Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VI)

10-6-10

EFFECT OF SURFACE WAVE ON THE DYNAMIC BEHAVIOR OF UNDERGROUND TRANSMISSION LINE UNDER EARTHQUAKE

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SUMMARY

Presented in this paper is the effect of the surface wave component on the dynamic behavior of the underground transmission line based on the 3-point array earthquake observation and strain measurement of the underground transmission line performed from 1981 to 1985 in Aichi prefecture, Japan. It is found that the longitudinal behavior of the underground transmission line under the earthquake is mainly controlled by surface wave even if the surface wave component is small.

INTRODUCTION

Since it is widely recognized that the behavior of underground lineal structure in the longitudinal direction such as submerged tunnels and pipelines is predominantly controlled by the deformation of the surrounding ground during earthquake(Refs.1, 2), many of the earthquake resistance design criteria in Japan employ the seismic deformation method for the design of the underground lineal structure.

Two kind of the earthquake wave, body wave and surface wave, deforms the ground, hence, underground lineal structure. In these design criteria, however, the amplitude of the ground deformation is calculated by assuming that the ground oscillates in shear mode due to vertically propagating body wave. Apparently, these ground deformation does not correspond with the earthquake motion by which the underground lineal structure is deformed in the longitudinal direction.

The reason why the surface wave is not taken into account in these design criteria seems that the earthquake observation records and researches are still not enough to establish the design criteria. Moreover, the effect of surface wave on the dynamic behavior of the underground structure is not estimated in sufficient accuracy and the surface wave is not predicted quantitatively. This paper describes the effect of the surface wave component on the dynamic behavior of the underground transmission line(UTL) based on the 3-points array earthquake observation and strain measurement of the UTL performed from 1981 to 1985 at the soft ground in Aichi prefecture, Japan.

CHARACTERISTICS OF EARTHQUAKE RECORD

Earthquake observation The observation was carried out in Tsushima City, Japan, which is shown in Fig. 1. Fig. 2 shows the arrangement of seismographs and strain meters. Three seismographs were placed on the surface(at the depth 1 meter) apart about 100 meters to each other, and a seismograph was set up at 42 meters under the ground surface at No.3 point. Each seismograph can measure two horizontal and a vertical components of the ground velocity. Strain meters were put on the longitudinal reinforcing bars of the underground transmission line at three cross sections.

