## 13.4.2 Damage Estimation

The definition of human casualty estimation is shown in Table 13.4.1. Casualties were calculated for scenario earthquakes Model 08, Model 13 and Model 18. In this estimation, the event is assumed to occur at evening because the damage function was derived from 1990 Luzon Earthquake damages. The major cause of damage is building collapse. In large-scale earthquakes, people may die from diseases in refugee camps, but these deaths are not included in the assumption. The dead are assumed to die either instantaneously or within a few days of the initial building collapse.

Human casualties are calculated for each Barangay, and the summary of the results is shown in Table 13.4.2. The death toll for each LGU is shown in Figure 13.4.4 to Figure 13.4.6 and the death ratio is shown in Figure 13.4.7 to Figure 13.4.9. Characteristics of damage of the three scenario earthquakes are as follows:

**1) Model 08**

In Manila and Quezon, more than 5,000 people will die. Along WVF, Marikina, Pasig, Muntinlupa show high death ratio of more than 0.5%.

**2) Model 13**

The death toll is estimated as 100 and injured people number 300. One-thirds of damage concentrates to Manila.

**3) Model 18**

The death toll is estimated as 3,100 and injured people number 9,500. The area along Manila Bay shows heavier damage. Navotas shows the highest death ratio.

**Table 13.4.1 Definition of Casualty Damage**

| | | |
|---|---|---|
| Time of event | Evening | |
| Cause of damage | Mainly building collapse | |
| Definition of damage grade | Death | - Instant death under collapsed building structure<br>- Suffocation under collapsed roofs or walls<br>- Trapped in collapsed building and not rescued promptly |
| | Injured | - Bone fracture, rupture of internal organs, crush syndrome, etc.; needs hospitalization |

**Table 13.4.2 Summary of Human Casualty Damage**

| Model | Death | | Injured | |
|---|---|---|---|---|
| 08 | 33,500 | (0.3%) | 113,600 | (1.1%) |
| 13 | 100 | (0.0%) | 300 | (0.0%) |
| 18 | 3,100 | (0.0%) | 9,500 | (0.1%) |

