and that there are 6 wells used for the water supply, and some other private wells. The municipal wells were visited and the locations confirmed with GPS. EMPRESO, the Civil Engineering Department of Puerto Santo Tomas, informed us of the construction boring details of the dock and helped us confirm geographic features and conditions in the aerial photos, as well as providing us with a detail map of Santo Tomas. They also informed us of the July 11, 1999 earthquake that caused damages to the dock foundation and damaged the customs building so badly that it is unsafe to use. Several neighborhoods were visited to investigate local conditions, and a large spring (Pozo Azul) was visited to confirm the location with GPS and observe the water level. The port authority of Puerto Barrios, COBIGUA, was visited and they informed us about some damages from the 1999 earthquake. The area of La Refinería was investigated and people interviewed told us about the flooding problems in this area.

6) Tacana volcano

We left San Marcos early in the morning of July 11, 2002 and, from the mountain pass in the east of Sibinal (about 3,500 meters in altitude), the highest peaks in Central America, i.e., Tajumulco and Tacaná Volcanoes. To confirm the topographic and geological features near the Tacaná volcano, we went down to Sibinal, checked with the local police chief about the access, and climbed via Haciendita to the Tacaná volcano. Along the road, we found collapses of weathered granite. We went down from Haciendita to Vega del Volcán and confirmed that thick layers of tephra were on the lava flow. Since carbonized trees were seen and volcanic bombs about 20 centimeters in diameter were found in the tephra, certainly the tephra comes from a source nearby, probably Tacaná Volcano. For the estimate of the volcanic hazard for Tacaná Volcano, it is necessary to consider the Plinian eruption and resultant pyroclastic flows as belonging to the eruption type.

Photo 2.3.7-18 Lava flows and tephra in North-Eastern Part of Tacaná Volcano

There are many houses at Vega del Volcán, with tin and shingle roofs, at least a few of which may be damaged if tephra falls. Also in the villages along the valley, houses are distributed higher than the valley and probably not in danger from lahar.

7) Santiaguito volcano

Santa María Volcano erupted in 1902, and made a crater in the SW flank. The eruption was one of the largest eruptions of the 20th century. Santiaguito is the dacitic dome that began to grow in 1922 in the crater of Santa María Volcano.

a) Observatory

A permanent volcanic and meteorological observatory situates upstream of Finca El Faro, 7 km south of the domes. INSIVUMEH and Centro de Prevención de Desastres Naturales en América Central (CEPREDENAC) have constructed it in order to monitor activity better at Santiaguito. The observatory opened in the second week of November of 1990 and is managed around-the-clock, by trained observers. They observe volcanic activity, rainfall, wind direction, and wind speed, etc. They said a rumbling of the earth is felt there when lahars flow down. In Japan, we have several sensors (for example, wire-sensor and video camera) to observe debris flow (or lahar) and make alert. They have ideas to establish those instruments, but it is not realized yet because of limit of budget.

Photo 2.3.7-19 Volcanic Observatory of Santiaguito

Photo 2.3.7-20 Volcanic Observatory of Santiaguito (from homepage of MTU)

b) Evidence of 1902 Santa María eruption

In 1902, Santa María Volcano erupted and approximately 6,000 people died. Volcanic edifice collapsed and debris avalanche occurred, which flowed down on the south flank of the volcano. More than a meter of ash and pumice fell around the volcano.

Deposits of this eruption were observed around the rivers Nimá I and Nimá II. The photograph shows the 1902 pumice layer at the point of about 1200m heights between Nimá I and Nimá II. Thickness of the layer is about 30cm and several bombs are included in the layer, and mean diameter of pumice is about 1cm at the place.

Debris avalanche deposit is observed along the riverbank of Nimá I and Nimá II. Thickness of the deposit at Nimá II near Finca La Florida is about 6m, and ash fall deposited on the debris flow with about 1m thickness. And on those, pumice layer is seen with thickness of about 20cm. Diameter of pumice is about 1-5mm. The pumice layer of

1902 Santa María eruption was observed in several sites at southwest of Siete Orejas Volcano. The thickness of the layer is about 50cm there. Because of the wind direction at the time of the eruption, air-fall deposits are thicker in the northwest direction from Santa María Volcano.

Photo 2.3.7-21 Air fall pumice of 1902 Santa María eruption seen at upstreem of Nimal

Photo 2.3.7-22 Air fall pumice(bottom) and deposit of debris avalanche (uupper part) of 1902 Santa María eruption at Nimá II river near Finca El Faro

Photo 2.3.7-23 Pumice layer seen at Siete Orejas Volcano

c) Lava flow from Santiaguito dome

Santiaguito continues extruding lava and the lava flow, which started to flow in 1999, still advances 3-4m per day now. It flows down along the Nimá II river. We observed 1999 lava flow from the east-next ridge at the altitude of about 1400m. This is most wide part of the lava flow. The temperature of the flow is high yet, and vapor rising in the air

Photo 2.3.7-24 1999 lava flow of Santiaguito

was observed. Sounds of collapsing and falling rocks are often heard during the observation. It seems dacite lava flow.

d) Lahar

Because of the pyroclastic materials supplied by lava flow and the erosion of volcanic slope along the lateral side of the lava, lahars occur frequently at the down stream of Nimá II. In other words, the lava flow supplies ash and blocks to the river and heavy rain carries them with volcanic surface materials to the down stream by lahars. Because of origin material, lahars are hot, and when lahar occurred vapor rose at the height of about 100m in the air until two years ago. Rainfall amount of 50-70mm or more at the observatory induces lahars, although there should be more amount of rainfall at the upstream of the river.

There is also a lava flow at the upstream of Nimá I river. The lava flow started to flow there in 1996, and first big lahar occurred in Nimá I river on 17 May of 1997.

Photo 2.3.7-25 Trace of lahar on the house wall of Finca El Faro

On 1st of June of 2001, the biggest lahar of this year occurred at Nimá I river. It overflowed the bridge near Finca El Faro, and lahar deposit is still observed on the road and riverbanks. In the downstream from this bridge, the lahar overflowed at the several places. At last, it hit Finca El Faro and damaged to the furniture in houses, although there was no damage to the inhabitants. Trace of the lahar is left on the wall of houses, which indicate that the flow came up to the height at about 60cm above the floor.

CONRED declares that following villages are under the risk of lahar; Finca San José, Finca El Faro, Finca La Mosqueta, Finca Santa Marta and Finca La Florida. We visited Finca La Mosqueta besides Finca El Faro, and found several damages caused by past lahars. Those villages situate near Nimá I river, in which a lot of lahars occur. Some early alert system is necessary to evacuate inhabitants safely.

e) Additional investigation in 2002

The Samalá River has a higher river bed than in June 2001 when it was investigated. Upstream from where the river runs parallel to CA2 (near San Sebastián), the lahar deposits found in June 2002 covered an extensive range of the current river bed. The Castillo Armas bridge over CA2 near San Sebastián, about six meters higher than the river bed as of July 2002, may be washed away if the river bed further rises or massive lahar deposits flow down in the future. The river, meandering toward the west, is significantly eroded on the San Sebastián side. Although gabions and stone embankments are used against erosion, the lateral erosion is so active that the western foundation of an old railroad is being eroded. The lahar tends to spread to the western side (San Sebastián). When the water level is low, the river is susceptible to lateral erosion due to meandering. The gabions may be scoured.

Photo 2.3.7-26 Eroded foundation of an old railroad near San Sebastián

We saw Santiaguito Volcano exploded (a small scale Vulcanian eruption with smoke much lower than Santa Maria) several times. Furthermore, collapse (avalanche) of rocks frequently occurred. We saw what looked like smoke coming up from the middle of the lava flow. The Nima 1 River still formed a deep valley as before but new lahar deposits were found in the riverbed.

