No.

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

METROPOLITAN DISTRICT OF CARACAS
BOLIVARIAN REPUBLIC OF VENEZUELA

STUDY ON

DISASTER PREVENTION BASIC PLAN IN THE METROPOLITAN DISTRICT OF CARACAS IN THE BOLIVARIAN REPUBLIC OF VENEZUELA

FINAL REPORT
MAIN REPORT

March 2005

PACIFIC CONSULTANTS INTERNATIONAL
In association with
OYO INTERNATIONAL CORPORATION

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Estimated Base Cost: as of 2005 price

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(1 January, 2005)

PREFACE

In response to the request from the Government of the Bolivarian Republic of Venezuela, the Government of Japan decided to conduct the Study on the Disaster Prevention Basic Plan in the Metropolitan District of Caracas and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA selected and dispatched the study team headed by Mr. Mitsuo MIURA of Pacific Consultants International (PCI) and composed of staff members of PCI and OYO International Corporation to Venezuela, seven times from December 2002 to March 2005. In addition, JICA set up the advisory committee headed by Mr. Yasuo NAKANO and Mr. Haruo NISHIMOTO, Japan International Cooperation Agency, from December 2002 to March 2005, which examined the Study from the technical points of view.

The team held discussions with the officials concerned of the Bolivarian Republic of Venezuela and conducted field surveys in the study area. Upon returning to Japan, the team conducted further studies and prepared this final report.

I hope that this report will contribute to the promotion of this project and to the enhancement of friendly relationship between our two countries.

Finally, I wish to express my sincere appreciation to the officials concerned of the Bolivarian Republic of Venezuela for their close cooperation extended to the team.

March, 2005

Etsuo Kitahara

Vice President

Japan International Cooperation Agency

THE STUDY ON THE DISASTER PREVENTION BASIC PLAN IN THE METROPOLITAN DISTRICT OF CARACAS, THE BOLIVARIAN REPUBLIC OF VENEZUELA

March, 2005

Mr. Etsuo Kitahara

Vice President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit you the final report entitled "the Study on the Disaster Prevention Basic Plan in the Metropolitan District of Caracas, Bolivarian Republic of Venezuela". This report has been prepared by the Study Team in accordance with the contracts signed on 9 December 2002, 7 May 2003 and 30 April 2004 between the Japan International Cooperation Agency and the Joint Study Team of Pacific Consultants International and OYO International Corporation.

The report examines the existing conditions related to earthquake and sediment disasters in the three municipalities in the Metropolitan District of Caracas and presents the master plan for the disaster prevention of the area. It also presents the result of the feasibility study of the priority projects selected from the master projects.

The report consists of the Summary, Main Report, Supporting Report, Data Book and Maps. The Summary summarizes the results of all studies. The Main Report contains the existing conditions, the proposed master plan, the results of the feasibility study, and conclusions and recommendations. The Supporting Report includes technical details of contents of the Master Plan. The Data Book contains basic data. The Maps contains the important maps prepared in the Study.

All members of the Study Team wish to express grateful acknowledgement to the Japan International Cooperation Agency (JICA), JICA Advisory Committee, Ministry of Foreign Affairs, Ministry of Land, Infrastructure and Transport, Japan Bank for International Cooperation, Embassy of Japan in the Bolivarian Republic of Venezuela, and other donors, and also to Venezuelan officials and individuals for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the disaster prevention of the Metropolitan District of Caracas, and that friendly relations of both countries will be promoted further by this occasion.

Yours faithfully,

Mitsuo Miura
Team Leader

EXECUTIVE SUMMARY

STUDY ON DISASTER PREVENTION BASIC PLAN

FOR THE METROPOLITAN DISTRICT OF CARACAS

Existing Problems and Target of the Master Plan

Caracas is the largest city of Venezuela and has a population of 3.1 million and 777 km^2 of area. It also has the largest concentration of asset is the nation. Much more, it has a function of capital city with the administration of national government, national congress and the supreme court as well as the headquarter of national bank.

Caracas has been experiencing several large scale earthquakes since its history began in 16th century. The largest earthquake hit the city is in 1812, when around 2,000 people lost their lives. The most recent earthquake is in 1967, when about 1,800 buildings damaged and 274 people died. Thus, Caracas has possibility of large earthquakes such as 1812 earthquake or 1967 earthquake.
Caracas also has a history of frequent sediment disasters. In December 1999, Caracas was hit by a heavy rainfall caused by cold weather front from Caribbean Sea and debris flow was generated in the mountain streams of Catuche and Anauco. It caused death of around 100 people. Similar debris flow occurred in February of 1951. Thus, Caracas has possibility of debris flow such as 1951 or 1999 in future.

The disaster prevention administration in the Metropolitan District of Caracas is defined in the "Law of Organization for Civil Protection and Disaster Administration" issued in 2001. The responsibility of Civil Protection of national and regional level is clearly defined there and one of the responsibilities of the Civil Protection of ADMC is to prepare a regional disaster prevention plan for the Metropolitan District of Caracas but the plan is not being prepared. The national disaster prevention plan, which would be the guideline for the regional disaster prevention plan is not being prepared either.

Thus, the Metropolitan District of Caracas, the most important city of the nation, is under a threat of natural hazard such as earthquakes and sediment disasters. However, the disaster prevention administration is under development and the regional plan for disaster prevention is not being prepared yet.

Based on the above mentioned background, the target of the disaster prevention master plan for the area is as follows;

1. Even with the occurrence of 1967 scale earthquake or 1812 scale earthquake, the human lives will be saved. The assets damage will be minimized. The important function of the city such as main road, lifelines and disaster prevention administration function will be preserved.
2. Even with the occurrence of debris flow with the scale of 1999 Caracas by the rainfall of once in hundred years, buildings and human lives along the mountain streams will be saved.
3. Human lives will be saved from landslides or steep slope failures in the area.

Master Plan

1. Master Plan Projects

In order to attain the above targets, 20 projects were proposed and seven major projects were selected among them taking into account "significance", "urgency", "intention of the counterpart", etc. The seven major projects are as follows;

Projects for "Making a Safer Caracas"

1. Seismic Reinforcement of Buildings (Ministry of Housing, FUNVI, Municipalities)
2. Seismic Reinforcement of Bridges (Ministry of Infrastructure)
3. Debris Flow Control Structures (Ministry of Environment and Natural Resources)
4. Resettlement of People Living in River Channels (Ministry of Planning and Development, Urban Planning and Environment Secretary ADMC, Municipalities)

Projects for "Acting Effectively in Emergency"

5. Early Warning and Evacuation (Ministry of Environment and Natural Resources, Civil Protection ADMC, Civil Protection Municipalities)
6. Emergency Command Center (Civil Protection ADMC)

Project for "Strengthening Coordination between the Government and the Citizens"

7. Strengthening Community Activities (Civil Protection National, ADMC, Municipalities)

2. Project Cost

Approximately 2,800 Million US$ for 16 years of period

3. Evaluation of the Master Plan

Economic	Total economic evaluation is difficult but the seismic reinforcement of building project, which occupies a large portion of the plan makes its economic benefit equivalent to the economic cost.
Financial	The total project cost is around 2 % of the national GDP and around 10% of the national budget. The financial effect is large considering the importance of the area.
Social	It is possible to reduce the number of casualties significantly by employing the projects of "seismic reinforcement of buildings", "debris flow control structures", "resettlement of people from risky area", and "land use and development regulation", giving big social benefit.
Technical	All the projects are possible by local technologies.
Environmental	The Sabo dams of the debris flow control structures are planned inside of the Avila National Park. The environmental aspect of the project was explained and admitted by the Ministry of Environment and Natural Resources, with the condition of design and construction method appreciating environmental conservation.

Feasibility Study of Priority Projects

1. Selection of Priority Projects

According to the selection criteria of “significance”, “urgency”, “prompt consequences”, “technology”, ”economics”, ”environmental effect”, “social needs”, “intention of the counterpart”, etc, two projects were selected for feasibility study.

Seismic Reinforcement of Buildings: Structural Measures for Earthquake Disaster Prevention (Joint Study with FUNVISIS)

Early Warning and Evacuation for Debris Flow Disaster Prevention: Non-structural Measures for Sediment Disaster Prevention (Joint Study with IMF-UCV)

2. Project Description

a. Seismic Reinforcement of Buildings

Among 310,000 buildings in the target area, around 180,000 buildings will be reinforced. The reinforcement method for urban area houses is proposed to be based on 2001 building code. The reinforcement method for barrio area houses was studied by a field test in the Study.

b. Early Warning and Evacuation for Debris Flow Disaster Prevention

The meteorological/hydrological observation network as well as communication network will be installed. The critical rainfall amount will be designed for early warning indicators. The institutional framework composed of the Ministry of Environment and Natural Resources, the Civil Protection ADMC, Civil Protection Municipalities and Communities, will be established based on the agreement signed by the parties involved.

3. Project Cost and Implementation schedule

3.1 Reinforcement of Buildings 2,600 MUSD

Rapid Visual Screening	2005-2008
Detail Seismic Evaluation	2005-2018
Reinforcement Design	2005-2019
Reinforcement Work	2007-2020

3.2 Early Warning and Evacuation 1 MUSD

Establishment of Agreement	2005-2006
Establishment of Information System	2006-2007
Emergency Command Center	2006-2007
Implementation of Early Warning and Evacuation	2006-2007

4. Effect of the Project

4.1 Seismic Reinforcement of Buildings

The project will reduce the number of heavily damaged buildings from aroudn 10,000 to around 1,300 and the number of casualties from froudn 4,900 to around 400 in the case of 1967 earthquake. It will reduce the number of heavily damaged buildings from around 32,000 to around 2,300 and the number of casualties from around 20,000 to around 2,300 in the caseof 1812 earthquake.

4.2 Early Warning and Evacuation for Debris Flow Disaster Prevention

By the implementation of the project, it will become possible for the 19,000 pople living in the risky area ofdebris flow of various scales.

5. Project Evaluation

5.1 Seismic Reinforcement of Buildings

Economic : The economic benefit is equivalent to the economic cost. The benefit of the project in the case of 1967 earthquake is calculated as around 530 million dollars by combining direct and indirect benefit. This value is equivalent to the reinforcement cost of 10,000 buildings, which are estimated to be heavily damaged by the 1967 earthquake.

Financial: The project cost is 3 % of the national GDP and the most of it is paid by the building owners. The people in urban area can afford to pay the cost but it is necessary ot subsidize for the people in barrio area.

Technical: The prject is technically feasible including barrio houses.

Social: It is th most effective method to reduce the number of casualties.

5.2 Early Warning and Evacuation for Debris Flow Disaster Prevention

Economic : The economic evaluation is difficutl because it will not preserve properties.

Financial: The project cost is 1 % of ADMC budget and it is justifed to invest considering the importance of the area.

Technical: The project is technically feasible based on the accurate meteorological/hydrological observation and debris flow observation by the initiative of the Ministry of Environment and Natural Resources.

Social: The community organizations of the area is generally active and it is possible to establish early warning and evacuation system utilizing the existing community organizations.

Limitation of the Study

There are following limitations of the Study. As the Study has been done with the following limitations, it is necessary to continue further investigations and discussion in order to supplement those limitations.

(1) Study Area

Although, the title of the Study is “Study on Disaster Prevention Basic Plan for the Metropolitan District of Caracas”, the Study area does not cover all the five municipalities in the Metropolitan District, namely Libertador, Chacao, Sucre, Baruta and El Hatillo. The Study area is limited to the three municipalities, namely Libertador, Chacao and Sucre. This is because the Scope of Work signed in March 21st, 2002 defines it and the Minutes of Meetings signed at the same time says that “ In the future the Metropolitan District of Caracas office of the Mayor will apply knowledge and methodology obtained through the course of the Study to formulate disaster prevention plan for

Baruta and El Hatillo municipalities”. It is expected that the Venezuelan side will formulate the plan for the rest of the Metropolitan District of Caracas based on the idea stated in the Minutes of Meetings.

(2) Legal Status of the Restlu of the Study
According to the “Law of the National Organization of Civil Protection and Administration of Disasters (Ley de la Organización Nacional de Protección Civil y Administración de Desastres) ”, regional disaster prevention plans shall be proposed by the regional Civil Protection offices to the Coordination Committee for Civil Protection and Administration of Disasters in each region for final authorization. Therefore, the Disaster Prevention Plan prepared in the Study shall be reviewed by the Metropolitan Civil Protection and shall be proposed to the Metropolitan Committee for Civil Protection and Administration of Disasters for final authorization.

(3) Employment of deterministic approach in earthquake disaster prevention
There are two approaches to evaluate the effect of earthquake, deterministic and probabilistic.
In this study, deterministic approach is employed, which defines several scenario earthquakes and estimates ground motions and its damages to establish a plan for earthquake disaster prevention.
On the other hand, the probabilistic approach considers all possible earthquakes that would affects the study area, to estimate the ground motion for fixed period of time and fixed probability of occurrence. The result ground motion is not the one that would happen during an earthquake, and will be used for the establishment of seismic code or calculation of insurance premium.
In this study, deterministic approach is employed and its results are used to prepare an emergency response plan, since the object of the study is to establish an earthquake disaster prevention plan. With respect to the seismic reinforcement plan of existing buildings, all the necessary buildings were considered, because the area that needs reinforcement cannot be specified due to the fact that the location of future earthquake cannot be predicted.

(4) Effect of scenario earthquake
In this study, typical past earthquakes were considered as scenario earthquake, because the earthquake prediction for future events is difficult. Scenario earthquakes considered in this study do not mean the prediction nor prophesy of earthquake in the future, but they should be used to understand the magnitude of damage in case same earthquake that occurred in the past happens today.
As there are numerous studies regarding the past major earthquakes, several models can be developed regarding the fault location of scenario earthquake. In this study, model that can best reproduce the observed damage or ground motion was adopted. It should be noted that higher damage degree in the northwestern part of Caracas metropolitan area by the 1967 and the 1812 scenario earthquakes are due to the fact that those earthquake fault are located in the northwestern part of Caracas.

(5) Damage function of buildings
In this study, statisitcal treatment is necessary to estimate damage of all the building in the study area by scenario earthquake. For this reason, the whole buildings needs be classified into several groups. While strucurral details such as configurations, irregularity, and disposition of wall are important factors to inspect individual buildings. However, basic factors such as structural type, year of construction, and number of floors are used to classify buildings for statistical damage estimation of all buildings in this study.
The damage function used in this study to estimate buildings‘ damage was developped through discussion with experts in FUNVISIS using earthquake damage data in Europian countries and the 1967 Caracas earthquake, based on EMS-98 (European Macroseismic Scale 1998). The defined function was calibrated by observed damage by the 1967 Caracas earthquake.
It sould be noted that building database of urban area was developped by field sampling in this study, because cadastral database was not a complete one. Building database for Barrio was developped also by estimation using the relationship between area and number of houses in Barrio. Development of

better quality database as well as damage study by statistical manner during major earthquake would be necessary to improve the methodology.

(6) Barrio Building breaking test

The building breaking test was executed to obtain a data on strength of houses in Barrio area, in addition to make an educational material to promote seismic reinforcement. By this nature, the test does not intended to propose a concrete method of reinforcement. As this kind of experiment was made for the first time in Venezuela, yet only four models are tested, it is recommended to continue this kind of experiment by Venezuelan side in the future.

(7) Exclusion of Flood and Urban Draiange Problems

The sediment disasters defined in the Study does not include flood problems nor urban drainage problems. Flood problems are for example, the inundation around Gaire River because of mal-cpacity of the river course. Urban drainage problems are for example, the inundation in the urban area because of mal-capacity of drainage system when a heavy rainfall ocures in the urban area itself. Both problems are different from sediment disasters defined in the Study (debris flow, land slide and steep slope failure) and are excluded from the Study Scope.

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ADMC	Government of the Metropolitan District of Caracas
AASHTO	American Association of State Highway and Transportation Officials
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AUAEV	Unique Authority for Vargas State Reconstruction
AVU	Analyzed Vulnerability Unit
C/P	Counterpart
CAD	Computer Aided Design
CADAFE	Electric Administration and Development Anonymous Company
CAEL	Action Committees for Local Emergencies
CAF	Andean Development Foundation
CAG	Canadian Association of Geographers
CANTV	National Anonymous Telephone Company of Venezuela
CAPCOMEA	Project for Training of Communities for Self-protection, Prevention, Mitigation and Attention of Adverse Events
CCSIEM	Committee for Contingencies and Emergency Situations of Miranda State
CENAMB, UCV	Center for Integral Environmental Studies, Central University of Venezuela
CESAP	Center for the Service of Popular Action
CIDIAT	Interamerican Center for Environmental and Territorial Development and Research
CLPP	Local Councils of public planning
CNU	National Council of Universities
COMIR, UCV	Committee for Risk Mitigation, UCV
CONAVI	National Housing Commission
COVENIN	Venezuelan Committee of Industrial Standards
DBMS	Data Base Management System
DIGITEL	Digitel Corporation C.A.
DMC	Metropolitan District of Caracas
DTM	Digital Terrain Model
EDELCA	Electrification of Caroni C.A.
EMS	European Microseismic Scale
F/S	Feasibility Study
FAV	Venezuelan Air Force
FEDE	Foundation for Educational Buildings and Equipment
FGDC	Federal Geographic Data Committee (USA)
FONACIT	National Fund of Science, Technology and Innovation
FONDUR	National Fund for Urban Development
FUNDABARRIOS	Foundation for Neighborhood Equipment
FUNDACOMUN	Foundation for Community Development and Local Promotion
FUNREVI	Regional Foundation for Housing
FUNVI	Housing Foundation, DMC
FUNVIS	Social Investment Fund of Venezuela
FUNVISIS	Venezuelan Foundation for Seismological Investigations
GIS	Geographic Information System

H/V	Horizontal/Vertical
HIDROCAPITAL	Aqueduct Institute for Capital District and Miranda and Vargas States
IAEM	Institute of Emergency Attention of Miranda State
IDEC-UCV	Institution for the Experimental Development of Construction, UCV
IERU, USB	Institute of Regional and Urban Studies, USB
IGVSB	Simon Bolivar Geographic Institute of Venezuela
IMAS	Water Service Institute of Sucre Municipality
IMF, UCV	Institute of Fluid Mechanics, Central University of Venezuela
IMME, UCV	Institute of Materials and Structural Models, Central University of Venezuela
INCE	National Institute of Educational Cooperation
INE	National Statistics Institute
INGEOMIN	National Geological and Mining Institute
INOS	Former name of HIDROCAPITAL (but in a national extent)
INPARQUES	National Institute of Parks
INTEVEP	Venezuelan Technological Institute of Petroleum
IPASME	Ministry of Defense, Prevention and Social Assistance Institute for the Education Ministry personnel
IPC	Civil Protection Institute, Municipality of Sucre
IPCA	Municipal Autonomous Institute of Civil Protection and Environment, Chacao Municipality
ISC	International Seismological Centre
ITCZ	Intertropical Convergence Zone
IUTB	University Institute of Firefighting Technology
IVSS	Venezuelan Institute of Social Security
JICA	Japan International Cooperation Agency
M/P	Master Plan
MARN	Ministry of Environment and Natural Resources
MARNR	Former Name of MARN
MCT	Ministry of Science and Technology
MEM	Ministry of Energy and Mines
MES	Ministry of Higher Education
MINDUR	Ministry of Urban Development
MINFRA	Ministry of Infrastructure
MMI	Mercalli Macroseismic (Modified) Intensity
MOP	Former Name of MINFRA
MPD	Ministry of Planning and Development
MSDS	Ministry of Health and Social Development
MYCT	Ministry of Science and Technology
Nd	Damage Extension
Ndp	Number of Collapsed Poles
NGO	Non Government Organization
NIP	Neighborhood Improvement Plan
OCEI	Former name of INE
OPR	First Response Organization
OPSU	Planning Office of University Sector

PAHO	Pan-American Health Organization
PCAD	Civil Protection Administration of Disasters
PDUL	Local Urban Development Plan
PDVSA	Petroleum of Venezuela S.A.
PGA	Peak Ground Acceleration
PGV	Peak Ground Velocity
PLACADE	Planning in Case of Disasters (Metropolitan Firefighters)
PRECOM	Office of Community Preparation, Metropolitan Firefighters
PREVENE	Assistance to Natural Disaster Prevention in Venezuela
RC	Reinforced Concrete
REGVEN	Venezuelan Geodesic Network
SCADA	Supervisory Control and Data Acquisition
SCS	Soil Conservation Service (U.S.A.)
SIRGAS	Geocentral Reference System for the Americas
SOCSAL	Local Support Service A.C.
SPT	Standard Penetration Test
SUMA	Humanitarian Supply Management System
S/W	Scope of Work
TELCEL	Telcel BellSouth of Venezuela
TSU	University Technician
UCV	Central University of Venezuela
UDU	Urban Design Unit
ULA	University of Los Andes
UNDP	United Nations Development Programme
UPEL	Libertador Experimental Pedagogic University
UPF	Physical Planning Unit
USB	Simon Bolivar University
USGS	United States Geological Survey
Vs	S Wave Velocity
WHO	World Health Organization

GLOSSARY

Hazard (Covenin):

Latent danger associated to the phenomenon with origin to natural, technological or provoked by mankind that can be manifested in a specific site and in a determined period producing adverse effects upon person, properties, and with that generating emergencies.

Vulnerability (Covenin):

Vulnerability is the susceptibility of loss or damage from an element or group of elements resulting from a specific hazard.

Risk (Covenin):

It is the probability of the occurrence of the economic, social or environmental consequences in a particular place and during a period of determined exposition. It is obtained by relating the hazard with the vulnerability of the exposed elements.

Hazard map (JICA Study Team):

A map showing the distribution of hazard. In this study hazard maps were prepared in both earthquake disaster and sediment disaster. A hazard map of earthquake is for example, a map showing the distribution of earthquake intensity expressed in MMI. A hazard map of sediment disaster is for example, a map showing the distribution of debris flow depth.

Risk map (JICA Study Team):

A map showing the distribution of risk. In this study risk maps were prepared in both earthquake disaster and sediment disaster. A risk map of earthquake is for example, a map showing the distribution of ratio of heavily damaged buildings expressed in percentage. A risk map of sediment disaster is for example, a map showing the area where buildings will be destroyed by the debris flow.

Physical Vulnerability (JICA Study Team):

Structural vulnerability against natural disasters. In this study, the physical vulnerability of buildings are expressed as a damage function showing the relationship between the seismic intensity and the ratio of heavily damaged building by the seismic motion.

Social Vulnerability (JICA Study Team):

Vulnerability against natural hazard related to social conditions such as economic, demographic, knowledge, facility, and community strength. In this study, social vulnerability was studied through social survey and a social vulnerability map was developed.

Damage function (JICA Study Team):

A function relating natural force and the damage caused by the force. In damage estimation on buildings, twenty different damage functions were estimated according to the type, construction year and number of stories of the buildings.

Sediment disaster (JICA Study Team):

Disaster caused by mass movement of sediment/soil/rock and is composed of “debris flow”, “landslide” and “steep slope failure”.

Debris flow (JICA Study Team):

Debris flow is a flood flow containing significant sediment and water which is generated in upper part of mountain stream because of slope collapse and erosion of unstable sediment on stream bed.

Landslide (JICA Study Team):

Landslide is a kind of slope mass movement. Generally, it occurs in a gentle slope as 5 to30 degrees, and on a slip plane such as thin clay layer or in a zone of weak materials. Movement is continuous, and it tends to recur. Velocity of movement is slow as 0.01 to 10 millimeters per a day. We can see some indications such as clacks, subsidence and bulge etc. on ground surface before landslide happen.

Steep slope failure (JICA Study Team):

Scale of steep slope failure is smaller than that of landside. Generally, a steep slope failure occurs on steep slope as more than 30 degrees. Gradients of the slip plane is 35 to 60 degrees. The velocity of collapse is very fast as more than 10 millimeters per a day. There are not so many symptoms before occurrence of slope failure, and then slope failure occurs suddenly. The steep slope failure often occur on the plane which is corresponding to the boundary between the surface soil layer and the base rock, or the boundary between the severe weathered soil layer and the light weathered soil layer.

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CHAPTER 1

INTRODUCTION

“Preventive behaviour for a safer Caracas”

Ana Teresa Aguilar

CHAPTER 1. INTRODUCTION

1. 1 General Information

In response to the request presented by the Government of the Metropolitan District of Caracas, through the Government of the Bolivarian Republic of Venezuela, (hereinafter referred to as the Government of Venezuela), the Japanese Government, through the Japan International Cooperation Agency (JICA), official agency responsible of the technical cooperation program, in accordance with the relevant laws and regulations in force in Japan, has agreed to conduct the Study on the Disaster Prevention Basic Plan in the Metropolitan District of Caracas.

Consequently, in March 2002, JICA dispatched the Preparatory Study Team headed by Mr. Yasuo Nakano, in order to make the preliminary evaluation as well as the Scope of Work for the Study. Based on the discussion between the Government of the Metropolitan District of Caracas and the JICA Preparatory Study Team, the Scope of Work was established by the respective Minutes of Meeting.

In accordance with the Scope of Work, the JICA Study Team was constituted, and later came to Venezuela in order to begin the Study on May 7th 2003. The Study has been conducted according to the initial schedule and by the end of March 2005, all the Study in Venezuela was completed. This Final Report includes all the result of the study up to date.

1. 2 Background

The Metropolitan District of Caracas, the capital of Venezuela, has a population of 3.1 million according to the “2001 Census” and is located in the southern side of the *Cordillera de la Costa*.

On December 15th and 16th, 1999, a large scale disaster caused by debris flows and floods in the Vargas State along the Caribbean Sea and also in the Caracas Metropolitan Area, resulted in a huge amount of casualties and damage. In the Vargas State, the disaster destroyed lifelines such as roads and drinking water supply systems, and partially devastated seven population centers in the coastal area. Thousand of houses were destroyed and many people lost their lives.

In the Caracas Metropolitan Area, the debris flow was fortunately small compared with that of the Vargas State, probably because of less rainfall, but still more than 300 landslides and slopes collapsed at some 70 locations, some 100 people were missing or dead.

Besides this, the Metropolitan Caracas is located on a series of alluvial fan, which is susceptible to suffer from earthquake effect. Historically in 1967, an earthquake, which recorded magnitude 6.4, took place in the Caracas area resulting in serious damage on buildings and at least 274 casualties. Because two oceanic plates and a continental plate adjoin near Caracas, seismic movements frequently jolt the area. Therefore, some catastrophic earthquake could take place in the future.

As mentioned above, the Metropolitan Caracas has experienced serious disasters due to both sediment flows and earthquakes and there is still a high possibility of such disasters.

In November 2001, the Law of the National Organization of Civil Protection and Administration of Disasters was enacted and the legal framework for disaster prevention was established. Also, after the experience of the 1967 earthquake and the 1999 sediment disaster, governmental agencies and research institutes have been conducting investigation of past major disasters and preparation of hazard maps. Some local communities are implementing disaster prevention activities. Thus Venezuela has started to work on disaster prevention.

The boundaries of the Metropolitan District are those of the Libertador Municipality, which replaces the Capital District, and the Municipalities of Sucre, Baruta, Chacao and El Hatillo, of the Miranda State. Article 18 of the Constitution of the Bolivarian Republic of Venezuela establishes the following: "The city of Caracas is the Capital of the Republic and setting of the Organizations of the National Power".

In that sense, the Special Law about the Regime of the Metropolitan District of Caracas was approved and published in the Official Gazette No. 36906 on March 8, 2000. Its purpose is to regulate the creation of the previously mentioned Government of the Metropolitan District of Caracas, and create the bases of its government regime, organization, operation, administration, responsibilities and resources. Therefore, the Metropolitan District of Caracas is autonomous within the limits of the Constitution and the Law, and its representation will be exercised by the organizations determined by the Law.

Therefore, the Metropolitan Government has as its main objective to contribute and minimize the vulnerability level of the District, by developing strategies that lead to the creation of a Master Plan for Natural Disaster Prevention.

1. 3 Objectives of the Study

The objectives of the Study, included in the Scope of Work, are as follows:

1. To formulate a master plan in order to prevent the Metropolitan District of Caracas from damage resulting from natural disasters due to sediment, mass movement or earthquake.
2. To conduct a feasibility study on urgent and priority project(s).
3. To transfer technology to the counterpart personnel in the course of the Study.

1. 4 Study Area

As a whole, the study area includes two different aspects: one for earthquake disaster prevention and another for sediment disaster prevention formed by debris flow, landslide and steep slope failure.

The area destined to the earthquake aspect covers all the territory of the Libertador, Sucre and Chacao Municipalities. The study area for sediment disaster is specified in the Figure 1.4.1, and covers all the previously mentioned municipalities limited from north to south by El Avila Mountain Range to the North and the Guaire River to the South, to the East the Caurimare Stream in the Sucre Municipality and the Caroata and Agua Salada Streams to the west.

1. 5 Study Organization

The organization of the JICA Study Team is showed in Figure. 1.5.1.

The members of the JICA Study Team are showed in Table 1.5.1.

Given the clearly established responsibilities and due to the complexity of the study, the Metropolitan Government, through its International Cooperation Direction, invited different institutions from national, regional and municipal level to participate and join knowledge and efforts to make a Metropolitan Disaster Prevention Master Plan, that can later be used as a National reference to formulate a National Disaster Prevention Plan, and also to apply the same methodology for the Municipalities of Baruta and El Hatillo.

For this, a task force has been made, integrated by a General Coordination, through the Metropolitan Direction of International Cooperation, a Steering Committee, Technical Committees and the National Counterpart Team as showed in Figure 1.5.2

The members of the Venezuelan counterpart team are showed in Table 1.5.2.

1. 6 Composition of the Final Report

This Final Report is composed of the following volumes;

Summary Report	English
Summary Report	Spanish
Main Report	4-English
Main Report	Spanish
Supporting Report	English
Supporting Report	Spanish
Data Book	English
Data Book	Spanish
Maps	English
Maps	Spanish

1. 7 Limitation of the Study

There are following limitations of the Study. As the Study has been done with the following limitations, it is necessary to continue further investigations and discussion in order to supplement those limitations.

(1) Study Area

Although, the title of the Study is "Study on Disaster Prevention Basic Plan for the Metropolitan District of Caracas", the Study area does not cover all the five municipalities in the Metropolitan District, namely Libertador, Chacao, Sucre, Baruta and El Hatillo. The Study area is limited to the three municipalities, namely Libertador, Chacao and Sucre. This is because the Scope of Work signed in March 21st, 2002 defines it and the Minutes of Meetings signed at the same time says that " In the future the Metropolitan District of Caracas office of the Mayor will apply knowledge and methodology obtained through the course of the Study to formulate disaster prevention plan for Baruta and El Hatillo municipalities". It is expected that the Venezuelan side will formulate the plan for the rest of the Metropolitan District of Caracas based on the idea stated in the Minutes of Meetings.

(2) Legal Status of the Restlu of the Study

According to the "Law of the National Organization of Civil Protection and Administration of Disasters (Ley de la Organización Nacional de Protección Civil y Administración de Desastres) ", regional disaster prevention plans shall be proposed by the regional Civil Protection offices to the Coordination Committee for Civil Protection and Administration of Disasters in each region for final authorization. Therefore, the Disaster Prevention Plan prepared in the Study shall be reviewed by the

Metropolitan Civil Protection and shall be proposed to the Metropolitan Committee for Civil Protection and Administration of Disasters for final authorization.

(3)Employment of deterministic approach in earthquake disaster prevention

There are two approaches to evaluate the effect of earthquake, deterministic and probabilistic.

In this study, deterministic approach is employed, which defines several scenario earthquakes and estimates ground motions and its damages to establish a plan for earthquake disaster prevention.

On the other hand, the probabilistic approach considers all possible earthquakes that would affects the study area, to estimate the ground motion for fixed period of time and fixed probability of occurrence. The result ground motion is not the one that would happen during an earthquake, and will be used for the establishment of seismic code or calculation of insurance premium.

In this study, deterministic approach is employed and its results are used to prepare an emergency response plan, since the object of the study is to establish an earthquake disaster prevention plan. With respect to the seismic reinforcement plan of existing buildings, all the necessary buildings were considered, because the area that needs reinforcement cannot be specified due to the fact that the location of future earthquake cannot be predicted.

(4)Effect of scenario earthquake

In this study, typical past earthquakes were considered as scenario earthquake, because the earthquake prediction for future events is difficult. Scenario earthquakes considered in this study do not mean the prediction nor prophesy of earthquake in the future, but they should be used to understand the magnitude of damage in case same earthquake that occurred in the past happens today.

As there are numerous studies regarding the past major earthquakes, several models can be developed regarding the fault location of scenario earthquake. In this study, model that can best reproduce the observed damage or ground motion was adopted. It should be noted that higher damage degree in the northwestern part of Caracas metropolitan area by the 1967 and the 1812 scenario earthquakes are due to the fact that those earthquake fault are located in the northwestern part of Caracas.

(5) Damage function of buildings

In this study, statisitcal treatment is necessary to estimate damage of all the building in the study area by scenario earthquake. For this reason, the whole buildings needs be classified into several groups. While strucurral details such as configurations, irregularity, and disposition of wall are important factors to inspect individual buildings. However, basic factors such as structural type, year of construction, and number of floors are used to classify buildings for statistical damage estimation of all buildings in this study.

The damage function used in this study to estimate buildings' damage was developped through discussion with experts in FUNVISIS using earthquake damage data in Europian countries and the 1967 Caracas earthquake, based on EMS-98 (European Macroseismic Scale 1998). The defined function was calibrated by observed damage by the 1967 Caracas earthquake.
It sould be noted that building database of urban area was developped by field sampling in this study, because cadastral database was not a complete one. Building database for Barrio was developped also by estimation using the relationship between area and number of houses in Barrio. Development of better quality database as well as damage study by statistical manner during major earthquake would be necessary to improve the methodology.

(6) Barrio Building breaking test
The building breaking test was executed to obtain a data on strength of houses in Barrio area, in addition to make an educational material to promote seismic reinforcement. By this nature, the test does not intended to propose a concrete method of reinforcement. As this kind of experiment was made for the first time in Venezuela, yet only four models are tested, it is recommended to continue this kind of experiment by Venezuelan side in the future.

(7) Exclusion of Flood and Urban Draiange Problems
The sediment disasters defined in the Study does not include flood problems nor urban drainage problems. Flood problems are for example, the inundation around Gaire River because of mal-cpacity of the river course. Urban drainage problems are for example, the inundation in the urban area because of mal-capacity of drainage system when a heavy rainfall ocures in the urban area itself. Both problems are different from sediment disasters defined in the Study (debris flow, land slide and steep slope failure) and are excluded from the Study Scope.

1. 8 Acknowledgements

All of the work presented in this Final Report has been accomplished thanks to the contribution of several public and private institutions, communities and non-governmental organizations. We sincerely acknowledge the fruitful cooperation and support of the Government of the Metropolitan District of Caracas, specially the Direction of International Cooperation as general coordinator of the Study, the Metropolitan Firefighters Department for making their facilities available, and the Direction of Civil Protection of the Metropolitan District for its kind support and contribution to the Study. Also, we would like to thank all the people and organizations that provided essential information and expertise, and those who had an instrumental role in making this international cooperation study possible. We would like to express our sincerest gratitude to all Venezuelan

counterpart who worked together with us through all stages of the Study, and all the people who participated in the exhaustive revision of this document. Our sincerest regards are to the following institutions:

ADMC, Direction of International Cooperation

ADMC, Direction of Public Works and Services

ADMC, Finance Secretary

ADMC, Secretary of Urban Planning and Environmental Management

Anauco Community

Andean Financing Corporation (CAF)

Catuche Community

Caracas Subway Rescue Group

Center for Integral Environmental Studies/Central University of Venezuela (CENAMB, UCV)

Civil Protection, ADMC

Civil Protection, Carabobo State

12 de Octubre (Petare) Community

Electricity of Caracas

Fifteen (15) Communities in Social Vulnerability Survey

Fluid Mechanics Institute/ Central University of Venezuela (IMF, UCV)

Geographic Institute of Venezuela Simon Bolivar

Hidrocapital and all its dependencies

Implementation Center for Environmental and Territorial Development Research (CIDIAT)

Institute of Psychology / Central University of Venezuela (UCV)

Institute for Experimental Development of Construction/Central University of Venezuela (IDEC, UCV)

Institute of Material and Structural Modeling/Central University of Venezuela (IMME, UCV)

La Floresta Community

Local Support Service A.C. (SOCSAL)

Los Chorros Community

Los Laños Community

Margarita (La Vega) Community

Metropolitan Civil Protection

Metropolitan Firefighters Department

Metropolitan Police

Ministry of Education

Ministry of Environment and Natural Resources and all its dependencies

Ministry of Foreign Affairs

Ministry of Infrastructure

Ministry of Planning and Development and all its dependencies

Ministry of Science and Technology

Municipality of Chacao and all its dependencies

Municipality of Libertador and all its dependencies

Municipality of Sucre and all its dependencies

National Anonymous Telephone Company of Venezuela (CANTV)

National Assembly (Congress)

National Civil Protection Direction

National Fund of Science, Technology and Innovation (FONACIT)

National Fund for Urban Development (FONDUR)

National Geological and Mining Institute (INGEOMIN)

National Housing Commission (CONAVI)

National Statistics Institute (INE)

Pan-American Health Organization (PAHO)

Petroleum of Venezuela S.A. (PDVSA)

San Bernandino Community

School of Political Science/Central University of Venezuela

Institute of Regional & Urban Studies /Simon Bolivar University (IERU USB)

Team of Volunteers, Metropolitan District

Venezuelan Foundation for the Seismic Investigations (FUNVISIS)

Venezuelan Red Cross

World Health Organization (WHO)

Table 1.5.1 List of JICA Study Team Members

Nº	AREA	JICA STUDY TEAM
1	Project manager / planner on urban disaster prevention	**M. Miura**
2	Project joint manager / urban planner / socio-economical analyst / project assessor	**T. Kudo**
3	Eng. of earthquake disaster prevention / earthquake engineer	**Y. Yamazaki**
4	Geotechnical engineer	**I. Tanaka**
5	Seismic structure designer (1)	**H. Kagawa**
6	Seismic structure designer (2)	**K. Shono**
7	Seismic structure designer (3)	**A. Inoue**
8	Infrastructure damage prevention designer	**T. Ueno/Y. Kobayashi**
9	Lifelines / infrastructure expert	**K. Ito**
10	Specialist in debris flow disaster prevention	**K. Inoue**
11	Specialist in topographical / geological studies / aerial photographical analysis	**F. Yokoo**
12	Specialist in topographical / geological studies / aerial photographical analysis	**T. Hara**
13	Specialist in hydrology / hydraulics / debris flow analysis / floods	**Y. Uchikura**
14	Expert in facilities design / cost estimation	**T. Kasahara**
15	Expert in GIS system design / database	**Bishwa Raj Pandey**
16	Expert in disaster prevention administration / legislation	**Bruce P. Baird/ W. Siembieda/ A. Linayo**
17	Expert in education / people organization (1)	**Paulina Chaverri**
18	Expert in rescue operations / health operations	**José Carlos Yamanija**
19	Expert in environmental evaluation	**Y. Muramatsu**
20	Coordinator / expert in education / people organization (2)	**H. Tomizawa**

Table 1.5.2 List of Counterpart Team Members

Nº	JICA STUDY TEAM MEMBERS	V. COUNTERPART	INSTITUTION
1	**M. Miura**	**William Martínez**	Metroplitan Civil Protection, Director
2	**T. Kudo**	**José Frá**	Metropolitan Civil Protection Sec. Plan.and Urban.Ord.,ADMC
3	**Y. Yamazaki**	**Michael Schmitz**	FUNVISIS
4	**I. Tanaka**	**Jesús Guerrero**	INGEOMIN
5	**H. Kagawa**	**Jorge González**	FUNVISIS
6	**A. Inoue**	**Julio Hernadez**	FUNVISIS
7	**K. Shono**	**Mariana Lotuffo**	FUNVISIS
8	**T. Ueno/Y. Kobayashi**	**Brau Clemente**	Infrastructure, ADMC
9	**K. Ito**	**Luz Chacón**	Cadastre - Sucre
10	**K. Inoue**	**Reinaldo García**	Fluids Mechanics Inst.
11	**F. Yokoo**	**Marylin Manchego** **Luis Melo**	INGEOMIN FUNVISIS
12	**T. Hara**	**Annie Castañeda**	Metropolitan Civil Protection, ADMC
13	**Y. Uchikura**	**José Pereira** **Giannina Paredes**	Air Force-Meteorology Fluids Mechanics Inst.
14	**T. Kasahara**	**Karen Jiménez**	Infrastructure, ADMC
15	**Bishwa Raj Pandey**	**Virginia Jiménez** **Giselle Croce** **Aldo Zamora**	Risk Map-IGVSB MARN Metropolitan Firefighters
16	**Bruce P. Baird/** **W. Siembieda/** **A. Linayo**	**Evelys España**	National Civil Protection
17	**Paulina Chaverri**	**Clementina Massiani** **Fidel Frontén**	Metrop. Civil Protection Metropolitan Firefighters
18	**José Carlos Yamanija**	**Felipe Aranguren /** **Gerardo Rojas /** **Mauro Aponte**	Metrop. Civil Protection Metropolitan firefighters Chacao Civil Protection
19	**Y. Muramatsu**	**Gila de Falcón**	Environment Office, ADMC
20	**H. Tomizawa**	**Marianela Gómez**	National Civil Protection

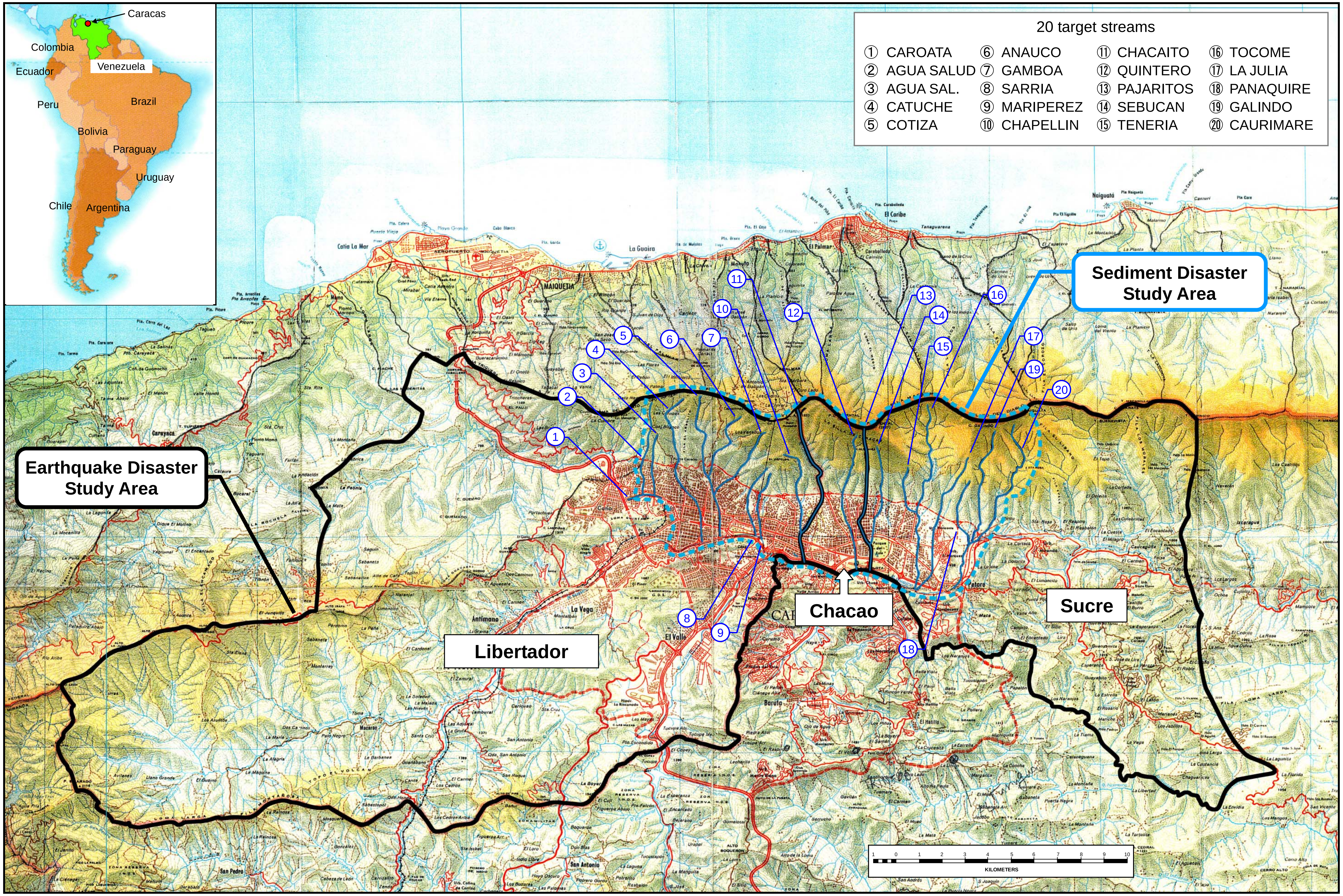

Figure.1.4.1 Study Area Map

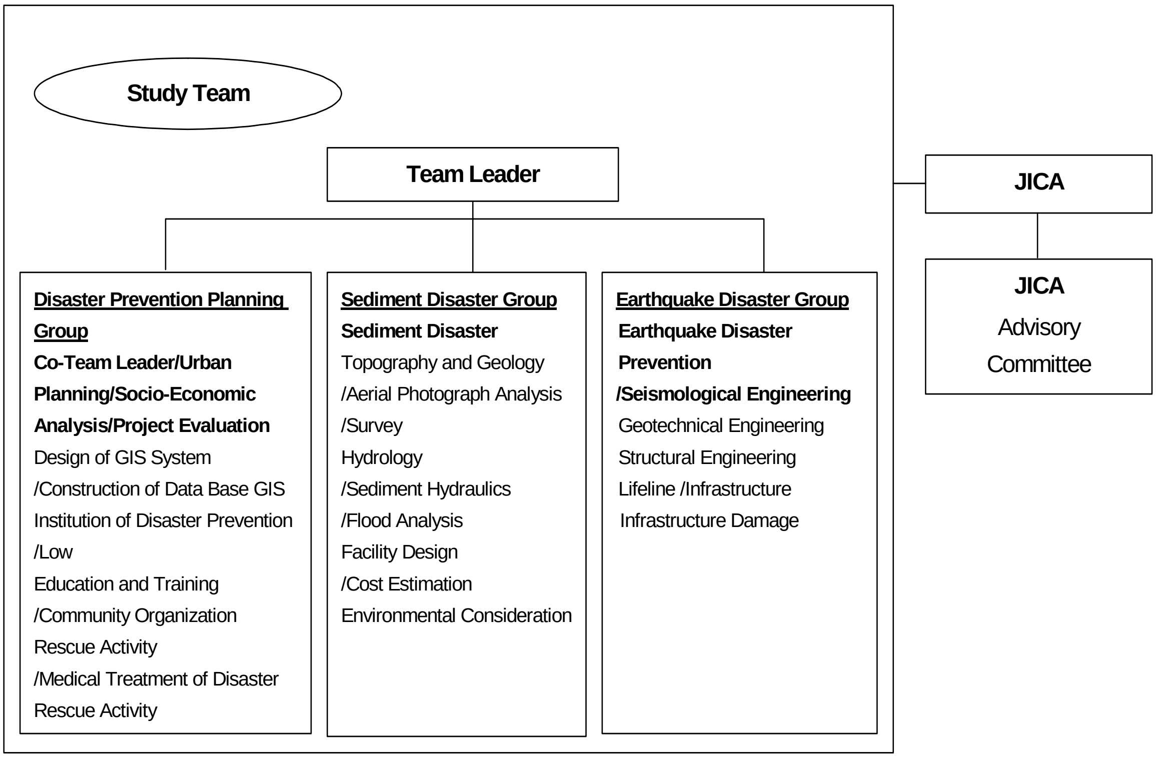

Figure 1.5.1 Organization of the Study Team

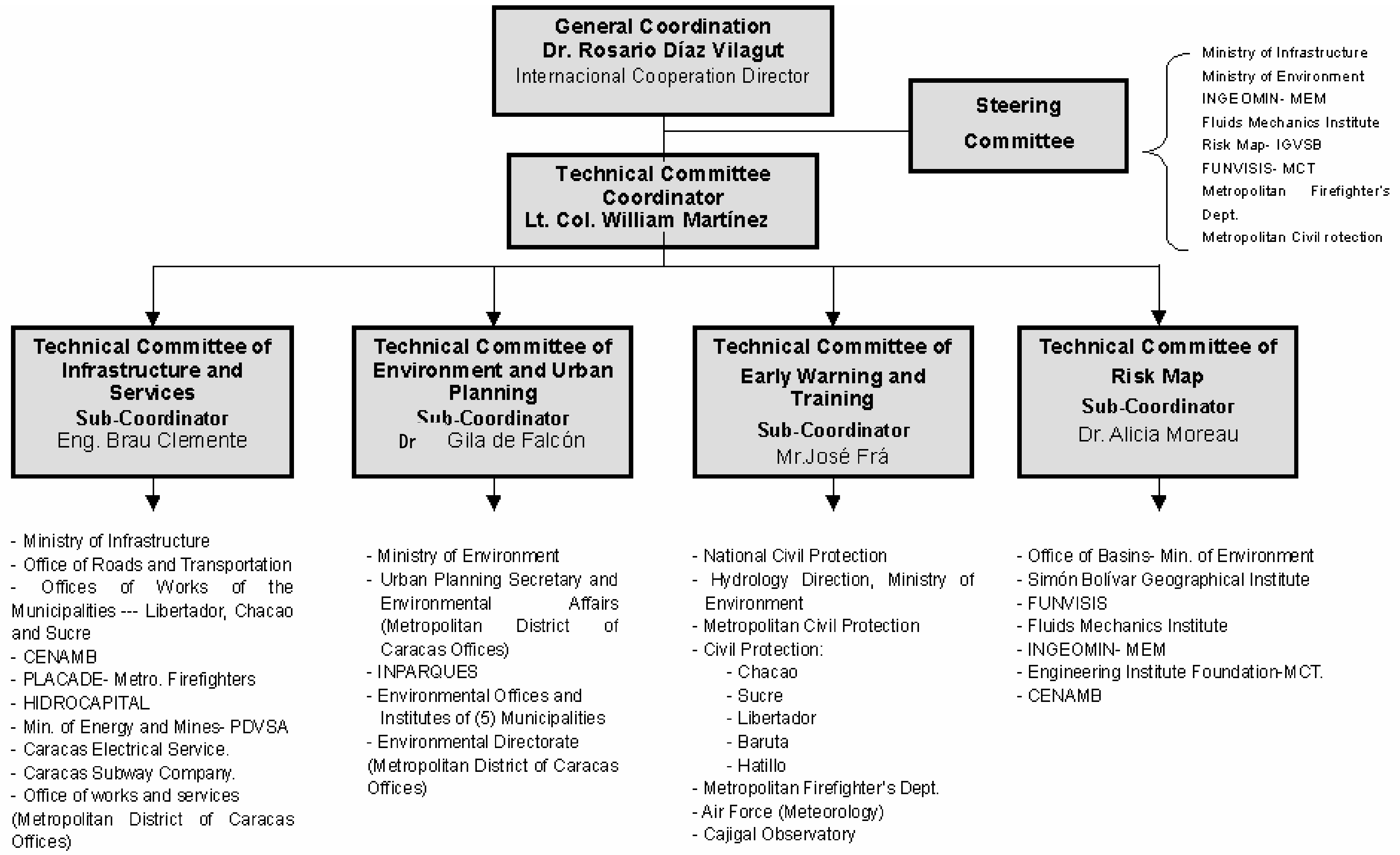

Figure 1.5.2 Organizational Flow Chart of the Venezuelan Counterpart

CHAPTER 2

EXISTING CONDITIONS

“The prevention of disasters is part of your life"

Antonio Aguilar M.

