Appendix for Chapter 4

APPENDIX 4.2.1 ON SELECTION OF SCENARIO EARTHQUAKE

1. SCENARIO EARTHQUAKE IN SEISMIC MICRO ZONING STUDY

In general, seismic micro zoning study is made to quantitatively estimate the damage and deficiencies after major earthquake, for the purpose of establishing effective disaster mitigation measures.

The seismic micro zoning study first defines fault model for scenario earthquakes. The parameters of scenario earthquake are defined from historical earthquake records, fault studies. The most probable and the most influential earthquakes are selected for scenario earthquake.

2. EXISTING SEISMIC CODE AND SEISMIC MICRO ZONING STUDY IN COLOMBIA

a) National seismic macro zoning and seismic code

In Colombia, seismic macro zoning study has been completed in 1996 to establish seismic hazard evaluation at national level using database of active faults, historical records, and instrumental records of earthquake. The study mentions 0.2g is expected base acceleration for 475 years return period at Bogotá and eight municipalities.

b) Base acceleration used in MZSB97

Existing seismic micro zoning study for Bogotá completed in 1997 deals three scenario earthquakes. Among them, the parameters for near scenario earthquake is defined as magnitude 6.4, the distance from Bogotá to the fault as 20km, and base acceleration as 0.2g.

c) Limitations of existing study

The existing study deals only in Bogotá, and base acceleration is assumed to be 0.2g in whole Bogotá.

3. ESTIMATION OF BASE ACCELERATION IN THIS STUDY

a) Detailed Procedure of calculation

This study needs to deal Bogotá and eight municipalities. To calculate more realistic ground motion for an area larger than existing study, it is necessary to incorporate the decay of acceleration at base along with the distance from fault. For this reason, specific fault location is assumed, and then attenuation of base acceleration is incorporated.

Among faults listed in MZSB97 as shown in Table 1, fault with higher activity rate and higher magnitude is selected for scenario earthquake.

This study maintains several parameters as assumed in the existing study in more specific manner. They are: magnitude as 6.4, the closest distance from center of Bogotá to the ruptured segment of fault as 20km, base acceleration at the center of Bogotá as 0.2g.

b) Detailed procedure of scenario earthquake selection for case-1 and case-2

The existing study lists two active faults within the radius of 50km from Bogotá, No. 6 and No. 7. Two faults have almost same parameters as a whole, maximum probable magnitude, length, and activity rate. The difference between two faults are distance. The fault No. 6 contains a segment with high and moderate, while the fault No. 7 contains segment with activity rate of moderate and low. Therefore, fault No. 6 was selected as a scenario earthquake. The length of rupture segment is defined as 10 km, which is taken from total length of active segment, and the assumed rupture length is reasonable for a class of earthquake with assumed magnitude.

The scenario earthquake for case-2 is selected from list of faults as shown in Table 2 by same principle as in case-1. There are other faults that have larger magnitude than No.27. However, they are not used because they are much distant than No. 27 fault to study area, so that base acceleration is less than that by fault No. 27 due to the attenuation.

4. LIMITATIONS AND RECOMMENDATIONS

The parameters used in this study are based on the assumption in existing study, which is based on the site recognition. Trench study or geophysical study to evaluate fault activity rate is recommended to improve the accuracy in probability estimation for scenario earthquake.

Table 1 Detailed List of Faults for Case-1 Scenario Earthquake

No.	Name of Fault	Longitude (km)	Longitude with Neotechtonic Features (km)				Activity Rate	Data Quality	Fault Type	Maximum Probable	Distance from Bogota
			High (km)	Medium	Low (km)	Total (km)					
1(-)	Bogota	50			10	10	L	C(?)	I	6.4	3
2(+)	Ubaque	15			4	4	L	C	I	6.0	20
3(+)	Sabaneta	15		1	2	3	L-VL	C	I	5.7	40
4(+)	Corraleja	10			3	3	VL	C	I	5.8	45
5(+)	Fusagasuga	10			5	5	VL	C	I	6.0	40
6(*)	La Cajita	35	5		5	10	M	B	ID	6.4	30
7(+)	Rio Tunjuelito	35		5	5	10	M	B	I	6.4	25
8(+)	Facatativa S-W	10		2	2	4	L	C	SI	5.8	40
9(+)	El Meson	20		2	3	5	L	C	SI	6.1	25
10(+)	Soacha	10		3		3	L	B	IS	5.8	15
11(+)	Usaquen	30(?)			5	5	L	C	S	6.0	15

Note: (-): Active Fault; (+): Potentially Active Fault; (*):Fault of Uncertain Activity
H: High; M: Medium; L: Low; VL: Very Low
A: Good; B: Acceptable; C:Insufficient
I: Inverse; N: Normal; D: Dextal; S: Sinistral

Source: Microzonificacion Sismica de Sabta Fe de Bogota, INGEOMINAS (1997)

