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WAVE PROPAGATION IN SOILS AND WOODEN HOUSES DUE TO MOVING TRAFFIC EXCITATIONS

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ABSTRACT

This paper describes the attenuation characteristics of soil vibration and the amplification of wooden houses. As the facter in determining damping constant in soil with a distance from vibration source, following items could be considered ; velocity and weight of a motorcar, soil characteristics, vibration component, frequency characteristics and so on. In this paper, we investigate the relation between the damping constant and velocity and weight of a motorcar in every vibration component at all range of frequencies. As the factor in determining the amplification of vibration in houses, the arrangement of the structural elements in a plane and the vibration component are considered.

KEYWORDS

wave propagation; soil; wooden house; attenuation; amplification; moving traffic excitation; velocity of a car; weight of a car; component of vibration

INTRODUCTION

The vibration generated by moving traffic excitation causes hindrance for daily life to light weight buildings such as wooden houses. This hindrance is depend on the characteristics of surrounding soil of a house and a house itself. Therfore, we intend to clear the influence of the vibration generated by traffic excitations to soils and houses based on the microtremor measurement.

In generally, ground motions of high frequency range generated by cars decayes with departing from a vibration source (for example, Irie et al., 1986). Many studies defined this wave as Rayleigh type and estimated the relation of the energy of velocity wave and a distance from a vibration source (for example, Shima et al.,1970; Nogoshi,1972; Ushigome et al.,1994).

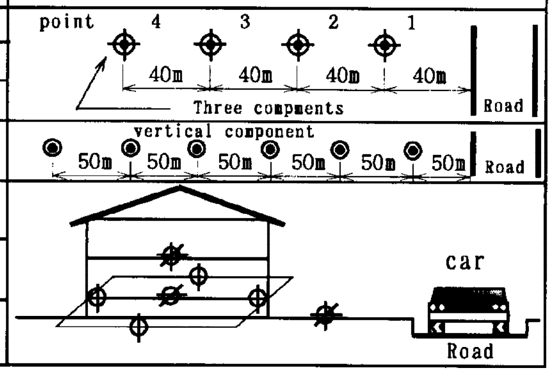
In this study we investigate the attenuation of soil at all range of frequencies. Furthermore, the amplification of this motion after entering in a house is investigated.

The dynamic characteristics of soils and houses are investigated by means of Fourier amplitudes and phases at all range of frequencies.

OUTLINE OF SUBSOILS, HOUSES AND MEASUMENT INSTRUMENTS

In order to investigate the soil attenuation three measurement sites are selected near by main streets in Utsunomiya city. Each soil is consits of loam of 5 to 10 meters thick on hard gravel. Seismometers in three components are setted on soils at every interval of 40 meters on a straight line which drawed radially to a road .

Table 1 Measurement sites, day and location of seismometers

Site	Y.M.D	Time	Location of seismometers
A	1994.5.29	1:00~4:00	
	1994.12.23	15:00~16:00	
B	1994.12.13	10:00~11:00	
C	1986.11.30	23:00~24:00	
D	1986.7.28	8:00~9:00	
E	1995.8.20	5:00~6:00	
F	1995.11.18	6:00~7:00	

In order to investigate the amplification of vibration in houses, three wooden houses are selected. Seismometers are setted in a house of first and second floors and it's subsoil. The outline of subsoils, houses and location of seismometers are shown in table 1.

The sensing instrument is 1-component (horizontal or vertical) moving coil type seismometer having a natural period of 1.0 sec, damping constant of 0.7 and sensitivity of 3 volts/kine. The signsls from 12 seismometers are recorded in digital form on floppy disks at sampling frequency of 100 Hz, after being amplified while monitoring by a pen-oscilografh.

