Study on the seismic response characteristics on the valley-bottom plain due to Representative Soil Profile Models by Tokyo lowland

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ABSTRACT

The central part of Tokyo, Japan's capital city can be roughly divided into a western diluvial upland and eastern alluvial lowland. In the dilluvial upland, the valley floor assumes a dendritic pattern due to the branching streams. The damage in the 1923 Great Kanto Earthquake concentrated on the valley floor. This study analyzes the seismic response focusing on three cross sections spanning the Kanda-gawa, and considers the effect that the difference in the ground structure of a valley floor has on seismic response characteristics. The seismic response results effect of the thickness of highly organic soil and its irregular form alluvial basis that is most likely to result in earthquake damage, particularly damage to buried pipes.

Keywords: Valley-bottom plain; Seismic response; Highly organic soil

1 INTRODUCTION

The central part of Tokyo, Japan's capital city can be roughly divided into a western diluvial upland and eastern alluvial lowlands. In the diluvial upland, the valley floor assumes a dendritic pattern due to the branching streams. This valley floor is occupied by a residential area and a crowded commercial district. Due to the previous earthquake damage to central Tokyo, much damage occurred in the 1923 Great Kanto Earthquake on the boundary part of alluvial lowlands, upland, and lowlands. Damage was concentrated along the valley bottom lands. The ground structure of these bottom lands consists of a very soft, cohesive, and highly organic soil.

This study analyzes the seismic response focusing on three two-dimensional cross sections spanning the Kanda-gawa, beginning with a representative soil profile model (RSPM), and using the FLUSH, a computer model for soil-structure interaction, and considers the effect that the difference in the ground structure of a valley floor has on seismic response characteristics. These cross-sections are marked in Figure 1 as A−A', B−B', and C−C'.

2 STRUCTURE OF THE VALLEY FLOOR ALONG THE KANDA-GAWA RIVER AND PAST EARTHQUAKE DAMAGE

The structure of the area under study, namely the valley floor bordering the Kanda-gawa river is shown in Figure 1. The Kanda-gawa stretches for about 25 km from its origin at the Inokashira pond. The valley floor in the study area is classified into the upper region bordered by steep inclination section, and the downstream region of the more gradual incline by which the aggradation was carried out in the alluvium. The former is an erosional plain and the latter is a depositional plain. Moreover, as for the characteristics of the crossing type of valley, there is an asymmetry between the steep inclination of the north-side upland and the slighter inclination of the south-side upland. The longitudinal section of the central part of this lowland is shown in Figure 2. Figure 1 shows the lower part of the Kanda-gawa running from the Tokyo Metro's Takadanobaba Station on the west end, to Otemachi Station on the east end. This RSPM was constructed by Yasuda et al (2010). This shows that the ground structure of the shallow part of a valley floor changes bordering on No.5 and No.6. The ground materials forming the valley floor are sand and sand gravels in the middle region of No.1 to No.5, and are cohesive soil and highly organic soil from No.6 in the downstream region. The layer model of the black hatching in the figure is a highly organic soil, distributed over the surface-layer part between Iidabashi (No.16) to the Edogawabashi (No.9) at about 2－4 m. The standard penetration test (SPT) *N*-values are very soft at 1－2 times. In the downstream area from Iidabashi, shallow ground is composed of alluvial cohesive soil with a SPT *N*-value of 1 to 4 times.

Damage points of this region from the 1923 Great Kanto Earthquake, summarized by Yasuda et al (1993), are shown in Figure 3. This figure is added to

