Seismometric Investigation of the Motion of a Submerged Tunnel in Earthquake and at Ordinary Time

by

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Synopisis A submerged tunnel was completed in 1974, by the Nippon Kokan Kabushiki-kaisha, joining the Mizue and Oogishima sites of the Company, which lie on both sides of the Keihin Canal. The seismological observation is being carried on for the purpose of clarifying the vibrational characteristics of tunnel. This is necessary for the integrity and control of this tunnel. In this observation, the seismographs are installed not only in the tunnel, but also on the ground nearby. Further the strainmeters and steel-strainmeters are laid on the body of tunnel. Thus, the simultaneous observation of the movements of the ground and tunnel is made possible. Some results of observations of microtremors, earthquakes and the motions due to blasting are reported.

Submerged Tunnel The tunnel cited here is an exclusive road connecting the Mizue site and Oogishima which is an island recently reclaimed from the sea, and about 5.16 million m^2 in area. The total length of the tunnel measures, 1,540 m, of which 660 m is occupied by the submerged tunnel laid on the bottom of the Keihin Canal, Fig. 1. This submerged tunnel is composed of six elements of steel-cell-caisson, each being 110 m in length, 21.6 m in width, and 6.9 m in height. Its base is laid at a depth of KP (- 21 m) ; KP, the standard level in the Kawasaki Port situated nearby. In other words, the base lies on an alluvial clay which has been proved to have a uniaxial compression strength of 1.5 $\sim$ 2.8 kg/cm^2.

The merits of the steel-cell form of tunnel lie in its resistibility against earthquake, tenacity, water-tightness, engineering easines and also in its comparatively low cost. As this tunnel is situated in a seismically active region as was shaken violently several times in the past, for examples, by the great Kwanto earthquake of 1923 and the like of 1703, this form of tunnel is suitable for the one which is constructed in such an area as necessitates the warning against a future big earthquake.

It should be remarked that, in parallel with the designing and construction works of this tunnel, a model experiment was carried out for the purpose of studying the vibrational characteristics of the steel pipes buried in the ground, with the results as was reported at the 5th WCEE, Rome in 1973. (See, Proc. 5th WCEE, Vol. 1, p 583, 1974.)

Seismographs and Strainmeters The instruments which have been installed in the tunnel and on the ground are as follows : (Particulars of instruments are omitted.)

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1) Acceleration Seismographs (Kinemetrics, installed in tunnel at Points B, C, D, E, G, I and at Points A, J on the ground).
   Underground Seismograph (installed at -60 m below J).
2) Strainmeters (by fours in Section D, and by twos in Sections E, F, H)
3) Steel-strainmeters (by fours in Sections F, H)

The strainmeter indicates the transient stresses produced in the concrete wall or ceiling of the tunnel, while the steel-strainmeter stresses caused in the steel bar buried in the concrete.

Microtremors Microtremors were observed on November 13 and 14, 1974, at eleven points in total, nine in the tunnel and two on the ground. The seismographs (transducers) used in this observation were those of the moving coil type having a natural period of 1.0 second. At each point, the measurement was made in three component directions, i.e., two horizontal directions which were parallel and perpendicular to the axial direction of the tunnel, and vertical direction. By means of the data-recorder the tremors were recorded continuously for 15 minutes. A part of the record thus obtained was digitized and then analyzed by means of the electronic computer. Power spectrum curves were constructed for the tremors observed at every point and in every component direction. Specimen curves are shown in Fig. 2, (a) and (b). In each figure, are illustrated the power spectrum curves, one for the ground surface and the other for point D, the middle point of the tunnel. In the axial direction, the peak-frequencies of 0.26 ∿ 0.30 Hz and 0.7 ∿ 0.8 Hz are seen commonly on the ground surface and at D, while in the lateral direction, the peaks of 0.8 ∿ 0.9 Hz and 1.1 Hz are seen commonly. In Table 1, are listed the predominant peak frequencies at point B, D and I.

Next, the deflections of the tunnel in a horizontal direction was investigated for the modes of vibration with frequencies of 0.8 and 1.1 Hz. (Fig. 3). In this figure are compared the deflections which were derived from the power spectra with those from the waves filtered by the band pass filter. It may be said roughly that the deflections as shown by full lines and broken lines are of a similar form in the cases of these frequencies. In the case of a feeble ground motions, such as the microtremors, there seems no perceptible difference between the motions of the ground and the tunnel.

