Proceedings of the Eighteenth (2008) International Offshore and Polar Engineering Conference
Vancouver, BC, Canada, July 6-11, 2008

ISBN 978-1-880653-70-8 (Set); ISBN 1-880653-68-0 (Set)

Damage of Houses and Residential Areas by Niigata Prefecture Earthquakes (Part 1)

Katsuya Matsushita
Misawa Homes Institute of Research and Development Co., Ltd.
Tokyo, Japan

Mamoru Fujii
Tokai University
Kanagawa, Japan

Toru Takata
Soil Design Inc
Tokyo,Japan

ABSTRACT

The earthquakes of Chuetsu (2004) and Chuetsu offshore (2007) in Niigata Prefecture caused frequent slope failures, landslides and ground liquefaction, and numerous instances of ground-induced damage to houses and residential areas were noted. In many cases, damage from liquefaction occurred not only on reclaimed land in coastal areas but also on residential areas where river channels had been filled.

This research investigates the characteristics and propensities of liquefaction damage to houses and residential areas. Case histories of damage are analyzed, and the current state of aseismic capacity evaluations of residential areas in Japan and future issues are reported.

KEY WORDS: Earthquake; damage; wooden building; foundation; ground; liquefaction; landslide

INTRODUCTION

Houses in Japan are typically made of wood, with the form of wooden building foundations being either continuous footing or raft foundation. The Swedish weight sounding test is employed widely for housing ground surveys. The allowable stress of ground is determined from the test results, and the form of the foundation decided.

Normally the bearing capacity is investigated, and buildings are designed with piles if the capacity is insufficient. For detached houses, however, cases where the bearing capacity is insufficient are extremely limited. When ground contact pressure is 20 to 30kN/m^2, a spread foundation can be used in the foundation design, with the foundation specifications determined approximately based on settlement.

While steps can be taken easily to address building inclination caused by settlement problems that make daily life difficult, implementing countermeasures against earthquakes that might occur without warning at any time is quite difficult. This is thought to become especially more difficult as the time passed since a major earthquake increases, or as the required countermeasure expense grows.

Although the fact ground hazards can occur more easily on new graded land and sloped land compared with existing residential land is widely recognized, and measures such as soil improvement or pile foundations are adopted in some cases in consideration of site safety when executing house designs, such hazards become more difficult to take into account for normal housing construction when, for example, the stability of surrounding sites including adjacent ground is considered.

Given such conditions, slope failures and liquefaction occurred in numerous instances on graded land during the earthquakes of Chuetsu (2004) and Chuetsu offshore (2007) in Niigata Prefecture, causing damage to residential areas and houses. In this report, case histories of damage are introduced, and the current state of aseismic capacity evaluations of residential areas in Japan and future issues are reported.

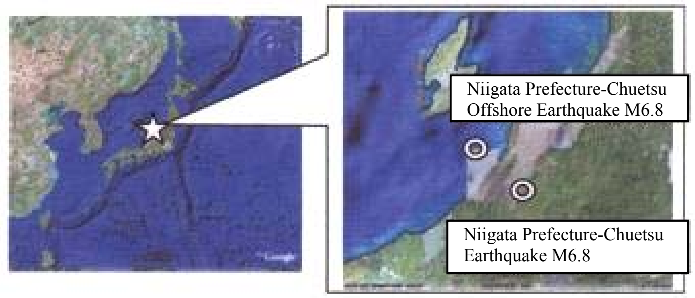


Fig.1 Epicenters of the two earthquakes

DAMAGE TO HOUSING FOUNDATIONS AND RESIDENTIAL LAND

General

Table 1 summarizes the scale of the earthquake damage resulting from the collapse or damage of houses since the 1995 Hyogo Prefecture-Nanbu Earthquake. According to the reports of housing firms that conducted disaster studies, of the damage caused by earthquakes that occurred during the ten years from 1995 to the Niigata Prefecture Chuetsu Earthquake in 2004, the frequency of housing damage in connection with ground settlement in residential areas was about 0.07% of the total number of homes constructed during this period. This result was approximately 40% of the frequency of occurrence of normal settlement damage. (Sato, et al, 2005)

