

Table 4.2.7 Criteria for Liquefaction Evaluation used in this Study

Seismic Intensity (MMI)	Area		
	Liquefiable area defined by boring data	Zone 5	Others
VIII or more	Highly Probable	Probable	None

Source: JICA Study Team

The result of the evaluation is as follows and is presented in Figure 4.2.11.

Case-1: La Cajita Fault

Probable liquefiable area appears to be in the newly defined liquefiable area, and possible liquefiable area appears to be in zone 5.

Case-2: Guayuriba Fault

Probable liquefiable area appears to be in most of the newly defined liquefiable area, and possible liquefiable area appears to be in zone 5.

Case-3: Subduction event

No possible liquefaction area is defined due to the low seismic intensity in the area for liquefaction area.

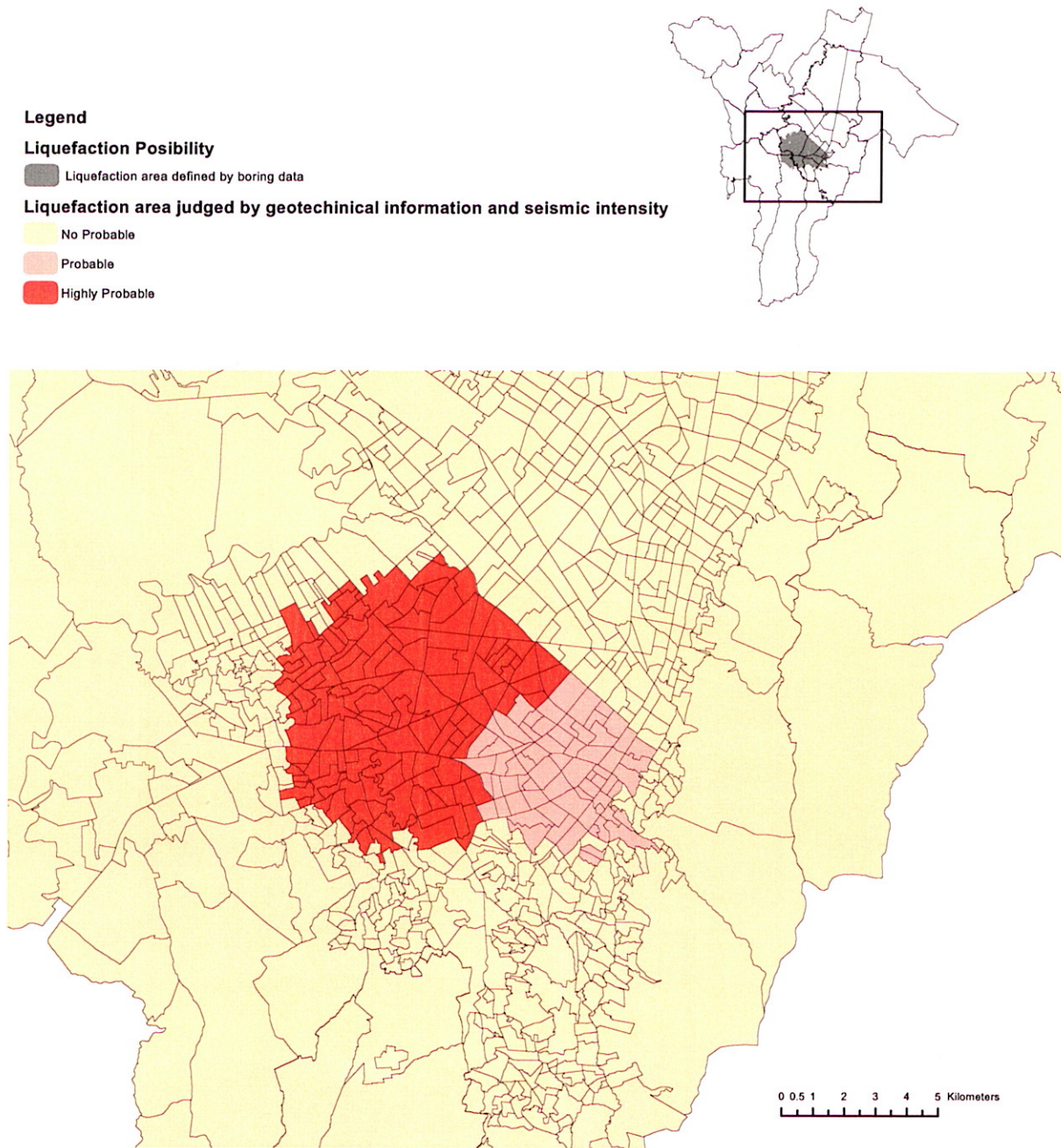


Figure 4.2.11

Liquefaction Potential Area

(4) Collected data for estimation

A. Building data

In this study, the building inventory database was prepared based on 2000 cadastral data. In Bogotá City, cadastral data are collected at the Bogotá cadastral office, while Cundinamarca data are prepared by IGAC office, which is the agency responsible for cadastral data collection in Cundinamarca. The flow chart of database preparation is shown in the following Figure 4.2.12.

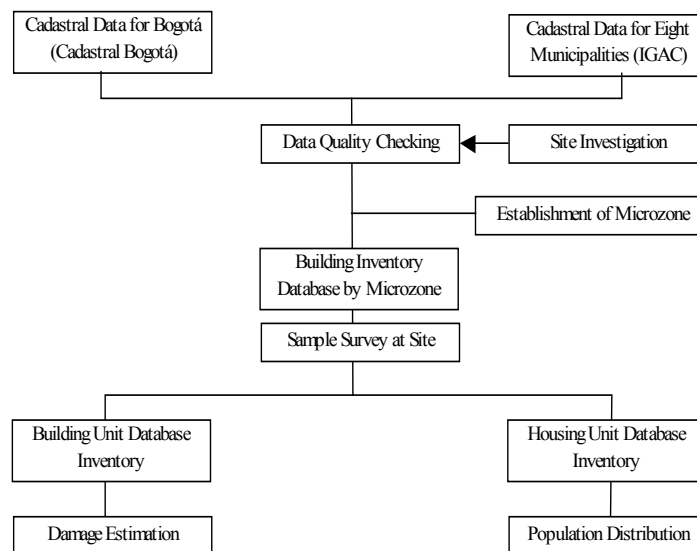


Figure 4.2.12 Building and Housing Unit Database Construction Process

The cadastral data of Bogotá City contain two types of information:

- Non-horizontal property data, which pertain to normal buildings.
- Horizontal property data, which are high-rise building data.

