TECHNICAL NOTE

RECORD OF LATERAL PRESSURE TAKEN DURING EARTHQUAKE

YUUKO IKUTA*, MASAO MARUOKA**, TAKAFUMI MITOMA** and MASATAKE NAGANOU**

ABSTRACT

This report describes a measured record of earth pressure and water pressure which acted upon the perimeter basement walls of a building during an earthquake. The record was obtained, when the “Off Miyagi Prefecture Earthquake” (magnitude 7.4) occurred on 12th June, 1978, at the alluvial formation area in Yokohama City about 380 km away from the epicenter. The number of record-taking points were 7 points for earth pressure and 3 for water pressure; 10 points in total in the perpendicular directions. The record was taken by detecting the earthquake with an acceleration transducer and by continuously measuring and recording, from the instant when the starter was triggered, with a dynamic strain meters. From this record, the properties of earth and water pressure were found to be as follows: 1) Maximum amplitudes of the earth and water pressure $\Delta p_k$ during the earthquake with respect to those $p$ at normal times were within the range of 2.74 to 6.37 kN/m², the ratios between them, $\Delta p_k/p$, were 0.011 to 0.374, and both the value and the ratio tended to become larger when getting closer to the ground surface, 2) a long-period component of about 10 sec was observed in the individual records, 3) water pressure and earth pressure indicated properties which noticeably resembled each other.

Key words: alluvial deposit, deep foundation, earth pressure, earthquake, measurement, underground structure, water pressure

IGC: HI/E 8

INTRODUCTION

The dynamic interrelationship between the ground and the building has been considerably clarified and put to practical application as a result of persevering efforts of researchers. However, the relationship between the basement structure and the ground has not yet been thoroughly clarified. Particularly records of earth pressure and water pressure which act upon an actual basement structure during earthquakes are virtually nil, and practically no research has been undertaken in this field. In carrying out research in this unknown field, it is one of the most important items to observe the behaviors of earth and water pressure during earthquakes in order to find out their properties.

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When the "Off Miyagi Prefecture Earthquake" (magnitude 7.4) occurred at 17:14 on 12th June, 1978, the authors took the records of earth pressure and water pressure that acted upon the perimeter basement walls of Yokohama Tenri Building in Yokohama City about 380 km away from the epicenter (Fig. 1). The seismic intensity of the earthquake in Yokohama City was judged to be "IV" according to the seismic intensity scales defined by the Japan Meteorological Agency. Maximum acceleration at the 2nd basement of this building was about 12.5 gal. The building was a high-rise office building with 2 basement floors and 27 stories above the ground. The foundation consisted of cast-in-place piles and basement walls which also served as piling wall (Fig. 2). The soil profile of the building site comprised a thick alluvial deposit of soft silt which reached the hard support layer of the diluvial deposit at a depth of 22 to 28 m (Fig. 3). The basement structure and basement

![Fig. 1. Epicenter and observation point](image1)

![Fig. 2. Outline of building and layout of earth and water pressure gauges](image2)

![Fig. 3. Geological profile and instruments setting depths](image3)
walls were rigidly connected with shear connectors. Earth and water pressure gauges were arranged on the south (S-side) and east sides (E-side) of the building, and the record was obtained from 7 points out of 26 points of earth pressure gauges and 3 points out of 7 points of water pressure gauges; 10 points in total (Fig.2 and 3) (Wakabayashi, 1971). Here the term “earth pressure” in this report means the total pressure acting upon the basement wall, and “water pressure” means the underground pore water pressure acting on the water pressure gauge through the porous stone.

RECORD TAKING SYSTEM & RECORD ANALYZING METHOD

The record taking system consisted of the sensor groups (LVDT), dynamic strain meters, recorder and starting apparatus (Fig.4 and Table 1). Seismic motions were detected by the acceleration transducer. When the acceleration of the earthquake reached 2gal, the starter was triggered and measurement was commenced. Seismic motions were continuously measured by the dynamic strain meters, and the measured values were recorded by the electromagnetic oscillograph. The time required for a set of measurements was 30 seconds.

The present record was obtained on a length of 18m of chart paper which was fed at a rate of 10cm/s. As for re-arrangement of the record, the measured values were read by a curve reader at an interval of 0.05 sec and given A/D conversion. Later the converted values were given zero-line compensation with the use of a filter. Although the record was divided at the time of reading, the divided records were treated as a continuous record for analyzing purposes (Ohashi, 1976).

![Fig. 4. Measuring system](image)

<table>
<thead>
<tr>
<th>Table 1. Specifications of measuring equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration transducer</td>
</tr>
<tr>
<td>Starter</td>
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<td></td>
</tr>
<tr>
<td>Dynamic strain meter</td>
</tr>
<tr>
<td>Electromagnetic oscillograph</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Earth pressure gauge</td>
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</tbody>
</table>

RECORD

A record of earth pressure and water pressure which acted upon the perimeter basement wall of the building during the earthquake was shown below (Fig. 5).