Table 1. Recent earthquakes that caused houses to collapse

Date	Earthquake name	Magnitude	Maximum seismic intensity	Structures damaged	Number of dead or missing
				Destroyed houses	
1995/01/17	Hyogo Prefecture-Nanbu Earthquake	7.3	7	104,906	6,436
2000/07/01	Niijima-Kozushima Near Shore Earthquake	6.5	Under 6	15	1
2000/10/06	Tottori Prefecture-Seibu Earthquake	7.3	Over 6	435	0
2001/03/24	Geiyo Earthquake	6.7	Under 6	70	2
2003/05/26	Miyagi Prefecture-Offshore Earthquake	7.1	Under 6	2	0
2003/07/26	Miyagi Prefecture-Hokubu Earthquake	6.4	Over 6	1,276	0
2003/09/26	Tokachi Offshore Earthquake	8	Under 6	116	2
2004/10/23	Niigata Prefecture-Chuetsu Earthquake	6.8	7	3,185	49
2005/03/20	Fukuoka Prefecture-Seiho Offshore Earthquake	7	Under 6	133	1
2005/08/16	Miyagi Prefecture-Offshore Earthquake	7.2	Under 6	1	1
2007/03/25	Noto Hanto Earthquake	6.9	Over 6	403	1
2007/07/16	Niigata Prefecture-Chuetsu Offshore Earthquake	6.8	Over 6	1,244	11

DAMAGE CAUSED BY SLOPE FAILURE OF GRADES LAND

This section reports on the case history of damage to the Takamachi-danchi and Tsurugaoka-danchi residential areas, which suffered the greatest damage from the 2004 earthquake.

At Takamachi-danchi, over 20 years had passed since the area was developed after 1975. About 70 homes among the total of 522 houses, including houses adjacent to the outer perimeter road on the graded land and houses located outside the perimeter road, were declared unsafe houses.

Before being graded this residential area was a range of steep hills. Because most of the area is now flat terrain, it is known that the higher portions of the hilly land were cut and used as fill and earthfill in the surrounding area to create level terrain. Consequently, the land inside the residential area can roughly be assumed to be cut land, while the outer perimeter area assumed to be earthfill.

Many of the damaged houses were homes where the house bearing ground was lost as a result of slope collapse or landslide of the earthfill in the buried ravines, which resulted in damage such as building inclination and cracks in structure foundations.

Fig.2 Collapse of buried ravine earthfill

Fig.3 Collapsed residential land

As shown in Fig.4(a)(b), such damage was not limited just to the perimeter areas and fractures and faulting of residential land and streets inside the perimeter road occurred in a number of locations. These areas are conjectured to be near the boundary between the cuts and earthfill. Houses where ground fissures opened directly beneath the house suffered damage such as foundation cracking, but on residential land where ground fissures veered away from houses, homes frequently escaped damage.

Tsurugaoka-danchi, a residential zone more than 30 years old, was graded beginning in 1965.

This zone is divided into a residential area composed mainly of ravines buried with earthfill in the vicinity of a storage reservoir, and a residential area located to the south where a range of steep hills was leveled. Damage in the residential area in the vicinity of the storage reservoir where the land is mainly ravines buried with earthfill was remarkable, with roads collapsed and houses destroyed or inclined as the result of slope collapse and landslides.

Fig.4 (a) Fractures and faulting near perimeter edge (b) Fractures and faulting of residential land

Fig.5 shows the damaged condition of a flank road on this residential land, where a landslide occurred in the direction of the storage reservoir.

Fig.6 shows an example of a retaining wall made a reinforced concrete, on a residential lot located on sloped land upstream of the storage reservoir, which was slid more than 1m. Although soil improvement was performed as a normal countermeasure to prevent settlement, the house was inclined toward the direction in which the retaining wall had slid.

Fig.5 Road collapse caused by landslide

Fig.6 Slide and settlement of residential land retaining wall

In the 2007 earthquake, residential land made with earthfill on sloped land on sandhills suffered a circular arc landslide over an area 30m wide and 60m long(Fig.7 and 8). There were six homes located within this range. The houses in the vicinity of the top part of the slide were moved 1m horizontally and subsided by more than 50cm. The houses in the center of the slide area suffered broken foundations and the houses were completely destroyed. The first floor area of the houses at the edge of the slide was completely destroyed by earth surge.

Fig.7 Lower side of slide

Fig.8 Upper side of slide

DAMAGE CAUSED BY LIQUEFACTION

In the 2004 earthquake, liquefaction occurred in the vicinity of the Kariyata River, a branch of the Shinano River. Roads in the area affected by liquefaction were covered with sand boils and muddy water (Fig.9).