WAVE PROPAGATION IN SOILS

Discrimination of the wave type

Displacement waves measured at the time when a truck pass through a road at the site A with the velocity of 60 km/h are shown in Fig. 1. Orbital motions in Radial(R)-Vertical(V) plane and transverse(T)-radial(R) plane and motion products of R and V

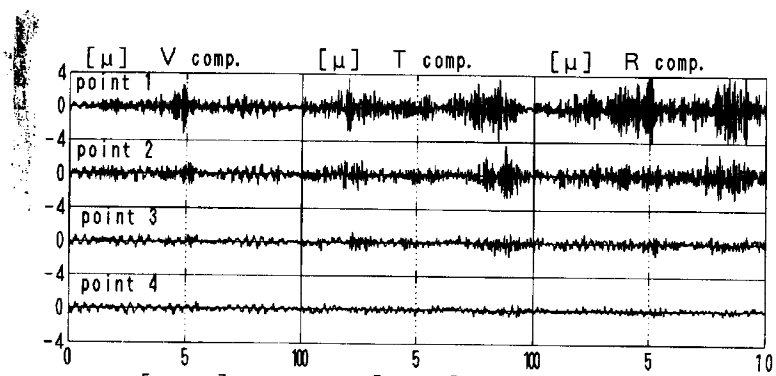


Fig.1 Displacement waves (V,T,R components)

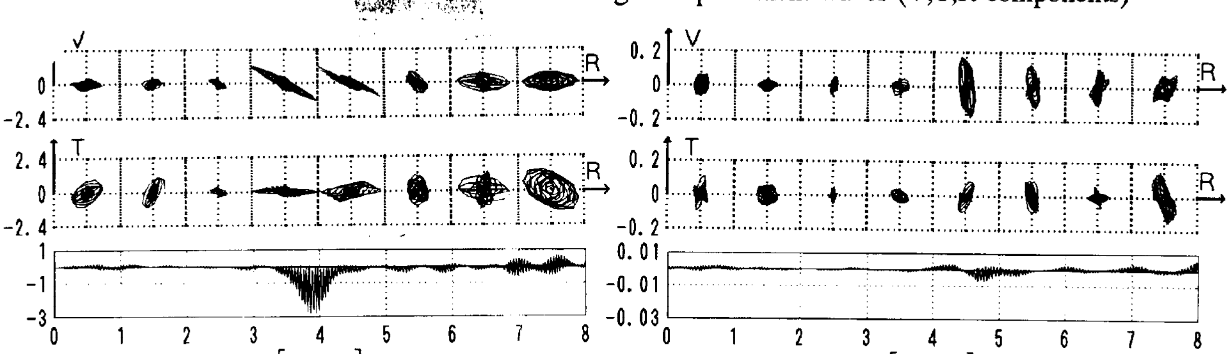


Fig.2 Orbital motions and motion products (the nearest point and the farthest point)

component at a frequency range of 9 ~ 11 Hz at the nearest and the farthest measurement point are shown in Fig.2. It reveales that body wave travels at near field from a vibration source and Rayleigh wave travels at far field from it.

Attenuation of vibration in soil

Fourier spectra   Fourier spectra of every vibration component (V,T,R) in case when a car pass along a road at the site A with the velocity of 60 km/h are shown in Fig.3. Spectral peaks are seen around 2.5 Hz in every component, at 8 ~ 16 Hz in V component and at 6 ~ 16 Hz in T and R components. The power of high frequency range is diminishes at a sufficiently far field from a vibration source. To estimate this phenomenon quantitatively, the Fourier amplitude at the frequencies marked as ∇ in Fig.3 versus distance from a vibration source are shown in Fig.4. From this figure, the power of high frequency range attenuates rapidly with the distance from a vibration source.

Attenuation constant of soil   We estimate the attenuation of soil by following method. First, take the ratios of an amplitude at a point to one of a neighboring point, next average these ratios, then taking a natural logarithm of this averaged ratio, and devide this value by 2π. We call this value as "attenuation constant of soil". We obtain this constant at every frequency, and show these results in Fig.5. Thick line shows a mean value and thin lines show standard deviations from the mean value. The attenuation constants are estimaed as 0.1 ~ 0.15 at the frequency range of 8 ~ 20 Hz which are generated by a driving car, and 0.01 ~ 0.05 at the frequency range of 1 ~ 4 Hz.

