Amplification properties of developed residential land for main shock and three aftershocks

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ABSTRACT :

Takamachi developed residential land was damaged in Niigata Chuetsu Earthquake in 2004. The maximum magnitude of acceleration of main shock is 818 gal and three big aftershocks took place within 40 minutes after the main shock. The magnitudes of aftershocks were 6.3,6.0 and 6.5. It was observed that many houses and soil structures failed progressively by the repeats of aftershocks. To make clear the influences of repeated aftershocks, two dimensional equivalent linear simulations were performed against damaged and undamaged area. The reduction tendencies of shear modulus of filled soils were measured by laboratory tests. The results of simulation for main shock could not express the generation of earthfill slope failure enough. However, the considering aftershocks gives more reasonable results, because the aftershocks has different predominant period. Of course, the slope angle of natural ground and fill thickness are influenced to the vibration behavior of development land. On the other hand, the maximum acceleration, velocity and relevant displacement were not enough for expression the slope failures, it is found that the average acceleration during principal motion is available index. In another static back analysis, the slopes of earthfills are failed when the horizontal seismic coefficient is over 0.25, this result corresponds with consequences of numerical analysis. This shows we have possibility of conversion between dynamic force to static force using the average acceleration, since the static force is adopted widely in the design for earthquake-proof.

KEYWORDS: amplification on slope shoulder, equivalent linear method, aftershocks

1. INTRODUCTION

It is well known that the artificial earth fill is suffered from severe damages in earthquake, Takamachi housing complex, which is target of our analysis, was also damaged as shown in Photo 1 and 2. Total number of houses in the Takamachi housing complex was 522 and about 70 houses were damaged by ground deformation. This housing complex was developed in latter 1970's; two low hills or summits were flattened by cutting and filing. Four large slope failures were occurred in artificial fill, however, not all artificial filling slopes failed.

Photo 1 Artificial filling slope failure 1

Photo 2 Artificial filling slope failure 2

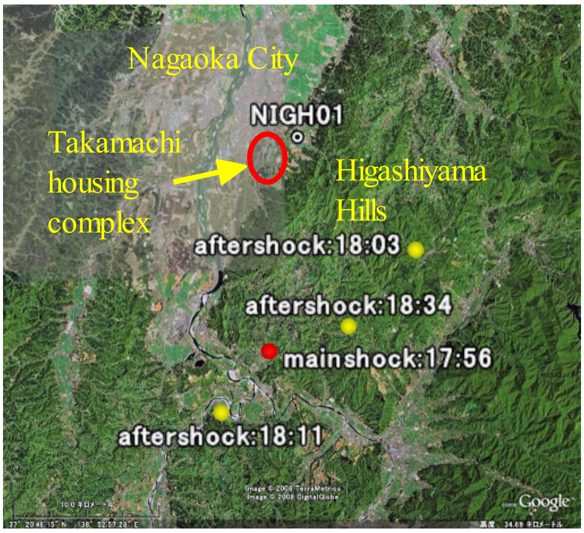


Figure 1 Locations of Takamachi housing complex, measure point of acceleration and epicenter of earthquake (map by Google Earth)

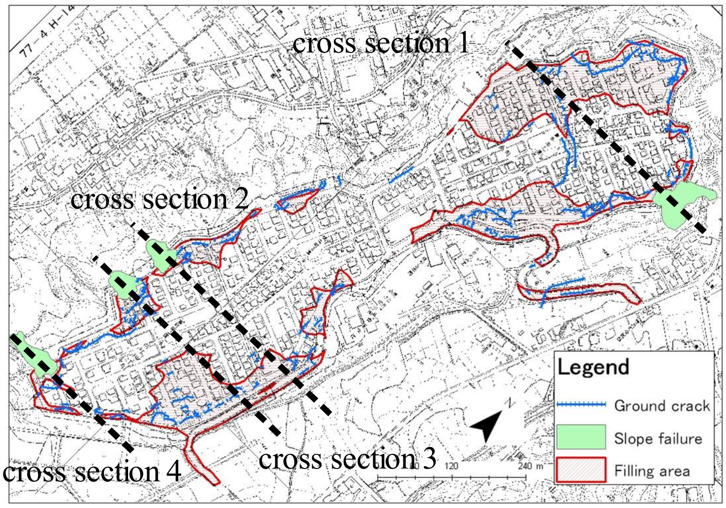


Figure 2 Plane view of Takamachi housing complex with positions of calculated cross sections, filling area and slope failures

