2.3 Hazard mapping

2.3.1

2.3.2

2.3.3

2.3.4

2.3.5

2.3.6

2.3.7

2.3.8 Hazard assessment methods

(1) Simulation for hazard mapping

Two approaches to the estimation of hazardous areas are available, namely by evaluating the accumulation of events in which the past disasters occurred and by estimating the range of influence through a simulation based on certain conditions.

The approach by evaluating the accumulation of events in which the past disasters occurred (empirical methods) allows creating a fairly accurate hazard map if disasters frequently occur and disaster records are sufficiently organized. However, since there are only a limited number of such places, a common practice is to use the disaster history as well as the topographic and geological conditions to estimate hazardous areas. For the estimation of volcanic disasters, hazard areas are often estimated from the distance to craters or the distribution of volcanic ejecta in the past, which represents a type of empirical method.

This approach, which allows to relatively rank the potential hazard of a point or area, may be adopted to establish land use plans. Also this approach avoids getting a wrong hazard estimation being itself concerned with cumulative hazard levels.

On the other hand, the approach based on digital simulations allows making a hazard estimation based on phenomena in other areas with similar disaster occurrence conditions even without any disaster record on the concerned area. In other words, a digital simulation model created based on phenomena that occurred in Japan, for example, can be applied to any spot in Guatemala having similar disaster occurrence conditions. The digital simulation also allows estimating the hazardous areas with various disaster types, disaster scales, and occurrence locations by changing the disaster occurrence conditions. However, since the estimation conditions are specified, any disaster that occurs with different conditions may result with corresponding results compared to the estimated ones. So that the estimated and actual results of a disaster agree with each other, it is necessary to thoroughly examine the estimation conditions and run simulations of multiple cases with different conditions.

Table 2.3.8-1 Approaches to estimation of hazardous areas in this project

Hazard Type	Major estimation item	Empirical Methods	Simulation-based evaluation
Seismic Hazards	Ground Motion		○
	liquefaction		○
Volcanic Hazards	Pyroclasitic Fall	○	○
	Pyroclasitic Flow		○
	Lave Flow		○
	Lahar		○
	Edifice Collapse	○	
Landslides	Landslide	○	
Floods	Inundation Area	○	○
	Inundation Depth		○

(2) Seismic hazards

1) Outline of simulation

There are five study areas: Guatemala City, Quetzaltenango, Mazatenango, Escuintla, and Puerto Barrios. The overall flow of seismic hazard estimation work is shown in Figure 2.3.8-1. The study items roughly consists of evaluation and classification of soil types, determination of target earthquakes, simulation of ground motion, and estimation of liquefaction potential. The following figure shows the outline of this study.

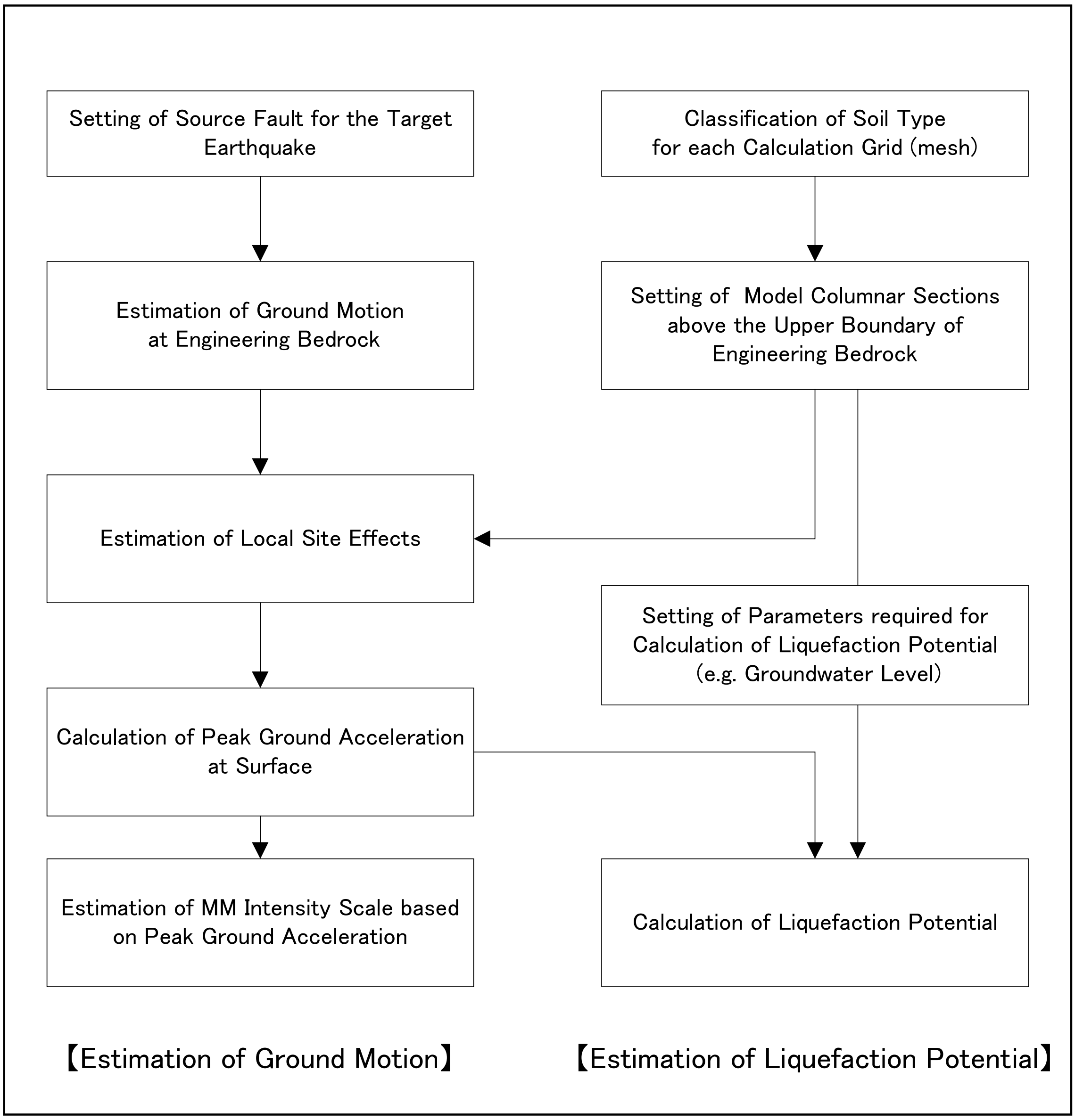

Figure 2.3.8-1 Flow chart of estimation of ground motion and liquefaction potential

2) Soil type classification

a) Soil type classification and mapping

Figure 2.3.8-2 shows the flowchart of evaluation and classification of soil types. To estimate the amplification factor of ground motion in the surface layer, we organized the topographic and geological data of the study areas and a field survey has been undertaken to come up with a soil type classification and a soil type map. The work process in each of the study areas is described in this section.