Ground Motion due to Explosion An explosion experiment was made on December 4, 1975, by a research group organized by geologists and seismoligists, for the purpose of exploring the geological structures at deep places in Tokyo and its vicinities. Taking advantage of this experiment, we made the observation in our tunnel.

The shot point was situated in Oogishima and at about 700 m from the Oogishima portal of the tunnel, but, measured obliquely against the extension of the axial direction of tunnel. An explosive (dynamite) weighed 300 kg was fired at 90 m below the ground surface.

The blasting motions were observed at three points B, D and I in the tunnel by means of the three-component moving coil type seismographs, and by the acceleration seismometers installed on the ground and in the underground (-60 m) near the Oogishima portal. Specimen records obtained are shown in Fig. 4.

Similarly as in the case of the microtremors, the power spectrum curves were constructed for the vibrations observed at points B, D and I, and the predominant peak frequencies were determined and listed in Table 1.

In comparing the peak frequencies determined here with those formerly determined for the microtremors, no much difference can be seen between.

The motion of the tunnel due to explosion has the maximum amplitude of 40 $\sim$ 50 μ in the lateral and vertical directions, and 10 $\sim$ 20 μ in the axial direction. The amplitudes are nearly ten times as large as those of microtremors. By the way, the maximum acceleration at 60 m below the ground surface is 20 $\sim$ 30 gal, while on the ground it is 40 $\sim$ 50 gal, showing that the magnification of intensity of the ground motion due to the superficial soil layer becomes 2.0 in this case.

From the comparison of the peak frequencies as shown in Table 1, the ground and tunnel show similar vibrational characteristics while the ground motion are feeble such as the microtremors and blasting.

Earthquakes Several number of earthquakes were observed since the installation of the instruments, but only the following earthquake will be taken up for an example.

Earthquake of December 15, 1975 - - - - Intensity III (JMA - scale), corresponding to IV $\sim$ V on MM - scale, at Tokyo and Yokohama. Epicenter (tentative) : 35.5° N, 140.2° E, (Central part of Chiba Prefecture) ; focal depth (tentative) 60 km.

In Fig. 5(a) are shown the specimen records of strain waves obtained at the time of this earthquake, at points D-1 and D-2 lying on both sides of the tunnel, see Fig. 1.

Strain analysis is made after the recorded waves are all digitized. Then, we have the axial strain produced in tunnel by adding the strain waves at D-1 and D-2, and by subtracting the waves at these points, we have bending strain. The strain waves thus determined are shown in Fig. 5(b), the upper waves relate to the axial strain and the lower to the bending strain. The strain waves which appear near the left end of the figure are surely produced by the principal earthquake motions (S phase). It is said that the earthquakes which originate near Tokyo and Chiba display the following type. The preliminary tremors are comparatively small, and after they have continued about 6 or 7 seconds, the principal wave with large amplitude suddenly appears, and after making one or two complete vibrations this phase suddenly diminishes in amplitude. From this fact, the strain waves which are seen near the right end of the figure are thought to be the ones produced by the coda waves. On the whole, waves of the periods of nearly 1.0 second and 0.4 second are predominant. The power spectrum curves were constructed for the axial and bending strain waves. On the other hand, the accelerogram of the earthquake motion in the underground (at -60 m) was analyzed, and the power spectrum curves are also constructed. Fig. 6 shows these spectrum curves.

It will be seen that the acceleration has predominant peaks at higher frequencies ranging 3 and 4, while the strain has the peaks at lower frequencies lying between 1 and 2. These lower frequencies have been proved to be the ones which are proper to the ground vibration, through the former investigations of the microtremors and the ground motion due to blasting.

As the results of observations so far mentioned above, it may be said that the motion of the tunnel is very similar to that of the surrounding ground, and therefore it is ruled by the vibrational characteristics of the ground. There may be, however, some possibility of getting a negative result in the case of a big earthquake motion.

