OBSERVATIONS OF THE SEISMIC BEHAVIOR OF OUTDOOR TELECOMMUNICATION FACILITIES

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SUMMARY

The authors have been carrying out observations of the seismic behavior of outdoor telecommunication facilities as a major part of comprehensive investigations. In this paper, the observation system is introduced first. Secondly, from the records obtained by 3 earthquakes, we present the results of analysis about the relation between seismic behavior of ground and conduit strain, and required further study as to application of the Seismic Deformation Method to seismic analysis method of underground conduit is mentioned. Finally, seismic performance of telephone poles by calculating stresses during earthquake based on the fundamental characteristics of seismic behavior of telephone poles is discussed.

INTRODUCTION

Among telecommunication facilities, underground conduits, telephone poles and so on, which are constructed outdoors, are especially susceptible to damage in earthquakes. Therefore, the authors have been carrying out investigations based on theoretical analysis, vibration test, observation and so on, in order to establish rational seismic design method and improve seismic performance. Observation plays a major part of comprehensive investigations in order to grasp the seismic behavior on actual ground and verify application of seismic analysis method.

OBSERVATION SYSTEM

Surface geological condition around the observing site is almost uniform. The surface is covered by volcanic soils and is underlaid by sand and clay. Base rock is composed of diluvial dense sand and gravel. Figure 1 shows typical soil profile at the observing site.

Figure 2 shows observation facilities and location of measuring

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instruments. Observation facilities comprise underground conduits in NS and EW directions (each has a length of 80m) and overhead line structures in NS and EW directions (each has a length of 105m). By the facilities, ground acceleration (at G.L.-2.2m and -35.0m), conduit acceleration and strain, telephone pole acceleration, guy and strand tension and other factors have been measured during earthquake.

Signals from the sensors are constantly transmitted to the data recording system. When the maximum surface acceleration exceeds 3 Gals, triggering of the signals is performed. Triggered signals, passing through sensor interface, are digitized by A/D converter and stored on magnetic tape. Stored data are illustrated as time history by the data processing system, and are analyzed using the NTT computer system (DEMOS-E). Figure 3 shows the outline of the data recording and processing system.

SEISMIC BEHAVIOR OF UNDERGROUND CONDUITS

Observation was initiated in March, 1982. Up to August, 1983, 26 earthquake records were triggered. Of these observed records, 3 earthquake records with large base rock acceleration shown in Table 1 which differed in magnitude and epicentral distance were analyzed.

Seismic Behavior of Ground

Ground acceleration records and power spectra are shown in Figure 4 and 5. For EQ-1 and EQ-2, predominant frequencies of surface acceleration exist in not only base rock acceleration, but around 1.8 Hz which is agreement with primary natural frequency of surface. This implies that ground motion is amplified according to characteristics of the surface. On the other hand, for EQ-3, predominant frequencies of surface acceleration is in agreement with those of base rock acceleration, and characteristics of the surface are not applicable.

The cross correlation functions were calculated for pairs of ground acceleration records measured both on the same vertical and horizontal planes as shown in Figure 6. For EQ-1 and EQ-2, peak and time lag are observed in both vertical and horizontal directions. Assuming that the time lag is associated with propagation of seismic waves, velocities of wave propagation are as shown in Table 2. Particularly, vertical velocities of wave propagation are in fairly good agreement with the equivalent velocities calculated from the results of seismic prospecting. That is,

$$Vs = \frac{\Sigma Vsi \cdot Hi}{\Sigma Hi} \qquad (1)$$

where

Vsi : S wave velocity in each layer
Hi : thickness of each layer

Substituting the values shown in Figure 1 in Eq. (1),

$$Vs = 247 \ (m/s)$$

On the other hand, for EQ-3, clear peak and time lag are not observed, so apparent velocity of wave propagation is significantly large. This shows that wave propagation is not apparently observed for EQ-3.

The above analysis proves that characteristics of ground motion for EQ-3 differ from that for EQ-1 or EQ-2.

Seismic Behavior of Ground and Conduit Strain

Various reports have been presented on the relation between conduit strain and seismic behavior of ground, namely ground acceleration or velocity. Ref. (1) presented the following results with the notation that it was dubious whether the results applied to earthquakes with large magnitude or with short epicentral distance:

(1) Conduit strain is more strongly correlated with surface velocity than with surface acceleration. Conduit strain is directly proportional to surface velocity.

