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# Study on dynamic earth pressure through observation

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ABSTRACT : In order to investigate the fundamental characteristics of the dynamic earth pressure acting on the underground external walls of embedded structures, we have observed the earth pressure and acceleration of the structure and the surrounding soil at an actual nuclear power plant site and some clear records have been obtained up to now. In this study, some characteristics of the earth pressure during earthquakes were confirmed from these seismic records. 1) The low frequency component of earthquakes have strong influence on the lateral earth pressure. 2) The phase of time history waves of the relative displacement between the structure and the surrounding soil agree well with those of the lateral earth pressure. The soil strain of the surrounding ground is also investigated using many observation points in the soil.

## 1. INTRODUCTION

During earthquakes, dynamic earth pressure acts on the underground external walls of embedded structures and it plays an important role in soil-structure interaction. Therefore it is necessary to understand its dynamic characteristics in order to develop rational earthquake-resistant design.

However, the investigations of the dynamic earth pressure are limited in number and there have been few observations of earth pressure acting on an actual structure, including observations of the surrounding soil and the structure's behavior.

Since 1989, we have been observing the dynamic earth pressure and the ground motion at an actual nuclear power plant site and some clear data has been obtained.

In this paper, we present the outline of our observations and consider the fundamental characteristics of dynamic earth pressure based on the obtained records.

## 2. OBSERVATION SYSTEM

Figure 1 shows the outline of the observation site and observation points.

The structure under the observation is an actual reactor building embedded to the depth of 36m in the ground. It is a stiff structure constructed of reinforced concrete, whose plane shape is a square of 80mx80m, and it has a spread foundation.

The ground surrounding the structure consists of two layers. In regard to the upper layer, the shear wave velocity (Vs) is approximately 300m/sec. and the thickness is about 15m. The Vs of the lower layer is approximately 500m/sec. The structure is supported by the lower layer. Backfill soil with a thickness of 10m exists at the surface of the ground around the structure.

Lateral earth pressure is measured through stress transducers installed on the side wall. Accelerometers were installed in the structure and the surrounding ground. These observation points in the ground have been arranged in a grid pattern in order to grasp the two dimensional deformation of the soil.

## 3. RESULTS OF THE OBSERVATION

Up to now, many seismic records for earth pressure have been obtained, but the values

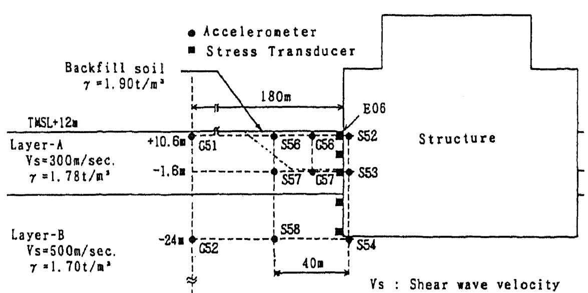



Fig. 1 Outline of the observation site and the observation points

Table 1 Profile of observed earthquakes

| No. | Name | Latitude (N) | Longitude (W) | Mag. | Focal depth (km) | Epicentral distance (km) | Date | Peak acceleration on the ground surface at the site (cm/sec²) |
|---|---|---|---|---|---|---|---|---|
| 1 | OFF S NIIGATA PREF | 37° 40.2′ | 138° 14.7′ | 3.2 | 24 | 42 | 1989 5/18 7:30 | 1.9 |
| 2 | MID NIIGATA PREF | 37° 23.1′ | 138° 35.9′ | 3.1 | 12 | 4 | 1989 5/27 17:15 | 8.64 |
| 3 | OFF S NIIGATA PREF | 37° 37.6′ | 138° 22.1′ | 3.0 | 18 | 31 | 1989 6/16 12:55 | 0.897 |
| 4 | FAR E OFF SANRIKU | 39° 51.3′ | 143° 3.4′ | 7.1 | 0 | 472 | 1989 11/02 3:25 | 0.783 |
| 5 | OFF S NIIGATA PREF | 37° 13.1′ | 138° 13.7′ | 4.0 | 13 | 39 | 1989 11/23 5:03 | 2.22 |
| 6 | SADOGASHIMA ISLAND REG | 38° 38.3′ | 138° 29.9′ | 4.9 | 28 | 135 | 1989 12/16 19:45 | 0.722 |
| 7 | NEAR IZU-OSHIMA ISLAND | 34° 45.6′ | 139° 14.0′ | 6.5 | 6 | 301 | 1990 2/20 15:53 | 1.0 |
| 8 | MID NIIGATA PREF | 37° 12.6′ | 138° 33.4′ | 5.4 | 14 | 27 | 1990 12/07 18:38 | 30.2 |