The non-horizontal property data (NHP) have 901,600 records, which include houses, lots and other establishments. Similarly, the horizontal property (PH) data has 49,901 representing units which represents 858,464 apartments units.

The horizontal property data are represented as follows:

- Representative and Representing apartment per building.
- Data of the summary of building complex.

For non-horizontal property, the number of houses is counted for each *manzana* and the number of housing units and number of buildings in each *manzana* are counted.

Cadastral data of Cundinamarca are collected from IGAC office. Their data comprise horizontal property and non-horizontal property of all eight municipalities. Similar analysis is carried out for the Cundinamarca data.

Table 4.2.8 Original Distribution of Records in the Database

Area	NPH records	PH records
Bogotá	901,600	49,901 Representing
		858,464 Represented
Eight Municipalities	148,610	6,000

In order to verify the reliability of the cadastral data, the Study Team carried out field surveys to match cadastral data and exact housing units at site. The Study Team selected randomly more than 300 samples from the whole Study Area. The field survey found that the cadastral data is reliable, except for the year of construction and number of stories in Bogotá. Cadastral data in Bogotá City shows that more than 90% has the year of construction as 1999 and the number of stories as a negative figure and huge figures like more than 70 stories. The Study Team could not use this data for analysis.

The Study Team found that there are few building units without data for the structure. This oversight was corrected based on the *manzana* data.

