LESSONS LEARNED FROM THE 15 JANUARY 1993 KUSHIRO-OKI, JAPAN EARTHQUAKE

Takeyasu SUZUKI
Research Engineer, Technical Research & Development Institute, Kumagai Gumi Co., Ltd.,
1043 Shimoyama, Onigakubo, Tsukuba-shi, IBARAKI 300-11, JAPAN

ABSTRACT

An earthquake attacked the southern area of Hokkaido island (North island of Japan) at 8:06 pm. January 15, 1993. The magnitude of the earthquake was 7.8 and its focal depth was 107 km. The fault rupture is reported to occur within Pacific Plate[1]. Kushiro City is located only 15 km away from the epicenter (see Fig.1) and over 900 gals of acceleration was recorded by Kushiro District Meteorological Observatory[2]. There were a few buildings completely collapsed and the damage due to this earthquake was not so severe compared with its magnitude. However, characteristic feature related to the damage originated from the geological and landuse conditions. This paper focuses on the relationship between the landuse condition and earthquake damage in the housing developments of Kushiro City.

GEOLOGICAL CONDITION

Kushiro is famous for the natural marsh which is one of the national park area. The marsh distributes widely in the northern area of Kushiro. Fig.2 illustrates the surface geology classification and the sites where microtremor measurements were conducted. The surface geology of Kushiro City and its vicinity is classified into three typical geological conditions: (1) marsh or fill over marsh which distributes widely in the northern area of Kushiro City : (2) diluvial sand dune area ; (3) diluvial hill which develops in the eastern side of old Kushiro River. This paper mainly concentrates on the two housing developments with geological conditions (1) and (3), where earthquake damages originated from geotechnical conditions were conspicuous.

Mihara is the newly developed housing development, the development of which was carried out several years ago by filling sand material over the marsh. The thickness of peat layer underlying the fill is ranged from 2.0 to 2.5 meters. Underneath the peat layer, alluvial sand deposit with the thickness from 20 to 30 meters is sedimented over the diluvial volcanic loam. On the other hand, Midorigaoka is the housing development located on the diluvial hill. It was developed about 30 years ago. Because the angulation of the hill was complicatedly distributed, the construction was conducted by cutting slopes and filling valleys. The material of the hill is diluvial volcanic loam, which is correspondent with the diluvial deposit existing under the alluvial deposit in the marsh area.

TYPICAL EARTHQUAKE DAMAGES

Earthquake damages at Mihara is characterized by the subsidence ranging from 30 to 40 cm as illustrated in Photo. 1. Hokkaido Island is located in the northern part of Japan and the temperature there is always under 0 degree in Centigrade in winter. Therefore, the surface soil is frozen even in the day time until May. The thickness of frozen soil is 150 cm in mid-winter. The subsidence was estimated to occur by the dynamic compaction of fill material and peat including dissipation of pore water pressure built up by cyclic loading. When the frozen soil on the surface melts in spring, secondary subsidence will occur[3]. Moreover, the excess pore water pressure built up in peat layer will be gradually dissipated year to year, which leads to gradual

Fig.1 Map of Hokkaido and Epicenter

increase in subsidence at Mihara. As shown in Photo.1, the gaps between the concrete plates of the entrance and ground can be seen in many houses. The foundation of houses in this region is deep and its thickness is about 1.0 m. However, such secondary subsidence may lead to tilting of houses.

Earthquake damages at Midorigaoka is characterized by the ground failure. Since Midorigaoka is located on diluvial hill, various slopes distribute around and on the hill. Photo. 2 illustrates one of the severest damage due to slope failure at Midorigaoka. As described later, high acceleration of earthquake motion with high frequency will have sufficient inertial force to cause slope failure. The typical damage due to ground failure other than slope failures is the large local amplification of ground acceleration in the area of fill over drowned valley[5], where the slope on the ground surface is not steep. Surface soil deposit filled using the material moved from cut slopes is irregularly bounded by fresh diluvial loam. The earthquake wave is highly amplified especially in the section of inclined bed rock and the surface deposit would move along the bed rock slope permanently. Due to such permanent displacement of surface deposit, large number of gas pipe damage took place in the area.