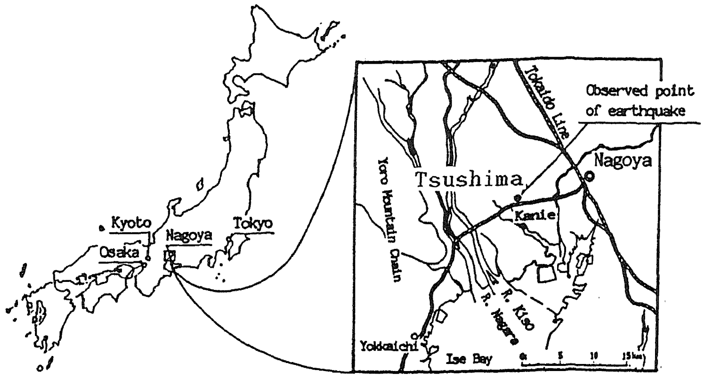

Figure 1 Location of earthquake observation

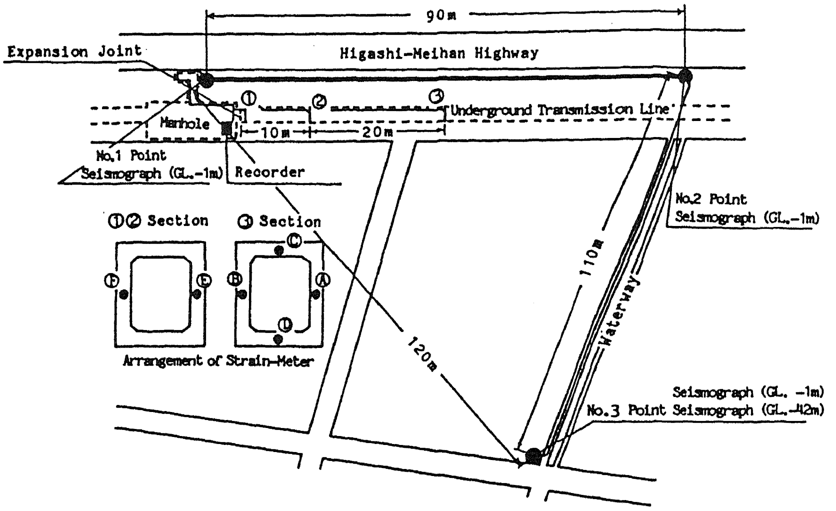

Figure 2 Arrangement of seismographs and strain meters

Characteristics of surface wave Earthquake records were obtained at 100 earthquakes in this duration among which twenty nine earthquakes are selected to use the following investigation based on the magnitude of the recorded acceleration. The epicenters of these earthquakes are shown in Fig.3.

First, the existence of surface wave is examined in the selected earthquake records. If surface waves are included, the unstationary spectrum(Ref.4) and the motion product(Ref.5) will show the following characteristics:

1) The unstationary spectrum at the ground surface and under the ground have the same properties, because the difference of the surface wave in the vertical direction is only the amplitude.
2) The maximum value of the unstationary spectrum, which corresponds to the arrival time of each frequency component of the surface wave, shows good agreement with the arrival time of the surface wave derived from the theoretical dispersion property.

3) As the trace of the particle movement due to Rayleigh wave is elliptic, the value of the motion product changes positive and negative alternately if Rayleigh wave exists.

Based on these criteria, 9 earthquake records are supposed to include surface wave. The epicenters of these earthquakes are shown in Fig.3 as solid circles.

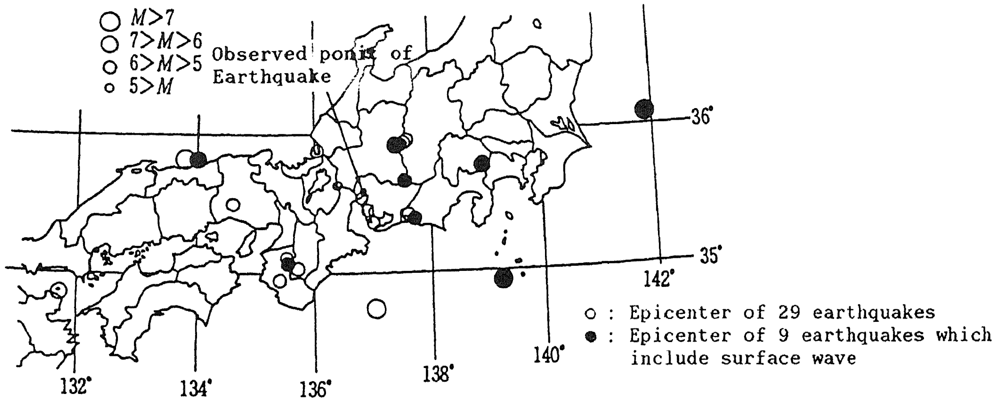

Fig. 3 Epicenter of the earthquakes used in the investigation

In the next step, surface waves are separated by the method proposed by Nakamura et al(Ref.6); the frequency component of the wave in the range of 5 seconds before and after the arrival time of the surface wave are supposed to be surface wave component and are separated. The relation between the maximum velocity of the separated surface waves and those of the original earthquake motion is shown in Fig.4. Fairly good correlation is observed between them; the maximum amplitude of velocity component of the separated surface wave is about a half of that of the original earthquake motions regardless of the magnitude of the earthquake. The maximum velocity of the separated surface wave and the original earthquake motion versus the epicentral distance relations are shown in Fig.5.The attenuation property of the maximum velocity of the separated surface wave is similar to that of the original earthquake motion.