The number of buildings in each locality and municipality is shown as follows:

Table 4.2.9 Summary of Buildings in the Study Area

Area	Number of Buildings
Bogotá	752,063
Eight Municipalities	127,561
Total	879,624

B. Population data

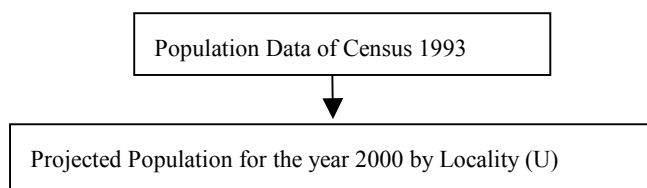
Population distributions for Bogotá and the other municipalities were done separately because of the availability of data in each area.

The population data for Bogotá are established based on the projection of the population for locality for the year 2000. This is done in three stages:

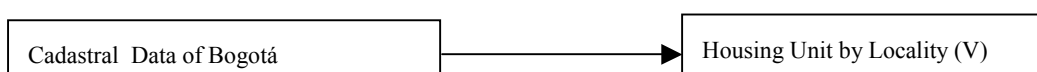
- Population Projection: The population of census 1993 by locality of Bogotá is projected for the year 2000 by the planning department of Bogotá. In the present study, these data are used.
- Housing Units Estimation: Using the cadastral data of Bogotá, housing units in microzones were estimated. These data were later grouped for each locality in Bogotá.
- Distribution of Population in Microzone: Once housing units were determined for each locality, number of residents in each housing unit was established for each locality.

This factor was used to determine the population in each microzone. The process is schematically shown in the next page.

1. Population Projection



2. Housing Units Estimation



3. Population Estimation by Microzone

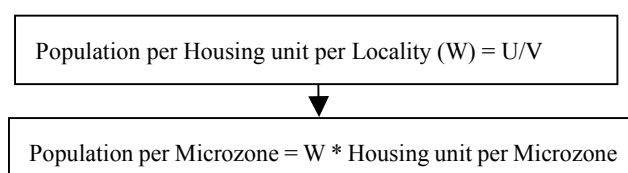


Figure 4.2.13 Population Projection Procedure

For eight municipalities, DANE data was obtained for rural and urban areas. For each microzone, housing units are estimated based on IGAC cadastral data. The total population was distributed in these microzones based on the number of residents living in each housing unit, a factor estimated previously for each municipality.

Based on the above method, the population obtained is as follows.

Table 4.2.10 Summary of Population

Area	Population
Bogotá	6,378,928
Eight Municipalities	606,581
Total	6,985,509

C. Establishment of microzone

The microzoning system was established in the Study Area by observing two factors:

- The possibility of aggregating data from the existing spatial division; and
- The homogeneous behaviour of a seismic event.

Based on the above, the microzoning system was established as follows:

Table 4.2.11 Summary of Microzoning System

Area	Rural	Urban
Bogotá	Village Boundary	Cadastral Barrio
Eight Municipalities	Village Boundary	Urbanized area of IGAC cadastral data divided in DANE Sector

The number of microzones in the Study Area is shown as follows:

Table 4.2.12 Summary of Microzones

Area	Number of Microzones
Bogotá	950
Eight Municipalities	110
Total	1,060

In each microzone, collected data are distributed and a database for microzones is established. The databases are used as a unit of analysis.

3) Damage Estimation

(1) Building

A. Collected data

The building database was established based on the cadastral data in 2000. Main structures of the buildings are categorized into several types such as adobe, stone, wood, bahareque, prefabrication, masonry and concrete. Bahareque is a vernacular for mixed structure of adobe and wooden timber. Prefabrication means manufactured structural elements of thin concrete panels. The thickness of the panel is so small, more or less 10 cm that the structural reliability is almost equal to the adobe structure. Masonry is clay-brick walled structure and has two types: non-reinforced masonry and confined or reinforced masonry. Non-reinforced masonry has only mortar and/or mud as adhesive for bricks without any reinforcing steel bars. Confined masonry denominates both reinforced brick wall structure with reinforcing steel bars and masonry filled slender RC (reinforced concrete) frame structure. Concrete structure is classified into two types, that is, the concrete structure with 3 stories or less and the concrete structure with more than 4 stories.