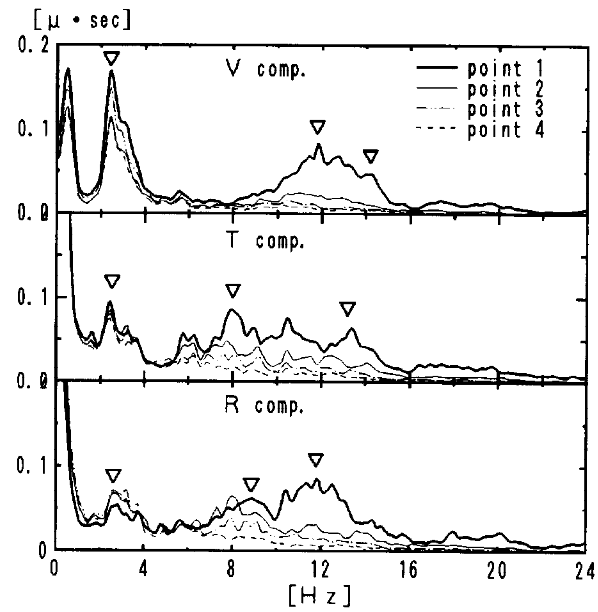


Fig.3 Fourier amp. spectra (excited by car, 60 km/h)

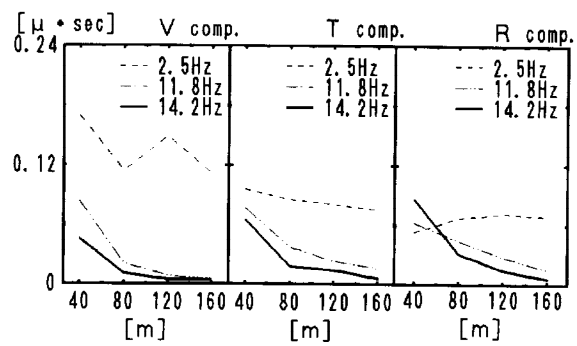


Fig.4 F.A.S. vs distance from vibration source

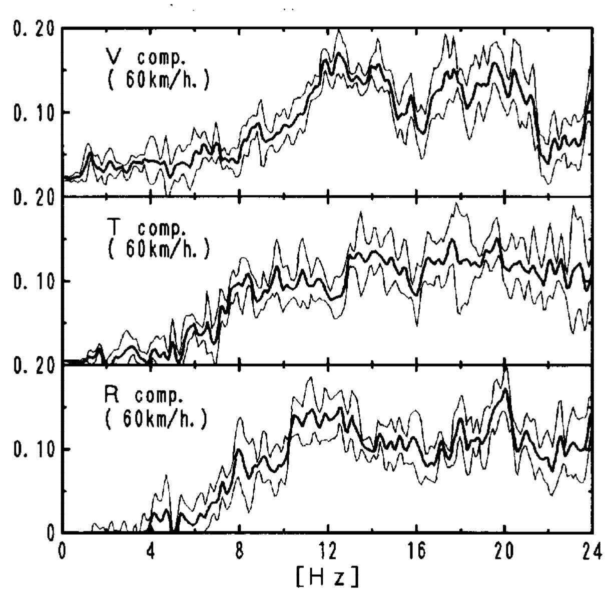


Fig.5 Attenuation constants (excited by car, 60 km/h)

