The seismic characteristics of surface ground of Zushisite during The 2011 East Japan Great Earthquake

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ABSTRACT

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In Tokyo Metropolitan University, the horizontal and vertical array earthquake observations has begun in June 1994 at the five stations ($k1\sim k5$) on the ground surface and bedrock (-30m depth k6) at Zushi-site. At The 2011 East Japan Great Earthquake (M=9.0), the largest surface ground acceleration (124.5gal) of the horizontal component was recorded.

In this study, the surface ground characteristics of the Zushi-site were examined during The 2011 East Japan Great Earthquake using the observed acceleration records at the k1 and k6 observation stations, and also the ground structure is identified by the developed FEM identification analysis using the observed acceleration records.

Moreover, the seismic response analyses of the Zushi-site were performed by TDAPIII using the observed acceleration record (k1&k6) of The 2011 East Japan Great Earthquake for input motion and the identified ground structure model.

From these results, the seismic response characteristics of the Zushi-site during The 2011 East Japan Great Earthquake were verified.

Keywords: The 2011 East Japan Great Earthquake, Earthquake Observation, Modal Analysis, FEM Identification Analysis, Dynamic characteristic of ground, Zushi, TDAPIII.

1. GENERAL INSTRUCTIONS

In Tokyo Metropolitan University, the horizontal and vertical array earthquake observations has begun in June 1994 at the five stations ($k1\sim k5$) on the ground surface and base rock (-30m depth k6) at Zushi-site with various soil conditions.

More than 200 medium and small earthquakes (smaller earthquakes) with the magnitude $5.0 \sim 7.3$ were recorded between 1994 and 2010, including the 1995 Hyogoken-Nanbu earthquake (M=7.3), the 1998 Tokyo -bay earthquake (EQ.1: M=5.4), the 1999 Chibaken-hokuseibu Earthquake (EQ.2: M=5.1), the 2005 Chibaken-Hokuseibu earthquake (M=6.0), and etc.

In The 2011 East Japan Great Earthquake (EQ.3.11), the largest surface ground acceleration (124.5gal) of the horizontal component was recorded at k1 station.

The objective of this study is to clarify the dynamic characteristics of the ground of Zushi-site during The 2011 East Japan Great Earthquake, comparing those subjected by the past smaller earthquakes (EQ.1&EQ.2) and to obtain the basic data for seismic disaster mitigation of this area.

The contents of this paper are shown as follows.

- (1) Firstly, the outline of the earthquake observations and the past observed data before The 2011 East Japan Great Earthquake at Zushi-site.
- (2) Secondly, the surface ground motion characteristics of Zushi-site (k1 & k6) using the observed data of EQ.3.11, compared with the characteristics using the data of EQ.1&EQ.2.

- (3) Thirdly, the ground structure models of the Zushi-site were identified by the modal analysis and the EEM identification analysis using the observed data of EQ.3.11 and EQ.1&EQ.2.
- (4) Finally, the seismic response analyses by TDAPIII using the identified models and the observed earthquake data (k1&k6) during The 2011 East Japan Great Earthquake.

2. THE EARTHQUAKE OBSERVATIONS AND THE OBSERVED DATA AT ZUSHI-SITE

The city of Zushi is located in Kanagawa Prefecture, in the southern part of the Tokyo metropolitan area and is particularly high seismicity area. The city suffered severe damages during the 1923 Great Kanto Earthquake (M=7.9).

Geographically, two major rivers (the Tagoe River and the Ikego River) run through the city. The city can be divided into three zones based on ground characteristics; the Holocene lowland zones along the banks and mouths of the main rivers; a zone consisting of reclaimed land near the coastline, and a hill zone (Figure 1-a). The Geological sections of the site along and across the Tagoe River are shown in Figures 1-b and 1-c.



Earthquake Observation Points at Zusi-city

Figure 1 Earthquake observation point at Zushi-site

2.1 EARTHQUAKE OBSERVATIONS AT ZUSHI-SITE ^{1), 2), 3)}

Seismic array observation has commenced in June, 1994, at five ground surface stations (designated by k1~k5). In 1998, one station in the borehole designated by k6 was added. Stations, k1, k2, k4 and k5 has located on the surface of Holocene low- land along the two rivers (Tagoe and Ikego), k3 was located on the outcrop rock, and k6 was located on bedrock (with -30m depth) just below k1 (Figure1).

The bedrock with the shear wave velocity (Vs m/s) greater than 400m/s occurs at a depth of -26m at k_1 , -12 m at K_2 , -15 m at k_4 , and -7 m at k_5 , respectively.

2.2 EARTHQUAKE OBSERVATION RECORDS (EQ.1 AND EQ.2) BEFORE THE 2011 EAST JAPAN GREAT EARTHQUAKE AT ZUSHI-SITE.

More than 200 earthquakes were recorded between 1994 and 2012, including The 1995 Chibaken-Nanbu earthquake (M=5.2), The 1995 Hyogoken-Nanbu earthquake (M=7.3), The 1998 Tokyo Bay Earthquake (EQ.1: M=5.4), The 1999 NW Chiba Earthquake (EQ.2: M=5.1) and etc., before The 2011 East Japan Great Earthquake, as shown in Figure 2.

