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UDC 550.34.016: 624.194

EARTHQUAKE OBSERVATION ON TRENCH TYPE SUBAQUEOUS TUNNEL

—MAINLY ON STRESSES AT THE WALL—

沈埋函に生ずる地震時応力の観測について

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1. Introduction

Recently at the estuary of the Tama River a long trench type subaqueous tunnel has been constructed for railway use. Since a trench type subaqueous tunnel is generally constructed in the soft surface layer, the dynamic behavior of the tunnel of this type may be quite different from that of the ordinary tunnels those excavated in rocks. Hence to have a clear understanding of the dynamic behavior of this tunnel, the earthquake observation at field has been continued from this spring.

The vibration model test[1] had already been carried out in this laboratory to investigate the dynamic properties of the pipes which pass through the soft layer, three years before. In that experiment the Tefron bar was used to simulate to the pipe and the gelatin to the soft layer. From the model test the following conclusions have been drawn;

—Even though that the ratio of the Young's modulus of the pipe material to that of the soft layer and also that of the density of the pipe to that of the soft layer, are very large compared to those in real structure, yet it was observed that the motion of the pipe was not independent to the soft layer, and that the natural vibration of pipe were not excited in ordinary cases.—

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The present work deals with the earthquake observations on the real structures based mainly on the strain at the tunnel wall.

The Tama Trench Type Subaqueous Tunnel is located at the estuary of the Tama River draining into the Tokyo Bay. The tunnel consists of 6 tube elements having elliptical cross section. Each of them being 80 m in length. The tunnel is made of steel shell and thick RC lining is provided inside the shell. Each element is connected according to the waterpressure joint method and finaly the inside of the joints have been covered by reinforced concrete in order to keep the same stiffness and strength as those of the tunnel tube elements.

The foundation along the tunnel consists of the alluvial silt layer lying over the diluvial silt, the thickness of the alluvial layer is about 40 m maximum and not being uniform, as shown in Fig. 9. The tunnel tube passes through the peaks of diluvial silt near both the sides of the banks and at the central part of the river it passes through the surface of alluvial sift layer about 40 m in thickness. In the tunnel 4 acceleration seismometers and 8 high sensitive dynamic strain meters which were developed in this laboratory have been installed.

From May to October in 1970, the records of 5 earthquake motions in the tunnel have been obtained. One of them, fortunately, had it's epicenter just under the observation point which originated on 30th September, 1970. The results of the analysis of these records and instrumentation are described as under.

2. The Arrangement of Apparatus for Observation

Before the completion of the construction work, the earthquake observation of this tunnel was started. The installation of the apparatus was carried out in 2 stages. The first stage was performed in May 1970 and, at the cross section A two acceleration seismometers were installed on the axis of the tunnel tube, as shown in Fig. 1,

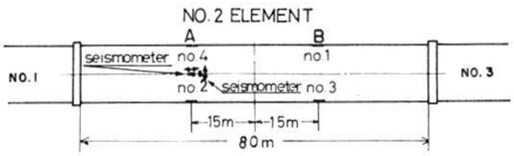


Fig. 1 Arrangement of seismometer and strainmeter in No. 2 Tube element

one being in the direction perpendicular to tunnel axis and the other in the direction of tunnel axis. At the cross section A and B, which are 30 m apart, two dynamic strain meters were installed, inside the tunnel wall, facing each other, as shown in Fig. 2. The second stage of installation

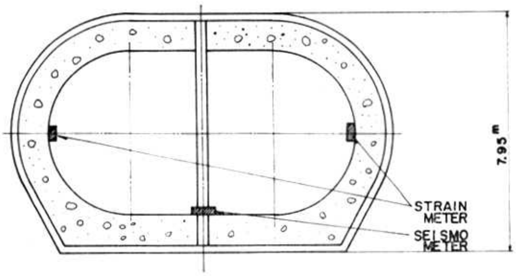


Fig. 2 Arrangement of straitmeter and seismometer at the section

was carried out in September 1970. The arrangement of the apparatus in Tube No. 4 is shown in Fig. 3 and is similar to the arrangement in Tube No. 2. This installation point of seismometers is

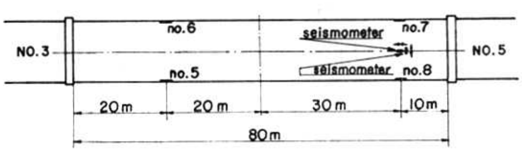


Fig. 3 Arrangement of seismometer and strainmeter in No. 4 Tube element

about 205 m far from that of the former installation point.