The database contains various information for property tax collection purpose. For this study, following data are utilized for the building damage estimation:

- Type of building.
- Number of stories.
- *Estrato*.

The characteristics of the buildings in the Study Area can be summarized as follows:

- Cadastral data indicates that the total number of buildings in Bogotá city is approximately 752 thousand while the masonry buildings are approximately 666 thousand occupying

almost 88% of the total. In the 8 municipalities, the total number of buildings is roughly 128 thousand while the masonry buildings are approximately 111 thousand occupying 88% of the total. Therefore, in the whole Study Area, the number of buildings in total is approximately 880 thousand and that of masonry buildings is around 777 thousand. Masonry buildings share approximately 88% in the Study Area.

- Masonry structures are mainly used for residential buildings in various scale such as independent housing units as well as apartment houses. Other public buildings such as hospitals, schools, hotels, offices and many other varied facilities have adopted masonry structures as well. Among these masonry buildings, especially old ones, the non-reinforced masonry type occupies large percentages.
- Other structural types, such as adobe, stone, wood and prefabrication, collectively share merely 6%, while concrete structure occupies approximately 6% of all the building types. Concrete structures were used for rather large-scale government and/or private office buildings. They are either massive structures or extremely slender and tall structures mainly located in the downtown area in Bogotá City.
- There are so many non-engineered building constructions in the Study Area that the vulnerability of the buildings is seriously increased. Especially, in the lower staged region, *estrato* 1 and 2, ratio of the number of non-engineered buildings looks very large. As results of non-skilled labor works, structural elements are not properly placed.

B. Methods and procedure

Procedure

Flowchart of the building damage estimation is shown in Figure 4.2.14.

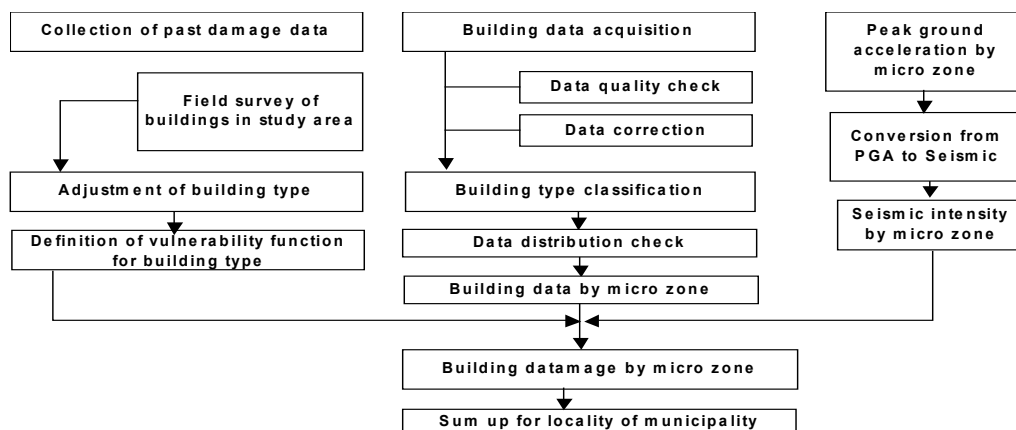


Figure 4.2.14 Flowchart of Building Damage Estimation

Damage Functions for Building Collapse

In order to establish a damage function for a seismic risk study in a given area, it is most desirable to study similar earthquake damage in a similar area, if any. This kind of study is important to incorporate building type and social situation in the similar area into the risk analysis in the given area.

In the case of Quindío Earthquake, monetary loss, defined as repair cost per building value, is calculated for each seismic intensity according to the ATC-13. In the ATC-13, damage state and each damage factor is specified as shown in Table 4.2.13.