CHAPTER 2. EXISTING CONDITIONS

2. 1 Natural Conditions

2. 1. 1. Topography and Geology

The area of Caracas can be subdivided into three topographic units (listed below from north to south), which form part of La Costa Mountain Range.

- *Topographic Unit 1, represented by the Avila Massif, with 2,765 m above sea level (m.a.s.l.) as maximum height (Naiguata Peak).*

- *Topographic Unit 2, comprised by the Caracas Valley, with heights that do not surpass 900m.*

- *Topographic Unit 3,* formed of hills at the east, west and south of Caracas, with heights between 1,200 and 1,500 m.a.s.l.

The Caracas area is lithologically formed by rocks that belong to the Avila Metamorphic Association and the Caracas Metasedimentary Association (RODRÍGUEZ et. al, 2002).
The Avila Metamorphic Association extends from Carabobo State to Cabo Codera, Miranda State (from west to east, respectively) and covers the southern part of the Avila Massif, in the area between the Avila's crest until the contact with the quaternary sediments that fill Caracas Valley, at about 900 – 1,000 m.a.s.l. It is formed of the metamorphic rocks of the San Julian Complex and the Peña de Mora Augengneiss.

The Avila Metamorphic Association rocks are from Pre-Cambrian to Paleozoic ages, and they are representatives of a continental crust passive margin, representing an exhumed basement, where the foliation shows large-scale antiforme structure. The Avila Massif is a horst structure, mainly controlled by Macuto, San Sebastian and The Avila faults (URBANI 2002).

The Caracas Metasedimentary Association is a continuous belt oriented E-W, which extends from Yaracuy State to the Barlovento Basin, Miranda State; it covers the 2 and 3 topographic units, with a fault contact with the Avila Metamorphic Association in the North (the Avila Fault). This Asociation is formed of Las Mercedes and Las Brisas Schists.

2. 1. 2. Meteorology and Hydrology of the Study Area

The climate of the Caracas Valley is affected by the North-Northeast trade wind, the South-Southeast trade wind, the position of the Inter Tropical Convergence Zone (ITCZ) and the topography of El Avila Mountain. The Caracas Valley is located at latitude 10 degree 30 minutes in the northern hemisphere and is within ITCZ, thus it is affected by unstable atmosphere. When ITCZ shifts close to the equator, the north and northeast wind become dominant over the entire Venezuelan territory as well as the Caracas Valley.

The annual rainfalls in the Cajigal and La Mariposa Stations are 834.8 mm and 891.2 mm, respectively whereas those in Maiquetia and Los Caracas, which are located in the Vargas State, are 530.4 mm and 1,091 mm, respectively. In Cajigal and La Mariposa, the rainy seasons are identical from May-June to November. The monthly average temperatures in Maiquetia and Los Caracas are higher than 25°C, however, those in Cajigal and La Mariposa are lower than 21°C because they are located at high altitude.

The Guaire River flows from Los Teques through Caracas Metropolitan Area to join the Tuy River in Miranda State and the catchment area is about 546 km^2 at Baloa Bridge in Petare and is 652 km^2 after the confluence of the Hatillo stream. The tributaries of the upper part of the Guaire River are the San Pedro River, Macarao River. The mountain streams from the Avila are the left side tributaries joining to the middle reach of the Guaire River. Also El Valle River having the Mariposa Dam watershed and the Guairita River in Municipality Baruta are joining to the middle and lower reach of the Guaire river from right side.

The riverbed slope of the main stream of the Guaire River varies from 9 meter / km in upstream reach to 2 meter / km in La California Sur at Petare.

2. 2 Socioeconomic Conditions

2. 2. 1. Administrative System

(1) Metropolitan District of Caracas

The Metropolitan District of Caracas is formed by five municipalities: Libertador, Chacao, Sucre, Baruta, and El Hatillo. During 1960's, this area was integrated by two districts, namely Sucre District and Federal District, as shown in Figure 2.2.1. In year 1977, the Sucre District was divided into four municipalities, namely Chacao, Sucre, El Hatillo, and Baruta. At the same time, the Federal District was divided into the Libertador and Vargas. In year 2000, the National Assembly, by mandate of the Constitution (Article No. 18), promulgated the "Special Law of the Caracas Metropolitan District Regime" (Official Gazette No. 36.906 of March 08, 2000). This Law establishes that the Metropolitan District of Caracas is formed by five municipalities as stated above (Figure 2.2.1). It should be noted, however, that four of these municipalities, namely Chacao, Sucre, El Hatillo and Baruta, are geographically located in the territory of the Miranda State even after the establishment of the Metropolitan District of Caracas.

The Mayor of the Metropolitan District of Caracas is the highest civil, political and administrative authority of the Metropolitan District, and is supported by a Government Council as an organization of superior consultation. The mayors of the five municipalities that form the Metropolitan District of Caracas integrate this Council.

(2) Municipal Administrative Units

The Administrative unit below the municipality level is called *Parroquia*. At present, Libertador consists of 22 parroquias, Chacao forms only one parroquia, and Sucre has five parroquias, as shown in Table 2.2.1 and Figure 2.2.2.

2. 2. 2. Population

According to the "2001 Census", Metropolitan District of Caracas has 3,090,447 people, accounting for 12.4% of the national total of 24,915,902. The study area has 2,740,381 people, accounting for 88.7% of the Metropolitan total. Libertador has 2,061,094 (75.2% of the study area), Chacao 71,806 (2.6%), and Sucre 607,481 (22.2%), as shown in Table 2.2.2.

Population of Caracas increased by 1.28% per annum from 1990, according to the last 3 census, much lower than a national average of 2.95% per annum. The study area recorded 1.25% per annum, with Libertador 1.12%, Chacao 0.65%, and Sucre 1.77%. Among the parroquias, El Junquito of Libertador shows highest growth rate at 3.56% per annum. In addition, Antimano (1.85%), La Candelaria (1.41%), La Vega (1.89%), Macarao (1.61%), and San Agustin (1.59%) show higher rate than the average of the Metropolitan District. Only San Bernardino of Libertador decreased its population by 0.76% per annum.

2. 2. 3. Economic Structure

Venezuela's GDP (Gross Domestic Product) recorded in 2003 was a total of 137,368,156 Million Bs (85.8 Billion US$, at 1602 Bs per dollar), 30,142,451 Million Bs (29.4%) by Public sector and 3,587,468 Million Bs (70.6%) by Private sector as shown in Table 2.2.3. Services sector accounts for 54.0% to the GDP, followed by petroleum (25.4%) and good production (18.5%). Government is predominant in Petroleum activity because of PDVA. Petroleum activity of government alone accounts for 22% of the national GDP. Private sector is dominant in non-petroleum activities as good production and service, occupying around 90 % of these sectors.

Venezuelan GDP per capita is 4,080US$ in 2002, 4,780US$ in 2001, and 3,540US$ in 2000, according to World Bank's country profile data.

Reflecting the economic characteristics of the Metropolitan District, employment in service supply (tertiary sector) of Caracas is dominant, accounting for 79% of the total employment of 1,444,360 persons in 1997, and increasing its share from 74% in 1990 to 78% in 1995, as shown in Table 2.2.4.

Employment in Caracas accounts for 17.9% of the total national employment rate; employment in tertiary superior sector accounts for 48.9 % of the national total, as shown in Table 2.2.5. The other important economic activity in the metropolitan area is transport and communication. Service and manufacturing appear third in the study area.

Venezuela has been suffering from an economic depression in the last two decades that deteriorated wages, creating general impoverishment of the national population since 1983. The unemployment rate of Caracas was at 9.8% in 1997, smaller than the national average.

Another feature about Caracas economy is its unregulated informal sector, which has grown very quickly, from 35.5% in 1990 to 48.6% in 1997.[1] In the metropolitan area informal sellers are found here are there as a result of the high unemployment rate.

2. 3 Development of the Study Area

2. 3. 1. Brief History of Growth of Caracas

Caracas was founded on July 25, 1567 and became the third capital of Venezuela in 1577.[2] The first map of Santiago de Leon de Caracas drawn up in 1578 shows that the city had 25 blocks altogether with the Plaza Mayor (Plaza Bolivar at present) as its center. According to the census taken by the colonial government in 1580, the city had 2,000 inhabitants. The city grew southward to the Guaire River and westward to between the Caroata and Catuche Rivers (Figure 2.3.1).

In June 1641, an earthquake hit the city, killing 300 to 500 people, damaging buildings and churches[3]. At the end of the seventeenth century, the city had about 6,000 inhabitants. The city grew as result of the introduction of coffee growing in the valley and expanded to hold 20,000 inhabitants in 1776. In 1812, an earthquake, estimated at about 7.1 on Richter scale, hit Caracas, and killed some 2,000 people[4], destroyed two thirds of the buildings, and cracked the rest of the buildings. Caracas had

[1] Strategic Plan of Metropolitan Caracas 2010 (Plan Estrategico Caracas Metropoli 2010), "Una Propuesta para la ciudad."
[2] Coro was the first in 1527-46, El Tocuyo the second in 1547-1577.
[3] Jiménez Díaz ,Virginia, "*Slope Failure in Caracas, Venezuela: the Influence of Squatter Settlement*," Thesis submitted for the Degree of Doctor of Philosophy at University of London, Aug. 1992, p 50.
[4] Altes, R., "Terremotos donfundidos: los sismos del 26 de Marzo de 1812 en Caracas y Mérida an Venezuela," USB,

70,509 people living in 9,224 houses in 1883, according to the census taken then. Population grew evidently with the construction of El Paraiso, urbanization or housing estate south of the Guaire River which was developed replacing the old farms (haciendas) there (Figure 2.3.2).

Then the oil boom came in the 1920s, which changed things rapidly. The development of the petroleum industry caused the beginning of migrations from the countryside (rural areas) to the city, which produced the urban expansion phenomena.

In the decade of the 1930s, many agricultural lands were developed into urban use: areas such as El Silencio, El Calvario, and Parque Los Caobos, La Florida, Mariperez, Las Delicias, Country Club, etc. were developed, gradually replacing the haciendas. In 1941, the population of the city was 269,030 inhabitants according to the census. Also, the Second World War expanded the oil boom, and more *urbanizations* were constructed. This then attracted barrio growth, and ten years later the area occupied by the barrios was five times bigger.[5] (Figure 2.3.3)

During the 1950s, the city expanded even more. The city had grown from an urban area of 4,000 ha in 1950 to 11,500 ha in 1966 (Figure 2.3.4). The central area of the city became a center of employment; this was supported by the government with the construction of the Simon Bolivar Center (a group of buildings for government offices).

During the 1960s, the central area kept attracting residential activities with high densities and also commercial activities. The most important stores, banks and government offices were located between Bolivar Avenue and Urdaneta Avenue. In the 1970s, the rapid growth of the high density development gave Caracas its metropolitan character, but at the same time caused many serious problems. During this period, high class neighborhoods were located in the east (Sucre Municipality). Middle class lived in houses or in apartments located in the east and in the center of the city. Low income people besides those who lived in barrios, lived in big but old houses (El Conde, La Pastora) or in old apartments located in the central area (Libertador Municipality).

The improvement of living standards caused an increment in the number of private cars in traffic, due to this problem the construction and widening of the road network was stimulated. In the decade of the 1980s, only a small change was observed in the urban structure. The neighborhoods in the southwest increased the density and some new residential areas appeared in that part of the city.

In the 1990s, the economic stagnation made it difficult to buy houses, not only for low income people, but also for middle class people. Many families divided the inside of their houses or bought land

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Caracas (en prensa)/contiene mapas, 2000

[5] Perma, C., *Evolucíon de la Geografía Urbana de Caracas*, Ediciones de la Facultad de Humanidades y Educacíon, Universidad Central de Venezuela, Caracas, 1981, p.120.

without basic utility services, thus decreasing their standard of living. Barrio areas are in process of expansion, taking areas that belong to urban parks or as a process of its densification. Reduced options to obtain places to live in Caracas, push people to peripheral areas outside the city, generating a new demand for transportation.

2. 3. 2. Urban Planning Aspects

(1) Urban Development Plan

The strategic and economic development plans for the government administration periods are based on the Organic Law of Municipal Régime (LORM) and the new Planning Law. On the other hand, the territorial plans are based on the Organic Law of Urban Ordinance (LOOU) that refer to special aspects and variables of urban development which are being planned for a long term range.

Municipality should formulate its own Local Urban Development Plans (Planes de desarrollo Urbano Local, PDUL) as indicated in the Organic Law of Urban Ordering (Ley Orgánica de Ordenación Urbanística, LOOU) of the year 1987. The first PDUL began to be formulated in Libertador, Chacao, Baruta and El Hatillo municipalities. Until this date they have not been sanctioned.

In the case of the Metropolitan District of Caracas, the following plans are applied: the municipal development plans, the PDUL and the Metropolitan Urban Development Plan (Plan de Desarrollo Urbano Metropolitano) which is being formulated by the Secretariat of Urban Planning and Environmental Management (Secretaria de Planificación Urbana y Gestión Ambiental) of the Metropolitan District of Caracas.

Although there is not any integrated development plan of the Metropolitan District of Caracas yet, each municipality and the Metropolitan District of Caracas should formulate consistent plans through inter-municipal coordination mechanisms among the relevant organizations at national, state, metropolitan, and municipal levels.

2. 3. 3. Barrio Area

(1) Barrio Area Characteristics

Spontaneous urban growth, uncontrolled or self produced settlement in Venezuela is known as "*barrio*." They are formed by "*ranchos*" (houses), and constitute a dynamic form of occupation in urban cities. Barrios are the product of migrations from the rural areas or from other cities of the country, attracted by the prosperity and economic opportunities that the metropolis offered.

The arbitrary occupation of the urban space is located mainly at the northwest, southeast, west, and east of the Caracas Valley, with some isolated barrios included in the urban area. The self produced settlements have been increasing both in the river banks and in the hillside areas. In may cases, invaders use scrap materials such as wood boards, metal sheet, cardboard etc, which are later are substituted by bricks and concrete. This continuous process has caused that many barrios get consolidated and their ranchos reach heights up to 6 floors with deficient structures and services.

(2) Magnitude of the Barrio Area[6]

A large portion of the population of Caracas occupies barrio areas. Barrio population is overwhelming in Libertador and Sucre municipalities. According to the 2001 census, barrio population is 1,403,414[7] for the Study Area, accounting for 51.2 % of the total population, 2,740,381, with Libertador 1,075,871 (52.2% of the total municipal population), Chacao 4,511 (6.3 %), and Sucre 323,032 (53.2%). From 1990 to 2001, barrio population grew by 382,758 people from 1,020,656 in 1990. About 27.3 % of the present barrio population has been grown during the decade.

Barrios emerged at earliest in 1917 and has kept invading into various parts of Caracas. Figures 2.3.3 to 2.3.7 show the extension of barrio areas. The 1941 census showed that Caracas had a population of 269,030 people. The urban area measured 2,900 ha, up from 300 ha in 1900. The oil boom triggered by the Second World War II expedited more urban development. At the same time, barrios grew rapidly and covered more of the city area. In 1951, barrios occupied about 1,000 ha of land. By around 1966, most of the flat land of the city was developed and urbanized, also the invasion of hillsides by barrios became more frequent. In 1971, barrios occupied 2,973 ha. By 1985, 61% of total population of the Metropolitan Area of Caracas (including Vargas) lived in barrios. Barrios covered an area of 3,657 ha in 1978, and 4,157 ha in 1985.[8] In 1990, FUNDACOMUN estimated, using the Second National Barrio Inventory (II Inventario Nacional de Barrios), that 77.58% of the total population lived in 406 barrios (354,097 houses) in the Metropolitan Area of Caracas (including Vargas).

[6] Jiménez Díaz (1992)

[8] Briceño-León, R. *El Futuro de las Ciudades Venezolanas*, Cuadernos Lagoven, Caracas, 1986

Based on the base map of the GIS data of the JICA Study Team[9], barrio area of the Study Area covers 4,341 hectares. The barrio areas account for around 20% of the urbanized area except for national park, protected area, and undeveloped areas in the Study Area. (Figure 2.3.7)

(3) Government Policies

Venezuelan government has tried to integrate barrio areas with urban areas. Reflecting this, actually, the policy of barrio improvement has been conducted. Many governmental institutions are promoting solutions for housing problems in barrio areas. Such institutes include CONAVI, FUNDACOMUN, FUNVI, FUNDABARRIOS and FONDUR, and municipalities as well as international organizations like the World Bank.

However, because of the magnitude of barrio, such efforts have not solved barrio issues effectively and have not generated a land policy, a program of plots with services, or a programmed development with technical assistance.

2. 4 Existing National Development Plan Related to Disaster Management

(1) National Plan for Regional Development

A National Plan for Regional Development (2001-2007) was formulated by the Ministry of Planning and Development in 2001. This Plan presents important elements to consider in order to articulate sustainable development in economic, social, political, institutional, territorial and international levels and to create the quality of life that Venezuelan people deserve. It contains objectives of social, economic, political-institutional, territorial and international integration, based on a strategy of decentralization, founded on participative democracy, transformation, productivity and equity, as well as the search of sustainable and balanced development, which generates better income distribution by better use of the regional potentials in Venezuela.

(2) National Plan for Economic and Social Development

A National Plan for Economic and Social Development (2001-2007) was formulated by Ministry of Planning and Development in 2001. The new development model for Venezuela in this plan stresses the balance of forces and factors that intervene in the multidimensional development of the country. At the same time the model promotes a sustainable and diversified capability of providing economic benefits and well-being for everyone.

The plan states that consensus solutions are to be sought as a base for the legitimacy of the country, promoting a society that is both democratic and co-responsible. These actions of society are to be manifested in the decentralization of decision making processes in order to spread the change dynamics to the total extension of the territory. These notions are expressed in five basic areas: Economic, Social, Political, Territorial, and International.

(3) National Plan of Territorial Order

The National Plan of Territorial Order (Plan National de Ordenacion del Territorio, 1998), has as objective to guide distribution of population, economic activities and physical infrastructure through harmonizing approaches of economic growth, social development, environmental protection and conservation, based on potentialities and restrictions of each geographical environment. The plan aims at the balanced growth of the nation through decentralization and deconcentration, and support to the territorial strategic urbanization process for economic efficiency, social justice, political invigorating.

And as one of its eight special objectives, the plan includes the promotion of actions directed to protect the population, economy and the environment before the occurrence of emergencies or disasters caused by nature, technology, and society.

2. 5 Disaster Prevention Administration and Legislation

2. 5. 1. Legal Framework for Disaster Prevention

The legal structure of laws as it relates to disaster mitigation and preparedness is shown in Figure 2.5.1. Relevant articles in various laws are listed by level. This provides the legal framework concurrency flow. In Figure 2.5.1, the main constitutional articles are cited at the national level. The main articles from the organic laws are highlighted as are the major metropolitan ordinances.

2. 5. 2. National Plan for Civil Protection and Administration of Disasters

According to the “Law of the National Organization of Civil Protection and Administration of Disasters,” “to elaborate and present the National Plan for Civil Protection and Administration of Disasters for the approval of the Coordinating Committee of National Civil Protection and Administration of Disasters” is the responsibility of the National Direction of Civil Protection and Administration of Disasters (Article 13). However, this national plan is under preparation and the preparation time schedule is not clear.

As the main focus of the National Civil Protection is “emergency response” rather than “mitigation,” the national plan of them may be oriented to that direction.

2. 5. 3. National Plan for Prevention and Mitigation of Disaster Risk

The Ministry of Planning and Development is preparing a "National Plan for Prevention and Mitigation of Disaster Risk" with the following objectives but the time schedule of the plan preparation is not clear.

Observing the following objectives, the national plan of the Ministry of Planning and Development may be oriented to "mitigation" of risk in national development planning.

- Establish the general framework of policies that will control the national actions related to the management of natural disaster risks, in order to contribute to reduce them;

- Provide the bases for channelling the efforts of the competent entities at national and local levels, establishing a binding and integrated framework for the coordination of the actions in prevention matters between the national and the decentralized levels and also the communities and private entities;

- Provide a reference framework to elaborate the sector and territorial prevention plans;

- Establish action priorities to reduce the socioeconomic impact generated by natural hazards or by antropic hazards associated to them with the purpose of optimizing the efforts (economic, human, etc.);

- Establish policies and normative mechanisms for institutional strengthening that will allow improving the institutional capacities and citizen organization, aiming towards accomplishing the introduction of the matters of prevention as a transversal subject within the process of planning and development management. For this, guidelines will be given to open institutional spaces, establish the national framework of disaster risk management and the support information system;

- Function as an instrument for participation and coordination among the authorities and the communities about the subjects of risk management, from the formulation stage; and

- Define relevant projects of national interest, which create positive dynamics to generate a culture of risk prevention in our society.

2. 5. 4. Metropolitan Plan for Disaster Management

The ADMC council passed the Urban Guidelines Ordinance, (September 2003) that again establishes the responsibility for efforts in disaster prevention. These actions include: citizen education on subject of the disasters (Art. 74), early warning systems and attention to mitigation measures (Art 75), information systems for disasters (Art. 76), and disaster prevention, especially in barrio areas (Art.

77). On March 9, 2004, the DMC council issued a degree establishing a metropolitan disaster coordination committee for civil protection and administration of disasters (CCCPAD). The CCCPAD functions are: (1) to plan, coordinate and develop activities with other governmental agencies and (2) to provide and coordinate measures for prevention, education, and administration of disasters. Thus, there is sufficient basis for the departments and agencies of the DMC to proceed with disaster mitigation and prevention activities.

2. 6 Activities of Other International Institutions

2. 6. 1. General

There are some activities of disaster prevention in the Metropolitan District of Caracas carried out by donors other than the Government of Japan in recent years. These include the comprehensive study of Columbia University on the disaster prevention in the area.

2. 6. 2. UNDP

In 2001, UNDP sponsored a study on "National Plan for Risk Management and Disaster Prevention/Mitigation" for Venezuela.[10]

The study is based on the Security and Defense Law (Ley de Seguridad y Defensa) which states that the Ministry of Justice and Interior Relations through its National Direction of Civil Defense, (Direccion Nacional de Defensa Civil) must attend the hazards and risks for the protection of the Venezuelan population.

The study covers the following items:

- Plan objectives and needs
- General strategic plan
- Plan actions
- Function of technical committee
- Financing plan
- Legal aspects
- Fundamental basis for the law to create the plan
- Implementation plan

[10] UNDP, National Plan for Risk Management and Disaster Prevention/Mitigation, July 21, 2001

- Institution
- Schedule and cost estimate

In the plan, objectives and needs are defined for: (1) disaster prevention and risk reduction, (2) effective response in case of disaster, and (3) fast recovery of affected areas.

The general strategic plan covers: (1) identification and evaluation of man-made and natural risks, (2) incorporation of risk reduction in the planning process, (3) planning of the capability of response, (4) Citizen participation in disaster prevention and mitigation, and (5) ensuring the financing.

Plan actions include: (1) hazard map evaluation, (2) high risk area, (3) technical and scientific training/capacity building, (4) guidelines and technical reference documents, (5) advisory technical committee, (6) resource inventory, (7) evaluation of the capability of operational response, (8) risk management, (9) educational program, (10) international assistance, and (11) information dissemination.

The Study gives general guidelines for financing of the plan, and preliminary estimate of the annual budget of 3.5 billion Bs during the five estimated years.

2. 6. 3. Study of Columbia University[11]

Columbia University of the USA conducted a study entitled "Disaster Resistance Caracas: urban planning studio – Spring 2001". The study covers earthquake disaster and sediment disaster for the Metropolitan District of Caracas. In that sense, this study has similarity with our Study.

"Disaster Resistance Caracas" is a rather comprehensive study from an academic group starting from the historical background of the city, the present conditions of the city, to make future development scenarios as the base of disaster prevention planning. Their concept of risk is expressed in the equation: Risk = Sum(Hazard x Assets x Fragility). Their research efforts are mostly from an urban planning approach while the scientific part is borrowed from Venezuelan researchers.

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[11] Columbia University, "Disaster Resistance Caracas; urban planning study – Spring 2001", 2001

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URBANI Franco (2002). Geología del área de la autopista y carretera vieja Caracas-La Guaira, Distrito Capital y Estado Vargas, guía de excursión (Geology of Caracas- La Guaira Highway and old road, Capital District and Vargas State, Field trip guide), Caracas, Geos 35, 27-41 page.

Table 2.2.1 Administrative Units in the Study Area - Name of the Parroquias in the Libertador, Sucre and Chacao Municipalities

Municipality	Parroquias	
Libertador	Altagracia, Antimano, Caricuao, Catedral, Coche, El Junquito, El Paraíso, El Recreo, El Valle, La Candelaria, La Pastora,	La Vega, Macarao, San Agustín, San Bernardino, San José, San Juan, San Pedro, Santa Rosalia, Santa Teresa, Sucre, 23 De Enero
Chacao	Chacao	
Sucre	Caucagüita, Fila De Mariches, La Dolorita, Leoncio Martínez, Petare	

Source: INE

Table 2.2.2 Population of Caracas

Municipal/Parroquia	Population (1990)	Population (2001)
Metropolitan District	**2,685,901**	**3,090,447**
Study Area	**2,390,987**	**2,740,381**
Libertador	**1,823,222**	**2,061,094**
Altagracia	42,724	44,101
Antimano	117,179	143,343
Caricuao	141,064	160,560
Catedral	4,821	5,422
Coche	49,834	57,276
El Junquito	29,024	42,658
El Paraiso	98,647	111,354
El Recreo	96,574	107,935
El Valle	133,900	150,970
La Candelaria	51,432	60,019
La Pastora	82,937	90,005
La Vega	111,574	137,148
Macarao	40,670	48,479
San Agustin	38,527	45,840
San Bernardino	29,348	26,973
San Jose	40,584	40,709
San Juan	98,009	104,471
San Pedro	55,967	63,274
Santa Rosalia	103,975	117,993
Santa Teresa	20,891	21,311
Sucre	354,012	395,139
23 de Enero	81,529	86,114
Chacao	**66,897**	**71,806**
Sucre	**500,868**	**607,481**
Caucaguita		55,939
Fila de Mariches		29,399
La Dolorita		66,625
Leoncio Martinez		61,618
Petare		393,900
Baruta	**249,115**	**289,820**
El Cafetal		48,104
Minas de Baruta		45,503
Nuestra Señora del Rosario de Baruta		196,213
El Hatillo	**45,799**	**60,246**

Source: INE, Population Census

Table 2.2.3 Gross Domestic Product by Type of Economic Activity (2003)

TYPE OF ECONOMIC ACTIVITY	Consolidated	Public	Private
1. PETROLEUM ACTIVITY	33,729,919	30,142,451	3,587,468
2. NONPETROLEUM ACTIVITY	96,080,700	9,656,485	86,424,215
2.1 Goods Production	25,450,276	2,696,301	22,753,975
2.2 Service	74,144,887	7,260,343	66,884,544
3. Less: Imputed Banking Services	3,514,463	300,159	3,214,304
SUB-TOTAL	129,810,619	39,798,936	90,011,683
4. Plus: Import Duties, Luxury and Wholesale Tax and Similar Taxes	7,557,537	595,390	6,962,147
TOTAL	137,368,156	40,394,326	96,973,830

Source: Ministry of Finance, http://:ww.mf.gov.ve/

Table 2.2.4 Employment Status of Caracas, 1990 - 1997

Year	Primary sector	Secondary sector	Tertiary sector	Total
1990	17,230	346,110	1,075,312	1,438,652
1995	8,815	305,194	1,095,941	1,409,950
1997	13,814	286,527	1,144,019	1,444,360

Source: OCEI, Socio-economic Surveys, 2nd semester 1998, Population estimation

Notes: Primary sector: Petroleum (crude oil) and natural gas, mining and agriculture activities
Secondary sector: manufacture, electricity & water and construction activities
Tertiary sector: financial, insurances real state and services to the enterprises, like financial assistance, administrative services, marketing investigation, quality control, publicity, commercial, transport and communication, etc

Table 2.2.5 Share of Caracas in National Employment

Economic Activity	Number	% to National total	% of National with high education
Agriculture	2,690	0.3	7.6
Mining, Oil	11,264	12.8	37.5
Manufacturing	192,365	18.6	27.9
Electricity, Gas, Water	10,727	17.6	48.9
Construction	83,435	13.0	19.3
Commerce	327,182	17.1	27.5
Transportation	119,278	23.1	38.1
Tertiary Superior*	230,853	48.9	55.5
Services	458,609	19.6	27.2
Not specified	8,097	43.0	53.5
Total	1,44,360	17.9	32.0

Source: OCEI, 1st semester, Socioeconomic Survey, 1997
Note: * tertiary superior includes Financial, Insurance, Real Estate, Service.

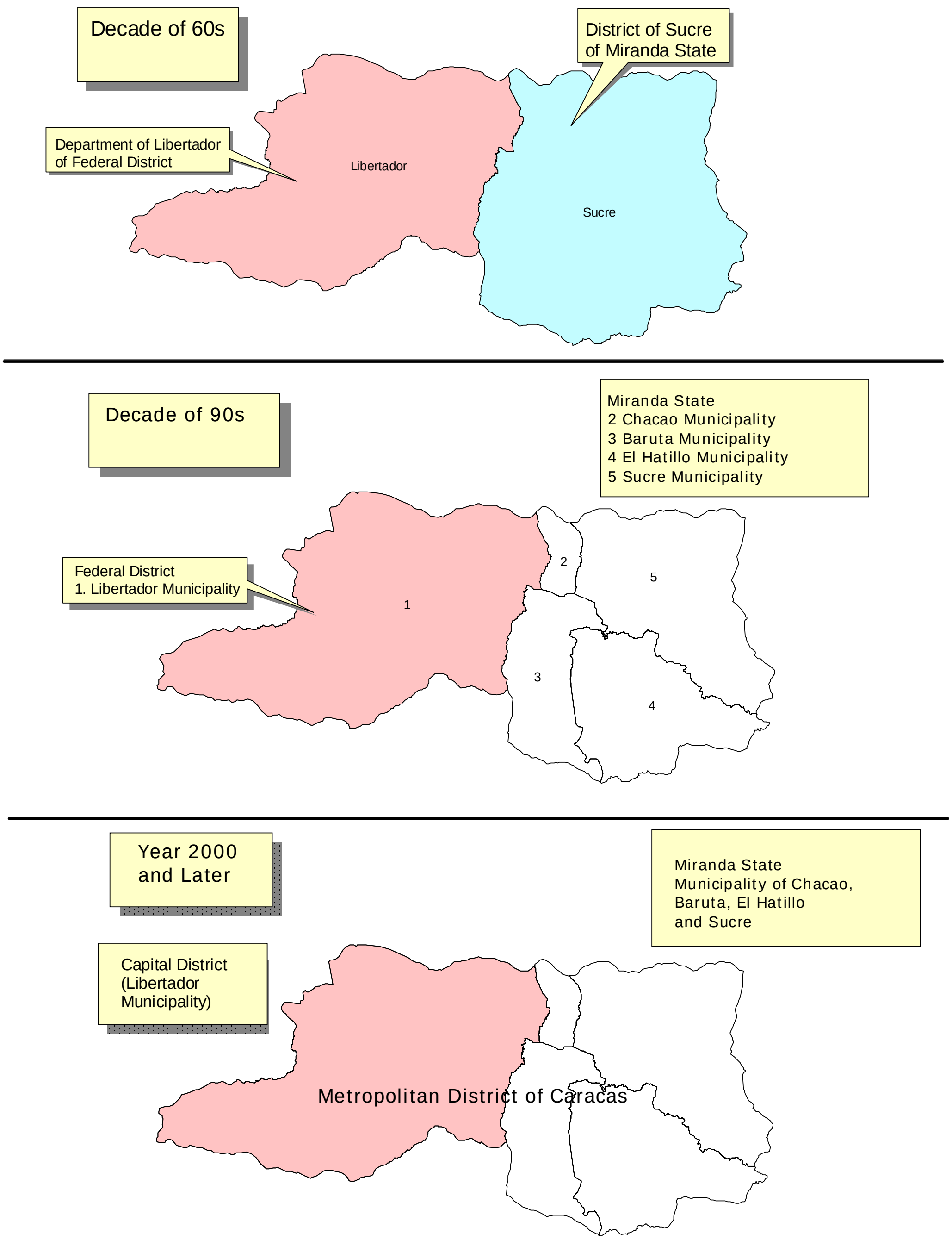


Figure 2.2.1 Recent Administrative Boundary Change of the Metropolitan District of Caracas

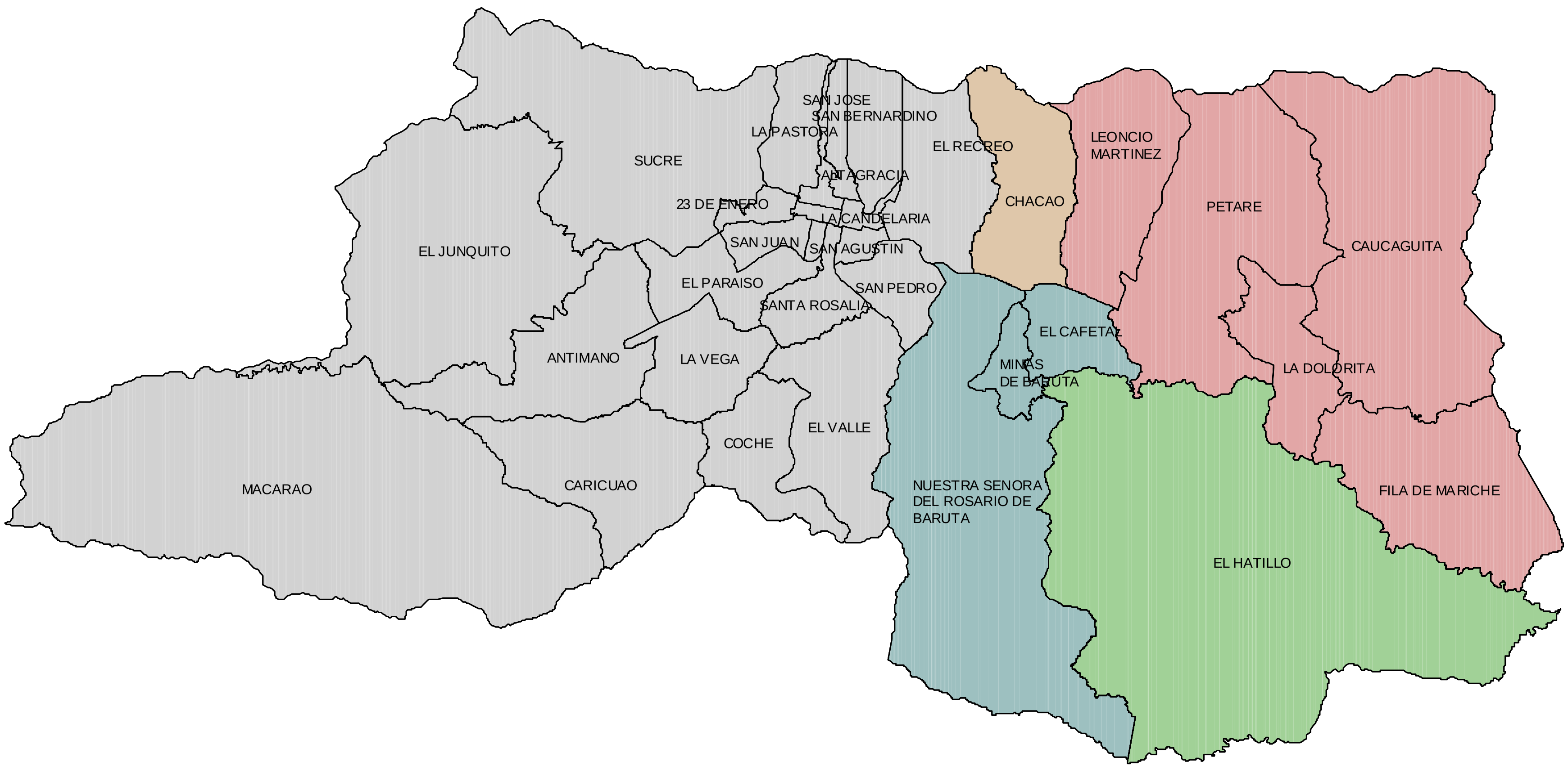
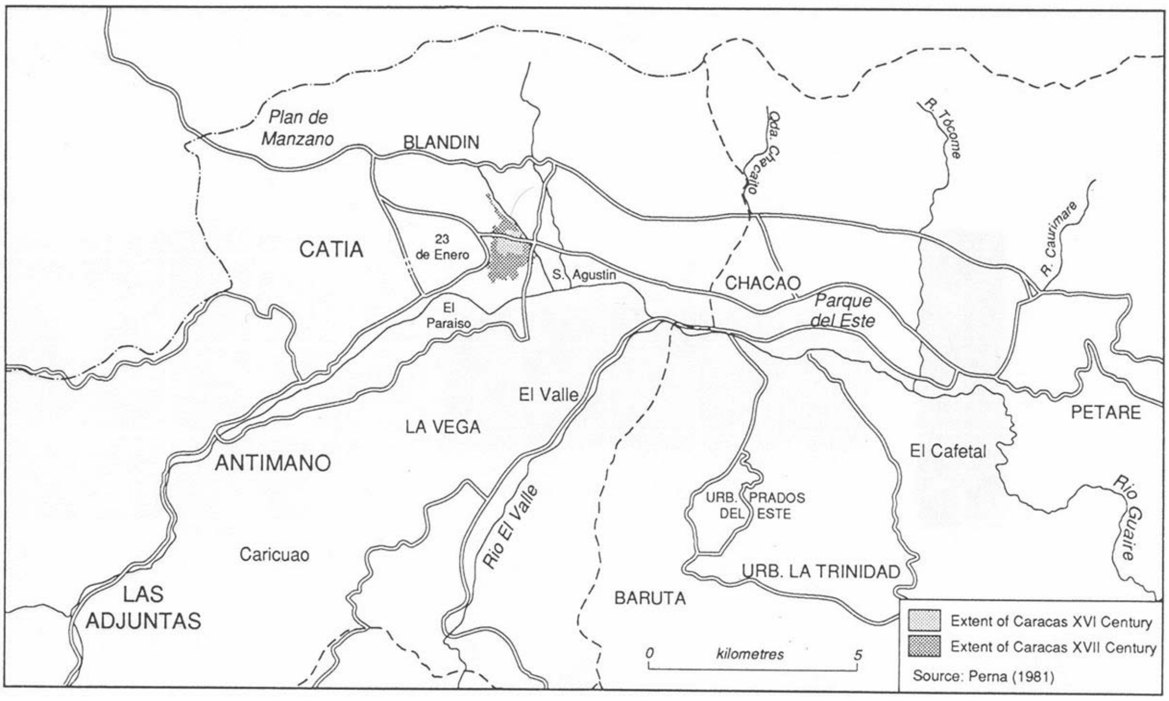
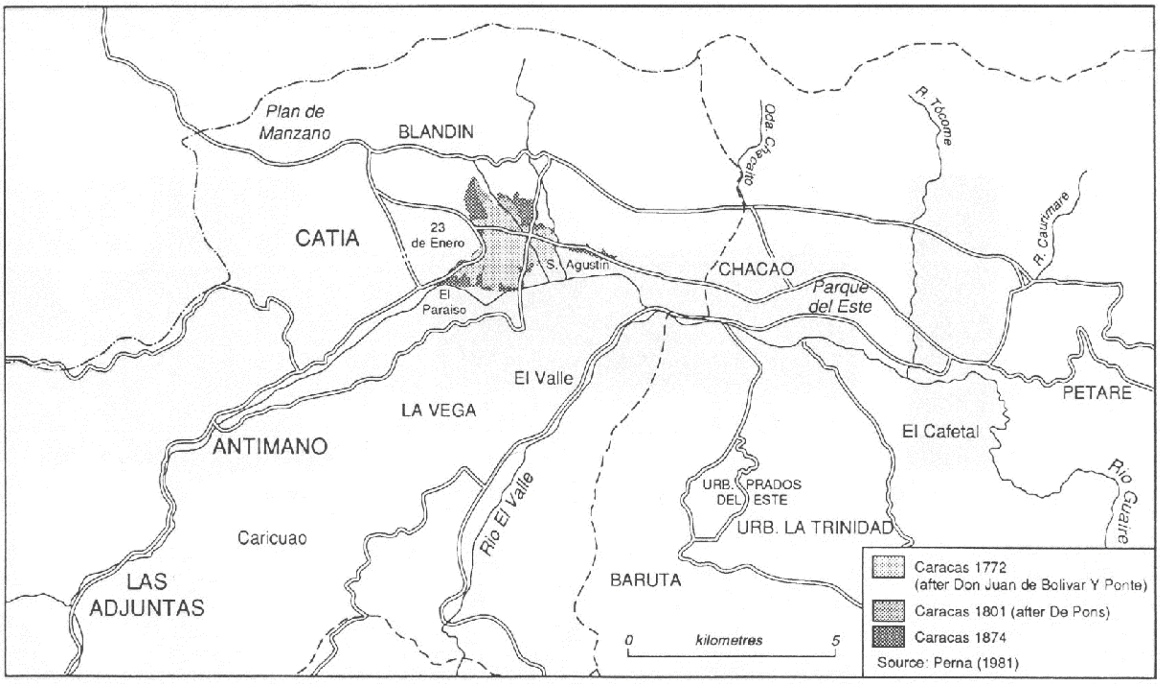


Figure 2.2.2 Political Administrative Boundary of Caracas



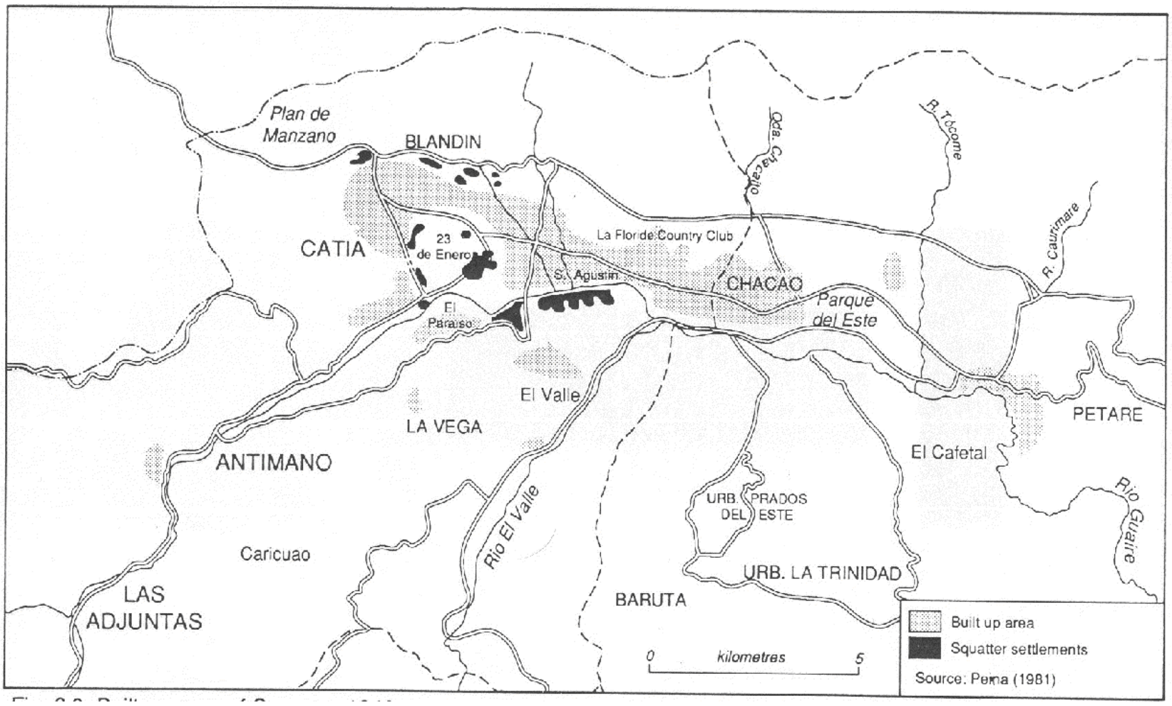
Source: Jiménez Díaz ,Virginia, *"Slope Failure in Caracas, Venezuela: the Influence of Squatter Settlement,"* Thesis submitted for the Degree of Doctor of Philosophy at University of London, Aug. 1992; originally from Perma, C., *Evolucíon de la Geografía Urbana de Caracas*, Ediciones de la Facultad de Humanidades y Educacíon, Universidad Central de Venezuela, Caracas, 1981

Figure 2.3.1 Growth of Caracas (16th Century to 17th Century)



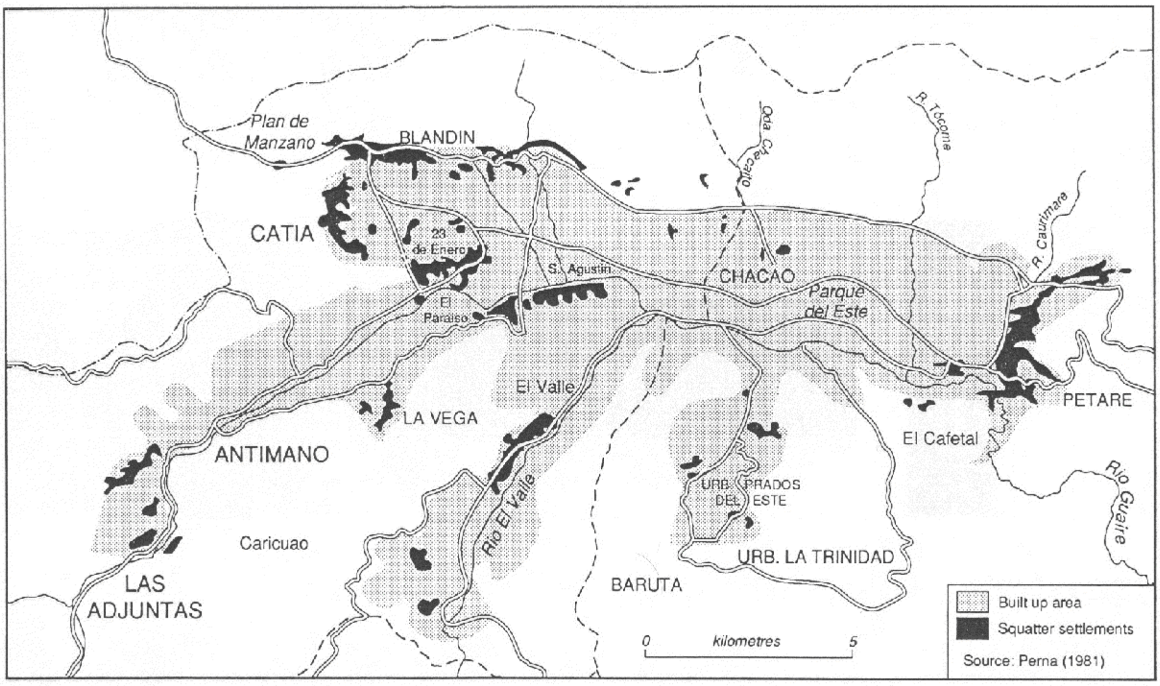
Source: Jiménez Díaz (1992), originally from Perma (1981)

Figure 2.3.2 Expansion of Caracas from 1772 to 1874



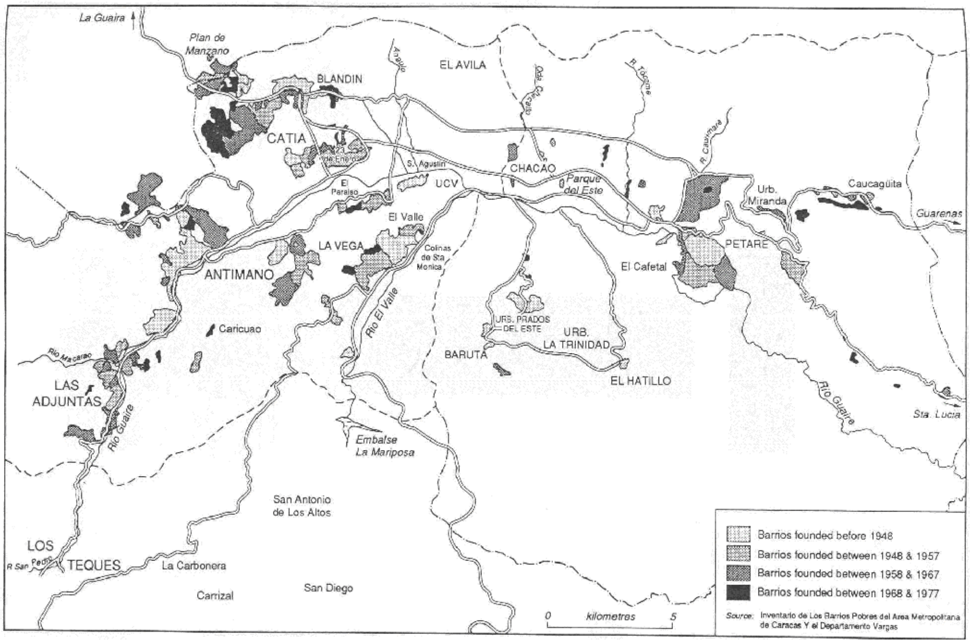
Source: Jiménez Díaz (1992), originally from Perma (1981)

Figure 2.3.3 Built up and Barrio Areas in Caracas in 1940



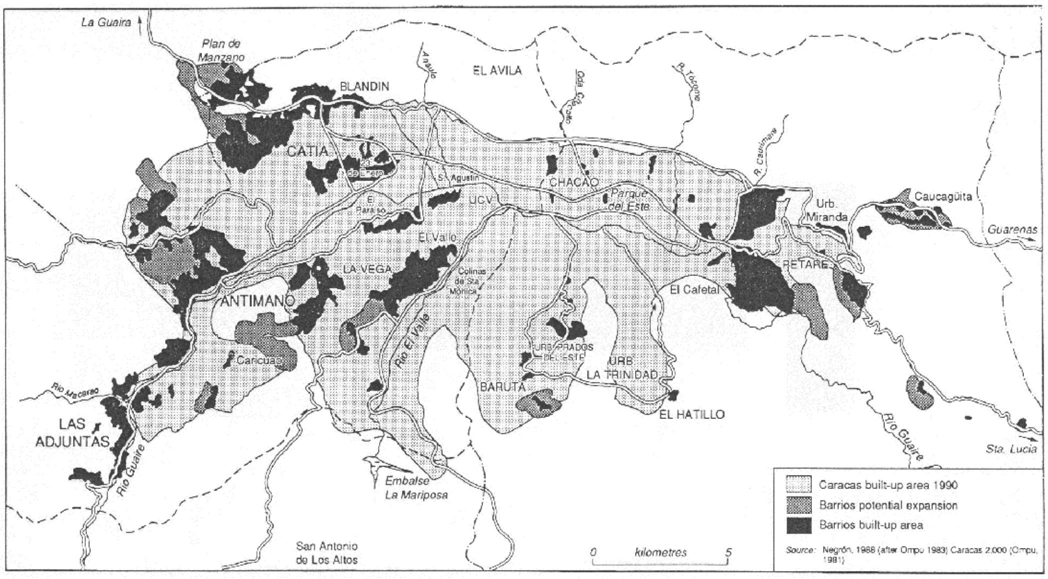
Source: Jiménez Díaz (1992), originally from Perma (1981)

Figure 2.3.4 Built up and Barrio Areas in Caracas in 1966



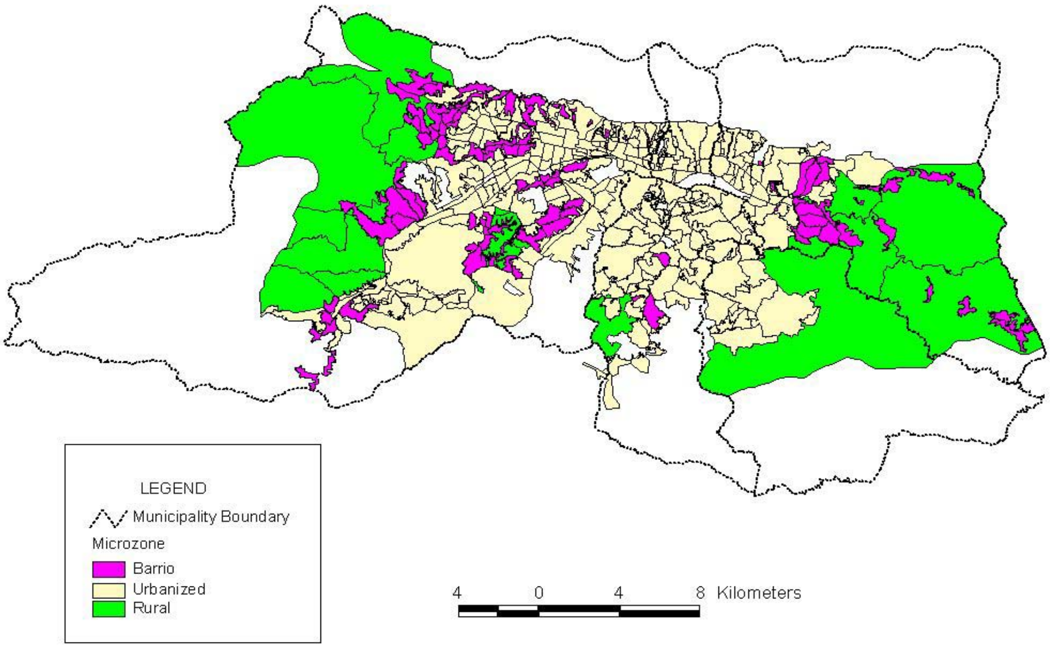
Source: Jiménez Díaz (1992), originally from Perma (1981)

Figure 2.3.5 Expansion of Barrio Area in Caracas (1948 to 1977)



Source: Jiménez Díaz (1992), originally from Negron (1981), and Caracas 2000 (OMPU,1981)

Figure 2.3.6 Expansion of Barrio Area in Caracas (1983)



Source: JICA Study Team, barrio boundary data for GIS given by CONAVI.