8) Cerro Quemado volcano

Cerro Quemado, which situates about 5km south of Quetzaltenango, consists of several lava domes and thick lava lobes.

a) Lava flows and lava domes of Cerro Quemado

Old lava lobes are observed in the western part of Cerro Quemado. Those are the result of the volcanic activity during Late Holocene. A rhyolite/dacite lava dome, which is called La Pedrera lava flow and lava dome, situates in the northern most part of Cerro Quemado. Rock falls often occur along the edge of this lava dome with earthquakes and heavy rain.

Photo2.3.7-27 The erosion head seen on the border of La Pedrera lava dome

b) Edifice collapse and debris avalanche about 1,150 years ago

The volcanic edifice of Cerro Quemado

collapsed about 1,150 years ago. The event produced debris avalanche, which flowed down the Llano del Pinal Valley. Debris flow mounds are seen in the west to north of Cerro Quemado. A lot of big blocks (diameter is several meters) also distribute around this region. A horseshoe shape crater remains around Cerro Candelaria.

Photo2.3.7-28 The debris flow mound and lava blocks seen in the west of Cerro Quemado

Photo2.3.7-29 Big blocks seen in the mound

c) Deposits in the Llano del Pinal

Volcano origin deposits are observed at several quarries in the Llano del Pinal valley, west of Cerro Quemado. Near Cerro Quemado, mixture of rocks, gravels, and ash is observed (site ①). Diameters of rocks are 10--50 cm. In the quarry (site ②), similar mixture was seen, but diameter of rocks are smaller than that of site ①.

Photo2.3.7-30 Location map of ① and ②

Photo2.3.7-31 Deposits on site ①

Photo2.3.7-32 Deposits on site ②

d) Almolonga

The village Almolonga situates in the east of Cerro Quemado is in the bottom of caldera of Almolonga Volcano and on the pyroclastic flow deposit (Los Chocoyos ignimbrite; Atitlán volcano origin). On several cutting, thick pyroclastic flow deposit is observed. From this village, lava flow that extrude in 1818 from Cerro Quemado is observed.

Photo2.3.7-33 Pyroclastic flow deposit at Almolonga

Photo2.3.7-34 1818 lava flow and Almolonga

9) Pacaya volcano

Pacaya Volcano is the volcanic complex that situates on the south rim of the Amatitlán Caldera.

a) Activity during Late Pleistocene

Eruptive history of Pacaya volcano is divided into four stages (Kitamura, 1995). During Late Pleistocene, there were two stages of volcanic activity. Stage II activity is characterized by several pumice fall and formation of lava domes. Besides, there were the pumice eruption from Laguna de Calderas caldera and phreatomagmatic eruption at the El Durazno crater.

Evidences of these activities were investigated and the hazard factor of these eruptions is considered on the first day.

Laguna de Calderas situates in the north of Cerro Grande. Around the lake, there are several tens of houses and a geothermal power plant (Photo2.3.7-35). If magma intrudes around this lake, phreatomagmatic eruption will occur. This phenomenon is explosive and accompanied by severe blast. Therefore, if it occurs, there will be heavy damages to houses and inhabitants.

Phreatomagmatic eruption occurred at El Durazno crater. In the crater, debris flow deposits are observed at the south (Photo2.3.7-36). Deposit of mixture of pumices and small pieces of broken lava is observed at the northern rim of the crater (Photo2.3.7-37). This crater situates near the Amatitlán Lake, the tourist place, and if the explosion occurs again, there will be severe influence to people.

There are several lava domes in the southwest of Amatitlán Lake accompanied with several lava flows. These are andesite lava domes, and steep slope is formed along the rim of the domes. Several rock falls are observed at the rim of the domes.

Photo2.3.7-35 Laguna de Calderas

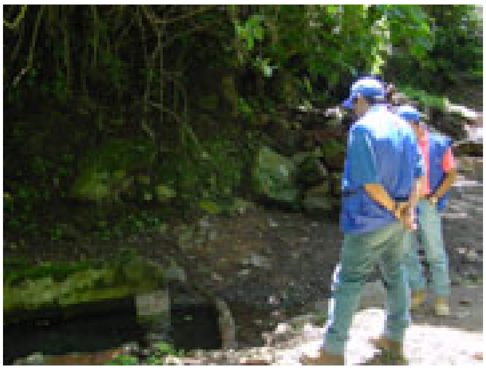

Photo2.3.7-36 Deposit at the south part of El Durazno crater

Photo2.3.7-37 Deposit at the northern rim of El Durazno crater

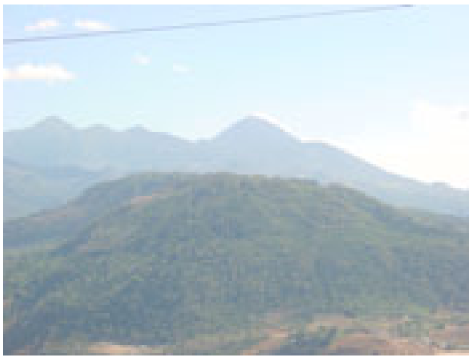

Photo2.3.7.38 Andecite lava domes in southwest of Amatitlán Lake

Photo2.3.7.39 Rock fall at the rim of lava dome

b) Activity of Cerro Grande

Photo2.3.7-40 Lava flow at Mesillas Bajas

Stage III activity is characterized as scoria fall presumably from the Cerro Grande. Several lobes of lava flow extend from its conical edifice to the south and to the noetheast (Kitamura, 1995). Basaltic lava flow is observed around Mesillas Bajas, in the northeast of the Cerro Grande.

c) Lava flows from MacKenney Crater

The last stage initiated about 1,500 years B.P. and continues today. Present activity is limitted to that from MacKenney Crater, which extrudes several lava flows and pyroclastics.

Lava flows from MacKenney Crater are observed in the west and south of the Pacaya Volcano. From the observatory on the Cerro Chino, the latest lava flows are observed. The Sep. 18, 1998 lava flowed down between the Cerro Chino and MacKenney Cone about 2km long (Photo2.3.7-41). It covered a part of older lava flows, for example, 1961 lava

Photo2.3.7-41 Lava flow of 1998 eruption

Photo2.3.7-42 Lava flow of 2000 eruption (the darkest lava flow)

Photo2.3.7-43 Old lava flow seen in the southwest flank (near side)

flow. In the photograph, the newer lava looks the darker. From the Cerro Chino crater rim, the Jan. 2000 lava flow was seen. It flowed down the northern flank of MacKenney Cone, and stopped between the Cerro Chino and MacKenney Cone (Photo2.3.7-42). All of these lavas are basaltic. Lava flows are observed also in the south of the Pacaya Volcano (Photo2.3.7-43). These lava flows are older (e.g. 1961) than those seen around the Cerro Chino.

d) Debris avalanche

About 1,200 A.D., the "Initial Cone" of present Pacaya Volcano collapsed and formed horseshoe shaped caldera open to the southwest. The event accompanied debris avalanche, which forms debris flow mounds from the west to the south flank of Pacaya Volcano. The debris avalanche deposit contains blocks at most a couple of meters in diameter. Those blocks are observed also in the village of El Patrocinio, and near the village of El Caracol.

Photo2.3.7-44 Debris flow mounds seen in the west flank of Pacaya Volcano

Photo2.3.7-45 Block seen in El Patrocinio

Photo2.3.7-46 Block seen near El Caracol

10) Antigua Guatemala

Despite landslide study area, no evidence of large landslides was found in this area. Mountain slopes are steep enough to collapse, only small rock falls occurred on the cutting slopes of CA-1 and National road 10. One of the reasons may be that considering the area is covered by air fallen pumice the large infiltration capacity of the materials do not allows retaining water during heavy rains, and there is no susceptibility to landslides because of the light weight and tight adhesion of pumice grains.

