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Observation of ground strains during earthquake

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ABSTRUCT: Direct measurement of ground strains during earthquake were devised and observation results were demonstrated. At the ground surface, three components of strains were obtained,in order to inspect properties of strain conditions. 27 earthquakes were observed. Strain conditions were considered to be mainly pure strain conditions. The gauge length of this apparatus is 1m, which seems to be too short on account of structural details of layer. Examining on such a problem, comparison the observed data with the evaluated value using acceleration data were attempted to be conducted.

1. Introduction

Investigation on earthquake resistance of underground structures such as submerged tunnel have been become to important problem, due to recent increasing construction. Underground structure is forced to be moved with the surrounding soil and it does not move freely as a structure on the ground surface. Therefore, it is not acceleration but the displacement of ground that influences strongly the behaviors of underground structures. Seismic behavior and general characteristics of ground strain are fundamental parameter in the earthquake resistant design of underground structures.

Few researchers are now making observation strains produced on the wall of submerged tunnel during earthquake,in order to obtain available data for seismic design of underground structures (1), (2). In the present time, many researchers obtain ground strains induced during earthquake by calculating relative displacements obtained from acceleration records observed in array observation systems(3), (4). Therefore, strains induced in ground surface are desired to be observed with high accuracy. Considering this background, the object of this paper is laid on the development of direct measuring methods for strains induced on the ground surface and also investigation on the observed results.

2. Observation Methods

Strains produced on the ground surface were observed. The observation site is located in the campus of the Science University of Tokyo (Noda city, Chiba). The topographical conditions of observation site are generally simple with the ground is almost flat. Geological condition is soft layer on alluvium.Typical soil profile obtained from representative boreholes driven in the neighborhood of the observation site is shown in Fig.1. The top of 4~5 meters of the site is covered with clay and loam layer.

The relative displacements of ground are directly measured by means of three displacement transducers as indicated in the followings. Steel piles (diameter:70mm) were driven on three points which are the vertices of a triangular network with three sides having 1m in length. Relative displacements between piles were measured. Distances between piles correspond to gauge length, which is one of the most important elements to be considered for strain measurement. It must be determined by taking account of various factors,but, in this case,only from practical viewpoint such as maintenance of the apparatus. Fig.2 shows the schematic layout of direct strain measurement equipment.

Furthermore, in the same observation site,three component piezo-electric accelerometers were installed. Triggering of the signals is performed when the logical sum or