<u>Change in Level of Tunnel</u> Generally, it is expectable that there occurs a certain chronic change in level of newly constructed structures for several years or months after the completion. To measure the change in level of this tunnel, the leveling survey started in January 1975, and repeated in March, September and November of the same year, and in May 1976. The standard (fixed) bench mark lies on the Mizue side and is considerably apart from the tunnel. In Fig. 7(a), are shown the results of leveling surveys carried out heretofore. The level which surveyed in January 1975 is taken as the standard, and to this all the changes in level caused thereafter are referred. As points 8 and 9 lie near Oogishima, the changes in level show somewhat larger amounts as compared with other points. This may be due to gradual settlement of Oogishima, a newly reclaimed land. In Fig. 7(b) are shown the changes in level with time measured at points 4, 5 and 7.

It was found that the subsidence of an order of 40 mm in the maximum occurred during one and a half years since the completion of the tunnel. This may be a natural result.

Acknowledgements

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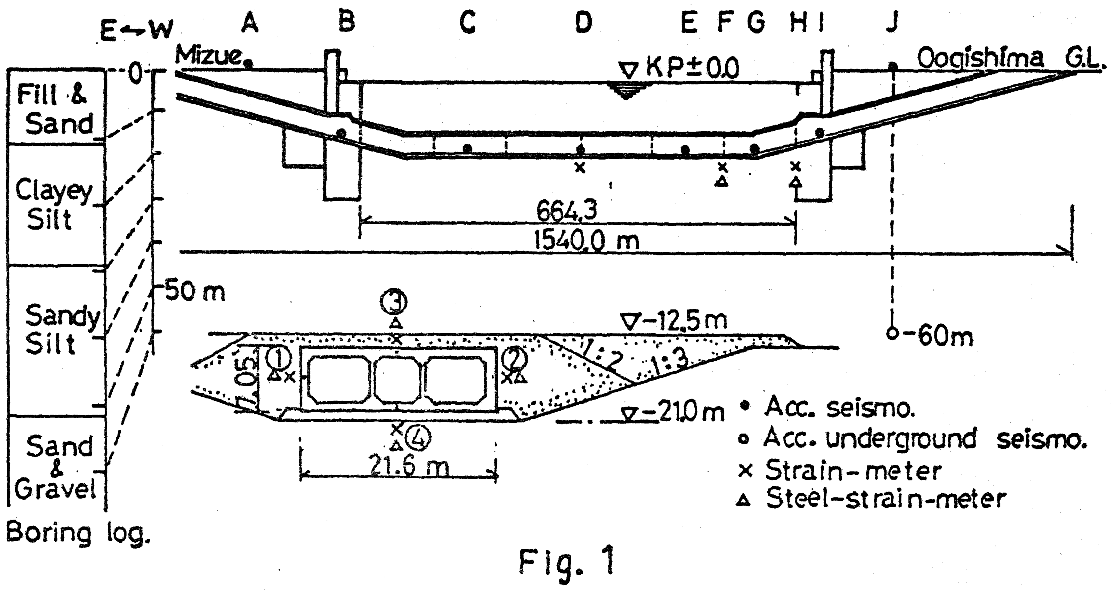

Fig. 1

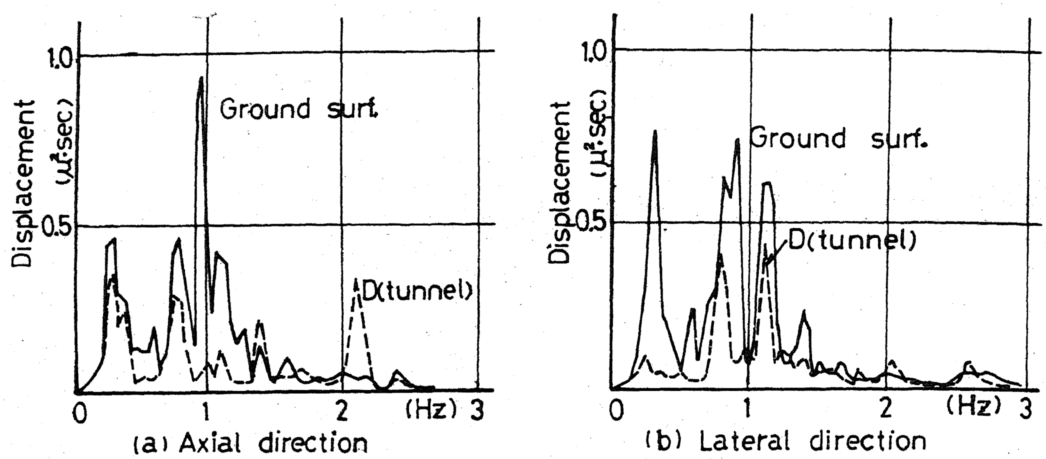

Fig. 2 Power spectra. (Microtremor)