Fig.9 Road buried under sand boil

In this area an urban district has formed centered on the natural levee along the Kariyata River, although it also contains a number of houses built on reclaimed land. From the topographical map shown in Fig.10, (Geographical Survey Institute) the peripheral reclaimed land can be seen to meander, following the former river channel of the Kariyata River. Liquefaction generally occurred in places located along this former river channel.

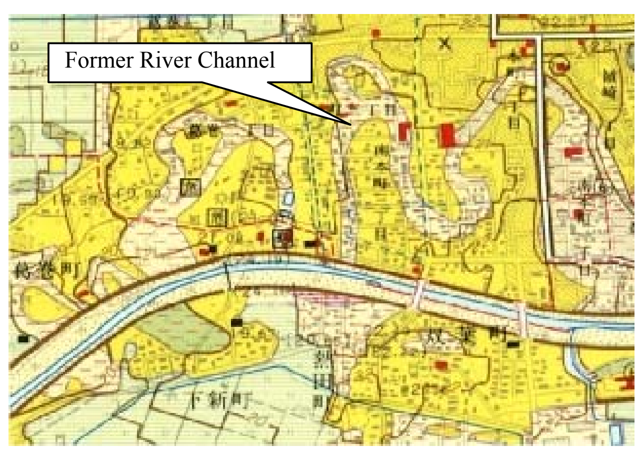
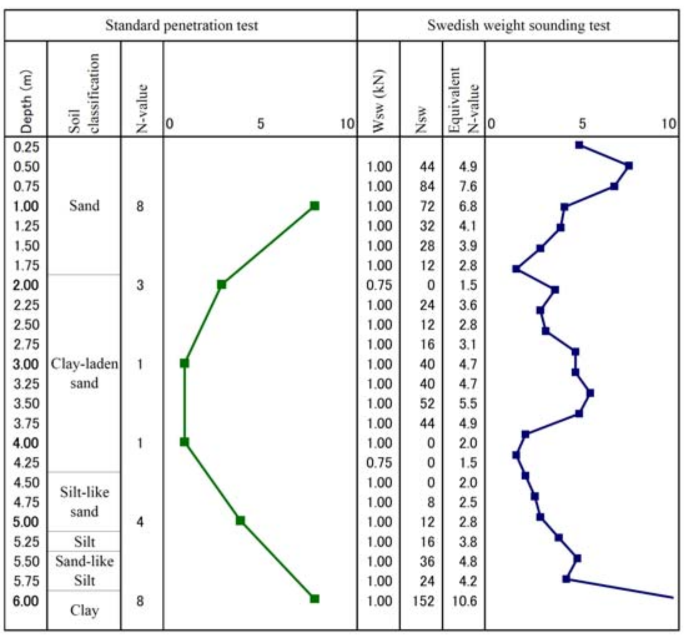


Fig.10 Topographical map

Damage to houses caused by liquefaction resulted from inclination that accompanied house settlement. Among houses where a spread foundation or friction type soil improvement had been adopted, there also were cases of differential settlement of more than 10cm. The extent of the inclination caused by settlement showed a propensity to increase at shallower ground water levels. The heavy rains from Typhoon No. 23 immediately before the earthquake are also believed to have had an affect, with the rise in the water level being one factor that caused differential settlement damage. The site investigation conducted after the earthquake occurred confirmed that the water level was only 50cm from the ground surface.

Figure 11 (Wakame, et al, 2005) shows the results of the standard penetration test and Swedish weight sounding tests conducted at the sites where liquefaction occurred, and Fig.12 (Wakame, et al, 2005)shows the grain size distribution of the soil samples collected during the standard penetration tests. In Fig. 11, the N-values for the standard penetration test are extremely small, ranging between GL-3.0-4.0m, in contrast to the results of the SWS tests, which exhibit a different trend.

Furthermore, according to the results of the grain size analysis, the nature of the soil of each depth is classified as sandy soil, but at depths greater than GL-4.0m the figures shows F_c(Fine fraction content)>30% and Pc(Clay content)≥10%, and the percentage of fine grained soil content has increased.



