their values are calculated using fundamental functions concerning displacement distribution in half space imposed a unit force on its surface . Then they are corrected approximately for layered soil condition based on the assumption that stress distribution in soil strata is the same as one in half space. The whole structure sustained by the soil springs is subdivided into 10 structural blocks. Each stiffness matrix is produced by 3-D frame analysis considering flexibility of slabs except 5 tube structures enclosing staircase inside. The objective restoring matrix of whole structure is composed by combining stiffness matrices of them by those of flexible slabs. Figure 7 shows a discrete vibration model of the structure with flexible slabs, static soil springs and virtual masses considering soil-structure interaction approximately.

ACTUAL RESPONSE BEHAVIOR AND FULL-SCALE ANALYSIS

Subsequently theoretical calculations are compared with the structural responses acquired at 3 observation points on the roof represented by notation 6ch, 10ch and 11ch in figure 1 when the Far Offshore Tokaido Earthquake occurred(Figure 8 and 9). In Figure 8, input ground motions are prepared by means of interpolating 3 simultaneous underground records under the assumption that they vary proportionally to the distance between observation points arrayed horizontally. In Figure 9, they are assumed uniform. Damping of the vibration system is 4 %. Obviously the assumption of uniform ground shaking gives extremely large amplitudes when compared them with those observed in the region from 3 to 6 seconds of the time history. In case of the Kashimanada Earthquake, the calculated results are not so clear because time phase differences of input motions are small (Figure 10 and 11). Figure 12 and 13 show comparisons of calculations under the condition of the variant motions with actual responses to the above earthquakes at the base points denoted by notation 2ch and 3ch in Figure 1. They comparatively coincide with each other. The maximum slab shears of the building under irregularly variant motions and uniform shaking are shown in Figure 14 and 15 respectively. The maximum input accelerations are set 100 gals for mutual comparison. The slab shears at 1st floor remarkably increase when subjected to the variant motions.

CONCLUDING REMARKS

Authors conclude that the response reduction of the building with long and large configuration due to spatially variant ground motions can be explained by means of comparison of observed behaviors and theoretical calculations. The shear force of the flexible slab at the 1st floor increase remarkably when subjected to the irregular motions. The effect can be thought a sort of kinematic interaction although this case is different to some extent from the idealized situations where the earthquake waves acting on rigid base are assumed to have a constant incident angle.

ACKNOWLEDGEMENT

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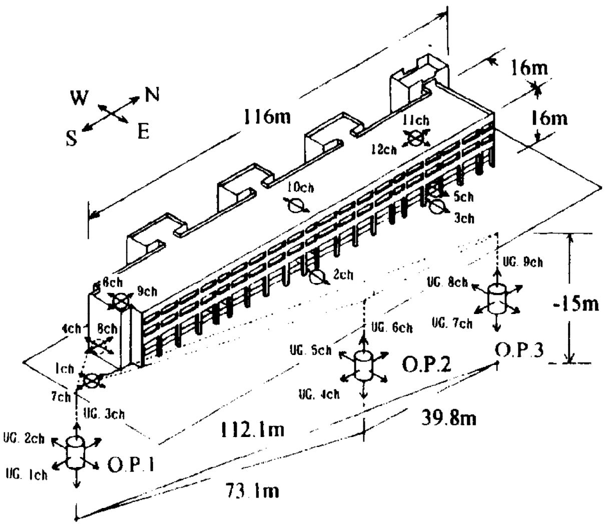


Fig. 1. Perspective view of a school building.