for most of them are too small to be accurate. This is due to the fact that the earth pressure level was smaller than the noise level of the stress transducers. There have been only eight earthquakes in which the earth pressure records could be observed accurately. These earthquakes' profiles are shown in Table 1.

The largest maximum acceleration of the ground surface was about 30cm/sec²· which was recorded during earthquake No. 8. The second largest one was about 10cm/sec², which was marked in earthquake No. 2. But, the other seismic records show small activity, with acceleration values of about 1 or 2cm/sec.² at the maximum.

From Table 1, the earthquakes can be classified into two groups. One group is the group of earthquakes which happened near the observation site and whose magnitude is relatively small. The other group is the group of earthquakes which happened far from the observation site and whose magnitude is relatively large. Nos. 1, 2, 3, 5, 6 and 8 are in the former group and Nos. 4 and 7 are in the latter group.

Figure 2 shows the distribution of the maximum acceleration for each earthquake. This figure shows two vertical arrays, that is, the array of the free field about 180m away from the structure and the array of the structure. The maximum acceleration of earthquakes Nos. 2 and 8 are larger than the others at every point. In the other earthquakes, the maximum values are smaller than 2 cm/sec² at every observation point. The distribution in the free field shows the tendency of the maximum values to increase towards the ground surface. Those of the structure don't show such a tendency because the structure is more rigid than the surrounding soil.

Figure 3 shows the vertical distribution of the maximum values of lateral earth pressure during each earthquake. The values of the earth pressure represent the dynamic part of the earth pressure except the static part. Two observation arrays are shown in this figure. One array is at the center of the underground external wall, and the other is at the corner of the structure. The distribution shapes are different from those of acceleration. Maximum earth pressure decreases in the