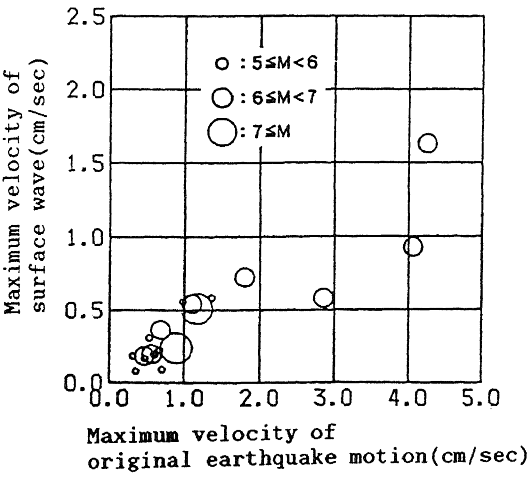

Fig.4 Maximum velocity of the surface wave versus that of the original earthquake motion relation

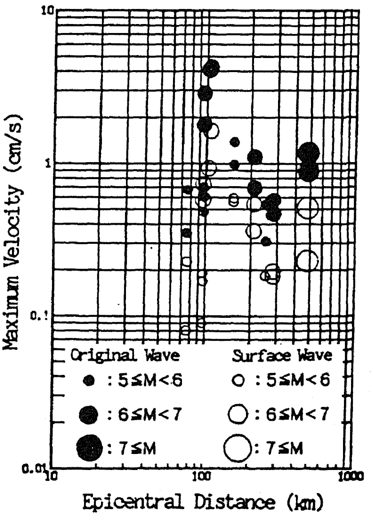

Fig. 5 Maximum velocity versus epicentral distance relation

Characteristics of the strain

Fig. 6 shows the relation between the maximum amplitude of the strain and the maximum velocity of the earthquake motion. It is well known that the velocity component of the earthquake motion is associated with the ground deformation, which can be comfirmed in Fig. 6.

The unstationary spectrum of the strain is compared with that of the velocity component of the earthquake motion to investigate the effect of the surface waves on the UTL. Fig. 7 shows the unstationary spectrum of the axial strain at the center between the expansion joints and that of the velocity component of the earthquake motion at the No.3 point for Naganoken Seibu Earthquake (1985). The dispersion properties are observed in both spectra and they are similar to each other, which indicates that the surface waves affect the behavior of the longitudinal strain of the UTL.