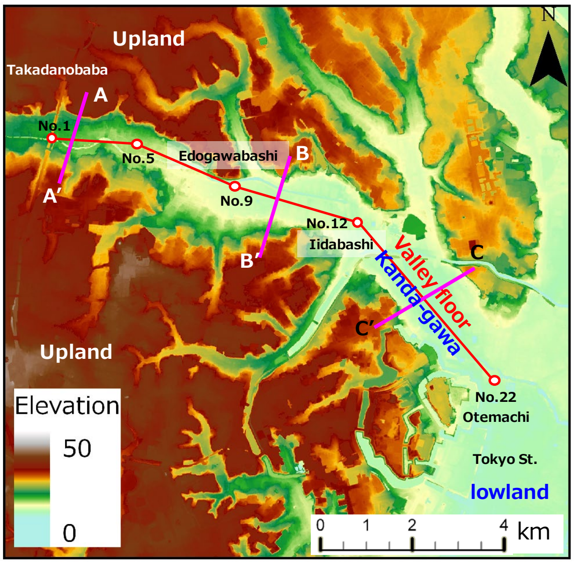


Figure 1 Elevation of the valley-bottom plain along Kanda-gawa

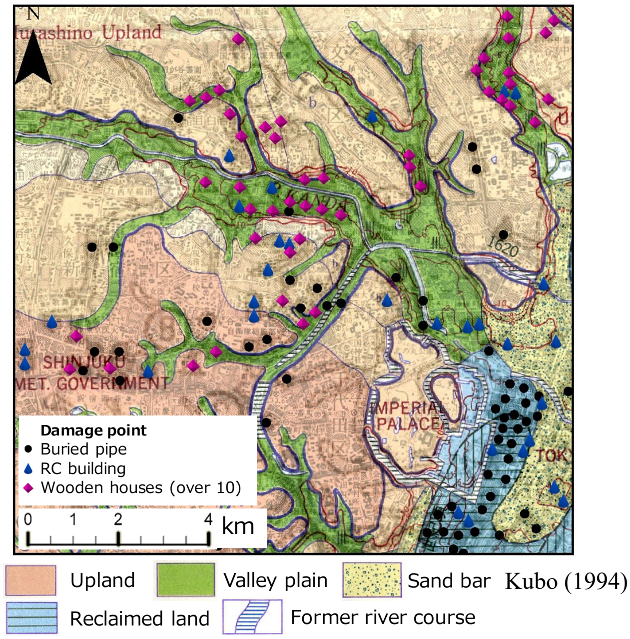
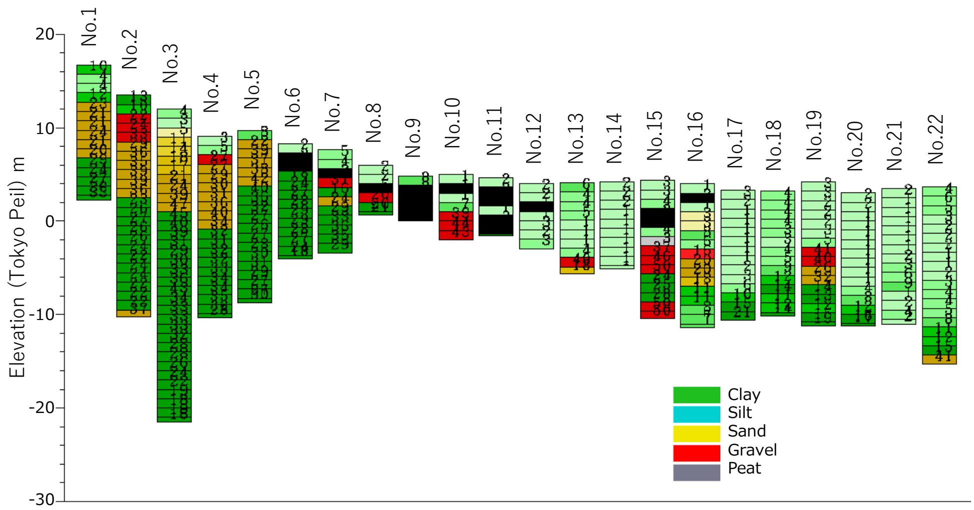


Figure 3 Geomorphologic map and the past earthquake damage



A number is the same as that of in Fig. 1.

No.1 — No.5: Middle class region (Steep inclination)

No.6 — No.22: Downstream region (loose inclination)

No.6 — No.16: The distributed section of a Highly organic soil

Figure 2 Longitudinal section of the central part of valley-bottom plain

Geomorphological map of the Tokyo lowland by Kubo (1994). The damage consisted of water pipe failures of 900 mm or less, damage to clusters of over ten or more wooden houses, and RC (reinforced concrete) building damage. These damage points are taken from the report of Japan Society of Civil Engineers or the Earthquake prevention association. The damage was concentrated near the boundary of alluvial lowlands and the upland, and lowlands of the east side of central Tokyo. Other damage is concentrated in the upland valley floor, which spreads out in a dendritic pattern. Damage is concentrated in the region over which a highly organic soil is especially distributed from the Edogawabashi to Iidabashi. Moreover, in the 2011 Great East Japan Earthquake, the suspended ceilings of the large hall located near the No.19 and No.20 collapsed killing two people. According to Kawaguchi et al (2018), as a result of estimating the earthquake motion of a main shock from the micro tremor exploration of an aftershock, there was a strong shake with a long duration, and it concluded that collapse of the suspended ceiling was due to huge swing. Thus, in a valley floor, it is suggested having an irregular form bedrock and the amplification character of an earthquake motion differs from a surrounding area since the ground soil structure is vulnerable.