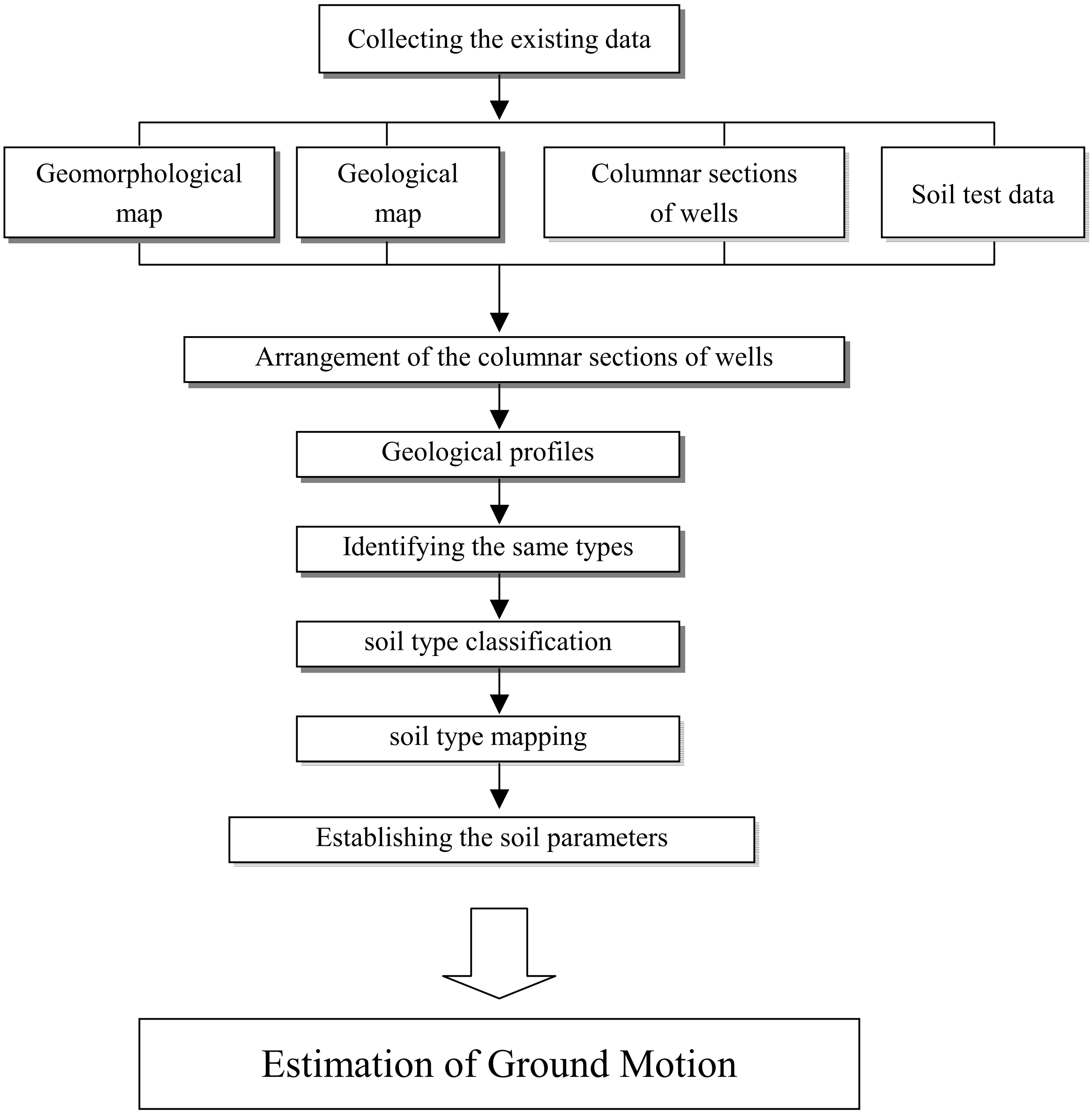

Figure 2.3.8-2 Flow of soil evaluation for estimation of ground motion

♦ Guatemala City Area

a. Collection of existing data

In the study areas, we acquired mainly 88 columnar sections of wells created by Empagua (General Directorate for Waterworks) which are more than 300 meters deep at the deepest or around 30 meters at the shallowest. We acquired and complied geological maps of 1:50,000 scale including the study areas. Regarding the soil test samples, we acquired data of Dirección General de Camino (DGC; General Directorate for Roads) and collected representative soil samples in the study areas to execute soil test.

b. Topographic and geological status

The landforms in the study areas consist of plateaus constituted of pumice and volcanic ash, hilly and mountainous region around the Guatemala basin, and the valley plain. The altitude is around 1500 m in the plateau zone or between 1700 and 1900 meters in the surrounding hilly and mountainous region.

The plateau consist of the Los Chocoyos pyroclastic flow deposits that spurted from around the Atitlán Lake and now form layers with a thickness of more than 200 meters. These pyroclastic flow deposits extend over a distribution area of more than 16,000 km^2.

Figure 2.3.8-3 shows a representative geologic column around Guatemala City. In this column, the ash flow H corresponds to Los Chocoyos pyroclastic flow deposits and, on the surface of the earth, the deposits above the ash flow H can be identified as outcrop. Between some pyroclastic flow deposits, pumice fall beds and lucustrine sediments are sandwiched. On the southern side of the plateau, fluvial and lucustrine sediments are distributed locally above the pyroclastic flow deposits.