Figure 2.3.7 Urban, Barrio and Rural Area

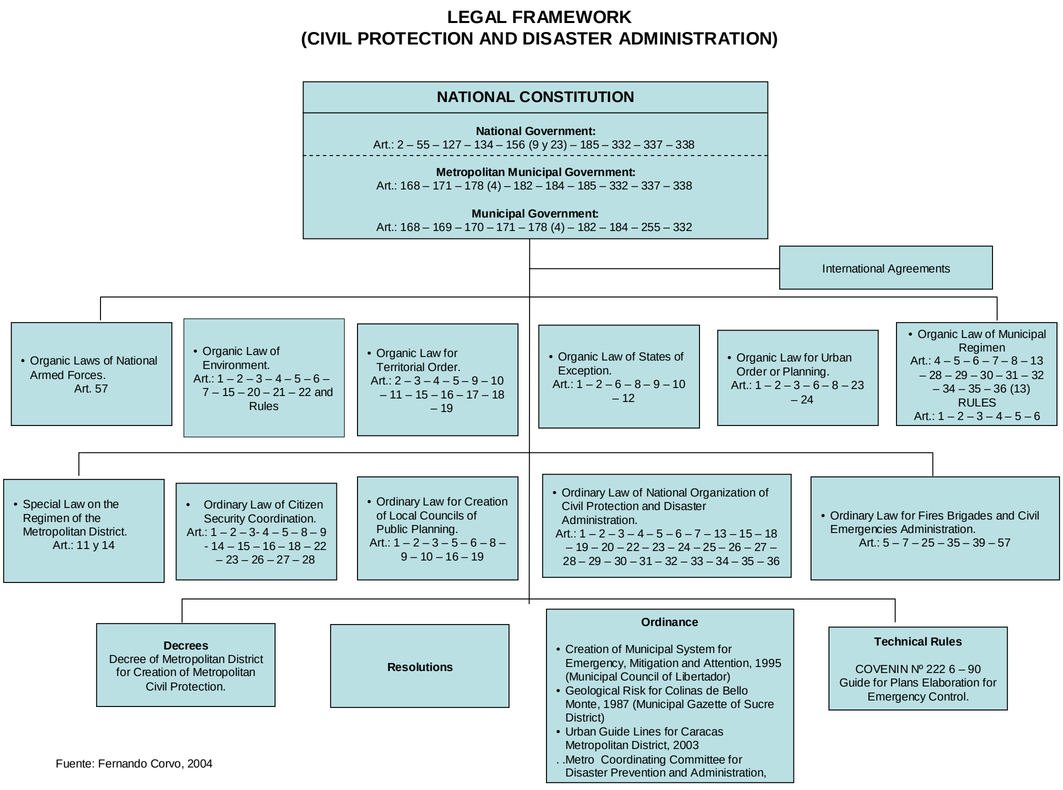


Figure 2.5.1 Legal Framework – Law Level

CHAPTER 3

EARTHQUAKE DISASTER STUDY

"If disasters you prevent, Caracas' progress you won't detain"

Alfredo Varela

CHAPTER 3. EARTHQUAKE DISASTER STUDY

3. 1 Seismic Hazard Analysis

3. 1. 1. Review of Collected Data

(1) Tectonic setting

Northern Venezuela is located in the interaction zone between the Caribbean plate moving eastward and South America plate moving westward. This plate boundary is a 100-km-wide active deformation zone, but dextral-lateral motion seems to take place along the dextral faults system, and the remainder of deformation is distributed across lesser but associated faults within and offshore of Venezuela.

Quaternary active faults in Venezuela are catalogued by Audemard et. al. (2000). The catalogue describes detailed description of each fault, such as fault length, fault type, and annual slip rate. A part of the map around Caracas is shown in Figure 3.1.1, and faults in the map are listed in Table 3.1.1.

Among them, San Sebastian fault system along the coast is the most active fault system, though its location, age, and activity rates are poorly known due to no marine survey available. In the south, La Victoria fault system with five sections has a less active slip rate between from 0.4mm/year to 1.1mm/year. In the north of Caracas Valley, there extends Tacagua - El Avila fault system, with less displacement rate from 0.17mm/year to less than 0.4mm/year.

(2) Historical Earthquakes

In Venezuela, catalogues on disastrous earthquakes can date back to 1530 (Centeno Grau (1968)), Grases (1900), Grases et. al. (1999), Audemard et al. (2000)). Figure 3.1.2 shows epicenters of major earthquakes that affected Caracas in the history estimated by Grases (1990). They can be classified into two categories.

- Earthquake that occurred in the North of Caracas such as 1641, 1812, 1900, and 1967 events. They occurred along the boundary of Caribbean plate and South American Plate, i.e. along San Sebastian, Bocono, or El Pilar fault systems. Though the epicenter of the 1641 earthquake may be located in the south of Caracas (Audemard, 2002), due to the observation of heavy damage in Cua.

- Earthquake that occurred in the South of Caracas such as 1837 and 1878 events. They can be attributed to La Victoria or Tacata fault systems.

Table 3.2.1 shows description of earthquake history in Caracas, compiled from different earthquake catalogues in Venezuela. This is because each catalogue has advantages and limitations as follows. Centeno Grau (1968) includes complete text of the key documents regarding the 1812 earthquakes, which are not included in later catalogues. Grases (1990) has parameters for most of the events, with brief description of damages and isoseismal map. Grases (1999) has collection of excerpts from various sources, but parameters and isoseismal maps are not included.

Major earthquakes are studied by various researchers, and isoseismal maps are estimated. The isoseismal maps and comparative review of parameters of major earthquakes that affected Caracas are shown in Table 3.1.3 to Table 3.1.5 and Figure 3.1.3 to Figure 3.1.5. Though isoseismal maps may be affected by population distribution at that time, they can serve as a basis to estimate magnitude of the earthquake as well as and damage distribution.

(3) Seismicity

Earthquake observation around Caracas has been carried out to study the seismicity since 1940. Figure 3.1.6 shows seismic activity of the region and histogram of magnitude and number of events. The depth histogram as shown in Figure 3.1.7 shows that the earthquake hypocenter depth mostly ranges between 16 km to 2 km beneath the ground surface. (Sobiesiak, (2003)).

(4) Strong Motion Records

Strong motion observation in Venezuela started since 1980's. The Figure 3.1.8 shows location of accelerograph stations, where most of them are located along major fault systems. The number of records obtained to date is more than 80, with its maximum acceleration of 178.90 gal.

(5) Avila Project

Seismic hazard study by probabilistic method was conducted by FUNVISIS (2001) within Avila project. In the project, faults around Caracas within the radius of 200km were taken into account, and attenuation law developed in Venezuela (INTEVEP, 1990) has been used to calculate expected acceleration on the bedrock.

The result shows that 0.3 g at the level of bedrock is expected for the mean return period of 475 years around Caracas. Regarding the contribution of each fault to the estimation result, San Sebastian fault has the largest effect, La Victoria fault and Avila fault then follow.

(6) Geological and Geotechnical data

1) Geological and geomorphologic data

Singer (1977) worked especially on north-east part of the valley. Matsuda (2001) worked in the urbanized area of Caracas valley, and Lopez V. (1948) shows the direction of sediment movement and its distribution in the alluvial deposit in Caracas valley.

2) Geotechnical data

A project to build a borehole database is underway since 2002 under FONACIT. Among them, data for about 287 boreholes were selected from the part of the database in urbanized area in Caracas valley. The study area was divided into meshes with areas 500 m by 500 m for assessing seismic hazards. FUNVISIS has collected well data to clarify the depth of base rock. Soil profiles as a result of soil investigation for construction of Metro (Metro de Caracas) is also used to evaluate liquefaction susceptibility.

As to the laboratory soil test data soil investigation reports for Metro was collected. However, enough information about wet density, shear modulus and dumping factor was not found. In addition, A. C. Alicia et al (1984) clarifies the soil mechanical properties of upper part of sedimentary deposit in Caracas.

As for groundwater data, several contour maps produced during 1950's shows that groundwater level had already started to decline in some parts of Caracas. MARN installed 80 wells for observation of groundwater table in Caracas valley by 1996. The observations, however, were dormant for these several years due to the shortage of funding. A groundwater contour map measured on 1 October, 2001 by MARN was collected and used for the evaluation of liquefaction susceptibility.

3) Geophysical investigation data

A seismic reflection survey in Caracas valley was implemented by Weston Geophysical Engeneers International, Inc., (1969) to understand the thickness of sedimentary deposit of the valley and obtain generalized bedrock contour map. Since then, the effort to improve the bedrock contour map is continuing and the map has been improved by FUNVISIS. (Kantak, (2001), Sanchez et.al, (2002), and Schmitz etal, (2003))

Gravity survey data was collected to understand the base rock level distribution. A gravity study in Los Palos Grandes basin was implemented, as a part the seismic micro-zonation project of the Caracas city supported by FUNVISIS (Sánchez et.al, 2001).

In Caracas valley, micro-tremor measurements were conducted systematically (Rocabado, et. al., 2001). In the first stage, measurement was implemented at an interval of 500 m. Measurements with an interval of 250 m is on going by FUNVISIS. The data was analyzed using the H/V spectral ratio or Nakamura method. A close relationship was derived for the sedimentary thickness and the associated predominant period. The periods obtained vary between 0.1 and 2.1 seconds, while the relative amplification shows a factor between 4 and 6 times the average value for Caracas. Basic results of micro-tremor measurement from FUNVISIS in GIS format and H/V spectral data from Professor Enomoto in Digital text format are collected.

Average S-wave velocities of surface layer by refraction method were reported by the Weston Geophysical Engineers International, Inc. PS-logging has been implemented along the Metro line by FUNVISIS（Campos et al., 2004）. However, the number is limited at present.

4) Existing studies about simulation of amplification

Seed et al. (1970) studied the relationships between soil and building damage in the 1967 Caracas earthquake. They have performed one-dimensional and two-dimensional simulations of ground motion. At present, FUNVISIS is studying two-dimensional simulation of ground motion.

5) Information about Liquefaction phenomena

Acosta et al. studied the historical earthquakes occurred between from 1530 to 1997, and summarized the occurrences of liquefaction phenomena. In this paper, there are no reports that show the occurrence of liquefaction in Caracas.

Empirical relation between the farthest liquefied site and the earthquake magnitude was studied by Acosta and De Santis (1997). They studied historical earthquakes and liquefaction that have occurred or might have happened, and derived an equation which shows the empirical relation between the farthest liquefied site and the earthquake magnitude.

3. 1. 2. Definition of Scenario Earthquake

(1) Introduction

The overall flowchart of seismic micro zoning study is illustrated in Figure 3.1.9. The object of micro zoning is to provide a basis to develop an earthquake disaster prevention plan for a region. This study assumes a specific scenario earthquake, which is a hypothetical earthquake.

It must be noted that the study is not a prediction of next earthquake in any sense, but a visualization of possible damages and outcomes under occurrence of a possible earthquake. The study does not treat individual structures but employs statistic analysis to assess vulnerability in a region. The result must not be used for seismic design of structures, nor be used for insurance propose.

(2) Definition of Scenario Earthquake

With the review of collect data as described in 3.1.1, and through discussion with FUNVISIS, four scenario earthquakes are defined for this study. Among them, three scenario earthquakes are based on studies of historical earthquakes. The rupture zone of the 1812, the 1878, and hypothetical Avila earthquake is located along fault line presented in Audemard(2000).

For the location of segment for the 1967 earthquake, epicenter location determined by ISC and also used in Suarez and Nabelek et. al, (1990) is used as one end, and another end is taken from Suarez and Nabelek (1990) as an epicenter of the second event, because these two events are the two major events out of four sub events studied in his work.

There are several interpretations regarding the 1812 earthquake, earlier studies regard it as three events, or two events recently. In this study, it is interpreted as two events after Grases & Rodriguez (2001), and magnitude is taken from this study. For the location of segment for the 1812 earthquake near Caracas, Grases (1990) and Isoseismal map by Altez (2000) was referred.

As for the 1878 earthquake, the fault segment is located along La Victoria Fault.

The hypothetical Avila earthquake is included, because the fault is known to be active from Quaternary fault study and seismological observation, even though there is no record of earthquake from this fault in historical documents. The magnitude of hypothetical earthquake from Avila fault for this study is defined to be 6.0, though the maximum credible magnitude is estimated to be 6.8. The segment location is taken from Quaternary fault study.

The magnitude is defined from comparative review of studies on historical earthquakes. The fault type is defined from Quaternary fault study and seismological observation. The fault size of scenario earthquake is estimated using empirical relation from fault size and possible magnitude. As a result, segment of scenario earthquakes are located as shown in Figure 3.1.10, and their parameters are defined as shown in Table 3.1.6.

It should be noted that there are numerous studies regarding the fault location for historical earthquakes, thus several models for fault location can be made. Among them, the most appropriate model than can best reproduce seismic intensity is adopted through calibration. The calibration was made via comparing estimated seismic intensity by methodology developed for this study with historically observed seismic intensity and damage degrees, as described later in Chapter 4 in Supporting Report S-3.

3. 1. 3. Development of Ground Model

In section 3.1.1 the results of data collection was described. In this section, at first we describe the key points of existing condition clarified by collected data, and then explain the method how to develop the ground model from the collected data.

(1) Development of Ground Model for Analysis of Seismic Force Amplification

1) Summary of Existing Condition about the information for developing ground model on Amplification of Seismic Force

The Study team use one dimensional earthquake response analysis program, named “Shake”, for analysis of seismic force amplification. The analysis requires such geotechnical data as S-wave velocities and their layer distribution, densities and shear modulus and dumping factors for each layer.

The key points on existing condition about the necessary geotechnical data for plain area and hill/mountainous area, respectively are summarized as below.

a) Plain area (Sedimentary deposit area)

- The deepest depth of collected borehole data with geotechnical information is about 30 m, and the most part are less than 20m in depth.
- The thickness of sedimentary deposit in Caracas valley is described as a contour map on GIS by FUNVISIS.

- Microtremor measurements were carried out at every 500m in distance by FUNVISIS and Japanese universities, and their average S-wave velocity map is displayed in Schmitz et al, 2003. This data has covered large plain area in Caracas valley.

b) Hill/Mountainous area

- There are scarcely any geotechnical data obtained.
- Small number of microtremor measurement data was obtained in limited area.

2) The Method of Development of Ground Model

a) Plain area (Sedimentary deposit area)

The Study Team have developed the ground model by making the most of the data of H/V spectrum curves and thickness of sedimentary deposit layers for each mesh with spacing of 500 m. To be more precise, the Study Team have determined S-wave velocity structure by inversion genetic algorithm, that is, which reproduce theoretically H/V spectrum obtained by microtremor measurement, seeking the best fit S-wave velocity structure for each mesh by trial and error.

In the early stage of developing the ground model, the Study Team checked some ideas to reproduce H/V spectrum to determine if they were effective or not. One layer, two layers and multi layers ground models were compared with each other.

Two layers model means that it divides the sedimentary deposit into an upper layer with Vs (S-wave velocity) lower than 400 m/s and a lower layer with Vs higher than 400 m/s. For the upper layer, collected borehole data has been applied, and the layer is subdivided into sub-layers according to each borehole datum.

Multi-layers model means that, in addition to two layers model, it divide its lower layer into multi layers.

As a result of having compared how well each model match with the H/V spectrum data, the difference in matching between the two layers model and the multi-layers one could not be found, so that the two layers model was adopted because of its simplicity.

The flow chart of development of the ground model for seismic force analysis described above is shown in Figure 3.1.11 and Figure 3.1.12.

In regards to the method of determining geotechnical properties such as density, shear modulus and dumping factors, please refer to 3) in this section.

b) Hill/Mountainous area

The Study Team have estimated the ground model from general geological information on weathered state of rocks and H/V spectrum data, for there were no effective existing boring information.

The Study Team have not distinguished man made lands by cut and fill from natural ground this time for the lack of concrete geotechnical information. This will be one of the important issues for hazard and risk estimation so that this information shall be clarified and included in future analysis by Venezuelan themselves.

Figure 3.1.13 is given for reference. This figure was made from collected borehole data, and suggests that fills lower than 10m has a tendency of a filled soil with relatively loose densities.

3) The method of determining each element of the ground model

a) Density of soil and rocks

An important information derived from gravity survey implemented at Los Palos Grandes is available. The survey result shows that the densities of sedimentary deposit, the thickness reached about 340 m, varied from 1.8 g/cm^3 to 2.4 g/cm^3. These values are almost equated with or little larger than those of Japanese. For that reason, the values shown in Table 3.1.7 (Japan Road Association, 2002) was adopted. (Sanchez et al., 2001)

b) S-wave velocities (Vs) of Upper layer

When S-wave velocities of upper layers is determined, boring data in each mesh and a relation between S-wave velocities and Blow numbers of Standard Penetration Test (SPT) are applied. In case of lack of borehole data in the mesh of interest, nearest borehole datum into the mesh is basically applied.

Applied relation is as follows:

$$Vs = 97 \cdot N^{0.314}$$

Where N is the number of blows by Standard Penetration Test.

This relation was derived from PS logging data in Japan (Imai et al., 1977). The number of data is more than one thousand. We hope that such a relation will be developed and analysis will be done in Venezuela in the near future.

Figure 3.1.14 shows the validity of applying this relation to the ground of Caracas. The S-wave velocities for subsurface soils are obtained from refraction survey by Weston Inc. and the corresponding average blow numbers of Standard Penetration Test for subsurface soils are obtained from existing borehole data located near the site where refraction survey was done.

c) Shear Modulus and Dumping Factor

Non-linear relations of shear modulus and dumping factor to upper layers (Vs < 400 m/s) and linear relation to lower layers (Vs > 400 m/s) to simulate actual behaviors of ground motion during earthquakes was applied.

The relations[2] applied at this time are shown in Figure 3.1.15 and Figure 3.1.16, developed in Japan (Imazu et al., 1986, Iwasaki et al., 1977a, Iwasaki et al., 1977b, Iwasaki et al., 1978), because existing such relations was not found in Venezuela. γ_0 in the Figure 3.1.15 means shear modulus at strain 10^{-6} is calculated from the equation below.

$$\gamma_0 = r/g*Vs^2$$

Where, r: density (g/cm^3)

g: gravitational constant ($9.81 m/second^2$)

Vs: S-wave velocity (m/second)

It is well known that strain dependencies of shear modulus and dumping factor of sand materials change according to their overburden pressure. Therefore different relations according to each overburden pressure at every 5 m in depth were prepared.

(2) Development of Ground Model for Analysis of Liquefaction

Existing report about occurrence of liquefaction phenomena in Caracas valley was not found. However, the possibility of liquefaction cannot be denied absolutely, though sedimentary deposit of Caracas valley is rather harder than that of coastal areas. Therefore the Study Team decided to estimate liquefaction susceptibility in Caracas valley as a preventive measure.

1) Summary of information on Existing Condition for developing the ground model on Liquefaction Susceptibility

There are various methods for estimation of liquefaction susceptibility in the world. For example, various index are used for the estimation such as Blow Number of Standard Penetration Test (N), the range of particle size distribution, fine particle content, plastic index, clay content and ground water level. In the case of Caracas, N values of the sedimentary deposit are generally high from the surface, so it is better to take particle size distribution into consideration for more accurate estimation.

The key points on existing condition about the necessary geotechnical data are summarized as below.

- Database by FONACIT (Feliziani, 2003) has geological description, N values and texture of gravel, sand and fine content. It doesn´t have each particle size distribution curve corresponding to N value.
- Soil investigation report about Metro construction can make up the shortage of such information foregoing mentioned to some extent. However, their location of data is limited to the site of Metro lines, and the number of laboratory tests per one borehole is few.
- A work that distinguishes particle size distribution of subsurface soil and typified it by regional group is available.

2) The Method of Development of the ground model for the estimation of liquefaction based on Existing Condition

Existing researches on the liquefaction phenomena in the world have made it clear that the distribution of liquefied soil limited to about 20m in depth and the ground water depth is shallower than 10m.

Standing on this result of existing study, study area for liquefaction estimation was limited to the meshes where groundwater tables are higher than 10m in depth using observation result by MARN.

Secondly, the borehole data and particle size distribution curve data in soil investigation report of Metro was used, if they are located in the mesh. When the mesh doesn’t have any data of Metro and there is another data located near the mesh, the data were applied to the mesh concerned. When any data related to Metro is not available, the boring database of FONACIT and typified particle size distribution curves are applied.

Concrete applied data items for every borehole are: Soil type, N value, Mean grain size diameter, 10% grain size, fine particle content, clay content, and Plastic index.

The flow of estimation of susceptibility of liquefaction is shown in Figure 3.1.17

3. 1. 4. Method of Ground Motion Estimation

(1) Selection of Attenuation Law

Seismic waves are generated by fault movement, and then propagate along bedrock, then affected by sediments. Therefore, in order to evaluate the ground motion at a site, it is necessary to study the effect of source, propagation path, and site.

In this study, bedrock motion is calculated using attenuation law. Various researchers had proposed attenuation laws. In order to select suitable equation among them, the study team and FUNVISIS had discussed and examined the applicability of various attenuation laws. In this study, an attenuation law is selected using the following criteria.

- Mechanism of earthquake can be specified as strike slip
- Distance from the fault to the site ranges between from 0 to 100 km.
- Ground conditions can be specified, because much data on subsoil condition is available in Caracas.
- Data set used to develop attenuation law includes large magnitude and close distance, and generated in shallow crusted earthquake.

As a result, the Study Team and FUNVISIS agreed to employ formula proposed by Campbell (1997), and the calculation results are shown in Figure 3.1.18.

(2) Selection of Input Waves

During the 1967 Caracas earthquake, strong motion was not recorded. Since then, many efforts had been made to record strong motion. However, strong motion datasets in Venezuela suitable for input waves for scenario earthquake in this study are not yet available. Therefore, input wave are selected from worldwide strong motion database, which are recorded under similar conditions of each scenario earthquake, and are capable to reproduce observed seismic intensity as show in Tables 3.1.8 and 3.1.9. Wave forms and spectrum are shown in Figure 3.1.19 to Figure 3.1.22.

(3) Seismic Response Calculation

Although it is desirable to employ two-dimensional or three dimensional calculation methods to simulate seismic response of a valley, such methods require appropriate two or three dimensional ground models and huge computation. Therefore, one-dimensional calculation by SHAKE is used in this study.

For the calculation, the maximum amplitude of input waves is adjusted according to the values calculated by attenuation law, and the ground model developed for each mesh as described in section 3.1.3 is used. Peak ground acceleration is then calculated for each 500 m sized square mesh as shown in Figure 3.1.23.

(4) Estimation of Seismic Intensity

In Venezuela, the Scale of Modified Mercalli Intensity (MMI) has been used to describe the intensity in a certain placeduring the earthquake. Seismic Intensity is a scale for the general description of ground motion and damages at a place, while peak ground acceleration is an objective physical parameter that can be measured by accelerometer..

Some correlation exists among the intensity in a place and the maximum acceleration of the land, but it doesn't estimate the total effects that can take place in the range of structures of different vibration periods. Particularly, the effects of places associated with the predominance of the vibration period of the soil are not always estimated accurately by means of the maximum acceleration of land.

A better measurement is obtained by the peak ground velocity, but the consideration of the spectral answer in the typical range periods of the buildings provide a more reliable appreciation of the possible damages. In this sense, and within the framework of the foreseen procedure of estimation of intensities from the accelerograms obtained as a dynamic response of the floor, FUNVISIS proposed that instead of correlating the maximum accelerations with the intensities, the spectral responses were obtained as an intermediate step, following the procedure suggested in the book Fundamentals of Earthquake Engineering of Newmark and Rosenblueth. The steps for this procedure are described as follows:

- Calculate the spectral intensity (SI) of Housner (1952) as the integral between 0,1 and 2,5 seconds of the spectral pseudovelocity of response, evaluated in cm/s, of systems with reduction equal to 20% of the critical.
- Obtain average ground velocity v as an average of pseudovelocity spectrum in the range of integration, i.e. v = SI/2,4

Estimate the seismic intensity by means of MMI = log(14v)/log2

(5) Estimation of Liquefaction Susceptibility

The study area is divided into mountainous/hill-side area and plain (sedimentary deposit) area. In Caracas valley, sedimentary deposit distributes in plain area. Those sedimentary deposits have varieties of their soil textures such as clay, silt, fine sand, medium sand, coarse sand and gravel. Generally speaking, these sedimentary deposits are stiff and hard, however, there are few possibilities that liquefaction phenomenon occurs depending on seismic force.

1) Analysis procedure of liquefaction susceptibility

The liquefaction susceptibility for individual layer is analyzed by the FL method. The whole liquefaction susceptibility as the analyzed points is evaluated by the PL method based on the results of the FL method.

F_L Method (Japanese Design Specification of Highway Bridge, revised 1996)

Ground condition to be evaluated

Quaternary sandy soil from ground surface to depth of 20 m

Groundwater table less than 10 m from ground surface

$F_L = R/L$

F_L: liquefaction resistance factor

$F_L \leq 1.0$: Judged as liquefied

$F_L > 1.0$: Judged as not liquefied

R: cyclic shear strength at effective overburden pressure

$R = C_w \times R_L$

C_w: correlation coefficient for earthquake type

Type 1 earthquake (plate boundary type, large scale)

$C_w = 1.0$

Type 2 earthquake (inland type)

$C_w = 1.0$ $(R_L \leq 1.0)$

$= 3.3R_L+0.67$ $(0.1<R_L \leq 0.4)$

$= 2.0$ $(0.4 < R_L)$

R_L: cyclic resistance ratio obtained by laboratory test

$R_L = 0.0882 \quad (Na/1.7)^{0.5}$ (Na<14)

$= 0.0882 \quad (Na/1.7)^{0.5} + 1.6\times10^{-6}(Na-14)^{4.5}$ (14 ≤Na)

Sandy Soil

$Na = c_1 N + c_2$

$c_1 = 1$ (0% ≤ Fc < 10%),

$= (Fc + 40)/50$ (10% ≤ Fc < 60%)

$= Fc/20 - 1$ (60% ≤ Fc)

$c_2 = 0$ (0% ≤ Fc < 10%)

$= (F-10)/18$ (10% ≤ Fc)

Fc : fine contents

Gravelly Soil

$Na = \{1-0.36\log_{10}(D_{50}/2.0)\}N_l$

N: SPT blow count

Na: N value correlated for grain size

N_l: $1.7N/(\sigma_v'+0.7)$

D_{50}: grain diameter of 50% passing (mm)

L: shear stress to the effective overburden pressure

$L = \alpha / g \times \sigma_v/\sigma_v' \times r_d$

r_d : stress reduction factor

$r_d = 1.0 - 0.015x$

x : depth in meters below the ground surface

α: peak ground acceleration (gal)

g: acceleration of gravity (= 980 gal)

σ_v: total overburden pressure

σ_v': effective overburden pressure

P_L Method (Iwasaki et al. 1980)

$$P_L = \int_0^{20} F \cdot w(z)dz$$

$15 < P_L$	Very high potential
$5 < P_L \le 15$	Relatively high potential
$0 < P_L \le 5$	Relatively low potential
$P_L = 0$	Very low potential

$F = 1-F_L$ $(F_L<1.0)$

$= 0$ $(F_L\ge1.0)$

$w(z) = 10 - 0.5z$

P_L: liquefaction potential index
F_L: liquefaction resistance factor
w(z): weight function for depth
z: depth in meters below the ground surface

2) The deposits to which the procedure applied

In general, liquefaction occurs in loose saturated sandy material. Japanese Design Specification of Highway Bridge defines the following soil conditions as required for liquefaction susceptibility evaluation.

In principle, saturated sandy deposits, which satisfy the following three conditions at a same time, require liquefaction susceptibility analysis:

- Saturated sandy deposits above the depth of 20 m with groundwater level within 10 m both from the present ground surface
- Sedimentary deposits with fine contents (Fc) less than 35%, or with plastic index less than 15% even the Fc is more than 35%.
- Sedimentary deposits with mean grain size (D_{50}) less than 10mm, and with grain size of 10% passing less than 1 mm.

3. 1. 5. Estimated Results of Ground Motion

(1) Estimated Seismic Intensity

Maps of estimated seismic intensity for scenario earthquakes are shown in Figure 3.1.24 to Figure 3.1.27. The estimated seismic intensity maps for the 1967, 1812, and 1878 scenarios were calibrated with the seismic intensity map or damage distribution map observed during the corresponded earthquake. (Fiedler (1968), Altez (2004), and Fiedler (1961), respectively)

(2) Estimated Liquefaction Susceptibility

Liquefaction susceptibility was evaluated using PL value. The results are summarized in Table 3.1.10. Maps of estimated liquefaction susceptibility for scenario earthquakes are shown in Figure 3.1.28 to Figure 3.1.31. In general, the sedimentary deposits in Caracas valley have enough strength to resist seismic force and keep stable state about liquefaction phenomenon. The areas where have high liquefaction susceptibility are limited to several meshes even against strong earthquakes such as 1812 and Avila.

3. 2 Seismic Risk Analysis of Building

3. 2. 1. Review of Collected Data

A lot of information on buildings for this study has been collected. In this section only the document and data which is referred in this report is described. Table 3.2.1 shows the summary of the referred document and data for the seismic risk analysis of building.

Development of Building Database

(1) Basic Concept

A Building Inventory was carried out by the Study Team to clarify the distribution of buildings in the study area. The concept of the development of building database is shown in Figure 3.2.1.

The study area is divided into tow areas. The first one is the urbanized area. The other is the barrio and rural area. The characteristics of both areas are summarized in Table 3.2.2.

Regarding the urbanized area, the unit area is the block. The GIS data of the block was provided by the Secretary of Urban Planning & Environmental Management, Metropolitan District of Caracas (ADMC). In a block there are several types of buildings. Therefore, the building number of each category in a block should be estimated. To know the number of building categories, a field sampling survey was conducted. The result of the survey is summarized to estimate the ratio of building category in a block. The GIS data 1/5,000 scale map contains shape of buildings. The 1/5,000 scale map covers the whole of the urbanized area. The total number of buildings is counted based on the 1/5,000 scale map data. The number of a building type in a block is estimated to multiply the total building number of the block by the ratio of the building type.

Regarding the barrio and rural area, the unit is an area which contains aggregated existing buildings. The area is sub-divided by the mesh of geological model. Base of GIS barrio data is provided by the Secretary of Planning and Environmental Management, ADMC. The mountain side boundary of barrio area is expanding. Therefore, the mountain side boundary was modified according to 1/5,000 scale map or aerial photos. The 1/5,000 scale map does not cover the whole of the barrio and rural area. The lack of 1/5,000 scale map is compensated by the aerial photo.

The building type of barrio and rural area is relatively simple. It is assumeed that a barrio or rural area contains only one type of low residential buildings. The residential buildings in the barrio and rural area are classified as informal buildings for the damage estimation work.

A lot of barrio and rural areas are located on steep slopes. On a steep slope, most of residential buildings have slender columns. It is essentially dangerous during earthquake. Therefore, special damage function was applied for buildings on steep slopes. Therefore, barrio and rural areas are divided into two areas. One is steep slope area and the other is gentle slope area. The threshold value is 20 degrees. This threshold value was decided after the discussion between FUNVISIS and The JICA Study Team.

There are a lot of factories in the rural area. The category of damage function "STEEL 1– 3F" is applied for the factories in the rural area. There are many high residential buildings in the rural area. The category of "RC-MOMENT FRAME 9-F '82-" is applied for high residential buildings in the rural area. The number of buildings in this area was counted by GIS based on the base map or aerial photos.

The category of building inventory and the damage function for the barrio and rural area, that were discussed and agreed with FUNVISIS, are summarized in Table 3.2.3.

(2) Urbanized Area

Figure 3.2.2 shows the flowchart of building inventory for the urbanized area. A field sampling survey was conducted to estimate the ratio of each category in a block. The survey items were decided based on opinion of several experts during the discussion between FUNVISIS and JICA Study Team. The survey form is shown in Figure 3.2.3. The number of sample is decided under consideration of the accuracy, term and cost. The number of the sample is 1000. It is an orthodox value for social sampling survey. The sampled buildings are selected randomly. The survey was conducted from July to middle of September, 2003.

Table 3.2.4 shows the field sampling survey result summarized by type, stories and constructed year. Table 3.2.5 shows the field sampling survey result summarized by the categories of damage function.

Analyzed Vulnerability Unit (AVU) is introduced to classify the urbanized area. AVU is sub-areas of the urbanized area. AVU is proposed by Dr. Virginia Jimenez (IGVSB) and Prof. Jesus Delgado (CENAMB, UCV). The urbanized area is divided into 30 sub-areas. It is considered that inside an AVU the characteristics of buildings are almost similar. The field sampling survey result is summarized by AVU. The same ratio is applied for all blocks in an AVU.

The concept of AVU is also introduced for social vulnerability study. The areas of AVU for social vulnerability study are almost the same. The Figure 3.2.4 shows the AVU for physical vulnerability study (physical AVU). Table 3.2.6 shows the number of buildings in each AVU.

Table 3.2.7 shows the result of field sampling survey summarized by the categories of damage estimation and AVU by number of samples. Table 3.2.8 shows the result of filed sampling survey summarized by the categories of damage estimation and AVU by percentage. Figure 3.2.5 shows the field survey result summarized by structure type and AVU. Figure 3.2.6 shows the field survey result summarized by stories and AVU. Figure 3.2.7 shows the field survey result summarized by constructed year and AVU.

(3) Barrio and Rural Area

Figure 3.2.8 shows the flow chart of building inventory for the barrio and rural area. The barrio and rural area is divided into two areas. One is covered by 1/5,000 scale map and the other one not covered by the 1/5,000 scale map. The area covered by the 1/5,000 scale map is shown in Figure 3.2.9. The barrio and rural area is also divided into two areas. In one the slope is steeper than 20 degrees. The other one is the area where slope is gentler than 20 degrees. The area where slope is steeper than 20 degrees is shown in Figure 3.2.10.

The number of buildings of the barrio and rural area in the 1/5,000 scale map area is summarized in Table 3.2.9. The number of buildings of the barrio and rural area out of the 1/5,000 scale map area is summarized in Table 3.2.10.

(4) Information for Human Damage Estimation

Table 3.2.11 shows the summary of required information for human damage estimation.

For RC Middle & High buildings, the relationship between death toll and number of heavily damaged buildings was derived. In this case, only number of heavily damaged buildings is used to estimate the death toll.

On the other hand, for the low rise buildings, the number of person per house is required. The damage function is derived based on statistics data of Quindio earthquake (1999, Colombia). The relationship between the number of death and heavily damaged buildings are depending on the number of person in a building. Therefore, the figure, which was calculated by the damage function, should be corrected by number of person per house.

The Census 2001 data, number of persons per house in the study area, was provided by INE. Figure 3.2.11 shows the Census 2001 data. The data is summarized in Table 3.2.12. The figure is employed for the human damage estimation.

3. 2. 2. Method of Damage Estimation

(1) Building Damage

In agreement with FUNVISIS and Dr. Safina's proposal (Safina, 2003), the European Macro seismic Scale, EMS was applied for building damage estimation and its applicability was checked with the 1967 Caracas Earthquake building damage. Figure 3.2.12 shows the damage functions associated to Level 4 "Heavily Damage", obtained for the vulnerability classes A, B, C, D, E and F defined according to the European Macro seismic Scale EMS-98, for the Macro seismic intensity values between V and XI, that correspond directly to the Modified Mercalli seismic Intensity (MMI). According to this definition, the vulnerability class A corresponds to the most vulnerable class, the vulnerability class F corresponds to the least vulnerable class and the proportion of severe damage should be understood as the proportion of buildings that are expected to reach damage level equal or greater than level 4 "Heavily Damage"; That is, they present severe damages and/or destruction and collapse.

These curves constitute an independent basis, so any category or structural typology of buildings can be expressed as a lineal combination of these curves applying properly weight factors to each vulnerability class.

<u>Categories of Buildings used in Caracas</u>

For classification of the different structural typologies of buildings into Vulnerability Classes the start point are the recommendations proposed by the European Macroseismic Scales EMS-98, summarized in Figure 3.2.13.

This recommendation classifies the buildings according to the predominant material (Masonry, Reinforced Concrete, steel, wood), the resistant system (moment resistant, walls) and the level of earthquake resistant design (high, medium, none). On the other hand, they don't classify according to the height of the building. Also they reproduce the typical construction culture used in the different European countries.

Table 3.2.13, summarizes the definition of the building categories used in Caracas, which were determined according to the results of the field survey and agreed on the work groups JICA-FUNVISIS.

The definition of the different structural typologies is based fundamentally on the predominant material (Reinforced Concrete, Steel, Pre cast Concrete, Masonry), the resistant system (moment resistant, walls), the height of the building, the age of the building and for informal, the ground slope. This last typology tries to represent the typical construction in the marginal zones of Caracas commonly referred as “barrios”, made of hollow clay bricks with “machones” (reinforced concrete columns) and load beams, floors of thin and long hollow clay brick and a light roof cover. The height of these buildings vary from 1 to 6 stories.

On the other hand, the masonry buildings (Masonry-Brick) represent the typical colonial building located in some sectors of the city’s downtown. The high prefabricated structures (Pre-cast 9F-) refers to the typical prefabricated construction system implemented in Caracas during the 70’s in buildings up to 17 stories high, which are concentrated in some housing developments in the Capital.

The classification by year of the reinforced concrete moment frame structures reflects the changes in the building design and construction practices which are associated to the changes in the design guidelines of 1967 and 1982.

Damage Functions for the categories of buildings employed in Caracas

In order to determine the damage functions of each one of these buildings typologies, a team of FUNVISIS professionals was formed to agree in a reasonable way to distribute a weight factor on the different vulnerability classes.

Table 3.2.14 shows the weight factor for each structural typology, assigned to each vulnerability class, which must add up to 1.

Based on the damage functions defined for every vulnerability class according to the EMS-98 scale described in Figure 3.2.14 and the distribution of weigh factors agreed for each structural typology described in Table 3.2.14, the characteristic damage function for every categories of buildings in Caracas (Table 3.2.13) can be obtained. Figure 3.2.15 represents the damage functions determined in the Study (Safina, 2003).

Calibration of the Proposed Damage Functions

In order to prove if the proposed damage function is representative, some of the registered results occurred during the July 29th, 1967 earthquake, were reviewed and compared with the calculation.

Using the damage function associated to Type 5- RC moment resistant frame with more than 8 stories and constructed before 1967 and a macro seismic intensity MMI equivalent to VIII, it is found that at least 6.0 % of the buildings have a damage level equal or grater than 4 – "Heavily Damage" representing approximately 18 buildings out of the 289 that existed then. This is an acceptable result compared with the actual phenomena of 23 buildings damaged.

For the sector of San Bernardino (FUNVISIS, 1978) of a total of 407 buildings mainly between 3 and 8 stories, only 3 presented a damage level 3 representing 0.72% of 417 buildings (407 evaluated and 10 not classified). Using the damage function associated to Type-2 RC moment resistant frame from 3 to 8 stories built before 1967 and a macro seismic intensity MMI equivalent to VII, it was obtained that approximately 1.0% of the buildings should have a damage level equal or greater than 4 – "Heavily Damage", representing 4-5 buildings of the 417 that existed then. This is an acceptable result compared with the actual phenomena of 3 buildings damaged.

(2) Human Casualties

Direct causes of earthquake casualties include collapse of buildings, fires, rockslides, landslides, etc. Among them, human casualties due to building collapse are a general phenomena observed in all areas subject to earthquake disasters. During past earthquakes such as Almenia, Kobe and Mexico, the victims were killed mainly by building collapse. Considering the weakness of building in the barrios, building collapse will be the most notable cause of human casualties in future earthquakes.

Therefore, to estimate the expected number of deaths, the relation of building damage to death toll was studied based on the past earthquakes. Damage function for death tolls and the number of people severely injured are derived from this analysis. Number of deaths and severe injuries is evaluated based on empirical relationships and building damage distribution. The flowchart of the human casualties' estimation is shown in Figure 3.2.16.

1) Human Death

a) Evaluation of existing human damage data in Venezuela

The data of human casualties of past earthquake in Venezuela is studied. However, no correlation can be derived from it. The damages of the 1967 Caracas earthquake and the 1997 Cariaco earthquake are studied.

<u>The 1967 Caracas earthquake</u>

No detailed information on the human death distribution of the Caracas earthquake has been found regarding the distribution of the number of death and the number of heavily damaged buildings. Only the total number of death is known as 274 (Grases, 1990). The number of heavily damaged building of the Caracas earthquake is 271 (Sozen et al., 1968).

The 1997 Cariaco earthquake

The human casualties of Cariaco earthquake was reported by PAHO[3]. There are two statistics of damaged buildings in the report. Table 3.2.15 shows the both statistics.

Figure 3.2.17 shows the relation between number of heavily damaged building and number of death. No correlation can be derived from the relationship.

b) Evaluation of existing human damage data outside Venezuela

Data, which can derive a correlation between number of death and number of heavily damaged building, has not been found from past earthquakes in Venezuela. Therefore, suitable data was looked for outside Venezuela. Under consideration of similarity of building and degree of damage, the Quindio earthquake (1999, Colombia) is selected.

The number of death and the number of heavily damaged building due to 1999 Quindio earthquake are studied by DANE[4], Colombia as shown in the table 3.2.16 and table 3.2.17. These quantities are in good correlation as shown in Figure 3.2.18. The type of buildings in the damaged area of Quindio earthquake looks like low rise buildings and informal buildings in the study area. However, it is different from the middle and high rise building in the study area. Therefore, following equation is proposed to estimate the human death due to the building damage for low rise buildings in the study area.

$$\text{Log } Y = 1.30 \text{ Log } X - 2.60$$

Where Y : Death

X: Heavily Damaged Building number

The number of person per building of the damaged area of Quindio earthquake is 4.46. Therefore, the estimated number of death should be corrected as following formula.

$$\text{The corrected number of death} = \text{The estimated number of death} \times \frac{\text{The number of person per house in the study area}}{4.46}$$

[3] Crónicas de Desastres Terremoto de Cariaco, Venezuela, 1997, PAHO, PAN AMERICAN HEALTH ORGANIZATION
[4] Social and Economic Dimensions of the Effects of the Earthquake in the Eje Cafetero. Diagnosis for the reconstruction., 1999, DANE, National Administrative Department of Statistics, Colombia

The number of person per house in the study area is 4.5 (See section 3.2.1.(4)).

c) Study on the summary of world data

The damage data, which can drive a correlation between death and number of damaged buildings for middle and high building in the study area, has not been found. Therefore, the summary of world data of number of death and heavily damaged building is studied. Figure 3.2.19 shows the summary of the world data.

The data of the 1967 Caracas earthquake and two famous earthquakes, of which damage was mainly caused by heavily damage of middle and high rise buildings, is connected by a straight line in Figure 3.2.17. The connected straight line passes through several famous earthquake damages, which are caused by primary collapse of RC buildings.

Therefore, following equation is proposed to estimate the human death due to the building damage for middle and high rise buildings in the study area.

$$Y = X$$

Where Y: Number of Death
X: Number of Heavily Damaged Building

The proposed death damage function for low rise buildings also studied with the summary of the world data. The damage data sets of the Cariaco earthquake (1997) are marked on the Figure 3.2.19. The line of proposed damage function pass through between two data sets of the Cariaco earthquake. Therefore, the proposed damage function for low rise buildings is considered as appropriate.

2) Human Injury

Same as the information on death, appropriate damage data in Venezuela for human casualty has not been found. Therefore, the data of Quindio earthquake (1999, Colombia) is studied.

The relationship between number of Death and Injury is also obtained from the previous Table 3.2.16 and 3.2.17, and is expressed in the Figure 3.2.20. Referring to the figure, the relationship between death and casualty is formulated by the following equation:

$$\text{Log } Y = 0.9824 \text{ Log } X + 0.9031$$

Where Y: Number of Injured

X: Number of Death killed by heavily damaged buildings

3. 2. 3. Results of Damage Estimation

The estimated number of buildings is summarized in Table 3.2.18, and a summary of estimated number of damaged buildings for four scenarios is shown in Table 3.2.19. The details of estimated damages for each cases are shown in Table 3.2.20 to Table 3.2.23.

3. 3 Inventory of Important Facilities

3. 3. 1. Seismic Evaluation Method of Important Facilities

The purpose of seismic evaluation of important facilities is to clarify whether the function of important facilities is preserved in the event of earthquake.

There are no particular seismic evaluation methods in Venezuela, because the seismic evaluation is not practiced here. Accordingly, JICA Study Team and FUNVISIS adopted seismic evaluation methods developed by Federal Emergency Management Agency (FEMA) of the US government and currently applied in the US.

There are over 1,000 important buildings in the study area of three municipalities (Liberutador, Chacao and Sucre). In this plan, 32 buildings were selected from the whole important buildings and Rapid Visual Screening (RVS) was performed in order to determine whether detail seismic evaluation is required or not. Then, detail seismic evaluation was performed to the required buildings screened through RVS.

(1) Rapid Visual Screening (RVS) for Important buildings

RVS was designed as a procedure not requiring structural calculation. Instead, the judgment whether the building is safe or not is based on a scoring system. In RVS, the inspection, data collection and decision making process, basically, are performed at the building site.

Threshold score value “S” of this scoring system was determined by modifying the value used by FEMA after discussion with FUNVISIS.

The threshold value: S = 2.0 / Important factor of Building (in 2001 Seismic Code)

An example of the scoring sheet with actual record is shown in Figure 3.3.1. The work flowchart for the Rapid Screening Procedure (RSP) identification procedure is shown in Figure 3.3.2. The breakdown of RVS results for 32 important buildings is shown in Table 3.3.1.

(2) Seismic Evaluation of Important buildings

According to the results of RVS, JICA Study Team and FUNVISIS used seismic evaluation method developed by FEMA as a detail seismic evaluation for typical buildings. The detail seismic evaluation was performed with proper modeling of structural frames and analysis to which current Venezuelan seismic code and following reference books are applied.

- The Seismic Evaluation of Existing Buildings: FEMA 178
- Evaluating the Seismic Resistance of Existing Buildings: ATC 14
- Seismic Rehabilitation of Buildings- Phase 1: FEMA 237
- NEHRP Handbook of Techniques for the Seismic Rehabilitation of Existing Buildings
- Seismic Evaluation Code for Existing Building of Reinforced Concrete in Japan

3. 3. 2. Seismic Evaluation Results of Important Facilities

(1) Result of Rapid Visual Screening

The relation of built year and the values of S is shown in Figure 3.3.3. Building use, year of construction and type of structure is shown in Table 3.3.3.

Out of 32 buildings, 24 buildings have smaller score than 2.0 and the detailed seismic evaluation are necessary. These 24 buildings are to be examined in the detail seismic evaluation stage as shown in Figure 3.3.4, Seismic Evaluation Procedure.

(2) Result of the Detail Seismic Evaluation

The Study Team tried to collect the existing building information for the 24 buildings. However, the Study Team got the drawings and calculation sheets of 4 buildings only.

These 4 important buildings are: 2-hospitals, 1-Government and 1-School building.

According to the collected drawings and calculation sheets, the detail seismic evaluation for four important buildings were performed. However, since collected information is not enough, the unknown structural components without drawings were assumed by the evaluation engineer.

Out of four buildings under the detailed seismic evaluation, three building were judged that reinforcement is necessary, comparing with the Seismic Code in 2001.

3. 3. 3. Plan of Building Reinforcement

(1) Procedure for Inspection

The seismic evaluation procedure is shown in Figure 3.3.4 and 3.3.5.

The existing building information (such as architectural drawings, structural drawings, calculation sheets, and other specifications) is necessary for detail seismic evaluation.

If the buildings have had some expansion works, related information is also necessary. The other information will be obtained by visual inspection of structural components and sampling test of structural materials such as concrete and reinforcing bars on site.

The criteria of seismic reinforcement plan will be discussed by building owner and/or operator, and structural engineer. Seismic reinforcement plan will be prepared based on the results of seismic evaluation and the above criteria.

Moreover, the structural engineer must discuss with building owner and operator and/or original design architect and building equipment engineer with regard to the building function and usage conditions.

Cost estimation of the reinforcement plan will be submitted to the building owner and/or operator by the structural engineer.

(2) Cost Estimate for Building Reinforcement Master Plan

As one of the master plan project, building reinforcement of all the necessary buildings was selected. The number of buildings to be reinforced was estimated by the result of sampling survey during the first study in Venezuela. The total cost for this project was estimated based on the following assumptions.

1) Urban Area

- buildings built before 1967 — 15% of new construction cost
- buildings built between 1968 and 1982 — 10% of new construction cost
- buildings built after 1983 — 5% of new construction cost

2) Barrio Area

- buildings on slope steeper than 20 degrees — 20% of new construction cost.
- buildings on slope less than 20 degrees — 15% of new construction cost

3) Rural Area

- buildings on slope steeper than 20 degrees 15% of new construction cost.
- buildings on slope less than 20 degrees 10% of new construction cost

3. 4 Seismic Risk Analysis of Lifelines & Infrastructure

3. 4. 1. General

(1) Introduction

The study area, Libertador, Chacao and Sucre in Caracas Metropolitan District, is located at the isolated valley where social and economic activity are supported by a wide road network and lifelines such as express highway, viaduct (elevated highway), water supply, gas supply, electric supply, telecommunication system etc. The population of study area was about 2.7 million in 2001.

Once a disastrous earthquake occurs near the study area, the road network and lifelines may incur serious damage and may cause physical disruption of city functions.

In order to secure and maintain the city functions of Caracas Metropolitan District, it is indispensable to strengthen the vulnerable infrastructures and lifelines against earthquakes.

Seismic damage estimations for infrastructure and lifelines in the study area were carried out and the necessary countermeasures are recommended for strengthening the structure against earthquakes.

(2) Collected Data of Infrastructure and Lifeline

Data of infrastructure and lifelines of the study area were obtained from the related Agencies or Authorities; however, the collected data was quite limited due to the insufficient inventory list. Therefore the seismic damage estimations could be made only for the collected data and the information available from the investigation at the site and map in the market.

(3) Scenario Earthquake

Scenario earthquakes 1967 and 1812 are adopted for the seismic damage estimations. The details of each scenario are shown in Table 3.4.1.