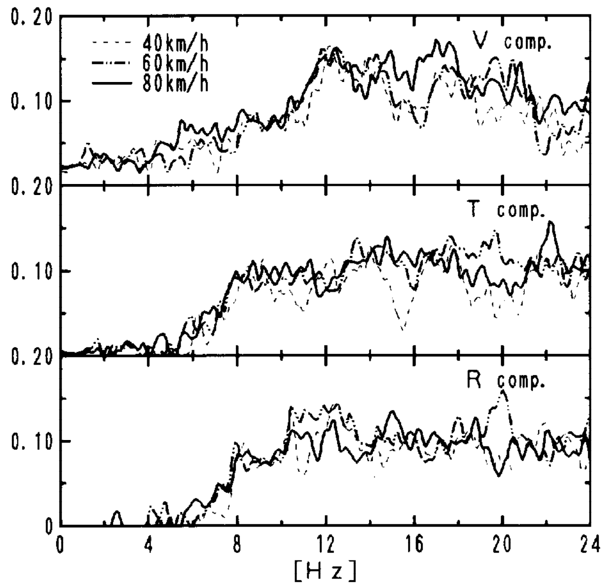


Fig.6 Attenuation constants
(influence of the velocity of a car)

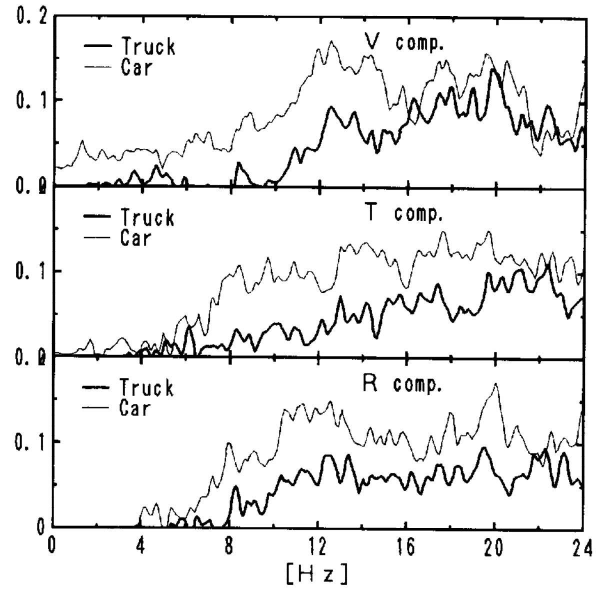


Fig.7 Attenuation constants
(influence of the weight of a car)

<u>Influence of the driving velocty and the weight of a car</u> Next, we investigate the influence of the driving velocty and the weight of a car based on the data obtained at the site A. The attenuation constants averaged by four data are shown in Fig.6. From this figure, the attenuatin constant are scarcelly influenced by the velocity of the driving car.

The attenuation constants obtained from vibration generated by a car weight of which is 1.2 tons and ones by a truck weight of which is 20 tons are shown in Fig.7. The attenuation constants by a car are 0.1 ~ 0.15 at 10 ~ 20 Hz and ones by a truck are 0.05 ~ 0.1 at 12 ~ 24 Hz. The former are 1.5 ~ 3.0 times larger than the latter.

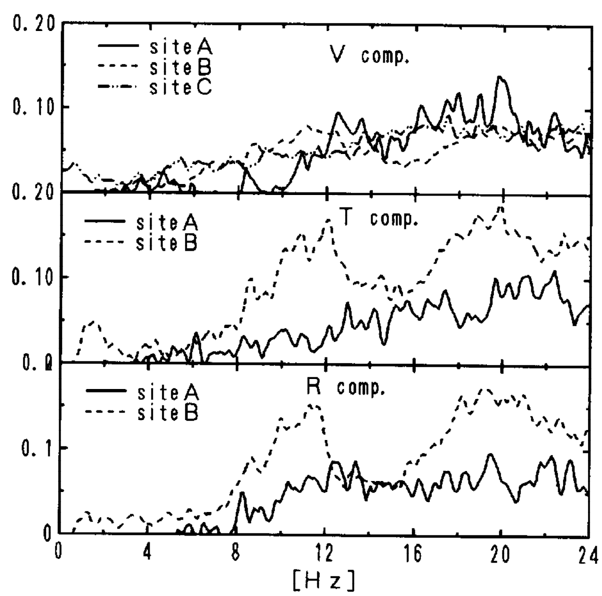


Fig.8 Attenuation constants (influence of the site)