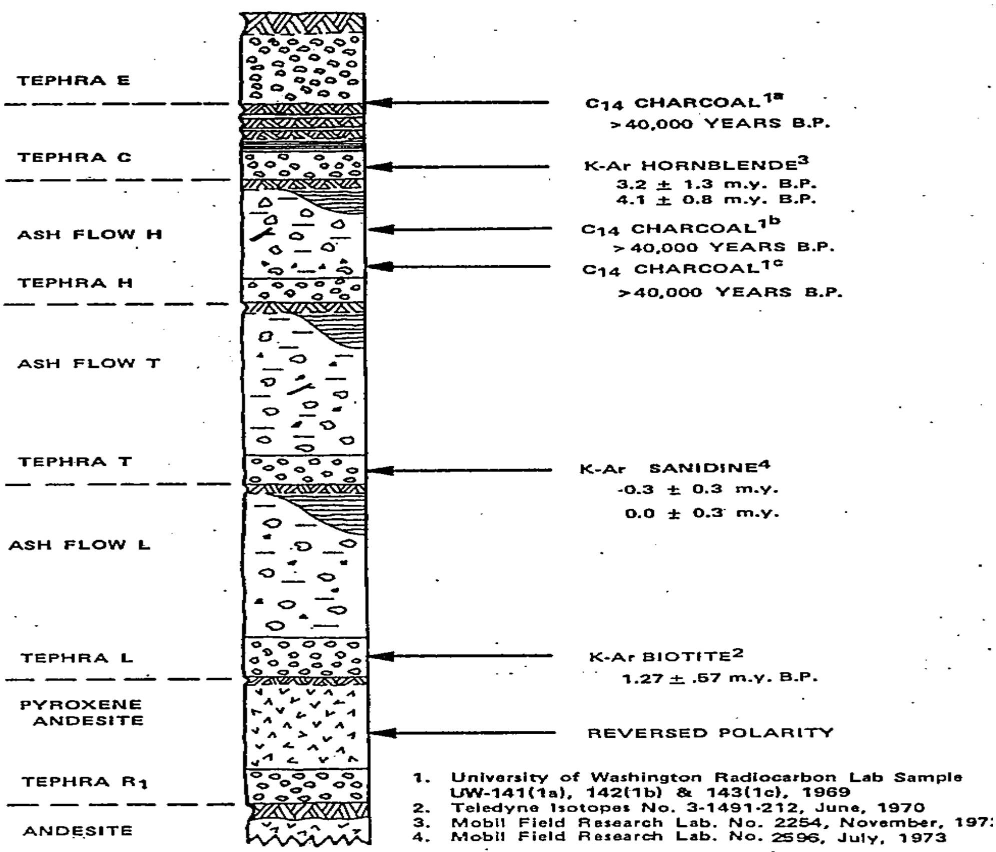

Figure 2.3.8-3 Basic geologic column in Guatemala City（Koch and Maclean, 1975）

Granite, limestone, and basaltic lava in the Tertiary period are distributed in the mountainous and hilly regions around the plateau on the north-eastern side of the study area.

Pyroclastic flow deposits, dacite, and welded tuff in the Tertiary period are distributed in the eastern and south-eastern parts of the study area. In the western part, there are pyroclastic flow deposits and lava in the Tertiary period and pumice fall beds that originated from Volcán de Agua to cover them.

Pumiceous alluvium, consisting mainly of secondary deposits such as pyroclastic flow deposits, is distributed in the valley plain along the Villalobos and Pinula Rivers.

c. Identification of geological features and soil type classification

The inscriptions of columnar sections of wells and geological maps were compared to identify the geological features. The data from the geological maps were indispensable because the inscriptions of columnar sections of wells could only inform whether the soil is rudaceous, dominated by sand or conglomerate, or silty. The geology in the Guatemala City area can be roughly classified into the soil groups shown in Table 2.3.8-2. These model columnar sections are shown in Figure 2.3.8-4 to Figure 2.3.8-5.

Table 2.3.8-2 Soil types in Guatemala City Area

Soil type No.	Geological character	Number of sub-soil type
1	Pumice fall beds and lucustrine sediments are distributed. Prequaternary sediments are distributed relatively shallowly.	2
2	No pumice fall beds but lucustrine sediments are distributed	1
3	Alluvia and pyroclastic flow deposits are distributed.	1
4	Pyroclastic flow deposits are distributed.	2
5	Pumice fall beds and pyroclastic flow deposits are distributed.	6
6	Basement rocks are distributed.	1

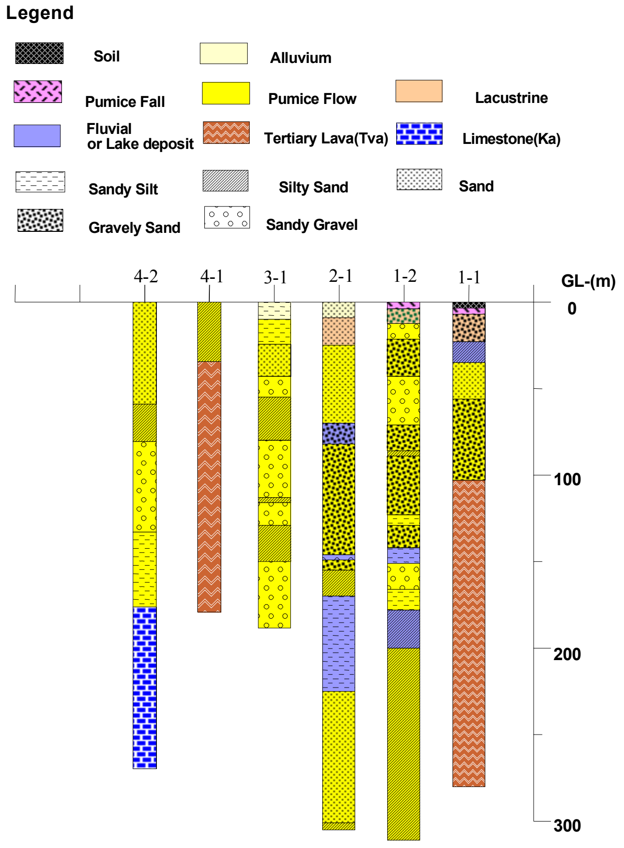

Figure 2.3.8-4 Model columnar sections in Guatemala City Area (1)

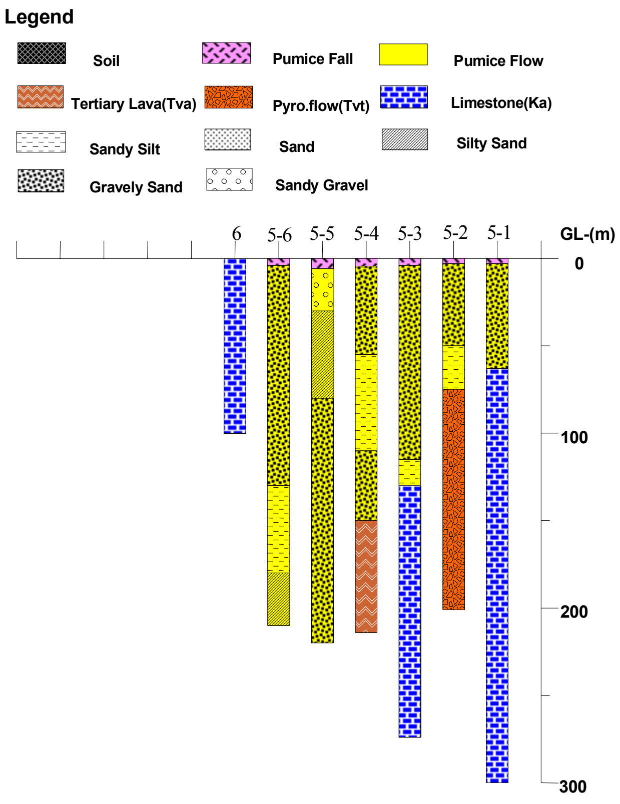

Figure 2.3.8-5 Model columnar sections in Guatemala City Area (2)

d. Creation of soil type map

Soil type map was created based on the soil type classification and the already created S-wave velocity in Guatemala City. Figure 2.3.8-6 shows the soil type map of the Guatemala City area.