As mentioned above, because of, that the foundation conditions at the both of the banks differ from that at the central part of the river, it was expected that the dynamic behavior of foundations at the banks would be much different from that at central part of the river. Hence it was decided to install the apparatus in Tube No. 2, which passes partly in the dilluvial and partly in the alluvial sift, and also in Tube No. 4 which passes only in alluvial silt about 40 m in thickness.

3. High Sensitive Dynamic Strain Meter

The ordinary strain gauge, if installed at the tunnel wall, would show too small strain due to the small earthquake to make it difficult to see and then used for proper analysis, it was thought necessary to magnify records. In order to magnify the direct strain at the wall during earthquakes, the high sensitive dynamic strain meter was developed in this laboratory, as shown in Fig. 4. AB

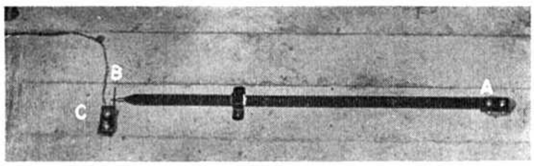


Fig. 4 Strain meter

is a steel Bar 1 m long, fixed at point A, and C is another fixed point to which a cantilever is attached. On both the sides of the cantilever, strain gauges were mounted. The distance between fixed point A and C is 1 m along the axis of the tunnel. The strain developed in 1 m length along the axis due to the earthquake is obtained as recorded by the strain guage, thus giving the strain at the tunnel wall. This being large in value facilitates to carry out the required analysis. The characteristics of this dynamic strain meter are the followings;

1) Since simple mechanism has been used to magnify the record, the apparatus has a good degree of dynamic stability and it also enables to

obtain the required degree of magnification of strain.

2) The sensitivity of this apparatus is quite high and it can measure the strain up to a minimum of 1×10^{-7}.

3) It is so sensitive to thermal changes that it needs to control the zero point movement if it is used for a long time. On the calculation the zero point should be adjusted by 150 μ per degree centigrade change in temperature.

By the observation it is possible to measure the the dynamic strain at the wall of the trench type subaqueous tunnel during earthquake. Since this observation will be continued for a long time, the authors are now making efforts to overcome this defect too.

4. Earthquake Record and it's Analysis

5 earthquake records have been obtained from May to September 1970, as shown in Table 1 and Fig. 11. From the records and the analysis, the following conclusions have been drawn;

1) The effect of the hypocentral distance on the maximum acceleration and the maximum strain developed at the tunnel tube;

The epicenter of the earthquake (Record-4) was off Miyako City, north-easten part of the Honshu Island, the magnitude being 6.8 and the seismic intenstiy bing 3 in JMA scale in Tokyo while the epicenter of the other earthquake (Record 5) was just under the observation point, the magnitude being 4～4.5 and it also had the same intensity 3. Although the intensity of both the earthquakes were same, yet, the acceleration records and the strain records were much different. From the analysis of the record 4 (far earthquake) and the record 5 (near earthquake), it can be observed that;—

Although the degree of acceleration is small in the record 4 (far earthquake), yet, the degree of the strain is large, while in the record 5 (near earthquake), the degree of strain is small even though the degree of acceleration is large. Also in the record 5 (near earthquake) the high frequency parts are predominant whereas in the record 4 (far earthquake) the low frequency parts are predominant. It is interpreted by the authors that the above said phenomenon is dependent on the frequency characteristic of the earthquake vibration.

2) Time lag between maxium acceleration and maxium strain.