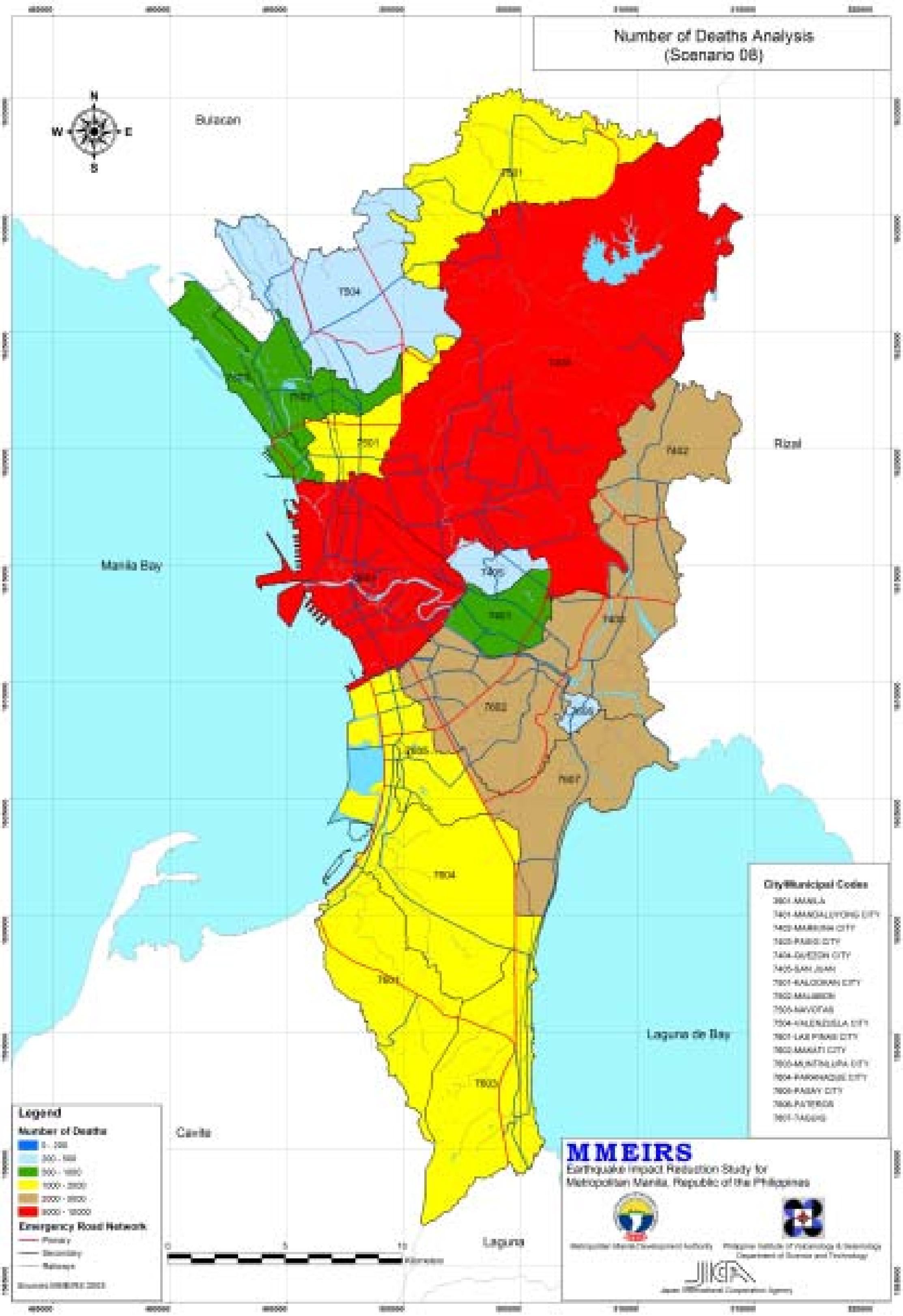


**Figure 13.4.4 Number of Dead People : Model 08**

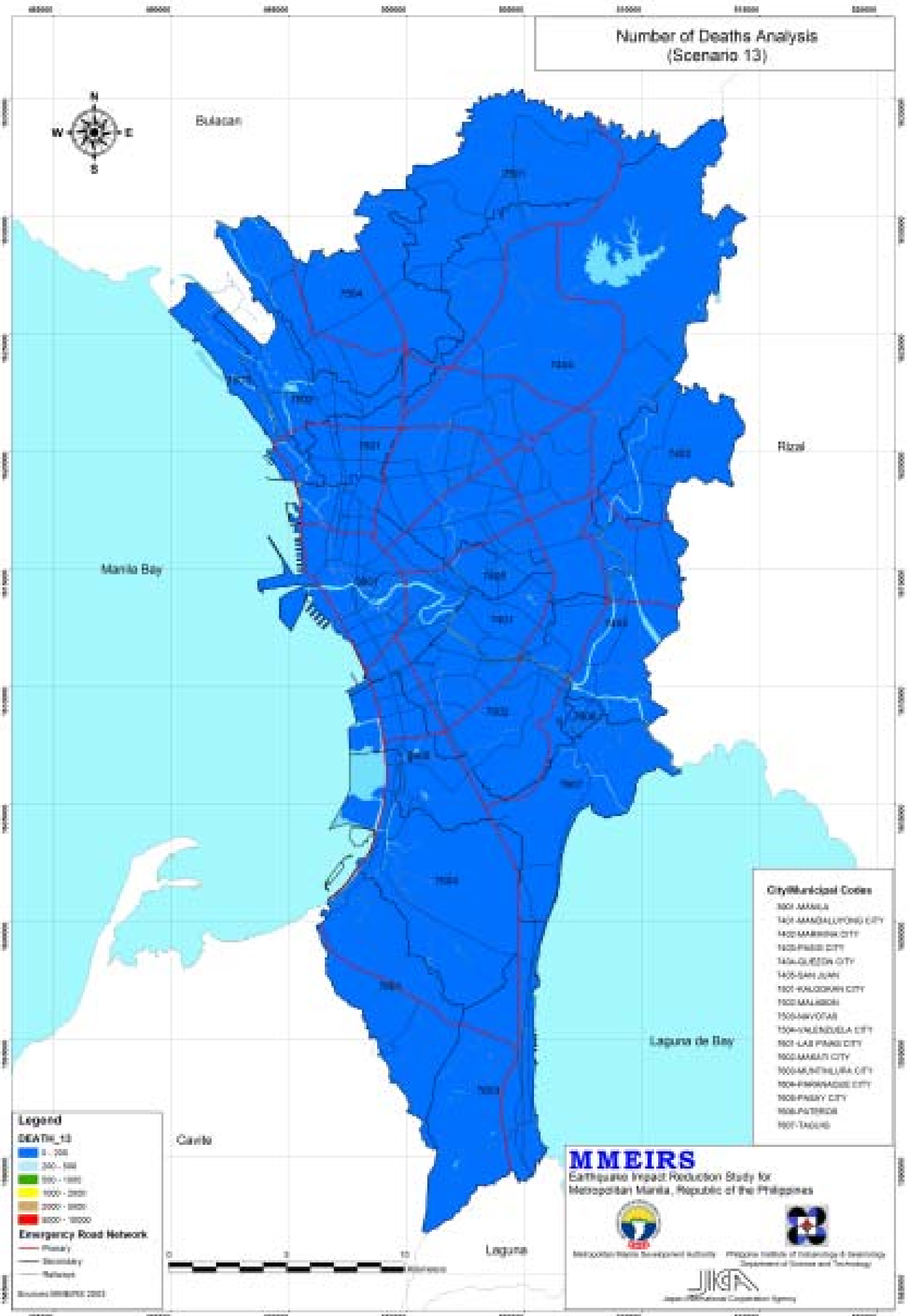


**Figure 13.4.5 Number of Dead People : Model 13**

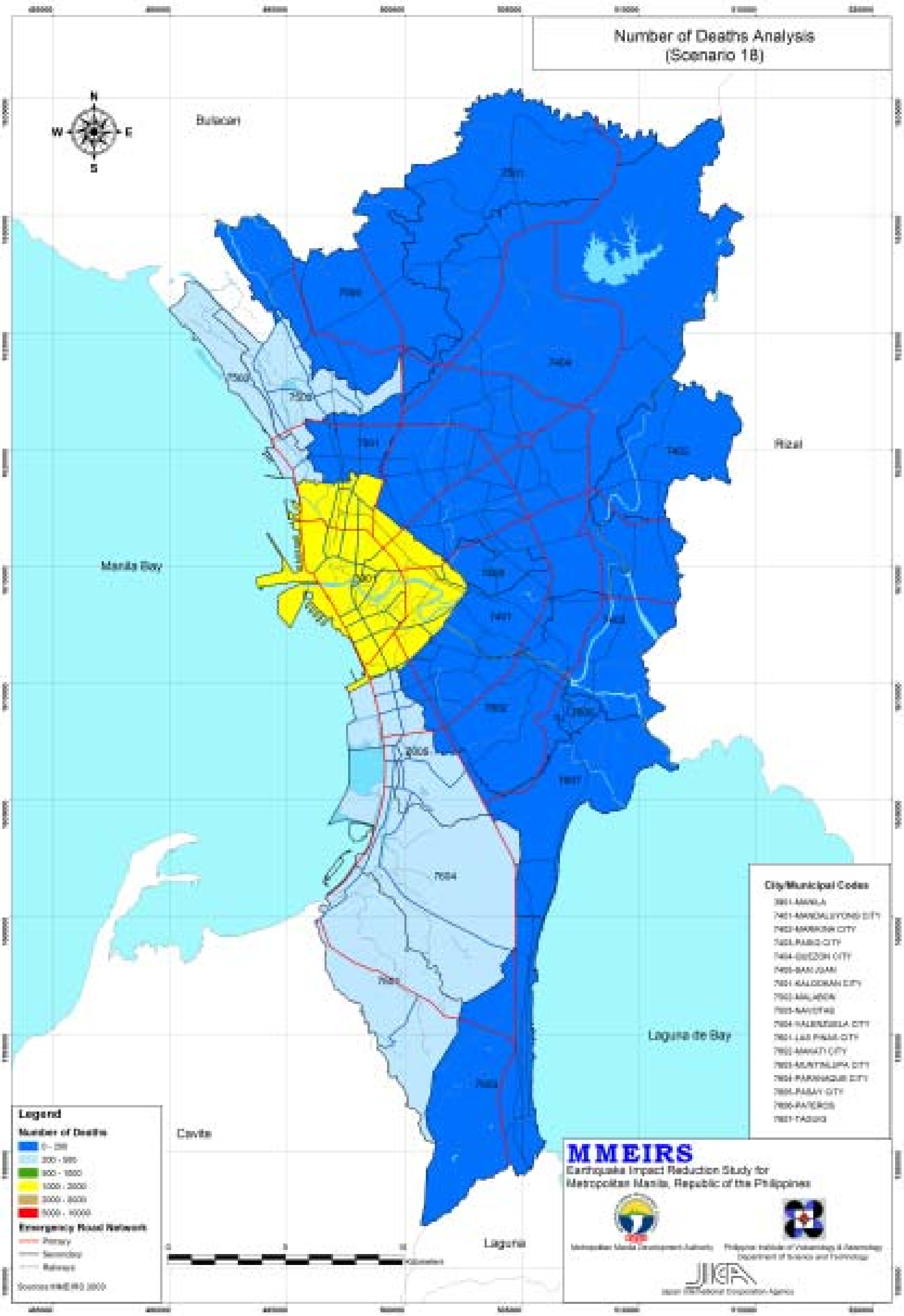


**Figure 13.4.6 Number of Dead People : Model 18**

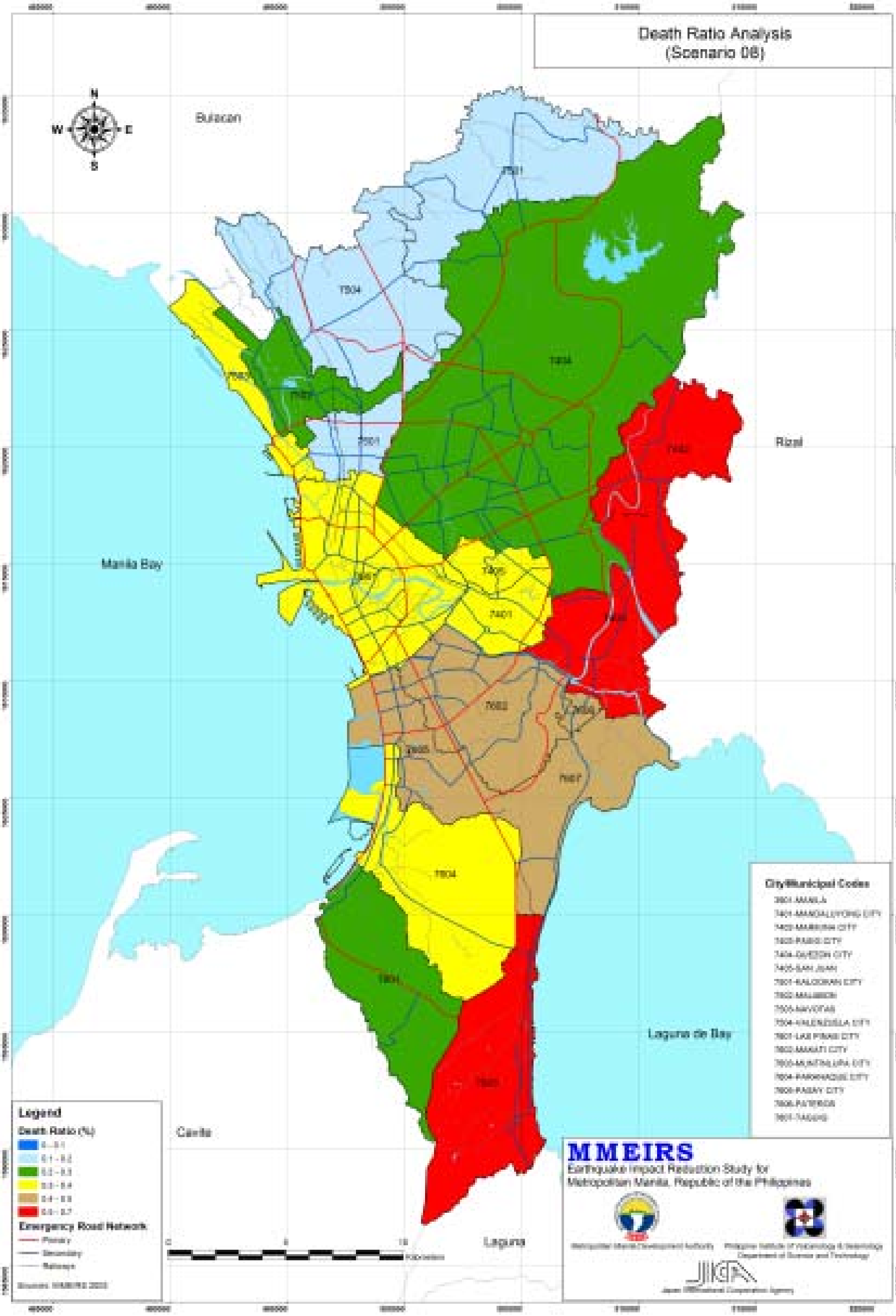


**Figure 13.4.7 Death Ratio : Model 08**

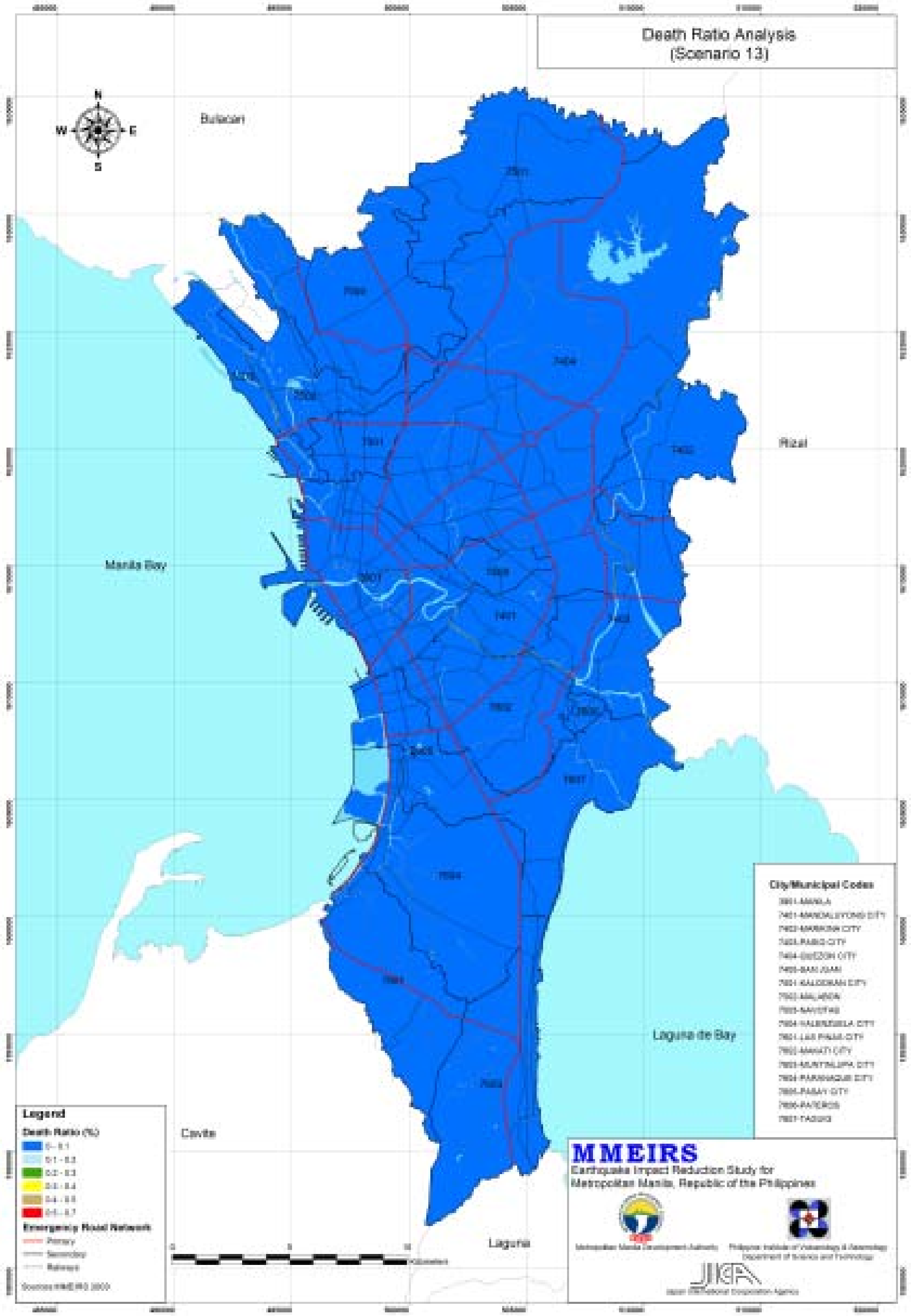


**Figure 13.4.8 Death Ratio : Model 13**

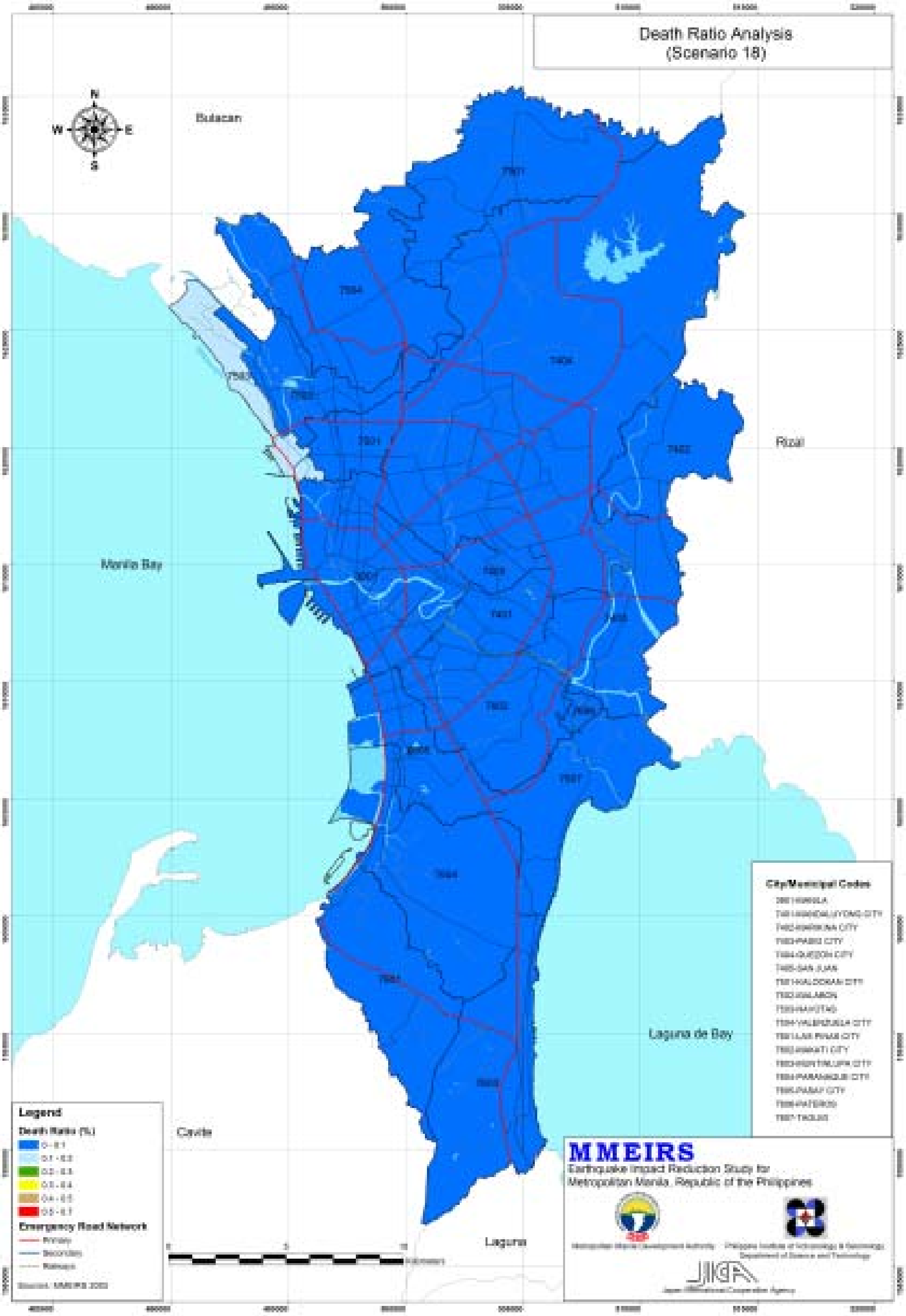