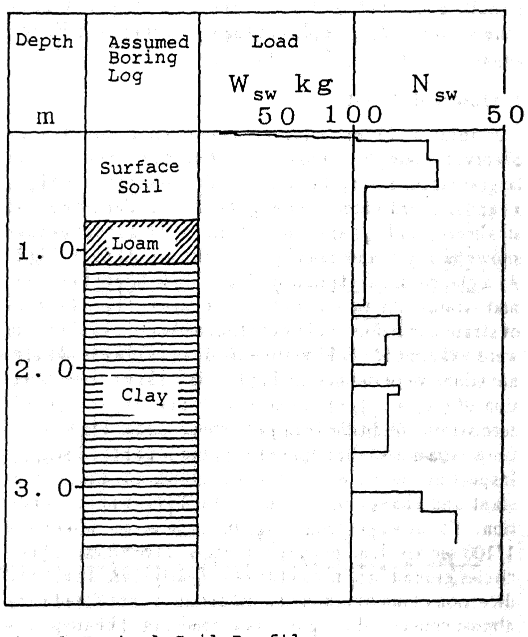


Fig.-1 Typical Soil Profile of Observation Site

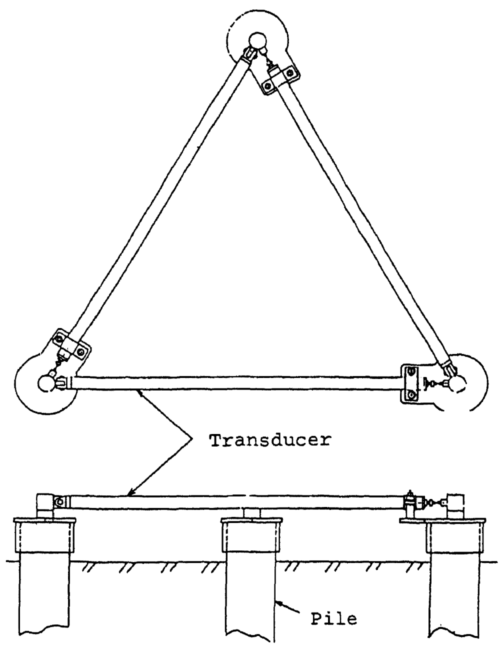


Fig.-2 Schematic Layout
Strain Measurement
Equipment

product of any arbitrary three components or ground acceleration exceeds a present threshold level. The signals are transmitted to the observation room,where,they are automatically digitized with a sampling interval of 1/100 sec by A/D converter. A general layout of seismometers as well as measuring device for strains is shown in Fig.3. The recorder has a digital magnetic tape with a recording capacity of more than 1 hour. Timing information is internally generated, and in addition, the absolute time is connected hourly by utilizing the signal from N.H.K.(the Japan Broadcasting Corporation).

3. Observed Results

A total of 27 earthquakes have been recorded. An observed example is shown in Fig.4, which contains the largest strain among the total results. As shown in Fig.3, x- and y-coordinates are designated. Calculating normal strains (ε_x and ε_y) and shear strain(γ) by use of the data shown in Fig.4, and calculated results are shown in Fig.5. At a glance, shear strains are found to be larger than normal strains. As an attempt to investigate characteristics of strain conditions,time variation of Mohr's strain circle were examined. Mohr's circle is demonstrated and also notations were defined in Fig.6. Fig.7 shows time variation of $((\varepsilon_x + \varepsilon_y)/\gamma)$ are shown. When $((\varepsilon_x + \varepsilon_y)/\gamma)$ is zero,strain condition is in pure shear fields. Fig.8 shows time variation of direction of maximum principal strains. Inspecting the time variation,directions are almost constant and change by 90 degree during out-phase condition. Variation of Mohr's strain circle at the interval of 1/100 sec are demonstrated in Fig.9. Investigating these circles,ground strain condition is nearly pure strain and direction of maximum principal strain is considered to be almost constant during in phase condition.The frequency contents of the strains showed several peaks within the range up to about 2.0 Hz. Each strain had dominant components at 2.88,2.29 and 2.49 Hz, respectively as shown in Fig.10.