Photo2.3.7-47 Sevaral meters to 10m thick porous pumice layers cover the mountain slopes

11) North-west region (El Quiché, Huehuetenango, San Marcos)

a) Debris flow at El Paraíso, Huehuetenango department

This event happened in three small basins of El Injerto River (107 km^2), Hoja Blanca River (16 km^2), and Agua Dulce River (45 km^2). Among these the first one that includes the village of El Paraíso was the most damaged, killing between 30 to 72 people according to accounts of the neighbors and reports of newspapers of that time. Missing persons were about 300 at some time and 65,000 persons remained isolated temporarily, due to the collapse or heavy damage of three important bridges in the region.

b) Cantzelá landslide, Huehuetenango department

This landslide is located at the village of Cantzelá, belonging to the Aguacatán Municipio of the Department of Huehetenango. The landslide has an approximate extension of 300x300m. According to accounts of some older person it had large movements from around 1920 and then on 1998 during Hurricane Mitch. The site is located in a contact of Formation Todos Santos (Jurassic-Cretacic), consisting of shales, siltstones, sandstones and conglomerates, with Formation Santa Rosa (Pensilvanian-Permian?), consisting of slates and slaty shales. This area also is surrounded by many local faults produced by the activity of the Chixoy-Polochic. The sliding surface seems to be the shales of Todos Santos.

Within the area of the landslide a primary school and about 5 houses are settled, with severe damages in the school especially, at the point that they are moving it from the present place.

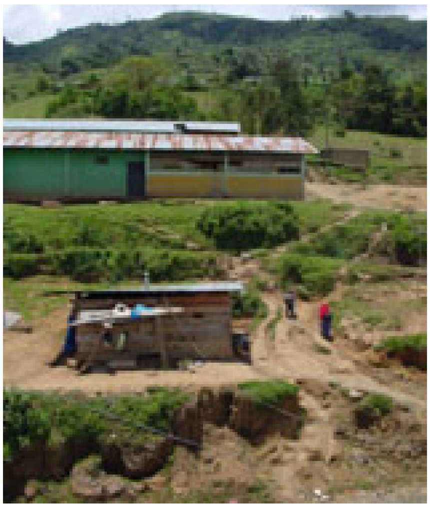

Photo2.3.7-48 The primary school damaged by the landslide

c) Landslide at La Barranca Village near Aguacatán, Huehuetenango department

This landslide is located at the left bank of Bucá River about 3km west from Aguacatán on the roadto Chiantla. In this area there are large masses of serpentinite, Chochal formation with massive bedded limestones of the Chochal formation (Pc) as well as lithoclastic limestones, dolomites, and dolomite breccia of the Ixcoy limestone (Kis). This area is highly unstable due to its variable geology with so many contacts, folded and cracked rock masses due to ancient and frequent movements of the Chixoy fault which runs just along this area.

Photo2.3.7-49 Landslide at La Barranca

d) Debris flow at Cuilco area, Huehuetenango department

In this area there are frequent debris flows along the Cuilco River, produced by unstable slopes upstream. The first bridge was constructed on 1960, lapsed 30 years, and destroyed on 1990. Then on 1998-9 it was constructed again and was washed out after six month of finishing it on Sept 15^{th} 1999 during a flood produced by debris flow.

12) Central region

a) Landslide of Los Chocoyos

It is located about 15 km from Tecpán, along the south wall of the valley of the Los Chocoyos River. The landslide probably began as a block slide and disintegrated into a debris avalanche that plummeted down the canyon wall to the river and then traveled some 600m downstream before coming to rest. The main scarp has a height of 50 to 60m, and total moved mass was about 1 million m^3 of debris derived from Pleistocene pumice deposits.

Photo2.3.7-50 Landslide of Los Chocoyos

This landslide killed 6-7 persons. The landslide blocked the river and formed a lake extending some 300m upstream.

b) Landslide at 2.5 km west from Los Chocoyos

This is an imminent landslide near the previous and older one known as Los Chocoyos. It can be observed with two scarps, one at top of hill and other one fourth down from the top. It cannot be appreciated in the aerial photos due to the narrowness of the cracks. It is composed of very fractured volcanic rock. It may be expected the slope fail during a coming rainfall or a relative large earthquake.

Photo2.3.7-51 Landslide at 2.5 km west from Los Chocoyos

c) Landslide at Patzún Village (Munic. San Andrés Semetabaj, Sololá)

This is a dip slope type of landslide where a mass of deeply altered material is sliding on the bedding plane of intact rock. Instability must have started from the construction of the road at the half hillside.

Photo2.3.7-52 Landslide at Patzún Village

d) Large landslide at San José Poaquil

At San Jose Poaquil in the north-west of Tecpan Guatemala, we took a short deviation from the eastern logging road into the valley side to reach the head of this landslide. A huge landslide scarp was found. The upper part of landslide scarp consists of Los Chocoyos pyroclastic flow deposits, which is lightly weathered on the surface to become yellowish brown. The lower part of landslide scarp consists of welded tuff. The huge landslide is more than 400 meters wide and 200 meters high. In the forward of the landslide scarp, there is an outcrop that is lightly inclined toward the landslide scarp side. The outcrop is a remnant of deposits that slipped down from the landslide scarp location and now is found slumped and inclined toward the landslide scarp side. This landslide occurred following the

Photo 2.3.7-53 Large Landslide at San José Poaquil

Guatemala Earthquake in 1976.

13) Samalá River

The Samalá River originates in the north of Quetzltenango and flows on the east side of the Santa María Volcano into the Pacific. The flood problem of the Samalá River results from lots of sediments supplied by lahar due to eruption of the Santiaguito Volcano. Therefore, the field study was conducted on an area from the tributaries Nima I River and Nima II River, into which the sediments flows from the Santiaguito Volcano, to the coast. The study reports on the Nima I River and Nima II River are provided in the volcano section.

a) From El Palmar to San Sebastián

The Nima I River joins the Samalá River in the south of El Palmar. Currently, no flood occurs because the Samalá River in this area flows down a deep valley and no sediments flow in from the Nima II River. The Samalá River joins the Nima I River in the south of San Felipe. Around this location, the river width becomes more than 100m and gravel accumulates on the riverbed. The area around the river is a terrace, posing no danger of flooding. Around the bridge in CA2 in San Sebastián, the Samalá River comes to have a narrow width, causing sediments to accumulate to raise the riverbed. At present, the river path is maintained at this location by excavating the riverbed. On the right bank, gabions are used to form embankment to prevent a flood. On both the banks, the landform changes from a terrace to a lowland area. Floods easily occur in the area downstream from this bridge. Inhabitants here say that, especially on the right bank where there is little difference in height between the riverbed and the lowland area, a flood current flows into the adjacent river, Muluá River. On the riverbank, there are remnants of a gas station washed away by a past flood.

Photo2.3.7-54 Status of the riverbed near CA2

b) From San Sebastián to junction of Oc River

The Samalá River, after diverging from the Ixpatz River, has a larger floodplain as it flows further into the lower reaches.

In particular, sediments supplied from the upper reaches are accumulated to raise the riverbed as high as the ground, which used to be three meters higher than it. Sediment accumulated at the junction has dammed up the tributaries to form a laguna. In La

Lolita,a laguna formed on the Mesa River raised the water level of the river, making it impossible to take a road across the river. Also, sediments flowing into this laguna are forming a delta. In a few dozens of years, sediments flowing in are expected to fill in the laguna to create a floodplain. On the other hand, the Izpatz River does not have a floodplain as large as the Samalá River but a flood often occurs in the pasture along the river. In Nueva Candelaria, deposits of sand due to flooding of the Izpatz River were seen.

c) From Oc River to Pacific coast

The Oc River is also being filled in by sediments flowing in from near the junction.

All over the lower reaches stretches a gently undulating hilly terrain (terrace). This is an old alluvial fan, which the river eroded to form a valley. Most of the hilly terrain (terrace) is either cornfields or pastures. The Samalá River in the lower reaches has a river path width of about 200 to 300 meters. Around the river, there is a flood plain about 500 meters in width. The current in this river is very slow and the depth is as little as about 30 centimeters. The riverbed deposits consist of sand. On the hilly terrain (terrace), there are shallow valleys and depressions eroded by streams. During a flood, water coming out of the Samalá River flows in to expand the flood.