3. 4. 2. Method of Damage Estimations

(1) Bridge

1) Assumptions

A statistical method based on Japanese experiences is adopted, since information on collapse of bridges in Venezuela is not recorded. The "point evaluation procedure", i.e. the multi-dimensional theory, was adopted. The result obtained from the "point evaluation procedure" describes what amount of damage to bridges may be expected at the time of an earthquake. If some bridges are estimated to collapse, a detailed seismic analysis should be undertaken as precise as the original design and countermeasures should be taken to avoid the serious damage by earthquake.

2) Procedures

The Express Highways in the Caracas Metropolitan Area connects the east-west and north-south area. JICA study team surveyed bridges in the field which are located along the express highways.

The bridges are evaluated in terms of seismic damages according to an earthquake scenario. The study workflow is shown in Figure 3.4.1.

3) Method of Damage Estimation

The criteria for seismic damage of bridges is based on the method proposed by Tsuneo Katayama, which has been adopted in the Disaster Prevention Council of Tokyo Metropolitan Area (1978), and is widely used in Japan for practical purposes. This method only evaluates bridge collapse due to the superstructure collapse, but not damages (widespread damages and slight damages, etc.) regarding all structural members.

The following items are taken into account for evaluation:

- Ground type, Liquefaction, Girder type, Number of spans
- Bearing type (shoe type), Minimum bridge seat width
- Maximum height of abutment and pier
- Foundation type, Material of abutment and pier
- Peak Ground Acceleration (Earthquake intensity scale)

Estimated seismic damage is expressed as a total score. Stability judgment of bridges is defined as shown in Table 3.4.2.:

The score regarding each item is shown in Table 3.4.3.

(2) Viaduct (Elevated Highway)

According to the Kobe Earthquake (M7.2, 1995), only a few bridges crossing over river/road collapsed, but many viaducts on express highways such as multi-span type collapsed.

The rate of collapses and damages in the Kobe Earthquake are shown in Tables 3.4.4 and 3.4.5.

The Disaster Prevention Council in the Tokyo Metropolitan Area analyzed the Kobe Earthquake data in the Table 3.4.4 and adopted the damage ratio per km in the table regarding the multi-span viaduct for estimation of seismic damage (1997).

There are some multi-span viaducts, which are on the Express Highway in Caracas Metropolitan Area. JICA study team applied the same damage ratios per km as proposed by the Tokyo Metropolitan Government in this project.

(3) Metro

The underground structure is rather stable against earthquake compared with the structure on the ground due to less seismic force underground. But those structures constructed by the cut and fill tunnel will be affected due to the embankment on the structure.

Damage of the subway tunnel during the Kobe Earthquake is shown in Table 3.4.6.

In the case of the Kobe Earthquake, some 2-cell reinforced concrete type box were collapsed by vertical motion of the overlying soil on the box. (Figure 3.4.2)

(4) Water Supply Pipeline

The facilities of the water supply network are shown in Figure 3.4.3.

1) Assumptions

The basic assumptions applied for damage estimation of water supply pipelines are as follows:

A statistical approach for damage estimation for city main pipes, distribution pipes and service pipes are applicable only when information on their materials, diameter, and lengths is available in any given area.

In the study, assumptions are:

- Node facilities are not included for damage estimation, such as inlet facility, water purification plant, and transmission pipe. In this study, the subject facilities are water pipe, distribution pipe (main and small), and service pipe. The individual diagnosis should be made on such node facilities to evaluate the safety against earthquakes.
- Damage due to the direct result of ground motion is estimated, such as breakage or disjoint of pipelines. Such damages caused by landslides or building collapses, so called secondary damages, are not included.
- The damage estimation method is based on the past damage experiences in Japan.

2) Method of Damage Estimation

The characteristics of water supply networks and pipeline structures are considered similar to those of Japan. Therefore, an analysis method for the damage estimation of water pipelines proposed by Disaster Prevention Council of the Tokyo Metropolitan Government was applied to the study, taking into account the experience in the Hanshin/Awaji Earthquake Disaster.

The standard damage ratio R1 for water pipeline proposed by the Tokyo Disaster Prevention Council (1997) has been commonly used to evaluate seismic damages of water pipelines in Japan. The damage ratio for pipeline Nd is defined as follows:

$$N_d = C_1 \cdot C_2 \cdot C_3 \cdot R_1 \cdot L$$

Where,

N_d: damage ratio (damage point/km)
C1 : correction factor for liquefaction.
C2 : correction factor for pipe material.
C3 : correction factor for pipe diameter.
R_1: standard damage ratio (damage point/km).

$$R_1 = 2.24 \times 10^{-3} (PGV-20)^{1.51}$$

PGV: peak ground velocity (cm/sec).

Flow chart of damage estimation for water supply is shown in Figure 3.4.4. The curve of standard damage ratio is shown in Figure 3.4.5.

(5) Natural Gas Pipeline

The facilities of the natural gas network are shown in Figure 3.4.6.

1) Assumptions

Assumptions are basically same as the case of the Water Supply Pipeline.

2) Methods of Damage Estimation

Damage estimation regarding gas pipelines is based on the data of the Kobe Earthquake in Japan. The Standard Damage Ratio is set for the relation between peak ground velocity and standardized steel pipe, and then the modification of the damage ratio is made according to pipe materials, diameter and liquefaction. This method was applied by Disaster Prevention Council of the Tokyo Metropolitan Area (1997). The damage ratio for pipelines, Nd is defined as follows:

$$Nd = C_1 \cdot C_2 \cdot R \cdot L$$

C_1 : correction factor for liquefaction.

C_2 : correction factor for pipe material.

R : standard damage ratio (damage point/km).

L: Pipeline extension in Total (km)

The standard damage ratio is:

$$R = 3.89 \times 10^{-3} \times (PGV-20)^{1.51}$$

PGV: peak ground velocity (cm/sec).

The correction factors are shown in Tables 3.4.9 and 3.4.10.

The curve of standard damage ratio is shown in Figure 3.4.7.

(6) Electric Power Supply

Electric Power Supply Network is shown in Figure 3.4.8.

The subject facilities for seismic damage estimation are to make for the electric pole and underground electric cable as shown Figure 3.4.8.

1) Assumptions

- ssumptions are basically same as the case of Water Supply Pipe Line.
- damage of an electric pole means collapse or severe damage.

2) Method of Damage Estimation

a) The seismic damage of an electric power pole is evaluated based on the Kobe Earthquake in Japan. And the number of collapsed poles Ndp is defined as follows:

$$Ndp=C1\times R/100\times N$$

Where

C_1: correction factor by liquefaction
R: damage ratio
N: number of poles in total

Damage ratio is assumed the same as Kobe Earthquake.

b) Seismic damage of underground structure such as buried electric power line is represented as follows:

$$Nd=C1\times R/100\times L$$

Where

Nd: extension of damage (km)

C1: correction factor by liquefaction

R : damage ratio

L : extension in total (km)

(7) Tele Communication Cable

The method of seismic damage estimation is the same as Electric Power Line.

(8) Hazardous Facility

Damage functions of hazardous facilities on the Seismic Micro-zoning Study of Tokyo Metropolitan Government are used in the statistical analysis of past earthquake ground motion

(PGA) with identified damaged of certain categories of hazardous facility by the Tokyo Metropolitan Fire Fighting Department.

The category of hazardous facility, type of damage, and damage ratio by PGA are shown in the table 3.4.14.

3. 4. 3. Result of Damage Estimation

(1) General

Seismic damage estimation was made for the infrastructures and lifelines. The data was obtained but quite limited from relevant Agencies/Authorities and site investigation.

The collected data is as follows.

1) Bridge

2) Viaduct (Elevated Highway)

3) Metro

4) Water Supply Pipeline

5) Telecommunication Line

6) Hazardous Facility (Gasoline Station)

(2) Bridge

115 bridges on the express highways were selected for the seismic damage estimation in consideration of the significance of emergency activity for rescue and transportation at the time of earthquake occurrence.

Most of the bridges were constructed before 1967 and no serious damage was reported when an earthquake occurred in 1967, except one minor damage of the pier at the interchange Pulpo.

The result of damage estimation of bridges indicates the existing bridges are strong enough against the scenario earthquake 1967 and the damage estimation also shows the same result.

In the case of scenario earthquake 1812, 15 bridges are estimated as a high seismic risk and two bridges estimated as a medium seismic risk to collapse when such scale of earthquake occurs. The details of those bridges and locations are shown in Tables 3.4.15~3.4.18 and Figure 3.4.9.

Among 15 bridges estimated as a high seismic risk, 10 bridges are located at the interchange Arana which are built on sedimentary deposit and susceptible for liquefaction. The interchange Arana is the biggest interchange in Caracas, which was opened to the traffic in 1966, and the height of bridge is more than 10 m at the center. This interchange plays an important role for transportation for both east-west and south-north directions. The security of this interchange is vital for social and economic activity in Caracas city.

(3) Viaduct (Elevated Highway)

Seismic damage estimation was made for the viaduct (elevated highway) referring to the experience of Kobe Earthquake data 1995 in Japan. Due to the estimation, two locations may collapse and three locations may incur damage at interchange Arana.

Damage Estimation, earthquake intensity and its length of Viaduct are shown in Table 3.4.19 and each viaduct location is shown in Fig. 3.4.10.

At the interchange Arana, the flyovers were constructed in 1966 and old seismic code was applied to the design. There are three flyovers constructed at the center of interchange Arana and the height of structure is more than 10 m and the structure may be easily affected by an earthquake.

It is recommended to investigate the design code applied to the bridges, and on the basis of the design code, it is required to take a countermeasure to strengthen the structures against earthquake.

(4) Metro

There are three Metro lines in Caracas Metropolitan District and their total length is 44.3 km. The outline of the Metro is shown in Table 3.4.20 and its location and open cut and box type tunnel locations are shown in Fig. 3.4.11.

Line 1 : Peak Ground Acceleration (PGA) is estimated Max.581 gal at the station between Capitolio and Chacaito (about 5.8 km) in case of scenario earthquake 1812.

In case of Kobe Earthquake, middle columns were collapsed due to the extra vertical force by the earthquake. Especially the weight of embankment is considered to apply to the tunnel structure vertically. It is recommended to check the design and the type of tunnel structure and strengthen the middle column in consideration of extra vertical force on the tunnel.

Line 2 : PGA is estimated Max.721 gal at the station of Antimano. The open and cut box type tunnel between Artigas and Mamera is recommended to reinforce at the middle column in consideration of scenario earthquake 1812.

Line 3 : PGA is estimated Max. 409 gal at the Box Type tunnel in scenario earthquake 1812. No damage of middle column collapse was recorded in Kobe Earthquake. However, the damage of Metro in Caracas may be different in accordance with the embankment thickness on the box tunnel. It is recommended to check the design and strengthen the middle column to see if the middle column is not strong enough against the vertical force to the tunnel.

The damage against shield tunnel of Metro in Kobe Earthquake was not reported but the shown shield tunnel is very strong structure against earthquake.

(5) Water Supply

No information of material is available, therefore seismic damage estimation was carried out on the assumption that the material would be ductile cast iron. Recently the water supply authority is promoting the policy that the ductile cast iron is being used gradually for the water supply pipe.

The damage estimation is shown in Fig. 3.4.12 in scenario earthquake 1812.

According to the damage estimation, no damage is expected in scenario earthquake 1967. In case of scenario earthquake 1812, the maximum estimated damage number of points per mesh (500 x 500 m) is only 0.56 points.

The most affected areas are Neveri and Sanpedro and these locations are shown in Fig.3.4.12, but the estimated damage points are quite small.

However, this estimation is based on the assumption that all pipe material is made of ductile cast iron. Ductile cast iron is strong against the earthquake. It is recommended to continue to promote the policy to use the ductile cast iron.

(6) Telecommunication

In the case of scenario earthquake 1967, most of the earthquake intensity is equal to or less than 5 of Japan Meteorological Intensity (JMI) and the possible damage is only 0.07% against the total length. In case of scenario earthquake 1812, 0.25% of total telecommunication cable may be damaged.

The length of damage estimation of telecommunication in each area is shown in Table 3.4.21.

(7) Hazardous Facility (Gasoline Station)

Total 54 gasoline stations are located in the study area and their locations are shown in Fig.3.4.13.

Scenario earthquake 1967: Estimated Max. PGA is less than 250 gal and the probability of small spill from tank and pipe joint is only 0.14% in accordance with the study of Tokyo Metropolitan Government, 1977 and no damage anticipated.

Scenario Earthquake 1812: Estimated Max. PGA is 400~450 gal and there are 13 gasoline stations in that area. The probability of small spill from tank and pipe joint is only 2.0% in accordance with the study of Tokyo Metropolitan Government,1977 and also the damage is quite small.

Even considering all area, the number of affected gasoline stations is less than one location.

The Max. PGA area and the area where gasoline stations concentrating are shown in Table 3.4.22.

Gasoline stations located at the high acceleration area should be improved in terms of seismic resistant structure.

The number of gasoline stations in accordance with the PGA are shown in Figures 3.4.14 and 3.4.15.

In case of scenario earthquake 1967, the PGA of location of gasoline stations is less than 200 gal. But in case of scenario earthquake 1812, the PGA is going up much higher and the figure is showing many gasoline stations are located at the high PGA area.

3. 5 Disaster Prevention Study for Earthquake Disaster

3. 5. 1. Study on Structural Measures

(1) General

To reduce human casualties due to possible earthquake, structural measures to ensure building safety is the most important factor. In addition, if building damage was successfully reduced, it would save much money otherwise spent for emergency response and recovery.

Generally, the effect of structural measures is permanent once installed, but more expensive than non-structural measures. However, non-structural measures such as training or education needs to be well maintained to be effective. To maximize prevention effort, both structural measures and non-structural measures should be optimized. Structural measures can be made by following:

- For new buildings, enforcement of latest seismic code will be effective. However, it will take time for old buildings in urban area to be replaced by new buildings, and the number of newly built building will be limited.

- Many existing buildings are built under the old seismic code, prior to the seismic code, or without engineering. Even though the seismic code has been revised, the strength of existing buildings remains the same. Since they can be a major problem if a major earthquake happens, they should be the main objects of seismic reinforcement.

- Among existing buildings, socially important facilities have priority for the seismic reinforcement, because they should maintain function during an emergency.

- From viewpoint of urban planning, consideration of open space and roads in disaster prevention planning is important. Open space can be used as a park during normal times, and then used as an evacuation space during an emergency period. In addition, it can prevent fire spreading, once a fire brakes out.

- The availability of roads is critical to emergency response activities, but narrower roads can be blocked by abandoned car or collapsed buildings. Therefore, preservation of main road access, together with their designation as emergency routes will be important to ensure effective transportation flow in an emergency.

In this study, feasibility of seismic reinforcement of buildings is principally investigated quantitatively in the following manners.

- As to the buildings in urban area, they are made with engineering so that technical data such as structural drawings and calculation sheets are available. Therefore, evaluation of seismic reinforcement can be made using the result of rapid visual inspection and detailed evaluations made in chapter 3.3 and in section report S-6.

- As to the buildings in barrio, there is little technical information available so far because they are made without engineering. However, considering the fact that they are the majority of the building in study area and the most vulnerable types of buildings against earthquake, it cannot be neglected to develop a disaster prevention plan. In this study, in order to understand the actual strength of houses in barrio as well as to see if it is possible to reinforce such buildings, the building breaking test using real scale houses are made.

(2) Field Test on Seismic Reinforcement of Buildings

1) Introduction

a) Barrio houses

A lot of Barrio houses have been built on slopes in Caracas (photo 3.5.1, photo 3.5.2). But the Seismic Code is not followed for the design and construction of these Barrio houses. A Barrio house under construction is shown in photo 3.5.3. Main frames are reinforced concrete structure and walls are clay hollow brick walls. The quality of reinforced concrete structure seems to be low. All houses are non-engineering buildings for the seismic design and construction against earthquakes.

b) Objectives of the Field Test

Barrio houses are non-engineering buildings, and those especially built on slopes will be the most vulnerable against earthquake. But the seismic strength of Barrio houses on slopes is not known up to the present.

The objectives of the field test are as follows;

- To assess the vulnerability of Barrio houses
- To assess the effect of seismic reinforcement for Barrio houses, with available techniques and affordable cost
- To raise public awareness of vulnerability of Barrio houses and effect of reinforcement.

c) Flow of the Field Test

At first, four same housing models are built as non-engineering buildings. Then seismic reinforcement for three out of four models is done. Seismic reinforcement is provided considering the cost impact and technical effect as described in the next section. Horizontal loading is applied to each model to measure strength and seismic reinforcement is assessed.

The video of the field test is taken and is used as the public awareness material.

2) Testing Models

a) A Base Model

An example of Barrio Houses built on slope is shown in photos 3.5.4and 3.5.5. Photo 3.5.4 shows 1 storey house but structurally of two stories. The lower floor is a reinforced concrete structure only. Upper floor seems to be brick walls only. Photo 3.5.5 shows a two to three storey house structurally. It is a reinforced concrete structure only in the lower floor and the upper floors are made with bricks walls. These are used as reference for a base model.

A Barrio house with 2 stories structurally built on the slope with approx. 20 degrees is selected as a base model of the field test. A full scale model is used for the test to realize actual condition of non-engineering building. Sizes of a model are 3mx4m in external dimension, 2.8mx3.8m in column span (center to center of columns), storey height is 2.4m for upper floor and 2.4m for lower floor (lower side of slope). Foundation sizes are 1.0mx1.0mx0.2m. Clay brick walls are installed for upper floor for horizontal loading direction only.

b) Testing Models

[Detail of Members]

Member sizes and reinforcing bars are specified based on the hearing of existing Barrio houses before construction of models, and monitored to construct non-engineering building.

Followings are the detail of members constructed and are common to each model;

Column sizes are 20cmx20cm, main re-bars are 4no of 1/2" (12.5mm, A=1.27cm^2) of A42 (fy =4,200kg/cm^2), hoop re-bars are 4mm of 5,000kg/cm^2 @200.

Beams are sizes are 20cmx20cm, main re-bars are 4no of 1/2" (12.5mm, A=1.27cm^2) of A42 (fy =4,200kg/cm^2), stirrup re-bars are 4mm of 5,000kg/cm^2 @200.

Floors are constructed using Tabelone floor. Tabelone floor is consisting of H-steel joist @800, clay brick floor (Tabelone) and concrete layer with wire mesh. Total thickness of a floor is 10cm.

The foundation is embedded in a depth between 1,0m and 1,2m from the existing surface after the site grading

[Seismic Reinforcement and Cost Impact]

There are two methods for seismic reinforcement generally, one is to improve resistance and the other is to improve ductility. To improve ductility is not feasible technically in this case, and to improve strength is used in this case. The criteria of selection such as technically and economically feasible method are considered for seismic reinforcement. As the result, providing grade beams, clay hollow brick walls and concrete block walls are used as the method of seismic reinforcement. These materials are purchased easily from the local market.

Total 4 no models are constructed and tested. Model 1 is a model without seismic reinforcement. Model 2 is a model with seismic reinforcement by providing grade beams. Cost impact is approx. 5 to 7% of total construction cost. Model 3 is a model with seismic reinforcement by providing grade beams and clay brick walls. Cost impact is approx.10%. Model 4 is a model with seismic reinforcement by providing grade beams and concrete block walls. One side of concrete block wall has vertical and horizontal re-bars. Cost impact is approx.15%. Summary is shown in Table 3.5.1.

Figures 3.5.1 to 3.5.10 show drawings of each model. Grade beams are the same size to beams and the connection to columns is detailed so that they can be installed as the reinforcement after the construction of columns (Figure 3.5.9). Column length of minimum 600mm (3 times of column width 200mm) is maintained between floor beam and grade beam (upper side of slope). Weight of a model for seismic assessment is 9.8 ton (2.45 ton/column) as shown in Table 3.5.2.

3) Construction of Models

a) Construction Sequence

Location of the site for 4 no models is Barrio Las Minas, Baruta. The site has been provided by Baruta municipality. The site is a backfilled area that was filled during the construction of highway roads in 1960's. The slope has the inclination of 21.8 degrees (1.0: 0.4). The reinforced concrete work for models was done at first, and seismic reinforcement works such as brick walls and concrete block walls at lower floor were completed by the middle of July 2004 (photo 3.5.6~3.5.13).

The embedment of foundation footing from the ground surface is assumed to be 1.0m to 1.2m by the hearing before construction, and 1.2m is used considering the condition of filled slope. Detail construction works are shown in photos 3.5.14~3.5.49. These photos show characteristics of construction works for Barrio houses.

b) Aspects of Non-Engineering during Construction

Following aspects of non-engineering works are observed during construction.

[Concrete mixing]

Concrete mixing is ‘homemade’ and made by hand based on experience. General mix-proportion of concrete at the site is 24 carts for fine aggregate (sand), 12 carts for coarse aggregate (gravel), 4 bags (45kg per bag) of cement, and some water for $1m^3$ concrete. It is noted that mix proportion of sand and gravel is opposite compared to engineering mixing due to workability, and volume of water which decides strength of concrete is not measured. AE additive agent is not used. Concrete strength is unknown at the time of mixing accordingly. Test pieces of cylinder are taken for the test of 28 day strength of concrete. Sizes of coarse aggregate seem to be too big considering small sizes of members (photo 3.5.14 - photo 3.5.17).

[Fabrication of Hoop Re-bars]

Hook of hoop re-bars is 90 degree and is not 135 degree that is required for seismic performance (photo 3.5.18, photo 3.5.19).

[Concrete Foundations]

The concrete of foundations is cast without perimeter framework. When mixing the soil into the concrete, it reduces the quality.

[Longitude of Overlap of Re-bars]

Short overlap length of column re-bars is observed. This is by the lack of engineering coordination of re-bar arrangement and position of construction joint (photo 3.5.23).

[Concrete Cover]

It is observed that the main column re-bars are uncovered and there is no concrete recovering , which reduces column strength and durability. This is caused by the lack of engineering coordination regarding the size of the hoops, the framework and the coarse aggregate of concrete (photo 3.5.27).

[Re-bar Anchorage]

Shortage of beam re-bar anchor to column is observed. The main re-bars of the beams hits the external face of the formwork, which reduces the resistance of the beam. This is caused by no-understanding of importance of re-bar anchorage. Un-proper re-bar arrangement at joint of beam and column is also observed. Appearance of cast concrete shows this (photo 3.5.33).

[Construction Joints]

Un-proper horizontal joint of beam is observed. Horizontal construction joint of beam reduces strength of beam (photo 3.5.34).

[Removal of Form work]

Early removal of beam bottom formwork is observed. Bottom formwork of beam is removed in one or two days only after concreting. This may cause deflection and cracks of beams. Longer curing is required subject to confirmation of concrete strength at the removal (photo 3.5.35).

[Others]

Twist of columns is observed. This is caused by the twisted installation of column re-bars by the lack of surveying before casting concrete of foundation (photo 3.5.28). Height difference of column joints is observed. This causes height adjustment of column by casting additional concrete or level difference of beams and floors later (photo 3.5.29).

4) Material Tests

a) General Information of Materials

Concrete: refer to previous section “Concrete Mixing”.

Reinforcing main steel bar: Grade A42 (fy(yield strength) =4,200kg/cm^2),diameter 1/2”(Area=1.27cm^2).

Hoop and stirrup re-bars: no specific standard materials, and fy=5,000kg/cm^2, diameter is 4mm.

Clay brick: no specific standard material, sizes are 10cmx20cmx30cm, ave.17pieces/m^2. Thickness of plate consisting hollow is 5~7mm (photo 3.5.44).

Concrete block: no specific standard material, sizes are 15cmx 20cmx40cm (photo 3.5.46).

Tabelone for floor: sizes are 6.5cmx20cmx80cm, and weight is 8kg/piece, thickness of floor concrete is ave.3.5cm, located on H-steel joist (weight 7kg/m).

Epoxy grout: used with drilling for the embedment of re-bar (3/8" Grade A36) to existing columns and beams for concrete block walls for Model 4.

b) Material Test

Concrete cylinder test at 28 days is summarized in Figure 3.5.11. Average strength of concrete for beam/column is 58 kg/cm^2 only and is about 1/3 of normal engineering concrete. Water cement ratio is estimated approximately 110%, that is very high compared to not more than 65% of normal engineering concrete. Other test results including concrete are summarized in Table 3.5.3. Materials are tested by IMME of UCV.

5) Horizontal Loading and Measurement

a) Horizontal Loading

Horizontal load is applied at the floor with slope direction. Horizontal load is applied statically by hydraulic jacks. 2 no synchronized hydraulic jacks with capacity of 50 ton each and with stroke of 50mm are used for loading of a model. Manual operation for pumping is used. Step of loading of $2kg/cm^2$ for hydraulic pump pressure is used for loading and this is converted to 500kg/step for hydraulic jacks according to the calibration test result. Re-setting of hydraulic jacks that has 50mm stroke only is planned when required.

Load cell for the measurement of loading is not used, and the loading after the maximum strength is not measured in this case. RC reaction wall is provided at the slope side to resist horizontal load by hydraulic jacks through steel frames. Steel frames have length of 2.85m, and are detailed for easy assembly and re-assembly. A steel loading beam is provided at the floor level, to transfer loads from hydraulic jacks to frames of a model. Sizes of reaction walls are 1.2mx3.0m for model 1 to 3, 1.2mx4.0m for model 4 (Photo 3.5.48, Photo 3.5.50- Photo 3.5.53, Figure 3.5.5).

b) Measurement

Horizontal deflection for models is measured by flex-meters (dial gauges) located at the floor level. Deflection at the roof level and ground level are also measured for reference. Total 8 locations are measured for horizontal deflection. Flex-meters have stroke length of 5cm or 2.5cm.

Loading and measurement is done by IMME of UCV (photo 3.5.53-3.5.54, Figure 3.5.10).

6) Results of the Field Test

As stated in chapter 5, strength of model 1 and strength increase for reinforced models 2, 3 and 4 is evaluated mainly through the load deflection curve up to the maximum strength. Load deflection curve is not measured after the maximum strength by the reason of the limitation of measurement equipment, while general behavior is observed visually up to the horizontal deflection of 100mm~130mm. Photos are also taken for record at this final stage.

a) Schedule of Test

Field test was done by following schedule;

- 26 August, 2004 : Field test for Model-2
- 27 August, 2004 : Field test for Model-1
- 31 August, 2004 : Field test for Model-3
- 1 September, 2004 : Field test for Model-4

b) Results

The load deflection curve up to the maximum strength for 4 models is shown in Figure 3.5.16. The data of load and deflection of each model is shown in Table 3.5.4 to Table 3.5.7. In this table, point 2 and 5 are the deflections at the floor, and average value is used in Figure 3.5.16. Point 1 and 4 are the deflections at the roof, point 3 and 6 are the deflections at the ground at upper side, and point 7 and 8 are the deflections at the lower side of the slope.

Odd number point is the right side and even number point is the left side of the frame from the view of hydraulic jacks. The surface ground level at the time of testing is, 20cm to 30cm at short column position and 50cm to 60cm for long column position respectively, higher than those shown in Figure 3.5.1 to 3.5.10, by the rainfall and other reason.

[Model-1]

Failure mode of model 1 frame is column collapse mode and plastic hinges are provided at the top of columns. Floor beams are not damaged seriously. Elastic stiffness is 8.25t/cm, and yield strength is 8.75 ton. Maximum strength (max. load) is 10.25ton (Photo 3.5.55- Photo 3.5.58). Deflection at yield strength is 10.6mm, and storey deflection is 1/170 (10.6/1,800) for short column and 1/226 (10.6/2,400) for long column respectively. Deflection at maximum strength is 16.4mm, and storey deflection is 1/110 (16.4/1,800) for short column and 1/207 (16.4/3,400) for long column respectively. Bending failure of columns is occurred at the beginning, and diagonal shear crack of short columns is also observed at mid-span at later stage (Photo 3.5.57). It is confirmed that the bottom of the short column is not damaged by the visual inspection after the excavation (Photo 3.5.58).

Yield point is evaluated as the yield of short columns, and point of the maximum strength is evaluated as the yield of long columns. It is evaluated from the appearance of top of column at the final stage of the test of which horizontal deflection is approx.120mm, ductility with some extent is expected.

Axial stress of column by vertical load is 2,500kg/20.5cmx20.5cm=5.95kg/cm^2, and stress ratio is 5.95/58=0.10. Shear stress of short column at yield strength is estimated as 11.6kg/cm^2 (8,750x0.85/(2x0.8BD)), if 85% is supported by short columns. This stress level is high and is approx. 1/5 of compressive strength of concrete.

[Model-2]

Failure mode of short columns is bending/shear mode at yield strength and shear failure occurs at final stage of test. Failure mode of long columns is bending failure mode, while shear diagonal crack is also observed (photos 3.5.60~3.5.65). Yield strength is 10.25 ton, which is 1.17 times of that of model 1. Maximum strength is 14.75 ton, which is 1.44 times of that of model 1. Initial stiffness is increased to 25.0ton/cm, which is 3.0 times of that of model 1. Deflection at yield strength is 4.1mm, and storey deflection is 1/439 (4.1/1,800) for short column and 1/829 (4.1/3,400) for long column respectively. Deflection at maximum strength is 17.6mm, and storey deflection is 1/102 (17.6/1,800) for short column and 1/193 (17.6/3,400) for long column respectively. Deflection at the ground surface (almost same to grade beam) at yield and maximum strength is 2.4mm (lower ground level) and 1.1mm (lower ground level) respectively.

Grade beams are provided so as to maintain ratio of column clear length/column depth is 3.0 to prevent shear failure which is brittle failure. It is assessed that shear failure of short columns occurre by the reason of unexpected low strength of concrete which is average 58 kg/cm^2.   It is confirmed that the short column under grade beam is not damaged by the visual inspection after the excavation (Photo 3.5.65).   Cost impact of strengthening is 5 to 7% of the total cost of building.

[Model-3]

Load deflection curve is similar to that of Model 2.   Separation of clay hollow brick walls from columns and beams appears from the beginning of loading and combined effect with frames is not expected.   Maximum strength is 16.75 ton, which is 1.13 times only of that of model 2, at the deflection of 17.6mm.   It is found that clay brick walls have no contribution to stiffness and strength compared to those of model 2.   Stiffness and strength of clay brick walls is very low for structural use and for structural reinforcement (Photo 3.5.66-Photo 3.5.70).   Cost impact is 10 % of the total cost of building.

[Model-4]

Separation of hollow concrete block walls without re-bars from columns and beams starts at early stage of load 6~7ton.   Yield strength appears at the load of 13.75 ton and deflection of 2.7mm, by the separation of hollow concrete blocks with re-bars from columns (Photo 3.5.71-Photo 3.5.76).   The maximum strength 15.25 ton is observed at deflection 12.8mm.   Initial stiffness is increased by providing hollow concrete blocks, while strength is almost similar to those of Model 2 and 3.   Horizontal deflection is increased after the max. strength and is provided more than 100mm as the final stage of loading.   It is found that the strength of hollow concrete blocks is low for structural use and for seismic reinforcement.   Concrete hollow block wall without re-bars is separated from column/beam at early stage, while wall with re-bars is not separated until lap joint of horizontal re-bars is broken.   Strength of concrete block is low, and lower than that of mortar (Photo 3.5.46, Photo 3.5.76).   Cost impact is 15% of the total cost of a building.

c) Summary

- Strength of frames without reinforcement is 9 to 10 ton for 4 columns.
- Providing grade beams is effective for seismic reinforcement and increases the strength by approx.40%, and need to pay attention clear length of column, to prevent shear failure considering strength of concrete.   Cost impact is 5%~7 %.

- Clay hollow brick wall is not effective for seismic reinforcement. Cost impact is 10%.
- Concrete block wall will be effective, if concrete strength of block is increased, together with the use of re-bars for seismic reinforcement. Drilling and epoxy grouting method is suggested for re-bar anchorage to existing column/beam. Cost impact will be 15%.
- Video report is used to improve awareness to the public
- Other seismic reinforcement methods (practical and economical method) are also suggested to investigate in future.
- This kind of full scale field test is done for the first time in Caracas. It is strongly recommended to continue and develop seismic assessment and reinforcement through model tests and analyses for Barrio houses in future.

(3) Seismic Safety of Existing Buildings in Caracas

The seismic safety of existing buildings in study area are obtained depending on the each seismic capacity during major earthquake. These seismic capacities are classified into two area as urban area, and rural and barrio area, otherwise engineering and non-engineering buildings.

1) Seismic Safety of Existing Buildings in Urban Area

The buildings in urban area had been approved and constructed based on the Venezuelan Seismic Code in each period. The single family houses in urban area had been not required to submit for the building permit, but these houses had retained an engineering level in each period. Accordingly, the buildings in urban area are basically engineering building including single family houses.

Throughout our study of seismic evaluation for urban buildings, the seismic capacities of each existing buildings are generally characterized due to "year of construction" because of based on the each seismic code.

However, some existing buildings have some vulnerability due to the other conditions such as height, plan and vertical irregularities, soft story, workmanship, disposition of walls, type of structural members, and etc..

a) Seismic capacity of existing buildings built in before 1967

The buildings constructed in this period had basically low seismic capacity with lack of strength and lack of ductility against to 1812 earthquake.

b) Seismic capacity of existing buildings built between 1968 and 1982

The buildings constructed in this period had from low to moderate seismic capacity mainly lack of strength against to 1812 earthquake.

c) Seismic capacity of existing buildings built between 1983 and 2001

The buildings constructed in this period had moderate seismic capacity against to 1812 earthquake.

d) Seismic capacity of existing buildings built in after 2002

The buildings constructed in this period had high seismic capacity against to 1812 earthquake. However, there are only a few buildings (less than 0.1% of building number in urban area) in study area.

2) Seismic Safety of Existing Buildings in Rural and Barrio Area

The buildings in rural and barrio area except factory and high-rise apartment houses are basically non-engineering buildings with low cost and low quality reinforced concrete building which located on sloped area. Since these houses are not required to submit for building permit and no check of construction work with engineer. Accordingly, these buildings have basically low seismic capacity, but it is difficult to obtained the actual seismic capacity. On the seismic evaluation stage, a seismic evaluation engineer can not get information of these existing buildings.

Therefore, JICA Study Team and FUNVISIS planed the building breaking test to obtain the seismic capacity of normal structure of barrio houses, and the effect of seismic reinforcement methods as described in Supporting Report “S-7”.

3) Seismic Reinforcement of Key Facilities

Key facilities must be resistant enough against a large earthquake, if it is found necessary by seismic evaluation. Governmental facilities of commanding offices, response and medical facilities, and evacuation facilities, should be reinforced for disaster management viewpoints. The following facilities should be operational even in the emergency situation, thus the buildings that house such entities are mandatory to be reinforced.

a) Commanding facilities

AMDC government

- 3 AMDC buildings in the study area

Municipality office of the Mayor and branch offices

- 30 municipal buildings in the study area

National governments related to disaster management

There are 26 buildings of central governments, out of which buildings that house headquarters of the following ministries related to disaster management are to be reinforced against a large earthquake.

- Ministry of the Interior and Justice
- Ministry of Infrastructures
- Ministry of Health and Welfare
- Ministry of Environment
- Ministry of Planning and Development
- Ministry of Housing

b) Response, rescue and medical facilities

Rescue operation entities

- Police offices (34 office in the study area)
- Fire stations (17 stations in the study area)

Medical facilities (in the study area)

- 25 hospitals,
- 134 ambulatories in the study area
- Private hospitals

c) Evacuation and refugee accommodation

- Schools (704 AMDC schools)

Schools should be reinforced also because many people gather.

- Stadiums
- Community halls
- Churches

(4) Seismic Reinforcement Plan of Existing Buildings

1) Basic Policy

The purpose of seismic reinforcement for existing fragile buildings against to strong and very rare earthquake as 1812 scale earthquake is varied from protection of life to protection of building function due to scenario earthquake and building use.

The target of seismic reinforcement plan for normal buildings as well as private houses is protection of life due to building damage under strong earthquake. It will be able to obtained protect property against to a moderate earthquake as 1967 scale earthquake, and no damage under a miner and frequent earthquake.

The target of seismic reinforcement plan for key facilities such as the emergency command center, and the priority buildings facilities is protection of function under strong earthquake. It will be able to obtained no damage on building structure under a moderate earthquake.

JICA Study Team propose the criteria of seismic reinforcement plan for each building-use, and each levels of earthquake as shown in Table 3.5.9.

In case of unsafe building, the engineer should be study and judge the result of seismic evaluation which is due to lack of strength or lack of ductility. Then, the engineer has to make reinforcement plan and its cost against to the above reason, and discuss with building owner and/or building operator and original architect regard to a function and uses of building.

The building owner who have fragile building should improve it as soon as possible.

The seismic capacity of non-engineering existing buildings in Barrio and rural areas will be studied on further research. For such buildings, reinforcement method with a cost of 10 % to 20% of the buildings is considered in this study.

a) Target Earthquake Scenarios

JICA Study Team propose the seismic reinforcement of existing buildings as improvement plans against to each target earthquake scenarios as follows;

- For long and middle term improvement plan: 1812 Scale Earthquake
- For short term improvement plan: 1967 Scale Earthquake

b) Seismic Code of Buildings to be Applied

The judging base of the seismic evaluation and reinforcement plan for each criteria are applied as following seismic code of Venezuela;

- For the judging base of the seismic reinforcement plan of normal existing buildings is applied the seismic code of Venezuela 2001 "NORMA VENEZOLANA COVENIN 1756-98 Rev.2001".
- For the public building's and buildings in use for a great number of people such as shopping mall and stadium etc. are applied the seismic code of Venezuela 2001 with use coefficient of 1.15.
- For the most strict judging base of the seismic evaluation of existing key facilities is applied the current seismic code of Venezuela 2001 with use coefficient of 1.30.

c) Proposed Procedure for Seismic Reinforcement

The seismic reinforcement plan is proceeded on following procedure;

Firstly, necessity of seismic reinforcement of the subject building is judged according to the result of seismic evaluation with seismic capacity as strength and ductility. Then, the feasibility of reinforcement methods is judged on structural condition and building function, and requirement with building owner and/or building operator. If the building has very low seismic capacity, and/or non-economical feasibility. In such special cases, it is judged to use restrictively or to be demolished.

In normal case, the subject building will be reinforced by following procedure;

- Prior investigation; hearing on the building function and special requirements etc. from building owner and/or operator and original design architect, and survey for condition of structural components.
- Definition of reinforcing target; reinforcing for lack of strength or ductility, and/or mixed them as shown in Figure 3.5.17.

- Selection of reinforcement methods; adequate reinforcement methods for each structure.
- Planning of reinforcement; due to effect of reinforcement, and building function and use.
- Confirmation of reinforcing effect; estimation of seismic capacity and cost of new reinforced structure.

(5) Selection of Seismic Reinforcement Methods for Each Building Type

A structural engineer will be selected adequate seismic reinforcement methods for a vulnerable building due to building function and use, and structural condition. Each seismic reinforcement method has a special feature as increment of strength, increment of ductility and combination of them. The Seismic reinforcement methods for each type of structures are provided as follows;

1) Reinforcement Methods for RC Structural Buildings in Urban Area

Major structural type of buildings is Reinforced Concrete (RC) Moment Frame that shares 82% in building number according to the sampling survey in this Study. The seismic reinforcement methods for RC structures are provided as follows, and are shown in Figure 3.5.18 and Figure 3.5.21 to 3.5.25.

a) Reinforcement Methods for Increment of Strength (Rigidity)

- Install of RC shear walls; without opening or with opening (refer to Figure 3.5.21 and 3.5.22)
- Install of Steel panels with frame; without opening or with opening (refer to Figure 3.5.23)
- Install of Steel bracings with frame (Refer to Figure 3.5.23 and 3.5.24)
- Install of Concrete block walls with reinforcing bars (refer to Supporting Report S7)
- Install of RC side walls (refer to Figure 3.5.18)
- Install of Additional frames (refer to Figure 3.5.18)
- Install of RC buttress (refer to Figure 3.5.18)

b) Reinforcement Methods for Increment of Strength/ Ductility

- Install of RC shear walls; without opening or with opening (refer to Figure 3.5.21 and 3.5.22)

- Install of Steel panels with frame; without opening or with opening (refer to Figure 3.5.23)
- Install of Steel bracings with frame (refer to Figure 3.5.23 and 3.5.24)
- Install of Concrete block walls with reinforcing bars (refer to Supporting Report S7)

c) Reinforcement Methods for Increment of Ductility

- Column and/or Beam reinforcing by Steel plate or Fiber Reinforced Plastic (refer to Figure 3.5.18)
- Wall slits at Short Columns (refer to Figure 3.5.18)

d) Reinforcement Methods for Balancing Rigidity Distribution

- Install of RC shear wall at Soft Story (refer to Figure 3.5.18)
- Remove of unbalanced weight
- Wall slits at Short Columns

e) Reinforcement Methods for Reduction of Building Weight

- Cutoff Penthouse or Over- loaded floors
- Decrease of Roof-load

f) Reinforcement of Foundation

- Additional foundation at uneven settlement parts
- Soil Improvement
- Additional Piles

g) Base Isolation or Seismic Response Control System

- Base Isolation System with Seismic Isolation Devices and Dampers (refer to Figure 3.2.25)
- Seismic Response Control System

2) Reinforcement Methods for Steel Structural Buildings

Minor structural type of buildings is Steel (S) structure that shares 3.7% in building number according to the sampling survey in this Study. The seismic reinforcement methods for S structures are provided as follows, and are shown in Figure 3.5.18.

a) Reinforcement Methods for Increment of Strength (Rigidity)

- Install of Steel panels with frame; without opening or with opening (refer to Figure 3.5.23)
- Install of Steel bracings; with frame or without frame (refer to Figure 3.5.23)
- Install of Concrete block walls with reinforcing bars (refer to Supporting Report S7)
- Install of Additional frames (refer to Figure 3.5.18)
- Make fix of column bases with Anchor bolts or RC pedestals

b) Reinforcement Methods for Increment of Strength/ Ductility

- Install of Steel panels with frame; without opening or with opening (refer to Figure 3.5.23)
- Install of Steel bracings; with frame or without frame (refer to Figure 3.5.23)
- Install of Moment columns
- Make fix of column bases with Anchor bolts or RC pedestals

c) Reinforcement Methods for Increment of Ductility

- Column and/or Beam reinforcing by Steel plate (refer to Figure 3.5.18)
- Install of Moment columns
- Make fix of column bases with Anchor bolts or RC pedestals

d) Reinforcement Methods for Balancing Rigidity Distribution

- Make fix of column bases with Anchor bolts or RC pedestals
- Remove of unbalanced weight

e) Reinforcement Methods for Reduction of Building Weight

- Cutoff Penthouse or Over- loaded floors

f) Reinforcement of Foundation

- Soil Improvement
- Additional Piles

g) Seismic Response Control System

- Seismic Response Control System

3) Reinforcement Methods for Brick and Adobe Masonry Structural Buildings

Brick and adobe masonry structural buildings are shares 3.7% in building number according to the sampling survey in this Study. The seismic reinforcement methods for brick and adobe masonry structures are provided as follows, and are shown in Figure 3.5.27.

a) Reinforcement Methods for Increment of Strength (Rigidity)

- Thickening of Masonry walls; without opening or with opening
- Reinforcing of exterior walls by Jacketing method (refer to Figure 3.5.27)
- Install of Additional masonry wall; without opening or with opening
- Install of RC beams and/or RC slab

b) Reinforcement Methods for Increment of Strength/ Ductility

- Reinforcing of exterior walls by Jacketing method (refer to Figure 3.5.27)
- Install of RC lintels at opening
- Install of RC reinforcements at wall ends and/or openings

c) Reinforcement Methods for Increment of Ductility

- Install of RC beams and/or RC slab
- Replace of new brick or adobe instead of deteriorated wall parts

d) Reinforcement Methods for Balancing Rigidity Distribution

- Remove of unbalanced weight

e) Reinforcement Methods for Reduction of Building Weight

- Cutoff Penthouse or Over- loaded floors

f) Reinforcement of Foundation

- Additional foundation at uneven settlement parts (refer to Figure 3.5.18)
- Soil Improvement

g) Base Isolation System

- Base Isolation System with Seismic Isolation Devices and Dampers (Refer to Figure 3.5.25)

4) Reinforcement Methods for Non-Engineering Buildings in Barrio and Rural Area

Non engineering houses in Barrio and rural area are shares 73% in overall building Number of study area. According to the result of building breaking test, concrete strength is very low which approximately 1/3 to 1/4 of normal concrete strength of engineering building.

The seismic reinforcement methods for non-engineering structures are provided as follows, and are shown in Figure 3.5.26.

a) Reinforcement Methods for Increment of Strength (Rigidity)

- Install of RC grade beam (refer to Supporting Report "S-7")
- Install of RC shear walls; without opening or with opening (Refer to Figure 3.5.19, Figure 3.5.20 and Figure 3.5.26.)
- Install of Steel panels with frame; without opening or with opening (Refer to Figure 3.5.23)
- Install of Steel bracings with frame (Refer to Figure 3.5.23)
- Install of Concrete block walls with reinforcing bars (refer to Supporting Report "S-7")
- Install of Additional frames (Refer to Figure 3.5.18)
- Install of RC buttress (Refer to Figure 3.5.18)

b) Reinforcement Methods for Increment of Strength/ Ductility

- Install of RC shear walls; without opening or with opening (refer to Figure 3.5.20 and 3.5.27)
- Install of Steel panels with frame; without opening or with opening (refer to Figure 3.5.23)
- Install of Steel bracings with frame (refer to Figure 3.5.23)
- Install of Concrete block walls with reinforcing bars (refer to Supporting Report S7)

c) Reinforcement Methods for Increment of Ductility

- Column and/or Beam reinforcing by Steel plate or Fiber Reinforced Plastic (Refer to 3.5.18)

d) Reinforcement Methods for Balancing Rigidity Distribution

- Remove of unbalanced weight

e) Reinforcement Methods for Reduction of Building Weight

- Cutoff Penthouse or Over- loaded floors
- Decrease of Roof-load

f) Reinforcement of Foundation and Sloped soil

- Soil Improvement
- Install of Retaining wall
- Protection for sloped soil surface by sufficient material

Recommendation of seismic reinforcement methods for barrio houses is shown in Figure 3.5.19 and Figure 3.5.20. These seismic reinforcement methods for each number of story are provided based on study of the building breaking test result. Seismic reinforcement methods for a single family houses are shown in Figure 3.5.19, and a multi family houses are shown in Figure 3.5.20.

(6) Effect of Seismic Reinforcement

The effect of seismic reinforcement is to make low vulnerability of existing buildings. Since after enforced of reinforcing work for existing buildings, the damage function is improved on each type of structures. As a result of seismic reinforcement of existing buildings, when will be attacked strong earthquake, the earthquake disaster will be decreased on number of heavily and collapse buildings, and human casualties of human death and injured due to building damage.

1) New Damage function after Seismic Reinforcement

After suitable reinforcing work for all vulnerable buildings, the each building damage function curve (Progress Report (2) page 3-61) will be improved as shown in Table 3.5.10.

2) Estimated Effect of Seismic Reinforcement

a) Monetary Loss of Building due to from Moderate to Collapse

The effect of the seismic reinforcement of all existing buildings in study area is shown by the difference of monetary loss between before and after seismic reinforcement.

A disaster loss due to heavy damage and collapse building is shown in Table 3.5.11 and 3.5.13. The monetary loss due to moderate damage building (repair cost) is shown in Table 3.5.12 and 3.5.14.

However, the human loss is can not estimated by monetary loss.

b) Estimation of Engineering Fee for Seismic Evaluation and Seismic Reinforcement Design

Total Engineering Fee = 1,466,100 M. Bs = 764 M. US$

Where;

- Building Number; Urban Area = 83,449 Buildings
  Rural Area = 25,175 Buildings
  Barrio Area = 205,983 Buildings
- RVS (Rapid Visual Screening) Fee
  Urban: 62,600 x 300,000 Bs/ Bldg. = 18,800,000,000
  Rural: 20,140 x 60,000 Bs/ Bldg. = 1,210,000,000
  Barrio: 164,760 x 60,000 Bs/ Bldg. = 9,890,000,000
  Total= 29,900 M. Bs = 16 M.US$
- Seismic Evaluation Fee
  Urban: 50,080 x 9,000,000 Bs/ Bldg. = 450,700,000,000
  Rural: 18,100 x 1,800,000 Bs/ Bldg. = 32,600,000,000
  Barrio: 148,300 x 1,800,000 Bs/ Bldg. = 266,900,000,000
  Total = 750,200 M. Bs = 391 M. US$
- Seismic Reinforcement Design Fee
  Urban: 40,060 x 10,000,000 Bs/ Bldg. = 400,600,000,000
  Rural: 15,510 x 2,000,000 Bs/ Bldg. = 31,000,000,000
  Barrio: 127,170 x 2,000,000 Bs/ Bldg. = 254,400,000,000
  Total = 686,000 M. Bs = 357 M. US$

3) Schedule of Seismic Reinforcement Plan for Buildings

The proceeding schedule of the seismic reinforcement for building between 2005 and 2020 is shown in Figure 3.5.28. It is including the Rapid Visual Screening (RVS), Detailed Seismic Evaluation, Seismic Reinforcement Design and Construction Work.

(7) Cost Analysis of Buildings

The effect of seismic reinforcement of existing buildings can be shown by the effective cost per the investment cost. However, the human casualties especially human loss is can not estimated by monetary loss. In this study, the current prices in Caracas is set up as of February 2004.

1) Unit Cost of New Building Construction Work (Building Replacement Cost)

JICA Study Team investigated each cost of new building construction work otherwise building replacement cost as shown Table 3.5.18.

The reference price of materials and material plus labor in Caracas as shown in Table 3.5.15 and 3.5.16.

The typical rough unit cost of building replacement work in Caracas as shown in Table 3.5.17.

2) Total Cost of Replacement and Seismic Reinforcement of Existing Buildings

According to the building inventory data, JICA Study Team assumed and investigated the building numbers and total floor area for each uses, the cost of building replacement and seismic reinforcing work of existing buildings in study area. Through our seismic evaluation and reinforcement planning, we assumed and investigated required ratio for seismic evaluation and reinforcement work, and cost of seismic reinforcement per building replacement cost.

The total floor area, total cost of replacement and seismic reinforcement work of existing buildings in study area are shown in Table 3.5.18. Number of Buildings in each area and uses are shown in Table 3.5.19. Ratio of required seismic evaluation and reinforcement, and cost of seismic reinforcement per replacement cost for each category of existing buildings are shown in Table 3.5.20.

3. 5. 2. Study on Non-Structural Measures

In this study, study from social aspects are focused on how to promote seismic reinforcement. From a viewpoint of legal and institutional aspects, refer to section report S-21. For education, community, and social survey regarding the promotion of seismic reinforcement, refer to section reports from S-22 to S-24.