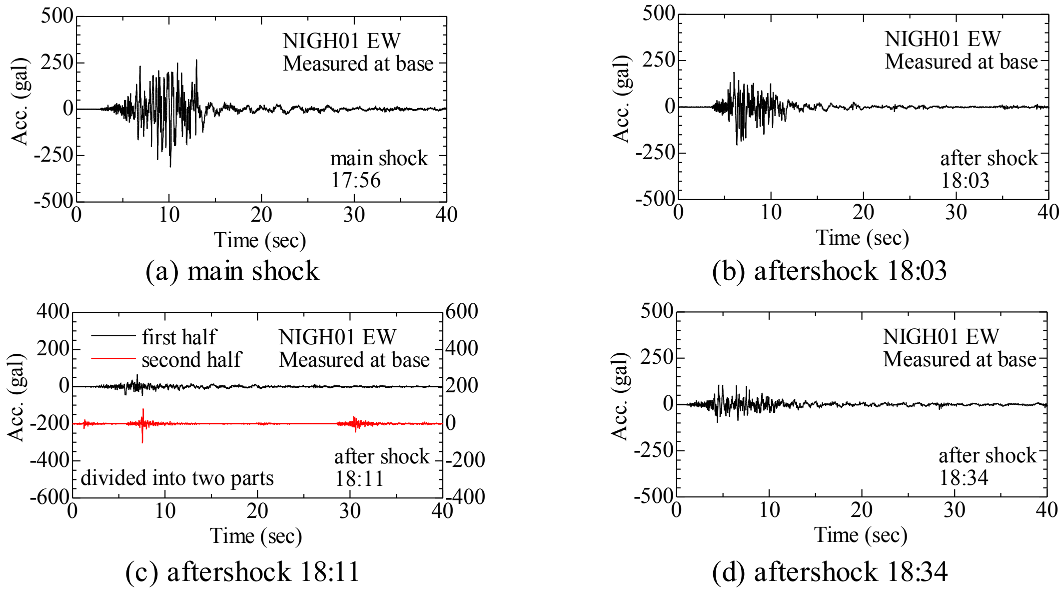
Surface wave exploration on the developed land and static and dynamic tri-axial tests for sampled fill soil were carried out. Therefore, we could obtain the soil parameters for dynamic analysis and the properties of artificial filling slope. In the present study, we focus dynamic amplification properties in two dimensional configurations, the ground water level is not considered. In further studies, these dynamic properties have to be compared with static stability analyses considered ground water level, though one cross section was analyzed by Ohtsuka et al., 2007. It seems that this study is also available for the highway filling.

The feature of earthquake motion exists in repeated aftershocks. Three big aftershocks took place within 40 minutes after the main shock. The magnitudes of aftershocks were 6.3, 6.0 and 6.5. It was observed that many houses and soil structures failed progressively by the repeats of aftershocks. Another cause for big disaster is pointed out as the effect of rainstorm three days before the earthquake. The precipitation was recorded as 100mm/day at Nagaoka JMA (Japan Meteorological Agency).

2. TOPOGRAPHY AND GEOLOGY OF TAKAMACHI HOUSING COMPLEX

Takamachi area is located southeast from Nagaoka urban district and at the west edge of the Higashiyama hill as shown in Fig.1. It is surrounded west-side by the Echigo plane and east-side by the Kagi River. The mid-Niigata area is actively folded and the Higashiyama hill forms an anticline line from north-northeast to south-southwest. The Takamachi area gently inclined to the Echigo plane macroscopically. The bedrock is a mudstone of the Nishiyama layer. The stratum is composed of the Oyama, the Uonuma and the Nishiyama layers from the top to the bottom. The Uonuma layer is made of sand, clay, gravel and andesite pyroclastic rock. The Oyama layer is made of sand, clay and gravel. In development of housing complex, the altitude of 70m was planed as the boundary altitude for cutting and filling. The Oyama layer is a target of construction work. The Oyama layer contains clayey silt so that the strength of soil reduces with water supply. The epicenters of main shock and three aftershocks are also indicated in Fig.1.