In the lowermost reaches, there is a floodplain three kilometers wide. There is little difference in height between the riverbed and the surrounding lowland area. In some parts, a road was washed away by a flood. When the Hurricane Mitch hit, the water level of the flood was 150 centimeters. At the estuary, there is a beach ridge along the coast, behind which there is a marsh in the background.

Photo2.3.7-55 Status of the lower reaches

Photo2.3.7-56 Road washed off in the lower reaches

14) Acomé River

The field study on the Acomé River was conducted on the area downstream from La Gomera.

a) From Santa Lucía Cotzumalguapa to La Gomera

The Acomé River has a very narrow catchment area in the upper reaches, being only a stream one meter in width in Santa Lucía Cotzumalguapa. The river flows through a relatively steep old alluvial fan up to eight kilometers north of La Gomera but through a lowland area downstream from there. In the lowland area, tributaries that diverge from the Achiguate River, adjacent river, flow to form netlike streams, making the boundary of the basin obscure. If a flood occurs in this lowland area, not only the Acomé River overflows but also many rivers overflow in combination.

The river meanders through a lowland area near La Gomera and joins the Aguero River in the north of the town. The river is about five meters wide and, since it erodes the lowland area while flowing down, the surrounding lowland area is a terrace about three meters higher than the riverbed. Therefore, land near the Acomé River has been flooded before but the town of La Gomera had scarce flood damage. Even Hurricane Mitch flooded the area near the Acomé River and the entrance of the town at the depth of about 0.5 meters for one night.

In El Terreno in the east of La Gomera was flooded by Hurricane Mitch at the depth of 0.5 meters for three days. Inhabitants said that the flood at this time had flowed from the north to the south, being probably resulted from the inundation of the Colojate River.

Photo2.3.7-57 Aguero River near La Gomera

Photo2.3.7-58 La Gomera: The blue line indicates the water level of the flood by Hurricane Mitch.

b) From La Gomera to Pacific coast

Sugarcane is cultivated in the lowland area from La Gomera to the coast. The Acomé River, about five meters wide, flows two meters lower than the ground. Hurricane Mitch flooded most of the villages along the Acomé River but did not flood others. On the other hand, some villages were submerged for as long as eight days. This seems to be related to the delicate height differences of land along the river and the direction of current.

There are dunes (dunas) on the coast. Since the dunes (dunas) are about five meters higher than the lowland area, there is little danger of flooding. Hurricane Mitch caused scarce floods in the town of Sipacate or El Paredón Buena Vista near the estuary of Acomé River. La Empalizada facing the coast was submerged not due to a flood but a high tide, according to the inhabitants.

Inland from the dunes, there is a laguna and a marsh (pantano). Despite the dunes extending for about 30 km, there is only one estuary, i.e., that of the Acomé River. Additionally, at the estuary of the Acomé River that flows slowly and meanders, water is not easily discharged due to the sand bar (barra). If the river has a higher water level, therefore, it seems that many of the river streams are dammed to cause a flood in the lowerland area behind the dunes.

The road between Sipacate on the coast and La Gomera is on a mound and thus is not likely to be submerged even if a flood occurs.

Photo2.3.7-59 Marsh and dunes near Sipacate

Photo2.3.7-60 Acomé River in the lowermost reaches

15) Achiguate River

The field study on the Achiguate River was conducted on the area from San Andrés Itzapa in the upper reaches of the Guacalate River, a tributary of the Achiguate River, to the estuary.

a) From San Andrés Itzapa to La Antigua

San Andrés Itzapa, located on a mountain foot slope, has the Itzapa River and the Neguro River on each of the sides of the town. Since these rivers flow through a valley, land along the valley may be flooded when it rains heavily. However, the flood is likely to be only temporary because the catchment basin is small. Hurricane Mitch caused inundation damage due to overflow of the Neguro River but did not cause any on the Iztapa River. Downstream from Iztapa, floods occurred in the land along the river only during Hurricane Mitch.

The Guacalate River flows through a deep valley in a mountainous area downstream from San Andrés Itzapa. In San Luis Carretas along the river, the river is three to four meters wide and about two meters lower than the ground. Hurricane Mitch did not cause any flood damage but a downpour on October 20, 1999 raised the water level to cause a flood in the town.

At the bridge at the entrance of the town of Postores, located at the curve of the river, the slip-off slope is buried with sediments. If a downpour occurs in the upper reaches, it is likely that not only the current of the river slows down at such a location but also the bridge dams up the river to cause an inundation. Downstream from this location, gabions were thrown up to prevent erosion on the undercut slope.

Photo2.3.7.61 Bridge in Postores

b) La Antigua basin

The basin where La Antigua is located is in a very flat landform. The Guacalate River is about four meters wide while the area five to ten meters along the river is sunken land, prone to inundation. In La Antigua, not the Guacalate River but the tributary Pensativo River often flooded. The Pensativo River, which presumably used to flow on the north side of the basin, changed its river path to the south side to go around the mountain foot. Thus, a flood tends to occur at the curve.

Photo2.3.7.62 Achiguate River in the north of Escuintla

The Ciudad Vieja in the south of La Antigua is a narrow section sandwiched between a mountainous area in the north and the lava of the Agua Volcano in the south. However, the Guacalate River is three to four meters lower than the ground surface and not likely to flood the area. The river runs through a deep valley from the south of Alotenango. Although there is no risk of flooding, the collapsed sediments from the Fuego Volcano flow in and downstream from this location, so gravel is accumulated on the riverbed.

c) From Escuintla to Masagua

In Escuintla, the river is surrounded by the hilly terrain area, about three meters higher than the riverbed and not prone to flooding. In Finca Los Cerritos, a lowland area in the south of Escuintla, Hurricane Mitch did not cause any flood but the 1969 Hurricane

Franceria caused a flood, according to the inhabitants.

Around Masagua, the terrace is changed to a lowland area (floodplain). The land is no longer higher than the river and prone to inundation. The surrounding land is used as pastures or sugar cane fields.

In Masagua, Hurricane Mitch submerged the area around the river. The bridge across the Guacalate River has eroded piers and is in danger. The riverbed deposits around this area consist mainly of gravel from about a few centimeters to 20 centimeters in size.

Photo2.3.7-63 Masagua bridge in danger because the foundation of bridge piers is eroded

d) From Masagua to El Pilar

Guacalate River joins the Achiguate River in the south of Masagua. Downstream from this location, the riverbed becomes more than 300 meters wide, many streams diverge from the river, and the land is prone to flooding. In the south of Masagua, the Achiguate River meanders and erodes the land on the undercut slope. There is a height difference of two to three meters between the surrounding land and the water surface. If it rains heavily such as during Hurricane Mitch, the land may be submerged. In Cuyuta, a flood current that flowed into streams washed away the road and deposited sand around it. If the Achiguate River rises, a flood current may flow into these streams, submerge relatively low land around them, and further expand the flood.

The riverbed deposits in the middle reaches consist mainly of sand and no gravel. In El Pilar on the opposite bank, the diverging streams expanded the flood during Hurricane Mitch, which submerged the town for three days.

Photo2.3.7-64 Achiguate River near Cuyuta

Photo2.3.7-65 Flood-caused deposits near Cuyuta

e) Pacific coast

In the lower reaches, there are streams that diverge from the Achiguate River, streams that are headed from a spring, and dry rivers. The area is an extremely low land, all of which is highly prone to flooding. In the east of the estuary, Hurricane Mitch raised the water level to 1.2 meters and submerged the area for seven days. The dunes on the coast were submerged to the depth of 0.4 meters. In Puerto San José, inundation occurred mainly due to a flood from the Achiguate River.

Near the estuary, there is little difference in height between the river and the surrounding land and the river is very shallow. The riverbed inclination is very gentle and the speed of the current is low. Thus, a considerable range of land is submerged if the water level rises. La Barrita near the estuary was submerged by Hurricane Mitch for four days.

The west side of the Achiguate River is a lowland area like the opposite bank. Hurricane Mitch brought about a flood current through the diverging streams that flooded the area. However, Los Ángeles, five kilometers away from the Achiguate River, was not flooded. What caused this difference could not be identified in the field study because this border has no distinct geomorphological difference around it.