Almost all the main part of strain records laged behind that of the acceleration records. It is de-

Table 1 List of earthquake observed

Record No.	Date	Time	Epicenter N	Epicenter E	Depth	Magnitude	Intensity of Earthquake (Tokyo)	Max. Acceleration
1	1970. 5. 17	23. 52	34. 6°	141. 1°			I	1. 34 gals
2	5. 27	21. 06	27. 5°	140. 0°	deep		II	3. 0
3	7. 11	23. 28	36. 6°	140. 5°	60km		I	0. 73
4	9. 14	18. 45	38. 9°	142. 0°	40 km	6. 8	III	2. 6
5	9. 30	4. 26	35. 6°	139. 7°	50 km	4～4. 5	III (Yokohama), II (Tokyo)	12. 1

Table 2 The effect of hypocentral distance on the acceleration, strain. frequency developed at the tube

Record No.	Max. Acc. (gal.)			Max. Strain (μ)	Predominant Frequency (Herz)
	In the Direction to Tunnel Axis (NO 2 Tube)	In the Direction perpendicular to Tunnel Axis (NO 2 Tube)	In the Direction perpendicular to Tunnel Axis (NO 4 Tube)		
4 (Far Earthquake)	10. 9	8. 24	12. 1	1. 2 (NO 1)	3. 5
5 (Near Earthquake)	2. 4		2. 6	1. 72 (NO 2)	1. 1

研究速報

duced that such a time lag takes place because of strain being closely connected to the displacement of earthquake vibration.

3) Deformation of the tunnel tube

From the earthquake record-2, the strain No. 1 and No. 2, being at the same cross section, had nearly equal degree of strain, reverse in phase. This could happen only if the tube is deformed in bending.

On the other hand from the earthquake record-4 the strain records No. 2 and No. 4, being at the same cross section, were in phase and similarly from the earthquake record-5 the strain records No. 1 and No. 3, being at the same cross section, were also in phase. Further from the record-4 and record-5, the acceleration records in the direction of tunnel axis and the corresponding strain records are nearly similar in shape and so is the case with the frequency characteristics records. There two points imply that in these cases the the tunnel tube must have been deformed in the direction to the tunnel axis (push and pull type).

From the foregoing results, the following conclusion are drawn;

"In the trench type subaqueous tunnel, the

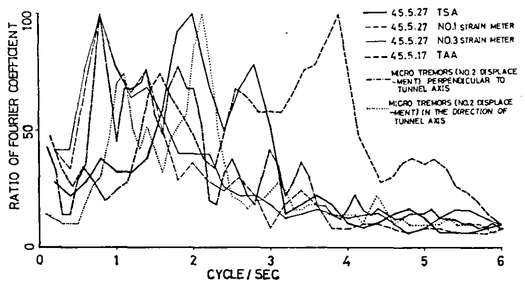


Fig. 5 Foursier analysis of micro tremor and earthquake record 1, 2.