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Table 3.1.1 Quaternary Faults Around Caracas (Audemard et. al.2000)

No.	Fault name	End to end length (km)	Cumlative length (km)	Maximum credible Ms	Recurrence interval	Slip Rate (mm/year)	Average Strike	Average Dip	Sense of Movement	Recent activity
8	La Victoria	354	466				N 78 E± 17			
8a	Guacamaya	146	235	7.0	2000	0.6	N 80 E± 22	Subvertical	Right-lateral	<1.6Ma
8b	La Caberera	26	26	6.3	545	1.1	N 72 E± 0	Subvertical	Right-lateral	<15ka
8c	El Horno	34	34	6.4	1200	0.5	N 72 E± 2	Subvertical	Right-lateral	<1.6Ma
8d	La Victoria	52	52	6.7	1500	0.55	N 77 E± 3	Subvertical	Right-lateral	<1.6Ma
8e	Pichao	118	118	6.9	2300	0.4	N 76 E± 3	Subvertical	Right-lateral	<1.6Ma
9	Rio Guarico	120	131				N 71 E± 19			
9a	North section	33	40	6.6	2300+	<0.3	N 59 W± 2	Unknown	Right-lateral	<1.6Ma
9b	Soyth section	89	91	6.6	2300+	<0.3	N 77 W± 18	Unknown	Right-lateral	<1.6Ma
10	Tacagua-El Avila	67.6	70.2				N 77 W± 13			
10a	Tacagua	19.7	20.1	6.5	4000	0.17	N 71 W	High dip to south	Right-lateral with significant normal component	<1.6Ma
10b	El Avila	48.8	50.1	6.8	2300-	<0.4	N 83 W	High dip to south	Right-lateral with significant normal component	<1.6Ma
11	Tacata	78	80	6.7	2000+	<0.4	N 64 W± 10	High dip to North	Right-lateral	<1.6Ma
12	Piritu	157	166	7.1	3250	0.3-0.4	N 65 W± 14	High dip to North	Right-lateral	<1.6Ma
16	San Sebastian	483	529	N/A	N/A	3-5(?)	N 86 E± 11	Subvertical	Right-lateral	<15 ka

Table 3.1.2 Lists of Earthquakes That Affected Caracas (Centeno Grau (1969), Grases (1990), Grases et. al. (1999))

Year	Month	Day	Local Time	Magnitude	Seismic Intensity in Caracas	Description
1641	6	11	8:15			The earthquake destroyed the first city of Cua. The new city was founded in 1690 with a name El Rosario de Cua, 1 km north from former location. The earthquake affected Caracas where Church and other buildings collapsed.
1766	10	21	4:30	7.9	V	For the extension of the felt area and for the duration of aftershocks, this earthquake is probably the major magnitude that had affected the northeastern Venezuela. The aftershocks were felt every one-hour during 14 months. The earthquake caused damages in various cities in the eastern Venezuela and in Caracas.
1812	3	26	16:07 (Caracas) 17:00 (Merida)	6.3 (Caracas), 6.2 (Barquisimeto - San Felipe), 7 (Merida),	IX	The earthquake affected severely in distant places such as Merida, Barquisimeto, San Felipe and Caracas. From the basis of damage distribution, it is postulated to be three different events. The number of victims was about 5000 in Merida, 3000 in San Felipe, 4000 to 5000 in Barquisimeto, and 10000 in Caracas. In total, the number of victims was about 40000 from Merida to Caracas. In Caracas, northern sectors of the city were almost completely destroyed, in the southern and eastern sectors, the damage was minor. In the Avila, there were large collapses, and cracks of large dimension were formed. The ground motion lasted 48 seconds in Caracas, in the direction of west to east. The recent study reveals that about 60% buildings were heavily damaged in Caracas and death toll in Caracas could be reduced to 2,000. (Altez, 2004)
1837	9	10	14:00			Strong earthquake in Caracas. Destructive in Santa Teresa of Tuy and Santa Lucia. Destruction of some consideration, houses collapsed. There were little victims and most of them were injury.
1878	4	12	20:40	5.9	VI-VII	Destructive earthquake to the south of Caracas that ruined the city of Cua where 300 to 400 died under debris out of 3000 habitants at that time. The field work indicated that houses in the lower part of the city on alluvial plane suffered relatively little damage, while higher areas of the city in rocky hill was destroyed (Ernst 1878). Death toll estimated to be 600 (The Times, London May 18, 1878). In Caracas, buildings suffered cracks. The ground motion lasted 8 to 10 seconds in Caracas.
1900	10	29	4:42	7.6	VII	The earthquake affected Macuto, Naiguata, Guatire, Guarenas, Higuerote, Carenero, and other cities of Barlovento that suffered great damages and victims. Many buildings suffered cracked and some collapsed in Caracas. 12 deaths. The second floor of British Embassy disappeared (The Times, London, October 30 to November 2, 1900). 250 aftershocks in 3 years. In Caracas, 20 houses collapsed and more than 100 were deteriorated, 21 death and more than 50 injured.
1967	7	29		6.3	VI-VIII	The earthquake caused important damages in Caraballeda, areas in Caracas and the central coast and felt in the north central of the country. Rial (1977) concludes it was multiple earthquakes、three events in the direction of northwest to southeast, possibly Tacagua fault system. According to the Venezuelan institution, death toll was 274, number of injured was 2000, and loss of 100 million dollars. Four buildings with ten to twelve floors, constructed between from 1962 and 1966, partial damage for other similar height in Caracas. No interruptions of service. The telegraphs and telephones were saved.

Table 3.1.3 Comparison of Parameters for the 1812 Earthquake

	Fiedler, 1961			Fiedler, 1968	Grases, 1990			FUNVISIS, 1997	Altez, 2000	Grases et. al, 2001		Altez, 2004
M	7	6.2	6.3	7.1	7	7.2	6.3			6.5-.7	6.9-7.2	
Lat.	8.5	10.2	10.6	10.8	8.5	10.2	10.6					
Lon	71.3	69.1	66.9	66.9	71.3	69.1	66.9					
Depth	19	7	6	10-20	19	7	6					
MMI				IX+	IX	IX	VIII	X	IX		IX	
MMI in CCS				8-8.5								
Area				Near Caracas	Merida	Barquisi meto-San Felipe	Caracas			Mérida	San Felipe	Caracas
Time					17:00		16:07					
Death				10000	5000	8000	10000					2000

Table 3.1.4 Comparison of Parameters for the 1878 Earthquake

1878/4/12	Fiedler 1968	Grases 1990	Grases et. al. 2001
MC	6.1		6.4-6.5
Lat	10.2 N	10.3 N	
Lon	66.9 W	66.8 W	
Depth	10-15km	13km	
MMI	7.5-8	VIII-IX	
MMI In Caracas	6-6.5	VII	
Time	21:11	20:40	
Death		300-400	

Table 3.1.5 Comparisons of Parameters for the 1967 Earthquake

1967/7/29	ISC	CAG	USGS	Fiedler 1968	Rial 1977	Rial 1978	Suarez & Nabelek 1990	Grases 1990
Ms	6.6		6.5	6.3		6.7		6.3
mb	5.5	6.3		5.6		6.5		
Mw							6.6	
Mm					7.1−7.2 ?			
Lat	10.68 N	11.06 N	10.56 N	11.00 N			10.68 N	11.06 N
Lon	67.40 W	67.15 W	67.26 W	67.25 W			67.40 W	67.15 W
Depth	26 km	20 km	10 km	12 km			14km	20 km
MMI max								VIII
MMI Caracas				7±1				VII−VIII
Distance to fault				60±5 km				
Length				13 km				
Events						3 events in NW−SE	4 events in E−W	

Table 3.1.6 Scenario Earthquakes and Their Parameters

Scenario	Mw	Seismogenic Depth (km)	Fault Length	Mechanism	Fault system
1967	6.6	5 km	42 km	Strike slip	San Sebastian
1812	7.1	5 km	105 km	Strike slip	San Sebastian
1878	6.3	5 km	30 km	Strike slip	La Victoria
Avila	6	5 km	20 km	Strike slip	Tacagua-El Avila

Table 3.1.7 Densities of Soil and Rock

Soil/Rock type	Density (g/cm^3)
Clay	1.8
Sand	2.0
Gravel	2.1
Hard deposit	2.1
Base Rock	2.6

Source: Japan Road Association, 2002

Table 3.1.8 Parameters of Earthquake that Generated Input Waves.

Scenario	Earth-quake	Country	Date	Mechanism	M	Ml	Ms	Mw	Depth (km)
1967	Imperial Valley	USA	1979/10/15	Strike Slip	6.5	6.6	6.9		12.1
1812	Duzce	Turkey	1999/11/12	Strike Slip	7.1	7.2	7.3		14
1878	Big Bear Lake	USA	1992/6/28	Strike Slip	6.5		6.6	6.4	7
Avila	Morgan Hill	USA	1984/04/24	Strike Slip	6.2	6.2	6.1		10

Table 3.1.9 List of Selected Input Waves.

Scenario	Site name	Closest Dist. to fault rupture	Site Condition Geo- matrix	Site Condition USGS	Compo- nent	PGA (G)	Source	Source
1967	6604 Cerro Prieto	26.5 km	Rock	Vs=360-750m/s	H-CPE237	0.157	UNAM/UCSD	PEER
1812	Mudurnu	33.6 km	Rock	--	MDR000	0.12	ERD	PEER
1878	Snow Creek	37.9* km	Hard granitic bedrock		Ch1 90Deg	0.164	CSMIP	COSMOS
Avila	47379 Gilroy Array #1	16.2 km	Rock	Vs>=750m/s	G01230	0.069	CDMG	PEER

(* Hypocentral Distance)

Table 3.1.10 Estimated Liquefaction Susceptibility

	PL Value			
Earthquake	1967	1812	1878	Avila
Earthquake type / MeshCord	Type II	Type II	Type II	Type II
C48R20	0.0	0.0	0.0	0.0
C49R20	0.0	1.4	0.0	1.7
C50R12	0.0	0.4	0.0	3.4
C51R12	0.0	0.0	0.0	0.0
C52R17	5.4	15.9	3.0	12.1
C53R16	0.0	0.5	0.0	0.0
C53R17	12.6	31.3	11.2	22.7
C54R16	0.0	1.2	0.0	0.0
C54R17	0.0	9.8	0.0	6.0
C55R16	0.0	0.1	0.0	0.0
C55R26	0.0	0.0	0.0	0.0
C55R27	0.0	6.7	0.0	3.6
C55R28	0.0	6.3	0.0	2.9
C55R29	0.0	5.8	0.0	2.2
C56R17	2.8	20.2	1.0	15.0
C56R27	0.0	6.4	0.0	3.9
C56R28	0.0	6.0	0.0	3.2
C57R24	0.0	1.4	0.0	1.1
C58R24	0.0	1.3	0.0	1.2
C58R25	0.0	1.3	0.0	1.1
C58R26	0.0	1.2	0.0	1.0
C59R24	0.0	1.3	0.0	1.2
C60R23	0.0	3.2	0.0	4.2
C78R19	0.0	0.0	0.0	4.0

Liquefaction Potenstial	Criterion
Very high	15<PL
Reralitively high	5<PL<=15
Reralitively low	0<PL<=5
Very low	PL=0

Plate boundary type	Type I
Inland type	Type II

Table 3.2.1 Summary of Collected Data

Title	Purpose	Type	Year	Source
Base map	Genenal	GIS data	2000	HIDROCAPITAL
	The number of buildings			
Area of manzana	The analyzed unit for urbanized area	GIS data	2000	Secretary of Planning, Alcadia Mayer
Area of barrios	Base of areas of barrios	GIS data	2000	
DTM	The slope degree	GIS data	2000	The JICA Study Team
Aerial photos	The areas of barrios & rural areas	Aerial photograh	2002	IGSB
	The number of buildings			
Census 2001	Population	Database	2003	INA
	The number of person /family			
PREMIO NACIONAL DE INVESTIGACION EN VIVIENDA 1993 DENSIFICACION Y VIVIENDA EN LOS BARRIOS CARAQUENOS	The number of person / building in barrioarea	Document	1993	CONAVI
UN PLAN PARA LOS BARRIOS DE CARACAS PREMO NACIONAL DE INVESTIGACION EN VIVIENDA	The number of person / building in barrioarea	Document	1995	CONAVI
	Areas of barrios			
Cronicas de Desasteres Terremoto de Cariaco, Venezuela	Number of killed and injured people of the Cariaco Earthquake of 1997	Document	1997	PAHO, PAN AMERICAN HEALTH ORGANIZATION
Social and Economic Dimensions of the Effects of the Earthquake in the Eje Cafetero. Diagnosis for the reconstruction.	Number of killed and injured people of the Quindio Earthquake of 1999	Document	1999	DANE, National Administrative Department of Statistics, Colombia
Enginering report on the Caracas earthquake of 29 July 1967	Number of killed people of the Caracas earthquke of 1967	Document	1968	Sozen. M. A., Jennings P. C., Matthiesen R. B., Housner G. W. , Newmark N. M., , National Academy of Sciences, whashington, D. C., USA

Source: The JICA Study Team

Table 3.2.2 The Characteristics of the Urbanized Area and the "Barrio and Rural Area"

	The Study Area		
	Urbanized Area	Barrio Area & Rural Area	
Unit	Block	Areas, which content aggregated existing buildings.	
GIS Data	Existing	Existing	Create by the Study Team.
Source	Secretary of Planning, ADMC		Aerial photos (2002)
Building Category in a Unit	Several categories	Single category	
Field Survey	Done	No	
1/5,000 Working Map	1/5,000 working map covers the whole area	1/5,000 working map doesn´t cover the whole area	

Source: JICA Study Team

Table 3.2.3 Category of Building Inventory and Damage Function in the Barrio and Rural Area

Building Inventory		Damage Function				
Area	Slope	No	Structure	Stories	Const. Year	Slope
Barrios	Less 20 degree	18	Informal (Barrio)	N. A.	N. A.	Less 20 degree
	More 20 degree	20	Informal (Barrio)	N. A.	N. A.	More 20 degree
Rural low buildings	Less 20 degree	17	Informal (Rural)	N. A.	N. A.	Less 20 degree
	More 20 degree	19	Informal (Rural)	N. A.	N. A.	More 20 degree
Rural Factory	N. A.	14	Steel	1-2 F	N. A.	N. A.
Rural High Building	N. A.	9	RC-Moment Frame	9F-	‘83-	N. A.

Source: JICA Study Team

Table 3.2.4 The Field Sample Survey Result

(Summarized by Type, Story and Constructed Year)

Type	Story		Year		nos
	Category	Ratio %	Category	Ratio %	
Adobe	1-3	0.5%	- '67	0.5%	5
Brick	1-3	13.2%	- '67	12.8%	128
			'68 - '82	0.4%	4
	4-8	0.5%	- '67	0.5%	5
RC	1-3	65.1%	- '67	29.8%	299
			'68 - '82	28.4%	285
			'83 -	6.9%	69
	4-8	12.2%	- '67	5.9%	59
			'68 - '82	4.6%	46
			'83 -	1.7%	17
	9-	4.7%	- '67	1.1%	11
			'68 - '82	2.5%	25
			'83 -	1.1%	11
Steel	1-3	3.9%	- '67	1.0%	10
			'68 - '82	1.6%	16
			'83 -	1.3%	13
Sum	---	100.0%	---	100.0%	1003

Table 3.2.5 The Field Sample Survey Result

(Summarized by Proposed Category of the Damage Function)

Type		Story		Year		nos
Category	Ratio %	Category	Ratio %	Category	Ratio %	
MASONRY BRICK	14.2%	1-3	14.2%	- '67	14.2%	142
RC - MOMENT FRAME	82.0%	1-3	65.1%	- '67	29.8%	299
				'68 - '82	28.4%	285
				'83 -	6.9%	69
		4-8	12.2%	- '67	5.9%	59
				'68 - '82	4.6%	46
				'83 -	1.7%	17
		9-	4.7%	- '67	1.1%	11
				'68 - '82	2.5%	25
				'83 -	1.1%	11
Steel	3.9%	1-3	3.9%	---	---	39
Sum	100.0%	---	100.0%	---	96.1%	1003

Table 3.2.6 Counted Building Number of Analyzed Vulnerability Unit

	Physical AVU	Social AVU	Location	Number of Buildings
In Avila project area	0	N.A.	----	---
	1	1	Altamira	3.535
	2	2	Caracas Country Club	895
	3	3	Candelaria	10.813
	4	4	California	2.989
	5	5	El Bosque	2.937
	6	6	Bello Campo	7.059
	7	7	La Urbina	2.267
	8	2	San Bernardino & El Rosario	3.598
	9	N.A.	Los Ruices	2.457
	10	12	Catia & Sarria	10.957
	11	8	23 de Enero & Pedoro Camejo	2.694
	12	N.A.	A.V. Coromoto	166
Out of Avila project area	101	12	Gramoven	9.620
	102	8	La Silsa	187
	103	10	Artigas	5.903
	104	3	San Juan	1.320
	105	2	Paraiso & Washington	2.457
	106	13	La Vega	2.788
	107	7	Montalban	1.116
	108	12	Antimano	469
	109	9	SAMBIL	3.081
	110	3	Los Carmenes	7.382
	111	9	Coche & EL Valle	3.656
	112	10 & 5	Las Acacias & Santa Monica	4.877
	113	4	El Llanito	3.223
	114	7	Palo Verde	769
	115	7	Terrazas del avila	177
	116	N.A.	Miranda	484
	201	N.A.	Petare	361
			Total	98.237

Source: The JICA Study Team

Table 3.2.7 The Result of Field Sampling Survey (Summarized by Category of Damage Estimation and AVU, Number of Sample)

No	Type	Story	Year	nos	1	2	3	4	5	6	7	8	9	10	11	12	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
1		1-3F	- '67	299	1	3	16	17	2	22	1	14	4	31	6		40	10	16	8	11	28		1		50	2	15				1
2		1-3	'68 - '82	285	18	1	12	10	3	21	10	7	6	27	6		40		17	3	7		4	3	2	27	22	11	26			2
3		1-3	'83 -	69	2		10			2		4	5	16	3		9							3	1	2	2	2	2	4		2
4		4-8F	- '67	59	2		10		7	7	1	4	1	1	1		7	1				1		1		6	2	6	1			
5	RC	4-8	'68 - '82	46	4		5	1	3	1	2	1	4		2		2		3	1	1		2		3	2	5	3	1			
6		4-8	'83 -	17	3		1			2		1		2			1											1	1	2		3
7		9F-	- '67	11			6			1					1	2	1															
8		9-	'68 - '82	25	2		4		1	1	1			1	1	2	1		1	2	2		1		1		2	1		1		
9		9-	'83 -	11					1		3	1															1			3	2	
14	Steel	1-3F		39	1	0	5	2	1	4	1	3	5	2	1	2	0	0	7	1	0	0	0	3	0	0	0	0	0	0	0	1
16	Msonary			142	2	3	44	0	10	10	2	5	1	18	2	0	17	5	5	1	0	0	1	0	0	11	0	5	0	0	0	0
Total				1003	35	7	113	30	28	71	21	40	26	98	23	6	118	16	49	16	21	29	8	11	7	98	36	44	31	10	2	9

Source: The JICA Study Team

Table 3.2.8 The Result of Field Sampling Survey (Summarized by Category of Damage Estimation and AVU, Ratio %)

No	Type	Story	Year	nos	1	2	3	4	5	6	7	8	9	10	11	12	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116
1		1-3F	- '67	299	2.9%	42.9%	14.2%	56.7%	7.1%	31.0%	4.8%	35.0%	15.4%	31.6%	26.1%	0.0%	33.9%	62.5%	32.7%	50.0%	52.4%	96.6%	0.0%	9.1%	0.0%	51.0%	5.6%	34.1%	0.0%	0.0%	0.0%	11.1%
2		1-3	'68 - '82	285	51.4%	14.3%	10.6%	33.3%	10.7%	29.6%	47.6%	17.5%	23.1%	27.6%	26.1%	0.0%	33.9%	0.0%	34.7%	18.8%	33.3%	0.0%	50.0%	27.3%	28.6%	27.6%	61.1%	25.0%	83.9%	0.0%	0.0%	22.2%
3		1-3	'83 -	69	5.7%	0.0%	8.8%	0.0%	0.0%	2.8%	0.0%	10.0%	19.2%	16.3%	13.0%	0.0%	7.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	27.3%	14.3%	2.0%	5.6%	4.5%	6.5%	40.0%	0.0%	22.2%
4		4-8F	- '67	59	5.7%	0.0%	8.8%	0.0%	25.0%	9.9%	4.8%	10.0%	3.8%	1.0%	4.3%	0.0%	5.9%	6.3%	0.0%	0.0%	0.0%	3.4%	0.0%	9.1%	0.0%	6.1%	5.6%	13.6%	3.2%	0.0%	0.0%	0.0%
5	RC	4-8	'68 - '82	46	11.4%	0.0%	4.4%	3.3%	10.7%	1.4%	9.5%	2.5%	15.4%	0.0%	8.7%	0.0%	1.7%	0.0%	6.1%	6.3%	4.8%	0.0%	25.0%	0.0%	42.9%	2.0%	13.9%	6.8%	3.2%	0.0%	0.0%	0.0%
6		4-8	'83 -	17	8.6%	0.0%	0.9%	0.0%	0.0%	2.8%	0.0%	2.5%	0.0%	2.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%	3.2%	20.0%	0.0%	33.3%
7		9F-	- '67	11	0.0%	0.0%	5.3%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	4.3%	33.3%	0.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
8		9-	'68 - '82	25	5.7%	0.0%	3.5%	0.0%	3.6%	1.4%	4.8%	0.0%	0.0%	1.0%	4.3%	33.3%	0.8%	0.0%	2.0%	12.5%	9.5%	0.0%	12.5%	0.0%	14.3%	0.0%	5.6%	2.3%	0.0%	10.0%	0.0%	0.0%
9		9-	'83 -	11	0.0%	0.0%	0.0%	0.0%	3.6%	0.0%	14.3%	2.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%	0.0%	0.0%	30.0%	100.0%	0.0%
14	Steel	1-3F		39	2.9%	0.0%	4.4%	6.7%	3.6%	5.6%	4.8%	7.5%	19.2%	2.0%	4.3%	33.3%	0.0%	0.0%	14.3%	6.3%	0.0%	0.0%	0.0%	27.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.1%
16	Msonary			142	5.7%	42.9%	38.9%	0.0%	35.7%	14.1%	9.5%	12.5%	3.8%	18.4%	8.7%	0.0%	14.4%	31.3%	10.2%	6.3%	0.0%	0.0%	12.5%	0.0%	0.0%	11.2%	0.0%	11.4%	0.0%	0.0%	0.0%	0.0%
Total				1003	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: The JICA Study Team

Table 3.2.9 Number of Buildings of the Barrio and Rural Area in the 1/5,000 Map Area

	Barrio	Rural	Rral Factory	Rural High Buil.	Total	%
Slope > 20 degree	78101	5179	76	28	83384	47.4
Slope < 20 degree	85024	7384	273	32	92713	52.6
Total	163125	12563	349	60	176097	100
%	92.6	7.1	0.2	0.0	100	

Source: JICA Study Team

Table 3.2.10 Number of Buildings of the Barrio and Rural Area out of the 1/5,000 Map Area

	Barrio	Rural	Rral Factory	Rural High Buil.	Total	%
Slope > 20 degree	261	5887	4	81	6233	36.7
Slope < 20 degree	702	9306	34	722	10764	63.3
Total	963	15193	38	803	16998	100
%	5.7	89.4	0.2	4.7	100	

Source: JICA Study Team

Table 3.2.11 Summary of Required Information for Human Damage Estimation

Type	Stories	Required information	
RC MOMENT-FRAME	Middle and High	N. A.	
	Low	Persons / House	4.5
INFORMAL	N. A.		

Source: JICA Study Team

Table 3.2.12 Number of Detached House and Persons Who Dwell in It

	Num of House	Num of Person	Person/ House
Libertador	209,610	939,113	4.5
Sucre	68,033	302,620	4.4
Chacao	1,268	6,249	4.9
Total	278,911	1,247,982	4.5

Source: Census 2001, INE

Table 3.2.13 Building Categories of Damage Function Used in this Study

Type	Structure	No. Stories	Year	Slope
1	RC – MOMENT FRAME	1-3	-67	---
2			68 – 82	
3			83-	
4		4-8	-67	
5			68 – 82	
6			83-	
7		9 -	-67	
8			68 – 82	
9			83-	
10	RC – SHEAR WALL	4-8	---	---
11		9-		
12	PRECAST	1-2	---	---
13		9-		
14	STEEL	1-3	---	---
15		4-		
16	MASONRY / Brick	---	---	---
17	INFORMAL (Rural)	---	---	Less 20°
18	INFORMAL (Barrio)	---	---	
19	INFORMAL (Rural)	---	---	More 20°
20	INFORMAL (Barrio)	---	---	

Table 3.2.14 The Weight Factor of Vulnerability Class for the Structural Typology

Type	A	B	C	D	E	F
1	0.05	0.20	0.40	0.35		
2		0.15	0.35	0.45	0.05	
3		0.05	0.25	0.55	0.15	
4	0.05	0.25	0.50	0.20		
5		0.05	0.30	0.45	0.20	
6		0.01	0.14	0.40	0.35	0.10
7	0.05	0.40	0.45	0.10		
8		0.10	0.35	0.45	0.10	
9		0.05	0.20	0.40	0.30	0.05
10			0.30	0.50	0.20	
11		0.05	0.30	0.50	0.15	
12		0.05	0.30	0.55	0.10	
13	0.05	0.40	0.45	0.10		
14		0.05	0.10	0.50	0.35	
15			0.15	0.35	0.45	0.05
16	0.05	0.30	0.60	0.05		
17	0.25	0.60	0.15			
18	0.40	0.55	0.05			
19	0.40	0.60				
20	0.60	0.40				

Table 3.2.15 Human and Building Damage Statistics of the Cariaco Earthquake

Municipality	Damaged Buildings				Casualty	
	FUNREVI		FUNDOSOES		Death	Injure
	Moderate	Heavily	Moderate	Heavily		
Ribero	687	799	1141	1308	35	360
Sucre	168	100	757	214	33	20
Andres E.. Blanco	699	133	90	130	1	65
Andres Mata	777	733	711	745	4	35
Mejias	140	36	35	57		12
Bolivar	119	10	625	76		29
Benitez	322	96	328	181		7
Marino	1	2	16	7		
Montes	22	3	52	16		
Bermudez	86	22	38	85		
Arismendi	576	50	33	5		
Valdez	25	10	19	9		
Cruz Salmeron	35	13	267	69		
Total	3657	2007	4112	2902	73	528

Source: Crónicas de Desastres Terremoto de Cariaco, Venezuela, 1997, PAHO

Table 3.2.16 The Number of Death and the Number of Heavily Damaged Building of Quindio Earthquake 1999, Colombia

Municipality	Population	Dead	Primary Affected	Building	Damage number			Heavily Damaged
					Totally	Uninhabitable	Partially	
chinchina	71,621	1	200	207	21	24	154	45
Armenia	280,922	929	96,534	49,163	11,163	10,380	19,734	21,543
Buenavista	5,194	2	383	218	37	58	117	95
Calarca	74,409	84	21,591	10,558	2,200	2,632	4,990	4,832
Circasia	26,422	8	2,483	1,510	240	312	809	552
Cordoba	6,951	2	1,410	594	204	130	219	334
Filandia	14,260	0	561	553	30	83	424	113
Genova	12,131	4	9	113	1	1	104	2
La Tebaida	27,527	59	10,562	5,129	1,806	736	1,902	2,542
Montenegro	41,040	11	5,041	2,550	364	689	1,261	1,053
Pijao	9,777	4	2,287	1,351	235	349	607	584
Quimbaya	40,070	7	2,484	2,021	160	348	1,357	508
Salento	8,609	0	325	308	18	56	211	74
Pereira	438,290	61	10,978	9,391	761	1,700	6,275	2,461
Dosquebradas	172,831	6	1,219	1,126	65	199	783	264
Marsella	22,959	0	158	214	5	27	173	32
Santa Rosa de Cabal	73,947	1	270	293	30	33	210	63
Cajamarca	20,856	3	1,372	1,369	83	212	1,050	295
Roncesvalles	8,528	0	40	58	0	7	49	7
Alcala	10,184	0	203	390	24	16	334	40
Argelia	9,555	0	101	73	9	12	51	21
Bolivar	20,138	0	32	84	1	3	79	4
Caicedonia	47,353	2	1,173	1,321	46	233	985	279
La Victoria	16,810	0	244	272	16	39	215	55
Obando	16,762	0	95	422	6	14	393	20
Sevilla	62,396	1	461	853	21	84	712	105
Ulloa	6,671	0	181	333	6	43	278	49
Total	1,546,213	1,185	160,397	90,474	17,552	18,420	43,476	35,972

Table 3.2.17 The Number of Death and the Number of Injured of Quindio Earthquake 1999, Colombia

Department	Dead	Injured
Caldas	1	8
Quindio	1,110	7,166
Risaralda	70	1,218
Tolima	3	23
Valle del Cauca	3	108
Total	1,187	8,523

Source: The JICA Study Team

Table 3.2.18 Summary of the Estimated Building Numbers

	Number of Buildings				
PARROQUIA	Urban -3F	Urban 4F-	Urban Sum	Barrio & Rural	Sum
23 DE ENERO	486	102	588	5,319	5,907
ALTAGRACIA	1,386	415	1,801	265	2,066
ANTIMANO	617	65	681	21,277	21,958
CARICUAO	805	1,129	1,934	9,240	11,174
CATEDRAL	544	160	704	2	706
CAUCAGUITA	0	440	440	7,093	7,533
CHACAO	4,703	1,547	6,250	274	6,524
COCHE	1,426	597	2,023	4,080	6,103
EL CAFETAL	2	0	2	0	2
EL JUNQUITO	0	105	105	10,279	10,384
EL PARAISO	4,587	576	5,163	4,454	9,617
EL RECREO	5,729	1,703	7,432	2,156	9,588
EL VALLE	693	266	959	16,913	17,872
FILA DE MARICHE	0	90	90	5,036	5,126
LA CANDELARIA	1,492	301	1,793	108	1,901
LA DOLORITA	0	529	529	9,128	9,657
LA PASTORA	3,514	465	3,979	7,352	11,331
LA VEGA	1,482	505	1,986	14,223	16,209
LEONCIO MARTINEZ	5,054	1,115	6,169	597	6,766
MACARAO	306	445	752	8,101	8,853
NUESTRA SENORA DEL ROSARIO DE BARUTA	40	13	53	0	53
PETARE	8,236	2,372	10,608	36,213	46,821
SAN AGUSTIN	1,122	317	1,440	3,197	4,637
SAN BERNARDINO	1,609	345	1,954	632	2,586
SAN JOSE	767	226	993	1,633	2,626
SAN JUAN	1,967	274	2,241	9,369	11,610
SAN PEDRO	3,562	1,183	4,746	429	5,175
SANTA ROSALIA	4,704	540	5,244	11,332	16,576
SANTA TERESA	657	196	853	0	853
SUCRE	10,777	1,215	11,992	42,456	54,448
Sum	66,265	17,234	83,499	231,158	314,657

Table 3.2.19　Summary of the Damage Estimation Result

Case 1967

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	849	8.5	19	3.2	144	3.3
Urban 4F-	17,234	5.5	170	1.7	170	28.2	1,225	28.4
Urban Sum	83,499	26.5	1,019	10.2	189	31.4	1,369	31.8
Barrio & Rural	231,158	73.5	9,001	89.8	413	68.6	2,937	68.2
Total	314,657	100.0	10,020	100.0	602	100.0	4,306	100.0

Case 1812

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	2,656	8.2	85	3.4	619	3.5
Urban 4F-	17,234	5.5	533	1.6	533	21.1	3,775	21.4
Urban Sum	83,499	26.5	3,189	9.8	618	24.4	4,394	24.9
Barrio & Rural	231,158	73.5	29,217	90.2	1,910	75.6	13,226	75.1
Total	314,657	100.0	32,406	100.0	2,528	100.0	17,620	100.0

Case 1878

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	74	4.1	0	0.0	0	0.0
Urban 4F-	17,234	5.5	15	0.8	15	24.2	90	19.8
Urban Sum	83,499	26.5	89	4.9	15	24.2	90	19.8
Barrio & Rural	231,158	73.5	1,713	95.1	47	75.8	365	80.2
Total	314,657	100.0	1,802	100.0	62	100.0	455	100.0

Case Avila

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	2,758	10.2	89	4.1	658	4.3
Urban 4F-	17,234	5.5	604	2.2	603	28.1	4,310	28.3
Urban Sum	83,499	26.5	3,361	12.4	692	32.2	4,968	32.7
Barrio & Rural	231,158	73.5	23,696	87.6	1,455	67.8	10,240	67.3
Total	314,657	100.0	27,057	100.0	2,147	100.0	15,208	100.0

Table 3.2.20 Damage Estimation Result Case 1967

		Urban 4F-			Urban 3F-			Barrio & Rural			Sum		
Municiparity	PARROQUIA	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured
Libertador	23 DE ENERO	1	1	0	3	0	0	220	7	51	224	8	51
	ALTAGRACIA	9	9	66	32	1	9	27	0	0	68	10	76
	ANTIMANO	1	1	0	5	0	0	982	49	347	987	50	347
	CARICUAO	1	1	9	1	0	0	240	8	58	242	9	67
	CATEDRAL	3	3	26	12	0	0	0	0	0	16	3	26
	COCHE	2	2	18	6	0	0	132	4	30	141	6	47
	EL JUNQUITO	1	1	8	0	0	0	346	13	94	347	14	102
	EL PARAISO	4	4	32	77	2	18	235	8	58	316	14	108
	EL RECREO	30	30	218	112	3	27	226	7	51	368	40	296
	EL VALLE	1	1	10	4	0	0	695	32	228	701	33	238
	LA CANDELARIA	9	9	67	40	1	9	7	0	0	56	10	76
	LA PASTORA	6	6	43	34	1	9	439	17	123	479	24	175
	LA VEGA	3	3	25	19	0	0	499	21	151	521	24	176
	MACARAO	1	1	0	0	0	0	216	7	51	218	8	51
	SAN AGUSTIN	6	6	47	26	0	0	192	6	44	224	12	91
	SAN BERNARDINO	6	6	48	32	1	9	79	2	15	117	9	72
	SAN JOSE	7	7	48	24	0	0	156	5	37	186	12	85
	SAN JUAN	4	4	29	42	1	9	482	20	144	528	25	182
	SAN PEDRO	13	13	96	44	1	9	17	0	0	75	14	105
	SANTA ROSALIA	8	8	57	53	1	9	454	18	130	515	27	196
	SANTA TERESA	5	5	41	20	0	0	0	0	0	25	5	41
	SUCRE	12	12	85	94	3	0	2,224	142	987	2,329	157	1,072
	Sub-total	133	133	971	680	15	108	7,869	366	2,600	8,682	514	3,679
Chacao	CHACAO	15	15	109	70	2	18	22	0	0	107	17	127
Sucre	CAUCAGUITA	1	1	0	0	0	0	92	2	15	93	3	15
	FILA DE MARICHE	0	0	0	0	0	0	39	1	8	39	1	8
	LA DOLORITA	2	2	13	0	0	0	120	3	22	122	5	35
	PETARE	6	6	41	41	1	9	827	40	284	874	47	334
	LEONCIO MARTINEZ	13	13	92	58	1	9	31	1	8	102	15	108
	Sub-total	22	22	145	99	2	18	1,110	47	337	1,230	71	500
	Sum	170	170	1,225	849	19	144	9,001	413	2,937	10,020	602	4,306

Table 3.2.21 Damage Estimation Result Case 1812

		Urban 4F-			Urban 3F-			Barrio & Rural			Sum		
Municiparity	PARROQUIA	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured
Libertador	23 DE ENERO	2	2	15	12	0	0	724	32	229	738	34	244
	ALTAGRACIA	39	39	277	140	4	30	93	2	15	273	45	322
	ANTIMANO	5	5	37	33	1	8	4,251	322	2,211	4,289	328	2,256
	CARICUAO	6	6	44	6	0	0	660	29	208	673	35	252
	CATEDRAL	8	8	58	28	1	8	0	0	0	36	9	66
	COCHE	22	22	158	60	1	8	636	27	194	718	50	359
	EL JUNQUITO	4	4	30	0	0	0	1,217	63	445	1,221	67	475
	EL PARAISO	14	14	101	229	8	59	635	27	194	878	49	354
	EL RECREO	83	83	581	302	12	88	491	19	137	876	114	807
	EL VALLE	9	9	66	28	1	8	2,670	176	1,221	2,708	186	1,295
	LA CANDELARIA	16	16	115	90	2	15	17	0	0	123	18	131
	LA PASTORA	42	42	298	207	7	52	1,843	109	763	2,092	158	1,113
	LA VEGA	11	11	80	55	1	8	1,474	81	570	1,540	93	657
	MACARAO	2	2	15	2	0	0	569	24	173	573	26	187
	SAN AGUSTIN	21	21	151	86	2	15	464	18	130	571	41	296
	SAN BERNARDINO	16	16	115	80	2	15	185	5	37	281	23	167
	SAN JOSE	13	13	94	46	1	8	551	23	165	611	37	267
	SAN JUAN	11	11	80	120	3	23	1,491	83	584	1,622	97	686
	SAN PEDRO	50	50	353	168	5	37	40	1	8	258	56	398
	SANTA ROSALIA	26	26	186	211	7	52	1,556	87	611	1,793	120	849
	SANTA TERESA	12	12	87	43	1	8	0	0	0	55	13	95
	SUCRE	45	45	319	356	14	103	7,525	677	4,588	7,925	736	5,010
	Sub-total	459	459	3,258	2,301	73	544	27,095	1,805	12,483	29,855	2,335	16,284
Chacao	CHACAO	29	29	207	118	3	23	37	1	8	184	33	237
Sucre	CAUCAGUITA	2	2	15	0	0	0	150	4	30	153	6	45
	FILA DE MARICHE	0	0	0	0	0	0	51	1	8	52	1	8
	LA DOLORITA	3	3	22	0	0	0	219	7	51	222	10	74
	PETARE	16	16	115	134	4	30	1,588	90	632	1,738	110	777
	LEONCIO MARTINEZ	22	22	158	103	3	23	76	2	15	202	27	195
	Sub-total	45	45	310	237	7	53	2,085	104	736	2,367	154	1,099
	Sum	533	533	3,775	2,656	85	619	29,217	1,910	13,226	32,406	2,528	17,620

Table 3.2.22 Damage Estimation Result Case 1878

Municiparity	PARROQUIA	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured
Libertador	23 DE ENERO	0	0	0	0	0	0	15	0	0	15	0	0
	ALTAGRACIA	0	0	0	1	0	0	2	0	0	3	0	0
	ANTIMANO	0	0	0	1	0	0	206	6	47	207	6	47
	CARICUAO	0	0	0	0	0	0	68	2	16	68	2	16
	CATEDRAL	0	0	0	0	0	0	0	0	0	1	0	0
	COCHE	1	1	10	2	0	0	72	2	16	75	3	26
	EL JUNQUITO	0	0	0	0	0	0	22	0	0	22	0	0
	EL PARAISO	0	0	0	5	0	0	31	1	8	36	1	8
	EL RECREO	3	3	22	8	0	0	24	0	0	35	3	22
	EL VALLE	0	0	0	1	0	0	227	7	54	229	7	54
	LA CANDELARIA	0	0	0	1	0	0	1	0	0	3	0	0
	LA PASTORA	0	0	0	2	0	0	28	0	0	30	0	0
	LA VEGA	0	0	0	1	0	0	97	2	16	98	2	16
	MACARAO	0	0	0	0	0	0	70	2	16	70	2	16
	SAN AGUSTIN	1	1	0	3	0	0	32	1	8	35	2	8
	SAN BERNARDINO	0	0	0	1	0	0	5	0	0	6	0	0
	SAN JOSE	0	0	0	1	0	0	12	0	0	12	0	0
	SAN JUAN	0	0	0	2	0	0	47	1	8	49	1	8
	SAN PEDRO	2	2	18	7	0	0	3	0	0	12	2	18
	SANTA ROSALIA	1	1	0	7	0	0	99	2	16	108	3	16
	SANTA TERESA	0	0	0	1	0	0	0	0	0	1	0	0
	SUCRE	0	0	0	3	0	0	63	1	8	66	1	8
	Sub-total	8	8	50	48	0	0	1,123	27	212	1,183	35	260
Chacao	CHACAO	1	1	9	3	0	0	2	0	0	7	1	9
Sucre	CAUCAGUITA	1	1	0	0	0	0	44	1	8	45	2	8
	FILA DE MARICHE	0	0	0	0	0	0	50	1	8	51	1	8
	LA DOLORITA	1	1	0	0	0	0	71	2	16	71	3	16
	PETARE	3	3	23	18	0	0	411	16	122	432	19	145
	LEONCIO MARTINEZ	1	1	10	5	0	0	12	0	0	18	1	10
	Sub-total	6	6	32	23	0	0	588	20	154	616	26	186
	Sum	15	15	90	74	0	0	1,713	47	365	1,802	62	455

Table 3.2.23 Damage Estimation Result Case Avila

		Urban 4F-			Urban 3F-			Barrio & Rural			Sum		
Municiparity	PARROQUIA	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured	Damaged Buil.	Death	Injured
Libertador	23 DE ENERO	2	2	16	11	0	0	650	29	210	663	31	226
	ALTAGRACIA	31	31	225	111	3	22	75	2	15	217	36	262
	ANTIMANO	1	1	9	8	0	0	1,192	63	450	1,201	64	459
	CARICUAO	1	1	0	1	0	0	124	3	23	125	4	23
	CATEDRAL	8	8	59	29	1	8	0	0	0	37	9	67
	COCHE	8	8	57	21	0	0	296	10	74	325	18	131
	EL JUNQUITO	1	1	0	0	0	0	173	5	37	174	6	37
	EL PARAISO	7	7	50	117	3	22	503	20	146	626	30	218
	EL RECREO	102	102	715	374	15	108	582	25	181	1,057	142	1,005
	EL VALLE	5	5	37	15	0	0	2,168	136	958	2,188	141	995
	LA CANDELARIA	22	22	156	110	3	22	19	0	0	151	25	179
	LA PASTORA	27	27	196	152	5	37	1,400	77	548	1,580	109	781
	LA VEGA	4	4	33	34	1	8	774	36	260	813	41	300
	MACARAO	0	0	0	0	0	0	74	2	15	74	2	15
	SAN AGUSTIN	19	19	139	78	2	15	553	23	167	650	44	321
	SAN BERNARDINO	20	20	144	99	3	22	200	6	45	319	29	211
	SAN JOSE	16	16	119	59	1	8	473	19	139	548	36	265
	SAN JUAN	9	9	68	89	2	15	1,279	69	492	1,377	80	575
	SAN PEDRO	46	46	327	155	5	37	54	1	8	255	52	372
	SANTA ROSALIA	24	24	172	193	6	44	1,604	92	653	1,821	122	869
	SANTA TERESA	12	12	86	42	1	8	0	0	0	54	13	94
	SUCRE	23	23	166	224	8	58	2,956	204	1,427	3,203	235	1,652
	Sub-total	388	388	2,776	1,920	59	433	15,151	822	5,847	17,460	1,269	9,056
Chacao	CHACAO	58	58	413	247	9	65	65	1	8	370	68	486
Sucre	CAUCAGUITA	17	17	122	0	0	0	1,006	50	359	1,023	67	481
	FILA DE MARICHE	2	2	15	0	0	0	211	7	52	213	9	67
	LA DOLORITA	21	21	149	0	0	0	1,066	54	387	1,087	75	536
	PETARE	59	59	420	317	12	87	6,031	516	3,551	6,408	587	4,058
	LEONCIO MARTINEZ	58	58	415	273	10	73	166	5	37	497	73	525
	Sub-total	157	157	1,121	590	22	159	8,480	632	4,386	9,228	811	5,667
	Sum	604	603	4,310	2,758	89	658	23,696	1,455	10,240	27,057	2,147	15,208

Table 3.3.1 Breakdown of Rapid Visual Screenings for 32 Important Buildings

Building Use	Government Bldg.: 9 Bldg.	School: 8 Bldg.	Hospital: 5 Bldg.
	Emergency Service: 6 Bldg.	Commercial: 3 Bldg.	Stadium: 2 Bldg
Year Built	Before 1955: 10 (31%)	1956 ~ 1967: 5 (16%)	1968 ~ 1982: 8 (25%)
	After 1982: 6 (19%)	Unknown: 3 (9%)	Unknown: 1
Type of Structure	RC Moment Frame: 24 (75 %)	RC S. W.: 1 (3 %)	Unknown: 1
	Steel M. F.: 4 (13 %)	B. Masonry: 3 (9 %)	-

Source: The JICA Study Team

Table 3.3.2 Result of RVS: Number of Buildings of Seismic Evaluation Required

Seismic Evaluation Not Required = OK: 8 Buildings (25 %)			
Seismic Evaluation Required: 24 Buildings (75 %)			
Building Use	Govt. Bldg.: 6/ 9	School: 8/ 8	Hospital: 5/ 5
	Emergency Service: 3/ 5	Commercial: 1/ 3	Stadium: 1/ 2
Year Built	Before 1955: 10/ 10	1956~67: 5/ 5	1968~ 82: 6/ 8
	After 1982: 2/ 6	Unknown: 1/ 3	-
Type of Structure	RC Moment Frame: 18/ 24	RC Sear Wall: 1/ 1	-
	Steel M. F.:2/ 4	Brick Masonry: 3/ 3	-

Source: JICA Study Team

Table 3.4.1 Scenario Earthquakes and their Parameters

Scenario	Mw	Seismogenic Depth	Fault Length	Mechanism	Fault system
1967	6.6	5 km	42 km	Strike slip	San Sebastian
1812	7.1	5 km	105 km	Strike slip	San Sebastian

Table 3.4.2 Stability Judgment of Bridges

Stability	Total Score
High Seismic Risk	30 ≦ S
Medium Seismic Risk	26≦ S ＜30
Low Seismic Risk	S＜26

Table 3.4.3 Seismic Damage Evaluation Factor

Item	Category		Score	Note
(1) Ground type	Stiff		0.5	The ground classification depends on the division of "Road Bridge Design for Earthquake-proof Indicator"
	Middle		1.0	
	Soft		1.5	
	Very Soft		1.8	
(2) Liquefaction	None		1.0	Depends on the Formula for "Road Bridge Design "
	Possible		1.5	
	Probable		2.0	
(3) Girder type	Arch/ Rigid Frame		1.0	
	Continuous		2.0	
	Simple/ Gelber		3.0	
(4) Bearing	Connection Device		0.6	F : Fixed support M : Movable Support
	F・M		1.0	
	M・M		1.15	
(5) Max Height of Abutment/Pier	<5m		1.0	Height is the maximum value from ground level
	5～１０		Interpolated	
	>10m		1.7	
(6) Number of Span	＝１		1.0	
	＞２		1.75	
(7) Bridge Seat Length	Long（A/S≥１）		0.8	A=Seat length(cm) S=(70+0.5L) cm L=Span Length (m) Ground type (very soft) D=A/70 Ground type (others) D=A/60
	Short（A/S<１）		1.2	
	Gelber bearing on pier cap	D> 1	0.8	
		D<1	1.2	
(8) Earthquake Intensity Scale	5*	120~209 gal	1.0	Mark * means earthquake intensity in Japan.
	5.5*	210~349 gal	1.7	
	6*	350~699gal	2.4	
	6.5*	700~1299 gal	3.0	
	7*	1300~3299 gal	3.5	
(9) Foundation Type	Excluding Pile Bent		1.0	1.4 for obviously weak foundation such as friction piles
	Pile Bent		1.4	
(10) Material of Abutment/Pier	Brick/ Plain concrete		1.4	
	Not listed above		1.0	
Total score	= (1)×(2)×(3)×(4)×(5)×(6)×(7)×(8)×(9)×(10)			

Table 3.4.4 Seismic Damage of Viaduct in Express Highway

Earthquake Intensity	Collapsed	Damage of Bearing Shoe	Damage of Pier	Viaduct Extension (km)	Rate of Collapse (place/km)	Rate of Damage (place/km)
7	19	-	1	18.8km	1.010	0.053
6+	5	5	7	58.2	0.086	0.206
6-	1	1	4	347.3	0.003	0.014
Total	25	6	12	424.3	-	-

Note : 6+ means 6.0<6+<6.5 and 6- means 5.5<6-<6.0

Table 3.4.5 Seismic Damage of Bridges (Ordinary Roads)

Earthquake Intensity	Collapse	Displacement of Girder and Pier	Damage of Abutment and Bearing shoe	Damage of Pier	Cracks on the Pier Stem
7	1	-	-	1	-
6+	1	3	5	1	-
6-		-	6	4	2
Total	2	3	11	6	2

Note : 6+ means 6.0<6+<6.5 and 6- means 5.5<6-<6.0

Table 3.4.6 Seismic Damage of Subway Structure in Kobe Earthquake

Intensity	Open Cut Type Tunnel			Mountain Tunneling	Shield Type
	Middle Column Collapse	Side Wall Damage	Other	Damage at Lining	
7	Hanshin Railway: 344 piece Kobe City Trans.: 457 piece Kobe express: 362 piece Kobe Railway: 59 piece Sanyo Railway: 36 piece	Hanshin Railway: 3365 m Kobe express: 595 m Kobe Railway: 14 m	-	Rokkou T. Higashiyama T. Kaishimoyama T	No Damage
6+	Sanyo Railway : 1 piece	-	-		
6-	-	Kobe Railway 84 m	-	Kikusuiyama T Arima T. Gosha T. Kitakami T	

Table 3.4.7 Correction Factor for (C_2) and (C_3)

Pipe material	Correction factor C_2	Correction factor C_3	
Ductile cast iron	0.3	C_3 <75mm	2.0
		100mm<C_3<450mm	1.0
		500mm<C_3<900mm	0.3
		1000mm<C_3	0.15
Cast iron	1.0	C_3 <75mm	1.7
		100mm<C_3<250mm	1.2
		300mm<C_3<900mm	0.4
		1000mm<C_3	0.15
Welded steel pipe	0.3	C_3 <75mm	2.8
		100mm<C_3<250mm	1.4
		300mm<C_3	0.8
Chloroethlene	1.5	C_3 <75mm	1.0
		100mm<C_3	0.8
Asbestos	3.0	C_3 <75mm	2.3
		100mm<C_3<250mm	0.9
		300mm<C_3	0.4

Table 3.4.8 Correction Factor for Liquefaction (C_1)

Liquefaction potential	Correction factor C_l
PL=0	1.0
0<PL<5	1.2
5<PL<15	1.5
15<PL	3.0

Table 3.4.9 Correction Factor for Liquefaction (C_1)

PL value	C_1
PL=0	1.0
0 <PL <5	1.2
5 <PL <15	1.5
15 <PL	0.068

Table 3.4.10 Correction Factor for Pipe Materials (C_2)

Pipe material		Correction factor C_2
Middle Pressure	Steel	0.01
	Cast iron	0.02
Low Pressure	Steel (welded)	0.02
	Steel (bolt)	1.00
	Steel (mechanical)	0.02
	Ductile cast iron (joint 1)	0.46
	Ductile cast iron (joint 2)	0.23
	Ductile cast iron (Gas type)	0.05
	Ductile cast iron (mechanical type)	0.02
	Polyethylene	0.00
	Polyvinyl chloride pipe	0.70

Table 3.4.11 Damage Ratio for Electric Pole

Intensity*	R (%)
Less 5	0.00
6	0.55

*Earthquake Intensity in Japan

Table 3.4.12 Damage Ratio for Electric Line

Intensity*	**R (%)**
Less 5	0.00
6	0.30

*Earthquake Intensity in Japan

Table 3.4.13 Correction Factor for Liquefaction

PL value	**C1**
PL=0	1.0
0 <PL <5	1.1
5 <PL <15	1.3
15 <PL	2.1

Table 3.4.14 Category of Hazardous Facility, Type of Damage and Damage Ratio of Tokyo Metropolitan Area