Table 2 Detailed List of Faults for Case-2 Scenario Earthquake

Faul System	No.	Name of Fault	Longitude (km)	Longitude with Neotechtonic Features (km)				Activity Rate	Data Quality	Fault Type	Maximum Probable	Distance from Bogota
				High (km)	Medium	Low (km)	Total (km)					
Romeral	1(*)	Armenia	60	3	10	9	22	H-M	B	ID	6.8	180
	2(-)	Manizales	40							I?	6.5	165
	3(*)	Montenegro	45	10	10		20	H-M	C	ID	6.7	190
Palestina	4(*)	Palestina	60					M-L		IS?	7.0	180
Chapeton - Pericos	5(+)	Chapeton	25			5	5	M-L	B	ID	6.0	125
Cucuana Rio Bogota	6(+)	Cucuana	55		8	14	22	M	B	D	6.7	170
	7(+)	Cucuana Este	55			5	5	M-L	B	D	6.5	115
Ibague	8(*)	Cocora	60	8	25		33	M	B	D	6.9	160
	9(*)	Ibague	45	35	5		40	H	A	D	7.0	110
	10(+)	Piedras	20		6	8	14	M	B	DI	6.4	85
Viani	11(-)	Viani	40		2	8	10	L	C	D	6.5	75
Samaria - La Colorada	12(+)	El Choho	30		5	1	6	L	C	ID	6.2	190
	13(*)	Doima	35	5	9	2	16	H	B	ID	6.7	115
Magdalena	14(+)	Mulatos	60			20	20	M-L	B	I	6.7	110
	15(+)	Honda Sur	45		9	7	16	M-L	B	I	6.7	90
	16(+)	Honda Narte	70			5	5	L-VL	B	IS?	6.1	125
	17(+)	Cambras	70			5	5	L	C	IS?	6.2	130
	18(+)	Cambao Norte	60			3	3	VL	B	I	6.0	90
	19(*)	Cambao Sur	20	3			3	M	B	ID	6.2	75
	20(+)	Alto del trigo	90			6	6	VL	C	ID	6.2	80
	21(+)	Bituima Norte	60		10	2	12	L	B	IS?	6.3	80
	22(+)	Bituima Sur	30			7	7	L	C	I	6.2	70
Noroeste	23(*)	El Palmar	20	1	8		9	M	B	S	6.2	100
Servita - Santa Maria	24	Colepato	40(*)		18		18	M	B	I	6.7	70
	25	Servita	60(*)		26		26	H-M	B	I	6.9	65
	26	Santa - Maria	90(+)			15	15	L	C	I	6.8	100
	27	Guayuriba	60(*)	11	18		29	H	B	ID	7.0	80
	28	Lengupa	65(+)		3	6	9	L	C	I	6.6	105
	29	Colonia	50(+)		10		10	L	B	I	6.5	80
	30	Acacias	30(*)	4	9		13	M	B	I	6.6	80
	31	Tesallia	75(+)		7	15	22	M	C	I	6.8	95
Guaicaramo	32	Cumaral	25(*)	7			7	H	B	I	6.3	80
	33	Guaicaramo Centro	80(*)	24	20		44	H	B	ID	7.2	135
	34	Guaicaramo Sur	65(*)	3	5		8	M	B	I	7.1	90
	35	Guaicaramo Norte	50(+)		8	3	11	M	C	I	6.8	200
	36	Guaicaramo W	35(+)		8		8	M	B	I	6.5	135
	37	Pajarito	60(*)	5	9		14	M	C	ID	6.7	200
Yopal	38	Yopal	65(*)	12	12		24	H	B	I	7.1	195
	39	San Pedro	80(*)		38		38	H	B	I	7.2	145
	40	Upamera	20(+)		10		10	M-L	B	IS(?)	6.4	160
Zona Axial	41	Boyaca	80(+)		3	2	5	L-VL	C	I	6.3	200
	42	San Francisco	15(+)			1	1	L-VL	C	I	5.3	150
	43	Soapaga	100(+)		4	3	7	L-VL	C	I	6.5	180

Note: (-): Active Fault; (+): Potentially Active Fault; (*):Fault of Uncertain Activity
H: High; M: Medium; L: Low; VL: Very Low
A: Good; B: Acceptable; C:Insufficient
I: Inverse; N: Normal; D: Dextal; S: Sinistral

Source: Microzonificacion Sismica de Sabta Fe de Bogota, INGEOMINAS (1997)

APPENDIX 4.2.2 PROCEDURES AND LIMITATION IN THE EVALUATION OF AMPLIFICATION BY SUBSOIL

1. DETAILED PROCEDURES IN THIS STUDY

1) The study team obtained transfer function in subsurface geology (curve that represents period of input ground motion versus amplification of ground motion) calculated at 57 points based on boring data within Bogotá for different level of input ground motion at base acceleration. The obtained curve contains predominant period of ground amplification up to ten seconds.
2) The numerical ground models such as thickness, shear wave velocity, density of each soil stratum used for calculation, were not fully available. The numerical model partly available contains approximation of upper subsurface, but lacks information on deeper stratum to sufficiently explain the mechanism of long predominant period.
3) The study team also obtained three different seismic waveform records as input motion. They have different frequency content, duration, and maximum amplitude, recorded similar condition as respective scenario earthquake.
4) Strong motion at ground surface is calculated using three input waveforms for scenario earthquakes by three different input levels (0.05g, 0.1g, 0.2g) at 57 points.
5) Amplification factor, defined by peak ground acceleration divided by input acceleration level, is calculated at 57 points for three input levels by three scenario cases. Amplification factors are averaged by geo technical zones.
6) Base acceleration for three scenario cases are calculated by attenuation formulae at the center of each micro zone. The closest distance to the fault segment is used for the distance in attenuation equation.
7) Peak ground acceleration is calculated by multiplying base acceleration by averaged amplification factor, defined by geo technical classification, scenario earthquake, and input base acceleration.
8) For micro zones outside Bogotá that lacks geotechnical information, same values of averaged amplification factor are applied as in Bogotá, depending on the geotechnical zone, scenario case, and base acceleration.

The advantage of this method lies in the fact that it can reflect the difference in frequency content of different scenario earthquakes, and spatial difference in base acceleration. Moreover, this method can be uniformly applied to Bogotá and surrounding municipalities.

In case-1, three geotechnical zones demonstrate amplification factor less than one, but such phenomena are observed in real records as the result of non-linear effect of soil during large earthquake.