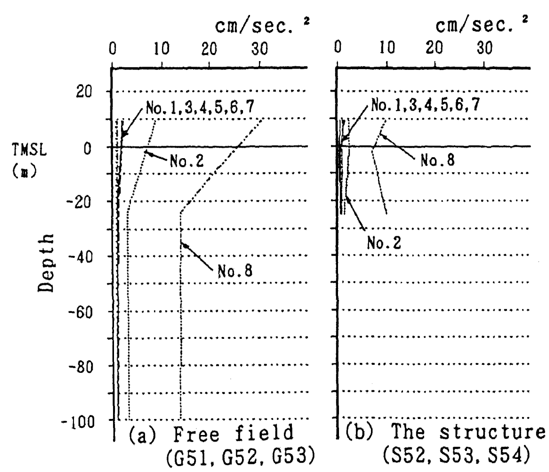



Fig. 2 Vertical distribution of maximum acceleration

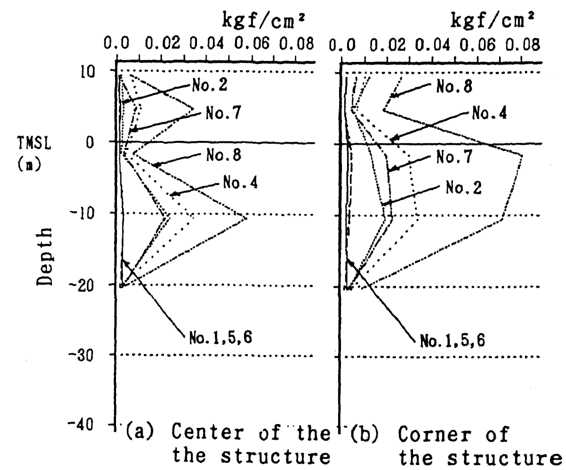
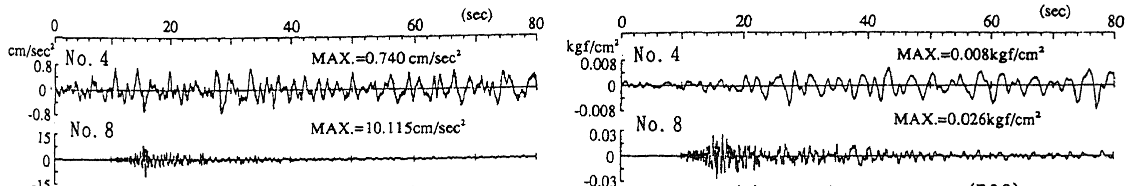
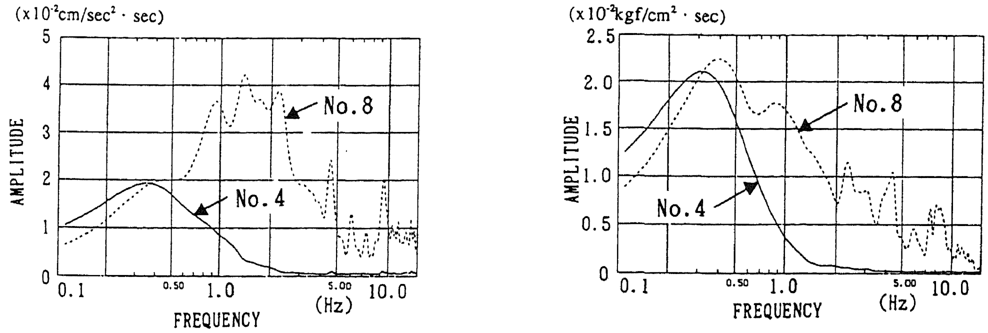



Fig. 3 Vertical distribution of maximum earth pressure




(a) Acceleration (S52) (b) Earth pressure (E06)

Fig. 4 Acceleration and earth pressure time histories of No. 4 and No. 8 earthquake




(a) Acceleration (S52) (b) Earth pressure (E06)

Fig. 5 Fourier spectra of Acceleration and earth pressure of No. 4 and No. 8 earthquake

region of backfill soil because the backfill soil is softer than the surrounding soil. From this figure, the difference in the characteristics of the two earthquake groups is evidently confirmed. In the near-earthquake group, the maximum earth pressure values of earthquakes Nos. 2 and 8 are larger than those of the others. Namely, the earth pressure is large when the acceleration is large. But in the distant-earthquake group, maximum earth pressure is relatively large in spite of the maximum acceleration being fairly small. From this fact, it is inferred that the characteristics of earthquakes have some influences on the magnitude of lateral earth pressure.

We also confirmed the characteristics of the two groups of earthquakes. Two earthquakes, Nos. 4 and 8, were selected from the two groups. Figure 4 shows the recorded acceleration and earth pressure time histories of each earthquake at the structure. It can be seen clearly that the low frequency component is predominant during earthquake No. 4. Figure 5 shows the Fourier spectra of these acceleration and dynamic earth pressure records. As for the Fourier spectra of the acceleration time histories, it can be seen that the predominant frequency of earthquake No. 4 exists in the low frequency range, lower than 1.0Hz., but the predominant frequency of earthquake No. 8 is higher than 1.0Hz. The amplitudes of the low frequency range of the two earthquakes are almost the same; the two earthquakes have the same power in the low frequency range. As for the dynamic earth pressure, the frequency range lower than 1.0Hz is predominant in each earthquake. Therefore the dynamic earth pressure is influenced mainly by the low frequency component of earthquakes. It can be inferred that earthquakes, which have high energy in the low frequency component, produce large dynamic earth pressure.

## 4. LATERAL EARTH PRESSURE AND BEHAVIOR OF THE GROUND

In order to confirm the correlation between dynamic earth pressure and seismic ground behavior, earthquake No. 8, whose records marked the largest peak acceleration and earth pressure, is examined in more detail.

Figure 6(a) shows the acceleration time history of the surrounding soil observation points about 40m away from the structure at GL-1.4m. Fig. 6(b) shows the acceleration time history of the structure at the same levels. The structural response is different from the surrounding soil response. Because the structure is fairly stiff, the amplitude of structural response decreases to approximately one-half that of the surrounding soil response. The difference between the structural and the ground response influences the dynamic earth pressure.