Fig.2 presents the plane view of Takamachi housing complex. The altitude of Takamachi housing complex is about from 60m to 90m. The area is 1.2km in length and 0.3km in width and distributes from north-northeast to south-southwest. It is made of hill with two low summits. By cutting the higher part, ravines and circumferential area were filled with cut soil. The fill was stabilized with concrete type retaining walls the size of which is 5m in height and 1m in width. As shown in Fig.2, Four slope failures occurred at narrow filling area, not at wide filling area.



Figures 3 (a)-(d) EW acceleration time records

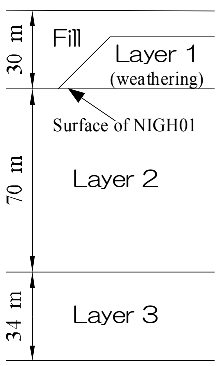


Figure 4 Model soil profile

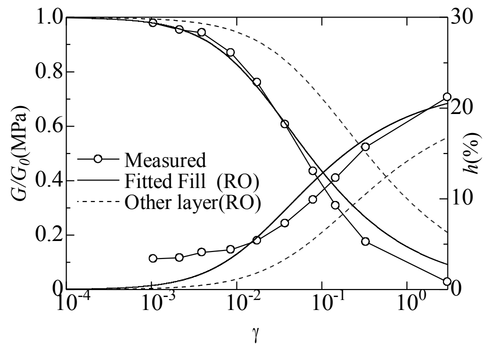


Figure 5 G/G_0-γ , h-γ relationship

Table 1 Estimated soil parameters

Layer	ρ(g/cm^3)	Vs(m/s)	ν
Earth fill	1.85	120	0.3
Layer 1	1.90	300	0.3
Layer 2	2.00	350	0.3
Layer 3	2.10	400	0.3

3. MEASURED SEISMIC WAVES AND ESTIMATION OF SOIL PARAMETERS

Figs.3(a)-(d) indicate the east-west direction acceleration time record of main and three after shocks measured GL-104m. This measured point is called NIGH01 and set by National Research Institute for Earth Science and Disaster Prevention, 1.5km northeast from the Takamachi housing complex. The aftershock of 18:11 has over 80 seconds duration, then the waves were divided into two parts each 40 seconds. The maximum accelerations at base are 312, 205, 104 and 110gal for main shock and aftershocks of 18:03, 18:11 and 18:34, respectively.
The NIGH01 has only boring core data without velocity logging or N-value. Then we have to estimate the soil parameters about 100m thick layers from surface. To estimate the soil parameters of intermediate layer between surface and base at NIGH01, the one dimensional back analysis using multi-reflection method was adopted. The intermediate layers, layer 2 and layer 3 shown in Fig. 4 were divided into two layers according to the boring core data. One is GL-0m to GL-70m (layer 2), and the other is GL-70m to GL-104m (layer 1) at NIGH01. There are two more layers, fill and layer 1, at Takamachi housing complex on those two layers, layer 2 and layer 3. Although the parameters of filled soil and surface layers until GL-20m to 30m are already obtained by surface wave exploration or laboratory tests as shown in Fig. 5.
Fig.5 shows hysteresis curves adopted in equivalent linear simulations. The white circles indicate the results of laboratory test for filled soil, solid lines are fitted RO model to the measurements. Although the natural ground has enough stiffness regarding as engineering base, the broken lines shown in Fig.9 are adopted to Layer 1 to 4 as hysteretic curves, because the maximum acceleration is very large in the Mid-Niigata prefecture earthquake. The hard hysteretic curves for natural ground are determined by considering properties of dynamic deformability for soft rock in earlier studies (e.g. Yasuda et al, 1993 and Standardization Committee of the

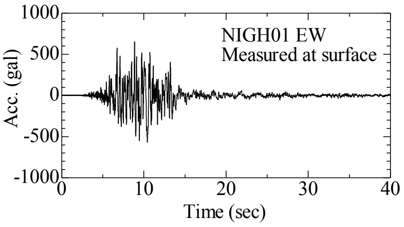


Figure 6 Measured EW acc. at surface.