Depth (m)	Soil classification	N-value	Wsw (kN)	Nsw	Equivalent N-value
0.25					
0.50			1.00	44	4.9
0.75			1.00	84	7.6
1.00	Sand	8	1.00	72	6.8
1.25			1.00	32	4.1
1.50			1.00	28	3.9
1.75			1.00	12	2.8
2.00		3	0.75	0	1.5
2.25			1.00	24	3.6
2.50			1.00	12	2.8
2.75			1.00	16	3.1
3.00	Clay-laden sand	1	1.00	40	4.7
3.25			1.00	40	4.7
3.50			1.00	52	5.5
3.75			1.00	44	4.9
4.00		1	1.00	0	2.0
4.25			0.75	0	1.5
4.50	Silt-like sand		1.00	0	2.0
4.75			1.00	8	2.5
5.00		4	1.00	12	2.8
5.25	Silt		1.00	16	3.8
5.50	Sand-like Silt		1.00	36	4.8
5.75			1.00	24	4.2
6.00	Clay	8	1.00	152	10.6

Fig.11 Results of SPT test and SWS test

The reclaimed land located along the periphery of the former river channel is conjectured to have similar ground conditions. For new houses in this vicinity, soil improvement or pile foundations were generally adopted as settlement countermeasures, and there was no settlement damage to houses where the ground had been improved to the load bearing stratum.

Although damage such as structural damage to buildings and overturned furniture also occurs frequently in houses in strong earthquake regions, such damage seldom occurred in the liquefaction zones. Liquefaction damage also occurred on low ground and on graded land in hilly areas.

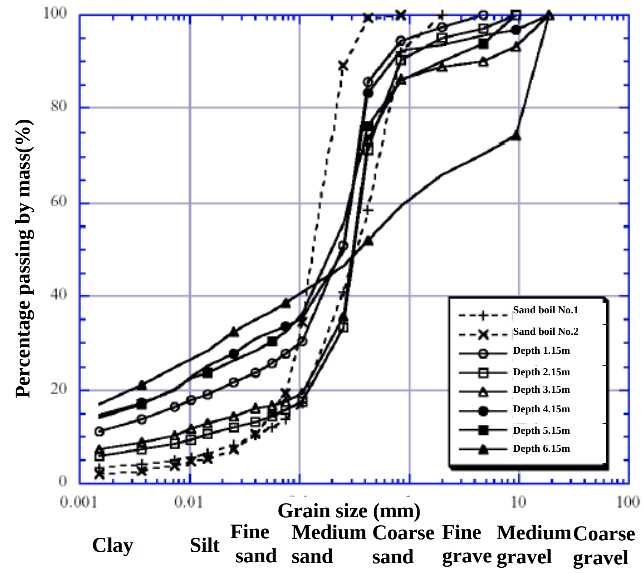


Fig.12 Results of grain size analysis

Nagaoka New Town is a large-scale residential area whose development began in 1975. Because the area was created out rolling hills, damage in Nagaoka New Town was confined to a very limited narrow range, in contrast to the extensive liquefaction that occurred near the coast in past earthquakes.

Figure 14 (Matsushita and Tamura, 2005) shows the results of the SWS test conducted at the site where liquefaction damage occurred. A stratum with a low resistance value, from the ground surface to a depth of approximately 6m, was confirmed. Because the houses that suffered damage settled by sinking into the ground surface, the liquefaction is conjectured to have occurred in a comparatively shallow stratum. Moreover, the site has a 1.5m high retaining wall, and it is thought the water level behind the wall had risen, thus causing the damage to be more extensive (Fig.13). In addition to house settlement, upheavals of earth floors and streets caused by sand boils also occurred.

Fig.13 House settlement and upheaval of earth floor

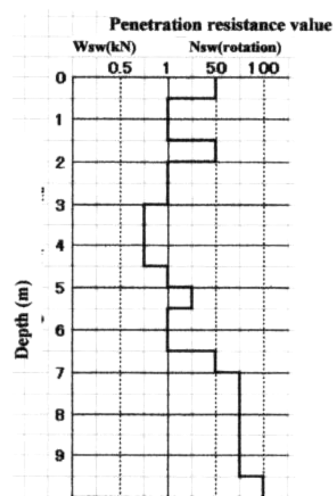


Fig.14 Results of SWS test

Figure 15 shows the areas where liquefaction caused by the 2007 earthquake occurred. Damage caused by liquefaction was concentrated around the bases of sandhills and in the vicinity of the Sabaishi River.

This region lies in the vicinity of the boundary where the alluvial deposits rapidly become very deep, as shown in Fig.16 and Fig.17. The thickness of the alluvial deposit layer ranges between 50 to 70m. Alluvial sand strata or reclaimed land were distributed in the areas where liquefaction occurred.