Figure 6(c) shows the relative displacement time history between the structure and the surrounding soil. This time history represents the difference between the structure and the ground displacements

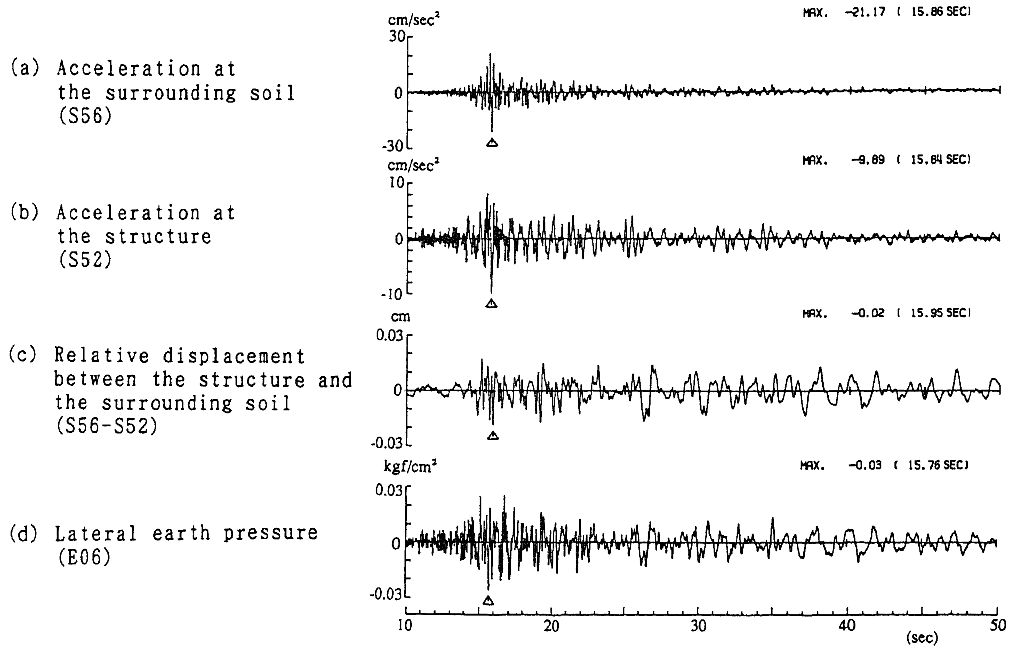



Fig.6 Time histories of earthquake No.8

which are calculated by integration of the acceleration time histories in a frequency domain. This method increases the noise in the low frequency range and it is necessary to use a low-cut filter. Through the parametric study of the integrated wave form, cut-off frequency is set at 0.4Hz.

Figure 6(d) shows the dynamic earth pressure time history obtained at a common depth on the external wall of the structure. When Fig.6(d) is compared with Fig.6(c), the relative displacement corresponds well to the earth pressure. Then, the relative displacement is shown with the earth pressure in Fig.7. Each time history is normalized by the maximum values. Figure 8 shows the product of the relative displacement time history and the earth pressure time history. If the two time histories change in the same phase, the product time history always shows positive values. In this figure, the product wave form is always in the positive region. From these figures, the phases of the time

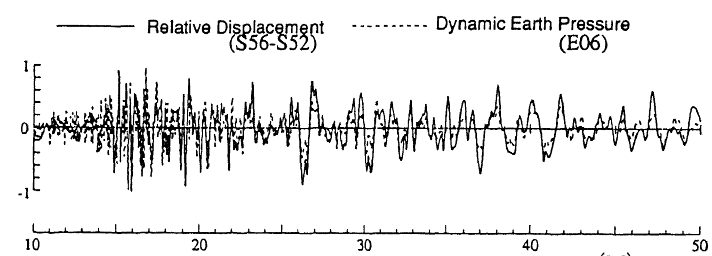



Fig.7 Comparison of the lateral earth pressure and the relative displacement

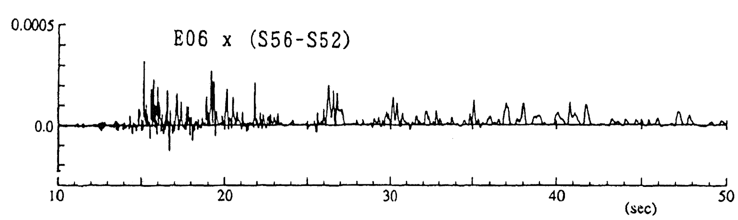



Fig.8 Time history of the product of the lateral earth pressure and the relative displacement