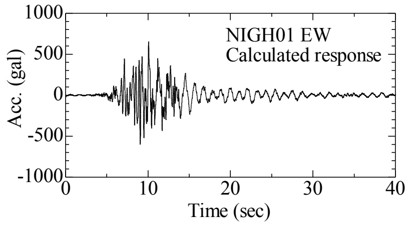


Figure 7 Calculated EW acc. at surface.

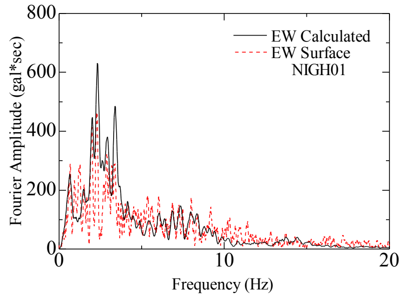


Figure 8 Comparison of Fourier spectrum

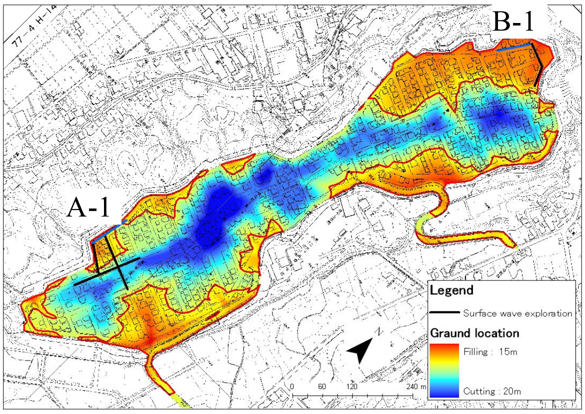
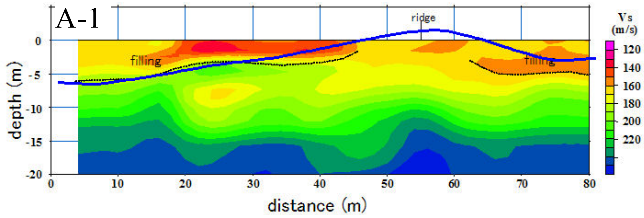
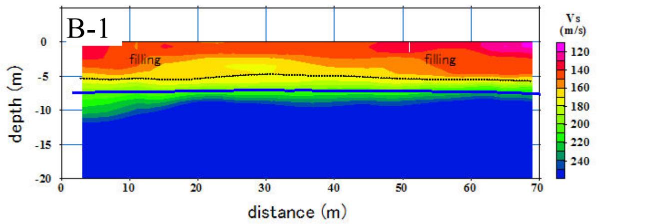


Figure 9 Distribution of cut and fill area



(a) Cross section A-1



(b) Cross section B-1

Figures 10 (a),(b) Surface wave exploration test

dynamic deformability test method for sedimentary soft rock, 1994). Actually, these natural ground layers behaved as almost elastic material in the present calculations.

Fig.6 and Fig.7 show measured and calculated EW acceleration time record at surface, respectively. The estimated soil parameters are indicated in Table 1, they were specified so as to fit the Fourier spectrum as shown in Fig.8.

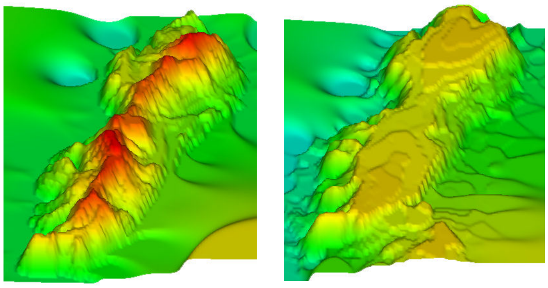
Fig.9 shows the distribution of cut and fill in Takamachi housing complex, and A-1 and B-1 in the figure indicate positions conducted surface wave exploration tests. The results of surface wave explorations are shown in Figs.10 (a), (b). The shear wave velocity of filled soil lies in 100 to 160 m/s.

The initial shear wave velocity in the Filling layer is set to 120m/s, considering the results of surface wave exploration and dynamic tri-axial tests as shown in Table 1. The layer under cut ridge is seemed to be suffered from weathering, then, the initial velocity in Layer 1 is specified to 300m/s.