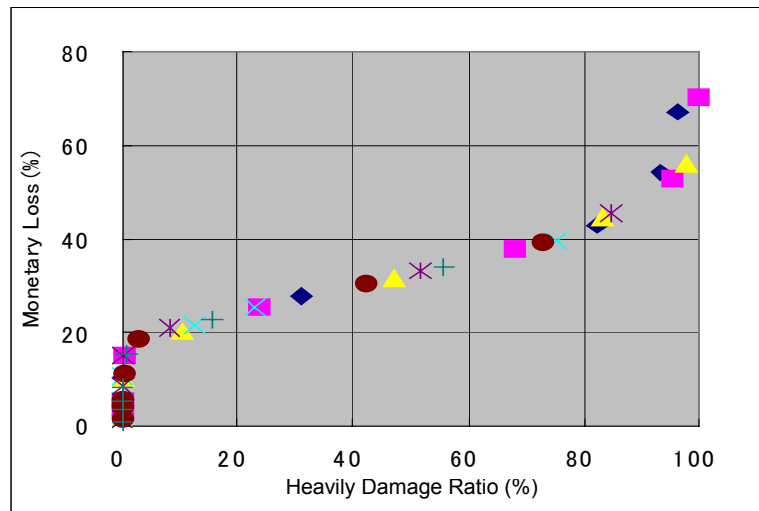
Table 4.2.13 Damage State and Central Damage Factor in Monetary Loss

Damage State	Central Damage Factor
Light	2.5%
Moderate	20%
Serious	45%
Severe	80%
Destructive	100%

Source: ATC-13

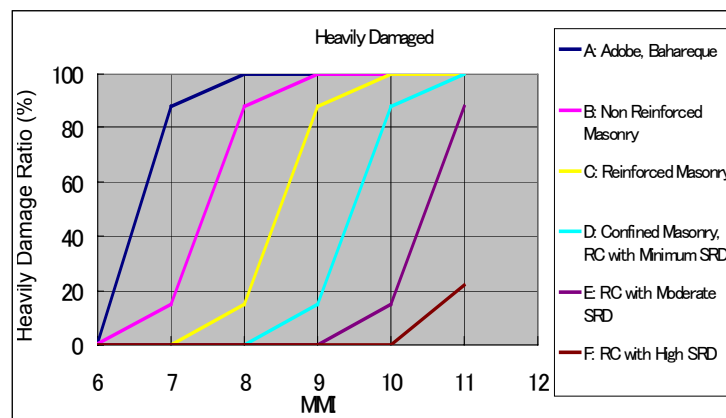
In general, damaged building is demolished at the state of monetary loss over 50%. Empirically, such buildings have damaged floor area exceeding 50%, and are considered extremely unsafe, thus not usable even as an emergency shelter as such. For example, the Turkish government recommended demolishing damaged buildings of monetary loss over 40% after the Kocaeli Earthquake in 1999.

Therefore, this study defines “heavily damaged building” as a building with a state of damage severer than “Serious,” i.e. damaged building to be demolished rather than to be repaired. Monetary loss as defined in ATC-13 and physical damage can be converted as shown in Figure 4.2.15. “Heavily (severely) damaged ratio” versus seismic intensity of the building is defined as shown Figure 4.2.16.



Source: JICA Study Team

Figure 4.2.15 Relation between Masonry and Heavily Damaged Ratio



Source: JICA Study Team

Figure 4.2.16 Heavily Damaged Structures in Quindío Earthquake referred from Figure 3.2.4

The building classification used in this study is shown in Table 4.2.14.

Table 4.2.14 Building Classification used in this Study

Type	Structure Type	Estrato
1	Wood, Prefabricated	1,2,3,4,5,6
2	Masonry	1,2
3	Masonry	3,4
4	Masonry	5,6
5	Reinforced Concrete Frame less than 3 floors	1,2,3,4,5,6
6	Reinforced Concrete Frame more than 4 floors	1,2,3,4,5,6

Source: JICA Study Team

All the structural types in cadastral data are supposed to correspond to the structural types depicted in Figure 4.2.16 and briefly explained below.

Wood

Type 1 should correspond to type A in the case of Quindío Earthquake shown in Figure 4.2.16.

Masonry

Type 2, 3 and 4 should correspond to type B, C and D in Figure 4.2.16.