Photo2.3.7-66 Water level of flood in a village in the lower reaches

Photo2.3.7-67 Achiguate River near the estuary

16) María Linda River

The basin of the María Linda River is a large area including the southern half of the city of Guatemala. The field study was conducted on an area from the Villalobos River, a tributary of the María Linda River, Amatitlán Lake, and Michatoya River to the coast.

a) Villalobos River

The Villalobos River flows through the city of Guatemala flows down the valley plain. The river path runs two to three meters lower than the ground surface. No inundation damage occurred during Hurricane Mitch but lateral erosion was found. The tributary

Sucio River, a stream that flows down a steep slope, easily floods because the riverbed is shallow. A flood occurred in Santa Inés Petapa.

The Villalobos River flows into the Amatitlán Lake to form a vast delta. This delta was formed in about 100 years, being supplied with ancient pyroclastic flow deposits from the upper reaches whenever it rains. Since the river path of the Villalobos River that flows through this delta erodes three to four meters into the ground surface, there is no danger of inundation when the river rises. Hurricane Mitch flooded only the lowermost reaches.

Photo2.3.7-68 Lateral erosion found in the Pinula River

Photo2.3.7-69 Delta of Villalobos River

b) Vicinity of Amatitlan Lake

In Amatitlán, the Micyatoya River flows down from the Amatitlán Lake (Lago de Amatitlán). The Amatitlán Lake has a function that temporarily reserves a flood current and regulates a flood. Thus, the inundation of the Micyatoya River is not likely to submerge the town of Amatitlán. Hurricane Mitch raised the water level of the river by 2.5 meters but did not cause inundation. However, the Mico River, a tributary that flows from the mountainous area in the west may flood when it rains heavily because it forms an alluvial fan and has a curved river path. Hurricane Mitch and other downpours caused the river to overflow many times. The Micyatoya River flows down a large valley plain in the south of Amatitlán. Here, factories and houses are built in a lowland area that used to be a marsh. Hurricane Mitch caused inundation to the depth of about 20 centimeters.

c) Micyatoya River and Brito

In the middle reaches where the Micyatoya River and the María Linda River flows down from a mountainous area to a plain, the river flows down while eroding the ground surface, thus forming a terrace a few meters high. In Brito in the middle reaches, the Micyatoya River meanders violently. Although the riverbed is dug down four to five meters lower than the ground surface, Hurricane Mitch raised the water level by five meters or more than the current one to submerge the entire town of Brito. In particular, the bridge piers were eroded on the undercut slope and the road surface was washed away. Currently, they are reinforced with gabions. For houses located lower than others, the water level reached almost the ceiling and one house was washed away. At a curve of a river, water tends to flow slower, the water level rises, and a flood easily occurs. Lateral eroding on an undercut slope may collapse precipices.

Closer to the front is an undercut slope. The discolored part of asphalt is where the road surface is washed away. At the foot of a person on the right is the reinforced section.

Photo2.3.7-70 Water level of flood in Brito

Photo2.3.7-71 Road surface washed away in Brito

d) Las Flores

In Las Flores, the María Linda River has a riverbed about four meters lower than the surrounding ground surface and precipices on both the banks. The river is about 20 meters wide and 0.5 meters deep and flows very slowly. Here is a water level observatory of INSIVUMEH, which observes the water level twice a day. The observatory uses radio to communicate with INSIVUMEH. Hurricane Mitch raised the water level by five meters and submerged the vicinity to a depth of about one meter. In this area, a flood was caused by the 1969 Hurricane Flanceria before Hurricane Mitch but there was no flood inbetween. Since some sections are mounds in CA2 that passes this location, the effect of controlling the expansion of a flood must be considered. The land in this area is used as sugar cane fields and pastures.

Photo2.3.7-72 María Linda River in Las Flores

e) From the junction of Michatoya River to swamp region

The area from the middle reaches to the coast is mostly farmland where sugar canes are cultivated and cattle graze.

In this area, the land is low marshes and lagoons are scattered, and streams and canals flow in a network. We also found an embankment constructed along the river according to the disaster experiences in the past and used as a road. Hurricane Mitch submerged all the surrounding land to the depth of about one meter, according to the inhabitants.

Photo2.3.7-73 Junction between the María Linda River and the Micyatoya River

At the junction of the María Linda River and the Micyatoya River, a flood caused by Hurricane Mitch eroded the undercut slope of the river for about 20 meters. At this location, too, embankment was built after the flood caused by Hurricane Mitch.

In Hacienda Guyscoyol about one kilometer away from the María Linda River, the flood caused by Hurricane Mitch was 0.8 meters deep and later dropped to about 0.2 meters but submerged the town for eight days. In the lower reaches, a flood tends to maintain the water level and submerge the land for a long time.

f) Pacific coast

In the coastal area, there is a dune zone about 100 meters wide along the coast. In the area inland from the dunes, rivers that diverge from the María Linda River and Achiguate River flow as netlike streams and are blocked by the dune zone to form marshes and lagoons. Thus, the land is easily submerged when a flood occurs. The María Linda River flows into the Pacific in the east of Iztapa. The lowland areas along the river have no difference in height from the water surface and are highly prone to inundation.

The town of Iztapa is located among sand dunes. Sand dunes constitute a land a few meters higher than a lowland area and are generally not prone to flooding. However, Hurricane Mitch raised the water level of lagoons in sand dunes from the María Linda River to Monte Rico and caused the water to overflow the sand dunes to reach the coastline.

Photo2.3.7-74 María Linda River near Iztapa

The area where there is a road from Iztapa to Puerto San José is located in a sand dune zone of 200 to 300 meters wide and not prone to flooding.

g) Puerto San José

Puerto San José is twelve kilometers away from the María Linda River and tends to be influenced by a flood from the Achiguate River. Most of the town is in a lowland area, where inundation damage occurred many times in the past. Especially, Hurricane Mitch flooded the area to the depth of three to four meters for a few days. In the east part of the town, there is a sand dune zone 600 meters long, 150 meters wide, a few meters higher than the lowland area and not prone to flooding.

Photo2.3.7-75 Puerto San José Hurricane Mitch caused a flood up to the blue line.

Photo2.3.7-76 Canals and streets of Puerto San José

(3) Soil Tests for landslide study

Soils were sampled in the area of Guatemala City and Chinautla in August 2001 .

The samples were taken by a laboratory team of the General Directorate of Roads and the Grain Size and Atterberg Limit tests were performed in this Laboratory. The remaining tests (Triaxial, Permeability, etc.) were performed in the Laboratory of the Engineering Research Center (Centro de Investigaciones de Ingeniería, CII) of the Engineering Faculty of the San Carlos University of Guatemala.

Although a due care was taken to obtain undisturbed samples in the field, the triaxial tests could finally be made as remolded ones because the elaboration of undisturbed specimens for test was troubled by the great contents of gravel size grains (between 4 to 13% based on USCS and 8 to 21% on AASHTO) larger than the allowed sizes for such tests (2mm). It was therefore impossible to shape it appropriately.

Similar trouble for obtaining undisturbed samples of such materials has already been reported in several sources, and also attempts to relate the remolded condition with the undisturbed ones have been already made, in order to overcome this difficulty.

Nevertheless, the laboratory specimens for this study were elaborated trying to obtain the natural density of the soils. Thus, the results will serve as gross references of the field condition.

1) Test results on pumice soils (Guatemala City Area)

The soils sampled were those of the pumice deposits in the area of Guatemala and surroundings. Though a hazard mapping study usually would not undertake a detailed geotechnical research, this type of soils was selected because nearly 90% of all landslides occurred with this type of soils (Pleistocene pumice deposits) according to studies concerning the earthquake of February 1976 (Harp et al, 1981[3],[4]). This leaves the remaining portion to Tertiary volcanic rocks (nearly 10%) and 1% in Cretaceous limestone and Paleozoic metamorphic rocks. It was thus necessary to know the mechanical characteristics of the soils, which are more susceptible to landslides, in case of earthquakes.