4. SPECIFIED FILLING THICKNESS AND GENERATION OF CALCULATION CONDITION

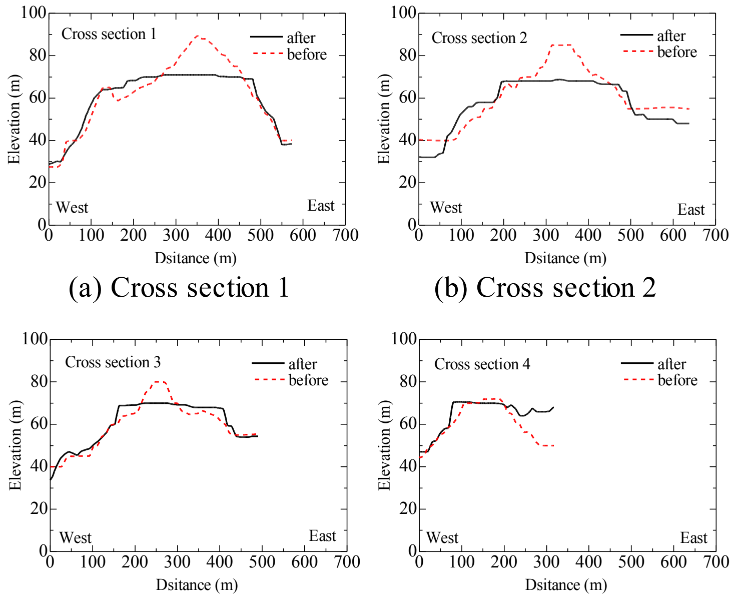
Figs.11(a),(b) indicate the topography of Takamachi area before and after developing land, respectively. To emphasize the height is shown as four times altitude in Figs.11. These altitude data was digitized from paper maps. The four cross sections in EW direction were selected including the four slope failures as shown in Fig.2, and numbered 1 to 4 from north in order. The boundary of cut and fill in each cross section is specified through these altitude data, its boundaries are shown in Figs.12 (a)-(d). In these figures, the elevation is five times to horizontal distance, and the positive direction in horizontal axis is from east to west.

In each cross section, western side is higher than eastern side in elevation because Higashiyama hilly terrains located in eastern side of Takamachi housing complex. The slope failure occurred at eastern side in cross section 1 and western side in others. In cross section 1, western side filling area is larger than eastern side. But it is found that the ridge exists at the edge of western filling area, and then the ridge prevents the occurrence of the



(a) Before development (b) after development

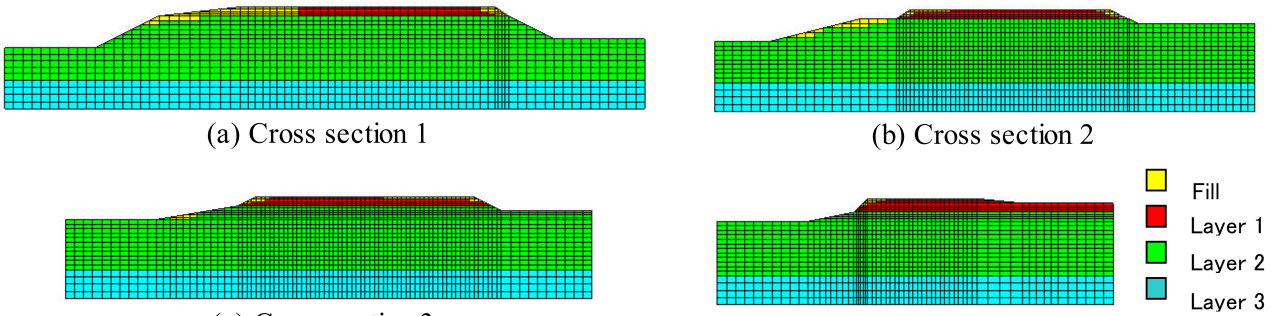
Figures 11 (a),(b) Topography of Takamachi



(a) Cross section 1 (b) Cross section 2

(c) Cross section 3 (d) Cross section 4

Figures 12 (a)-(d) Elevation before and after development



(a) Cross section 1 (b) Cross section 2

(c) Cross section 3 (d) Cross section 4

Figures 13 (a)-(d) FEM mesh for each cross section

slope failure.