3 OUTLINE OF THE SEISMIC RESPONSE ANALYSIS TO THE GROUND MODEL OF A VALLEY FLOOR

The cross sections of the Kanda-gawa valley which were studied are the A — A' line of an upper region, B — B' line of a middle region, and C — C' line of the downstream region, respectively, as shown in Figure 1. The analysis model was based on the 250 m mesh ground model from a nation-wide electric geotechnical database system, and constructed to line up these ground models.

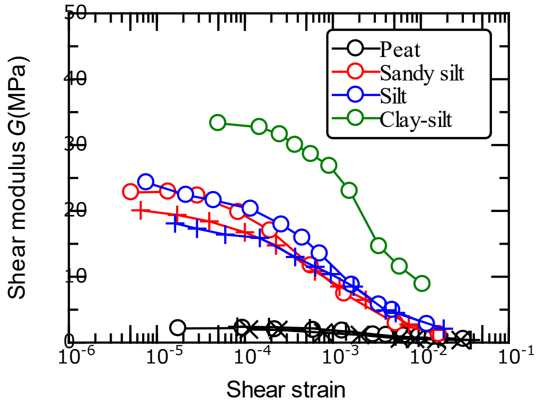


Figure 4 Dynamic deformation characteristic test resuls

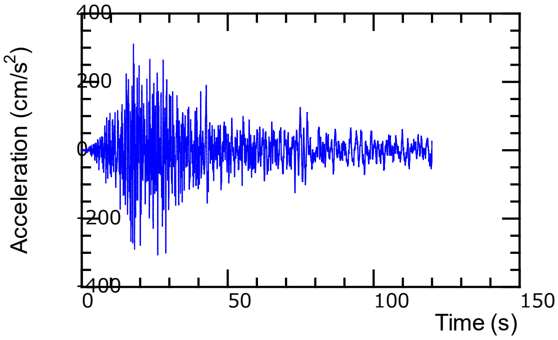


Figure 5 Input earthquake motion

The form of a ground surface in an elevation surface model is due to the 5 m digital elevation model by the Geospatial Information Authority of Japan (2018). The layer boundary in the cross-sectional forms was in conformity with the geologic map by the Metropolitan Tokyo (2018).

For the two-dimensional seismic response analysis, we used FLUSH, a computer model for soil-structure interaction. A shear wave velocity and a shear modulus are calculated with the following estimate equations from the soil and SPT N-value based on ground information from a RSPM.

$$V_S = \begin{matrix} 80 \times N^{(1/3)} \\ 100 \times N^{(1/3)} \end{matrix} \text{(m/s)} \begin{matrix} \text{Coarse grained soil} \\ \text{Fine grained soil} \end{matrix} \tag{1}$$

$$G_0 = \rho \times {V_S}^2 \text{ (kN/m}^2\text{)} \tag{2}$$

A highly organic soil is a test value of $G_0 = 2{,}200$ kN/m^2 from the previous dynamic deformation characteristic test result shown in Figure 4. As shown in this figure, a highly organic soil is a problem soil and with a very small value compared with other cohesive soils. A dynamic deformation character is a proposal equation which uses average grain size as a parameter as introduced by Yasuda and Yamaguchi (1985). A bedrock is a bearing layer distributed continuously widely, a SPT N-value is over 50 and shear wave velocity is 350 m/s. Input earthquake motion is the Tokyo Bay littoral district simulated earthquake waveform shown in Figure 5, and is input into the bedrock of an analysis model. This wave form models force comparable to the 1855 Ansei Edo earthquake, the 1923 Kanto earthquake, or the assumption Tokai earthquake. A boundary condition makes a lateral face an energy transmitting boundary, and the bottom is an elastic bedrock (V_S = 350 m/s, Damping = 0.5 %).

4 SEISMIC RESPONSE ANALYSIS RESULTS OF A CROSS SECTION MODEL

Figure 6－8 show the results from analysis of each cross section studied. Each figure shows, for one of the three cross-sections, the layer cross section, the maximum acceleration distribution, the maximum displacement distribution, and the maximum horizontal strain distribution of the ground surface sequentially from the top.