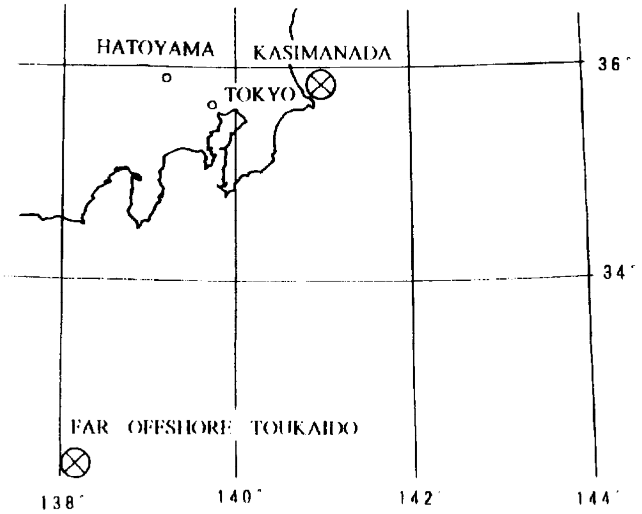


Fig. 2. Map showing epicenters and an observation site.

Table 1.List of observed earthquake for simulation

NO.	EARTHQUAKE NAME (DATE)	M	D(km)	X(km)	MAX.ACC(gal)	
EQ.1	KASHIMANADA (SEPT.13,1993)	5.1	30	125	NS EW UD	1.93 2.04 1.08
EQ.2	FAR OFFSHORE TOUKAIDO (OCT.12,1993)	7.1	388	315	NS EW UD	5.54 6.38 3.69

note: M:Magnitude D:Focal Depth X:Epicentral Distance

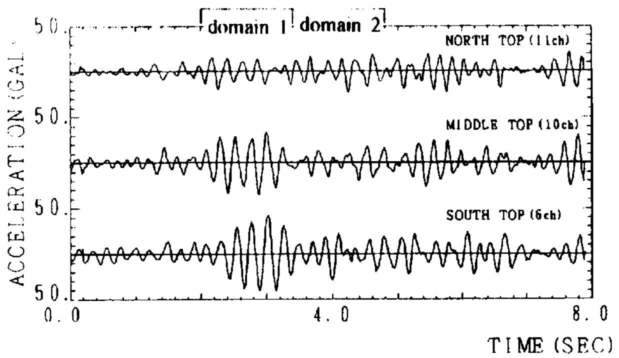


Fig. 3. Accelerograms obtained at the top of a school building.

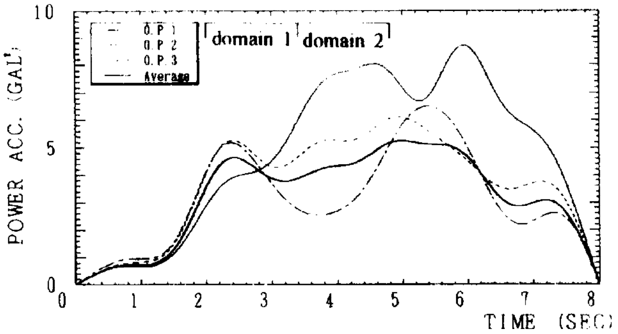


Fig. 4. Comparison of powers of accelerograms at the observation points 15m under the ground.

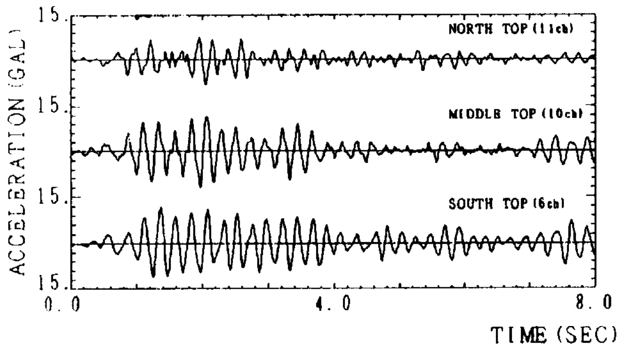


Fig. 5. Accelerograms obtained at the top of a school building.