Table 1 Averaged Amplification Factors by Geotechnical zone

		Scenario case and base acceleration level								
		Case 1			Case 2			Case 3		
Geotechnical zone	Name	0.05g	0.10g	0.20g	0.05g	0.10g	0.20g	0.05g	0.10g	0.20g
1	Sedimentary rocks	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2	Residual, piedmont	2.60	2.38	2.12	2.49	2.40	2.25	2.42	2.37	2.29
3	Lake deposit A	1.69	1.27	0.81	3.17	2.69	2.05	3.28	2.84	2.26
4	Lake deposit B	1.32	0.99	0.66	2.54	2.18	1.67	2.84	2.46	2.00
5	Terrace and cone	2.05	1.73	1.34	2.71	2.58	2.27	2.85	2.58	2.32
6	Riverbed and wetland	1.33	1.01	0.62	1.81	1.67	1.44	2.26	1.89	1.45

Source: JICA Study Team

2. SIMPLIFIED METHODS PROPOSED IN JAPAN

Simplified methods to estimate relative ground amplification factor is proposed in Japan as shown in Table 2, in case detailed information on dynamic properties of the ground is not available. These methods are based on ground data in Japan, and classification is made on different points of view. For example, Shima's classification is made from the viewpoint of geology, while Midorikawa's classification is made from the viewpoint of the age in geological unit, thus these method cannot be directly applicable in this study. Besides, these methods only shows relative amplification factor for any case, and does not take into account the difference in frequency content or intensity of strong ground motion.

Table 2 Simplified methods to estimate relative ground amplification factor

Geological unit	Relative amplification factor
Peat	1.6
Humus soil	1.4
Clay	1.3
Loam	1.0
sand	0.9

Shima (1978)

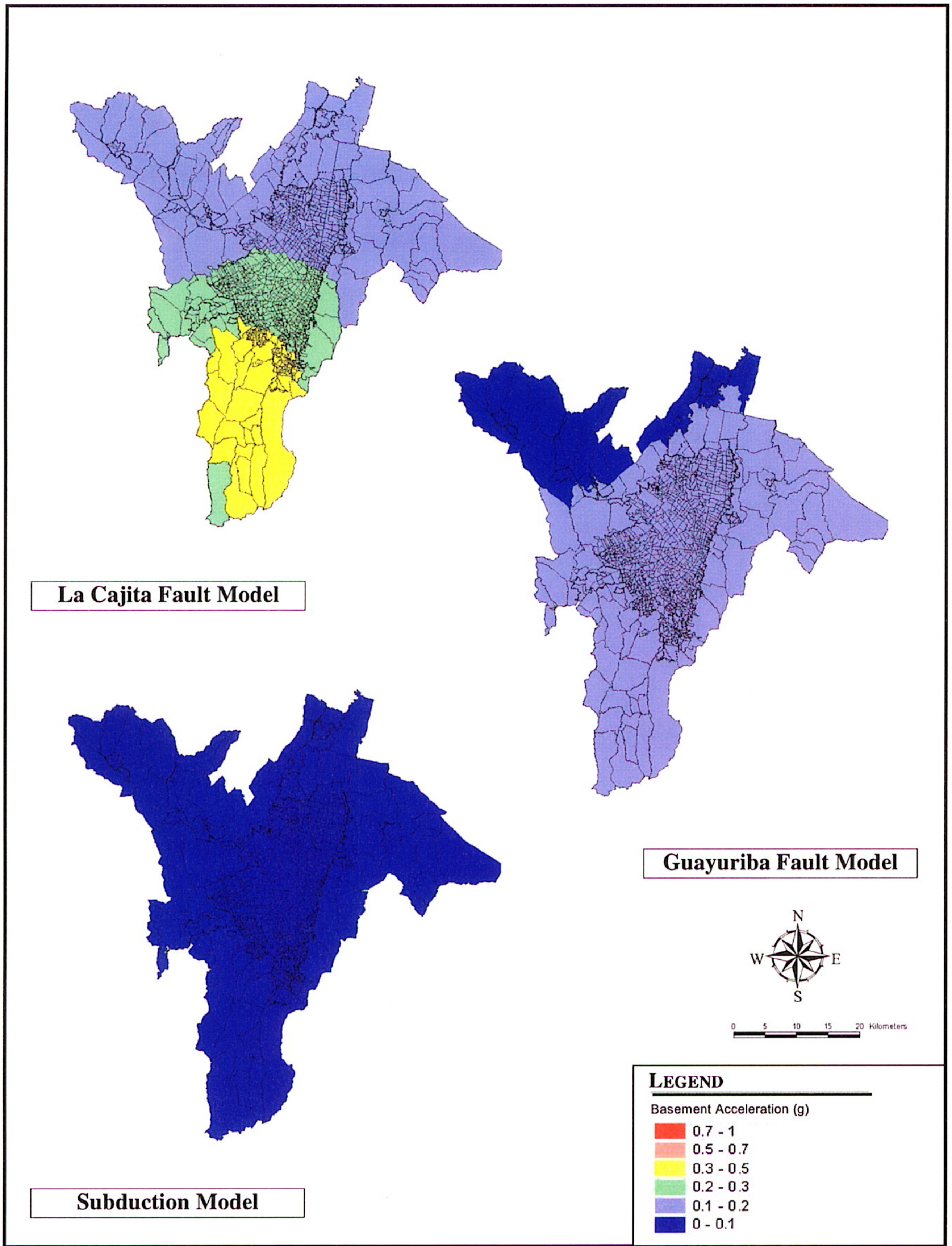
Geological unit	Relative amplification factor
Holocene	3.0
Pleistocene	2.1
Quarternary volcanic rocks	1.6
Miocene	1.5
Pre-Tertiary	1.0

Midorikawa (1987)