(2) For the same level of maximum surface acceleration, conduit strain increases with earthquake magnitude or epicentral distance.

For this study, records were obtained by 3 earthquakes which differ in magnitude and epicentral distance one another. Especially, it is proved that characteristics of ground motion for EQ-3 differ from that for EQ-1 or EQ-2, as mentioned above. So, we analyze the relation between seismic behavior of ground and conduit strain.

Table 3 shows the comparison between maximum surface acceleration, maximum surface velocity and maximum conduit strain. For EQ-1 and EQ-2, surface acceleration by EQ-1 is larger than that by EQ-2, but surface velocity and conduit strain by EQ-2 is larger. And between EQ-1 and EQ-2, conduit strain is directly proportional to surface velocity. This result is similar to the result of previous reports. On the other hand, for EQ-3, conduit strain is small considering surface velocity. This assumed that the reason why conduit strain is small is that velocity of propagation, namely wave length is very large as stated above.

Application of the Seismic Deformation Method

As stated in the previous paragraph, underground conduit strain during earthquakes differs according to the characteristics of ground motion. However, in the Seismic Deformation Method, which is now thought to be a simple analysis method of seismic behavior of underground conduit, characteristics of ground motion are not considered. So, in this paragraph, we analyze difference between observed conduit strain and calculated conduit strain by the Seismic Deformation Method, and investigate application of this Method to seismic analysis method of underground conduit.

Table 4 shows the comparison between calculated maximum conduit strains and observed maximum conduit strains. In the calculation, observed maximum base rock accelerations were substituted in seismic coefficient in order to compare the calculated with the observed. As for Table 4, calculated maximum conduit strains exceed observed ones, but the ratios are various values according to the earthquakes.

Consideration for EQ-3 were as stated above, namely for EQ-3, wave length is very large, but it cannot be evaluated exactly by the Seismic Deformation Method in which assumed wave length is fixed according to the surface geological condition at the site. So, EQ-3, which may be regarded as near-field earthquake considering its epicentral distance, further study is required as to evaluating wave length based on characteristics of ground motion.

Comparing between for EQ-1 and EQ-2, the ratios are different each other. Considering that conduit strain is directly proportional to surface velocity, if surface velocities are evaluated exactly in the calculation, the ratios must be similar. However, in the Seismic Deformation Metod, surface velocity per the unit seismic coefficient is given fixed value according to the surface geological condition at the site, so calculated conduit strain is proportional to base rock acceleration. Therefore, the way of evaluating surface velocity directly or indirectly during different earthquakes must be investigated in order to apply of the Seismic Deformation Method to analysis method of underground conduit.

SEISMIC BEHAVIOR OF OVERHEAD LINE STRUCTURES

We have been carrying out observations of the seismic behavior of overhead line structures during earthquakes, and we find out the fundamental response characteristics of overhead line structures. From this result, we calculate the magnitude of stress which occurs at telephone poles due to earthquakes.

Maximum accelerations of telephone poles and ground, during earthquakes, are shown in Figure 7. As this result, we conclude that the average acceleration at the top of poles is about 5.6 times that of ground acceleration and that the response of telephone poles parallel to the line is larger than the perpendicular by about 2.0 times. The result of the latter is obtained from calculated displacement by integrating acceleration, too.

Amplitude spectra of poles are shown in Figure 8. On the basis of this result, we determined that primary natural frequency of telephone pole is about 3 Hz and that secondary is about 15 Hz. However, the width of ground frequency is about 1 to 3 Hz, so the pole vibration element of 15 Hz is lower than 3 Hz by approximately 1/18. So, the behavior of pole is restricted by the first mode.

Incidentally, the amplitude spectra of end poles and main poles contain the amplitude spectra of guy, strand and pole. However, the first mode of end poles and main poles is much larger than the second mode, so the behavior of end poles and main poles is restricted by the first mode as in the case of separation pole described above.

Therefore, shear and bend stress are calculated as shown in Figure 9 when telephone pole behaves first mode and acceleration rate at the top of the pole is regarded as 5.6. Our conclusion is that poles which are erected in similar ground with the observing site are not destroyed by stronger than 200 Gals ground acceleration, which is standard level to design a building. It is proved that telephone poles are seismic proof structures.

CONCLUSIONS

Based on the results presented, the following conclusions may be deduced.