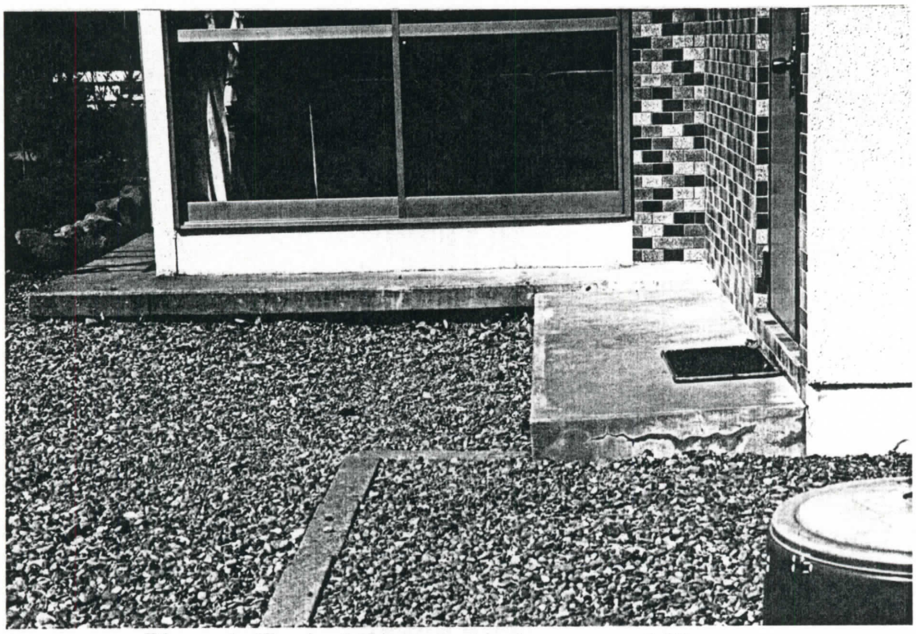

Photo.1 Typical Earthquake damage at Mihara

Photo.2 Typical Earthquake damage at Midorigaoka

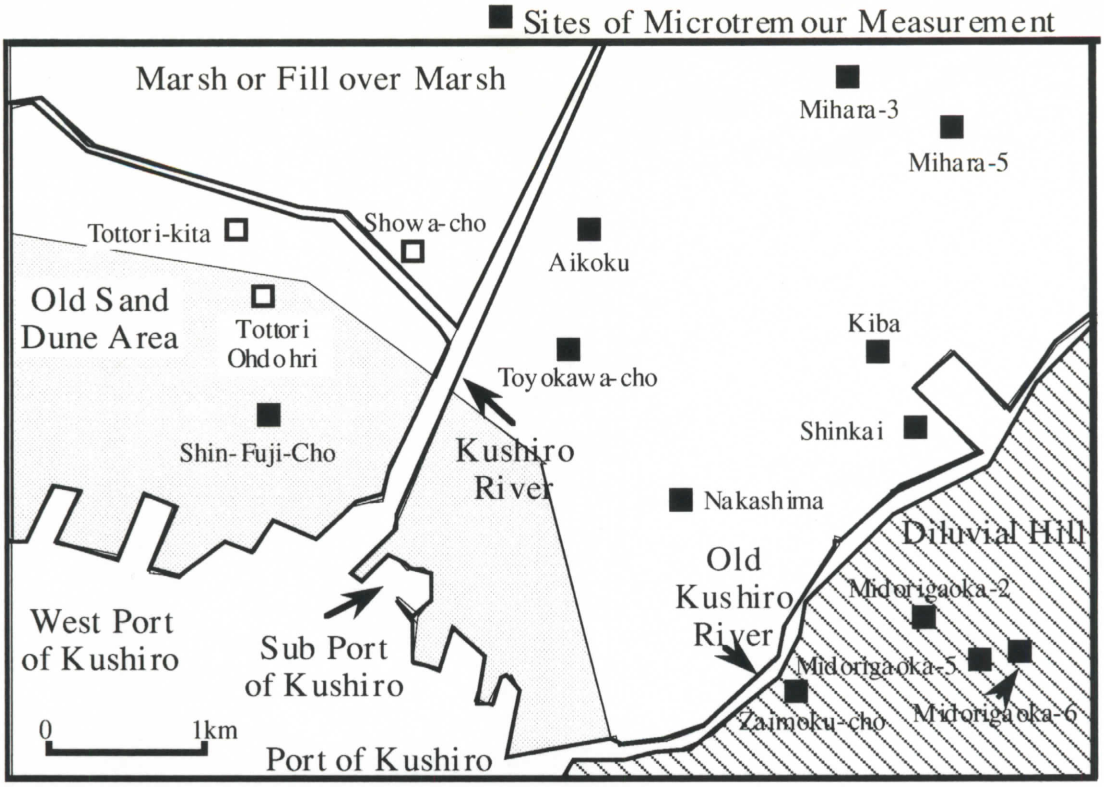

Fig.2 Classification of Surface Ground Conditions and Locations of Microtremor Measurement in Kushiro City

PROCEDURE OF MICROTREMOR MEASUREMENTS

Microtremor measurements were conducted in Kushiro City as shown in Fig.2 two months after the earthquake, for the purpose of clarifying predominant frequencies and amplification characteristics of various locations in Kushiro City. In this paper, focus was centered on the two sites: Mihara (fill on marsh); and Midorigaoka (diluvial hill). Three components of microtremor (NS, EW, and UD) were measured three times at a site. The number of data recorded was 8192, the time interval of which was 100 Hz.