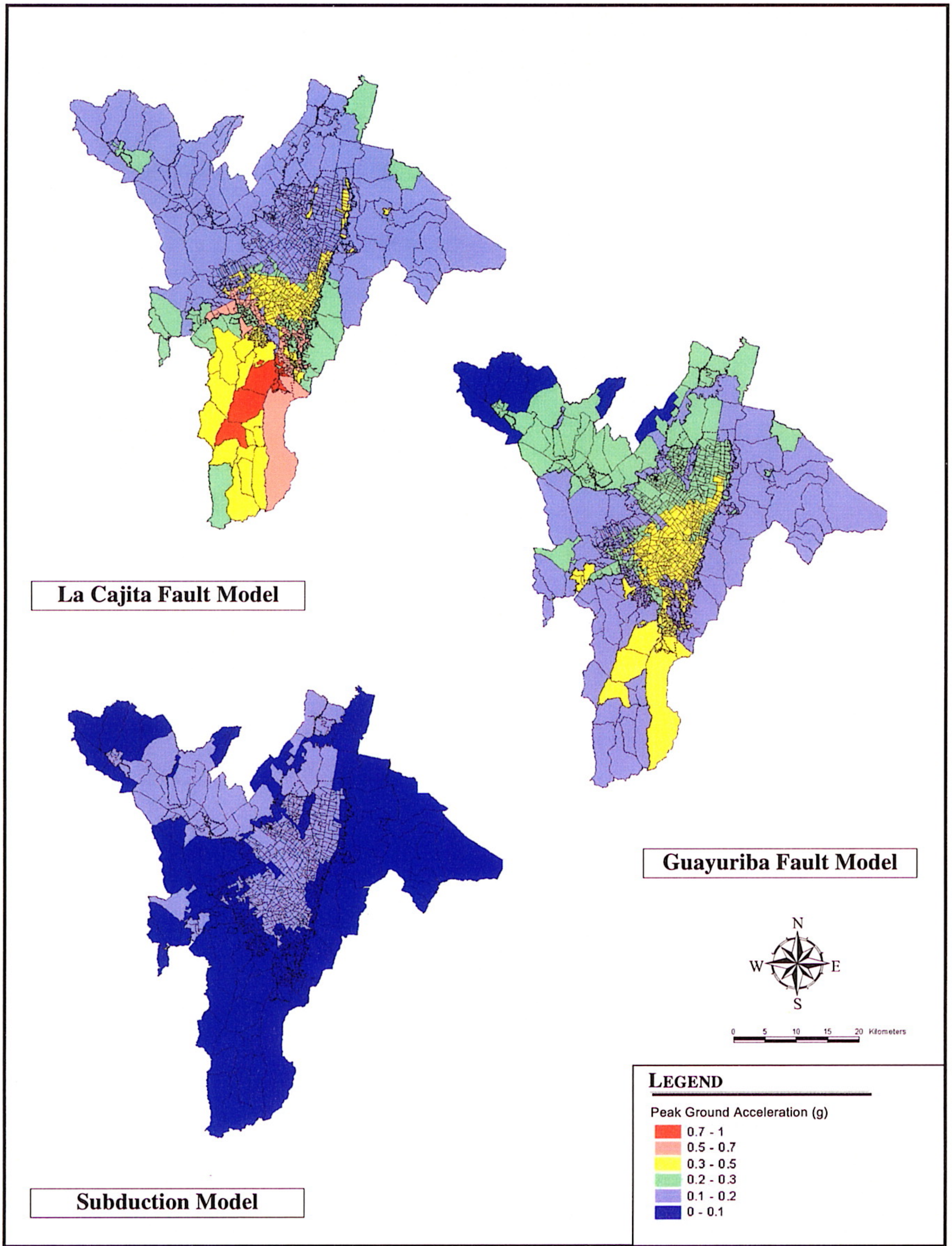
Source: "Manual for Zonation on Seismic Geotechnical Hazards" by International Society for Soil Mechanics and Foundation Engineering (1993)

3. LIMITATION OF EXISTING STUDY AND RECOMMENDATIONS

Above all, numerical ground model used to calculate amplification curve was not fully available. The available information suggests that it is assumed in calculation of soil response that deep stratum will be excited in case of large earthquake. However, dynamic properties of deep stratum are not well studied, and such records are not . Though detailed geotechnical boring data was available in Bogotá, collected borings in municipalities in Cundinamarca lacks such data, and maximum depth was limited to 30m. It is recommended that dynamic properties of subsoil should be studied to improve the reliability of the geotechnical model.



Appendix 4.2.3	Basement Acceleration



Appendix 4.2.4	Peak Ground Acceleration Distribution

Appendix 4.2.5 Modified Mercalli Intensity Description

MMI	PGA (gal)	Description of shaking Severity	Full Description
I.	2		Not felt. Marginal and long period effects of large earthquakes
II	4		Felt by persons at rest, on upper floors, or favorably placed.
III.	8		Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake
IV	16		Hanging objects swing. Vibration like passing of heavy trucks, or sensation of a jet like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV, wooden walls an frame creak.
V.	33	Light	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing close, open. Shutters, picture move. Pendulum clocks stop, star, change rate.
VI	65	Moderate	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, etc, off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school): Trees, bushes shaken (visibly, or heard to rustle).
VII	130	Strong	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.
VIII	259	Very Strong	Steering of motor cars affected. Damage to masonry C; partial collapsed. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	518	Violent	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapsed; masonry B seriously damaged. (General damage to foundations). Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters.
X	1033	Very Violent	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly
XI			Rails bent greatly. Underground pipelines completely out of service.
XII			Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

Source: Richter, C.F., 1958. Elementary Seismology. (PGA correspondence is calculated using Trifunac & Brady's formula.)