(1) In case of EQ-3, which may be regarded as near-field earthquake, wave length calculated by the Seismic Deformation Method cannot apply.
(2) Except for EQ-3, conduit strain is directly proportional to surface velocity. For the same level of maximum surface acceleration, conduit strain increases with earthquake magnitude or epicentral distance.
(3) Further study is required as to evaluating wave length and surface velocity based on characteristics of ground motion rationally in order to apply of the Seismic Deformation Method to seismic analysis method of underground conduit.
(4) Response of telephone poles in the longitudinal direction of the line is larger than that in the transverse direction.
(5) The primary and secondary natural frequency of a telephone pole is found to be about 3 Hz and 15 Hz, respectively. The first mode of the pole is dominant, because the predominant frequency of ground is 1 to 3 Hz at the observing site.

REFERENCES

(1) M. NAKAMURA : Estimation of Seismic Ground Strain by Quantitative Analysis of Observed Strains in Underground Structures, Proc. of the Sixth Japan Earthquake Engineering Symposium, 1982

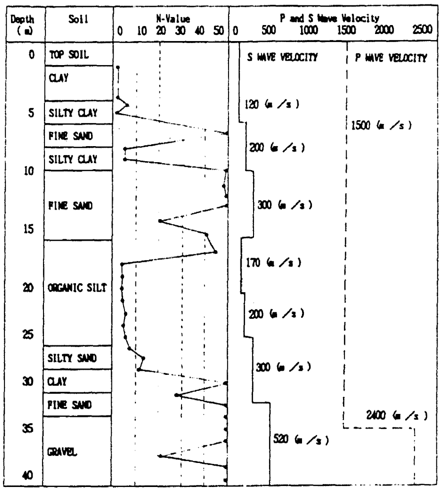
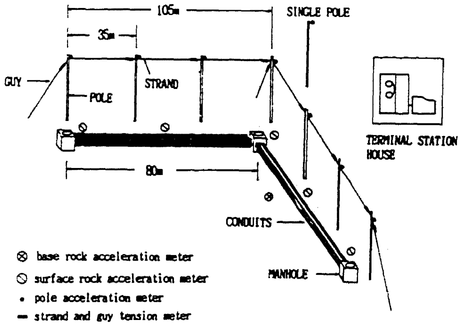
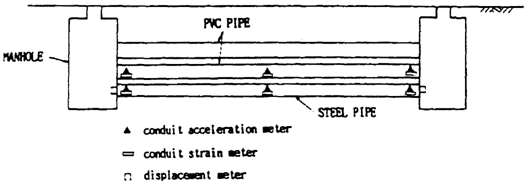


Fig.1 Typical Soil Profile



(a) General View of Underground Conduits and Overhead Line Structures



(b) Cross Section of Underground Conduits

Fig.2 Observation Facilities

Table.1 Earthquake Records

EQ.No	Date	Epicenter			Epicentral	JMA	Depth	Max.Acceleration (Gal)	
		Region	Longitude	Latitude	Distance (km)	Magnitude	(km)	Base Rock	Surface
1	1982.3. 7	KASHIMA-NADA	140°42′	36°30′	50	5.6	60	52	81
2	1982.7.23	OFF-IBARAKI PREF.	141°55′	36°15′	170	7.0	10	31	55
3	1983.2.27	S IBARAKI PREF.	140°06′	35°58′	15	6.0	70	49	134