Category of Hazardous Facility	Type of Damage	PGA										
		100	150	200	250	300	350	400	450	500	550	600
1. Large storage tank of flammable Liquid	1. small spill from tank and pipe joint	4.10E-05	1.50E-04	4.90E-04	1.40E-03	3.30E-03	6.90E-03	1.30E-02	2.00E-02	3.00E-02	3.80E-02	4.70E-02
	2. continuous certain volume of spill	1.00E-05	3.80E-05	1.20E-04	3.40E-04	8.20E-04	1.70E-03	3.20E-03	4.90E-03	7.50E-03	9.40E-03	1.20E-02
	3. overflow from protection dike	2.40E-06	8.90E-06	2.90E-05	8.00E-05	1.90E-04	4.00E-04	7.40E-04	1.10E-03	1.70E-03	2.20E-03	2.80E-03
	4. fire outbreak of oil in protection dike	1.00E-06	3.80E-06	1.20E-05	3.40E-05	8.20E-05	1.70E-04	3.20E-04	4.90E-04	7.50E-04	9.40E-04	1.20E-04
	5. large fire spreading on tank-yard	2.40E-07	8.90E-07	2.90E-06	8.00E-06	1.90E-05	4.00E-05	7.40E-05	1.10E-04	1.70E-04	2.20E-04	2.80E-04
2. Tanks and gas-holder of flammable gas	6. spill from pipe joint to tank (emergency shut-down)	1.50E-05	4.20E-05	1.10E-04	2.50E-04	5.60E-04	1.10E-03	2.20E-03	3.70E-03	6.30E-03	9.50E-03	1.40E-02
	7. continuous spill of certain volume (hazard of explosion)	3.80E-06	1.00E-05	2.70E-05	6.30E-05	1.40E-04	2.80E-04	5.40E-04	9.20E-04	1.60E-03	2.40E-03	3.50E-03
	8. fire outbreak of spilled gas in protection dike	3.80E-07	1.00E-06	2.70E-06	6.30E-06	1.40E-05	2.80E-05	5.40E-05	9.20E-05	1.60E-04	2.40E-04	3.50E-04
	9. explosion of large spilled gas	3.80E-08	1.00E-07	2.70E-07	6.30E-07	1.40E-06	2.80E-06	5.40E-06	9.20E-06	1.60E-05	2.40E-05	3.50E-05
3. Tank of toxic gas/ liquid nitrogen	10. spill from pipe joint of tank	3.00E-06	8.40E-06	2.10E-05	5.10E-05	1.10E-04	2.30E-04	4.30E-04	7.40E-04	1.30E-03	1.90E-03	2.80E-03
	11. continuous spill of certain volume (hazard for citizen)	7.60E-08	2.10E-07	5.30E-07	1.30E-06	2.80E-06	5.70E-06	1.10E-05	1.80E-05	3.20E-05	4.70E-05	7.10E-05

Source: Damage ratio of hazardous facility on the Seismic Micro-zoning Study of Tokyo Metropolitan Government, 1997

Table 3.4.15 List of Bridges Estimated Risk A and B

Level of Risk	Code No.	Name or Number of Bridge	Name or No of Road	Name or number of crossing road/river/metro	Year of Built before'87 : 1 unknown : 2 after '87 : 3
A	61	Dist. Ciempies, Pte. S/Autopista enlace Norte-Sur	Rampa de entrada Autopista del Este desde Chacao	Autopista Fco. Fajardo (2 vías)	1
A	62	Dist. Ciempies, Pte. S/Autopista enlace Sudeste-Oeste	Salida a Autopista Fco. Fajardo sentido Oeste desde Autopista del Este	Salida a las Mercedes desde Chacao ida y vuelta (2 vías)	1
A	63	Dist. Ciempies, Pte. S/Autopista enlace Sudeste-Este	Salida desde Autopista del Este hacia Chacao	Salida a las Mercedes desde Chacao ida y vuelta (2 vías)	1
A	82	Dist. Baralt, Pte.Oeste	Entrada desde Av. Baralt hacia el Paraiso (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías) y Río Guaire	1
A	83	Dist. Baralt, Pte.Este	Entrada desde la Av. Baralt hacia Autopista sentido Este (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías) y Río Guaire	1
A	86	Dist. La Araña, Pte. Paraiso-Planicie	Salida desde Planicie dirección El Paraiso (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías)	1
A	87	Dist. La Araña, Pte. Caricuao-Paraiso	Vía Caricuao-Paraiso (1 vía)	una (1 vía)	1
A	88	Dist. La ArañA, Pte. Paraiso-Qta. Crespo	Vía Qta. Crespo-Paraíso (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías)	1
A	89	Dist. La Araña, Pte. Caricuao-Planicie	Vía Caricuao-Planicie (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías) y entrada Barrio (1 vía)	1
A	90	Dist. La Araña, Pte. Qta. Crespo-Planicie 1	Vía Qta Crespo-Planicie (1 vía)	Paralela una vía del Dist. La Araña	1
A	91	Dist. La Araña, Pte. Qta. Crespo-Planicie 2	Vía Planicie-Qta Crespo (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías)	1
A	92	Dist. La Araña, Pte. Planicie-Caricuao	Vía desde Planicie 1 hacia Caricuao (1 vía)	Paralela una vía del Dist. La Araña	2
A	93	Dist. La Araña, Pte. Planicie 2-Qta.Crespo	Vía Planicie-Qta. Crespo (1 vía)	Autopista Fco. Fajardo ambos sentidos (2 vías)	1
A	94	Dist. La Araña, Pte. Qta. Crespo-Paraíso	Vía Qta. Crespo-El Paraíso (1 vía)	Río Guaire	1
A	95	Dist. La Araña, Pte. Planicie 2-Caricuao	Vía Planicie-Caricuao (1 vía)	Paralela una vía del Dist. La Araña	1
B	15	Puente Santander (Puente Lara)	Avenida Santander	Autopista Francisco Fajardo, Rio Guaire	1
B	98	Pte. Ricardo Zuluaga	Vía Sta. Mónica-Los Chaguaramos ambos sentidos (2 vías)	Autopista Valle-Coche ambos sentidos (2 vías) y Río Guaire	1

Risk A: High Seismic Risk Risk B: Medium Seismic Risk

Table 3.4.16 Bridge Damage Estimation in Some Case of Earthquake Scenario 1967

Code No.	(1) Ground Type	(2) Liquefaction	(3) Girder Type	(4) Bearing Type	(5) Max. Height of Abut./Pier	(6) Number of Spans	(7) Min. Bridge Seat Width	(8) PGA *Japanese Earthquake Intensity	(9) Foundation Work	(10) Materials of Abutment and Pier	Total Score	Code No.
	Stiff : 0.5	None : 1.0	Rigid : 1.0	girder connection	Less 5m : 1.0	one span : 1	wide : 0.8	5* 120-209 : 1.0	Pile bent:1.4	Brick : 1.4		
	Middle : 1.0	Possible : 1.5	Continuous : 2.0	device :0.6	5-9.9m : 1.35	more 2 span :1.75	narrow : 1.2	5.5* 210-349 : 1.7	others :1.0	others : 1.0		
	Soft : 1.5	Probable : 2.0	Simple : 3.0		more 10m : 1.7			6* 350-699 : 2.4				
	Very Soft : 1.8			Fix & Mov : 1.0				6.5* 700-1299 : 3.0				
				Mov & Mov : 1.15				7* 1300-3299: 3.5				
15	1.0	1.5	2.0	1.00	1.35	1.75	1.20	1.0	1.0	1.0	8.5	15
61	1.5	1.0	3.0	1.15	1.70	1.75	1.20	1.0	1.0	1.0	18.5	61
62	1.5	1.0	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	62
63	1.5	1.0	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	63
82	1.5	1.5	2.0	1.15	1.35	1.75	0.80	1.0	1.0	1.0	9.8	82
83	1.5	1.5	2.0	1.15	1.35	1.75	0.80	1.0	1.0	1.0	9.8	83
86	1.0	1.5	3.0	1.00	1.70	1.75	1.20	1.0	1.0	1.0	16.1	86
87	1.0	1.5	3.0	1.00	1.35	1.75	1.20	1.0	1.0	1.0	12.8	87
88	1.0	1.5	3.0	1.15	1.00	1.75	1.20	1.0	1.0	1.0	10.9	88
89	1.0	1.5	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	89
90	1.0	1.5	3.0	1.15	1.00	1.75	1.20	1.0	1.0	1.0	10.9	90
91	1.0	1.5	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	91
92	1.0	1.5	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	92
93	1.0	1.5	3.0	1.15	1.70	1.75	1.20	1.0	1.0	1.0	18.5	93
94	1.0	1.5	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	94
95	1.0	1.5	3.0	1.15	1.35	1.75	1.20	1.0	1.0	1.0	14.7	95
98	1.5	1.0	3.0	1.15	1.00	1.75	1.20	1.0	1.0	1.0	10.9	98

Stability	Total Score
High Seismic Risk	30≦S
Medium Seismic Risk	26≦S＜30
Low Seismic Risk	S＜26

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Table 3.4.17 Bridge Damage Estimation in Some Case of Earthquake Scenario 1812

Code No.	(1) Ground Type	(2) Liquefaction	(3) Girder Type	(4) Bearing Type	(5) Max. Height of Abut./Pier	(6) Number of Spans	(7) Min. Bridge Seat Width	(8) PGA *Japanese Earthquake Intensity	(9) Foundation Work	(10) Materials of Abutment and Pier	Total Score	Code No.
	Stiff : 0.5	None : 1.0	Rigid : 1.0	girder connection device :0.6	Less 5m : 1.0	one span : 1	wide : 0.8	5* 120-209 : 1.0	Pile bent:1.4	Brick : 1.4		
	Middle : 1.0	Possible : 1.5	Continuous : 2.0		5-9.9m : 1.35	more 2 span :1.75	narrow : 1.2	5.5* 210-349 : 1.7	others :1.0	others : 1.0		
	Soft : 1.5	Probable : 2.0	Simple : 3.0		more 10m : 1.7			6* 350-699 : 2.4				
	Very Soft : 1.8			Fix & Mov : 1.0				6.5* 700-1299 : 3.0				
				Mov & Mov : 1.15				7* 1300-3299: 3.5				
15	1.0	2.0	2.0	1.00	1.35	1.75	1.20	2.4	1.0	1.0	27.2	15
61	1.5	1.0	3.0	1.15	1.70	1.75	1.20	2.4	1.0	1.0	44.3	61
62	1.5	1.0	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	35.2	62
63	1.5	1.0	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	35.2	63
82	1.5	2.0	2.0	1.15	1.35	1.75	0.80	2.4	1.0	1.0	31.3	82
83	1.5	2.0	2.0	1.15	1.35	1.75	0.80	2.4	1.0	1.0	31.3	83
86	1.0	2.00	3.0	1.00	1.70	1.75	1.20	2.4	1.0	1.0	51.4	86
87	1.0	2.00	3.0	1.00	1.35	1.75	1.20	2.4	1.0	1.0	40.8	87
88	1.0	2.00	3.0	1.15	1.00	1.75	1.20	2.4	1.0	1.0	34.8	88
89	1.0	2.00	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	46.9	89
90	1.0	2.00	3.0	1.15	1.00	1.75	1.20	2.4	1.0	1.0	34.8	90
91	1.0	2.00	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	46.9	91
92	1.0	2.00	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	46.9	92
93	1.0	2.00	3.0	1.15	1.70	1.75	1.20	3.0	1.0	1.0	73.9	93
94	1.0	2.00	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	46.9	94
95	1.0	2.00	3.0	1.15	1.35	1.75	1.20	2.4	1.0	1.0	46.9	95
98	1.5	1.0	3.0	1.15	1.00	1.75	1.20	2.4	1.0	1.0	26.1	98

Stability	Total Score
High Seismic Risk	30≦S
Medium Seismic Risk	26≦S<30
Low Seismic Risk	S<26

Table 3.4.18 Result of Damage Estimation of Bridges

Earthquake Scenario	Earthquake 1967	Earthquake 1812
High Seismic Risk	0	15
Medium Seismic Risk	0	2
Low Seismic Risk	115	98
Total No. of Bridges	115	115

Table 3.4.19 MMI of Viaduct and Damage Estimation Based on Kobe Earthquake Data

Location	Total Length (km)	Earthquake 1967						Earthquake 1812					
		MMI	JMI	Rate of Collapse (place/km)	No. of Collapse Place	Rate of Damage (place/km)	No. of Damage Place	MMI	JMI	Rate of Collapse (place/km)	No. of Collapse Place	Rate of Damage (place/km)	No. of Damage Place
Distribuidor La Arana	13.4	VIII+	5.5～6	0.003	0.04	0.014	0.19	IX−	6	0.086	1.15	0.206	2.76
Distribuidor Ciempies	4.0	VII＋～VIII−	5～5.5	0.003	0.01	0.014	0.06	VIII+	5.5～6	0.003	0.01	0.014	0.06
Distribuidor Pulpo	3.2	VII+	5	−	−	−	−	VIII+	5.5～6	0.003	0.01	0.014	0.04
Francisco Fajardo	3.3	VII−～VII+	4.5～5	−	−	−	−	VIII−～VIII+	5～6	0.003	0.01	0.014	0.05
Planicie	1.1	VII−～VII+	4.5～5	−	−	−	−	VIII+	5.5～6	0.003	0.00	0.014	0.02
Cotal Mil	2.2	VI+～VII−	4.5～5	−	−	−	−	VII+～VIII−	5～5.5	0.003	0.01	0.014	0.03
Cementerio	0.8	VI+	4.5	−	−	−	−	VIII+	5.5～6	0.003	0.00	0.014	0.01
Total	28.0				0.05		0.25				1.19		2.97

JMI	PGA
5	120～ 209
5.5	210～ 349
6−	350～ 524
6+	525～ 699
6.5	700～ 1299
7	1300～ 3299

1) MMI:Modified Mercalli Intensity
2) JMI:Japan Meteorological Intensity

*Relationship between MMI and PGA
MMI=(Log(PGA)−0.014)/0.3

Table 3.4.20 Outline of Metro

Line Name	Total Length (km)	Com-plete Year	Station No.	Length (km)				
				Shield Type	Mountain Tunnel Type	Open Cut Type	Others	Station
Line 1: Propatria-Palo Verde	20.6	1983	22	n.a.	n.a.	n.a.	n.a.	n.a.
Line 2: Silencio-Zoo Logico/Las Adjuntas	18.4	1987	13	1.6	1.7	4.5	8.4	2.2
Line 3: Plaza Venezuela-El Valle	5.3	1994	5	2.2	1.0	1.2	0	0.9

n.a. : not available

Table 3.4.21 Damage Estimation of Telecommunication Line in Each Central

Central	Length (km)	Earthquake Scenario 1967					Earthquake Scenario 1812				
		Av.MMI	Av.JMI	R (%)	C1	Nd	Av.MMI	Av.JMI	R (%)	C1	Nd
23 De Enero	38.1	7.42	5.0	0.0	1.0	0.00	8.26	5.5	0.3	1.0	0.11
Alta Florida	75.3	7.77	5.5	0.3	1.0	0.23	8.41	6.0	0.3	1.0	0.23
Alto Prado	5.5	6.77	4.5	0.0	1.0	0.00	7.35	5.0	0.0	1.0	0.00
Bello Monte	113.9	7.37	5.0	0.0	1.0	0.00	8.12	5.5	0.3	1.0	0.34
Boleita	184.3	7.37	5.0	0.0	1.0	0.00	7.92	5.5	0.3	1.1	0.61
Caobos	98.7	7.94	5.5	0.3	1.0	0.30	8.52	6.0	0.3	1.0	0.30
Caracas	75.2	8.33	5.0	0.0	1.0	0.00	8.70	6.0	0.3	1.0	0.23
Caricuao	238.0	6.92	5.5	0.3	1.0	0.71	7.71	5.5	0.3	1.0	0.71
Chacao	226.8	7.77	5.0	0.0	1.0	0.00	8.21	5.5	0.3	1.0	0.68
Chaguaramos	73.8	7.44	5.0	0.0	1.0	0.00	8.30	5.5	0.3	1.0	0.22
Chuao	5.0	7.59	5.0	0.0	1.0	0.00	8.35	5.5	0.3	1.0	0.02
Coche	69.0	7.02	4.5	0.0	1.0	0.00	7.81	5.5	0.3	1.1	0.23
El Cafetal	168.6	6.84	5.5	0.3	1.0	0.51	7.35	5.0	0.0	1.0	0.00
El Rosal	46.2	7.85	5.0	0.0	1.0	0.00	8.46	6.0	0.3	1.0	0.14
Fajardo	202.1	7.29	5.0	0.0	1.0	0.00	8.14	5.5	0.3	1.1	0.67
Fco. Salias	278.0	6.91	5.0	0.0	1.0	0.00	7.50	5.0	0.0	1.0	0.00
Jardines	78.0	7.25	5.5	0.3	1.0	0.23	8.09	5.5	0.3	1.1	0.26
La florida	130.3	7.91	5.5	0.0	1.0	0.00	8.65	6.0	0.3	1.0	0.39
La Salle	54.9	7.73	5.0	0.0	1.0	0.00	8.46	6.0	0.3	1.0	0.16
La Urbina	33.7	6.90	5.5	0.3	1.0	0.10	7.31	5.0	0.0	1.0	0.00
Las Mercedes	160.7	7.85	4.5	0.0	1.0	0.00	8.52	6.0	0.3	1.0	0.48
Los guayabitos	13.0	6.70	5.0	0.0	1.0	0.00	7.28	5.0	0.0	1.0	0.00
Los Palos Grande	156.7	7.60	5.0	0.0	1.0	0.00	8.04	5.5	0.3	1.0	0.47
Macaracuay	57.4	7.18	5.5	0.3	1.0	0.17	7.66	5.0	0.0	1.0	0.00
Maderero	134.6	7.76	5.0	0.0	1.1	0.00	8.52	6.0	0.3	1.3	0.52
Miranda	1.9	6.68	4.5	0.0	1.0	0.00	6.91	5.0	0.0	1.0	0.00
Palo Verde	63.0	6.91	5.0	0.0	1.0	0.00	7.39	5.0	0.0	1.0	0.00
Pastora	282.1	7.65	5.0	0.0	1.0	0.00	8.50	6.0	0.3	1.0	0.85
Petare	11.2	6.91	5.0	0.0	1.0	0.00	7.35	5.0	0.0	1.0	0.00
Prado De Maria	36.8	7.39	5.0	0.0	1.0	0.00	8.33	5.5	0.3	1.0	0.11
Rdo. Zuoloaga	106.1	7.46	5.0	0.0	1.0	0.00	8.31	5.5	0.3	1.1	0.35
San Agustin	30.3	8.16	5.5	0.3	1.0	0.09	8.72	6.0	0.3	1.0	0.09
San Martin	69.2	7.62	5.0	0.0	1.1	0.00	8.34	5.5	0.3	1.3	0.27
Url Valle Arriba	98.8	6.59	5.0	0.0	1.0	0.00	7.54	5.0	0.0	1.0	0.00
Total (km)	3417.20					2.34					8.43
Total (%)	100%					0.07%					0.25%

Table 3.4.22 Max. PGA and G.S. Concentrating Area

Item	Location Code No.	No. of G.S.	PGA	Area Name
PGA Max. Area	No.37, No.26	2	714, 723	Antimano, Catedral La Candelaria
G.S. Massed Area At High PGA (I)	No.17, No.19 No.21~No.24	6	356~559	Neveri (near interchange Arana)
G.S. Massed Area At High PGA (II)	No.10~No.13 No.15 No.28~No.30	8	359~590	Las Acascias、Valle Abajo Collinas Las Acalias Lios Chaquaramamos

Table 3.5.1 Seismic Reinforcement and Cost Impact of each Model

No.	Strengthening	Cost impact	Method of strengthening
1	No	0 %	None
2	Yes	5 to 7%	Grade beams
3	Yes	10%	Grade beams & brick walls
4	Yes	15%	Grade beams & concrete block walls

Table 3.5.2 Weight of a Model

Dead load

Floor	Concrete t=3.4cm x 2.4kg/cm/m^2	= 82kg/m^2		
	Tabelone (8kg/piece(20cmx80cmx6cm))	= 50kg/m^2		
	Steel joist (7kg/m@800)	= 9kg/m^2	total	141kg/m^2
Beam	20cmx20cmx2,400kg/m^3	=96kg/m		
	20cmx30cmx2,400kg/m^3	=144kg/m		
Column	20cmx20cmx2,400kg/m^3	= 96kg/m		
Brick wall	3kg/piecex17piece/m^2+joint mortar30(ver.)+6(hor.)kg/m^2	= 88kg/m^2		

Roof

Floor	141kg/m^2x2.6mx3.6m	= 1,320kg
Beam	144kg/mx(2.8m+3.8m)x2	= 1,901kg
Column	96kg/mx2.2m/2x4	= 422kg

Floor

Floor	141kg/m^2x2.6mx3.6m	= 1,320kg
Beam	144kg/mx(2.8m+3.8m)x2	= 1,901kg
Column	96kg/mx(2.2m/2x4+0.6x2+2.2x2)	= 422kg
Brick wall	88kg/m^2x(0.9mx1.2x4m+3.6mx1.1mx2)	= 1,077kg
	Sub total	8,901kg

Total 900kg of sand bags (20 no x 45 kg) are provided on a floor to compensate live load (40kg/m^2x2.8mx3.8m=420kg) and transversal brick wall (60 kg/m^2 x 2.0m x 2.0m x 2 = 480 kg, doors are estimated, and internal mortar is not considered).

Total 9,800kg

Table 3.5.3 Material Tests (Concrete, Re-bar, Clay brick, Concrete Block)

Concrete Test

Cylinder	max. stress (kg/cm^2, for full section)	
1	124	Foundations
2	113	
3	96	
4	97	
5	122	
6	121	
7	103	
8	101	
9	49	Columns over foundation to beam
10	53	
13	58	
14	68	
15	72	Beams
16	68	
17	37	Grade beam
18	39	
19	66	Grade beam model 1
20	57	
21	69	Floor
23	64	Columns model 1 -2
25	62	Beam roof model 1
26	66	Column model 3 - beam model 2
28	29	roof
29	133	roof
40	62	wall
41	40	wall

Reinforced bar

Diameter	yielding stress	max stress (Kg/cm^2)
3/8"	4729	6643
3/8	4761	6789
1/2	4532	6683
1/2	4532	6532

Diameter: 3.85 mm max load: 840 kgf max stress: 7216 kg/cm^2

Clay brick:	max stress (kg/cm^2 for full section)
10 cms	23
10 cms	23
10cms	17
10 cms	21.8
10 cms	23

Clay brick sizes:

9.60 x 19.6 x 29.7cm weight 3.80 kg
9.60 x 19.9 x 29.7cm weight 3.80 kg
9.80 x 20.2 x 29.8cm --- 3.9 kg

Concrete block sizes:

14.3 x 19.8 x 39.0 weight 10.40 Kg

Concrete block strength (kg/cm^2, for full section)

15cms 19

Table 3.5.4 Model 1 Load and Deflection

Manometer	Pressure	Loading (t)			Reading #5 (mm)	Reading #2 (mm)	Deflection #5 (mm)	Deflection#2 (mm)	Average Deflection(mn
					19.74	19.36			
3	0	0	19.74	19.36	19.74	19.36	0	0	0
6	3	0.75	19.74	19.36	19.65	19.3	0.09	0.06	0.075
8	5	1.25	19.74	19.36	19.26	19.14	0.48	0.22	0.35
10	7	1.75	19.74	19.36	18.84	18.78	0.9	0.58	0.74
12	9	2.25	19.74	19.36	18.98	18.15	0.76	1.21	0.985
14	11	2.75	19.74	19.36	17.11	17.4	2.63	1.96	2.295
16	13	3.25	19.74	19.36	15.74	16.26	4	3.1	3.55
18	15	3.75	19.74	19.36	14.48	15.23	5.26	4.13	4.695
20	17	4.25	19.74	19.36	13.23	14.14	6.51	5.22	5.865
22	19	4.75	19.74	19.36	12.28	13.24	7.46	6.12	6.79
24	21	5.25	19.74	19.36	11.75	12.58	7.99	6.78	7.385
26	23	5.75	19.74	19.36	11.44	11.94	8.3	7.42	7.86
28	25	6.25	19.74	19.36	11.2	11.25	8.54	8.11	8.325
30	27	6.75	19.74	19.36	11.02	10.54	8.72	8.82	8.77
32	29	7.25	19.74	19.36	10.85	9.88	8.89	9.48	9.185
34	31	7.75	19.74	19.36	10.69	9.16	9.05	10.2	9.625
36	33	8.25	19.74	19.36	10.49	8.39	9.25	10.97	10.11
38	35	8.75	19.74	19.36	10.3	7.54	9.44	11.82	10.63
40	37	9.25	19.74	19.36	9.72	5.7	10.02	13.66	11.84
42	39	9.75	19.74	19.36	8.49	2.75	11.25	16.61	13.93
44	41	10.25	19.74	19.36	6.43	-0.1	13.31	19.46	16.385
46	43	10.75	20.39	20.78					

Reading #6 (mm)	Reading #3 (mm)	Deflection#6 (mm)	Deflection#3 (mm)
20.8	20.2		
20.8	20.2	0	0
20.72	20.19	0.08	0.01
20.52	20.05	0.28	0.15
20.21	19.81	0.59	0.39
19.6	19.35	1.2	0.85
18.96	18.78	1.84	1.42
17.98	17.84	2.82	2.36
17.05	16.88	3.75	3.32
16.14	16.07	4.66	4.13
15.44	15.28	5.36	4.92
15.05	14.69	5.75	5.51
14.81	14.14	5.99	6.06
14.62	13.45	6.18	6.75
14.52	12.78	6.28	7.42
14.37	12.09	6.43	8.11
14.28	11.41	6.52	8.79
14.17	10.66	6.63	9.54
14.04	9.95	6.76	10.25
13.55	8.58	7.25	11.62
12.61	6.7	8.19	13.5
11.05	4.09	9.75	16.11

Reading #7 (mm)	Reading #8 (mm)	Deflection#7 (mm)	Deflection#8 (mm)
0.39	0.95		
0.39	0.95	0	0
0.42	0.96	0.03	0.01
0.47	0.99	0.08	0.04
0.56	1.05	0.17	0.1
0.77	1.18	0.38	0.23
1.04	1.36	0.65	0.41
1.49	1.72	1.1	0.77
1.95	2.09	1.56	1.14
2.46	2.49	2.07	1.54
2.84	2.85	2.45	1.9
3.05	3.11	2.66	2.16
3.23	3.37	2.84	2.42
3.41	3.67	3.02	2.72
3.55	3.97	3.16	3.02
3.68	4.28	3.29	3.33
3.82	4.56	3.43	3.61
4.04	4.87	3.65	3.92
4.24	5.22	3.85	4.27
4.59	5.97	4.2	5.02
5.19	6.91	4.8	5.96
5.98	8.15	5.59	7.2

Reading #1 (mm)	Reading #4 (mm)	Deflection#1 (mm)	Deflection#4 (mm)
53.6	48.39		
53.6	48.39	0	0
53.6	48.29	0	0.1
53.6	47.95	0	0.44
53.12	47.48	0.48	0.91
52.35	46.58	1.25	1.81
52.35	45.6	1.25	2.79
50.12	44.22	3.48	4.17
49.35	42.92	4.25	5.47
47.82	41.65	5.78	6.74
46.78	40.67	6.82	7.72
46	40.15	7.6	8.24
45.4	39.82	8.2	8.57
44.5	39.6	9.1	8.79
43.7	39.4	9.9	8.99
42.86	39.27	10.74	9.12
41.85	39.12	11.75	9.27
41.1	38.94	12.5	9.45
40.12	38.73	13.48	9.66
38.27	37.92	15.33	10.47
35.73	36.71	17.87	11.68
31.42	34.72	22.18	13.67

Table 3.5.5 Model 2 Load and Deflection

Manometer	Pressure	Loading (t)	Reading #5 (mm)	Reading #2 (mm)	Deflection #5 (mm)	Deflection#2 (mm)	Average Deflection(mr	Reading #6 (mm)	Reading #3 (mm)	Deflection#6 (mm)	Deflection#3 (mm)
8	5	1.25	18.21	17.26				17.01	19.25		
10	7	1.75	18.06	17.25	0.15	0.01	0.08	17.01	19	0	0.25
12	9	2.25	18.06	17.19	0.15	0.07	0.11	16.98	19	0.03	0.25
14	11	2.75	17.87	16.98	0.34	0.28	0.31	16.85	18.93	0.16	0.32
16	13	3.25	17.7	16.84	0.51	0.42	0.465	16.77	18.83	0.24	0.42
18	15	3.75	17.44	16.55	0.77	0.71	0.74	16.61	18.69	0.4	0.56
20	17	4.25	17.16	16.3	1.05	0.96	1.005	16.45	18.51	0.56	0.74
22	19	4.75	16.81	15.93	1.4	1.33	1.365	16.27	18.31	0.74	0.94
24	21	5.25	16.5	15.65	1.71	1.61	1.66	16.08	18.17	0.93	1.08
26	23	5.75	16.18	15.24	2.03	2.02	2.025	15.88	17.89	1.13	1.36
28	25	6.25	15.8	14.89	2.41	2.37	2.39	15.62	17.66	1.39	1.59
30	27	6.75	15.41	14.4	2.8	2.86	2.83	15.37	17.33	1.64	1.92
32	29	7.25	15.24	14.08	2.97	3.18	3.075	15.29	17.15	1.72	2.1
34	31	7.75	15.08	13.83	3.13	3.43	3.28	15.23	17	1.78	2.25
36	33	8.25	15.02	13.65	3.19	3.61	3.4	15.21	16.89	1.8	2.36
38	35	8.75	14.91	13.35	3.3	3.91	3.605	15.17	16.66	1.84	2.59
40	37	9.25	14.81	13.11	3.4	4.15	3.775	15.14	16.54	1.87	2.71
42	39	9.75	14.71	12.83	3.5	4.43	3.965	15.11	16.38	1.9	2.87
44	41	10.25	14.59	12.6	3.62	4.66	4.14	15.07	16.36	1.94	2.89
46	43	10.75	14.39	12.04	3.82	5.22	4.52	15.02	15.91	1.99	3.34
48	45	11.25	13.83	10.28	4.38	6.98	5.68	14.72	14.7	2.29	4.55
50	47	11.75	13.18	8.22	5.03	9.04	7.035	14.45	13.69	2.56	5.56
52	49	12.25	12.99	5.92	5.22	11.34	8.28	14.29	13.04	2.72	6.21
54	51	12.75	12.57	5.5	5.64	11.76	8.7	14.08	12.43	2.93	6.82
56	53	13.25	12.34	4.15	5.87	13.11	9.49	13.88	11.65	3.13	7.6
58	55	13.75	11.92	2.74	6.29	14.52	10.405	13.59	10.95	3.42	8.3
60	57	14.25	11.46	0.5	6.75	16.76	11.755	13.06	9.33	3.95	9.92
62	59	14.75	11.46	15.44	6.75	17.81	12.28	10.99		6.02	
62	59	14.75	9.59	5.99	8.62	27.26	17.94				
64	61	15.25	7.8		10.41						
66	63	15.75									

Reading #7 (mm)	Reading #8 (mm)	Deflection#7 (mm)	Deflection#8 (mm)	Reading #1 (mm)	Reading #4 (mm)	Deflection#1 (mm)	Deflection#4 (mm)
3.2	1.9			47.78	49.49		
3.2	1.9	0	0	47.78	49.49	0	0
3.2	1.92	0	0.02	47.78	49.38	0	0.11
3.22	1.98	0.02	0.08	47.63	49.12	0.15	0.37
3.26	2.01	0.06	0.11	47.45	49	0.33	0.49
3.3	2.09	0.1	0.19	47.15	48.66	0.63	0.83
3.35	2.14	0.15	0.24	46.88	48.33	0.9	1.16
3.42	2.21	0.22	0.31	46.52	48.02	1.26	1.47
3.51	2.29	0.31	0.39	46.26	47.68	1.52	1.81
3.58	2.39	0.38	0.49	45.8	47.25	1.98	2.24
3.67	2.51	0.47	0.61	45.37	46.8	2.41	2.69
3.76	2.64	0.56	0.74	44.81	46.34	2.97	3.15
3.83	2.72	0.63	0.82	44.45	46.15	3.33	3.34
3.86	2.81	0.66	0.91	44.15	46.02	3.63	3.47
3.89	2.85	0.69	0.95	43.98	45.97	3.8	3.52
3.91	2.92	0.71	1.02	43.62	45.93	4.16	3.56
3.94	3.01	0.74	1.11	43.28	45.85	4.5	3.64
3.99	3.1	0.79	1.2	42.87	45.81	4.91	3.68
4.03	3.19	0.83	1.29	42.4	45.69	5.38	3.8
4.1	3.37	0.9	1.47	41.63	45.55	6.15	3.94
4.28	3.72	1.08	1.82	39.7	44.89	8.08	4.6
4.46	4.04	1.26	2.14	38.05	44.5	9.73	4.99
4.56	4.32	1.36	2.42	36.87	44.21	10.91	5.28
4.67	4.55	1.47	2.65	35.49	43.82	12.29	5.67
4.81	4.91	1.61	3.01	34.05	43.5	13.73	5.99
4.95	5.24	1.75	3.34	32.57	43.03	15.21	6.46
5.17	5.86	1.97	3.96	30.29	42.37	17.49	7.12
5.49	7.1	2.29	5.2				

Table 3.5.6 Model 3 Load Deflection

Manometer	Pressure	Loading (t)	Deflection #5 (mm)	Deflection#2 (mm)	Average Deflection(mr	Deflection#6 (mm)	Deflection#3 (mm)	Deflection#7 (mm)	Deflection#8 (mm)	Deflection#1 (mm)	Deflection#4 (mm)
3	0	0	0	0	0	0	0	0	0	0	0
6	3	0.75	0	0	0	0	0	0.01	0.02	0	0.17
8	5	1.25	0.05	0.06	0.055	0.01	0	0.01	0.02	0.07	0.17
10	7	1.75	0.13	0.15	0.14	0.07	0.08	0.03	0.03	0.16	0.17
12	9	2.25	0.22	0.28	0.25	0.1	0.11	0.04	0.06	0.29	0.16
14	11	2.75	0.29	0.34	0.315	0.11	0.13	0.06	0.06	0.39	0.27
16	13	3.25	0.45	0.51	0.48	0.18	0.19	0.09	0.1	0.58	0.41
18	15	3.75	0.61	0.66	0.635	0.25	0.24	0.12	0.13	0.73	0.59
20	17	4.25	0.79	0.84	0.815	0.28	0.29	0.15	0.18	0.95	1.02
22	19	4.75	0.99	1.08	1.035	0.3	0.37	0.19	0.22	1.25	1.38
24	21	5.25	1.24	1.34	1.29	0.37	0.44	0.22	0.28	1.53	1.52
26	23	5.75	1.61	1.71	1.66	0.43	0.53	0.28	0.36	1.91	2.17
28	25	6.25	2.22	2.36	2.29	0.5	0.64	0.38	0.49	2.65	2.65
30	27	6.75	2.82	2.99	2.905	0.58	0.77	0.48	0.61	3.32	3.27
32	29	7.25	3.24	3.48	3.36	0.65	0.82	0.57	0.72	3.79	3.77
34	31	7.75	3.62	3.97	3.795	0.71	0.95	0.64	0.84	4.35	4.09
36	33	8.25	3.94	4.52	4.23	0.75	1.07	0.69	0.96	4.9	4.47
38	35	8.75	4.08	4.82	4.45	0.77	1.15	0.74	1.04	5.2	4.72
40	37	9.25	4.19	5.17	4.68	0.79	1.23	0.78	1.11	5.59	4.73
42	39	9.75	4.28	5.47	4.875	0.8	1.31	0.81	1.18	5.87	4.87
44	41	10.25	4.36	5.94	5.15	0.81	1.41	0.83	1.32	6.4	5.27
46	43	10.75	4.645	6.43	5.5375	0.875	1.58	0.9	1.455	7.065	5.46
48	45	11.25	4.81	6.845	5.8275	0.91	1.73	0.945	1.57	7.535	5.705
50	47	11.75	5.28	7.43	6.355	1.07	2.04	1.07	1.75	8.2	6.3
52	49	12.25	5.465	7.875	6.67	1.115	2.265	1.125	1.855	8.38	6.64
54	51	12.75	5.635	8.505	7.07	1.16	2.585	1.17	1.995	9.36	6.765
56	53	13.25	5.95	9.31	7.63	1.22	3	1.24	2.15	10.24	7.36
58	55	13.75	6.07	10.09	8.08	1.23	3.35	1.28	2.27	10.99	7.37
60	57	14.25	6.3	12.17	9.235	1.24	4.33	1.34	2.61	12.91	7.94
62	59	14.75	6.38	14	10.19	1.24	4.95	1.4	2.87	14.47	7.94
64	61	15.25	6.62	16.07	11.345	1.24	5.475	1.485	3.115	16.665	8.365
66	63	15.75	7.81	19.52	13.665	1.24	6.08	1.65	3.21	20.27	9.76
68	65	16.25	8.82	22.42	15.62	1.17	6.95	1.81	3.43	23.39	10.34
70	67	16.75	9.53	25.595	17.5625	1.155	8.01	1.995	3.55	25.87	10.57
72	69	17.25	14.14	37.23	25.685	1.35	9.18	2.2	3.49	38.71	14.6
72.5	69.5	17.375		50	25					50	

Table 3.5.7 Model 4 Load Deflection

Manometer	Pressure	Loading (t)	Deflection #5 (mm)	Deflection#2 (mm)	Average Deflection(mr	Deflection#6 (mm)	Deflection#3 (mm)	Deflection#7 (mm)	Deflection#8 (mm)	Deflection#1 (mm)	Deflection#4 (mm)
3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6.00	3.00	0.75	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.23
8.00	5.00	1.25	0.07	0.08	0.07	0.05	0.05	0.00	0.00	0.00	0.26
10.00	7.00	1.75	0.12	0.12	0.12	0.06	0.07	0.00	0.00	0.26	0.33
12.00	9.00	2.25	0.17	0.16	0.17	0.09	0.09	0.00	0.00	0.26	0.41
14.00	11.00	2.75	0.24	0.21	0.23	0.13	0.13	0.00	0.01	0.31	0.49
16.00	13.00	3.25	0.30	0.25	0.28	0.16	0.16	0.00	0.02	0.34	0.56
18.00	15.00	3.75	0.42	0.32	0.37	0.22	0.20	0.00	0.04	0.44	0.76
20.00	17.00	4.25	0.44	0.41	0.43	0.31	0.26	0.00	0.05	0.59	0.95
22.00	19.00	4.75	0.64	0.46	0.55	0.35	0.29	0.00	0.07	0.64	1.00
24.00	21.00	5.25	0.67	0.53	0.60	0.39	0.33	0.00	0.07	0.64	1.11
26.00	23.00	5.75	0.91	0.62	0.76	0.43	0.39	0.00	0.09	0.66	1.21
28.00	25.00	6.25	1.07	0.71	0.89	0.63	0.46	0.00	0.10	0.66	1.38
30.00	27.00	6.75	1.25	0.83	1.04	0.75	0.54	0.00	0.13	0.78	1.62
32.00	29.00	7.25	1.45	0.96	1.21	0.86	0.63	0.00	0.16	1.15	1.87
34.00	31.00	7.75	1.61	1.09	1.35	0.95	0.71	0.03	0.18	1.16	2.02
36.00	33.00	8.25	1.82	1.27	1.55	1.06	0.83	0.07	0.23	1.33	2.23
38.00	35.00	8.75	1.94	1.39	1.67	1.13	0.92	0.09	0.25	1.52	2.42
40.00	37.00	9.25	2.07	1.51	1.79	1.20	1.00	0.12	0.27	1.58	2.61
42.00	39.00	9.75	2.19	1.66	1.93	1.26	1.11	0.14	0.30	1.99	2.88
44.00	41.00	10.25	2.26	1.78	2.02	1.31	1.18	0.15	0.32	2.32	2.95
46.00	43.00	10.75	2.32	1.88	2.10	1.34	1.27	0.17	0.35	2.32	2.95
48.00	45.00	11.25	2.38	2.01	2.20	1.37	1.35	0.20	0.38	2.41	2.99
50.00	47.00	11.75	2.45	2.22	2.34	1.42	1.48	0.20	0.43	2.54	3.08
52.00	49.00	12.25	2.49	2.37	2.43	1.43	1.58	0.21	0.46	2.56	3.16
54.00	51.00	12.75	2.54	2.59	2.57	1.48	1.70	0.21	0.53	2.76	3.33
56.00	53.00	13.25	2.59	2.74	2.67	1.50	1.80	0.22	0.58	3.27	3.41
58.00	55.00	13.75	2.62	2.89	2.76	1.53	1.90	0.22	0.63	3.52	3.51
60.00	57.00	14.25	4.42	3.17	3.79	2.41	2.41	0.51	0.90	4.52	5.47
62.00	59.00	14.75	6.74	4.30	5.52	3.81	3.04	0.88	1.22	6.26	7.61
64.00	61.00	15.25	16.73	6.68	11.71	8.98	4.79	2.12	2.10	9.38	18.52
66.00	63.00	15.75	25.63		12.82	13.36					25.79
68.00	65.00	16.25									
70.00	67.00	16.75									
72.00	69.00	17.25									
72.50	69.50	17.38									

Table 3.5.8 Key Facilities to be Reinforced

Government

Municipality	Central	AMDC	Municipal	State
Libertador	23	3	22	0
Chacao			3	
Sucre	3	0	5	1
Study Area	26	3	30	1

Source: GIS data by Secretariat of Planning and Environmental management, AMDC

Rescue response entities

Municipality	Fire-station	Police		
		Central	ADMC	Municipal
Libertador	13	13	14	1
Chacao	3	1		
Sucre	1	1	3	1
Study Area	17	15	17	2

Source: GIS data by Secretariat of Planning and Environmental management, AMDC

Educational facilities

Municipality	School	University	College
Libertador	468	13	41
Chacao	53	4	9
Sucre	95	9	12
Study Area	616	26	62

Source: GIS data by Secretariat of Planning and Environmental management, AMDC

Table 3.5.9 Criteria of Seismic Reinforcement Plan

	Miner & frequent Earthquake	Moderate & rare Earthquake (1967)	Strong & very rare Earthquake (1812)
Private Houses	No damage	Protect property	Protect life
Public buildings	No damage	Protect function	Protect property
Key facilities	No damage	No damage	Protect function

Source: The JICA Study Team

Table 3.5.10 New Building Damage Function

Urban Area				Rural & Barrio Area	
Before Reinforcement	**(New)** After Reinforcement	Before Reinforcement	**(New)** After Reinforcement	Before Reinforcement	**(New)** After Reinforcement
Curve 1 & 2	Curve 9	Curve 10	Curve 6	Curve 17	Curve 11
Curve 3	Curve 9	Curve 11	Curve 6	Curve 18	Curve 8
Curve 4 & 5	Curve 15	Curve 12	Curve 10	Curve 19	Curve 2
Curve 6	Curve 15	Curve 13	Curve 4	Curve 20	Curve 1
Curve 7 & 8	Curve 14	Curve 14	Curve 15	----	----
Curve 9	Curve 14	Curve 15	Curve 15	----	----
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Source: JICA Study Team

Table 3.5.10 (2) Summary of the Damage Estimation Results by Case

(With Seismic Reinforcement)

Case 1967 with seismic reinforcement

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	390	30.0	7	13.7	54	13.8
Urban 4F-	17,234	5.5	24	1.8	24	47.1	182	46.7
Urban Sum	83,499	26.5	414	31.9	31	60.8	236	60.5
Barrio & Rural	231,158	73.5	884	68.1	20	39.2	154	39.5
Total	314,657	100.0	1,298	100.0	51	100.0	390	100.0

Case 1812 with seismic reinforcement

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	1,288	24.5	33	12.0	248	12.3
Urban 4F-	17,234	5.5	103	2.0	103	37.6	762	37.7
Urban Sum	83,499	26.5	1,392	26.4	136	49.6	1,010	50.0
Barrio & Rural	231,158	73.5	3,868	73.5	138	50.4	1,011	50.0
Total	314,657	100.0	5,260	100.0	274	100.0	2,021	100.0

Case 1878 with seismic reinforcement

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	29	19.6	0	0.0	2	6.7
Urban 4F-	17,234	5.5	2	1.4	2	66.7	16	53.8
Urban Sum	83,499	26.5	31	20.9	2	66.7	18	60.5
Barrio & Rural	231,158	73.5	117	79.1	1	33.3	12	39.5
Total	314,657	100.0	148	100.0	3	100.0	29	100.0

Case Avila with seismic reinforcement

	Building Number		Heavily Damaged Buil.		Death		Injured	
	number	%	number	%	number	%	number	%
Urban -3F	66,265	21.1	1,346	30.2	35	13.7	263	14.0
Urban 4F-	17,234	5.5	121	2.7	121	47.5	890	47.3
Urban Sum	83,499	26.5	1,467	32.9	156	61.3	1,152	61.3
Barrio & Rural	231,158	73.5	2,989	67.1	99	38.7	728	38.7
Total	314,657	100.0	4,456	100.0	255	100.0	1,880	100.0

Table 3.5.11 Monetary Loss of Building due to Heavily Damage and Collapse by 1967 Earthquake (As of Feb. 2004)

Area	Category: Type of Building	Category: Item	Building Replacement Cost (M. Bs)	Monetary Loss of Building (M. Bs): **(B)** Before Reinforcement	**(A)** After Reinforcement	Saved Loss **(B) - (A)**
Urban Area	Dwelling House	High Class	526,000	3,000	1,500	1,500
		Mid. C.	2,271,000	27,600	12,200	15,400
		Low C.	1,754,000	22,000	9,900	12,100
		Sub Total	4,551,000	52,600	23,600	29,000
	Apartment	1 ~ 3F	1,442,000	19,400	10,800	8,600
		4 ~ 8F	7,594,000	95,600	6,800	88,800
		9F ~	6,074,000	59,200	9,100	50,100
		Sub Total	15,110,000	174,200	26,700	147,500
	Office Building	1 ~ 3F	939,000	14,300	10,000	4,300
		4 ~ 8F	4,131,000	52,800	3,300	49,500
		9 F~	4,506,000	43,200	7,200	36,000
		Sub Total	9,576,000	110,300	20,500	89,800
	Hospital and Govern. Office	/w Beds	479,000	17,100	5,700	11,400
		No Bed	440,000	3,400	1,000	2,400
		G. Office	2,570,000	30,800	5,500	25,300
		Sub Total	3,489,000	51,300	12,200	39,100
	Other Important Building	1 ~ 3F	501,000	11,000	5,500	5,500
		4 ~ 8F	1,102,000	5,500	1,100	4,400
		9F ~	900,000	3,600	1,800	1,800
		Sub Total	2,503,000	20,100	8,400	11,700
Urban Area Total			35,229,000	408,500	91,400	317,100
Rural Area	Dwelling House	Slope > 20^o	611,000	18,700	1,400	17,300
		Slope = 20^o	5,216,000	19,400	900	18,500
Barrio Area	Dwelling House	Slope > 20^o	2,349,000	112,600	16,400	96,200
		Slope =20^o	3,058,000	138,400	8,900	129,500
Rural & Barrio Area Total			11,234,000	289,100	27,600	261,500
Ground Total (M. Bs)			46,463,000	697,600	130,700	566,900
M. US$ (1920 Bs= 1US$)			24,200	363	68	295

Source: JICA Study Team

Table 3.5.12 Monetary Loss of Building due to Moderate Damage by 1967 Earthquake (As of Feb. 2004)

Area	Category: Type of Building	Category: Item	Building Replacement Cost (M. Bs)	Monetary Loss of Building (M. Bs): (B) Before Reinforcement	Monetary Loss of Building (M. Bs): (A) After Reinforcement	Monetary Loss of Building (M. Bs): Saved Loss (B) - (A)
Urban Area	Dwelling House	High Class	526,000	600	300	300
		Mid. C.	2,271,000	5,500	2,400	3,100
		Low C.	1,754,000	4,400	2,000	2,400
		Sub Total	4,551,000	10,500	4,700	5,800
	Apartment	1 ~ 3F	1,442,000	3,900	2,200	1,700
		4 ~ 8F	7,594,000	19,100	1,400	17,700
		9F ~	6,074,000	11,800	1,800	10,000
		Sub Total	15,110,000	34,800	5,400	29,400
	Office Building	1 ~ 3F	939,000	2,900	2,000	900
		4 ~ 8F	4,131,000	10,600	700	9,900
		9 F~	4,506,000	8,600	1,400	7,200
		Sub Total	9,576,000	22,100	4,100	18,000
	Hospital and Govern. Office	/w Beds	479,000	3,400	1,100	2.300
		No Bed	440,000	700	200	500
		G. Office	2,570,000	6,200	1,100	5,100
		Sub Total	3,489,000	10,300	2,400	7,900
	Other Important Building	1 ~ 3F	501,000	2,200	1,100	1,100
		4 ~ 8F	1,102,000	1,100	200	900
		9F ~	900,000	800	400	400
		Sub Total	2,503,000	4,100	1,700	63,500
	Urban Area Total		35,229,000	81,800	18,300	63.500
Rural Area	Dwelling House	Slope > 20°	611,000	5,600	400	5,200
		Slope = 20°	5,216,000	5,800	300	5,500
Barrio Area	Dwelling House	Slope > 20°	2,349,000	33,800	4,900	28,900
		Slope = 20°	3,058,000	41,500	2,700	38,800
Rural & Barrio Area Total			11,234,000	86,700	8,300	78,400
Ground Total (M. Bs)			46,463,000	168,500	26.600	141,900
M. US$ (1920 Bs= 1US$)			24,200	88	14	74

Source: JICA Study Team

Table 3.5.13 Monetary Loss of Building due to Heavily Damage and Collapse by 1812 Earthquake (As of Feb. 2004)

Area	Category: Type of Building	Category: Item	Building Replacement Cost (M. Bs)	Monetary Loss of Building (M. Bs): **(B)** Before Reinforcement	**(A)** After Reinforcement	Saved Loss **(B) - (A)**
Urban Area	Dwelling House	High Class	526,000	10,200	5,100	5,100
		Mid. C.	2,271,000	63,800	29,600	34,200
		Low C.	1,754,000	80,500	37,600	42,900
		Sub Total	4,551,000	154,500	72,300	82,200
	Apartment	1 ~ 3F	1,442,000	56,900	11,500	45,400
		4 ~ 8F	7,594,000	293,500	45,500	248,900
		9F ~	6,074,000	186,600	54,600	132,000
		Sub Total	15,110,000	537,000	111,600	425,400
	Office Building	1 ~ 3F	939,000	42,000	25,800	16,200
		4 ~ 8F	4,131,000	160,100	24,800	135,300
		9 F~	4,506,000	138,000	39,600	98,400
		Sub Total	9,576,000	340,100	90,200	249,900
	Hospital and Govern. Office	/w Beds	479,000	45,600	11,400	34,200
		No Bed	440,000	13,400	7,700	5,700
		G. Office	2,570,000	91.300	28,600	62,700
		Sub Total	3,489,000	150,300	47,700	102,600
	Other Important Building	1 ~ 3F	501,000	34,500	17,000	17,500
		4 ~ 8F	1,102,000	17,600	4,400	13,200
		9F ~	900,000	12,600	3,600	9,000
		Sub Total	2,503,000	64,700	25,000	39,700
	Urban Area Total		35,229,000	1,246,600	346,800	899,800
Rural Area	Dwelling House	Slope > 20^o	611,000	58,900	6,400	52,500
		Slope = 20^o	5,216,000	66,600	5,300	61,300
Barrio Area	Dwelling House	Slope > 20^o	2,349,000	354,300	64,300	290,000
		Slope = 20^o	3,058,000	454,000	45,900	408,100
Rural & Barrio Area Total			11,234,000	933,800	121,900	811,900
Ground Total (M. Bs)			46,463,000	2,180,400	468,700	1,711,700
M. US$ (1920 Bs= 1US$)			24,200	1,135	244	891

Source: JICA Study Team

Table 3.5.14 Monetary Loss of Building due to Moderate Damage by 1812 Earthquake

(As of Feb. 2004)