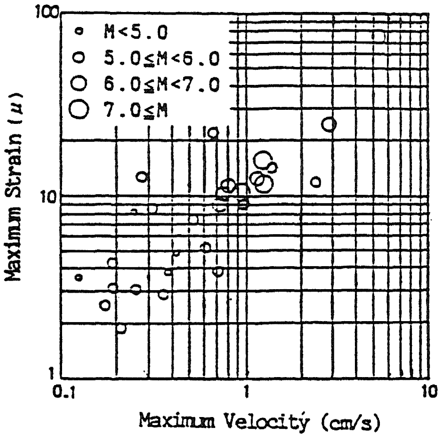

Fig. 6 Relation between maximum strain and maximum velocity

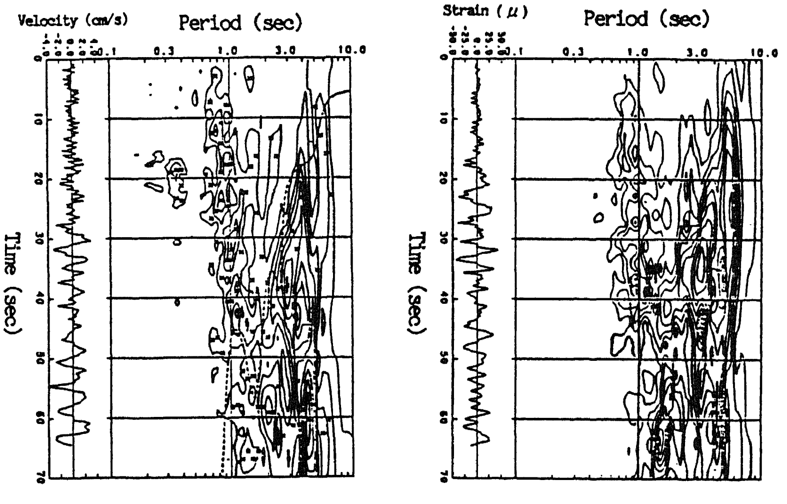

Fig. 7 Unstationary spectra of velocity and axial strain

Earthquake response analysis The effect of the surface wave on the dynamic behavior of UTL in the longitudinal direction is investigated by the earthquake response analyses in which either surface wave or diagonally propagating body wave is considered as the input motion.

Two kinds of analysis are performed. In the first method(Method 1), the response of the UTL due to diagonally propagating body wave is calculated in which the soil-UTL interaction system is modelled upon the beam on the elastic foundation. Fig. 8 shows the method schematically. The ground up to the design bedrock is modelled on the multiple mass-spring system, the constants of which are calculated using the method shown by Tamura et al(Ref.1). The motion $f(t-x/c)$ is applied to the bedrock,where $f(t)$ is the measured motion at the design bedrock at No.3 point and c indicates the apparent horizontal phase velocity. The value of

1400m/sec is used for c, which velocity is mean phase velocity of the phase velocity calculated from the observed earthquake motion(Ref. 3). In the second method(Method 2), the response of the UTL due to surface wave is calculated.Fig. 9 shows the method schematically. The same soil-UTL interaction model with Method 1 is used in Method 2. The input surface wave fs(t)is calculated by

$$fs(t) = \int_{-\infty}^{\infty} F_s(\omega) e^{i\omega x/C(\omega)} d\omega \qquad (1)$$

Here x indicates coordinate axis along the structure, t indicates time, $C(\omega)$ indicates theoretical phase velocity, $Fs(\omega)$ indicates Fourier spectrum of the separeted surface wave from observed earthquake motion, respectively.

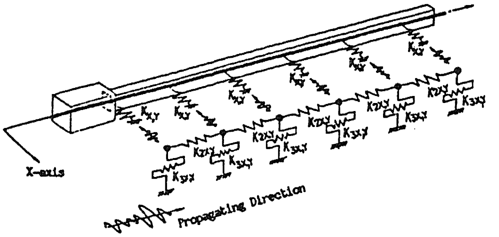

Fig. 8 Analytical model(Method 1)

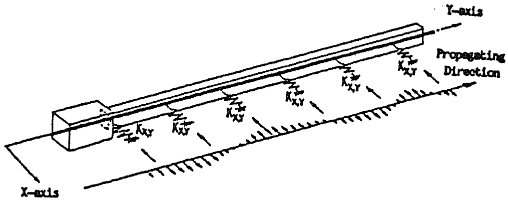

Fig. 9 Analytical model(Method 2)

The time histories of the axial strain at the center between the expansion joints for Naganoken Seibu Earthquake(1985) are shown in Fig. 10 as an example. The waveform of the observed strain between 20 seconds and 60 seconds is similar to the strain calculated by Method 2.