4. Examination on Observed Results

Observed results are said to be localized value,because of such a small gauge length. Taking account of gauge length and structural details of layer, properties of observed strain results should be examined with other approaching. For such a purpose, ground strains were evaluated by using acceleration records,in order to use for comparison with the observed ground strains. The intervals between acceleration observation points are from 70m to 110m.

Displacements were evaluated by using acceleration records. In the next step, relative displacements were divided by observation point intervals. The ground displacement should be calculated by double integrating acceleration data,however, in this paper,the following concept was adopted.

The concept of integration in frequency domain is as follows. In general,if $F(\omega)$ is the Fourier transform of $f(t)$ it can be shown

$$\text{if} \qquad f(t) \leftrightarrow F(\omega)$$

$$\text{then} \qquad \int_{-\infty}^{\infty} f(t)dt \leftrightarrow \frac{1}{i\omega}F(\omega)$$

$$\text{and} \qquad \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(t)dtdt \leftrightarrow -\frac{1}{\omega^2}F(\omega).$$

The inverse Fourier transform of filtered function

$$-\frac{1}{\omega^2}F(\omega)$$

is the required integral. Furthermore, as an attempt, frequency range of displacement is considered to be from 2.5 to 15 Hz.

The list of the earthquakes A schematic map of the locations of recording strain and the epicenters of the 27 earthquakes is shown in Fig.11. and their characteristics are summarized in Table 1. For the sake of simplicity, an earthquake is referred to by its event number assigned in the first column of Table 1, in the remaining parts of the thesis. Columns of principal strains (ε_1 or ε_2) and maximum shear strain(γ_{max}) show absolute maximum values,and values indicated in parentheses were evaluated by integration mentioned above. With a few exception, it is said that numerical values of the observed strains and of the evaluated one are in the same order and some results agree reasonably.