**Figure 13.4.9 Death Ratio : Model 18**

### 13.4.3 Validation

Coburn and Spence (1992) surveyed worldwide earthquake damage to identify the relationship between building damage and human casualties. The relationship is shown in Figure 13.4.10. The general trend of the relationships and the results of the Study are added onto this Figure. “Building damages” consist of only heavily damaged and collapsed buildings, to the exclusion of buildings destroyed by fire or tsunami. In cases where the number of damaged buildings is 1,000, the distribution of fatalities will range from zero to 1,000. This range of distribution decreases as the number of heavily damaged buildings increases.

The most serious earthquake resulting in the largest number of casualties of the 20th century is the Tangshan Earthquake in China in 1976; killing 240 thousand people and heavily damaging one million buildings. The number of deaths compared to building damage is high if the deaths were mainly caused by the collapse of RC high-rise buildings, as seen in the 1999 Izmit Earthquake, 1986 Armenia Earthquake and 1985 Mexico City Earthquake. The ratio of fatalities to building damage is low in the case of Japanese timber frame buildings because spaces remain if the buildings collapse. The 1975 Haicheng earthquake is the exception because this earthquake was predicted.

The relationship between the number of heavily damaged buildings and the number of deaths of three scenario earthquakes locates mid of the upper and lower trend line. The 1990 Luzon Earthquake locates around lower trend line. This may be resulted from that there is no large city in damaged area. This figure shows that if the earthquake of Model 08 may occur, the disaster may become catastrophe like Manjil Earthquake or Gujarat Earthquake.