Area	Category: Type of Building	Category: Item	Building Replacement Cost (M. Bs)	Monetary Loss of Building (M. Bs): **(B)** Before Reinforcement	**(A)** After Reinforcement	Saved Loss **(B) - (A)**
Urban Area	Dwelling House	High Class	526,000	2,000	1,000	1,000
		Mid. C.	2,271,000	12,800	5,900	6,900
		Low C.	1,754,000	16,100	7,500	8,600
		Sub Total	4,551,000	30,900	14,400	16,500
	Apartment	1 ~ 3F	1,442,000	11,400	2,300	9,100
		4 ~ 8F	7,594,000	58,700	9,100	49,600
		9F ~	6,074,000	37,300	10,900	26,400
		Sub Total	15,110,000	107,400	22,300	85,100
	Office Building	1 ~ 3F	939,000	8,400	5,200	3,200
		4 ~ 8F	4,131,000	32,000	5,000	27,000
		9 F~	4,506,000	27,600	7,900	19,700
		Sub Total	9,576,000	68,000	18,100	49,900
	Hospital and Govern. Office	/w Beds	479,000	9,100	2,300	6,800
		No Bed	440,000	2,700	1,500	1,200
		G. Office	2,570,000	18,300	5,700	12,600
		Sub Total	3,489,000	30,100	95,000	20,600
	Other Important Building	1 ~ 3F	501,000	6,900	3,400	3,500
		4 ~ 8F	1,102,000	3,500	900	2,600
		9F ~	900,000	2,500	700	1,800
		Sub Total	2,503,000	12,900	5,000	7,900
	Urban Area Total		35,229,000	249,300	69,300	180.000
Rural Area	Dwelling House	Slope > 20^o	611,000	17,700	1,900	15,800
		Slope = 20^o	5,216,000	20,000	1,600	18,400
Barrio Area	Dwelling House	Slope > 20^o	2,349,000	106,300	19,300	87,000
		Slope = 20^o	3,058,000	136,200	13,800	124,400
Rural & Barrio Area Total			11,234,000	280,200	36,600	243,600
Ground Total (M. Bs)			46,463,000	529,500	105,900	423,600
M. US$ (1920 Bs= 1US$)			24,200	276	55	221

Source: JICA Study Team

Table 3.5.15 Reference Price in Caracas as of February 2004 (Continued on to table below) (1920Bs = 1US$)

A. Basic Materials: (+IVA)	
1. Ready mixed Concrete: Fc250	240,000 Bs/ m3 + Labor cost
2. Concrete in site mixing	200,000 Bs/ m3 + Labor cost
3. Reinforcing Bar: fy4,200 (12m length)	1,400 Bs/ Kg : 1 package: 2 tons
4. Steel fabric mesh	1,500 Bs/ m^2
5. Brick 15 cm in thickness	380 Bs/ No. 17 Nos./m^2
6. Concrete Block 15 cm in thickness	500 Bs/ No. 17 Nos./m^2
7. Cement	10,000 Bs/ package 42.5 Kg/ 1 package
8. Gravel/ Sand/ Plastering material	18,500/ 22,500/ 20,000 Bs/ m^3
9. Wooden form: Plate; 0.3m x 2.4m x 25mm Sheet; 1.2m x 0.6m x 25mm Square Bar; 50mm x 100mm	30,000 Bs/ m^2: for Beam & Column 10,000 Bs/ Bs: for Slab & Wall 3,000 Bs/ ml: for Support
10. Ceramic Tile: 33cm x 33cm	10,000 Bs/ m^2 : 9 units/ 1m^2
B. Material and Labor: (+IVA)	
1. New Construction (Total Price)	500,000 ~ 600,000 Bs/ m^2
2. Structure and Masonry Wall (no finish)	280,000 Bs/ m^2
3. Labor cost of structure only	60,000 Bs/ m^2
4. Labor cost of wall only	4,000 Bs/ m^2
Wall + plastering both sides	12,000 Bs/ m^2
5. Paint finishing	8,000 Bs/ m^2
6. Asphalt Waterproofing 6mm thk.	12,000 Bs/ m^2
7. Installation of Ceramic Tiles w/ mortar	10,000 Bs/ m^2
8. Structural Steel Fabrication work	6,500 Bs/ kg
9. Square Steel Pipe	8,000 Bs/ kg
10. Base Plate	10,500 Bs/ kg
11. Anchor Bolt (A-32S)	16,500 Bs/ kg

Source: JICA Study Team

Table 3.5.16 Reference Price in Caracas as of February 2004 (Continued) (1920Bs = 1US$)

C. Others: (+IVA)	
1. Demolition by hand and disposal of Debris	6,000 Bs/ m^3
2. Excavation by Machine	5,000 Bs/ m^3
3. Excavation by Hand	7,000 Bs/ m^3
4. Electrical work (Cable 12mm)	45,000 Bs/ point : 6 points/ 50 m^2
5. Sanitary Plumbing (PVC)	30,000 Bs/ point : 2 points/ 50 m^2

Source: JICA Study Team

Table 3.5.17 Typical Rough Unit Cost of Building Replacement Work in Caracas (As of February 2004, 1920Bs = 1US$)

1A. Dwelling Houses in Urban area	
1) Low class of dwelling (80-100 m^2) (100 m^2)	400,000 - 600,000 Bs/ m^2 50,000,000 Bs/ 1 House
2) Middle class of dwelling (100-200 m^2)	600,000 - 800,000 Bs/ m^2
(150 m^2)	105,000,000 Bs/ 1 House
1B. Dwelling Houses in Barrio area (70-100 m^2)	150,000 - 200,000 Bs/ m^2
(100 m^2)	17,500,000 Bs/ 1 House
Selling cost	300,000 Bs/ m^2
2A. Apartment Houses in Urban area	600,000 Bs/ m^2
(150 m^2)	90,000,000 Bs/ 1 Family
2B. Apartment Houses in Barrio area	300,000 - 400,000 Bs/ m^2
(100 m^2)	35,000,000 Bs/ 1 Family
3. Office Buildings	
1). Reinforced Concrete Buildings Architectural work Structural work Building Equipment work Electric work Plumbing work Air Conditioning work Elevator Total	 210,000 Bs/ m^2 (42%) 190,000 Bs/ m^2 (38%) 100,000 Bs/ m^2 (20%) 30,000 Bs/ m^2 20,000 Bs/ m^2 20,000 Bs/ m^2 30,000 Bs/ m^2 500,000 Bs/ m^2
2). Structural Steel Buildings Architectural work Structural work Building Equipment work Total	250,000 Bs/ m^2 (41.7%) 250,000 Bs/ m^2 (41.7%) 100,000 Bs/ m^2 (16.6%) 600,000 Bs/ m^2
3). Masonry Buildings (Existing Building) Architectural work Structural work Building Equipment work Total	 330,000 Bs/ m^2 (60%) 150,000 Bs/ m^2 (25%) 120,000 Bs/ m^2 (20%) 600,000 Bs/ m^2
4). Commercial Building (Excluding inside finishing)	500,000 Bs/ m^2
5). Hospital Buildings (Excluding Medical Equipments) Small Hospital (without Bed) Large Hospital (with Beds)	 600,000 Bs/ m^2 900,000 - 1,000,000 Bs/ m^2
6. School Buildings	400,000 Bs/ m^2
7. Factory Buildings (Steel structure with light roof)	200,000 Bs/ m^2

Source: JICA Study Team

Table 3.5.18 The Total Floor Area, Cost of Replacement and Seismic Reinforcement of Existing Buildings in Caracas (As of Feb. 2004)

Area	Category: Type of Building	Category: Item	Total Floor Area (m2)	Building Replacement Cost (M. Bs)	Seismic Reinforcement Cost (M. Bs)
Urban Area	Dwelling House	High Class	526,000	526,000	36,200
		Middle Class	3,244,000	2,271,000	156,500
		Low Class	3,507,000	1,754,000	120,900
		Sub Total	7,277,000	4,551,000	313,600
	Apartment	Low Rise: 1 ~ 3	2,404,000	1,442,000	99,400
		Middle Rise: 4 ~ 8	11,683,000	7,594,000	629,500
		High Rise: 9 ~	9,345,000	6,074,000	434,900
		Sub Total	23,432,000	15,110,000	1,163,800
	Office Building	Low Rise: 1 ~ 3	1,878,000	939,000	64,700
		Middle Rise: 4 ~ 8	7,511,000	4,131,000	342,500
		High Rise: 9 ~	7,510,000	4,506,000	322,600
		Sub Total	16,899,000	9,576,000	729,800
	Hospital and Governmental Office	with Beds	504,000	479,000	39,700
		without Bed	734,000	440,000	30,300
		Governmental Office	4,672,000	2,570,000	213,000
		Sub Total	5,910,000	3,489,000	283,000
	Other Important Building	Low Rise: 1 ~ 3	1,002,000	501,000	34,500
		Middle Rise: 4 ~ 8	2,004,000	1,102,000	91,400
		High Rise: 9 ~	1,500,000	900,000	64,400
		Sub Total	4,506,000	2,503,000	190,300
	Urban Area Total		58,024,000	35,229,000	2,680,500
Rural Area	Dwelling House	Slope ＞ 20degree	1,527,000	611,000	58,700
		Slope = 20degree	9,639,000	816,000	173,000
Barrio Area	Dwelling House	Slope ＞ 20degree	13,424,000	2,349,000	300,700
		Slope = 20degree	17,474,000	3,058,000	275,200
	Rural & Barrio Total		42,064,000	11,234,000	807,600
Ground Total			100,088,000	46,463,000	3,488,100
US$ (1920 Bs= 1US$)				24,200 M.US$	1,817 M.US$

Source: JICA Study Team

Table 3.5.19 Number of Buildings in Each Area and Uses

Area	Nos. of Bldg.	%	Category	Nos. of Bldg.	%	Class, Story	Nos. of Bldg.	%
Urban Area	83,449	100	Dwelling House	58,449	70	High C.	1,753	3
						Mid. C.	21,626	37
						Low C.	35,070	60
			Apartment House	6,680	8	1 ~ 3	2,004	30
						4 ~ 8	3,340	50
						9 -	1,336	20
			Office Building	12,526	15	1 ~ 3	3,758	30
						4 ~ 8	5,010	40
						9 -	3,758	30
			Hospital and Governmental O.	3,340	4	w/ Beds	84	2.5
						No Bed	918	27.5
						Govn. O.	2,338	70
			Other Important Building	2,504	3	1 ~ 3	1,002	40
						4 ~ 8	1,002	40
						9 -	500	20
			Urban Area Total	83,449	100		83,449	
Rural Area	25,175	10.9	Slope ＞20degree	10,182	40.4	---	---	
			Slope ≦ 20degree	14,993	59.6	---	---	
			Sub Total	25,175	100			
Barrio Area	205,983	89.1	Slope ＞ 20degree	89,491	43.4	---	---	
			Slope ≦ 20degree	116,492	56.6	---	---	
			Sub Total	205,983	100			
	231,158	100	Rural & Barrio Total	231,158	100			
	314,657		Grand Total	314,657	100			

Source: JICA Study Team

Table 3.5.20 Ratio of Required Seismic Evaluation and Reinforcement, and Cost of Seismic Reinforcement per Building Replacement Cost

Area	Category: Type	Category: Item	Category: Year Built	Ratio of Building Number	Ratio of Required Seismic Evaluation (Ratio of Seismic Reinforcement)	Cost of Seismic Reinforcement / Building Replacement Cost
Urban Area	Type of Structure	R. C. Structure		82.1%		
		Steel Structure		3.7%		
		Masonry		14.2%		
	Year Built	Before 1967 *1		51.7%		15%
		1968 ~ 1982 *2		37.4%		10%
		After 1983		10.9%		5%
	Number of Story	Low Rise: 1 ~ 3	*1	44.1%	80%, (80%)	15%
			*2	30.4%	75%, (70%)	10%
			*3		70%, (60%)	5%
		Middle Rise: 4~8	*1	6.4%	90%, (90%)	15%
			*2	4.6%	80%, (80%)	10%
			*3		70%, (70%)	5%
		High Rise: 9 ~	*1	1.1%	95%, (70%)	15%
			*2	2.5%	90%, (60%)	10%
			*3		85%, (50%)	5%
Rural Area	Dwelling House	Slope＞20degree	---	40.4%	80%, (80%)	15%
		Slope≦20degree	---	54.6%	80%, (75%)	10%
Barrio Area	Dwelling House	Slope＞20degree	---	43.4%	80%, (80%)	20%
		Slope≦20degree	---	56.6ºº%	80%, (75%)	15%

Source: JICA Study Team

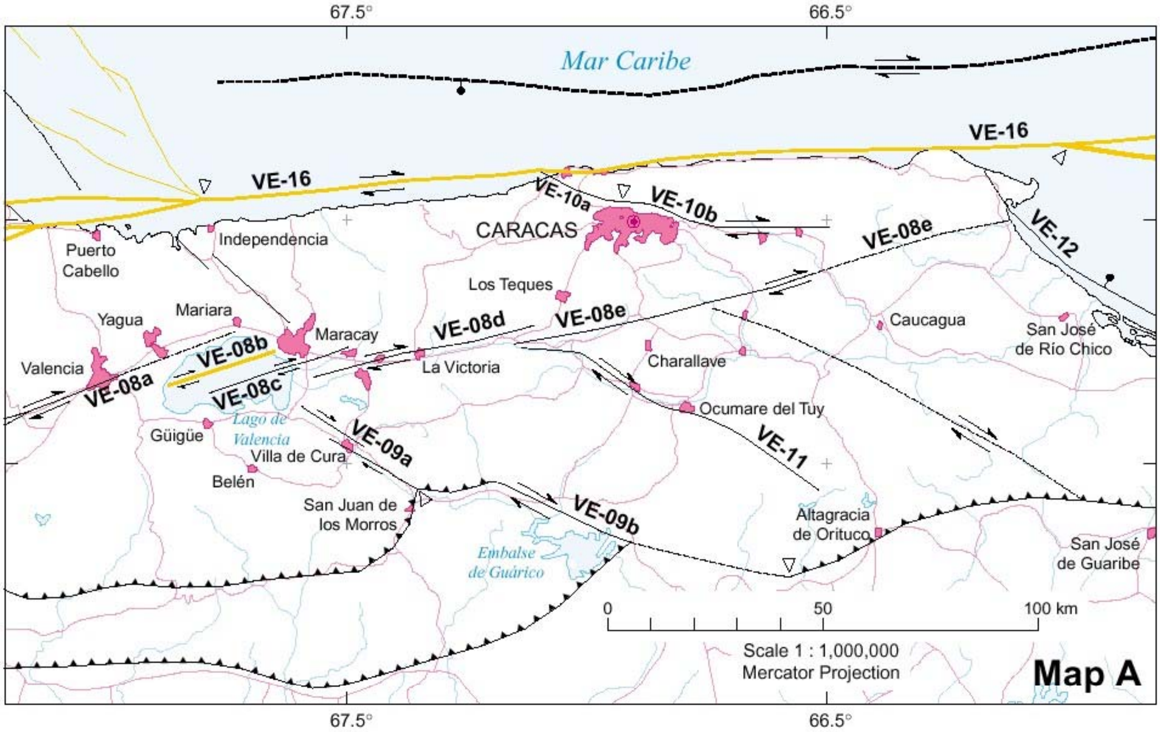


Figure 3.1.1 Quaternary Faults Around Caracas (Audemard et. al, 2000)

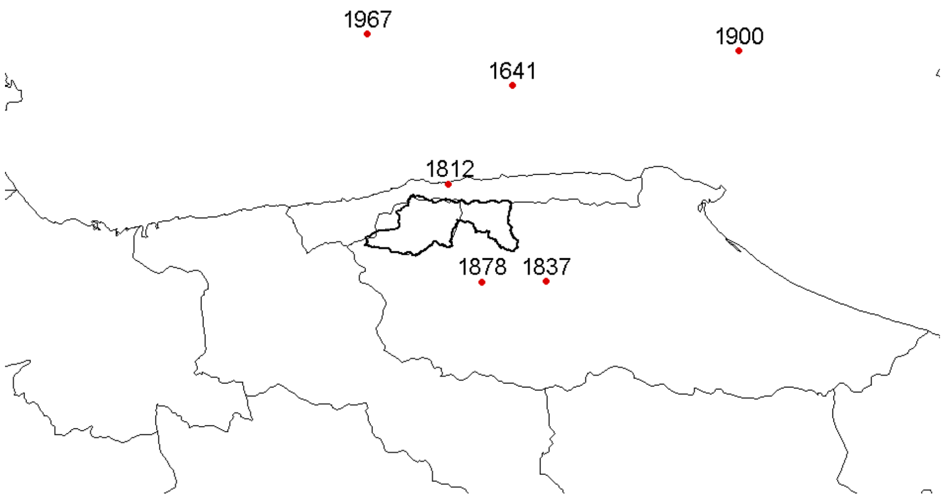


Figure 3.1.2 Epicenters of Earthquakes that Affected Caracas (Grases, 1990)

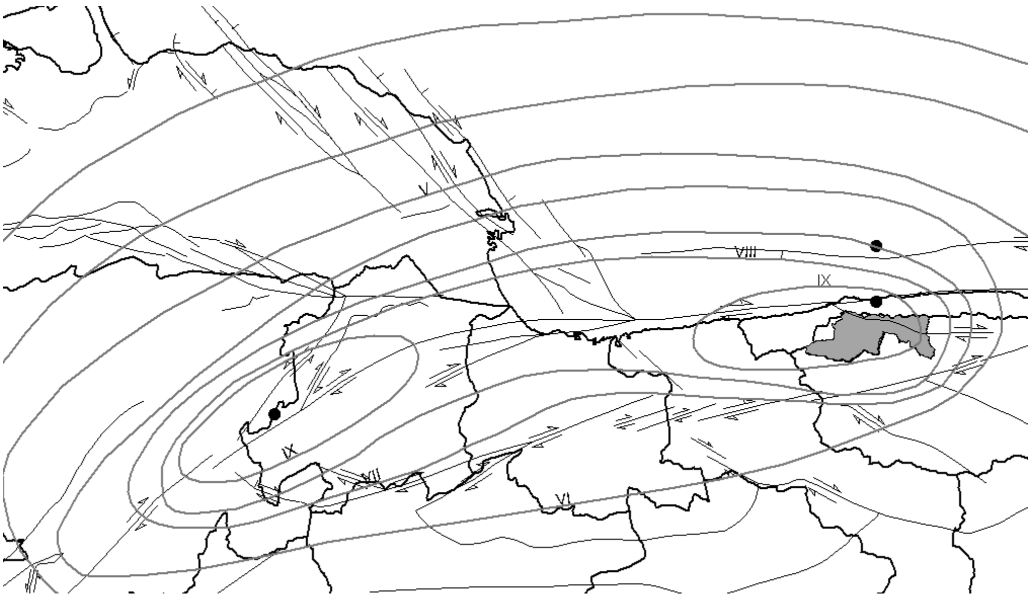


Figure 3.1.3 Isoseismal Map for the 1812 Earthquake (Altez, 2000)

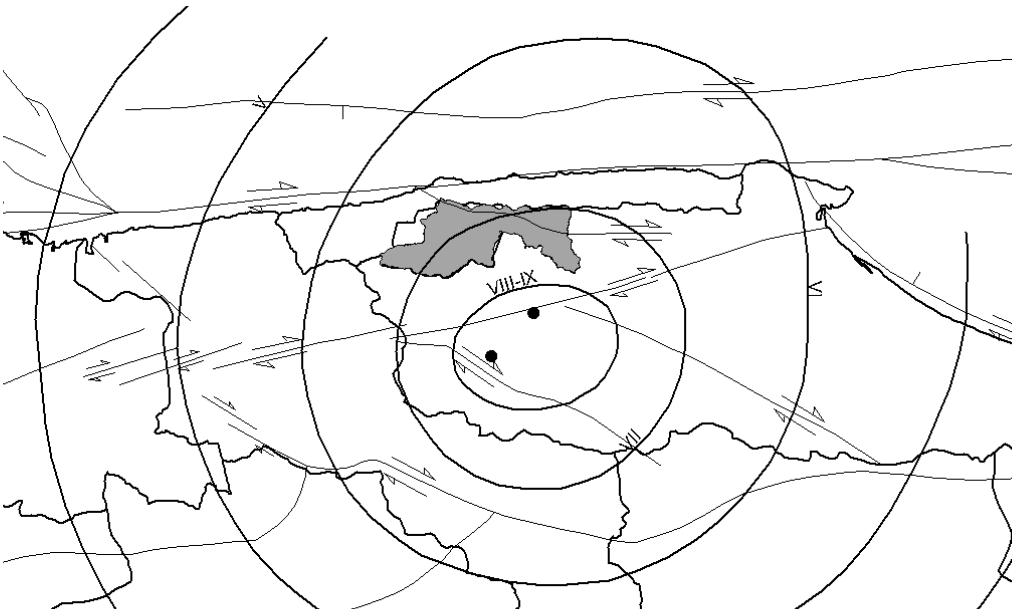


Figure 3.1.4 Isoseismal Map for the 1878 Earthquake (Fiedler, 1961)

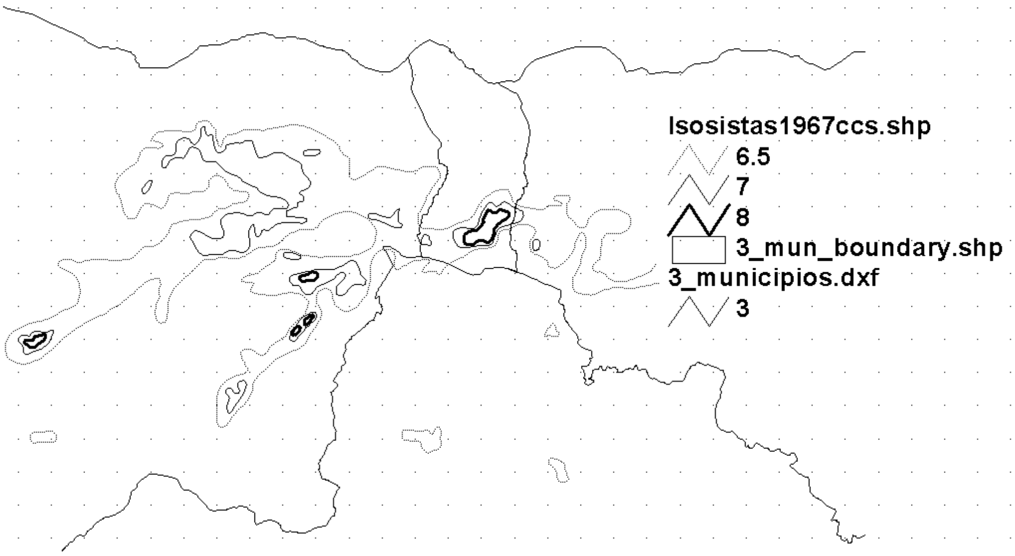


Figure 3.1.5 Isoseismal Map in Caracas for the 1967 Earthquake (Fiedler, 1968)

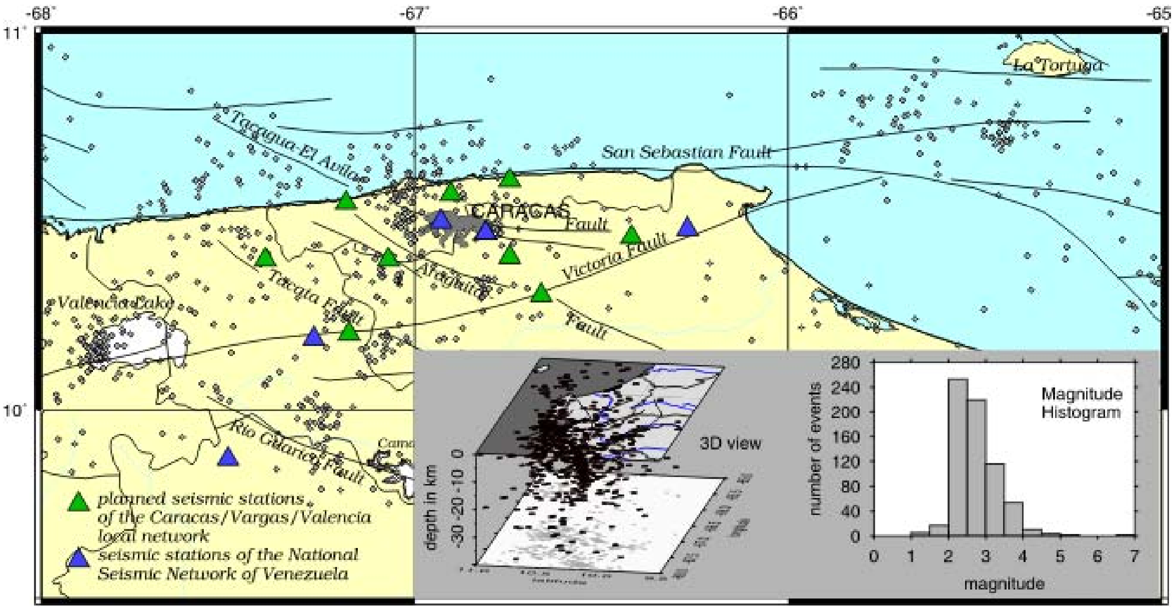


Figure 3.1.6 Seismic Activity in Central Venezuela (Sobiesiak and Romero, 2002)

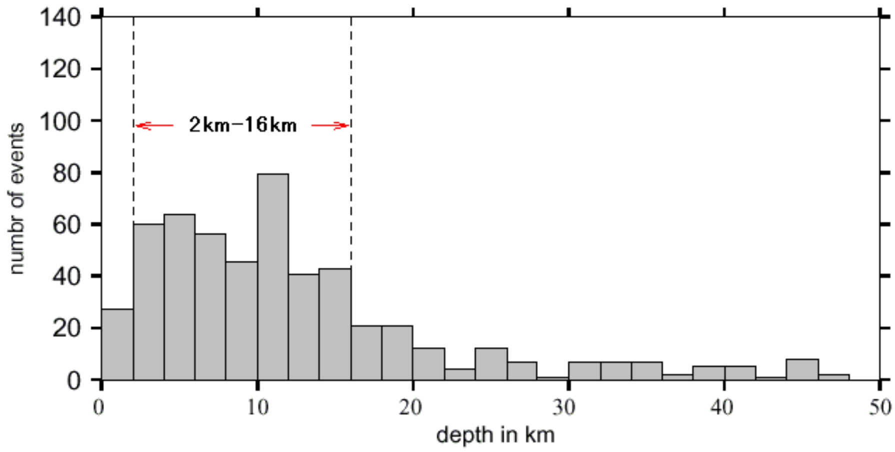


Figure 3.1.7 Depth Histogram of North Central Venezuela 1961-July 2002, Excluding Events with Depth=0, (Sobiesiak, 2003)

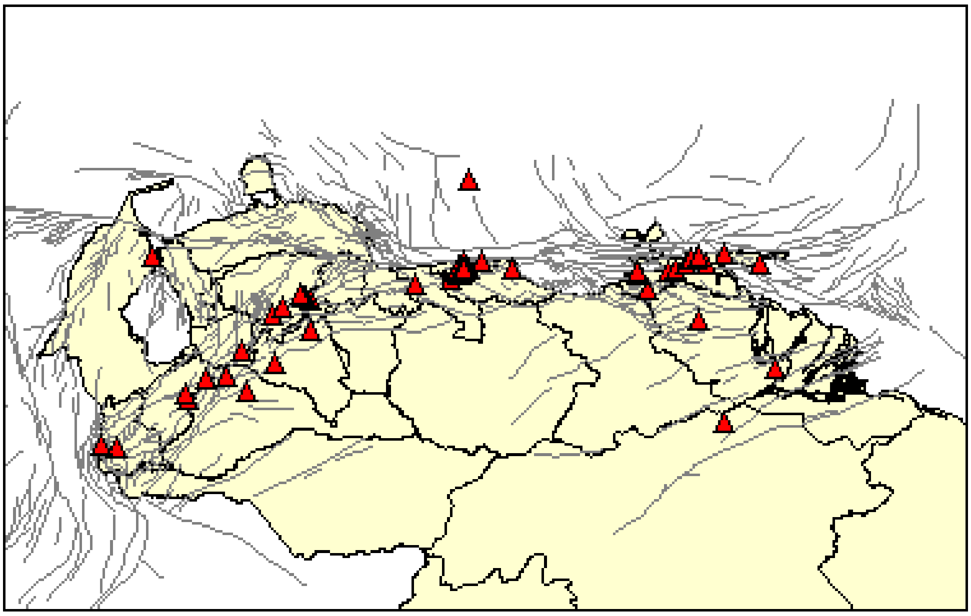


Figure 3.1.8 Accelerograph Stations in Venezuela (FUNVISIS)

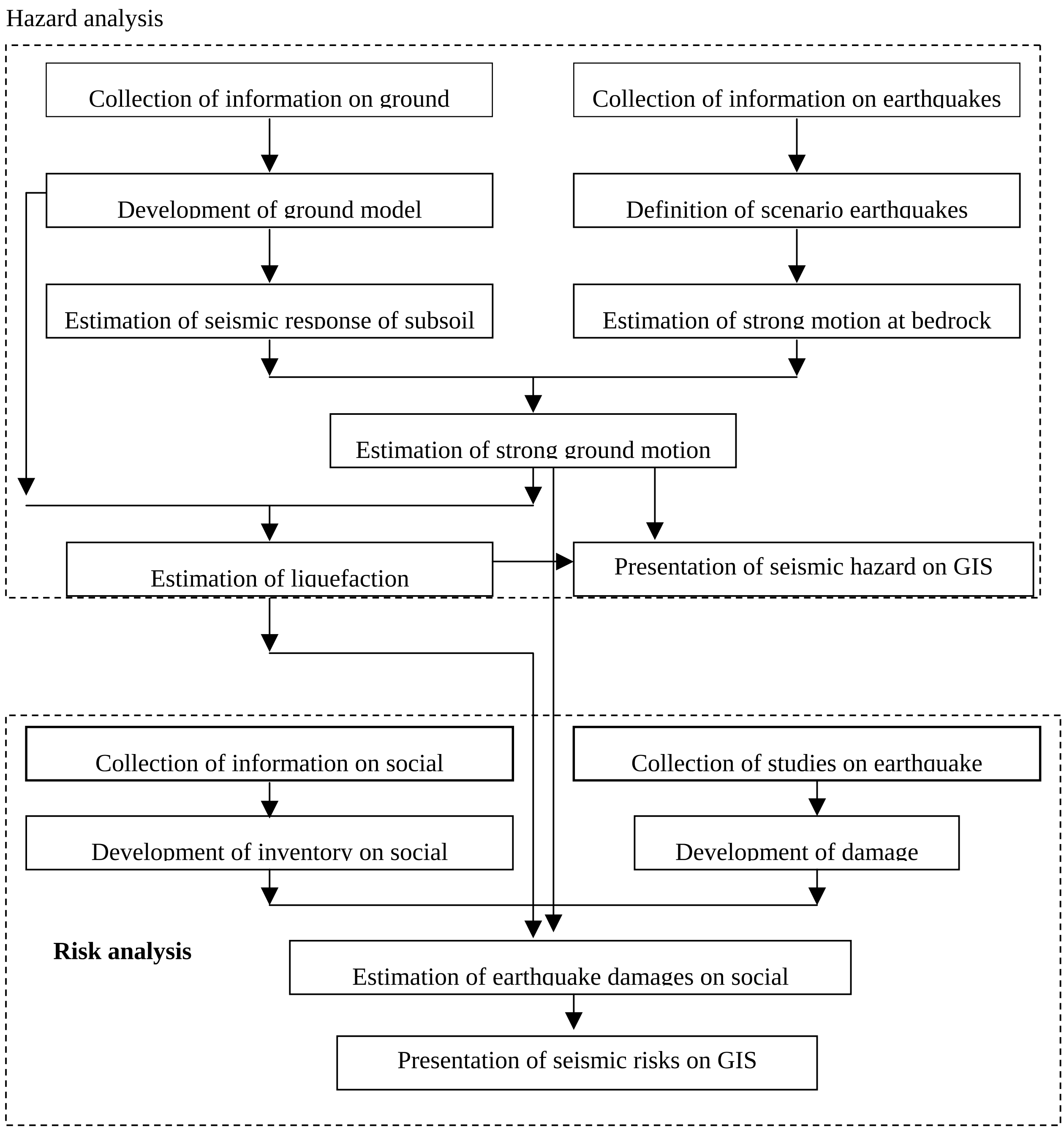


Figure 3.1.9 Flowchart of Seismic Micro Zoning Study

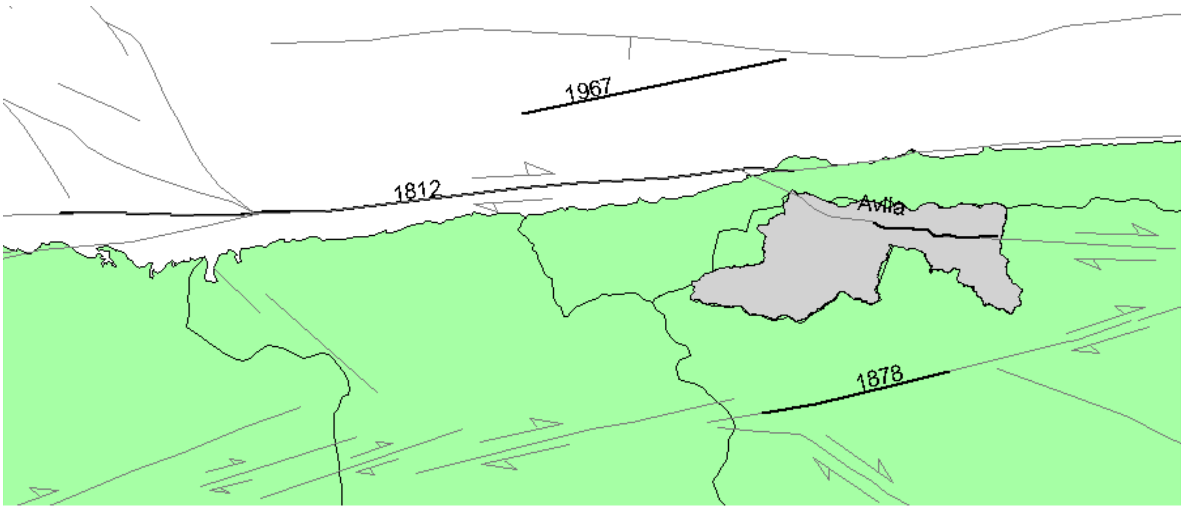


Figure 3.1.10 Locations of Faults for Scenario Earthquake

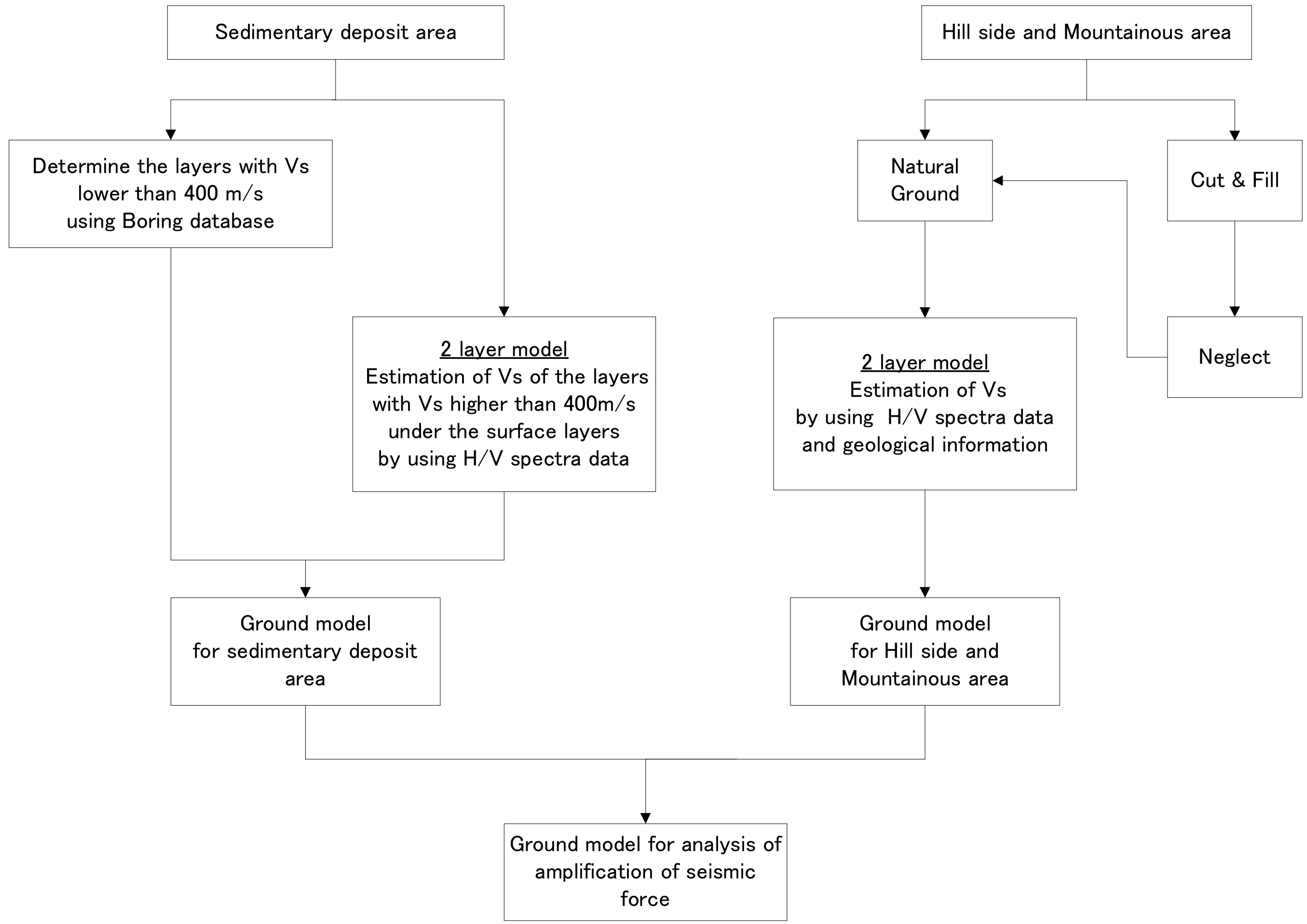


Figure 3.1.11 Outline of Development of Ground Model for Amplification of Seismic Force

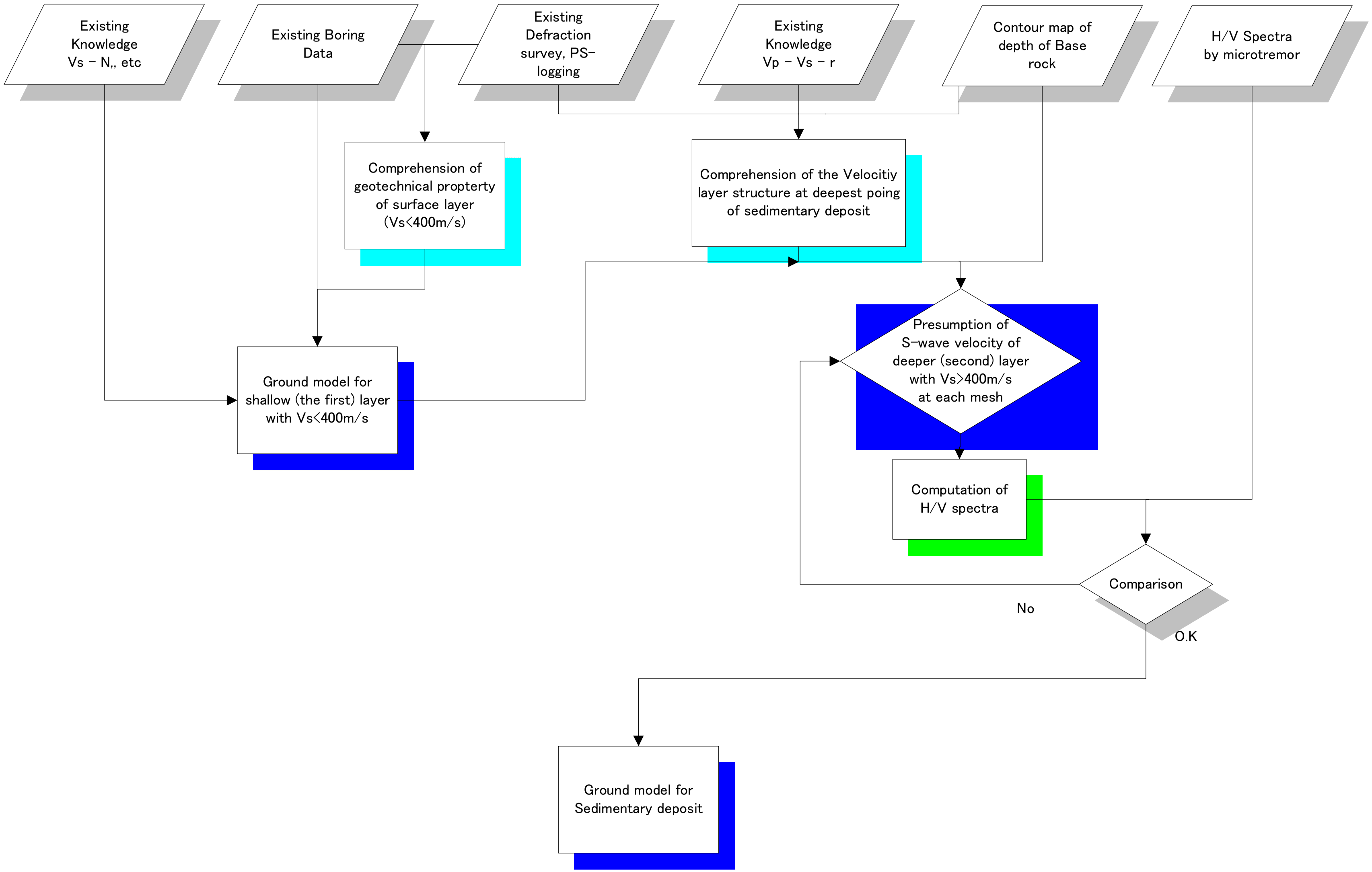


Figure 3.1.12 Precise Flow of Development of Ground Model for Amplification of Seismic Force

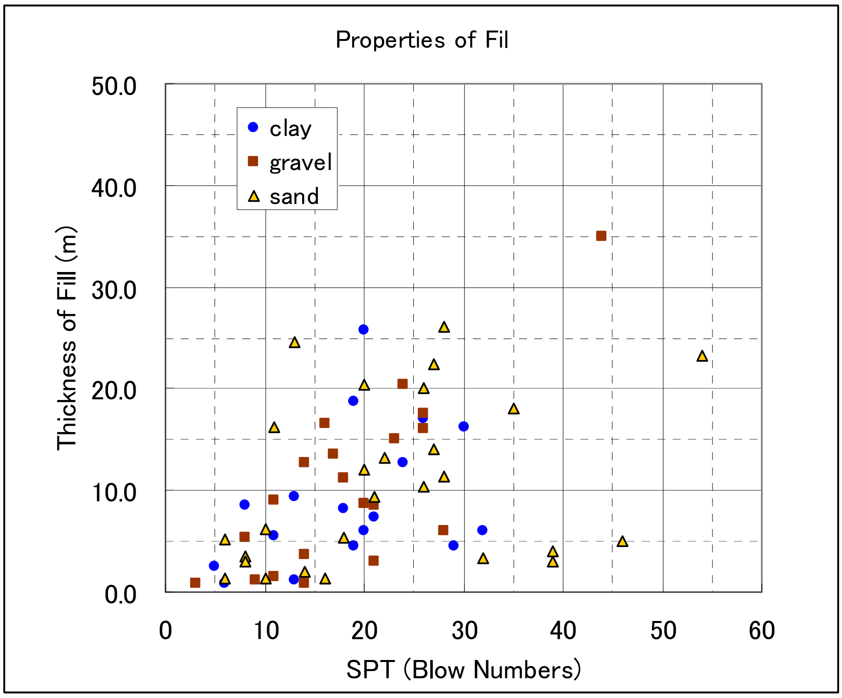


Figure 3.1.13 The Degree of Compaction of Fills

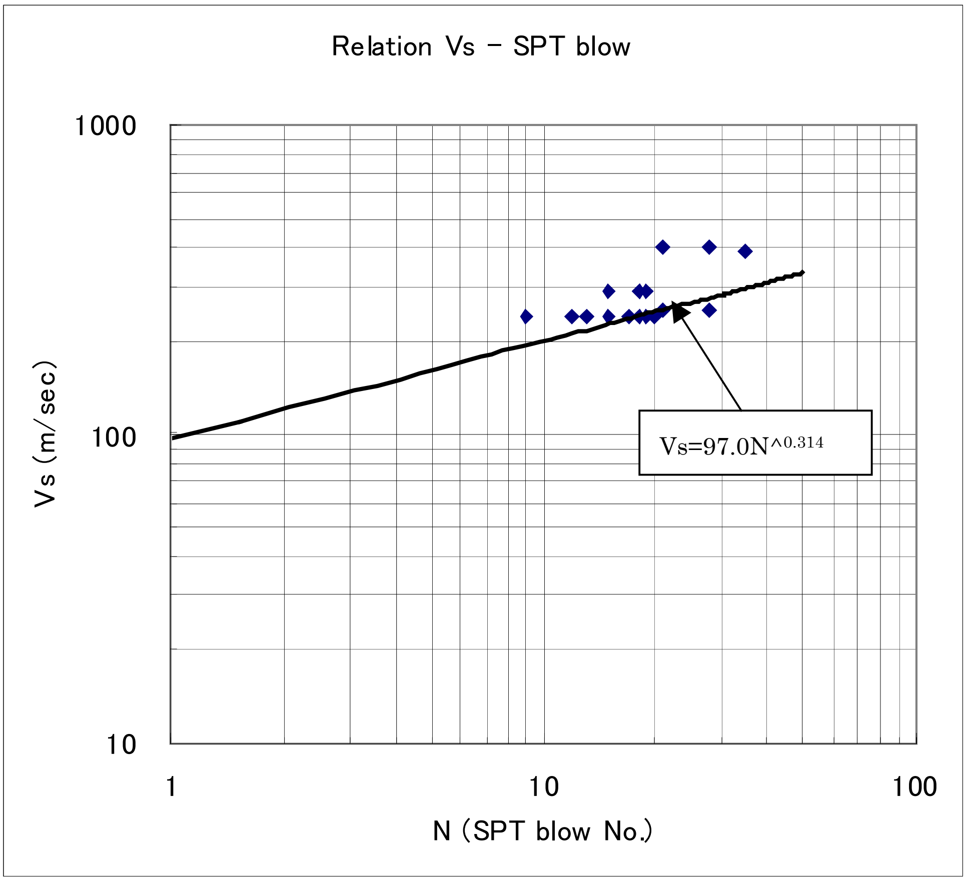


Figure 3.1.14 Relation Between Vs and SPT Blow Numbers

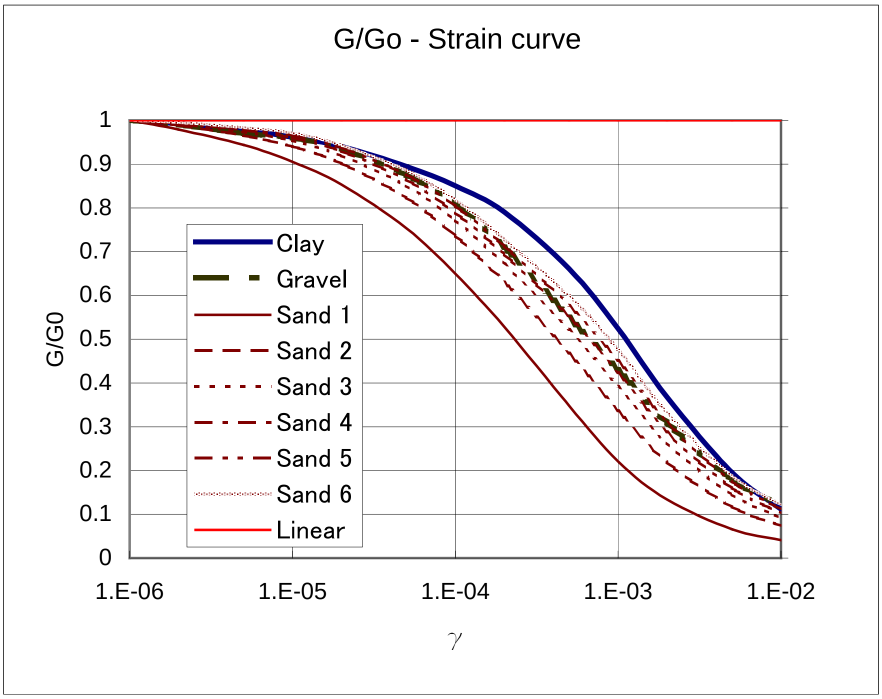


Figure 3.1.15 Normalized Shear Modulus

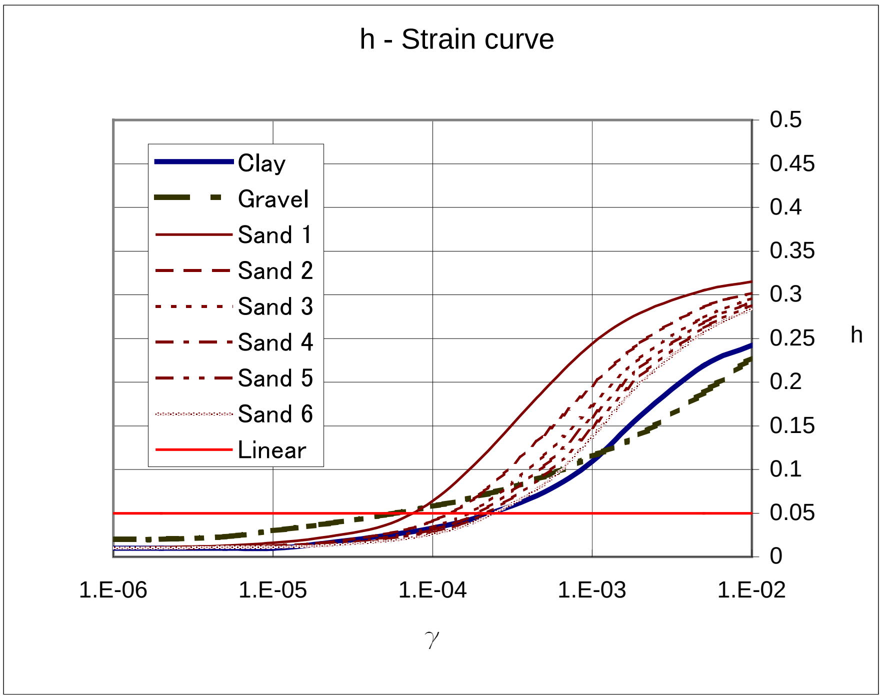


Figure 3.1.16 Dumping Factors

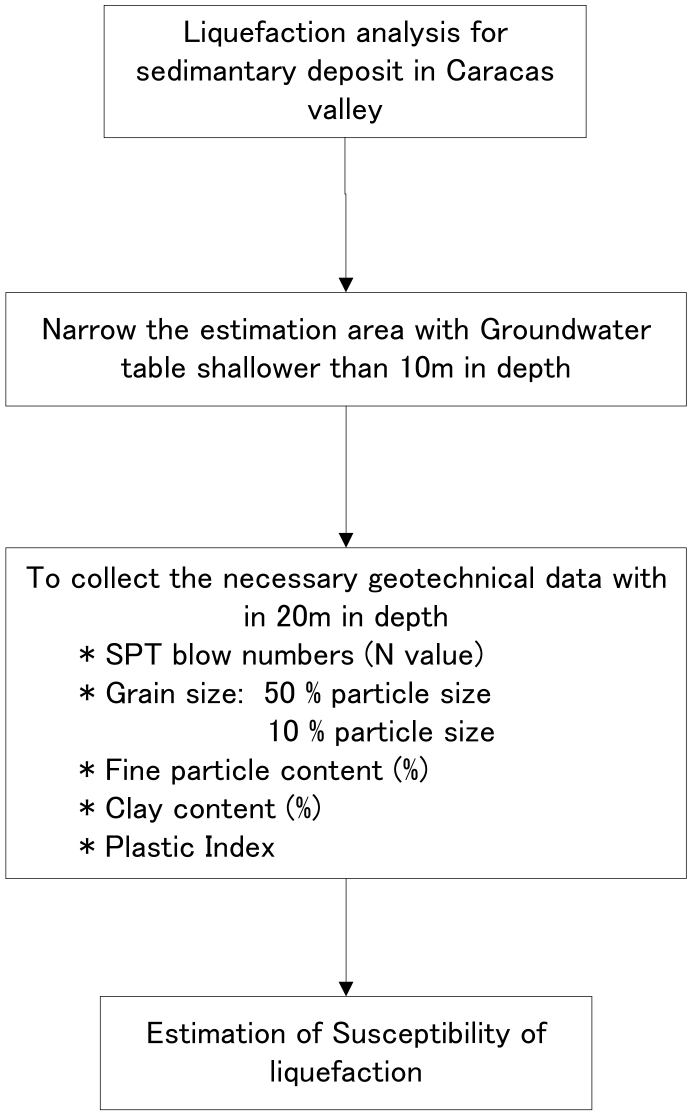


Figure 3.1.17 Flow of Estimation on Liquefaction Susceptibility

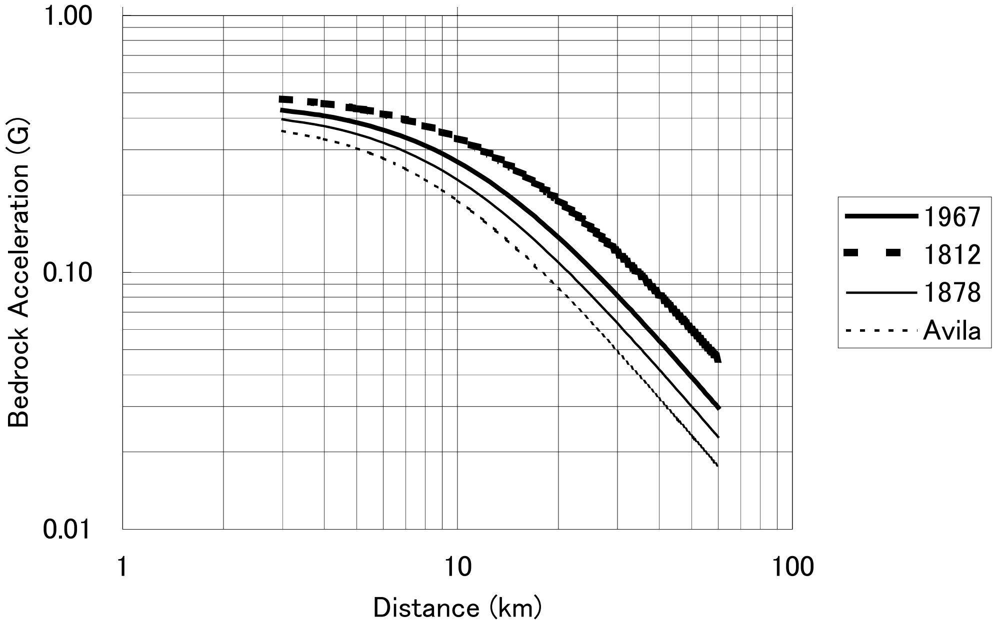


Figure 3.1.18 Attenuation of Bedrock Acceleration for Scenario Earthquakes (Campbell, 1997)