histories of the relative displacement agree quite well with those of the earth pressure. Because it is inferred that the response of the surrounding soil about 40m away from the structure is not affected by the structure, it seems safe to consider the surrounding soil response as the free-field response. According to the above mentioned results, we think that the lateral earth pressure is produced by the relative displacement between the structure and the free-field soil during earthquakes .

5. EVALUATION OF THE DYNAMIC SOIL STRAIN

Using the acceleration records which were obtained at a lot of accelerometers installed in the surrounding ground, we tried to evaluate the dynamic soil strain in the surrounding soil and to consider the influence of the soil deformation on the earth pressure. The earthquake record used in this investigation is earthquake No. 8.

For evaluation, the displacement records which were obtained by the integration of the acceleration records are used, and the element is defined using three or four observation points as nodal points as in FEM. The soil strain is estimated from the displacement field which has been approximated through the application of the shape function, which is used in FEM, to each element.

We divided the surrounding soil into eight elements as shown in Fig. 9.

Figure 10 shows the time histories of the horizontal and vertical axial strains and shear strain in the No. 1 elements.

Figure 11 shows the distribution of the

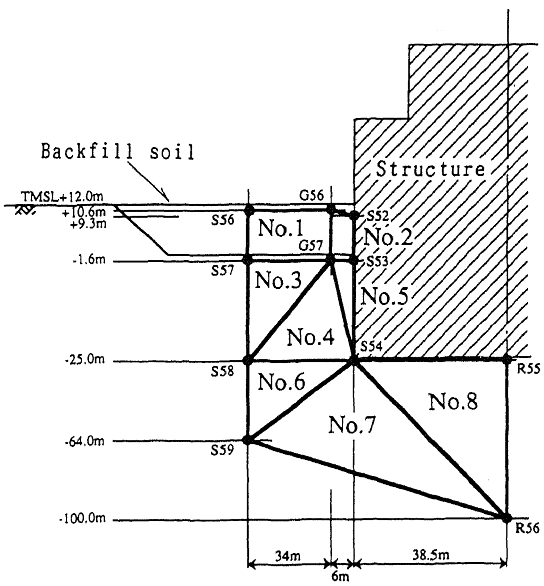



Fig. 9 Elements for the evaluation of soil strain

maximum strains.

The quantity of soil strain is on the order of 1. $\sim 10.\times10^{-6}$. The strain levels of the backfill soil and surrounding soil are almost equal. In regard to the distribution of strain, the horizontal component of axial strain and the shear strain increase in the elements in contact with the structure because the structure influences the surrounding ground motion. The horizontal axial strain increases by approximately three times near the structure. The shear strain increases by approximately one and half times. The horizontal strain and vertical strain are of almost equal amplitude in the elements at a distance from the structure.

Figure 12 shows the comparison of the earth pressure with the horizontal axial strain, It is confirmed that the horizontal components of the axial strain time histories of the correspond well to the dynamic earth pressure time histories. However, the earth pressure corresponds better to the relative displacement than to the soil strain.

6. CONCLUSIONS

Concluding remarks based on observation of the earth pressure and the soil deformation are as follows:

1) From the earth pressure time histories, the predominant component of earth pressure is the low frequency component. The high frequency component of earthquakes does not have large influence on earth pressure.

2) The phase of time histories of the relative displacement between the structure and the free-field soil agree quite well with that of the dynamic earth pressure acting on a underground external wall.

3) Near the structure, the horizontal component of axial strain and the shear strain of surrounding soil increase by approximately two or three times because the dynamic behavior of the structure influences the surrounding ground motion.