In the A－A' cross section of Figure 6, the aggradation of most valley parts consists of a diluvium clayey, and diluvium sandy soil and a sand gravel, and the surface layer part is covered with about 2 m of alluvial cohesive soil. The surface response value of a lowlands part, a maximum acceleration is 220－300 cm/s^2, maximum velocity is 75－80 cm/s, and the maximum displacement is 3－4 cm. In such layer structure, the conspicuous amplification character of the earthquake motion within a valley-bottom plain was not seen. It is also verified, using a maximum horizontal strain distribution of a ground surface, that there was no ground strain sufficient to cause buried pipe damage.

In the B－B' cross section (Figure 7), the aggradation of the valley consists of a highly organic soil, with thickness of up to 5 m. Furthermore, the layer boundary under the alluvium is the concave irregular form layer structure due to a buried terrace layer distributed near the upland in the valley bottom. The surface response value of a lowlands part, maximum surface acceleration, the north side is 250－270 cm/s^2, the central part is 160－240 cm/s^2, the south side is 230－460 cm/s^2, and surface acceleration response greatly differs between the north and south of the valley bottom. The model shows a maximum displacement of 4－18 cm in the central part of the valley bottom with its highly organic and thickly distributed soil. The displacement response is specifically present in this part of the valley floor. In addition, the difference in surface displacement depends on the deposition layer thickness of the highly organic soil. The resulting, maximum of 0.6 % of horizontal strain is sufficient to cause buried pipe damage occurs. Such displacement response matches the damage of the 1923 Great Kanto Earthquake.

In cross section C－C' Figure 8, the aggradation of most valley parts consists of an alluvial cohesive soil, with a thickness up to 12 m. It is the irregular form alluvial basis form in which a valley floor on the south has a buried terrace. The maximum surface acceleration of valley-bottom plain is 360－490 cm/s^2, and the acceleration response on the surface is amplified greatly with 380－490 cm/s^2 by the inclination of an alluvial

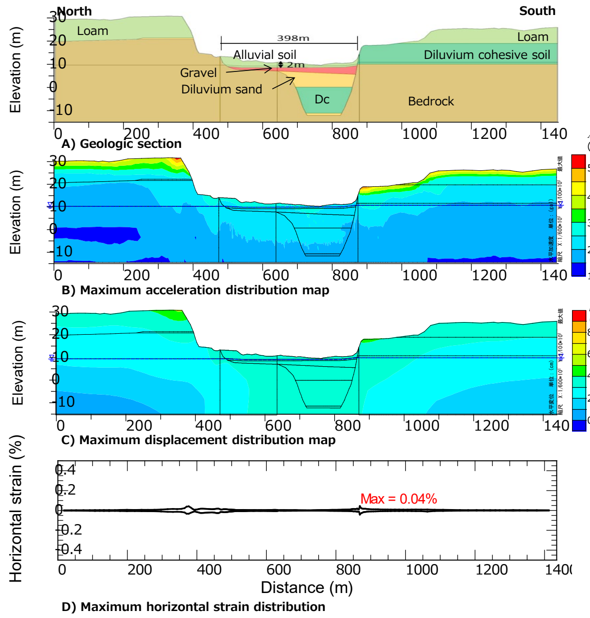


Figure 6 Analysis results of the cross section of A－A' line

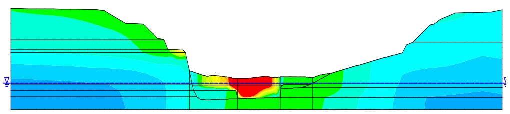


Figure 7 Analysis results of the cross section of B－B' line

basis on a buried terrace. Maximum velocity is 10－27 cm, maximum displacement is 0.5－4 cm, which implies not enough horizontal strain to cause buried pipe damage. However, the strain of the ground tends to concentrate near the surface of above the boundary of the buried terrace.

These seismic response characteristics harmonize with the damage conditions in case of the Great Kanto Earthquake.

CONCLUSIONS

Analysis and modeling using RSPMs of these cross

Figure 8 Analysis results of the cross section of C－C' line

sections spanning the Kanda-gawa indicate that only the center one, B－B' (Figure 7), has the characteristics, including the thickness of highly organic soil and its irregular form alluvial basis that is most likely to result in strong earthquake damage, particularly damage to buried pipes, and this is in fact where most of the damage occurred in the 1923 Great Kanto Earthquake.

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