<u>Influence of the measurement site</u>

Then, we investigate the influence of the measurement site when a truck pass along a nearby road. The vibration source at the site B and C are unspecified, therefore the weight and the velosity of a truck are unknown. Number of data are 7 at the site A, 10 at the site B and 25 at the site C. The mean value of attenuation constaants at every site are shown in Fig.8. The influence by the site are scarecely noticed in V component. However, the attenuation constants of the site B are 2 ~ 3 times larger than ones of site the A in T and R components. The reason of this phenomenon is considered that measurment instruments are setted at a soft surface soil, therefore largely amplified at the nearest point from the vibration source. These three sites are located within 5 km and natural frequencies of these soils are similar to each other. Therefore, the difference of these site does not influence the attenuation constants.

Estimation of the attenuation constant

Equation of the attenuation of soil About attenuation characterics of ground motion with predominant surface waves in the period range of about 2 to 20 second are studied in detail (for example Sato et al., 1994).
At these sites detailed informations of soils are not obtained. About ground motions generated by motorcar, an reaching extent of a vibration and the frequency range of vibration are entirely different from long-period ground motions. Therefore, we estimate the attenuation of high frequency range as the form of equation (1).

$$A_i = \alpha \cdot \frac{1}{D^{\beta}} \cdot A_0 \qquad (1)$$

A_0 : Amplitude at a nearest point from a vibration source
D : Distance from a point where A_0 is measured

The value of α expresses a viscous and radiation damping facter, one over the β th power of D expresses a geometrical damping facter.

Investigation of the value of β In case of taking β to be 0.5 and 1.0 are shown in Fig.9 and in Fig10, respectively. In these figures thick lines are the mean value of α and thin lines are standard deviation from the mean value. These deviations show the difference of α obtained from neighborring points, that is, the small error of α means α is confirmed highly precised in whole measuring line. Small α means large damping, therefore the figure of α shows the tendency of reversion of Fig.5. From these figures, limitting the frequency range caused by traffic excitation, the error i.e. standard deviation is small in case of β is 1.0.

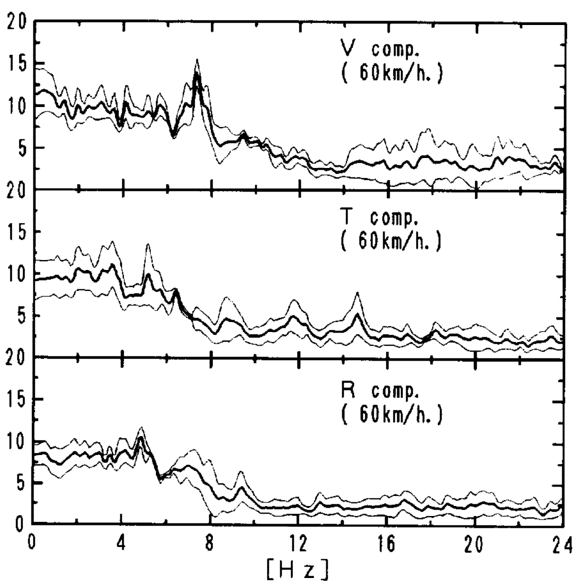


Fig.9 Constants α (in case of β =1/2)