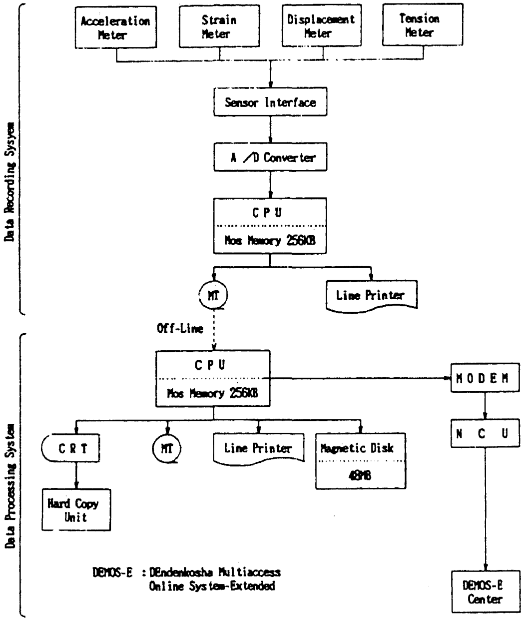


Fig.3 Outline of Data Recording and Processing System

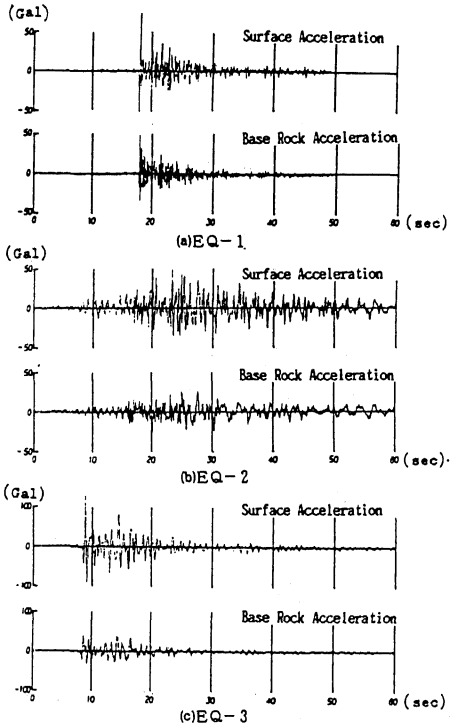


Fig.4 Ground Acceleration Records

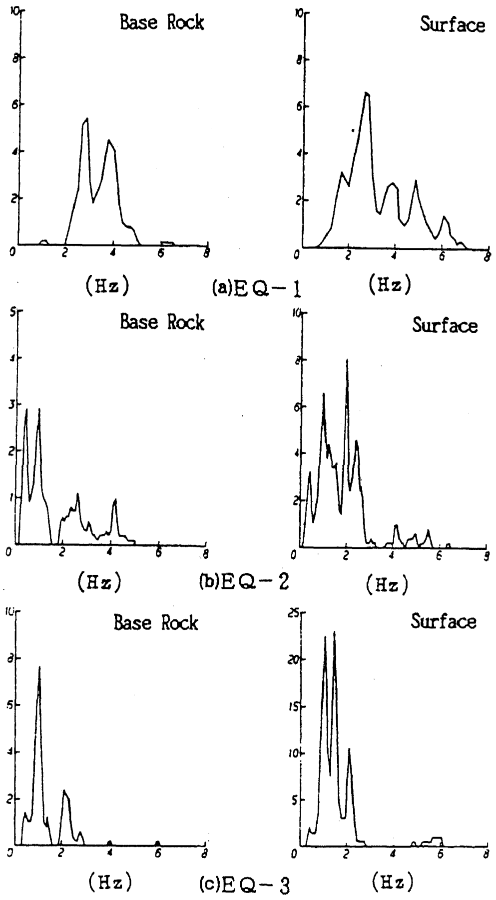


Fig.5 Power Spectra of Ground Acceleration

Table.3 Comparison between Maximum Conduit Strain and Maximum Surface Acceleration, Maximum Surface Velocity

EQ.No	Conduit Strain (μ)		Surface Acceleration	Surface Velocity
	Steel Pipe	PVC Pipe	(Gal)	(cm/s)
1	46	56	81	4.2
2	77	96	55	7.4
3	19	25	134	14.4

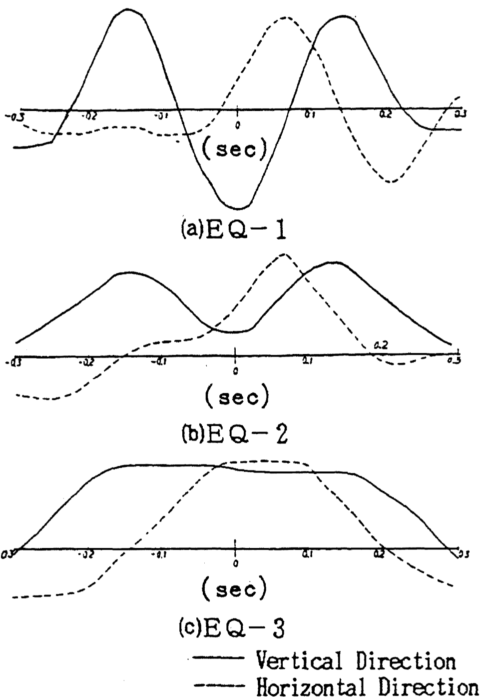


Fig.6 The Cross Correlation Functions

Table.2 Velocities of Wave Propagation

EQ.No	Velocity of Wave Propagation (m/s)	
	Vertical Direction	Horizontal Direction
1	230	1890
2	240	1530