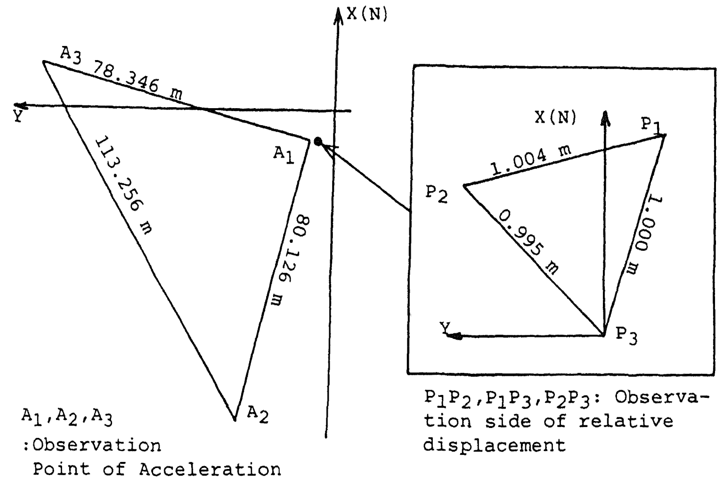


Fig.-3 Layout of observation site

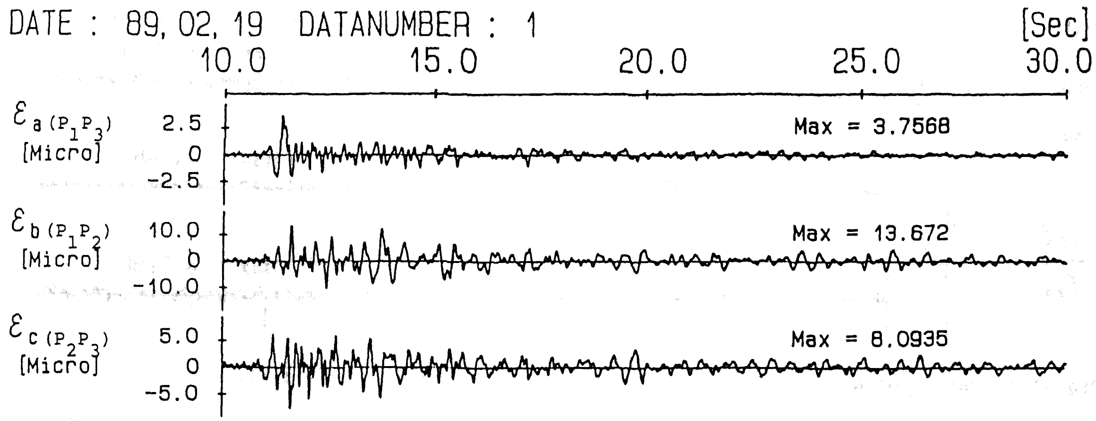


Fig.-4 Observed Results

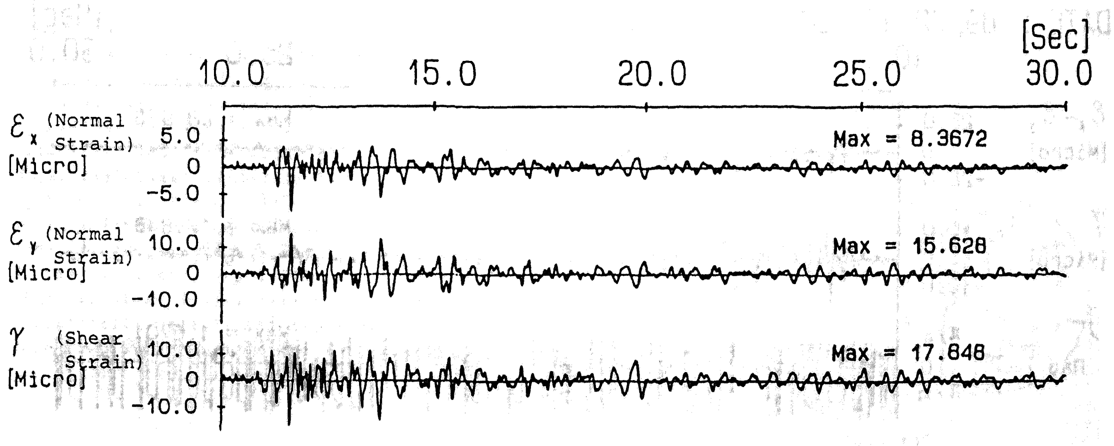
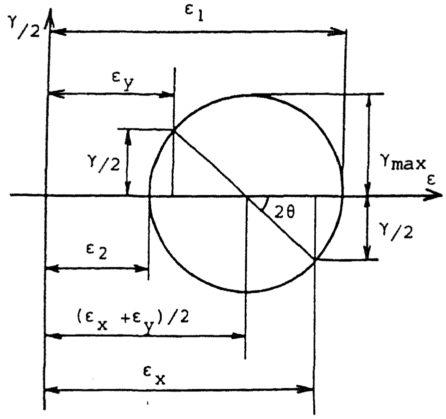