APPENDIX 4.2.6

METHODS TO ESTIMATE LIFELINE INFRASTRUCTURES DISTRIBUTION

1. INTRODUCTION

The information of the existing lifeline distribution systems was used for seismic damage estimation on the lifeline by the JICA Study team in 2001. However, the most of data for the existing lifeline systems were incomplete and not sufficient to estimate realistic impacts of the earthquake on the cities. Therefore, the missing parts of the information of the cities' systems were estimated based on the existing data and available information. Methods to estimate lifeline distribution systems are described in this section.

2. OBJECTS OF ESTIMATION

The objects to be estimated are distribution networks of lifelines: water supply pipe network, natural gas supply pipe network, electric supply wire network and telephone wire network. Table 1 shows the specification of the networks.

Table 1. Specifications of Concerned Lifelines Networks

Types of lifeline networks	Specifications	Sources of Information
Water supply	Water supply pipes with 1 to 78 inch diameters. The lines between buildings and the networks are not included. In Cundinamarca, only urban area is the Study's object since information on its rural area is not available.	EAAB
Natural gas supply	Low-pressure (60psi) natural gas supply network. In Cundinamarca, only Chia and Soacha have natural gas supply system	Gas Natural
Electric supply	11kv electric supply wire network.	Codensa
Telecommunication	Telephone wire network. Wires connecting between poles and houses are not included.	ETB & Capitel

3. SUMMARY THE ORIGINAL DATA

The original data and their reliability are summarized in Table 2. Accuracies of estimated locations of the lifeline networks depend on the format and quality of the original data. Table 3 indicates the accuracies of the information and the estimations on the lifeline networks for different data type.

Table 2 Summary of Original Data for the Estimation

Area		Water	Gas	Electricity	Telephone	
		EAAB	Gas Natural	Codensa	ETB	CAPITEL
Bogotá	urban	GN	IV	PN,FT	GD&IV	GN
	rural	GN	IV	PN,FT	GD&IV	GN
Chia	urban	CN	N	N	N	---
	rural	CN	N	N	N	---
Cota	urban	CN	---	PN	N	---
	rural	N	---	PN	N	---
Facatativa	urban	CN	---	N	N	---
	rural	N	---	N	N	---
Funza	urban	CN	---	PN	N	---
	rural	N	---	PN	N	---
La Calera	urban	CN	---	N	N	---
	rural	N	---	N	N	---
Madrid	urban	CN	---	N	N	---
	rural	N	---	N	N	---
Mosquera	urban	CN	---	PN	N	---
	rural	N	---	PN	N	---
Soacha	urban	GN	IV	PN	GD&IV	GN
	rural	GN	IV	PN&N	N	---

Table 3. Legend and Accuracy of Estimation

Legend	Form of information	Accuracy of estimation
GN	GIS Network data	High
GD	GIS data	High
CN	CAD drawing Network data	High
PN	Printed Network data	Middle
FT	Figure table	Middle
IV	Information on figure by interview	Middle
N	No information available	Low
---	Network does not exist	

4. METHODOLOGY OF DISRIBUTION ESTIMATION

In this section, details of the original data and the methodologies of the estimation are explained for the lifelines.

4.1 Water Supply Network

4.1.1 Object of Study

The pipes with diameters between 1 and 78 inches are the sole object for the water distribution network estimate. The water supply lines between the main distribution pipe network and houses and/or buildings are not concerned.

4.1.2 Status of the Original Data

The original data contains information on topology, diameter and material of the distribution pipes in the most of urban areas covered for the Study. There was no information available for the urban areas in Cota and Facatativa. Information on all of the rural areas in Cundinamarca was not available either.

Table 4. Details of the Original Data of Water Supply Networks

Area		Type of Data	Information		Figure
			Diameter	Material	
Bogotá	urban	GIS	O	O	Figure 1
	rural	GIS	O	O	
Chia	urban	CAD	O	O	Figure 2
	rural	CAD	O	O	
Cota	urban	CAD	O	X	Figure 3
	rural	---	---	---	---
Facatativa	urban	CAD	O	X	Figure 4, 5
	rural	---	---	---	---
Funza	urban	CAD	O	O	Figure 6
	rural	---	---	---	---
La Calera	urban	CAD	O	O	Figure 7
	rural	---	---	---	---
Madrid	urban	CAD	O	O	Figure 8
	rural	---	---	---	---
Mosquera	urban	CAD	O	O	Figure 9
	rural	---	---	---	---
Soacha	urban	GIS	O	O	Figure 1
	rural	---	---	---	---

O: Available
X: Not available

4.1.3 Method of Estimation

The quantities and quality of the original data on the water networks were adequate for the Study purpose. Therefore, it was not necessary to develop a method to make estimation

4.2 Natural Gas Supply Network

4.2.1 Main Target

Low-pressured (60psi) natural gas supply system was chosen for the Project. Such a network exists only in Bogotá, Soacha and Chia but not in the other 6 municipalities in Cundinamarca.

4.2.2 Details of the Original Data

The total lengths of the gas distribution pipeline in Bogotá and Soacha were determined based on the interviews given to the residents by Gas Natural Company. No information for the system in Chia was available. Table 5 shows the total lengths of the gas distribution systems in Bogotá and in Soacha.

Table 5 Total Lengths of the Natural Gas Networks in Bogotá and in Soacha

City	Total length of the natural gas network (m)
Bogotá	8,023,800
Soacha	584,113

4.2.3 Method of Estimation

Two assumptions are adopted to estimate the natural gas network distribution system.

Such adopted assumptions are as follows.

1. Length of network segments is proportional to the numbers of buildings within a micro-zone.
2. Average network segment length per building in Chia is the same as that in Soacha.

Figure 1 shows the flow chart of the method to estimate gas distribution network lengths.