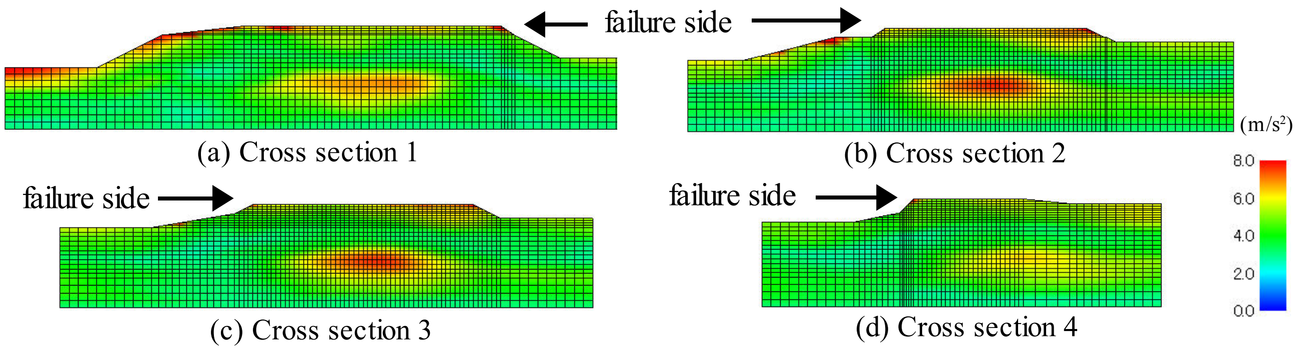
For numerical simulations, EW and UD (up-down) direction's acceleration waves are used for main shock and three aftershocks.

The calculation models are shown in Figs.13 (a)-(d). The yellow area shows fill, and red area, green area, and light blue area show layer 1 to layer 3, respectively. The bottom boundary is rigid, and the side boundary is energy transfer boundary.

5. CALCULATION RESULTS AND DISCUSSION

The distributions of maximum horizontal acceleration inputting main shock are shown in Fig.14 (a)-(d) for each cross section. The distributions are gathered the maximum value generated at some nodal point, which is independent of time. It is found that the amplification of acceleration is greater at slope shoulder and filled area in each section. In the present calculation, the reflection waves are not disappeared well, the large acceleration area is located at the middle depth of FEM meshes.

Table 2 shows the maximum horizontal acceleration and velocity of western and eastern slope shoulder, and hatched row indicates failed side. In cross section 1 and 4, the amplified area for main shock are seemed to be located at wide filling area, as shown Figs.14 (a) and (d), though the slope failure occurred at opposite side. However, the maximum acceleration is generated at failure side shoulder with any input waves, as shown in Table 2. On the other hand, the maximum acceleration for main shock was generated at eastern non-failure side in cross section 2 and 3. The equivalent linear simulation for main shock can express the slope failure in cross



(a) Cross section 1 (b) Cross section 2

(c) Cross section 3 (d) Cross section 4

Figures 14 (a)-(d) Maximum horizontal acceleration for main shock

Table 2 Maximum value for each earthquake

Section 1	Max. Acc. (gal)		Max. vel. (kine)		seismic coefficient	
	western	eastern	western	eastern	western	eastern
MS 17:56	-666	-1140	-121.6	-114.2	0.154	0.318
AS 18:03	-496	-689	-50.8	59.2	0.107	0.127
AS 18:11(1)	-209	289	-23.9	-23.4	0.061	0.061
AS 18:11(2)	-235	517	8.0	-20.4	0.019	0.023
AS 18:34	-271	374	-32.7	-32.9	0.064	0.079

Section 2	Max. Acc. (gal)		Max. vel. (kine)		seismic coefficient	
	western	eastern	western	eastern	western	eastern
MS 17:56	-686	862	90.1	-90.1	0.236	0.264
AS 18:03	611	-559	44.5	46.6	0.101	0.098
AS 18:11(1)	193	-228	24.2	-25.8	0.057	0.060
AS 18:11(2)	453	445	-15.0	-13.7	0.026	0.026
AS 18:34	436	401	-34.9	36.1	0.081	0.086