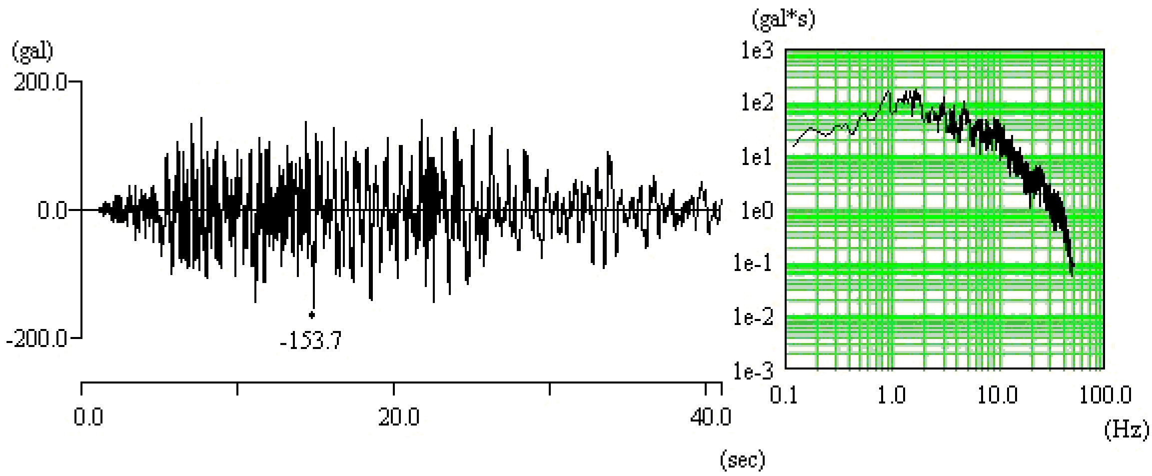


Figure 3.1.19 Input Accelerogram Used for the 1967 Earthquake (PEER)

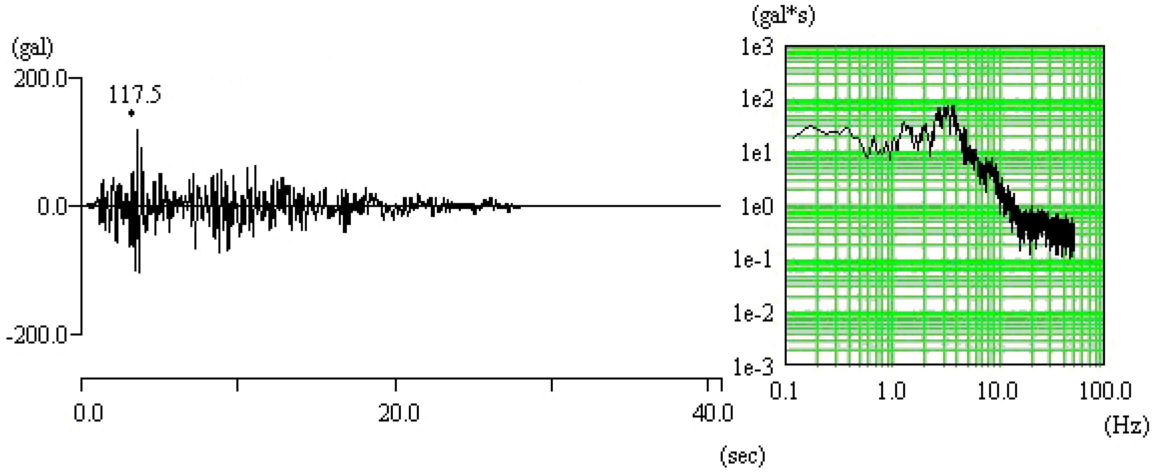


Figure 3.1.20 Input Accelerogram Used for the 1812 Earthquake (PEER)

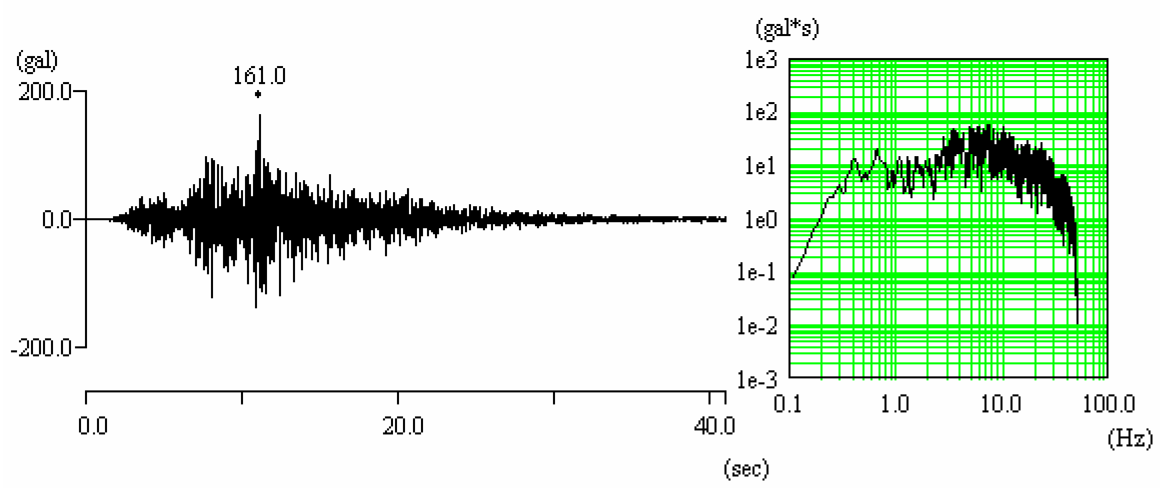


Figure 3.1.21 Input Accelerogram Used for the 1878 Earthquake (COSMOS)

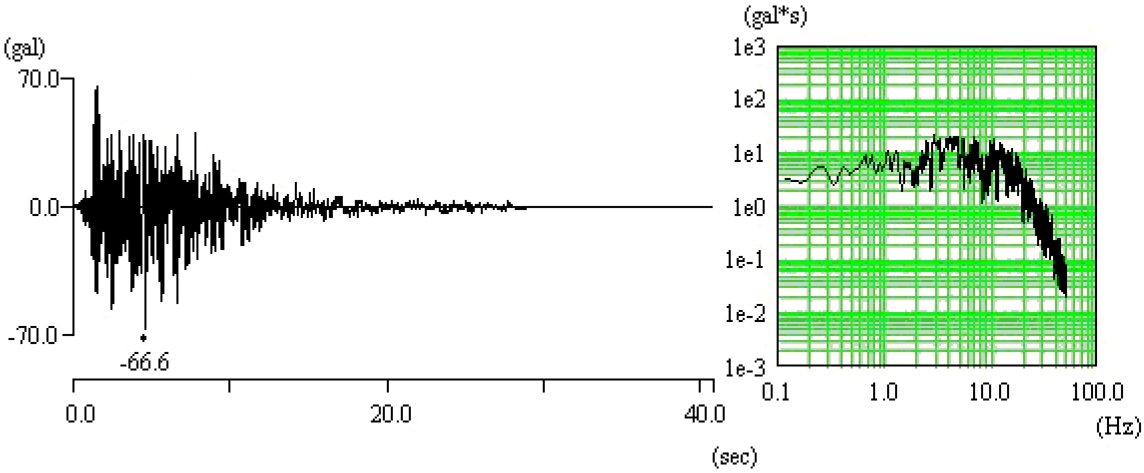


Figure 3.1.22　Input Accelerogram Used for the Hypothetical Avila Earthquake (PEER)

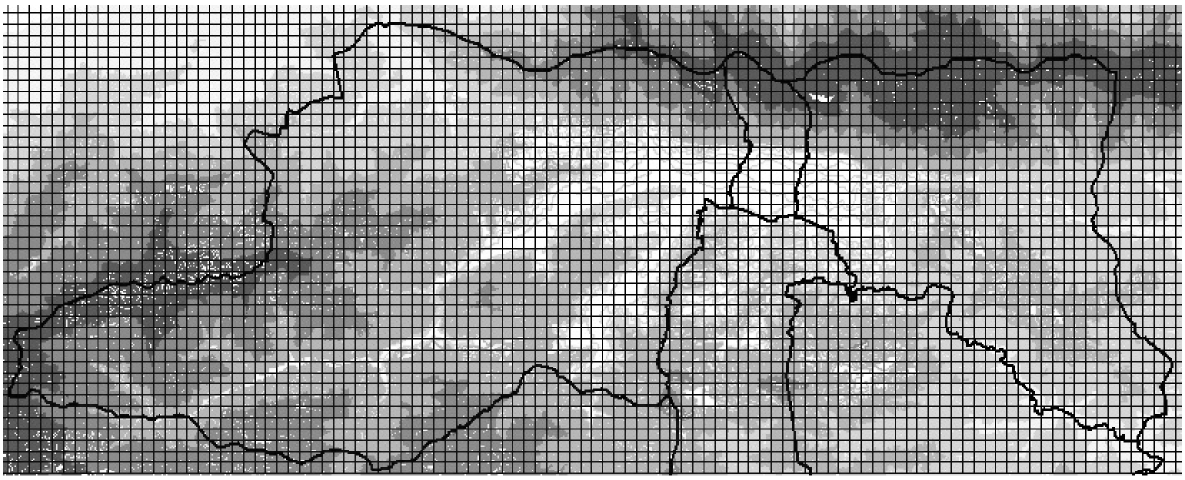


Figure 3.1.23　Mesh Systems for Seismic Hazard Analysis

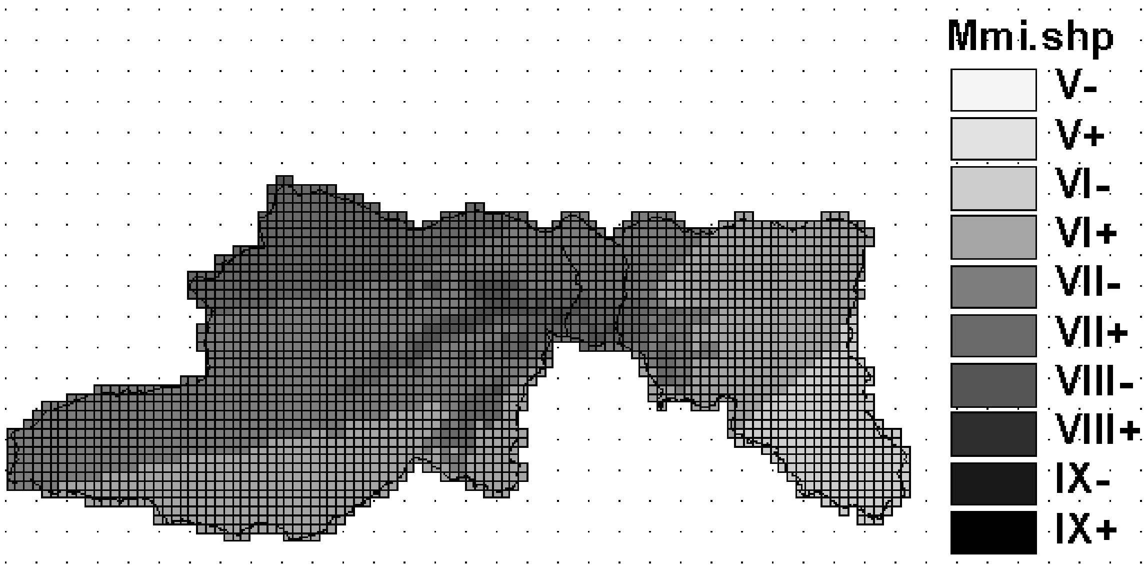


Figure 3.1.24 Estimated Seismic Intensity for the 1967 Earthquake

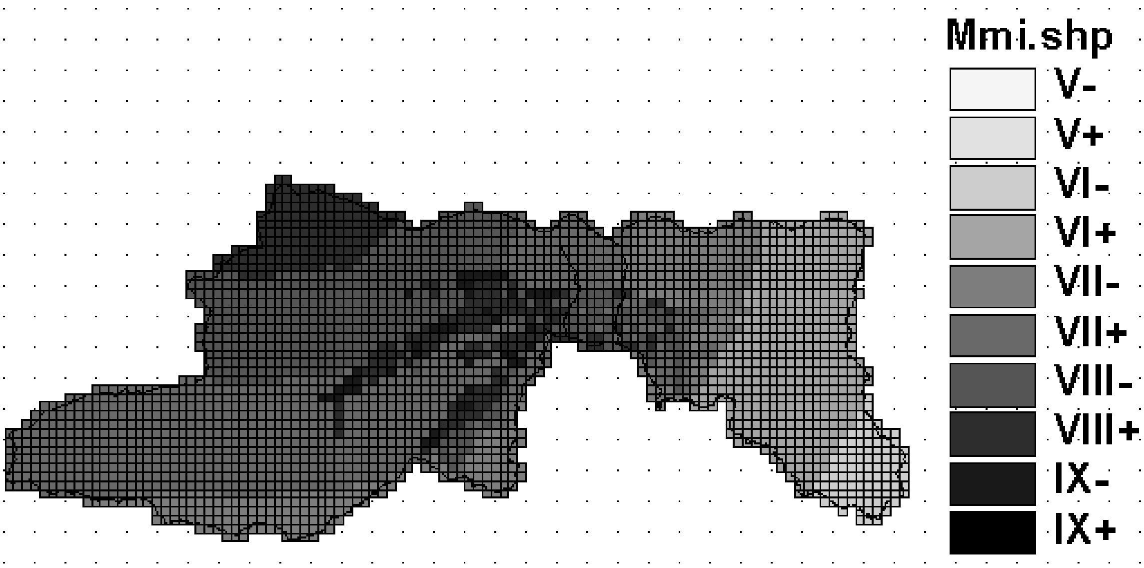


Figure 3.1.25 Estimated Seismic Intensity for the 1812 Earthquake

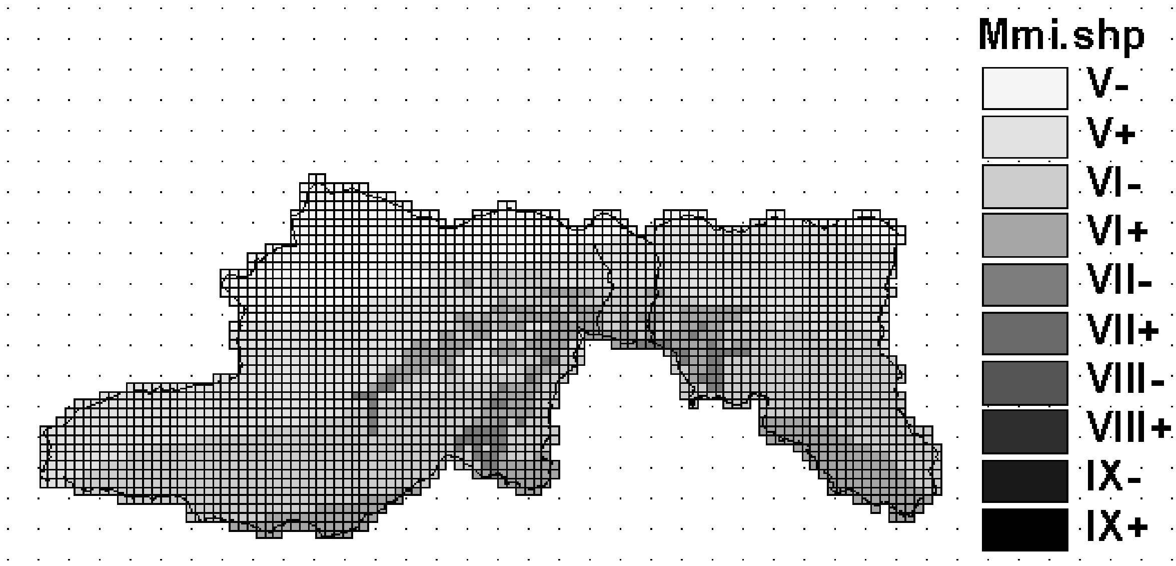


Figure 3.1.26 Estimated Seismic Intensity for the 1878 Earthquake

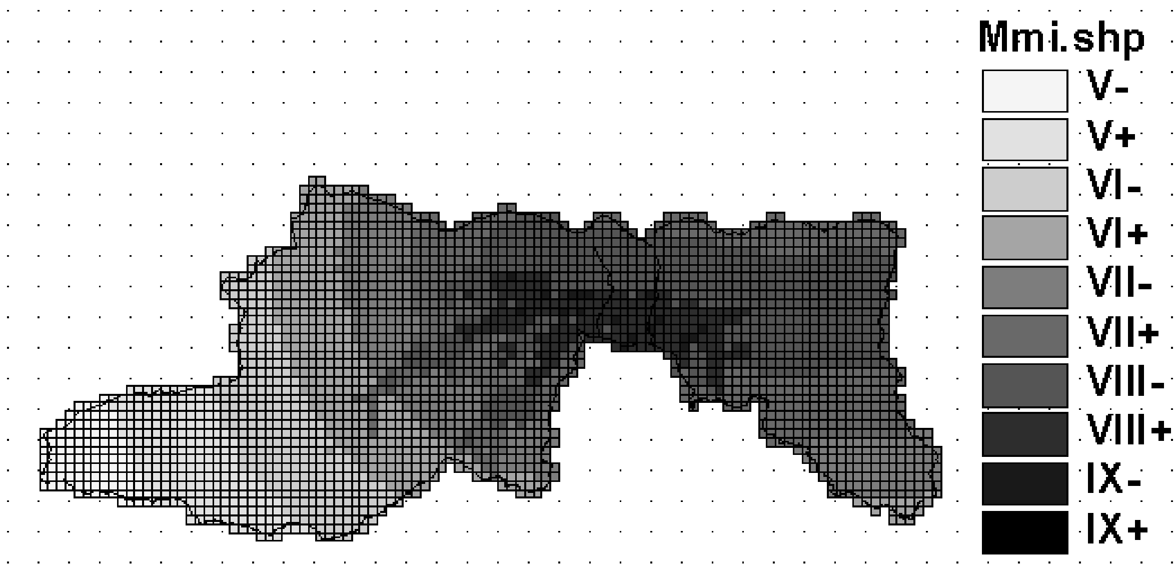


Figure 3.1.27 Estimated Seismic Intensity for Hypothetical Avila Earthquake

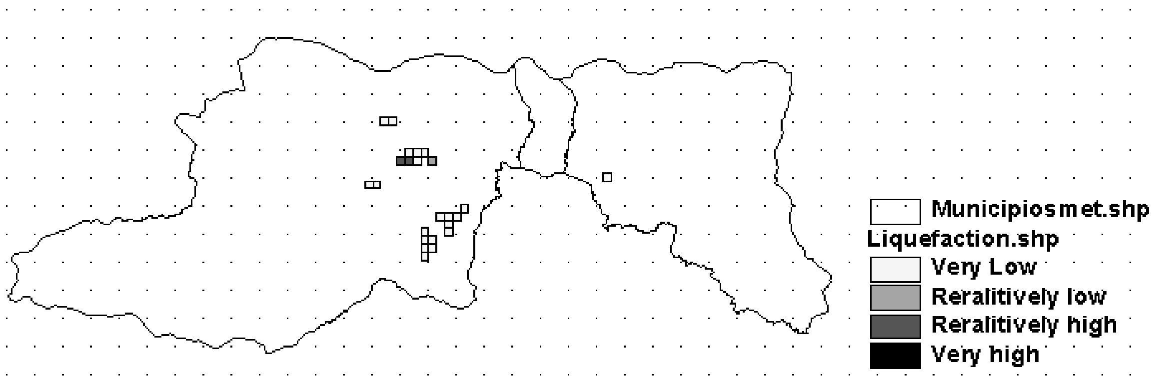


Figure 3.1.28 Estimated Liquefaction Susceptibility for the 1967 Earthquake

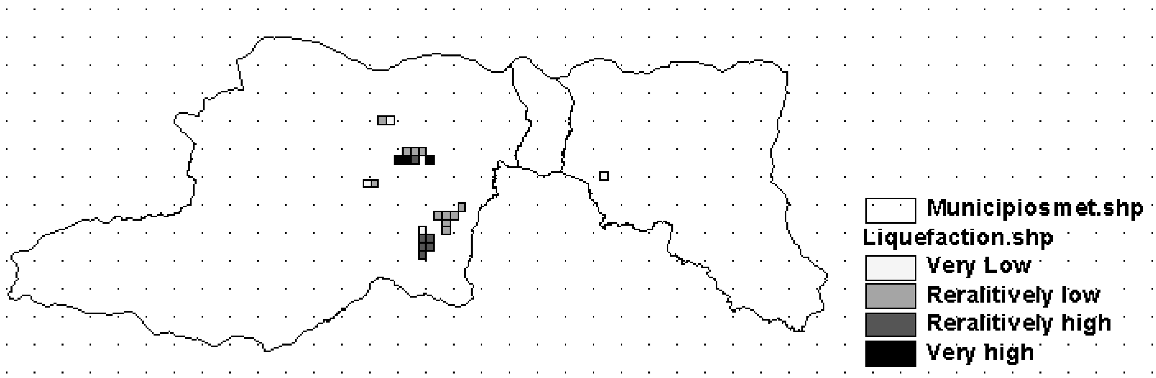


Figure 3.1.29 Estimated Liquefaction Susceptibility for the 1812 Earthquake

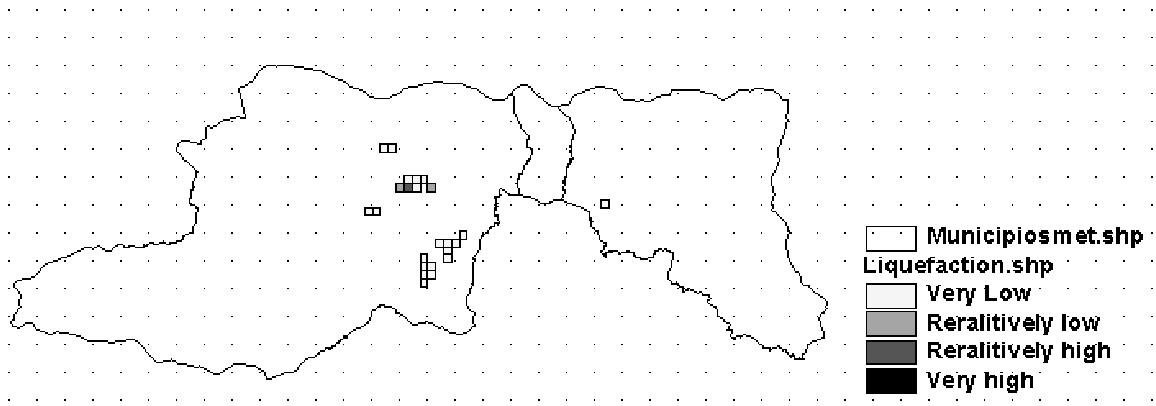


Figure 3.1.30 Estimated Liquefaction Susceptibility for the 1878 Earthquake

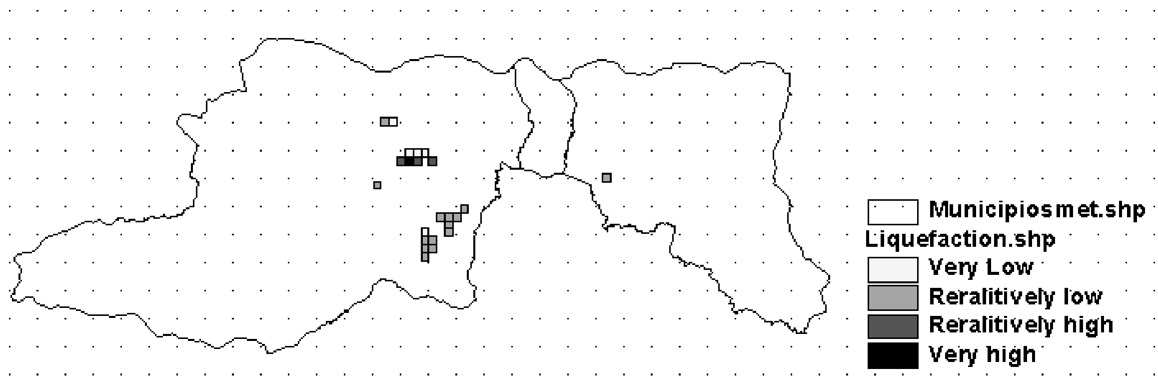


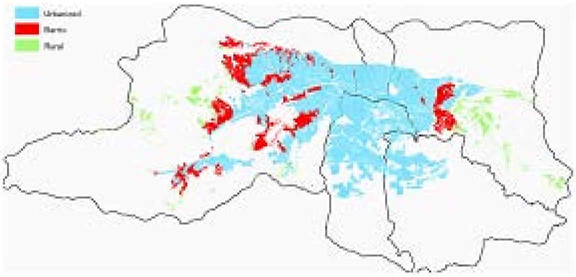
Figure 3.1.31 Estimated Liquefaction Susceptibility for Hypothetical Avila Earthquake

Basic Concept

The study area is divided into urbanized area and barrio & rural area.
The frameworks of inventory is different between
the two kinds of area.

The Study Area

Urbanized Area | **Barrio & Rural Area**

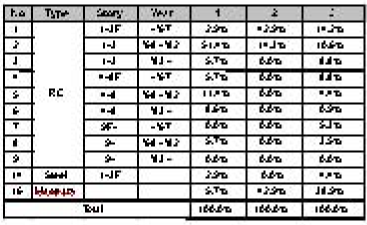


Urbanized Area

The unit is the block. A block has several types of buildings. Therefore, building numbers of each category in a block are estimated for urbanized area. The urbanized area is divided into 30 sub-areas according to the character of building in the area. An field sampling survey was conducted to estimate the ratio.

Total building number of block × **Ratio of each category** ⇒ **Building Number of each category**

The total number of building in a block is counted by GIS.



The field sample survey result is summarized by sub-zone.

Barrio and Rural area

The building category of barrio and rural area is simple. An area has only one category. Therefore, the inventory of barrio and rural area is the number of building in an area.

In Base map area

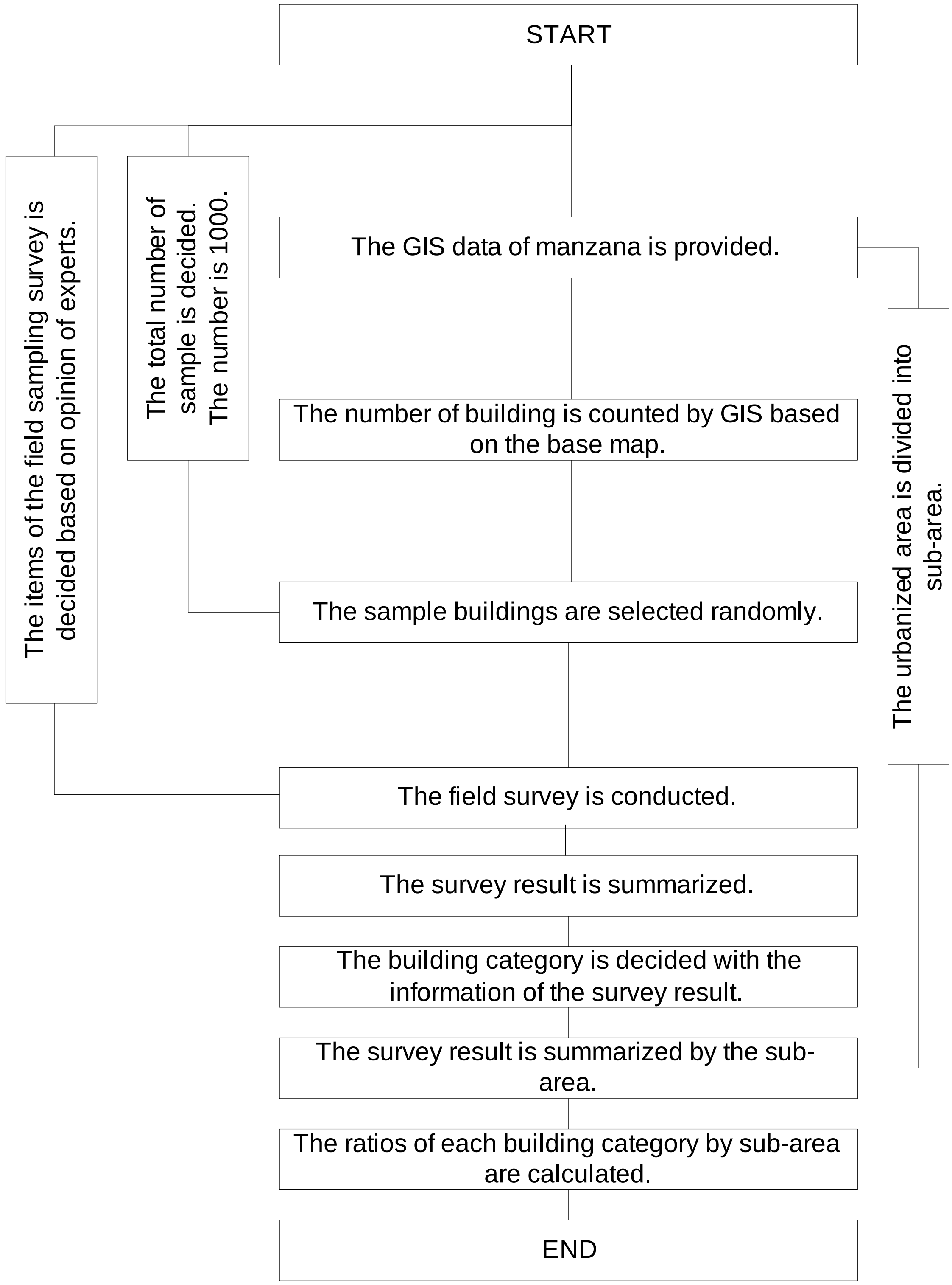
Same as the urbanized area. The number of buildings in a area is counted by using based on the base map.

Out of Base map area

The number of buildings in a area is counted by using GIS based on the aerial photo.

Source: The JICA Study Team

Figure 3.2.1 Concept of Inventory Establishment



Source: The JICA Study Team

Figure 3.2.2 Flow Chart of Building Inventory for Urbanized Area

Building Survey Form

Date: Time: Surveyor:

Building Name:

Manzana ID Building ID

Address:

☐Libertador ☐Chacao ☐Sucre

Land Use Zoning: ☐Residential Zone (1-2) ☐Residential Zone (3-)
☐Commercial Zone ☐Industrial Zone

Number of family ________(Apartment House only)

Building Criteria: ☐Dwelling House ☐Apartment House ☐School ☐University

☐Office Building ☐Governmental Offic ☐Hospital ☐Fire Station

☐Commercial Building ☐Hotel ☐Church ☐Factory ☐Gymnasium

☐Other ________________

Construction Type: ☐Prefabrication Reinforced Concrete (R.C.) Structure

☐R. C. Structure ☐R.C.Shear Wall without Moment Frame

☐Steel Structure ☐Adobe or Stone

Year of Completion: ☐Before 1955 ☐1955-67 ☐1968-82 ☐After 1983
(Building age: Years Month)

Number of family ________(Apartment House only)

Number of Stories: ☐ 1 ☐2 ☐3 ☐4 ☐5 ☐ 6～8 ☐9～14 ☐Over 15

Nos. of Basement Floor: ☐None ☐1 ☐ 2 ☐ 3 ☐ 4

Number of Penthouse: ☐None ☐1 ☐ 2 ☐ 3 ☐ 4
(Small projection on roof)

Site Area: ________ sqm

Building Area: ________ sqm Total Floor Area: ________ sqm

Structural Height: Total Height ________ m (Exclude Penthouse)

Plan Irregularity ☐"H" shape ☐"L" shape ☐"U" shape ☐"E" shape ☐"T" shape

Vertical Irregularity ☐Major setbacks ☐Major cantilevers ☐Pilotis

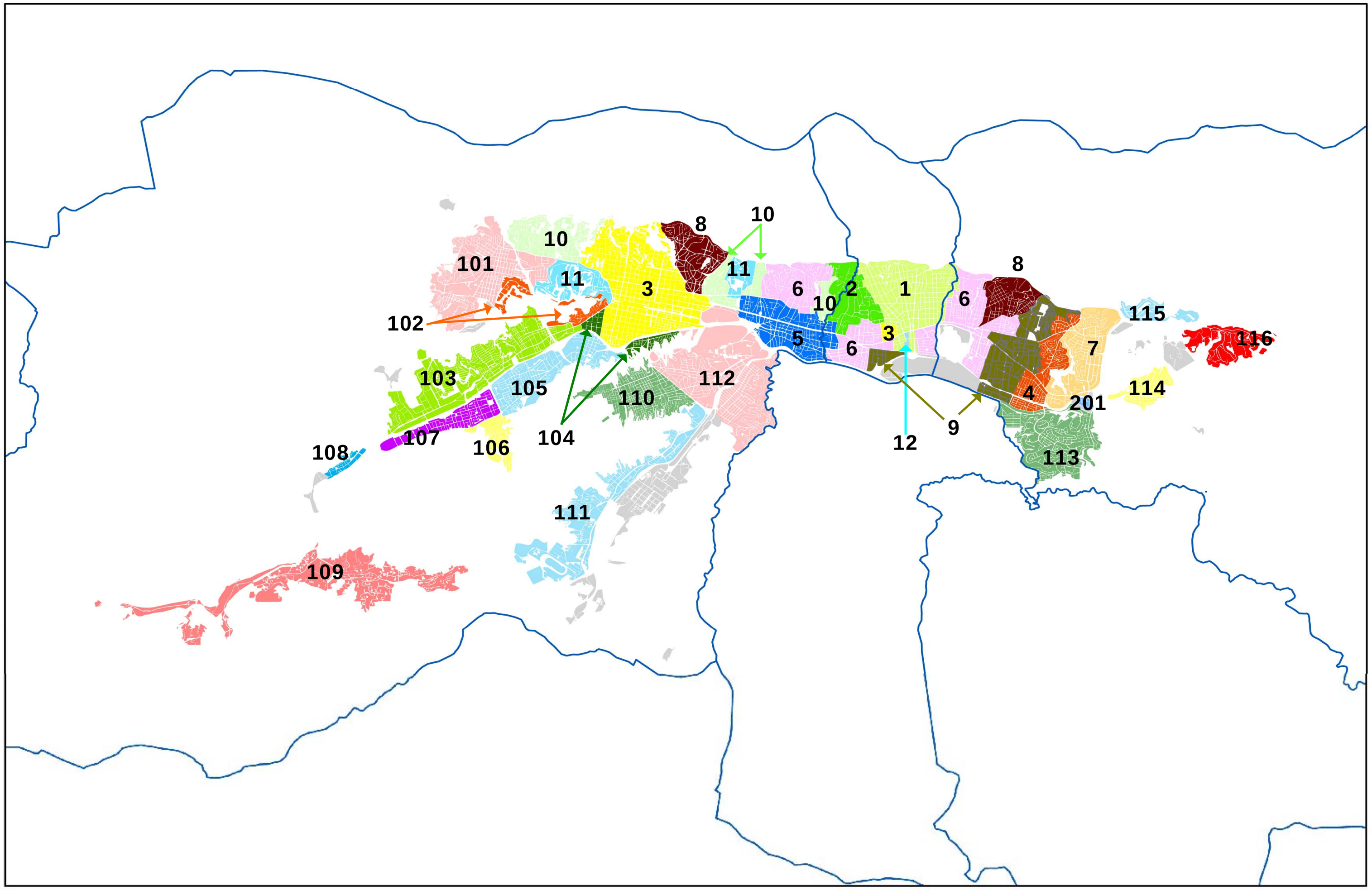
♦ over ♦5 ☐Building on hill ☐Building on slope ☐Building at hill bottom

Pounding ☐No problem ☐Problem observed (☐Wall ☐Slab ☐Column)

Note : The information of in this hattecd area is for refarence.

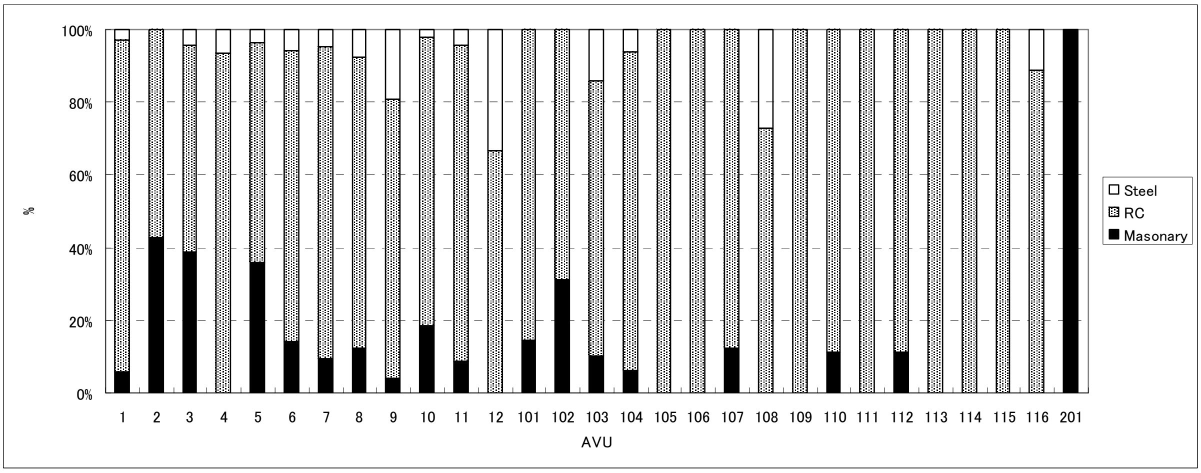
Source: The JICA Study Team

Figure 3.2.3 Building Survey Form



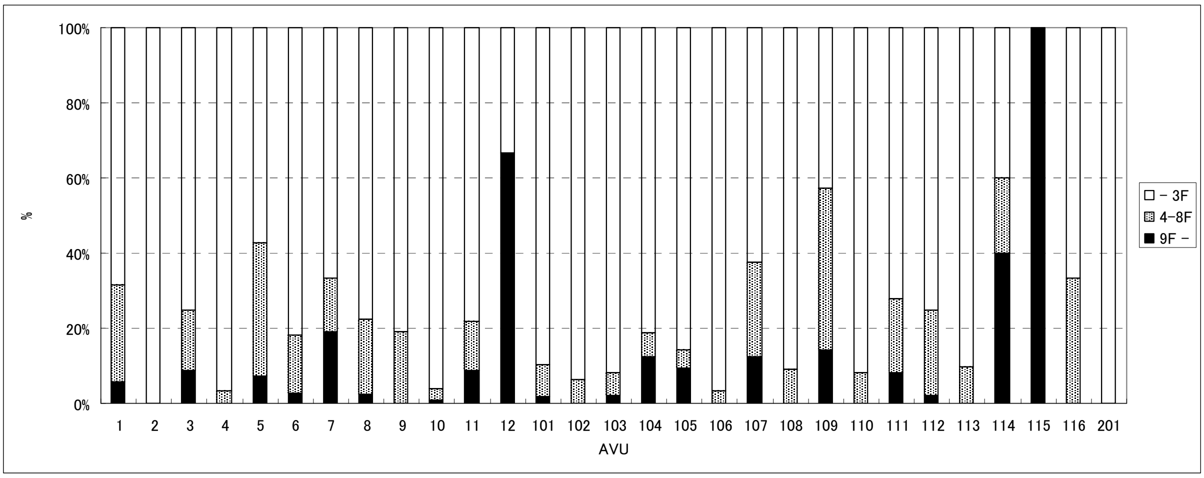
Source: The JICA Study Team

Figure 3.2.4 Physical Analyzed Vulnerability Unit (AVU)



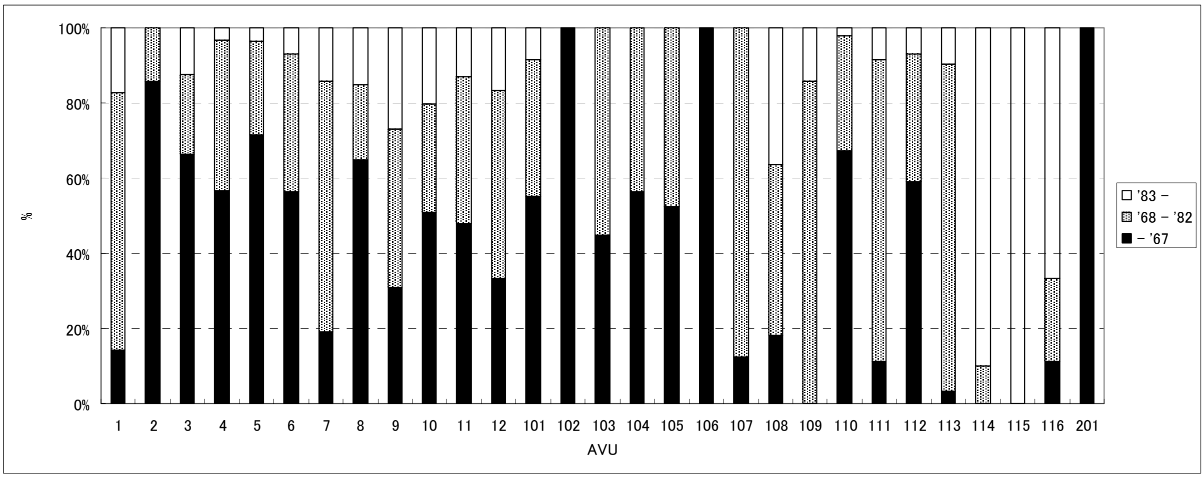
Source: The JICA Study Team

Figure 3.2.5 Field Survey Result (Summarized by Structure Type and AVU)



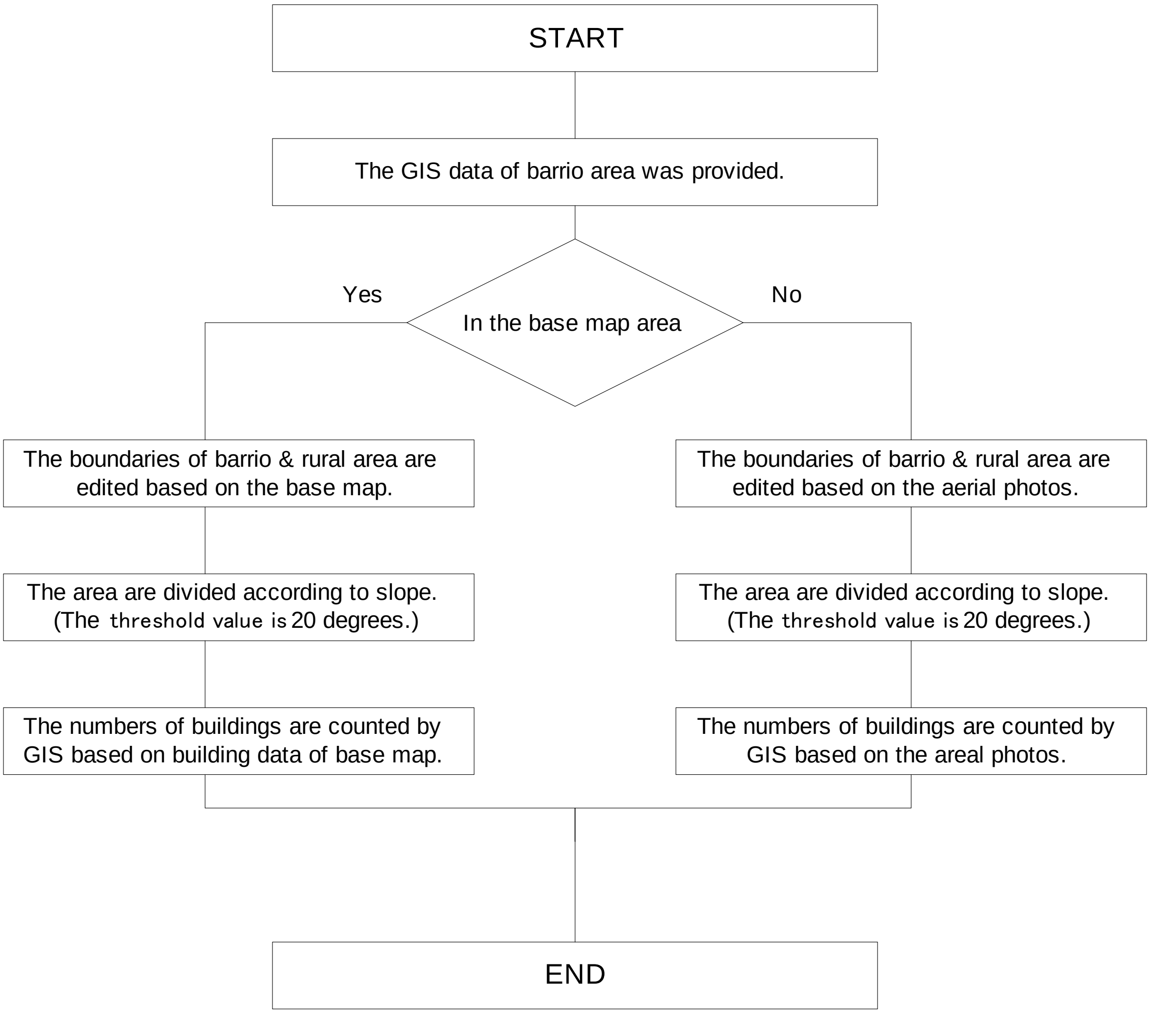
Source: The JICA Study Team

Figure 3.2.6 Field Survey Result (Summarized by Story and AVU)



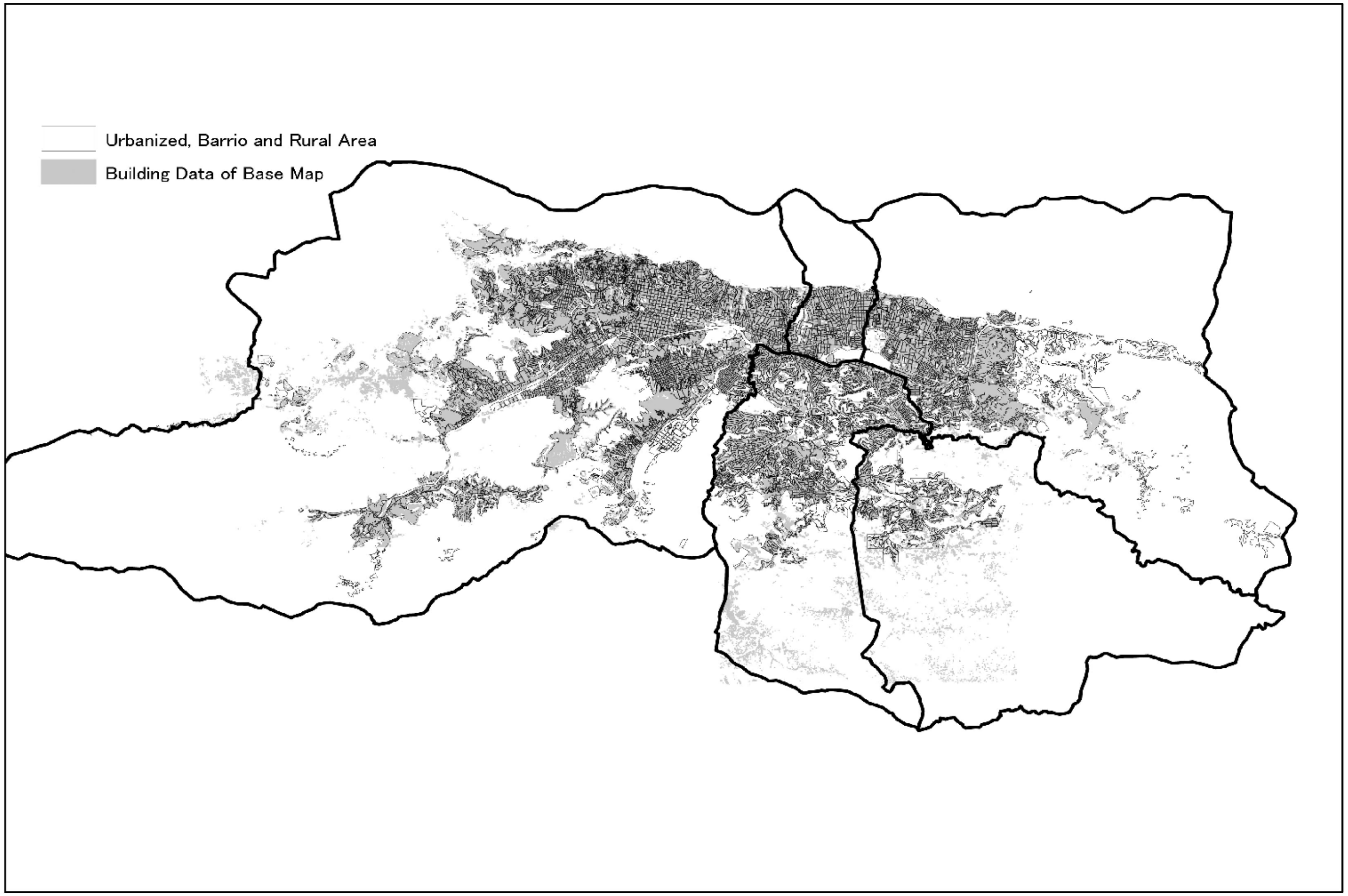
Source: The JICA Study Team

Figure 3.2.7 Field Survey Result (Summarized by Constructed Year and AVU)



Source: The JICA Study Team

Figure 3.2.8 Flowchart of Building Inventory for Barrio and Rural Area



Source: The JICA Study Team

Figure 3.2.9 Area of Working Map (Scale 1/5 000)