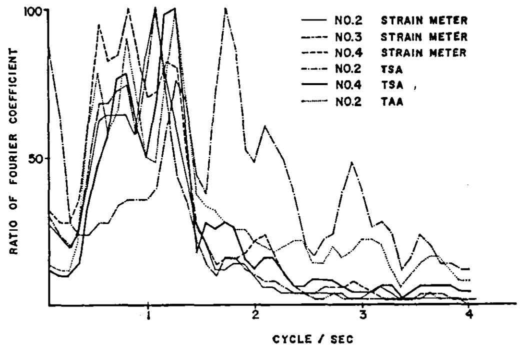


Fig. 6 Fourier analysis of earthquake record 4

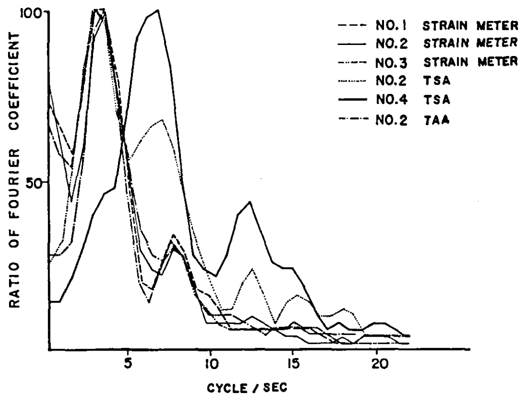


Fig. 7 Fourier analysis of earthquake record 5-1

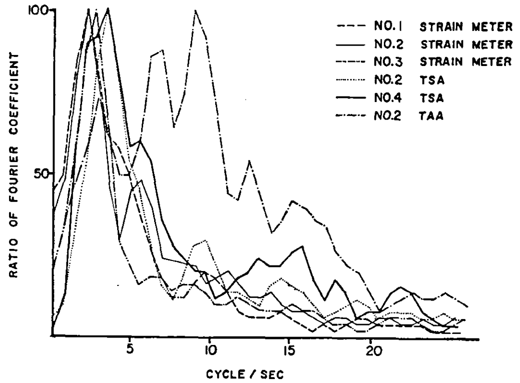


Fig. 8 Fourier analysis of eathquake record 5-2

Table 3 The predominent frequency of the micro tremor records (displacement)

Observation Point	In the Dioection to Tunnel Axis (Herz)	In the Direction Perpendicular to Tunnel Axis (Herz)
Riverside Land at Kawasaki Side	2.9, 3.7	2.0, 2.5
Central Part of NO 2 Tube	0.8, 1.1, 2.2	1.1, 1.9, 2.5
Observation Point of NO 2 Tube	0.8, 1.3	1.1, 2.2
At 20 m from joint of NO 3 and NO 4 Tube	0.9, 1.3	1.0, 1.4
Central Part of NO 5 Tube	0.8, 1.3	1.4
On the Bank at Haneda Side	1.1, 2.5	1.4, 2.1

Table 4 Predominant frequency in the earthquake records (Herz)

Record No	Strain Record	Acceleration Record		
		In the Direction to Tunnel Axis of NO 2 Tube	In the Direction Perpendicular to Tunnel Axis of NO 2 Tube	In the Direction Perpendicular to Tunnel Axis of NO 4 Tube
2	0.9		1.9, 2.8	
4	1.1	1.2, 1.8	0.8, 1.2	0.8, 1.2
5—1	4.5	4.5	4.5	6.0
5—2	1.1	1.3, 3.0	1.6	1.6, 2.4

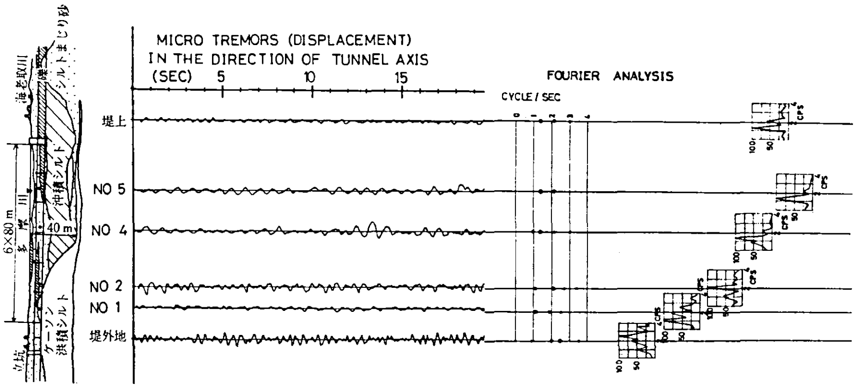


Fig. 9 Micro tremos (displacement) in the direction of tunnel axis
多　摩　川→the Tama River
沖積シルト→alluvial silt
洪積シルト→diluvial silt

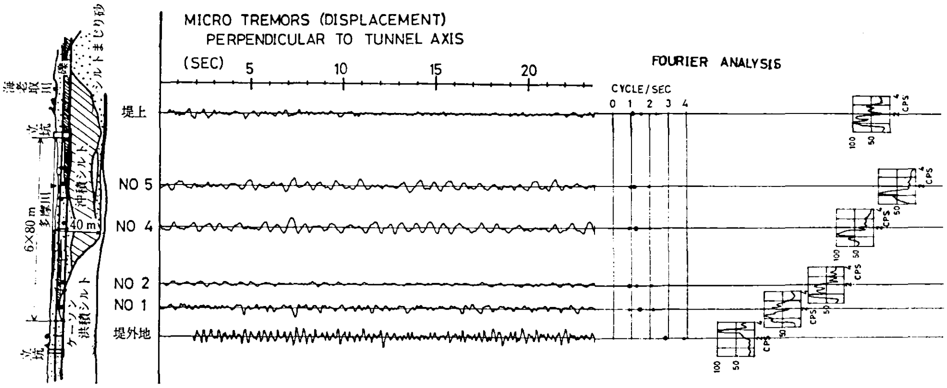


Fig. 10 Micro tremors (displacement) perpendicular to tunnel axis
多　摩　川→the Tama River
沖積シルト→alluvial silt
洪積シルト→diluivial silt

bending and the push and pull deformation take place along the axis of the tunnel during earthquake. It is also clear from the records that the degree of strain due to axial deformation is larger as compared to that due to the bending.