It also happens that the same kind of soils are those which form the steep ravines in the Capital city, and are responsible for slope failures during rainy season and long rain conditions produced by hurricanes or tropical storms.

The sampled pumice soils in the area of Guatemala City mostly correspond to silty sands (SM), having a shear strength with average values of Cohesion Cu=5.94 t/m2, and Friction Angle φ=34o (Table 2.3.7.6).

[3] E.L. Harp et al, 1978. Earthquake-induced Landslides from the February 4, 1976 Guatemala Earthquake and their Implications for Landslide Hazard Reduction. International Symposium on the February 4th., 1976 Guatemalan Earthquake and the Reconstruction Process.

[4] E.L. Harp et al, 1981. Landslides from the February 4th, 1976, Guatemala Earthquake, Geological Survey Professional Paper.

Table 2.3.7-6 Summary of soil test results, Guatemala City

(Tested in Roads Bureau Geotechnical Lab. and San Carlos Univ. Lab.)

Sample No.	1	2	3	4
Sampling Date	06/08/2001	06/08/2001	06/08/2001	07/08/2001
Depth (m)	0.30-0.60m	0.30-0.60m	0.30-0.60m	0.30-0.60m
Unified Classif. (USCS)	SM	SM	SM	SM
AASHTO Classif.	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)
Place	50m Right Side Pumping Station EMPAGUA, Hincapié	200m Gasol. Station, Arenera Villalobos, route to San Cristobal	150m down Villalobos bridge	Scarp Amatitlancito Landslide
Sieve (Inch/No.)	Passing (%)	Passing (%)	Passing (%)	Passing (%)
3/8"(9.5mm)	100	100	100	100
Gravel, (Unified) No.4(4.75mm)	87	95	96	94
Gravel, (AASHTO) No.10(2mm)	79	89	92	87
No.40(0.42mm)	54	64	66	58
No.100(0.15mm)	35	41	56	41
Sand, No. 200(0.075mm)	26	28	31	31
Portions (USCS)				
Gravel	13	5	4	6
Sand	61	67	65	63
Fines	26	28	31	31
Total:	100	100	100	100
Portions (AASHTO)				
Gravel	21	11	8	13
Sand	53	61	61	56
Fines	26	28	31	31
Total:	100	100	100	100
Liquid Limit (LL) (%)	NL	NL	NL	NL
Plasticity Index (IP) (%)	NP	NP	NP	NP
Specific Gravity (Gs)	2.245	2.428	2.490	-
Dry Unit Weight (gr/cm3)	1.285	1.385	1.475	-
Wet Unit Weight (gr/cm3)	1.38	1.623	1.648	-
Permeability Coef., k(cm/sec)	1.75E-05	4.79E-05	6.26E-05	-
Triaxial Test(UU)(Remolded):				
Cohesion, Cu (T/m2)	-	5.63	6.25	-
Friction Angle Phi (Degrees)	-	34.0	34.0	-
Description	silty pumice sand	pumice sand	pumice sand	pumice sand
Color	gray	gray	gray	gray

The relative high values of cohesion in this sandy-silty soil (without plasticity) are attributable to the interlocking and cementation between grains inside of these soil masses.

The Coefficient of Uniformity (UC=D60/D10) in average is 15, which means a well-graded soil, with a large range of particle sizes, which allows a good internal contact between grains.

The average permeability coefficient obtained in Laboratory was 4.27x10-5 cm/sec, which corresponds to a very low permeable soil condition. However, in view of the limitations of such tests in laboratory where remolding of samples may produce a larger compaction (less permeability) than that of the field, and considering the INSIVUMEH study in 1978 (Estudio de Aguas Subterráneas en el Valle de Guatemala), based on the transmisivity values found in the field for 28 wells (depth between 122 and 305 meters), we find the values of permeability in the range between 1.5x10-2 to 2.6x10-5 cm/sec, for an average of 1.4x10-3cm/sec. This value of permeability seems to be more acceptable for such soils in the study area.

Further checking was made by using the Hazen equation (k=C(D10)2), and the grain sizes curves of the materials sampled until now, with values of k found between 7.35x10-3 cm/sec to 1.69x10-4 cm/sec for air fall ash (INSIVUMEH study 1978) and 2.77x10-5 cm/sec to 4.0x10-6 cm/sec for flow ash (JICA-2001 and INSIVUMEH-1978). We would like to use these results only for the confirmation of statement made in the INSIVUMEH-78 study, that the air flow ashes are less permeable than the air fall ones.

With the above-mentioned results, we can conclude that the permeability of these types of soils requires more investigation. For reason of safety we will consider the previous average value of the wells as the average permeability in the ash deposits of Guatemala City area 1.4x10-3cm/sec (or 1.4x10-5m/sec).

Thus, these shear strength (and permeability) characteristics explain the capability of these pumice deposits to stand in nearly vertical cliffs of up to 100m in height or more. It is known the ravines (barrancos as known locally) are located in pyroclastic deposits of the quaternary, with thickness between 0 to 250 meters according to a zoning study elaborated by Universidad del Valle and OEA[5] published on 1988.

Moreover, it is known that in soil with gravel content, the amount of gravel presents a significant effect on shear strength, increasing the strength as the gravel content is increased up to 50 or 60%. Beyond this point the material becomes less well graded and the density does not increase[6]. Thus, with the gravel content of the field materials being larger than the laboratory specimens (with maximum size limited to 2mm), it can be said that the tests results may be conservative compared with the field conditions.

[5] Universidad del Valle/OEA, 1988 ?. Zonificación Preliminar de Perfiles de Suelo en el Valle de Guatemala.

[6] Fred G. Bell, 2000. Engineering Properties of Soils and Rocks. Fourth Edition. Blackwell Science, page. 25.

a) Susceptibility to failure by saturation during rains.

Effects of Voids Ratio and Porosity on the Saturation of this Type of Soils

The void ratio is a physical property of the soils, which shows the volume of voids related to the volume of solids, it is expressed as:

e = Vv/Vs

where:

e = void ratio

Vv = volume of voids

Vs = volume of solids

On the other hand, the porosity n, represents the volume of voids related to the total volume of soil, and is expressed as:

n=e/(1+e)

Thus, based on the values of Table 2.3.7-6 we can estimate the void ratio and porosity of soils as follows (Table 2.3.7-7):

Table 2.3.7-7 Estimation of void ratio and porosity of soils

Sample No.	1	2	3
Sampling Date	06/08/2001	06/08/2001	06/08/2001
Depth (m)	0.30-0.60m	0.30-0.60m	0.30-0.60m
Unified Classif. (USCS)	SM	SM	SM
AASHTO Classif.	A-2-4(0)	A-2-4(0)	A-2-4(0)
Place	50m Right Side Pumping Station EMPAGUA, Hincapié	200m Gasol. Station, Arenera Villalobos, route to San Cristobal	150m down Villalobos bridge
Water volume: Vw (cm3)	0.09	0.24	0.17
Solids Volume: Vs (cm3)	0.57	0.57	0.59
Voids Volume: Vv (cm3)	0.43	0.43	0.41
Void Ratio: e=Vv/Vs	0.75	0.75	0.69
Porosity Index: n=e/(1+e)=Vv/Vt	0.43	0.43	0.41
Air Volume: Va=Vv-Vw (cm3)	0.33	0.19	0.24
Air Percentage Va=Va/Vtx100 (%)	33	19	24
Saturation Degree (%)	22.22	55.30	42.32
Saturated Unit Weight (gr/cm3)	1.71	1.81	1.88

We can conclude from these results that the average value of void ratio “e” is 0.73, which represents a large volume of voids compared with that of the solids. On the other hand, the average porosity “n” is 0.42, which represents a large volume of voids compared with the total volume of soil.

Not necessarily a high porosity implies that saturation condition could be attained. A good example in rocks is the case of vesicle basalt. It depends on the interconnection capability of the porous inside the soil mass. It is estimated that for pumice soils there must be some lack of interconnection of porous in shallow and uncracked zones; however it may increase with the depth (larger gradient or water pressure) and cracking condition of the soil mass.