Fig.-5 Calculated Results



$\varepsilon_x, \varepsilon_y$: Normal Strain in x-, y-direction
γ : Shear Srain
$\varepsilon_1, \varepsilon_2$: Maximum, Minimum Principal Strain
γ_{max} : Maximum Shear Strain
θ : Direction of Maxmum Strain

$$\gamma_{max} = \sqrt{(\varepsilon_x - \varepsilon_y)^2 + \gamma^2}$$

$$2\theta = \tan^{-1} \frac{\gamma}{\varepsilon_x - \varepsilon_y}$$

Fig.-6 :Mohr's Strain Circle and Notations

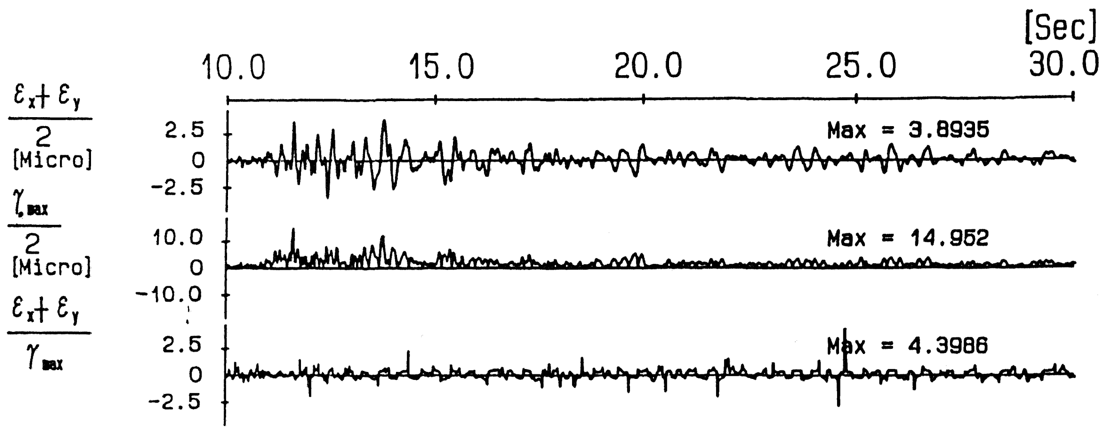


Fig.-7 Summation of Normal strains and Maximum Shear Strain

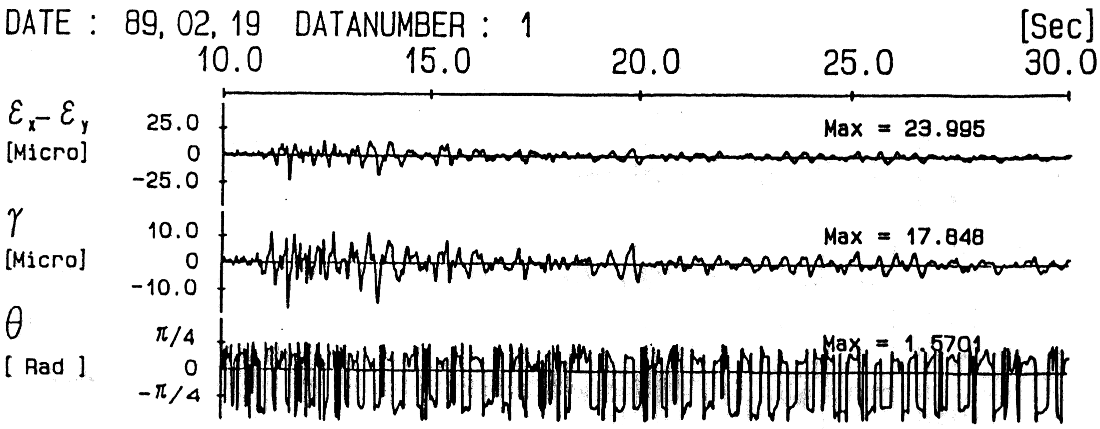


Fig.-8 Time Variation of Direction of Maximum Normal Strain

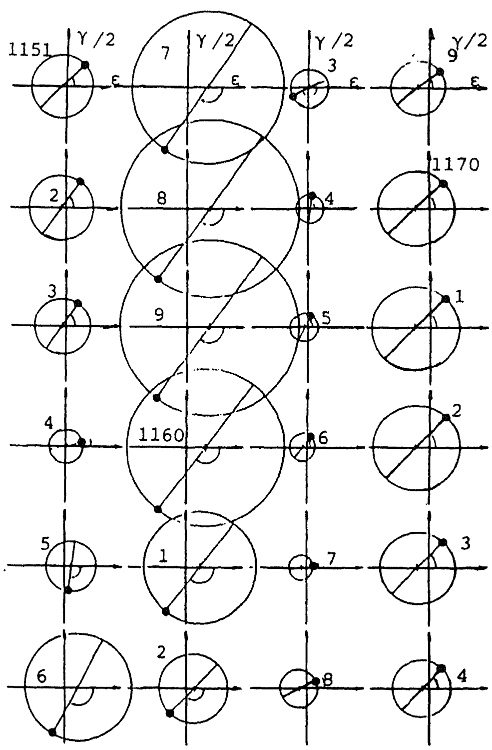


Fig.-9 Time variation of Mohr's Srain Circle at the interval of 1/100 sec.Numbers are data number.
● means ordinate(ε_x, $\gamma/2$)