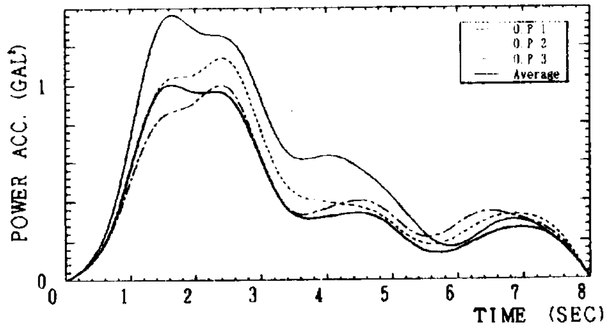
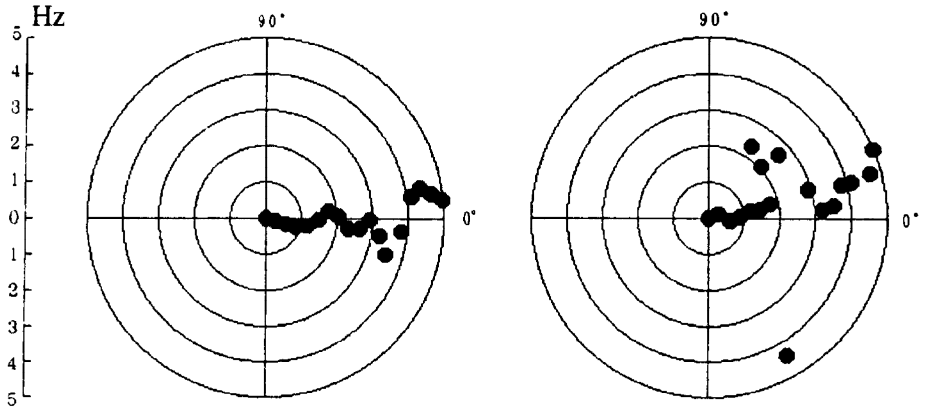


Fig. 6. Comparison of powers of accelerograms at the obsevation points 15m under the ground.



(a) domain 1

(b) domain 2

Fig. 7. Phase delay in frequency domain of accelerogram at O.P.3 against one at O.P.1.

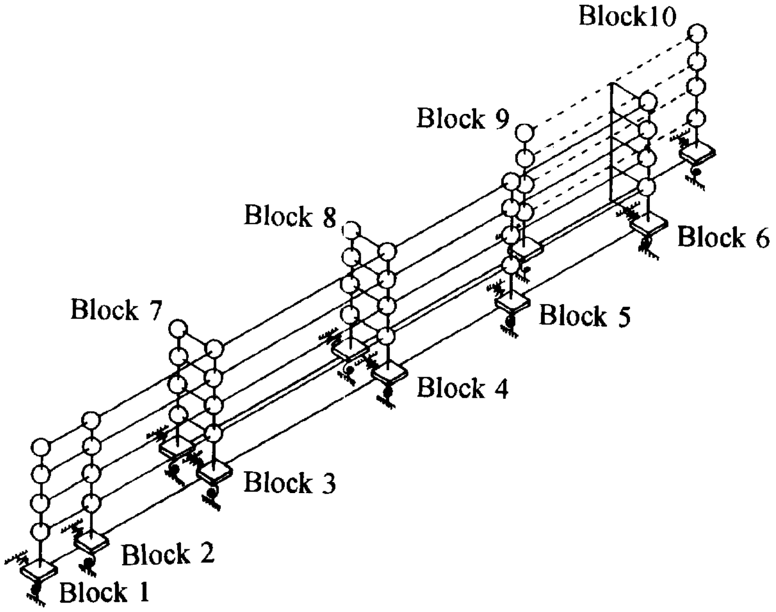


Fig. 8. A discrete vibration model with flexible slab.