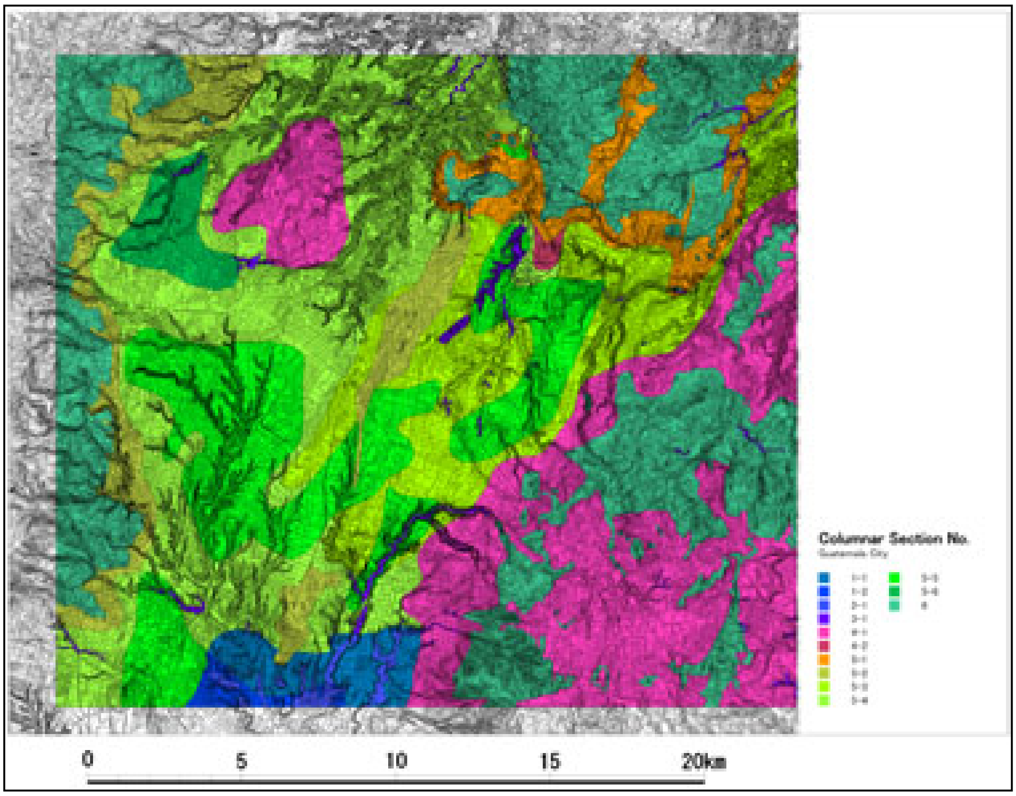

Figure 2.3.8-6 Soil type map in Guatemala city area

♦ Quetzaltenango Area

a. Collection of Existing Data

We acquired 25 columnar sections of wells in the Quetzaltenango area including those areas out of the study area. The depths of columnar sections range from 4.5 m to 200 m. The topographic and geological features of the study area were based on the geological maps of 1:50,000 scale and the geomorphotolocal maps that were created in the current project.

b. Topographic and geological status

The landforms in the study areas consist of plateau constituted of pumice and volcanic ash, hilly and mountainous region on the southern side of the plateaus, and the valley plain. The altitude is around 2300 m in the plateau zone or between 2500 and 2800 meters in the surrounding hilly and mountainous region.

As in the Guatemala City area, the plateaus consist of the Los Chocoyos pyroclastic flow deposits that spurted from around the Atitlán lake and form layers more than 200 meters thick. The ash flow H layer (Chocoyos pyroclastic flow deposits) was found to include a pink layer due to high-temperature oxidation. The pumiceous layer as secondary deposit largely extends over the lower slope and bottom of valley. On the western side of the study area, the ash flow H layer and the lower sediments were found to be distributed in an inconsistent relationship. In the study area, the ash flow T layer below the ash flow H layer is expected to be distributed. On the southern side of the plateau, the lava and debris flow deposits that make up Cerro Quemado Volcano are distributed.

The sediments in the valley plain can be found in the cross section along the Samalá River. They consist mainly of pumiceous silt and mud layers, which are probably fluvial deposits because clear-cut bedding can be identified.

c. Identification of geological features and soil type classification

The inscriptions of columnar sections of wells and geological maps were compared to identify the geological features in the Quetzaltenango area. Furthermore, the outcrop statuses in the field and the geomorphological maps were examined to estimate the distribution of pyroclastic flow deposits and volcanic ejecta from the Cerro Quemado Volcano and pumiceous alluvia consisting mainly of secondary deposits. The geology in the Quetzaltenango area can be roughly classified according to the soil groups as shown in Table 2.3.8-3 These model columnar sections are shown in Figure 2.3.8-7.

Table 2.3.8-3 Soil types in Quetzaltenango Area

Soil type No.	Geological character	Number of sub-soil type
1	Fluvial deposits consisting of soil and silt layers exist near the surface layer. Pyroclastic flow deposits are distributed under them.	1
2	Pyroclastic flow deposits and their secondary deposits are distributed.	6
3	Both debris flow deposits and pyroclastic flow deposits are distributed. The volcanic rocks in the Quaternary period exist in a relatively shallow location.	1
4	The volcanic rocks in the Quaternary period are distributed on the surface.	1

d. Creation of soil type map

Soil type map was created based on the collected columnar sections of wells and the existing geological and geomorphological maps. Figure 2.3.8-8 shows the soil type map of the Quetzaltenango area.