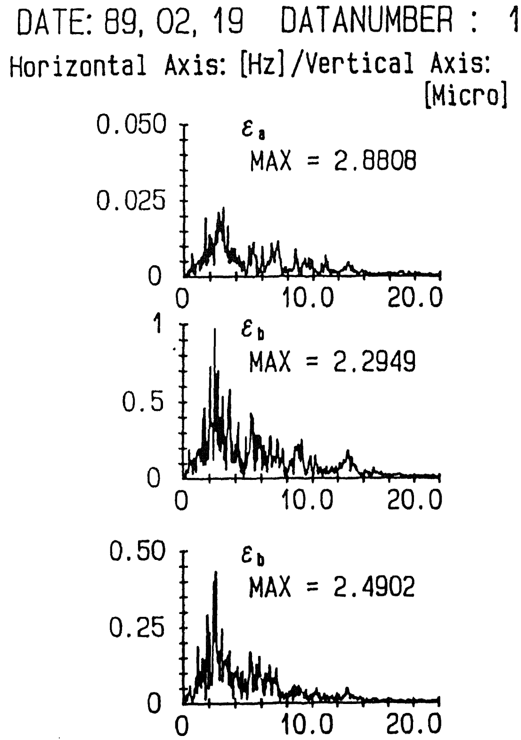


Fig.-10 Fourier Spectra for Strain Components

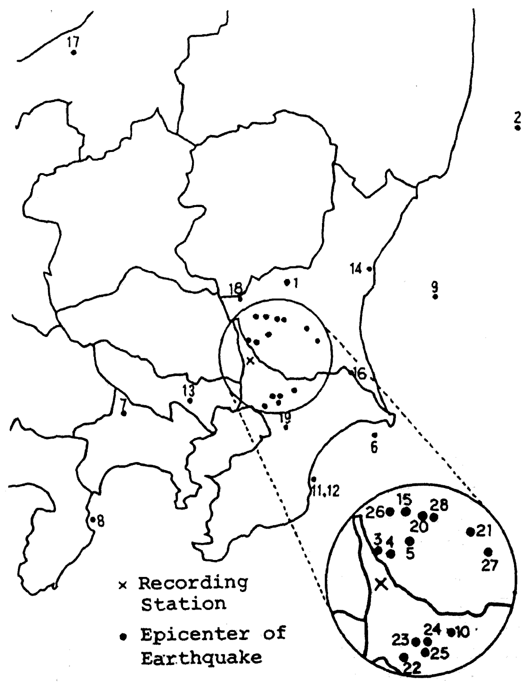


Fig.-11 Map of Location of Recording Station and Epicenter of Earthquake

5. Conclusion

Direct observation method of ground strains during earthquake was devised and observed results were demonstrated. 27 earthquakes were observed. Strain conditions were found to be nearly pure shear. Examinations on amplitudes of strains were attempted to be conducted by using evaluated results obtained from acceleration data.

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Table 1 List of earthquakes and max. amount of strains and accelerations, ( ):evaluated by use of acceleration data.

Event No.	Date	M*	I**	Focal Depth (km)	Epicentral Distance (km)	maximum value		max.Acc. (gal)
						ε_1 or ε_2 (μ)	γ_{max} (μ)	
1	'88.07.15	4.4	II	59	40	1.06 (0.67)	1.55 (0.78)	8.61
2	89.02.04	5.4	III	61	197	0.78 (0.71)	1.21 (1.05)	1.83
3	89.02.19	5.6	III	55	10	18.6 (53.1)	29.9 (68.1)	87.0
4	90.05.29	3.5	-	56	15	0.22 (0.20)	0.33 (0.23)	1.65
5	90.06.01	6.0	IV	59	85	2.21 (2.09)	3.21 (2.94)	4.15
6	90.06.05	5.4	III	123	75	1.24 (1.45)	1.84 (2.31)	3.85
7	9006.27	5.4	II	148	125	2.09 (2.75)	3.20 (3.28)	3.66
8	90.08.05	5.8	II	39	120	2.75 (2.61)	4.46 (3.61)	7.20
9	90.08.08	4.7	II	114	31	1.06 (1.12)	1.62 (1.51)	2.75
10	90.08.23	5.4	IV	50	79	3.11 (2.41)	4.91 (3.09)	7.20
11	90.08.23	5.2	III	50	79	2.16 (6.30)	3.13 (7.40)	4.76
12	90.08.24	3.7	-	42	37	0.99 (0.76)	1.52 (1.01)	3.05
13	90.10.06	5.0	III	51	89	3.35 (5.04)	5.23 (6.29)	12.6
14	90.10.29	3.5	-	50	21	1.05 (0.85)	1.68 (1.05)	4.52
15	90.11.18	4.3	II	36	60	1.75 (1.67)	2.66 (2.56)	5.31
16	90.12.07	5.4	-	14	190	1.94 (2.49)	2.93 (3.16)	3.48
17	90.12.08	4.1	-	65	34	1.40 (2.86)	2.33 (3.48)	7.08
18	90.12.16	4.0	II	77	8.8	1.62 (3.32)	2.44 (4.17)	5.01
19	91.01.07	3.8	-	56	22	1.17 (1.30)	1.81 (1.73)	3.91
20	91.09.07	4.4	-	111	35	0.60	1.08	3.42
21	91.09.26	2.7	-	41	28	0.79	1.33	4.46
22	91.09.29	4.9	II	79	27	1.29	2.18	5.37
23	91.09.29	4.2	I	82	29	0.31	0.53	2.08
24	91.09.29	4.3	II	81	30	0.48	0.82	2.08
25	91.10.19	4.3	I	59	19	3.93	4.70	19.9
26	91.10.27	5.2	I	32	41	0.46	0.79	2.14
27	91.11.19	4.9	III	80	23	2.29	4.07	14.5

* Magnitude(Richter Scale)
** Intensity(J.M.A)