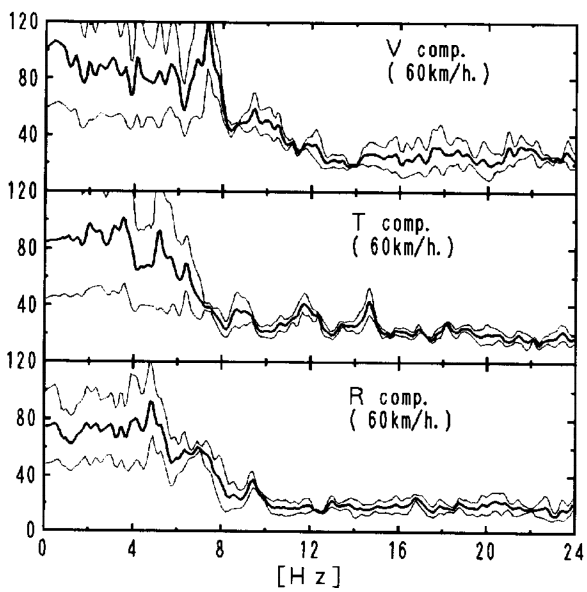


Fig.10 Constants α (in case of β =1)

Investigation of the value of α The influence of the velocity and the weight of a motorcar on the value of α are shown in Fig.11 and Fig.12, respectively. From Fig.11, α are not influenced by the difference of the velocity of a motorcar. From Fig.12, α are not influenced by the difference of the weight of a motorcar in R component, on the other hand, remarkably influenced in vertical component. From these results, it can be recognized that the difference of attenuation in R component is due to radiation damping.

Estimation of the attenuation constant The investigations mensioned above are summarized as equation (1) and Fig.13, that is, the amplitude of ground motions generated by motorcars are estimated by equation (1), in which β is 1.0 and α can be represented by the approximate lines shown in Fig.13.

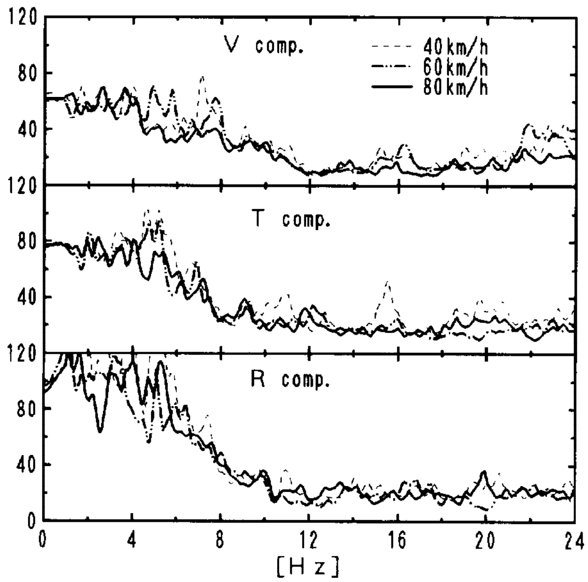


Fig.11 Constants α
(influence of the velocity of a car)

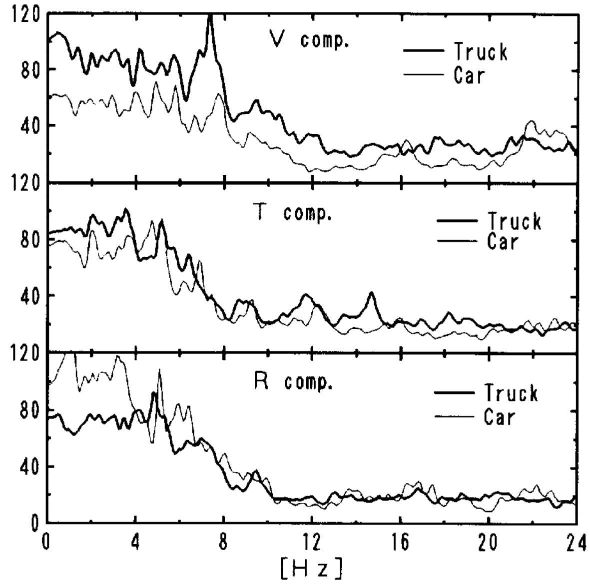


Fig.12 Constants α
(influence of the weight of a car)

WAVE PROPAGATION IN WOODEN HOUSES

Outline of wooden houses

Plans of 1st and 2nd floor of wooden houses of D and E are shown in Fig.14. The lines show walls, that is, a thin line shows a wall of structurally unreinforced, a thick line shows a wall with a diagonal beam and a more thick line shows a wall with diagonal beams crosswise. A point means a pillar. Structural elements are arranged well balanced in the house D, on the other hand, curioslly arranged in the house E.