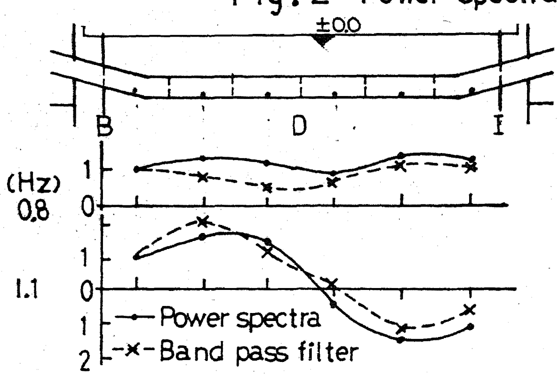

Fig. 3 Deflection curves. (Microtremor)

Table 1 Peak frequencies (Hz)

Pt	Microtremor					
B	0.85	1.15	1.30			2.10
D	0.85	1.10	1.30		1.65	2.10
I	0.90	1.10			1.70	2.00
Pt	**Blasting**					
B	0.80	1.15		1.55		2.10
D	0.80	1.15	1.40	1.55	1.75	2.05
I	0.85	1.00	1.45			

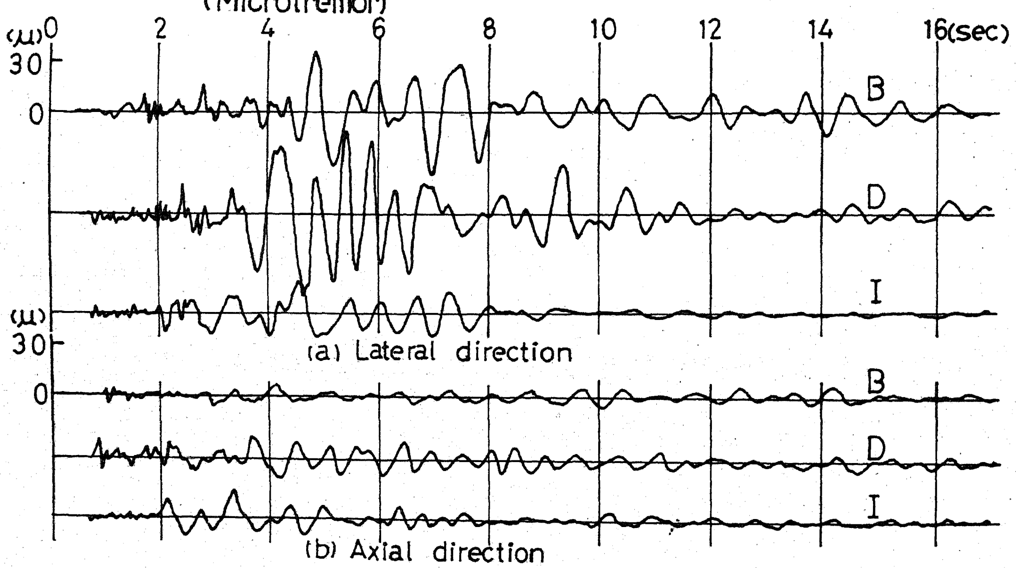

Fig. 4 Observed waves in tunnel. (Blasting)