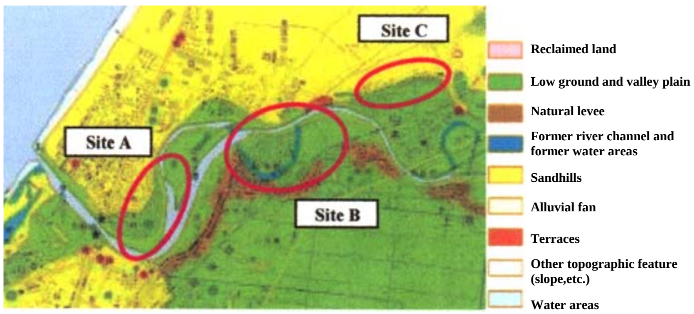


Fig.15 Geomorphological land classification map (Geographical Survey Institute)

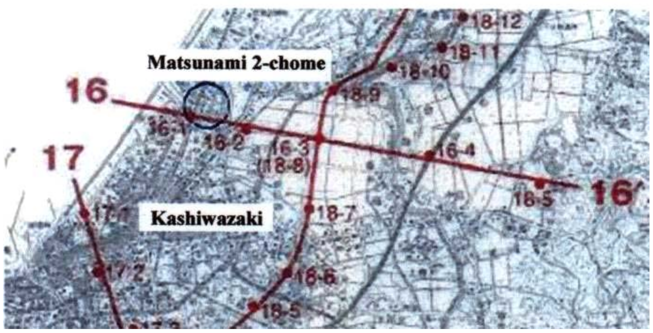


Fig.16 Geologic cross section position map

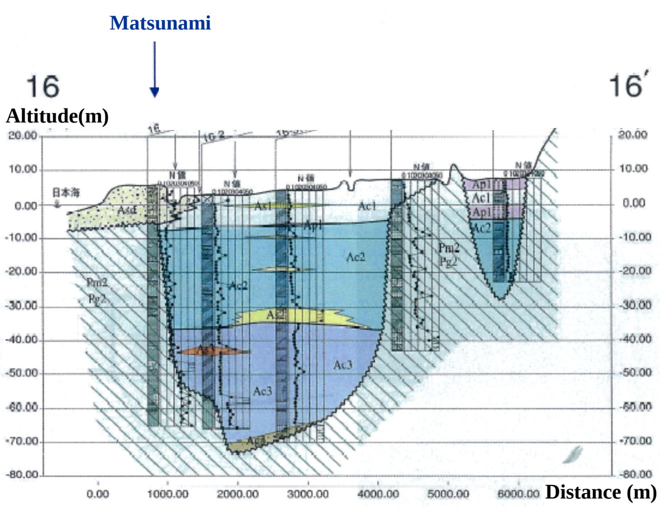


Fig.17 Geologic cross section (Niigata Prefecture Geotechnical Consultants Association)

At Site A, houses that suffered structural damage caused by liquefaction were dwellings located near the boundary of the sandhills and low-lying alluvial ground or houses on residential land that had been filled prior to house construction.

Fig.20 shows the results of the standard penetration test on the residential area ground where damage caused by liquefaction occurred, and Fig.21 shows the results of the liquefaction layer grain size analysis.

Fig.18 Sand boil caused by liquefaction

Fig.19 Deformed house

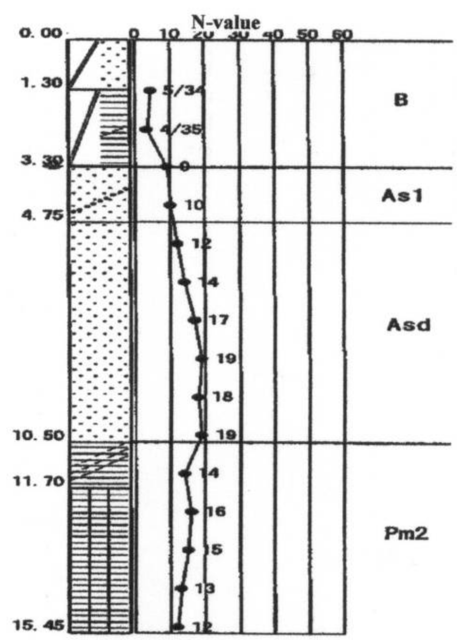


Fig.20 Results of standard penetration test

Sand strata composed mainly of medium sand are distributed from GL-3m to about GL-11m, showing an N-value of roughly 10-20 and comparatively high "median" relative density at depths of GL-4m and lower. At GL-3m, the ground water level is high. Maximum ground level acceleration is estimated to have been about 400gal, and liquefaction is thought to have occurred in ground where large acceleration had a comparatively high N-value.