Bogota

Averaged gas pipeline length per building in Bogota × Numbers of buildings at a micro-zone = Estimated gas pipeline length in a micro-zone of total Study area

Where Averaged gas pipeline length per building in Bogota = (Total length of the pipelines in Bogota) / (Total number of buildings in Bogota)

Soacha

Averaged gas pipeline length per building in Soacha × Numbers of buildings at a micro-zone = Estimated gas pipeline length at a micro-zone in Soacha

Where

Averaged gas pipeline length per building in Socha = (Total length of the pipelines in Soacha) / (Total number of buildings in Soacha)

Therefore, the gas network length in Chia can be estimated as below:

Chia

Average length per buildings of Soacha × Numbers of buildings at a micro-zone in Chia = Estimated gas pipeline length at a micro-zone in Chia

Figure 1 Method of Estimation of Natural Gas Network Distribution

Table 6 below summarized the data that were used to estimate lengths of the gas supply networks.

Table 6 Summary of Figures of the Natural Gas Networks

Area	Total length of the Natural gas network (m)	Number of buildings (nos)	Average length per buildings (m/bui.)
Bogotá	8,023,800	752,593	10.66
Soacha	584,113	57,930	10.08
Chia	182,544	18,104	10.08

4.3 Electric Supply Network

4.3.1 Object of Study

Electric distribution network system with 11 kV power supply was selected for the Study. The network consists of both overhead cable and under ground cable systems. Therefore, the lengths of overhead cable and of under ground cable are estimated separately.

4.3.2 Details of the Original Data

The map of the local electric distribution system network was provided by the supplier, Codensa. Also the table for the lengths and types for both overhead and under ground cables was provided by Codensa.

4.3.3 Method of Estimation

1) Summary of the method

Several methods were adopted to estimate the electric network according to the given information. Figure16 shows the relationship between the study area and the map. From the Figure 16 the study area was divided into 3 parts Described below.

1st part: High-density network area

This area corresponds to the urban area of Bogotá. An appropriate estimation method was developed for the high-density area since it was difficult to digitize the network.

2nd part: Low-density network area

This area corresponds to all the parts of Cota, Funza, and Mosquera and some part of Chia, Madrid, Soacha, and Bogotá. The length of the network was measured by using GIS system directly.

3rd part: The area which is out of the drawing

This area corresponds to Chia, Facatativa, La Calera and some parts of rural area of Bogotá and Soacha. The drawing doses not cover all study area. Therefore correlation method, which was derived from the information of 2nd part, were adopted.

Table 7 shows the summary of the areas and the adopted methods for estimation of the electric cable distribution.

Table 7 Summary of Methods for the Electric Distribution Networks

City	urban/rural	Part	Method	Accuracy
Bogotá	urban	1st	Estimation by drawing & table	Medium
	rural	1st 3rd	Estimation by drawing & table Estimation by correlation	Medium
Chia	urban	3rd	Estimation by correlation	Low
	rural	3rd	Estimation by correlation	Low
Cota	urban	2nd	Directly measuring from the drawing	High
	rural	2nd	Directly measuring from the drawing	High
Facatativa	urban	3rd	Estimation by correlation	Low
	rural	3rd	Estimation by correlation	Low
Funza	urban	2nd	Directly measuring from the drawing	High
	rural	2nd	Directly measuring from the drawing	High
La Calera	urban	3rd	Estimation by correlation	Low
	rural	3rd	Estimation by correlation	Low
Madrid	urban	3rd	Estimation by correlation	Low
	rural	3rd	Estimation by correlation	Low
Mosquera	urban	2nd	Directly measuring from the drawing	High
	rural	2nd 3rd	Directly measuring from the drawing Estimation by correlation	Medium
Soacha	urban	2nd	Directly measuring from the drawing	High
	rural	2nd 3rd	Directly measuring from the drawing Estimation by correlation	Medium

2) Estimation method for 1st part:

The assumptions, which are adopted in the estimation for 1st part, are as follows.

1. The length of the network in a certain area is proportional to the area in a Codensa's local service zone.
2. The length of network in a area of the local service zone is proportional to the numbers of buildings in the same area.

Because the network map given by the electric provider, Codensa, was available, it was difficult to trace and measure all the dense networks in 1st part. Also, the micro-zones were smaller than Codensa's local service zones. Therefore, the lengths of Codensa's local service zones were converted into localities according to area size. After the conversion, the lengths of localities were converted to micro-zones. Figure 2 shows the flowchart of the estimation method for the 1st part.

Summing up the length from the Table.8 for each Codensa's local service zone. (See Table 8)

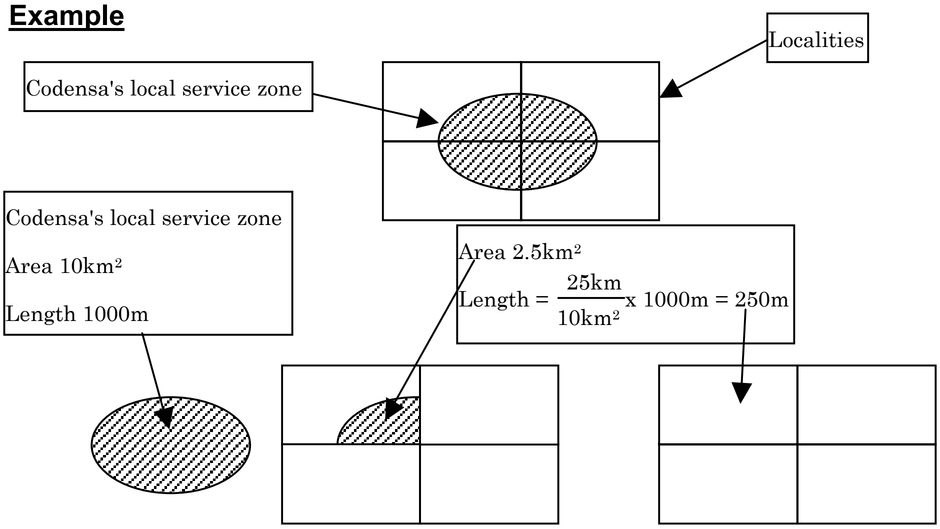
↓

Identifying Codensa's local service zone on GIS.