Section 3	Max. Acc. (gal)		Max. vel. (kine)		seismic coefficient	
	western	eastern	western	eastern	western	eastern
MS 17:56	-783	-810	90.3	-94.4	0.255	0.240
AS 18:03	650	-509	44.7	47.4	0.105	0.097
AS 18:11(1)	175	-220	23.4	-25.1	0.058	0.059
AS 18:11(2)	536	437	-17.7	-13.4	0.027	0.025
AS 18:34	-448	415	9.9	-36.6	0.089	0.082

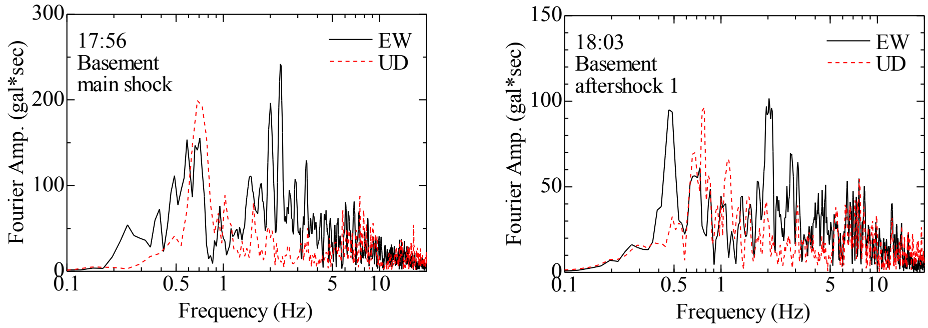
Section 4	Max. Acc. (gal)		Max. vel. (kine)		seismic coefficient	
	western	eastern	western	eastern	western	eastern
MS 17:56	-783	-571	94.0	93.4	0.245	0.161
AS 18:03	-779	-398	-53.2	40.4	0.112	0.059
AS 18:11(1)	-208	120	19.0	16.8	0.031	0.023
AS 18:11(2)	588	-207	-20.3	-6.5	0.027	0.013
AS 18:34	-455	280	34.8	-31.6	0.067	0.046

section 1 and 4, but can not express in cross section 2 and 3. However, it is found that the maximum accelerations for some aftershocks are larger at failure side even in cross section 2 and 3 as shown in Table 2. This result shows the possibility that slope failures in Takamachi housing complex caused or progressed by repeated after shocks. It is noted that the maximum acceleration for second part aftershock of 18:11 give high amplification in each cross section, in spite of its small maximum acceleration as shown in Fig. 3 (c). This result is lead from the differences of predominant frequency in each earthquake, as shown in Figs. 15 (a)-(e) which show Fourier spectrum of EW and UD waves. Although it is attend to The differences of vertical axis extend, the second half wave of aftershock 18:11 has high predominant frequency compared with other waves.

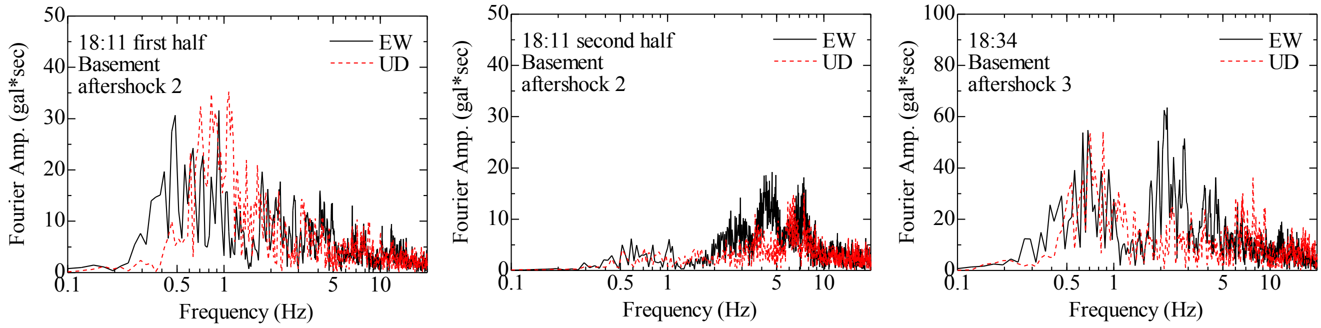
Meanwhile, the maximum velocity can not express the slope failure as shown Table 2. Even in cross section 1, the maximum velocity at failure side is not so large compared with non-failure side. Moreover, the differences of both side is not so large, it is seemed that the maximum acceleration is not suitable index for slope failure in the present calculations. This is against that maximum velocity, such as PGV, has good relationship with actual damages generally.