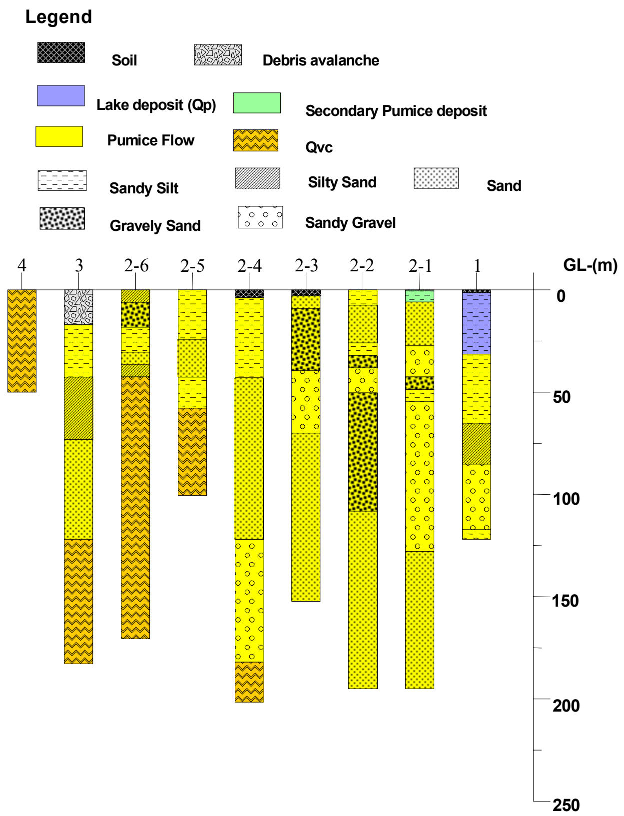

Figure 2.3.8-7 Model columnar sections in Quetzaltenango Area

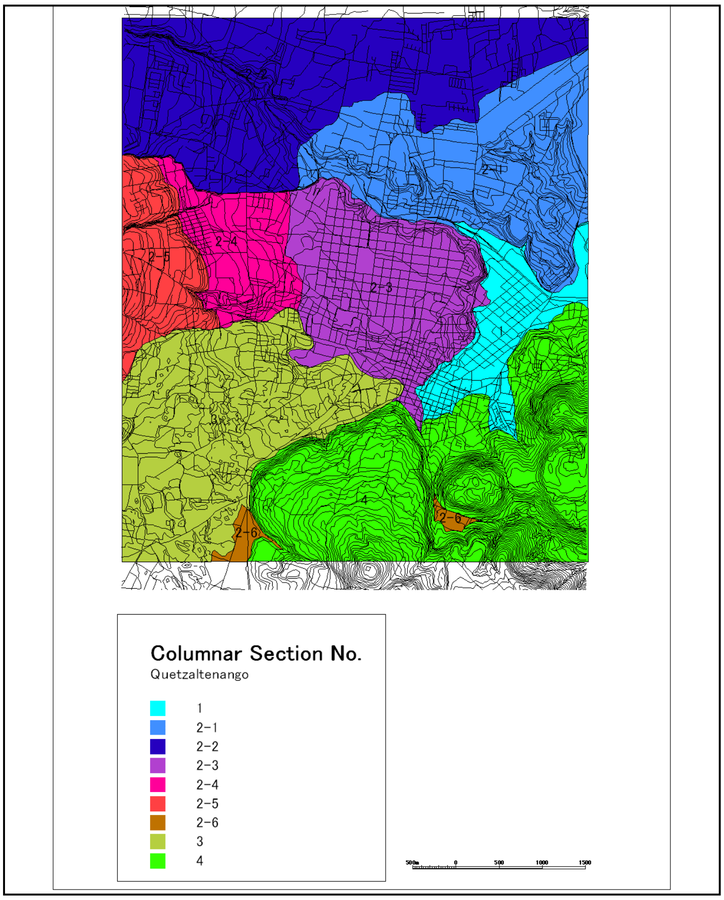

Figure 2.3.8-8 Soil type map in Quetzaltenango Area

♦ Mazatenango Area

a. Collection of Existing Data

We acquired five columnar sections of wells in the Mazatenango area. Of these, only one is clearly inscribed and 128 meters deep. The geological maps of 1:25,000 scale were used and geological data were also collected in the field.

b. Topographic and geological status

The Mazatenango area, located on the southern side of the volcanic front, is a volcanic fan of Volcán Santo Tomás. The altitude in the study area ranges from 300 to 500 meters. In the Mazatenango area, most of the geology consists of conglomerate layers originating from debris and lahar deposits in the ancient periods. Fairly clear-cut gravel and conglomerate layers are found along the small rivers that run from the north to the south. In the southern part of the study area, loam layers studded with conglomerates which must be volcanic ashes washed away by floods are distributed on the surface.

c. Identification of geological features and soil type classification

The inscriptions of columnar sections of wells and the result of field study were used to identify the geological features in the Mazatenango area. The geologic columns allowed us to confirm the presence of loam layers studded with conglomerates in the surface and whether conglomerates or sand is dominant. The geology in the Mazatenango area can be roughly classified into the soil groups shown in Table 2.3.8-4. These model columnar sections are shown in Figure 2.3.8-9.

Table 2.3.8-4 Soil types in Mazatenango Area

Soil type No.	Geological character	Number of sub-soil type
1	Soil and loam layers with conglomerates exist in the surface layer. Lahar deposits consisting of gravel layers are distributed under them.	1
2	The loam layers in the surface layer are localized. Lahar deposits consisting of gravel and conglomerate layers are distributed under them.	1

d. Creation of soil type map

Soil type map was created based on the columnar sections of wells and the existing geological and geomorphological maps. Figure 2.3.8-10 shows the soil type map of the Mazatenango area.

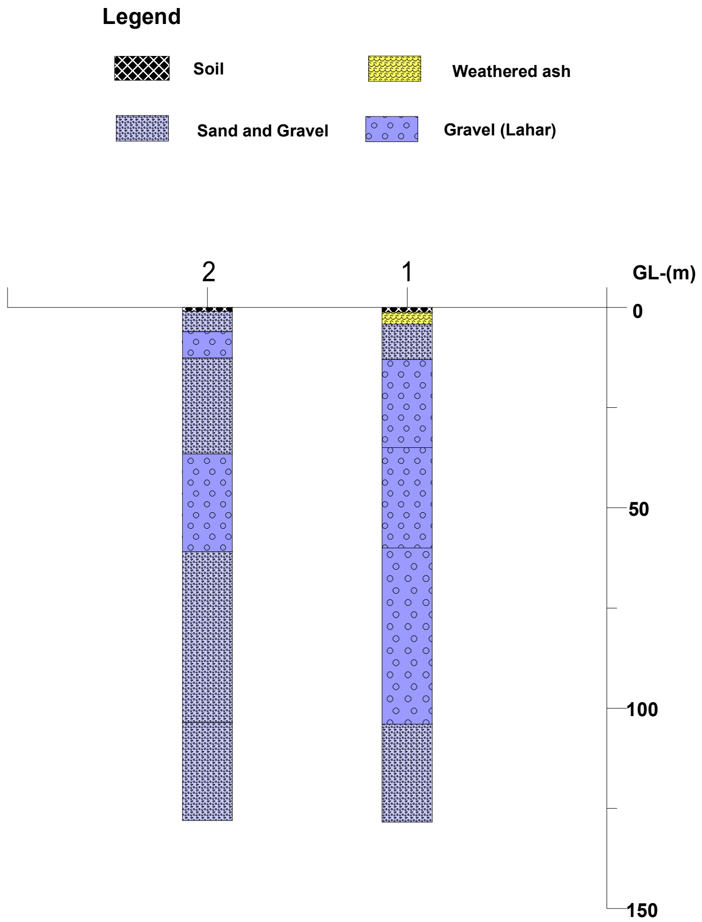

Figure 2.3.8-9 Model columnar sections in Mazatenango Area

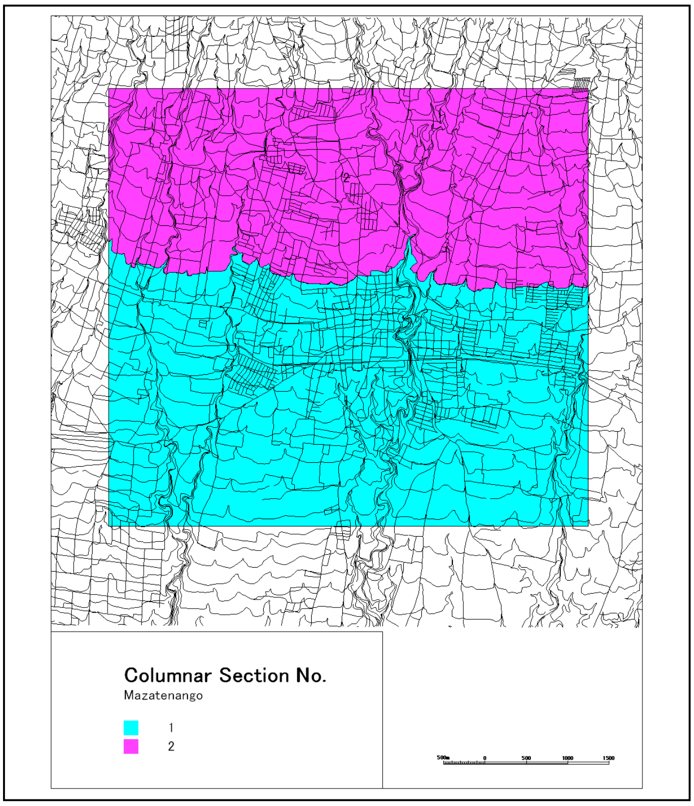

Figure 2.3.8-10 Soil type map in Mazatenango Area

♦ Escuintla Area

a. Collection of Existing Data

In the Escuintla area, we acquired ten columnar sections of wells. Of these, only one is clearly inscribed and 91 meters deep. The geological maps of 1:50,000 scale as well as the geomorphological maps created in the current project were used as references. Furthermore, geological data were also collected in the field.