↓

Distributing the length to localities from Codensa's local service zones according to the area.

Example



↓

Deliver the length of electric supplying wire in the micro-zone from localities according to number of building.

Example

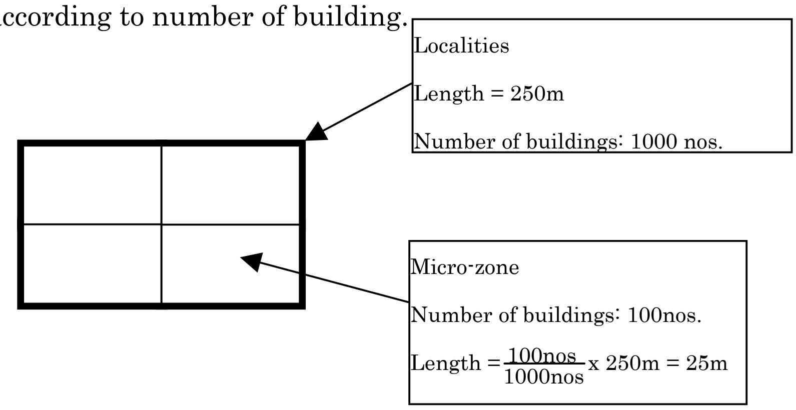


Figure 2 Flowchart of the Estimation Method for Electric Network Part 1

Table 8 Summary of length of Condensa's Local Service Area

Codensa's local service area code	Type of cable	Length (km)	Codensa's local service area code	Type of cable	Length (km)
AJ	Overhead	21.19	MZ	Overhead	135.33
AJ	Under ground	92.7	MZ	Under ground	13.28
AU	Overhead	39.03	RS	Overhead	38.6
AU	Under ground	202.27	SA	Overhead	44.97
BL	Overhead	244.28	SA	Under ground	230.12
BL	Under ground	22.48	SC	Overhead	98.67
BO	Overhead	203.47	SC	Under ground	11.1
BO	Under ground	22.08	SF	Overhead	4.56
CC	Overhead	17.69	SF	Under ground	82.82
CC	Under ground	104.2	SJ	Overhead	13.65
CN	Overhead	77.41	SJ	Under ground	25.28
CN	Under ground	68.4	SU	Overhead	165.52
CP	Overhead	82.34	SU	Under ground	28.61
CP	Under ground	17.99	T0	Overhead	188.03
CR	Overhead	11.09	T0	Under ground	70.88
CR	Under ground	58.3	TB	Overhead	125.57
CS	Overhead	22.54	TB	Under ground	56.55
CS	Under ground	97.25	TE	Overhead	204.84
CT	Overhead	54.39	TE	Under ground	20.67
CT	Under ground	162.54	TU	Overhead	141.99
CU	Overhead	14.41	TU	Under ground	24.49
CU	Under ground	48.25	UM	Overhead	349.66
FO	Overhead	183.4	UM	Under ground	9.38
FO	Under ground	86.89	US	Overhead	56.98
GG	Overhead	15.24	US	Under ground	217.47
GG	Under ground	57.06	VE	Overhead	103.81
LP	Overhead	44.23	VE	Under ground	22.7
LP	Under ground	105.72	VI	Overhead	213.7
MR	Overhead	121.59	VI	Under ground	1.3
MR	Under ground	74.79			

3) Estimation method for 2nd part

The length of the network was measured by using GIS system directly.

Overhead electric lines were only considered for the target of the estimate in this part .

4) Estimation method for 3rd part

Some correlations were assumed for estimation of the 3rd part. The correlations are based on the information of the 2nd part.

Assumptions adopted in the estimation are as follows:

1. Network in the 3rd part is overhead cable.
2. The micro-zones can be classified according to sizes and density of buildings.

3. Network length is the same as road length of a micro-zone, of which area is bigger than $25km^2$ and density of building is smaller than $25nos/km^2$.

Classification and correlations between the length of network and the area of a micro-zone, numbers of buildings and the density of the buildings were studied by using the data of the 2nd part. Some correlation equations were determined, of which correlation coefficients were better than 0.7.

The classification and correlation is shown in Table9.

Table 9 Classification and Correlation for the 3rd Part

Area (km^2)	Density of buildings (nos/km^2)	Correlation	Correlation coefficient
---	Higher than 1000	$L = 4915 \times A - 20.975$	0.7
Smaller than 20	Lower than 1000	$L = 1529.4 \times A + 89.43$	0.7
Bigger than 20	Lower than 1000	$L = 16.836 \times A^{1.9424}$	0.9
Bigger than 25	Lower than 25	L = Road length	----

L: length of network (m), A: area of micro-zone (km^2)

4.4 Telephone Network

4.4.1 Object of Study

In this analysis wires between pole and each building were not included. The lengths of overhead cable and under ground cable were estimated separately.

The telephone networks, which belong to ETB and CAPITEL, were the objects of the estimation. Three telephone companies (ETB, CAPITEL and EPM) have telephone cables networks in the Study area. The telephone network of EPM was not included since their information was not available.