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(a) Horizontal component of axial strain

(b) Vertical component of axial strain

(c) Shear strain

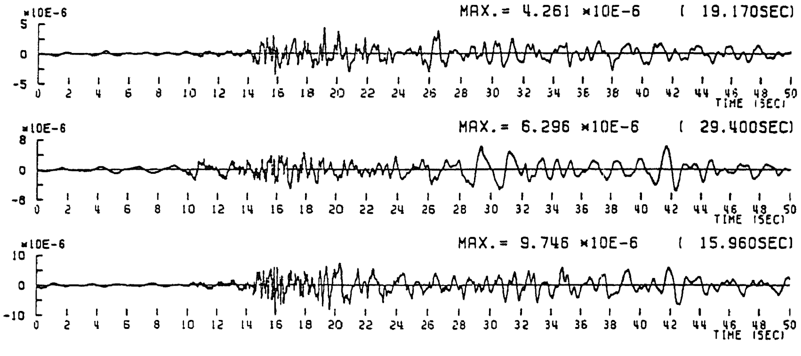


Fig. 10 Strain time histories in No. 1 element

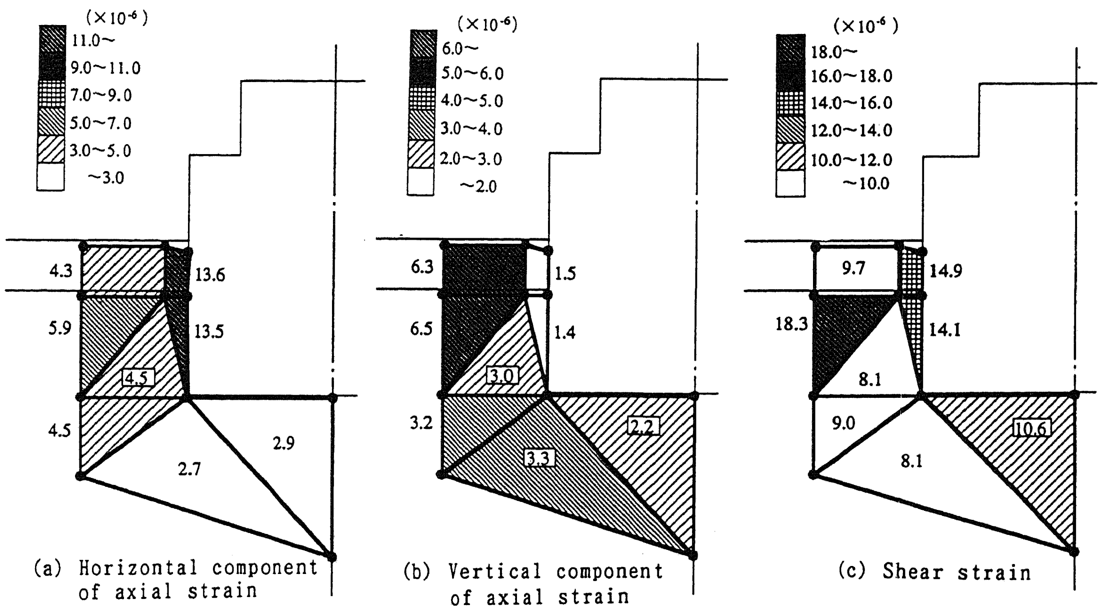


Fig. 11 Distribution of the maximum soil strain

(a) Horizontal component of axial strain in No. 1 element

(b) Horizontal component of axial strain in No. 2 element

(c) Lateral earth pressure (E06)

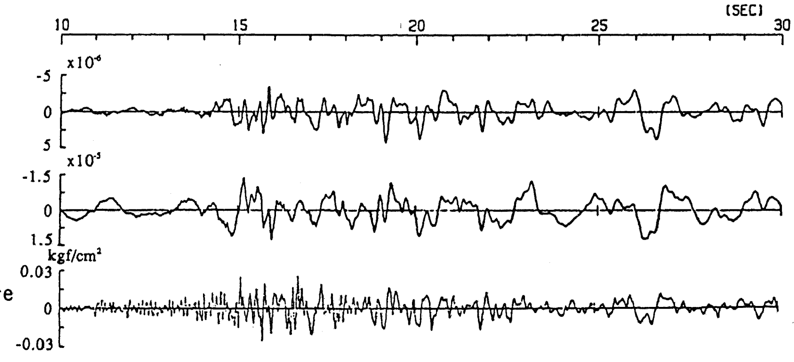


Fig. 12 Comparison of lateral earth pressure and the horizontal component of axial strain