5. Micro Tremors

Authors observed the micro tremor (displacement) in order to investigate the natural period of the tunnel tube and the foundation. Observation points, micro tremor records and results of the analysis are as given by Fig. 9, Fig. 10 and Table 3. Fig. 5, 6, 7, 8 and Table 4 show the comparison between the predominant frequency of micro tremor records and the predominant frequency of earthquake records.

Comparing Table 3 with Table 4, the predominant frequency of the micro tremor records are nearly same to that of the earthquake records.

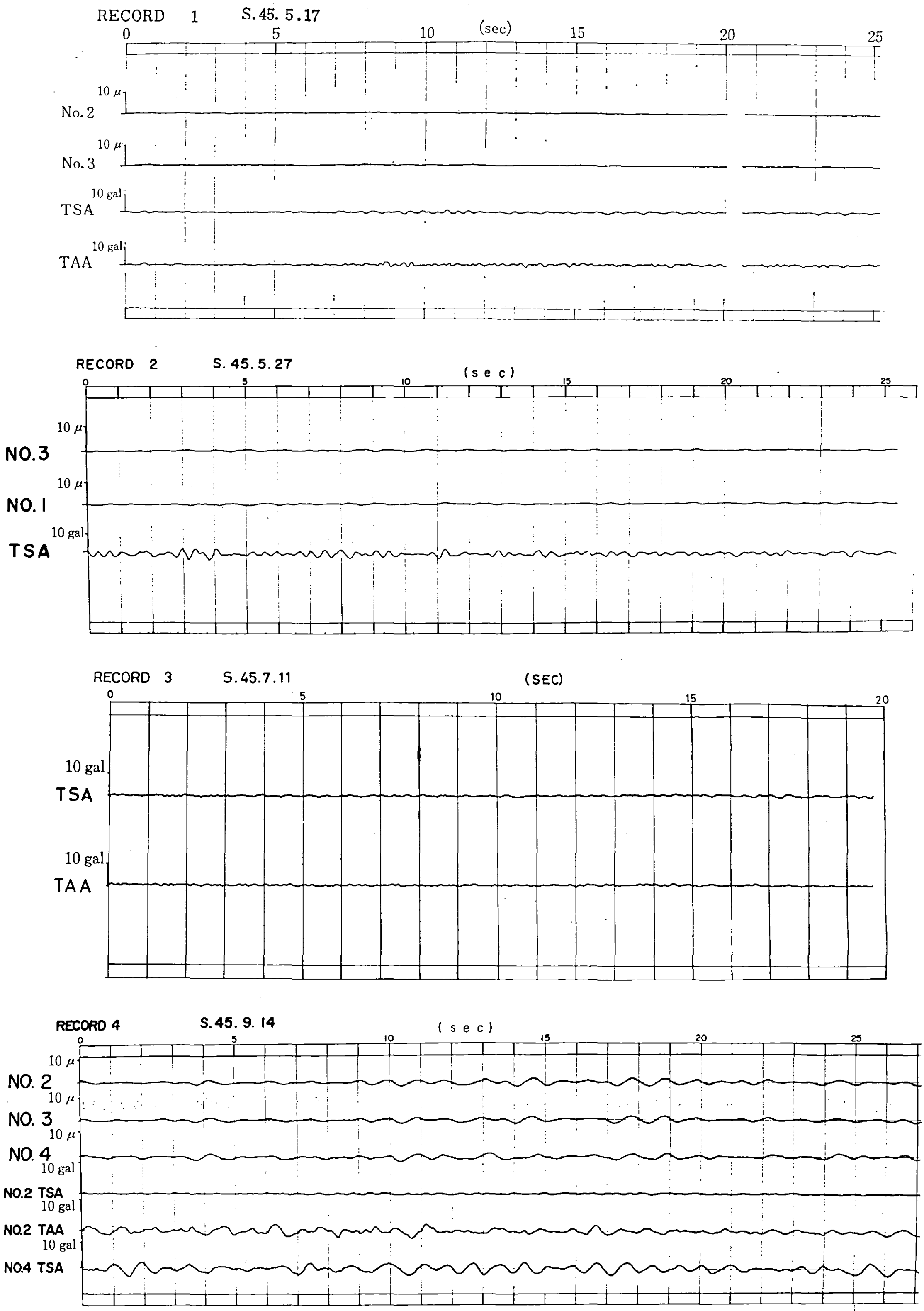


Fig. 11 (Record 1～4)

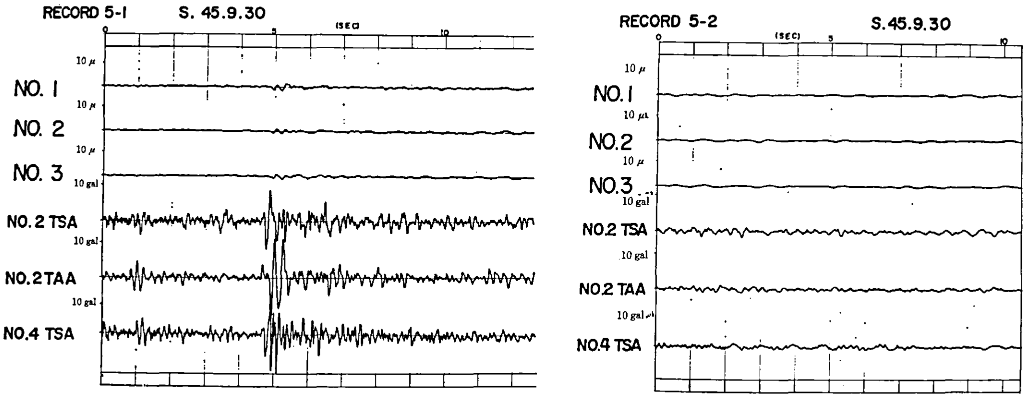


Fig. 11 (Record 5)

Reading of the erathquake records

The follwing notation have been used in order to read the earthquake records.

TAA·········means the acceleration in the direction of the tunnel axis.

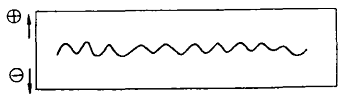
TSA·········means the acceleration in the dioection perpendicular to the tunnel axie.

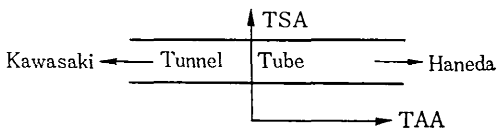
Acceleration records

While studying the acceleration record, it is necessary to have the proper direction of acceleration and that can be obtain as given below, The two directions of acceleration rscords are assumed positive as shown below in the figure. It should be noted that the case when the records show a using tendency a negative sign must be applied to have the proper direction of the acceleration

Strain record

When studying the strain record, it should be noted that the tendency of using upward of the record indicate the tension in the tunnel wall, while the tendency of going down indicate the compression in the tunnel wall.





6. Future Developement of the Programme

In the time span of 5 months from May to September 1970, only five earthquake records could be obtained, having a maximum acceleration of 12 gals and the maximum strain of the order of 1 to 2 micro. Fortunately one of these five records was having the epicenter just at the observation point.

The onward study of the programme is continued and whenever some large earthquake records are obtained in near future, it is expected that the analysis would reveal quite interesting results.

7. Acknowledgement

The auothers wish to express their appreciation and sincere thanks to the staff of main office of J. R. C. C. and also to the staff of SHIOHAMA construction section of J. R. C. C. who permitted to observe the earthquake behavior of the Tama Trench Type subaqueous Tunnel.

(Manuscript received November 5, 1970.)

References

(1) S. Okamoto and C. Tamura: Vibration model test of pipe buried in soft layer, SEISAN-KEN-KYU (Vol. 19. No 12)