4.4.2 Details of the original data of telephone network

Table 10 Summary of Original Data for Telephone Network

Institution	Contents	Type of data
ETB	Location of cabinets	GIS data
	Examples of primary network length of 7 ETB central stations	Printed table
	The total pole number in Bogotá & part of Soacha	interview
	Ratio between overhead cable and under ground cable	interview
CAPITEL	Over head cable network	GIS network data
	Under ground cable network	GIS network data
	Location of Poles	GIS data

The total number of ETB cabinet is 4,628. This number was counted by using GIS.

The information on ETB telephone network by interview is as follows:

1. The total pole number in Bogotá and part of Soacha, which has cabinets of given GIS data, is 120,000 nos.
2. The overhead cable to the underground cable ratio of secondary network is such that shown in Table 11

Table 11 Ratio between overhead Cable and Under Ground Cable of ETB Network

	Ratio (%)	
Type	Overhead	Under ground
Primary network	1	99
Secondary network	49	51

4.4.3 Method of Estimation

1) Summary

The original data of CAPITEL was GIS network data. Therefore it can be used directly and no estimation is required. On the other hand, estimation was necessary for ETB network.

The lengths of ETB network were estimated by using the following three methods.

1. Estimation based on the number of cabinets in a micro-zone. This method is adopted for the area where ETB cabinets are located (Figure.3).
2. Estimation based on correlation between CAPITEL network and the electric supply network. This method was adopted for the area where ETB cabinets are not located in Figure.3 and the building density is higher than 1,000nos/km^2.
   No information, which based on ETB cabinet, was available in this area. The length of electric network had been already estimated in this area. Therefore, the estimate was used. However, the length of telephone network was not same as the electric's one in the area, where the building density was higher than 1,000nos/km^2. Therefore, the correlation between CAPITEL network, of which information was high accuracy, and electric network was adopted.
3. The length of electric network was considered as the length of ETB network. This method was adopted for the area where ETB cabinets are not located in Figure3 and the building density was lower than 1,000nos/km^2.
   No information was available in this area based on the ETB cabinet data. The information based on CAPITEL network was not available either in this area since the CAPITEL network was not exist in the area low in the building density. The length of electric network had been already estimated in this area. Therefore, the length of electric network was adopted as the length of telephone network.

2) Estimation based on numbers of cabinets

Assumptions for this estimation method are as follow:

1. The average distance between two poles is 30m. This was figured out based on the information from CAPITEL.
2. The lengths of telephone lines in Bogotá and part of Soacha are proportional to the number of cabinets.
3. The average length of primary network per central station of 7 stations shown in Figure 3.
4. Primary network is underground cable.

The flowchart of estimation based on numbers of ETB cabinets is shown as below.

Total overhead cable length and under ground cable length in the area where ETB cabinets are located, are estimated.

⇓

Average of overhead cable length and under ground cable length per cabinet are estimated.

⇓

The numbers of cabinets of each micro-zone are counted.

⇓

Length in micro-zone = Number of ETB cabinets × Average length per cabinet

Figure 3 The flowchart of estimation based on number of ETB cabinet

The total lengths for the area where ETB cabinets were located were estimated as below.

Estimate total length of overhead cable of secondary network

Total number of poles × Average distance of between two poles of CAPITEL data

120,000 nos. × 30 m ⇒ 3,600,000m

Estimate total length of under ground cable of secondary network

$$\text{Total length of overhead cable} \times \frac{\text{Ratio of under ground cable}}{\text{Ratio of under overhead cable}}$$

$$3{,}600{,}000\text{m} \times \frac{51}{49} \Rightarrow 3{,}746{,}939\ \text{m}$$

Estimate total length of under ground cable of primary network

$$\text{Total length of 7 central stations in Table.12} \times \frac{\text{37: total number of central stations}}{\text{7: total number of central stations in Table.12}}$$

$$134{,}415\text{m} \times \frac{37}{7} \Rightarrow 710{,}479\text{m}$$

The average lengths per cabinet were estimated as below.

Estimation of overhead cable length per cabinet

$$\frac{\text{Total length of overhead cable of secondary network}}{\text{Total number of cabinet}}$$

$$\frac{3{,}600{,}000\ \text{m}}{4{,}628} \Longrightarrow 777.87\text{m / cabinet}$$

Estimation of under ground cable length per cabinet

$$\frac{\text{Total length of underground cable of secondary network} + \text{Total length of underground cable of primary network}}{\text{Total number of cabinet}}$$

$$\frac{3{,}746{,}939 + 710{,}479}{4{,}628} \Longrightarrow 963.14\text{m / cabinet}$$

Counting the numbers of ETB cabinets and calculation for each micro-zone have been done by using GIS and database system.

3) Estimation based on correlation between CAPITEL and electric network

Assumptions, for this estimation method are as follows:

1. Electric supply network in a micro-zone where no cabinet was shown in Figure23 is overhead cable network.
2. The length of ETB network is the same as the length of CAPITEL network in a micro-zone, and building density is higher than 1,000 nos/km^2. The length of CAPITEL is estimated by using correlation between CAPITEL and electric cable.

A correlation between the length of overhead cable of CAPITEL and the length of electric cable is derived based on the data of locality of ANTONIO NARINO, BARRIOS UNIDOS, LA CANDELARIA, MARTIRES, PUENTE ARANDA, RAFAEL URIBE and TUNJUELITO, where building density is 1,440 - 3,900 nos/km^2.

Such correlation is expressed as follow:

Length of CAPITEL (m) = 0.6719$\times$length of electric network (m) + 11754

The correlation coefficient is 0.89.

4) Estimation assuming the length of electric network as the length of ETB network

Assumptions for this estimation method are as follows

1. Telephone networking of a micro-zone where no cabinet is shown in Figure.23 is overhead cable.
2. The length of ETB network is the same as the length of electric network in micro-zone, and building density is lower than 1,000 nos/km^2.