b. Topographic and geological status

The Escuintla area, located on the southern side of the volcanic front, is a volcanic fan about 17 kilometers away from the top of Volcán de Agua. The altitude in the study area ranges from 300 to 400 meters. In the Escuintla area, the geology consists of debris flow deposits, lahar deposits sandwiching a mud layer, and pyroclastic products in the Tertiary period.

c. Identification of geological features and soil type classification

The result of field study, analysis of columnar sections of wells, and two-dimensional classification based on geological and geomorphological maps were used to identify the geological features of the Escuintla area. The geology of the Escuintla area can be roughly classified according to the soil groups shown in Table 2.3.8-5. These model columnar sections are shown in Figure 2.3.8-11.

Table 2.3.8-5 Soil types in Escuintla Area

Soil type No.	Geological character	Number of sub-soil type
1	Debris flow deposits and, pyroclastic products in the Tertiary period are distributed under them.	1
2	The conglomerate and gravel layers sandwiching a mud layer and pyroclastic products in the Tertiary period are distributed under them.	3
3	Pyroclastic products in the Tertiary period are exposed on the surface.	1

d. Creation of soil type map

Soil type map was created based on the columnar sections of wells and the existing geological and geomorphological maps. Figure 2.3.8-12 shows the soil type map of the Escuintla area.

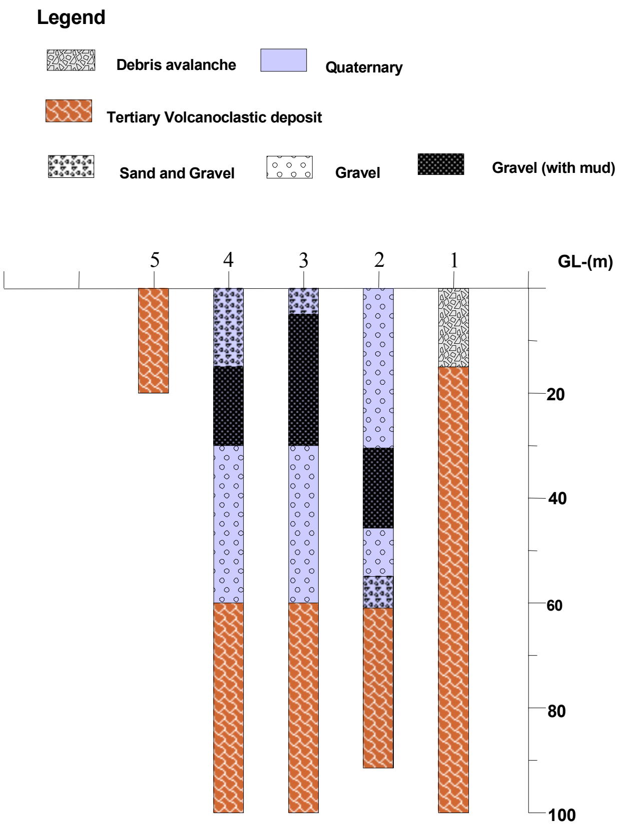

Figure 2.3.8-11 Model columnar sections in Escuintla Area

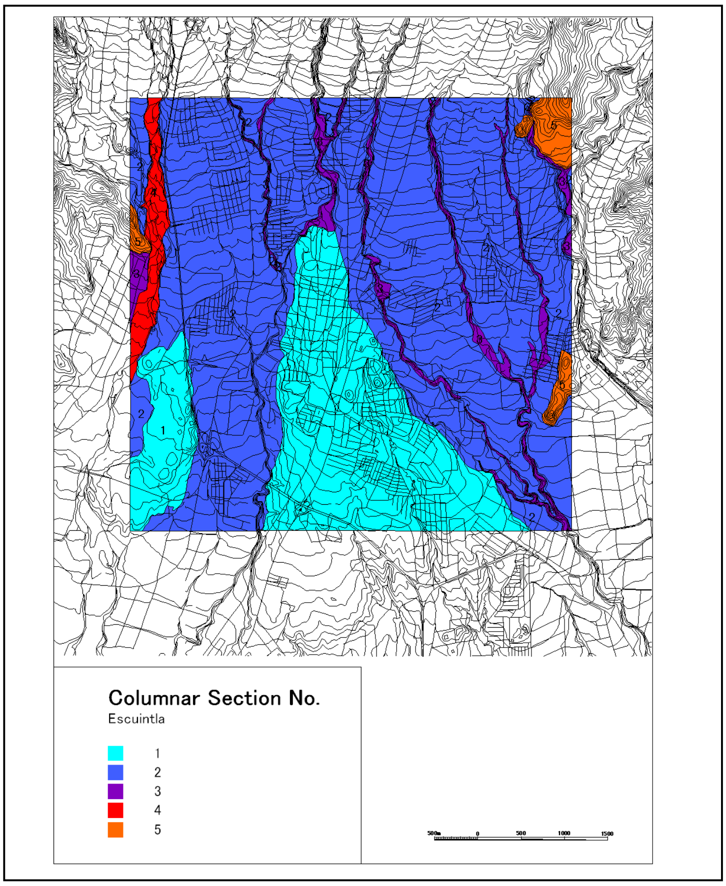

Figure 2.3.8-12 Soil type map in Escuintla Area

♦ Puerto Barrios Area

a. Collection of Existing Data

In the Puerto Barrios area, we acquired six columnar sections of wells. The geological maps 1:250,000 and 1:50,0000 scale were used.

b. Topographic and geological statuses

The Puerto Barrios area surrounds the eastern side of the Santo Tomás Bay and extends from the lowland area along the coast to the hilly terrain. In the Puerto Barrios area, the altitude is about 200 meters in the hilly terrain and less than 10 meters near the coast.

The geology consists of alluvium made of sand and silt in the coastal plain whereas fluvial sediments are distributed in the valley plain in the hilly terrain. As the hilly terrain is divided by an estimated fault extending from north-northeast to south-southwest, quaternary formations are distributed on the northern side and Tertiary layers on the southern side. Furthermore, limestone is distributed in the mountain range.

c. Identification of geological features and soil type classification

The inscription of columnar sections of wells and two-dimensional classification of geological and geomorphological maps were used to classify the soil types. The soil types in the Puerto Barrios area can be roughly classified as shown in Table 2.3.8-6. These model columnar sections are shown in Figure 2.3.8-13.