The simulation in the present study is total stress analysis, therefore the ground water level and static stability of slopes are not considered. Combined discussion will be required in future study. At that time, the dynamic and cyclic motion in seismic wave must be transferred into some static factor appropriately for easy design, because the seismic coefficient, which is ratio of maximum acceleration to gravity, is generally used in static stability analysis. Therefore, the average of response acceleration in main motion is picked up, although the influences of wave period and predominant frequency are not able to be considered. The range of main motion was regarded from 5% to 95% in summation of squared acceleration (Trifunac and Brady, 1975). For examples, the ranges of main motion for main shock and aftershock of 18:34 in cross section 1 are shown in Figs. 16 (a), (b). And the average acceleration was divided by gravity, and then equivalent seismic coefficient was obtained. The results for main shock and after shocks are shown in last field of Table 2.

The equivalent seismic coefficients show intermediate tendency between maximum acceleration and velocity. But the failure side coefficients in cross section 3 is larger than non-failure side, contrary to other index. It is seemed to be preferred the equivalent seismic coefficient rather than maximum acceleration in cross section 3. In cross section 2, any index has not enough differences between failure and non-failure side, it is difficult to

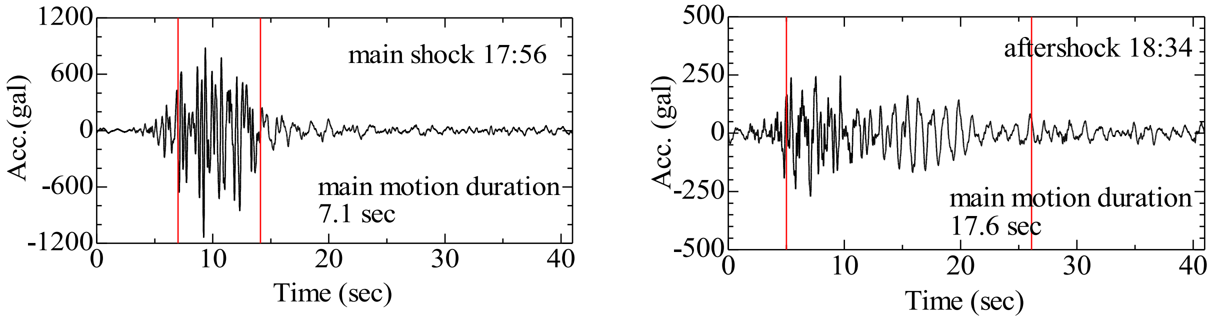


(a) Main shock (17:56) (b) Aftershock (18:03)



(c) Aftershock first half (18:11) (d) Aftershock second half (18:11) (e) Aftershock (18:34)

Figures 15 (a)-(e) Fourier spectrum of measured EW an UD acceleration wave at base



(a) Main shock (17:56) (b) Aftershock (18:34)

Figures 16 (a), (b) Duration of main motion and response horizontal acceleration

express the factor only by the present calculation. However, the equivalent coefficient factors in cross section 1 and 4 show the same tendency with maximum acceleration, it can be said that this factor has possibility to be new index for slope failure and its design.

It is supposed that the slope failure is occurred by results of present calculations, when the equivalent seismic coefficient is over 0.25. This value is reasonable for static stability analysis. It shows the possibility that equivalent seismic coefficient can be one of transfer methods. Of course, we have to check using other waves and consider the influences the frequency properties between seismic wave and predominant frequency of earth fill.

6. CONCLUSION

To evaluate the influences of two dimensional topography, such as fill thickness or natural ground slope angle and so on, into the amplification properties, the equivalent linear simulations were performed against Takamachi housing complex. In result, the consideration of after shock is available for expression the actual failure, and average acceleration in main motion will be preferred to express the slope failure in earthquake.

7. ACKNOWLEDGEMENT

The present study is supported by Special Coordination Fund for Science and Technology. We express our gratitude by inscription.

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