It was pointed out that predominant ground motion in the horizontal direction became conspicuous when the Fourier spectrum of horizontal motion was divided by that of vertical motion[4]. Nakamura suggested that the ratio of the spectra would be correspondent with the amplification ratio from bed rock to ground surface. This idea may not be valid when every type of surface ground is taken into consideration. However, the ratio will be greatly related with the amplification factor. Fourier spectra of every microtremor data were calculated and were smoothed using Hanning window filter first. Then, three spectra at each site and in each direction were averaged. Finally, the Fourier spectral ratios of two averaged horizontal spectra divided by a vertical spectrum were calculated at each site.

FOURIER SPECTRAL RATIOS

The Fourier spectral ratio at Mihara-5 in the NS direction is illustrated in Fig.3. The predominant frequency around 1.0 Hz can be clearly demonstrated in the figure. The aforementioned ratio at the peak is 5.0. When Fig.3 means the frequency response function at Mihara, one can recognize that the fundamental mode of shear vibration is greatly predominant and that the vibration in high frequency does not amplified by the surface layer. Earthquake motions recorded at Kushiro District Meteorological Observatory, located on diluvial hill area near the sea, shows high frequency of vibration and short duration time. The acceleration at Mihara due to this earthquake is considered to be comparatively low, because of high damping in soft soil and lack of low frequency input motions. The trace of liquefaction was discovered in the area. However, the damage was characterized by the subsidence due to the dissipation of excess pore water pressure in fill, peat layer and sand underlying peat layer.

The Fourier spectral ratio at Midorigaoka in the NS direction is illustrated in Fig.4. The figure shows the predominant vibration ranging widely from 1.5 to 3.5 Hz. This means that high frequency of vibration is predominant and 2 or 3 modes of vibration occur originated from the irregularly bounded surface ground. The peak value of the ratio is about 4.0, which is low compared with that at Mihara. As mentioned above, over 900 gals of acceleration was recorded on the diluvial hill. The amplification ratio is not so high on this area. However, acceleration is estimated to be considerably high with high frequency. Fig.4 describes why earthquake damage like Photo.2 occurred at Midorigaoka.

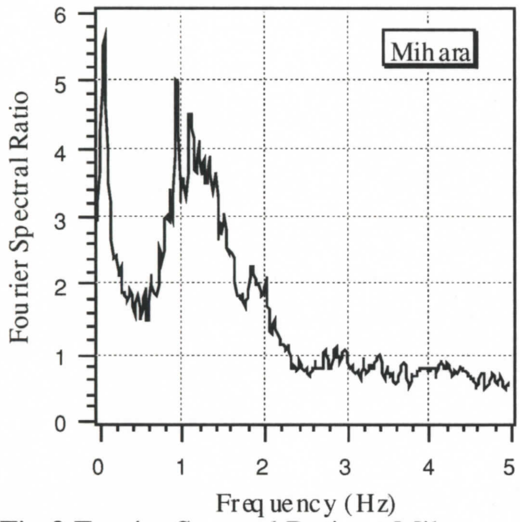

Fig.3 Fourier Spectral Ratio at Mihara

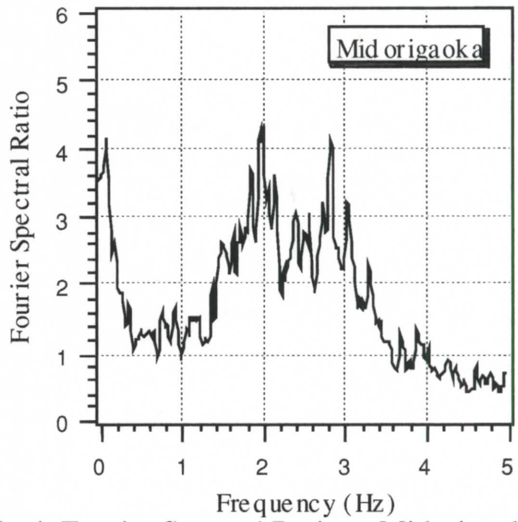

Fig.4 Fourier Spectral Ratio at Midorigaoka

CONCLUDING REMARKS

This paper focussed on earthquake damages of two different housing developments located at sites on two different geological conditions. Built environment causes various type of earthquake damages originated from both the frequency characteristics and the amplification of earthquake ground motions. Through the earthquake damage investigation and microtremor measurement, the followings are concluded as lessons learned from this earthquake:

(1) In case of horizontally layered soft soil deposit, the development should be conducted in deep consideration of both static and dynamic subsidence. The appropriate method of construction should be adopted. Furthermore, methods of soil improvement with low cost is necessary to be developed.

(2) In case of irregularly bounded soil deposit, the amplification of earthquake motions at local area should be considered in terms of earthquake-resistent design.

(3) On relatively hard diluvial hill, the earthquake motions with high acceleration and high frequency may predominate. In this area, there is a possibility that high inertial force generates.

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