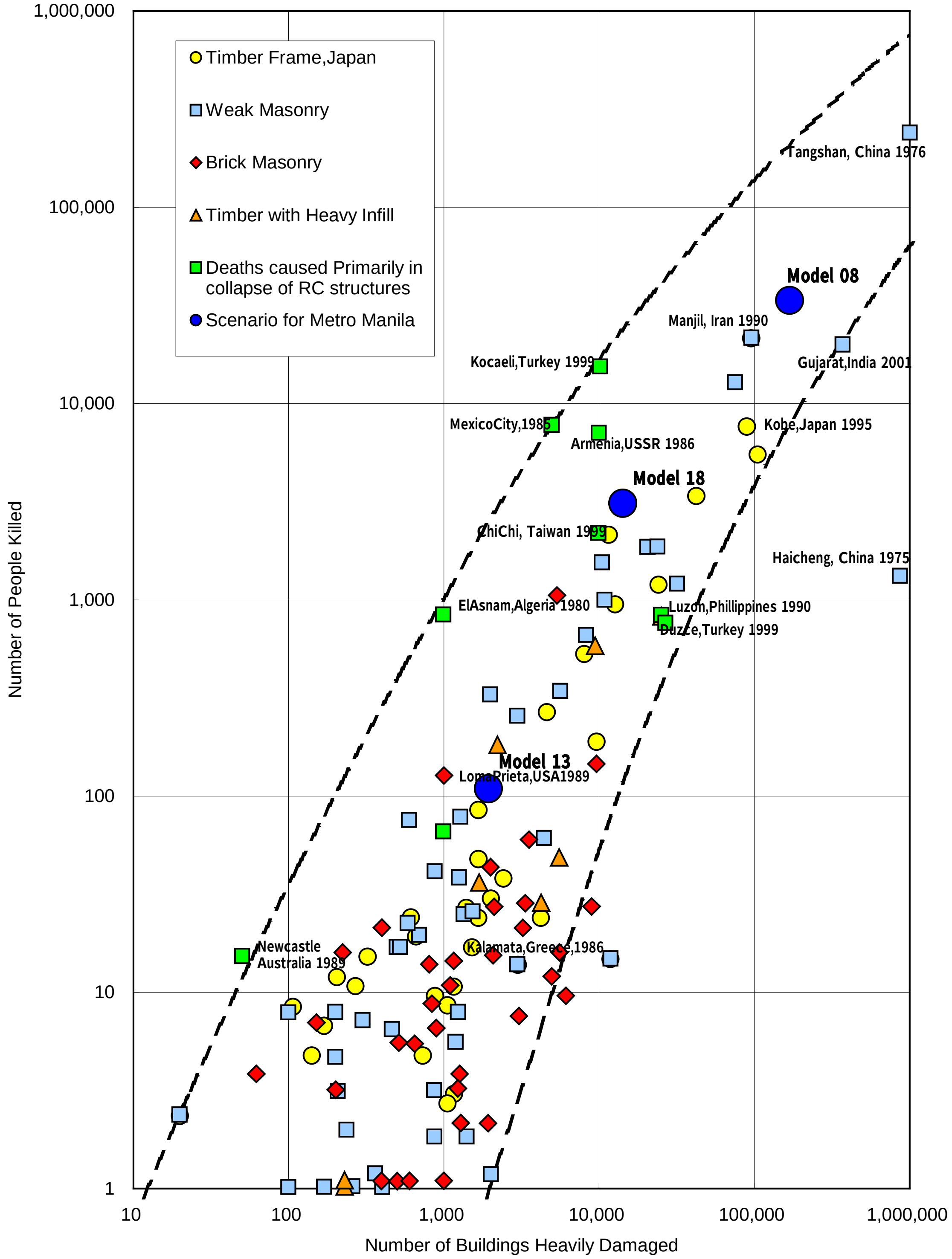


**Figure 13.4.10 Relationship between total casualty figures and total building damages statistics (Retouched to Coburn and Spence 1992)**

## 13.5 Fire

### 13.5.1 Fire Outbreak Statistics

Metropolitan Manila is constantly suffering from fire. Figure 13.5.1 shows the annual fire outbreaks from year 1995 to 2002 by city/municipality. The total number of fire outbreaks in one year is around 3,000 to 4,500 in Metropolitan Manila. The most fire outbreaks in Quezon, numbers 1,000 to 1,500 in one year. Many fires spread to other buildings because of the congested wooden/half wooden houses. From January to March in 2003, more than 3,000 buildings have burnt down and more than 10,000 households lost their houses.

Figure 13.5.2 shows the origin of fires in Metropolitan Manila. The most cases were due to the electrical related origin, about 40% of all cases. The leakage of electricity due to the inadequate wiring or lack of fail-safe devices may be the main cause.

After an earthquake, fire may outbreaks due to many origins. If the earthquake occurs during mealtimes, cooking stoves may become the main sources of fire outbreaks. Electric leakage or short circuits will also be significant sources of outbreaks. No significant fire is reported due to the 1990 Luzon Earthquake fortunately. In this section, the damage by the fire after earthquake is studied based on the experience in Japan.

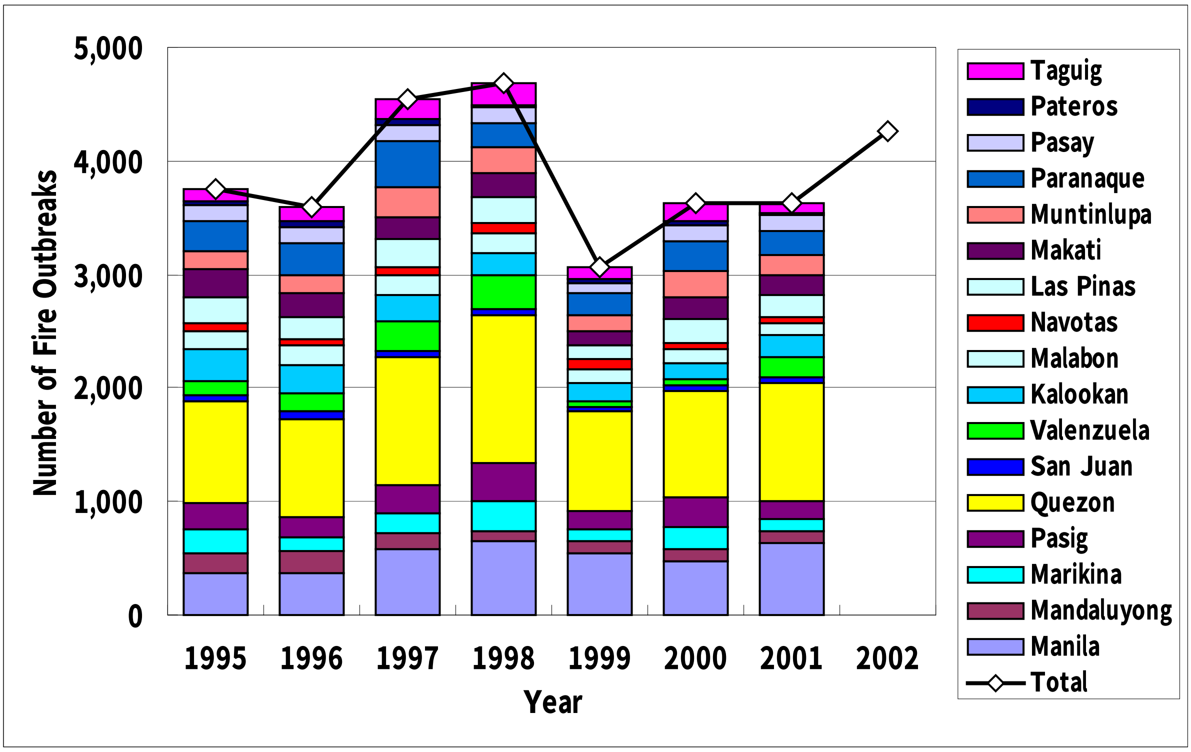


**Figure 13.5.1 Number of Fire Outbreaks from 1995 to 2002**

Source: BFP(2003)