Table.4 Comparison between Calculated and Observed Conduit Strain

EQ.No	Conduit	Strain (μ)		①/②
		①Calculated	②Observed	
1	Steel Pipe	167	46	3.63
	PVC Pipe	167	56	2.98
2	Steel Pipe	100	77	1.30
	PVC Pipe	100	96	1.04
3	Steel Pipe	157	19	8.26
	PVC Pipe	158	25	6.32
			Average	3.92

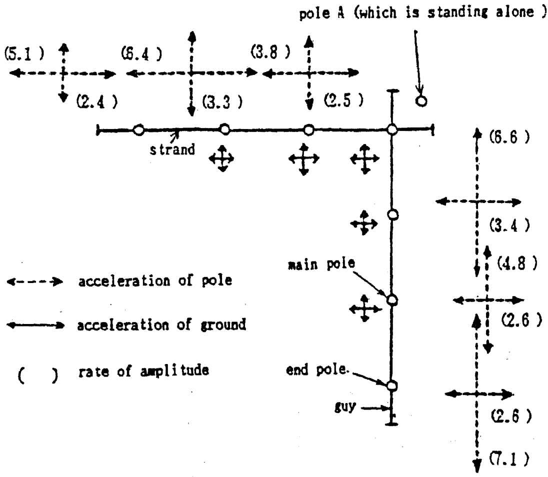
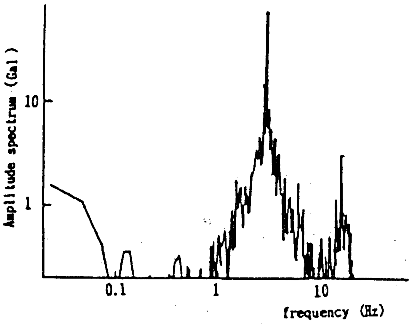
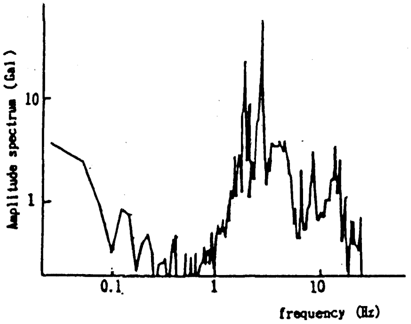


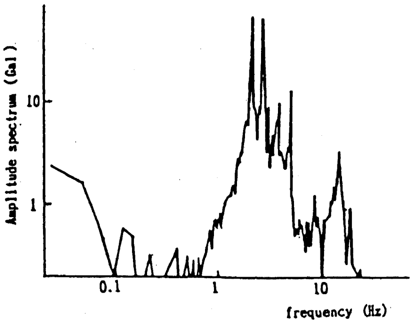
Fig.7 Maximum Accelerations of Telephone Poles and Ground



Acceleration of pole A

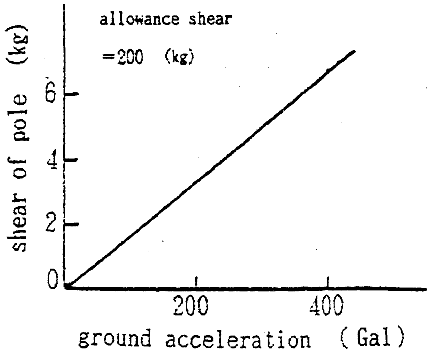


Acceleration of main pole

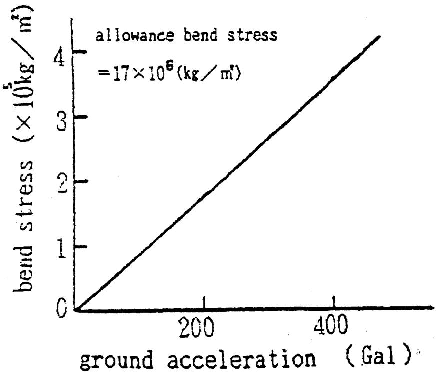


Acceleration of end pole

Fig.8 Amplitude Spectra of Poles



Shear of pole



Bend stress of pole

Fig.9 Calculated Shear and Bend Stress