Table 2.3.8-6 Soil Types in Puerto Barrios Area

Soil type No.	Geological character	Number of sub-soil type
1	Alluvial and diluvial formations in the coastal plain are distributed.	1
2	Fluvial sediments and Tertiary layers are distributed.	1
3	Terrace deposits and basement rocks are distributed.	1
4	Quaternary diluvial formations (partly embankment) and Tertiary layers are distributed.	3
5	Tertiary layers is distributed.	1
6	Basement rocks are distributed.	1

d. Creation of soil type map

Soil type map was created based on the columnar sections of wells and the existing geological and geomorphological maps. Figure 2.3.8-14 shows the soil type map of the Puerto Barrios area.

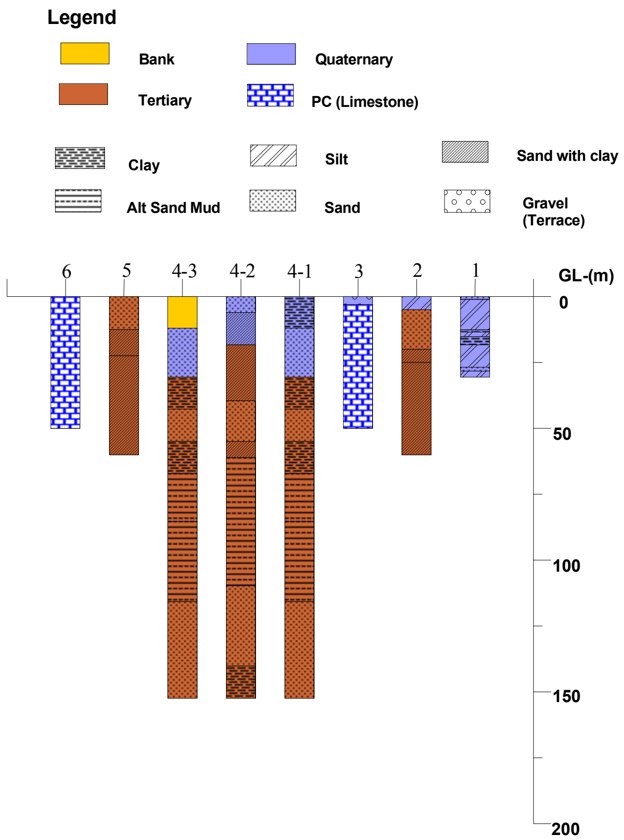

Figure 2.3.8-13 Model Columnar Sections in Puerto Barrios Area

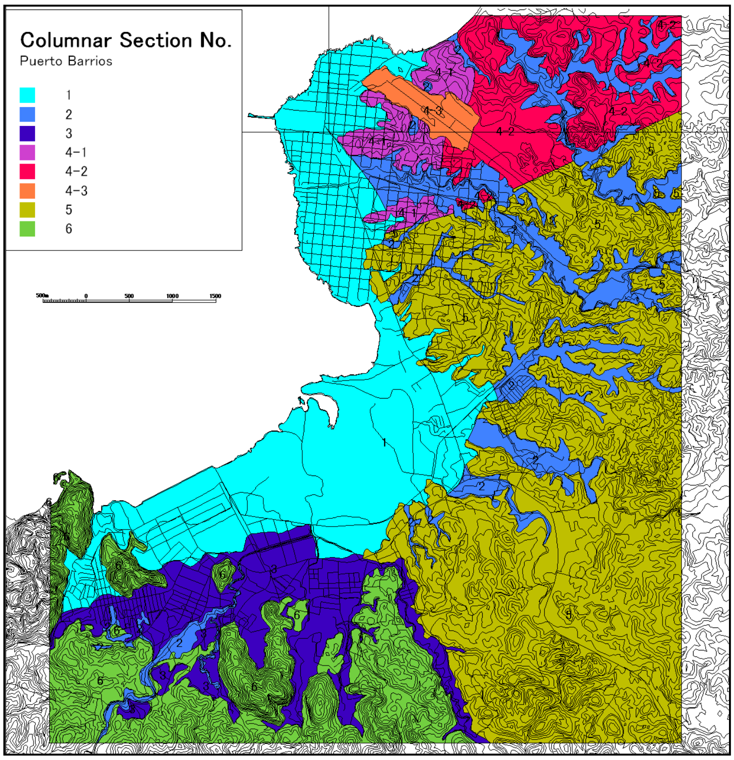

Figure 2.3.8-14 Soil type map in Puerto Barrios Area

b) Settings of parameters

The soil parameters required to estimate the ground motion include, for each layer, the geological time (distinction between Holocene and Pleistocece), soil type (distinction among viscous and sandy soil, gravel, etc.), sounding value, density, S-wave velocity, layer thickness, and depth from the surface.

We were able to acquire test data on S-wave velocities in the Guatemala City, Quetzaltenango, and Escuintla areas. In the Guatemala City area, facies and S-wave velocities were compared to create an S-wave velocity map shown in Table 2.3.8-7. The values in this map were used as reference. We adopted the density of pyroclastic flow deposits in Japan because we were unable to acquire that in the Guatemala and other areas.

Table 2.3.8-7 Summary of site categories in New Seismic Codes

Site Class or Soil Profile Type		Description	Shear Wave Velocity *Vs* Top 30m (m/sec)	Standard Pen. Resistance *N* or *Nch* (blows/ft)	Undrained Shear Strength *Su* (kPa)
S1	A	Hard Rock	>1500	—	—
	B	Rock	760-1500	—	—
S1 and S2	C	Very dense soil/ soft rock	360-760	>50	>100
	D	Stiff soil	180-360	15-50	50-100
S3 and S4	E	Soft soil	<180	<15	<50
	F	Special soils requiring site-specific evaluation	—	—	—

(from 1994 and 1997 NEHRP Provisions and 1997 UBC), including approximate correspondence with old site categories S1 to S4

3) Settings of Target Earthquakes

Based on the distribution of damage-causing earthquakes in the past and plate boundaries, we assumed 11 target earthquakes and set fault parameters according to the definitions shown in Figure 2.3.8-15. The distribution of the target earthquakes and fault parameters are shown in Figure 2.3.8-16 and Table 2.3.8-8. The target earthquake of No.10 (or No.11) is assumed to have the source fault, of which size corresponds to moment magnitude 7.7, as a part of the shallow (or deep) segment of subduction zone, and to occur in the closest part to each study area on the segment.

For each study area, we assumed a target earthquake that could influence it and estimated ground motion and liquefaction potential for the combinations shown in Table 2.3.8-9.