Through field observation of the buildings in Bogotá, low quality RC frame structure was categorized as masonry structure in cadastral data, while masonry structure was not classified as RC frame structure. Therefore, it is conjectured that type 2, 3 and 4 should include low quality RC frame structures.

Through field observation in Bogotá conducted by the Study Team, correspondence and contribution of each type of masonry is defined as shown in Table 4.2.15. Notice that the difference of the buildings' seismic quality caused by the difference of *estrato* is considered as well.

Table 4.2.15 Contribution of Structural Type to Classification of Masonry

	B	C	D
Type 2	80%	20%	0%
Type 3	40%	50%	10%
Type 4	20%	40%	40%

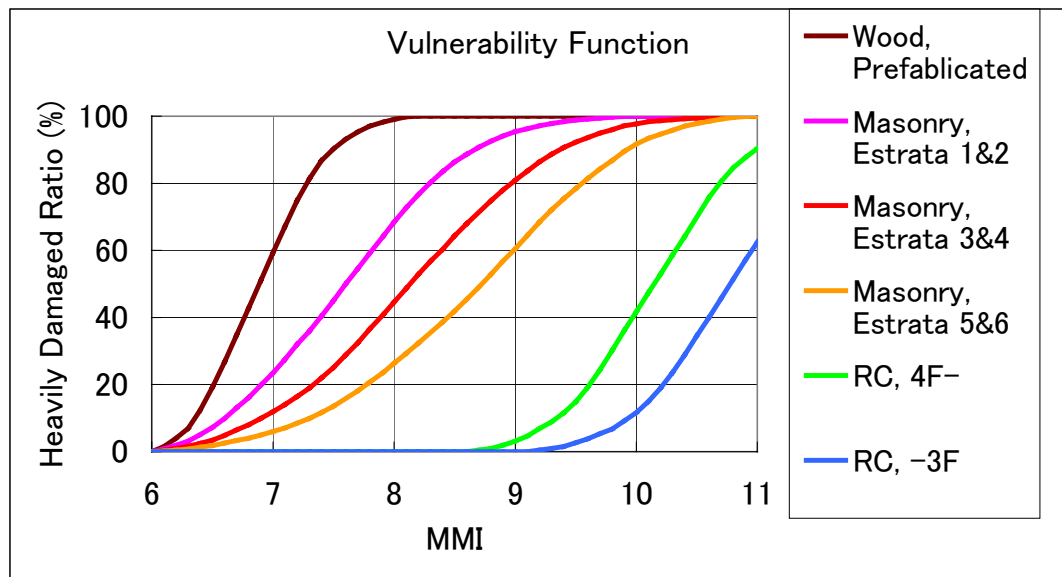
RC Frame

Among the heavily damaged buildings for all the types of structures in the 1999 Quindío earthquake, 84% had floors less than three, while buildings higher than 10 floors have a percentage of 0.4%. Though the ratio of RC frame buildings in this statistics is unknown, the damage ratio for type E and type F in Figure 4.2.16 would show the damages of RC buildings with lower stories.

The damage ratio for type F as shown in Figure 4.2.16 is almost the same as that for RC frame structures in general in California. However, few buildings would exist in affected areas having equal quality as that in California. Therefore, type E is taken for setting standard damage function.

In cadastral data, RC frame building is classified into two categories: 3 stories and up and under 3 stories. In general, higher storied buildings are more likely to suffer damage. Damage function for type E shows average damage ratio for RC frame structures. Damage function for type F is defined so that damage ratio is 30% higher on the average, since the difference in damage ratio between E and F is 20% at MMI X and 60% at MMI XI.

Damage function defined for each MMI as a discrete value is finally smoothed out as shown in Figure 4.2.17, because damage ratio should vary continuously according to the seismic intensity that varies continuously as well.



Source: JICA Study Team

Figure 4.2.17 Proposed Heavily Damaged Ratio of Buildings

C. Results of estimation

As shown in the table and figures below, the ratio of whole building collapse is between 45% and 48% in case of near and medium distance earthquakes, a range much higher than the results of the previous study. The results are shown in Table 4.2.16 and Figure 4.2.18 (1) and 18 (2).