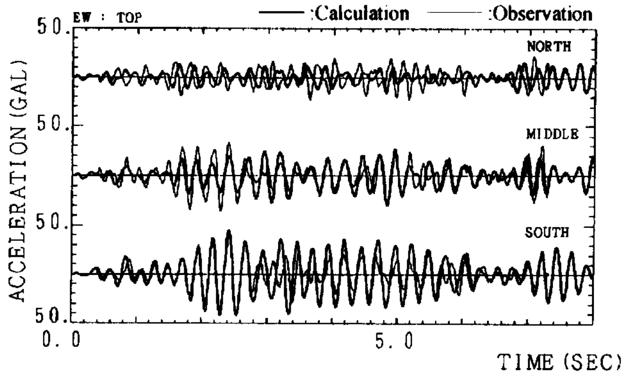


Fig. 9 Comparison of calculated response acceleration at the top with measured one (Far offshore Tokaido Earthquake of Oct.12,1993; variant excitation).

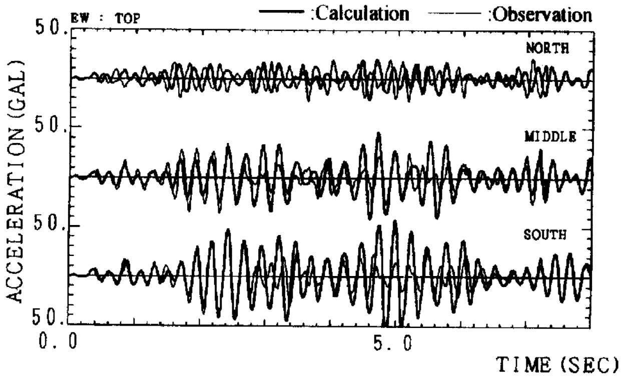


Fig. 10. Comparison of calculated response acceleration at the top with measured one (Far offshore Tokaido Earthquake of Oct.12,1993; uniform excitation).

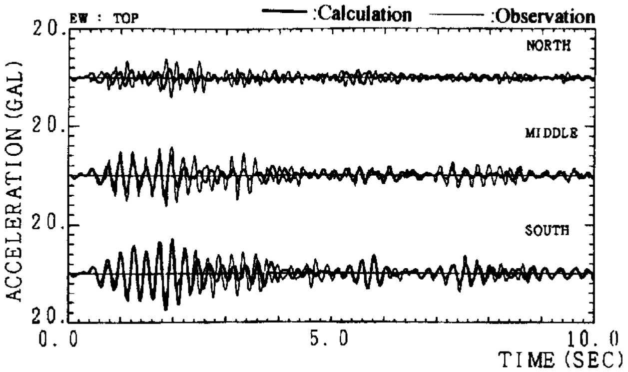


Fig. 11. Comparison of calculated response acceleration at the top with measured one (Kashimanada Earthquake of Sept.18,1993; variant excitation).

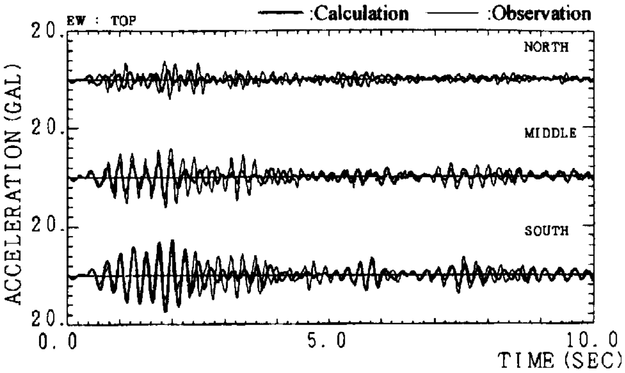


Fig. 12. Comparison of calculated response acceleration at the top with measured one (Kashimanada Earthquake of Sept.18,1993; uniform excitation).