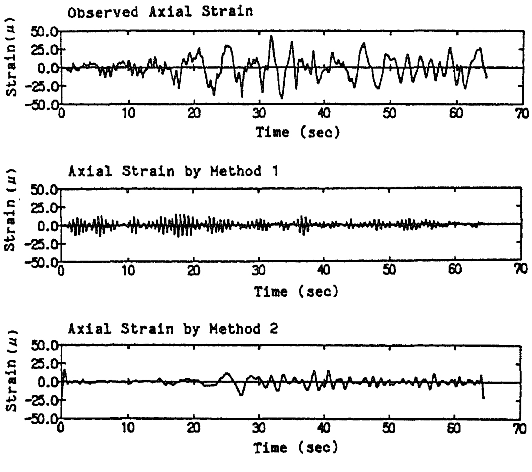

Fig. 10 Observed and calculated axial strain at Naganoken Seibu Earthquake

The distribution of the axial force calculated from the observed strain and the strain calculated by both Methods are shown in Fig. 11 for Naganoken Seibu Earthquake(1985,M=6.8) and Miyakejima Kinkai Earthquake(1982,M=6.4). The axial force calculated by both Methods is smaller than that calculated from the observed strain for the former earthquake. However, for the latter earthquake, the axial force calculated from the observed strain shows good agreement with that calculated by Method 2. For the other earthquake, ratio of calculated maximum axial strain to observed one is shown in table 1. It is recognized that Method 2 usually predicts maximum axial force well although it underestimates a little, but Method 1 somotimes predicts maximum axial force much smaller.

CONCLUDING REMARKS

This paper describes the effect of the surface wave component on the dynamic behavior of the underground transmission line, which are summarized as follows:

1) Maximum amplitude of the velocity of surface wave is a half of that of the observed earthquake motion.
2) There is adequate correlation between the maximum strain of underground transmission line and the maximum velocity of the earthquake motion.
3) The axial deformation of the underground transmission line is predominantly controlled by the surface wave.

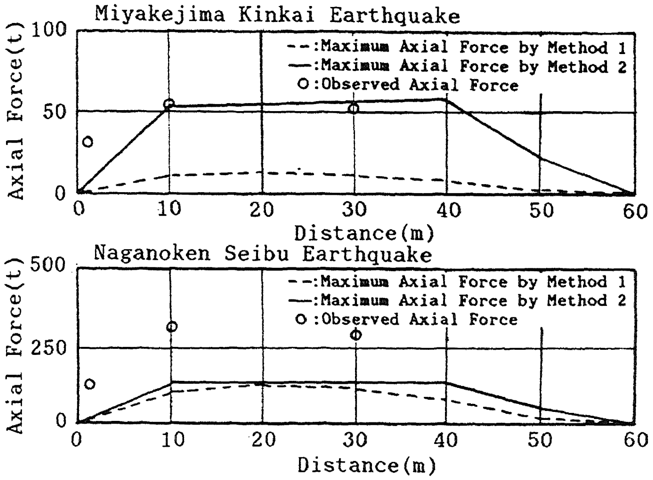

Fig. 11 Maximum axial force distribution

Table 1 Ratio of calculated maximum axial strain to observed maximum axial strain

Name of earthquake	Method 1	Method 2
Southern Chubu	0.586	0.707
Miyakejima Kinkai	0.214	0.977
West Setonaikai Region	0.386	0.676
Naganoken Seibu	0.375	0.404
North West Wakayama Pref.	0.378	0.919

REFFERENCES

1. Tamura, C., Okamoto, S. and Hamada, M., "Dynamic behavior of a submerged tunnel during earthquake", Report of The Institute of Industrial Science, The University of Tokyo, Vol.24, No.5, (1975).
2. Oishi, H., Sekiguchi, K., "Earthquake Observation of Underground Pipeline and Seismic Response Analysis", Proceedings of the 8th World Conference on Earthquake Engineering, 295-302, (1984).
3. Ieda, R., Tsuchiyama, S., Yoshida, N., Nakamura, S. and Tsujino, S., "Effect of Earthquake motion on the Dynamic behavior of underground transmission line", Proceeding of Third International Conference of Soil Dynamics and Earthquake Engineering,Structure and Stochastics Methods, 295-310, (1987)
4. Dziewonski, A., Block, S. and Landisman, M., "A Technique for the analysis of transient seismic signals", Bull. Seis. Soc. Am., Vol.59, No.1, 343-356, (1971)
5. Sutton, G., H. and Pomeroy, "Analog analysis seismograms recorded on magnetic tape", Journ. Geophs. Res., 68, 2791-2815, (1963)
6. Nakamura, S. and Yanagisawa, E., "Application of non-linear surface wave response analysis to liquefaction damage to Hachirougata reclaimed dike due to Nihonkai Chubu Earthquake",Proceedings of the 2nd International Conference of Numerical Models in Geomechanics, 661-668, (1986)