In the case of clays[7] a combination of low permeability and high suction produce saturation above the water table[8]. As it is known, the thickness of the capillary fringe depends on soil type; while for coarse sands it is only of some few centimeters, for clays it can be of several meters. The thickness of the capillary fringe is inversely proportional to the radius of the inter-grain conducting channel[9],[10].

A wet shallow front line is formed during long periods of rain. It advances downwards and will meet the underground wet front line corresponding to the water table and capillary fringe, producing in this way the total saturation of the whole mass.

In our case, the air content for these soils varies between 19% and 33% with an average of 25% (it is worthy to mention that the saturation may not be complete even under laboratory conditions, as some 2% of air may remain trapped inside the soil sample). This implies that samples were not saturated under the natural condition, and confirms the degree of saturation attained between 22% and 55%.

The air contents of 25% means that in a unit layer of 1 m thick, there is an air space of 25 cm which can be filled with water, if interconnection between pores can be attained. An accumulation of 250 mm of rainfall would be required in that case.

According to the previous average value of permeability, we found (k=1.4x10-3cm/sec), the time needed to cross this space will be about 5 hours, which means that a complete saturation of this unit layer would occur through this period of exposure to rain. As seen before, the period for flow ashes would be longer than for air fall ashes, due to their different permeability characteristics.

Moreover, the real field conditions may cause a variation of these results according to the number of discontinuities, and the real grain size distribution along the whole soil profile for each position, with a large permeability if discontinuities are numerous or the grain size distribution is uniform with coarse particles.

7 Only for considering the extreme case of difficult saturation compared with the granular soils which are much more pervious.

8 Whitlow, Roy. 1994. Fundamentos de Mecánica de Suelos, 2a. Edición. CECSA, México. Page 95

9 E. Simmons Robinson, 1990. Geología Física Básica. Editorial Limusa, México. Page 416.

10 K.Terzaghi/R.B.Peck, 1967. Soil Mechanics in Engineering Practice. John Wiley & Sons. New York. Page. 136.

b) Critical height of vertical slopes

The critical height of vertical slopes for cohesive-frictional soils can be estimated as follows:

$Hc = 4C\sqrt{N_\varphi}/\gamma$

Where:

C = Cohesion (Ton/m^2)

N_φ = Tan2(45^o+φ/2) = (1+Sinφ)/ (1-Sinφ)

φ = Friction angle

γ = Unit weight (Ton/m^3)

Based on the results of soil tests performed in this study (2001), and several other studies (CONRED-INSIVUMEH (2002), tests and calculations made by Koose (1978), a graduation thesis (Semrau, 1968) performed in soils of similar type but out of the scope of the study area (Salamá and Quezaltepeque)), the critical height (Hc) which these soils can attain without support is calculated as shown in Table 2.3.7-8.

As shown, the critical height of the vertical slopes increases with the test changing from the conservative type (direct shear test) to the Triaxial Consolidated Drained Test, with minimum values of 13 m (Direct Shear Tests) to maximum values of 122 m (Triaxial CD tests), respectively. On the other hand, the remolded condition produces values from 26 m to 69 m depending on density conditions.

Table 2.3.7-8 Estimated critical height (Hc) of vertical slopes in pumice soils without support (static condition)

Place	Condition	Unit Weight (Ton/m^3)	Cohesion (Ton/m^2)	Friction Angle (Degrees)	$Hc=4C\sqrt{N_\varphi}/\gamma$ (m)
A) JICA-Study(2001), Triaxial UU Tests					
Villalobos(Quarry)	Remolded	1.62	5.63	34.0	26
Villalobos(Bridge)	Remolded	1.65	6.25	34.0	29
B) CONRED Study(2002), Triaxial UU Tests					
Guacamayas	Natural	1.47	14.5	29.7	68
Sta. Fe(aver. of 5)	Natural	1.60	10.8	25.5	43
Sta. Fe	Disturbed	1.41	9.8	31.0	49
C) Koose (1978) *, Direct Shear Tests					
Guatemala City	Natural	1.28	2.0	40.0	13
Ave. Indep.9C.Z.2	Back-calculation**	1.28	11.0	40.0	74
D) Dr. Semrau´s Thesis(1968), Triaxial CD Tests					
c.1) Salamá					
Km 142+500	Natural	1.08	18.0	32.6	122
Km 142+500	Natural	1.10	15.0	35.4	106
Km 142+500	Natural	1.06	16.0	36.9	121
Km 142+500	Remolded	1.08	4.0	33.7	28

Place	Condition	Unit Weight (Ton/m^3)	Cohesion (Ton/m^2)	Friction Angle (Degrees)	Hc=4C$\sqrt{N_\varphi}/\gamma$ (m)
Km 142+500	Remolded	1.08	5.0	32.5	34
Km 142+500	Remolded	1.12	10.0	35.4	69
c.2)Quezaltepeque					
Km 32+500	Natural	1.43	19.0	36.5	105
Km 32+500	Natural	1.47	18.0	40.3	106
Km 32+500	Natural	1.47	12.0	40.3	71
Km 32+500	Remolded	1.45	11.0	41.0	67
Km 32+500	Remolded	1.45	10.0	40.6	60

* Direct rapid shear tests in soils similar to those of the ravines of Guatemala City. Tests performed in its own Laboratory.

** Back-calculation using conditions of representative landslide (1976-2-4) of Ave. Independencia y 9a.Calle Z.2 of Guatemala City: H=80 m, Aver. Crack Depth=38 m, Slope Angle=75 Degrees, and assumed Acel=0.1 g.

Source: F. Koose S., 1978. Estudio de Deslizamientos de Taludes de Barrancos en la Ciudad de Guatemala. Memoria del Simposio Internacional sobre el Terremoto de Guatemala, del 4 de Febrero de 1976 y el Proceso de Reconstrucción

c) Susceptibility to erosion (soil erodibility factor)

The erodibility of the soil constitutes the susceptibility to erosion, which represents the reciprocal of its resistance to erosion.

K can be estimated by using the following equation[11]:

$$K = 2.1 \times 10^{-6} \times M^{1.14} \times (12 - a) + 3.25 \times 10^{-2} \times (b - 2) + 2.5 \times 10^{-2} \times (c-3)$$

where:

M = (100 - clay ratio (%)) [% (silt + fine sand)] is a particle size parameter
a = organic matter ratio (%)
b = soil structure code
c = profile-permeability class

Estimation of the Particle Size Parameter, M

The factor M is estimated by the grain size analysis of soils in the study area.

Estimation of Organic Materials, a

Organic materials must be analyzed for the topsoils to be sampled. a=0 is assumed for critical soil condition (without vegetation cover).

[11] W.H. Wischmeier & D.D. Smith, 1978, page 10

Estimation of Soil Structure Code, b

The soil structure code, b, is classified as follows:

1. very fine grained
2. fine grained
3. medium or coarse grained
4. blocky, platy, or massive

Estimation of Profile Permeability Class, c

The Profile Permeability Class is divided as follows (Whischmeier, 1978):

1. rapid
2. moderate to rapid
3. moderate
4. slow to moderate
5. slow
6. very slow

The Coefficients of Permeability are classified as follows:

Table 2.3.7-9 Soil classification according to coefficients of permeability

Degree of Permeability	Coefficient of Permeability (cm/sec)	Typical Soil
High	more than 1×10^{-1}	coarse gravel
Medium	1×10^{-1} ---- 1×10^{-3}	sand, fine sand
Low	1×10^{-3} ---- 1×10^{-5}	silty sand, dirty sand
Very low	1×10^{-5} ---- 1×10^{-7}	silt, fine sandstone
Almost impermeable	less than 1×10^{-7}	clay

Sources: 1) Karl Terzaghi & Ralph B. Peck, 1967. Soil Mechanics in Engineering Practice, 2nd John Wiley &Sons, page 381. 2) George B.Sowers et al, 1972. Introducción a la Mecánica de Suelos y Cimentaciones, Limusa-Wiley S.A. México, page 130

The results of K for 4 samples of pumice soils taken along the study area are shown in Table 2.3.7-10. As shown, K values vary from 0.48, relatively resistant to erosion due to content of gravel, to 0.71, highly susceptible to erosion for fine sandy-silty soils.