Generally, the maximum accelerations of these earthquakes were small less than 100gals and these duration times were short less than 60 second. For example, in case EQ.1, the maximum acceleration

values were about 34.01gal for horizontal NS component, and about 13.75gal for vertical one and the duration time was about 40 seconds. The acceleration value was about 1/5 smaller, and the duration time was 1/8 shorter than those of EQ.311.



Figure 2 The epicenters of the past observed earthquakes (Red-dots), The 2011 East Japan Great Earthquake (Star-mark) and Zushi site (Triangel-Mark)

2.3 EARTHQUAKE OBSERVATION RECORDS OF THE 2011 EAST JAPAN GREAT EARTHQUAKE AT ZUSHI-SITE

In the 2011 East Japan Great Earthquake (M=9.0), the recorded data are quite different from the past recorded ones, that is, the duration time was a quite long (more than 300 seconds) and the maximum acceleration values of the data were the largest among of all data, which were 124.5 gal in horizontal NS component recorded at k1-station and 45.5gal in horizontal NS component recorded at k6-station, respectively, as shown in Figure 3.



Figure 3 Recorded data (k1, k6: NS Component) of the 2011 East Japan Great Earthquake

3. THE SURFACE GROUND MOTION CHARACTERISTICS OF ZUSHI-SITE

In order to examine the surface ground motion characteristics of Zushi-site (k1 & k6) using the observed date (k1 & k6) of The 2011 East Japan Great Earthquake (EQ.3.11) and the data of the past-observed smaller earthquakes (EQ.1 and EQ.2), the transfer functions, (T2 (k1/k6) for EQ.3.11, T1 (k1/k6) for EQ.1&EQ.2) between surface (k1) and the bedrock (k6:-30m) were estimated, shown in Figure 4. Comparing T1 (k1/k6) and T2 (k1/k6), these results were obtained as follows.

The predominant frequency (f1) was about 2.1Hz~2.3Hz for T1 and 1.9Hz~2.1Hz for T2 were obtained, respectively. The frequency (f1) for T2 is about 10% smaller than that for T1. So, the material property (Vs) of the surface ground, were decreased about 10% on an average due to EQ.3.11.



Figure 4 The transfer functions(k1/k6), comparison between the past observed smaller earthquakes(T1) and The 2011East Japan Great Earthquake (T2)

4. THE GROUND STRUCTURE MODELS OF THE ZUSHI-SITE ESTIMATED BY MODAL ANALYSIS AND THE FEM IDENTIFICATION ANALYSIS $^{\rm 3)}$

4.1 APPLICATION OF MODAL ANALYSIS AND FEM IDENTIFICATION ANALYSIS

In order to identify the ground structure model of Zushi-site more correctly, the modal analysis and the FEM identification analysis were applied using the initial model and the observed earthquake acceleration data (k1&k6) of EQ.1&EQ.2 and EQ.3.11, as follows.

- (1) The initial ground structure model was made using the existing soil data, the seismic exploration test data and the micro tremor observation data.
- (2) The two types of ground structure models were identified using the observed acceleration data of EQ.311 for the strong earthquake motion (Case2) and of EQ.1 &EQ.2 for smaller earthquake motions (Case1).

In the analyses, the seismic responses of the surface ground and the transfer functions (k1/k6) were estimated using the observed accelerations of NS component of k6 for the input motions.

4.2 RESULTS

 Figure 5 shows the acceleration time histories of k1 NS component due to EQ.3.11, comparison between the observed results and the calculated ones by the modal analysis. These results agree well with each other.



Acceleration of K1 on the ground surface : Great East Japan Earthquake

Figure 5 The acceleration time histories of k1due to EQ.3.11compared with the result by modal analysis and observed one

(2) Figure 6 shows the transfer function (k1/k6) due to EQ.3.11, comparison between the calculated result by modal analysis and observed one. These results also agree well with each other.

From Figure 5 and Figure 6, the calculated results by modal analysis were reasonable for estimate the seismic response of the surface ground.



EO.1&EO.2 (Case1)

(3) Figure 7 shows the transfer functions (k1/k6) estimated by the modal analysis, comparison between for EQ.3.11 and for EQ.1&EQ.2, respectively.

calculated one due to EO.3.11

(4) Table 1 shows the eigen values (the eigen frequency f (Hz) and the damping factor h (%)) estimated by the modal analysis, comparison between for EQ.3.11 (Case2) and for EQ.1&EQ.2 (Case1), respectively.

Compared Case1with Case2, in Case2, f (Hz) is about 0.90 times smaller and h (%) is 1.5 times larger than those of in Case 1.

Mode	Case1		Case2	
	Smaller earthquakes		Grate East Japan Earthquake	
	(EQ.1&EQ.2)		(EQ.3.11)	
	f(Hz)	h (%)	f(Hz)	h (%)
1	2.23	6.60	1.95	9.38
2	6.40	5.60	5.80	7.15

Table 1 Eigen frequency and damping factor

(5) Table 2 shows the material property values of the identified models comparison between Case1 and Case2.