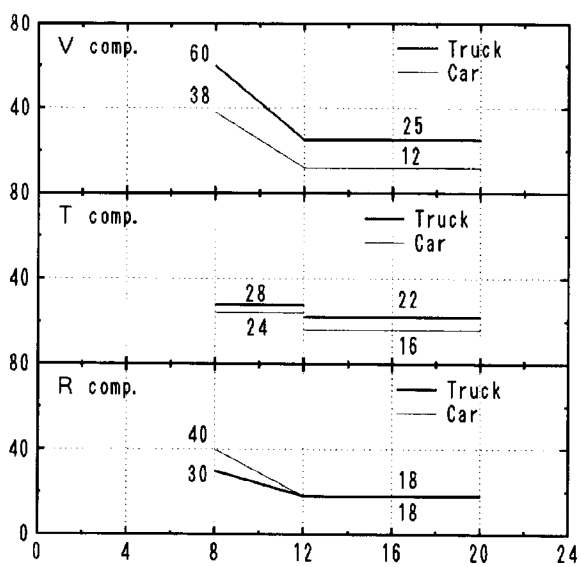


Fig.13 Approximate values of constants α

Rosponse of soils and houses

Fourier spectra of soils and houses at the site D and E are shown in Fig.15 and Fig.16, respectively. Ground motions attenuate after entering in 1st floor of houses especially in high frequency range, and amplified around the natural frequency of these houses. In order to ascertain the amplification of motion in houses, we take the ratio of spectrum of 2nd floor to one of 1st floor. From the lower part of Fig.15, the shape of spectral ratios in calm and excited by car are very similar in the house D. On the other hand, from the lower part of Fig.16, the shape of spectral ratios in excited by a car are extremely amplified in low frequency range in contrast to one of calm time. Furthermore, phase lag between 1st floor and 2nd floor of the house D and the house E are shown in Fig.17 and Fig18, respectively. There is no significant difference between phase lag in calm time and in excited time in the house D (Fig.17), on the other hand, clear difference is seen in the house E (fig.18). The result obtained from a house F is similar to the one of a house D, because of having well balanced structural elements.

From these results, a house such as having curious balanced structural elements suffers a change of it's dynamic characteristics of natural predominant frequency and phase lag.