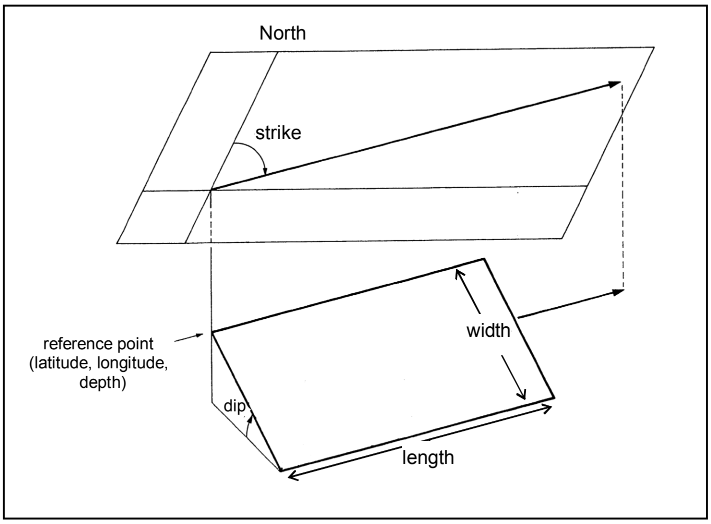

Figure 2.3.8-15 Definition of Parameters

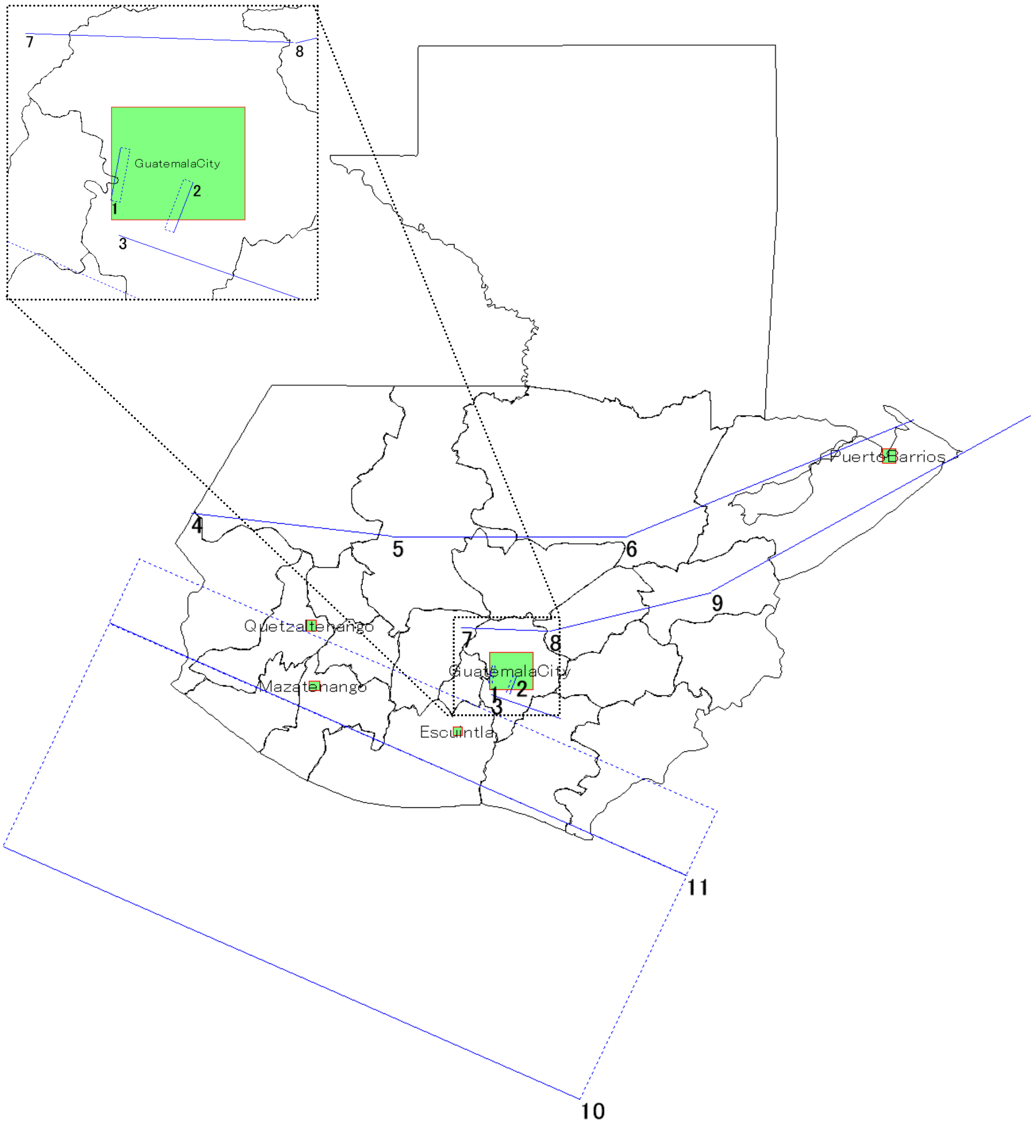

Figure 2.3.8-16 Distribution map of target earthquakes

(Numbers correspond to ones shown in Table 2.3.8-8)

Table 2.3.8-8 Fault parameters of target earthquakes

No	Fault Name	Lat. [deg]	Lon. [deg]	Depth [km]	Length [km]	Width [km]	Strike [deg]	Dip [deg]	M_W
1	Mixco	14.55139	-90.6247	0	10	20	10	85	6.9
2	Sta. Catarina Pinula	14.58161	-90.4880	0	10	20	200	85	6.9
3	Jalpatagua West Segment	14.49167	-90.6111	0	40	20	110	90	6.9
4	Chixoy-Polochic West Segment	15.41667	-92.1333	0	110	30	97	90	7.6
5	Chixoy-Polochic Central Segment	15.30000	-91.1167	0	127	30	90	90	7.6
6	Chixoy-Polochic East Segment	15.30000	-89.9333	0	170	30	67	90	7.6
7	Motagua West Segment	14.83333	-90.7667	0	48	30	92	90	7.6
8	Motagua Central Segment	14.81667	-90.3167	0	90	30	76	90	7.6
9	Motagua East Segment	15.01667	-89.5000	0	200	30	60	90	7.6
10	Subduction Shallow Segment	12.41667	-90.1667	20	345	145.1	294.5	16	7.7
11	Subduction Deep Segment	13.56397	-89.6335	60	345	56.6	294.5	45	7.7

Lat.: Latitude, Lon.: Longitude, Mw: Moment magnitude

Table 2.3.8-9 List of assumed cases of ground motion and liquefaction potential

No	Target earthquake	Guatemala City	Quetzal-tenango	Maza-tenango	Escuintla	Puerto Barrios
1	Mixco	○				
2	Sta. Catarina Pinula	○				
3	Jalpatagua West Segment	○				
4	Chixoy-Polochic West Segment		○			
5	Chixoy-Polochic Central Segment	○				
6	Chixoy-Polochic East Segment					○
7	Motagua West Segment	○				
8	Motagua Central Segment	○				
9	Motagua East Segment					○
10	Subduction Shallow Segment	○	○	○	○	
11	Subduction Deep Segment	○	○	○	○	