ANALYSIS OF RECORD

Sensor groups were installed to the perimeter basement walls in March, 1971 while the
Fig. 5. Record of earth pressure and water pressure during earthquake

building was being constructed. Distribution of earth and water pressure varied with the progress of the construction, and settled down to constant values after the completion of the construction (Fig.6). The sensor groups were considered to have maintained their normal functions ever since the installation and have been showing stable values after the earthquake.

This record closely resembled to the record of seismic motions of the same earthquake
detected at Yokohama Local Meteorological Observatory (Fig.7). From this comparison, it could be observed that these two records resembled in their respective periods and that the record of the present measurement had a long-period component of about 10 sec. This long-period component was considered to be the effect of the ground formation at the depth (see Fig.3) and the properties of the epicenter.

As for the maximum value in the record, normal earth and water pressure \( p \), maximum amplitude of pressure \( \Delta p_E \) corresponding to \( p \) during the earthquake and the ratio between the two values were shown (Table 2). The maximum amplitudes of pressure \( \Delta p_E \) were within the range of 2.74 to 6.37 kN/m² and tended to become larger when closer to the ground surface. The ratios \( \Delta p_E/p \) were within the range of 0.011 to 0.374, and it was noteworthy that at GL-4.2m the ratio showed an increase of nearly 40% over the normal time.

Autocorrelation functions in both the records of earth and water pressure showed different characteristics which depended on the location where each sensor was installed (Fig.8). Namely, these different characteristics were divided into those in the diaphragm zone (D.Z., see Fig.3) and in the structure zone (S.Z.). Those in the D.Z. were simple and contained a predominant long-period component. Those in the S.Z. showed complicated motions which were considered a manifestation of the interacting effects between the building and the ground. Water pressure showed properties which were similar to those of earth pressure in the comparatively nearer location.

The power spectra in all the records had predominant frequency at about 0.1Hz (10sec)
Table 2. Quantities of fluctuations of earth and water pressure due to earthquake

<table>
<thead>
<tr>
<th>No.</th>
<th>Depth (m)</th>
<th>p (kN/m²)</th>
<th>Δpₑ (kN/m²)</th>
<th>Δpₑ/p × 100(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.3</td>
<td>72.13</td>
<td>5.68</td>
<td>7.88</td>
</tr>
<tr>
<td>2</td>
<td>15.8</td>
<td>176.20</td>
<td>3.53</td>
<td>2.00</td>
</tr>
<tr>
<td>3</td>
<td>18.8</td>
<td>225.89</td>
<td>3.72</td>
<td>1.65</td>
</tr>
<tr>
<td>4</td>
<td>20.3</td>
<td>246.03</td>
<td>2.74</td>
<td>1.11</td>
</tr>
<tr>
<td>5</td>
<td>4.2</td>
<td>17.65</td>
<td>6.37</td>
<td>37.36</td>
</tr>
<tr>
<td>6</td>
<td>11.2</td>
<td>104.96</td>
<td>4.21</td>
<td>4.01</td>
</tr>
<tr>
<td>7</td>
<td>18.2</td>
<td>145.53</td>
<td>5.88</td>
<td>4.04</td>
</tr>
<tr>
<td>8</td>
<td>7.4</td>
<td>34.59</td>
<td>3.63</td>
<td>10.48</td>
</tr>
<tr>
<td>9</td>
<td>20.9</td>
<td>121.81</td>
<td>3.04</td>
<td>2.49</td>
</tr>
<tr>
<td>10</td>
<td>10.2</td>
<td>58.80</td>
<td>3.92</td>
<td>6.67</td>
</tr>
</tbody>
</table>

S-Side Earth pressure

E-Side Earth pressure

S-Side Water pressure

E-Side Water pressure

Fig. 8. Autocorrelation between earth pressure and water pressure during earthquake

as mentioned earlier (Fig.9). Trends of spectra closely resembled each other and showed directivity according to the side. The spectrum of water pressure also closely resembled that of earth pressure at a nearby location. Transfer functions with respect to the records at maximum depths of earth pressure at the S- and the E-sides and water pressure at the S-side were shown (Fig.10). They indicated the trends of increased magnification factors nearer to the ground surface. Directivity according to the side was also observed. Water pressure indicated a trend similar to that of earth pressure.

CONCLUSION

From the above-mentioned record and its analysis, the following points could be observed as properties of earth pressure and water pressure which acted upon the perimeter basement walls during the earthquake:

1. Fluctuations of earth and water pressure during the earthquake became greater when closer to the ground surface. Even during the earthquake under consideration here, earth pressure and water pressure fluctuated nearly 40% over normal time.

2. Earth pressure and water pressure during the earthquake closely resembled those which appeared on the ground displacement record (taken by the single-magnification strong-
Fig. 9. Power spectra of earth pressure and water pressure during earthquake

Fig. 10. Transfer functions of earth pressure and water pressure during earthquake

motion seismograph installed at Yokohama Local Meteorological Observatory) and contained a longperiod component wave.

3. The waves at the D.Z. and S.Z. showed properties different from each other.

4. Directivity according to the side was observed.

5. Water pressure and earth pressure had properties which closely resembled each other.

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