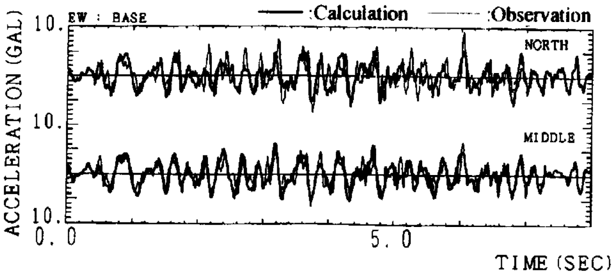


Fig. 13. Comparison of calculated response acceleration at the base with measured one (Far offshore Tokaido Earthquake of Oct.12,1993; variant excitation).

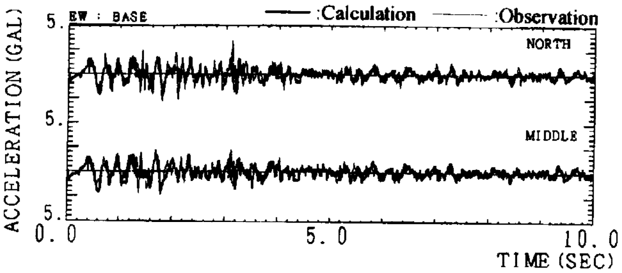
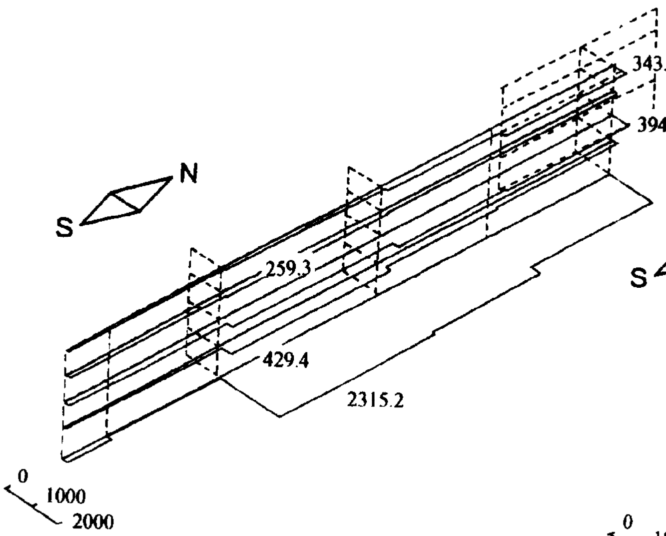


Fig. 14. Comparison of calculated response acceleration at the base with measured one (Kashimanada Earthquake of Sept.18,1993; variant excitation).



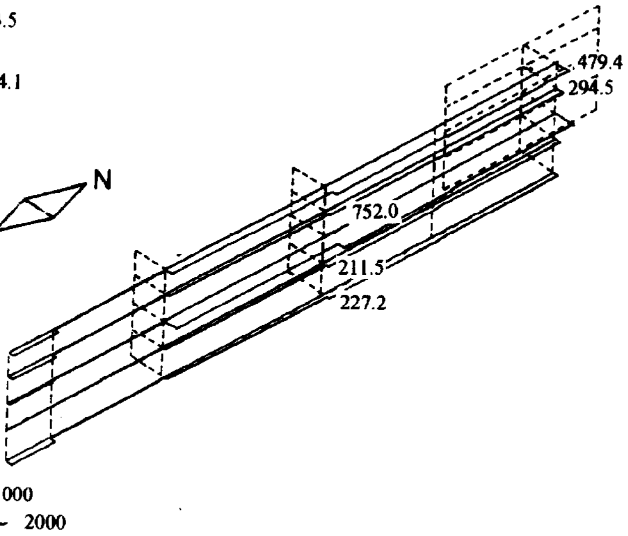


Fig. 15. Maximum slab shears of a building (Far offshore Tokaido Earthquake of Oct.12,1993; variant excitation).

Fig. 16. Maximum slab shears of a building (Far offshore Tokaido Earthquake of Oct.12,1993; uniform excitation).