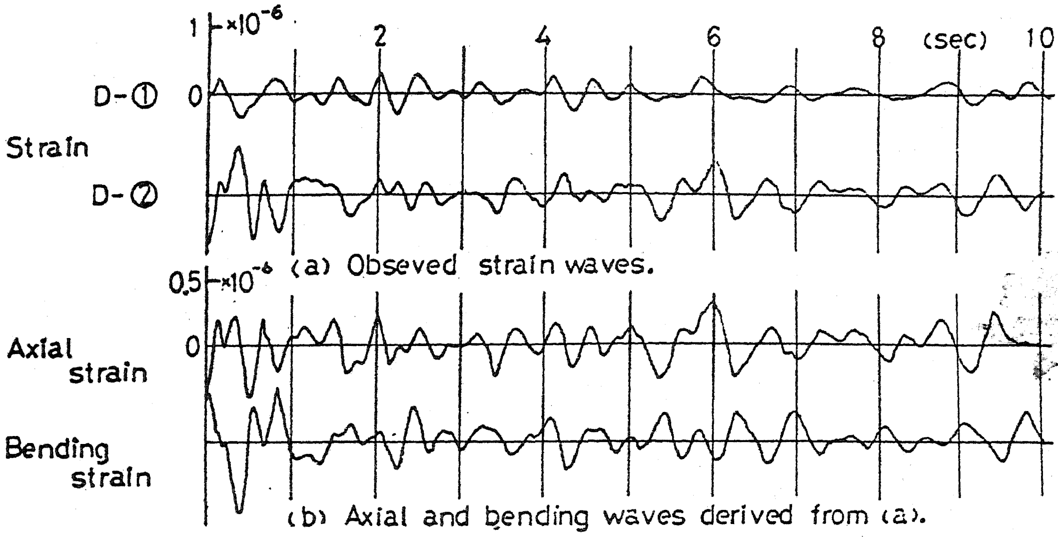

Fig. 5 Strain waves. (Earthquake: Dec. 15, 1975)

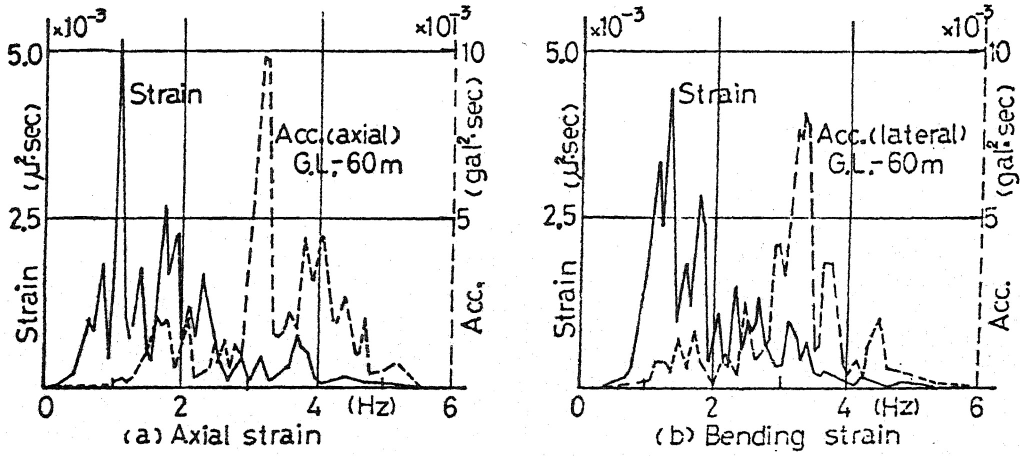

Fig. 6 Power spectra.(Earthquake: Dec. 15, 1975)

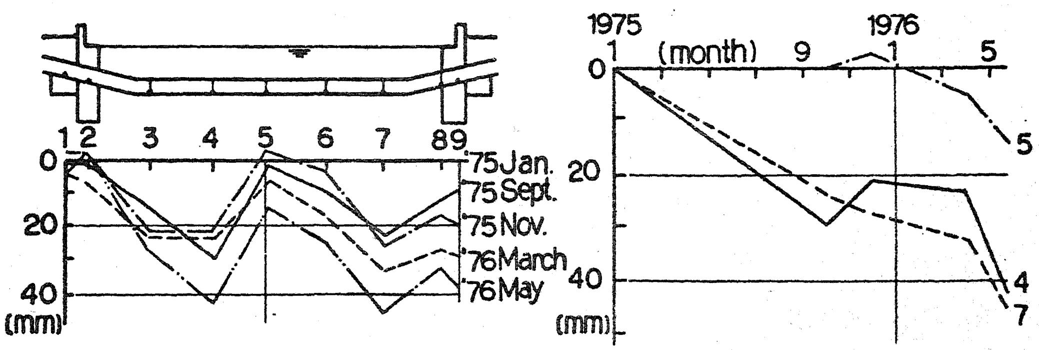

Fig. 7 Change in level.