It is confirmed that, in Case 2, the shear wave velocity (Vs m/s) of the third layer decreases most greatly (about 15.6%) than that of in Case1.

From these results, the material properties of the surface ground of Zushi-site were extremely decreased and non-linear characteristics of the surface ground were verified during The 2011 East Japan Great Earthquake.

Layer	Unit weight	Shear wave velocity Vs(m/s)		Rate of	Depth
No.	(t/m^3)	Case1	Case2	decrease (%)	(m)
		Smaller earthquakes	Great East Japan		
		(EQ.1&EQ2)	Earthquake (EQ3.11)		
1	1.70	150.1	150.0	0.07	1.0
2	1.80	134.6	132.5	1.56	4.0
3	1.50	222.5	187.6	15.60	20.0
4	1.90	237.6	228.9	3.66	24.0
5	2.00	253.3	251.6	0.67	25.0
6	2.00	400.8	400.4	0.10	26.0
7	2.10	700.6	700.3	0.04	30.0

 Table 2 Material property values of identified models

5. SEISMIC RESPONSE ANALYSIS BY TDAPIII⁴⁾

The seismic response analyses of the Zushi-site were performed by TDAPIII using the observed acceleration record (k1&k6) of The 2011 East Japan Great Earthquake for input motion and the two identified ground structure models (Case1 & Case2).

5.1 ANALYTICAL MODEL AND CONDITIONS

Figure 8 shows the geological sections A-A' & B-B'. Three-dimensional model was created based on two cross-sections (A-A'&B-B') of the model as shown in Figure 9. The analytical model and the conditions are as follows.

(1) The number of elements of three-dimensional model is 77412. (2) The thickness of all elements is 1.0m, and the width of all elements is 50m. (3) The boundary condition of each side was roller, and bottom was fixed restraint. (4) Material properties of the ground structures model were decided by the identification analysis, as shown in Table 2.

(5) Dynamic analyses (direct integral method) were performed by TDAPIII using the observed horizontal accelerations NS & EW components of k6 of EQ.3.11 for input motions.



Figure 8 The Geological sections A-A' & B-B'



Figure 9 Three-dimensional model

5.2 RESULTS

 Figures10&11 show the maximum shear strain (γ_{YZ}) distributions in X (EW) direction of A-A' section of Case1 and Case2, respectively. Compared Case1 with Case2, the maximum shear strain in Case2 is about 1.42 larger than that in Case1. In both case, the maximum shear strains were occurred around X=-400m section (k1&k6 exist) in

EW direction, where the depth of the surface layer is largest.

- (2) Figures12&13 show the maximum shear strain (γ_{YZ}) distributions in Z (depth) direction of X=-400m section of Case1and Case2 respectively. Maximum shear strains occurred in the 3rd and the 4th layer, where the Vs were the smaller than that of the other layers of the ground model.
- (3) Figures 14 and 15 show the transfer functions between the bedrock and the surface at 2points (point1: X=-400m, point2: X=0m), comparison between Case1 & Case2. In Case2, the predominant frequency decreases about 10% than in Case1 at each point (point1&point2). From the calculated results, the non-linear property of the surface ground was confirmed due to The 2011 Great East Japan Earthquake.



Figure 10 Shear strain (γ_{YZ}) distribution of A-A' section (Case1)



Figure 11 Shear strain (γ_{YZ}) distribution of A-A' section (Case2)





- (4) Figures 16, 17 show the surface acceleration distributions of NS component of X=-400m section and x=0m (B-B') section, respectively.
 The accelerations of the surface around were varied with the depth of the surface layer from about 90gal to 270gal for X=-400m section, and from about 90 gal to 160gal for X=0 section, respectively.
- (5) In both sections, the maximum accelerations were obtained at K1(Y=0m), where the depth of the surface layers were deepest, respectively.
- (6) Figure 18 shows the acceleration response distributions of NS component of A-A' section from about x=-700m to X=2800m. The acceleration responses were also varied with the depth of the surface layer. The maximum values were obtained at west side of the surface ground where the depth of the surface layer was deepest.



Figure 18 Surface acceleration response distribution (NS) of A-A' section

6. CONCLUSION

- 1. The earthquake observation data were obtained on the surface ground at Zushi-site during The 2011 East Japan Great Earthquake. In the earthquake, the largest accelerations and the longest duration-time were recorded.
- 2. The non-liner seismic response characteristics of the surface ground at Zushi-site due to The 2011 East Japan Great Earthquake were clarified by the observed earthquake acceleration data and the modal analysis.
- 3. The ground structure models were examined and identified by the modal analysis and the FEM identification analysis using observed earthquake acceleration data.
- 4. The seismic responses of the surface layer of the surface ground Zushi-site during The 2011 East Japan Great Earthquake were verified by TDAPIII.
- 5. These results will be useful for seismic disaster mitigation and seismic design of the structures in Zushi-site.

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