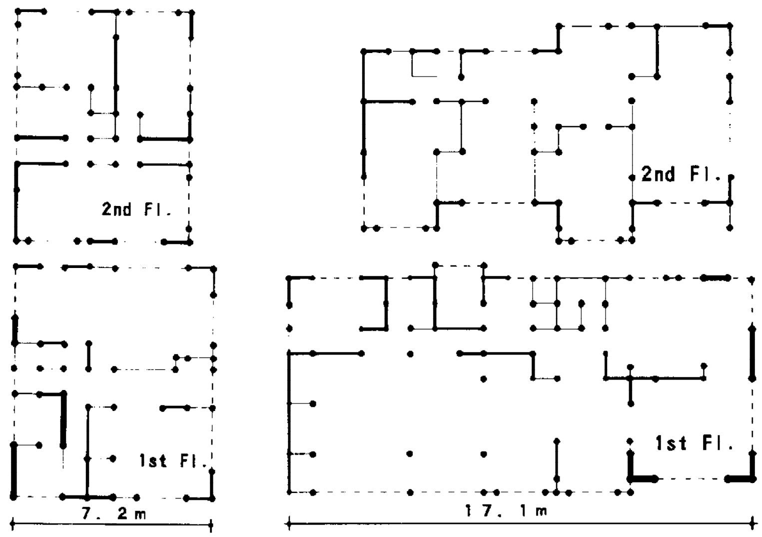


Fig.14 Plans of the house D and E

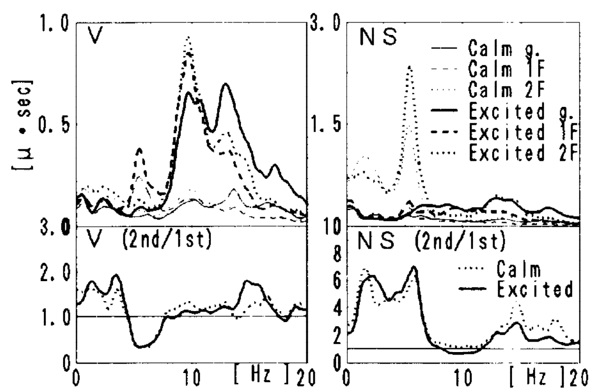


Fig.15 F.S. and it's ratios in house D

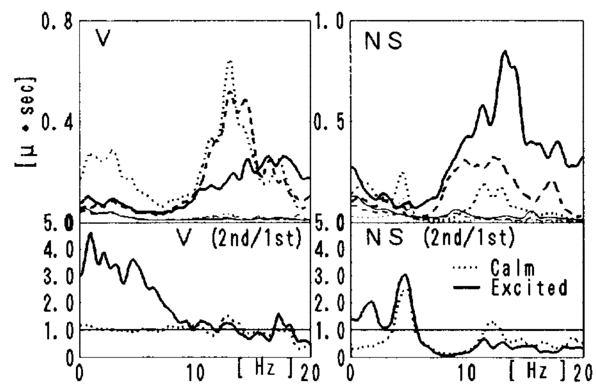


Fig.16 F.S. and it's ratios in house E

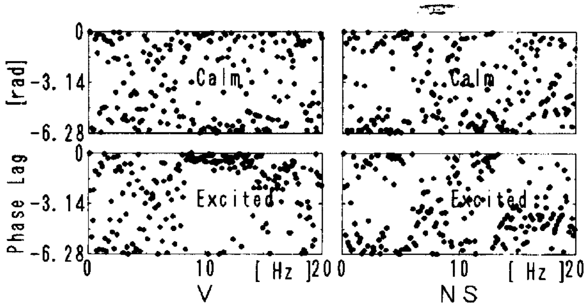


Fig.17 Phase lag between
1st floor and 2nd floor in house D

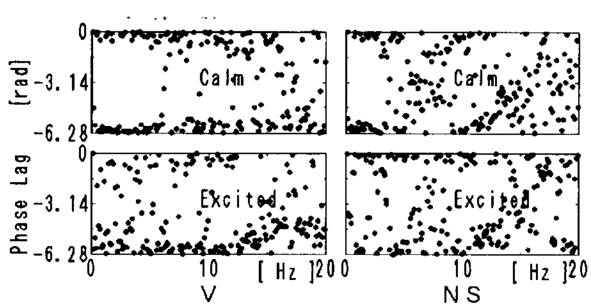


Fig.18 Phase lag between
1st floor and 2nd floor in house E

CONCLUSIONS

The following properties became clear after examining the experimental results.

wave propagation in soils;

- The wave generated by a motorcar shows the body wave property at near a vibration source and the surface wave property at far away from a vibration source.
- The vibration of high frequency range decays rapidly.
- The damping constant of soil vibration is scarcely affected by the difference of the velocity of a motorcar, on the other hand considerably affected by the difference of the weight of a motorcar.
- The soil vibration of each component decreases at the inverse of the distance from a vibration source.
- The amplitude of ground motion can be expressed as a form of equation (1).

wave propagation in wooden houses;

- The ground motions attenuate after entering in 1st floor of houses especially in high frequency range, and amplified around the natural frequency of these houses.
- A house such as having curious balanced structural elements suffers a change of it's dynamic characteristics of natural predominant frequency and phase lag.

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