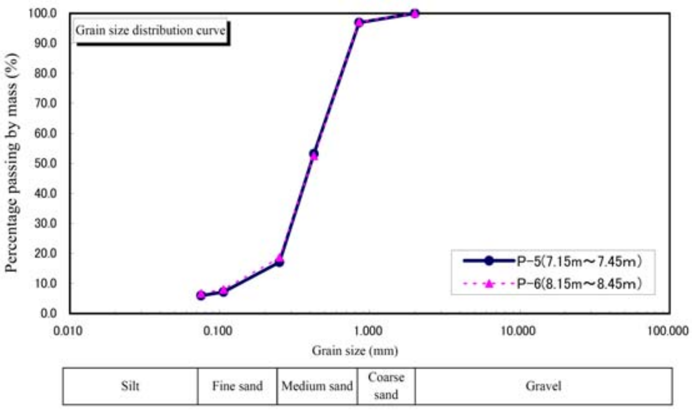


Fig.21 Results of liquefaction layer grain size analysis(GL-7~9m)

At Site B, liquefaction occurred in the vicinity of the former river channel and houses suffered settlement damage. Liquefaction occurred in this area in both the earthquakes of Chuetsu (2004) and Chuetsu offshore (2007) in Niigata Prefecture. Numerous houses located on the former river channel suffered from settlement or inclination, with ground fissures opening in the residential land straddling the former river channel and its bank that that damaged houses or their foundations.

Houses where soil improvement to the load bearing stratum had been undertaken as a normal measure against settlement were also confirmed to be effective against liquefaction (Fig.22).

Fig.22 Result of soil improvement, heave

CONCLUSIONS

When areas such as newly graded land are used as building sites, differential settlement of houses or other problems will occur as a result of ground consolidation settlement caused by earthfill load. Moreover, in addition to such normally occurring settlement, slope failures and landslides, as well as numerous instances of house foundation or residential land ground damage originating in ground, are also recognized to occur frequently in a major earthquake.

Unfortunately, studies that give consideration to the seismic hazards of residential land are seldom performed today when constructing residential housing. Reasons cited include the fact ground disaster prevention is impractical in view of the cost-effectiveness, and the difficulty of obtaining ground improvement information. Consequently it is not easy to consider residential land seismic hazards as an element of design.

One necessary point for detached housing foundation design in the future will be the upgrade of ground surveys. Although the SWS test is the main test for house ground surveys, soil typing or water level confirmation is difficult simply because of the test's simplicity. In cases of topographic features whose topographical classification can be confirmed by means such as a topographical map, and where there is the possibility of liquefaction, considerations such as conducting additional studies are critical. Moreover, because soil improvement design is thought to not be adopted to improve aseismic capacity as a practical matter, there is a danger of settlement damage occurring if the surrounding surface frictional force on piles is lost as a result of liquefaction, or if liquefaction occurs beneath the surface layer improvement load bearing stratum. This is a matter of clarifying the necessity of soil improvement, and seeking the rationalization or upgrade of the soil improvement designing methods.

REFERENCES

Sato S, Tamura M, Matsushita K and Wakai A, "Development of Housing Foundation Ground Performance Assessment Technology (1. Basic Approach)," *Japanese Geotechnical Society*, July 2005.

Geographical Survey Institute, *Land Condition Map* (Sanjo)

Wakame Y, Tamura M, Matsushita K and Sasaki T, "Damage to Small-scale Building Residential Land and Foundations Caused by the 2004 Niigata Prefecture-Chuetsu Earthquake (4. Liquefaction Evaluations)," *Architectural Institute of Japan*,August 2005.

Matsushita K and Tamura M, "Detached Housing Foundation and Ground Settlement Damage and Ground Damage", *Proceedings of the Symposium on Evaluation of Safety and Performance of Residential Ground*, Japanese Geotechnical Society, July 2005.

Niigata Prefecture Geotechnical Consultants Association, Niigata Prefecture Ground Map Editing Committee, ed., *Niigata Prefecture Ground Map Guide*, 2002.