Table 2.3.7-10 Values of erodibility factor K for tested pumice soils in Guatemala City

Sample No.	1	2	3	4
Sampling Date	06/08/2001	06/08/2001	06/08/2001	07/08/2001
Prof (m)	0.30-0.60 m	0.30-0.60 m	0.30-0.60 m	0.30-0.60 m
Unified Classif.	SM	SM	SM	SM
AASHTO Classif.	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-2-4(0)
Place	50 m Right Side Pumping Station EMPAGUA, Hincapié	200 m Gasol. Station, Arenera Villalobos, route to San Cristobal	150 m down Villalobos bridge	Chinautla. Amatitlancito Landslide

Sample No.	1	2	3	4
Gravel (%)	13	5	4	6
Sand (%)	61	67	65	63
Fine sand+silt (%)	40	48	59	46
Clay (%)	0	0	0	0
K (cm/sec) (test)	1.75E-05	4.79E-05	6.26E-05	4.27E-05 *
1.Particle Size Parameter (M) M=(100-%clay)(%silt + fine sand)	4,000	4,800	5,900	4,600
2.Organic matter, a (assumed)	0	0	0	0
3.Soil structure code, b	2	2	2	2
4.Profile Permeability Class, c	5	5	5	5
5.Soil Erodibility Factor K	0.37	0.45	0.55	0.43
6.Factor K in metric unitsX1.292	0.48	0.58	0.71	0.55

* Estimated value

2) Test results on clayey soils (Chinautla Area, northern part of Guatemala City)

Besides the previous tests in pumice soil, two samples of clayey soil were taken in the urban area of Chinautla, with one at about 100 m from the Amatitlancito landslide, in a private property where it could be sampled superficially. This clay material is assumed to underlie the landslide mass.

The clayey soils are classified as CL and CH, having both high plasticity (PI=22 and LL=47-51) and with a portion of fines between 94% and 99%.

Both clay samples present a low shear strength with average values of Cohesion Cu=4.97 t/m^2, and Friction Angle φ=17o (Table 2.3.7-11).

Table 2.3.7-11 Summary of soil test results, Chinautla Area

(Tested in Roads Bureau Geotechnical Lab. and San Carlos Univ. Lab.)

Sample No.	5	6
Sampling Date	07/08/2001	07/08/2001
Depth (m)	0.30-0.60 m	0.30-0.60 m
Unified Classif. (USCS)	CH	CL
AASHTO Classif.	A-7-5(25)	A-7-6(25)
Place	Property of Refrain Martinez	100m from Chinautla bridge, 50 m length of road settlement
Sieve (Inch/No.)	Passing (%)	Passing (%)
Gravel (AASHTO) No.10	100	
No.40	99	100
No.100	96	99
Sand No. 200	94	99
Portions (USCS)		
Sand	6	1
Fines	94	99

Sample No.	5	6
Total:	100	100
Portions (AASHTO)		
Sand	6	1
Fines	94	99
Total:	100	100
Liquid Limit (LL) (%)	51	47
Plasticity Index (IP) (%)	22	22
Specific Gravity (Gs)	2.64	2.64
Dry Unit Weight (gr/cm3)	1.36	1.57
Wet Unit Weight (gr/cm3)	1.72	1.93
Permeability Coef., k(cm/sec)	<1.0E-07	<1.0E-07
Triaxial Test (UU), remolded:		
Cohesion, Cu (T/m2)	2.4	7.53
Friction Angle Phi (Degrees)	18.4	17.20
Description	silty clay	silty clay
Color	brown	light brown

Though the cohesion parameter is rather similar to the pumice soils, the friction angle is small, half the other pumice soils. Since the cohesion is lost ($C \rightarrow 0$) soon after the soil mass gets the peak strength along the failure plane, the remaining shear strength is only provided by the residual friction angle (φ_r). Due to this fact, the stabilization of the landslides in clayey steep slopes is rather difficult, and land will continue to slide whenever the stress condition along the sliding surface overcome the residual friction, which happens in case of heavy rains and earthquakes.

The permeability coefficient for these clays is less than 1.0×10^{-7} cm/sec, which corresponds to a very impermeable soil condition. Water is thus retained in the upper layers of this masses, which become saturated due to water flow along the discontinuities and the relatively more permeable condition of the surface sandy soils.

3) Coordinates of soils sampled in this study or others

Table 2.3.7-12 shows the coordinates of the soils sampled in this study. Also it shows the coordinates of samples taken in other studies when available.

Table 2.3.7-12 Coordinates of soils sampled by JICA and other studies

Place	Sample No.	North	West	Observations
Hincapié, Río Pinula. Empagua Station Zona 2.	JICA-01/1	14°34´	90°31´	JICA-2001
Villalobos, Cantera	JICA-01/2	14°33´	90°34.5´	JICA-2001
Río San Lucas	JICA-01/3	14°33.2´	90°34.6´	JICA-2001
Amatitlancito. Chinautla	JICA-01/4	14°34.2´	90°30´	JICA-2001
Property of Efraín Martínez. Chinautla	JICA-01/5	14°42.5´	90°30´	JICA-2001
Chinautla Bridge 100 m upstream (right)	JICA-01/6	14°42.3´	90°30´	JICA-2001
El Frutal, Villa Nueva	JICA-02/1	14°30´58´´	90°33´44´´	JICA-2002.Ash flow.
Road to San Miguel Petapa and Villa Hermosa (500 m from sample 02/1	JICA-02/2	14°30´47´´	90°34´00´´	JICA-2002.Pink material.
Km.23+200 road to San Lucas	JICA-02/3	14°36´22´´	90°37´36´´	JICA-2002.Ash fall.
Guacamayas, Zona 7	CR-1	14°39.5´	90°34.0´	CONRED-2002
Lomas de Portugal, Mixco	CR-2,3	14°38.0´	90°36.0´	CONRED-2002
San Julián, Sector 8. Chinautla	CR-4-6	14°41.0´	90°29.5´	CONRED-2002
San Julián, Sector 10. Chinautla	CR-7	14°41.0´	90°29.5´	CONRED-2002
Santa Faz, Jocotales, Zona 6. Chinautla	CR-8-9	14°41.5´	90°29.5´	CONRED-2002
Las Torres, El Incienso	CR-10-13	14°38.5´	90°32.0´	CONRED-2002
Prados de Linda Vista. Villa Nueva	CR-14-15	14°30.0´	90°35.5´	CONRED-2002
Los Cerritos, El Incienso	CR-16-20	14°39.0´	90°31.5´	CONRED-2002
Colector Municipal 9-10	Mach/1-3	?	?	Machón-1972
Colector Municipal 10-13-14	Mach/4-5	?	?	Machón-1972
Colector Municipal 10-13-14	Mach/6-10,12	?	?	Machón-1972
8Ave.16C.Zona1	Mach/11	?	?	Machón-1972
Edificio Ministerio de Finanzas	Mach/13-17	?	?	Machón-1972
Ciudad Universitaria	Mach/18	?	?	Machón-1972
La Mirada, Ciudad Guatemala	Cal-6	?	?	Calderón-1999
Ciudad Guatemala, Zona 9	Cal-8	?	?	Calderón-1999
Ciudad Guatemala, Zona 9	Cal-9	?	?	Calderón-1999
Ciudad Guatemala, Jocotales, Zona 6	Cal-10	14°41.0´	90°29´.5	Calderón-1999
Ciudad Guatemala, Jocotales, Zona 6	Cal-11	14°41.0´	90°29´.5	Calderón-1999
Ciudad Guatemala, Zona 10	Cal-12	?	?	Calderón-1999
Guatemala, San José Villa Nueva	Cal-15	?	?	Calderón-1999
Guatemala City		?	?	INSIVUMEH-78