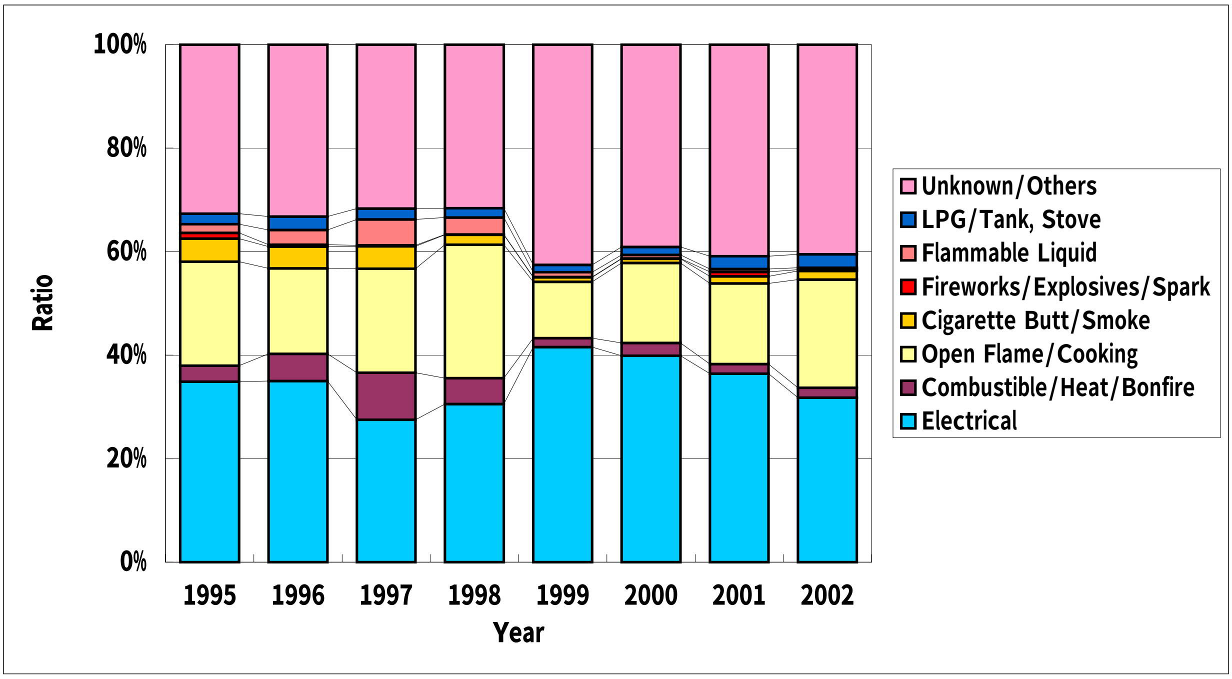


**Figure 13.5.2 Origin of Fire from 1995 to 2002**

Source: BFP(2003)

## 13.5.2 Fire Outbreak after Earthquake

Due to the 1995 Kobe Earthquake, 285 fire outbreaks are reported within 10 days after earthquake. The number of fire outbreak in the day of event is 206. The most cause of fire is electric related origin, about 30% of all cases, and the second highest is due to leakage of natural gas. The usual most cause of fire in Kobe is the careless handling of the cigarettes. The electric related origin is not so much, 10% of all. The fire after earthquake is characterized by increase of electrical related origin.

In Metropolitan Manila, different from Kobe, the most cause of fire is electric related in usual. This fact leads to the expectation of much fire outbreaks after earthquake due to electrical origin. This situation can be easily imagined from the inadequate “spaghetti” wiring in everywhere. In Metropolitan Manila, the most cooking stoves use LPG, but the gas cylinder is not equipped with overturning protection devices in many cases. It is most likely to overturn the gas cylinder and the leaked gas catches fire.

To estimate the number of fire outbreaks after earthquake, there is many indefinite elements to consider. The condition of gas and electric appliances in the family, whether overturning devices are equipped or not, the rate of electric leakage and short-circuit, etc. and the effect of earthquake motion to them are the elements. These elements are strongly affected by living circumstances.

Therefore, the best way to estimate the fire outbreaks after earthquake is to use the experiences in the study area, but there is no information in Philippines. So, in this study, the fire outbreaks are estimated based on the experience in Kobe by 1995 Kobe Earthquake.

a. Usual Fire Outbreak Ratio

The number of fire outbreaks in Kobe in the year 2002 is 811, namely 13.06 incidents per 10,000 households. The number of fire outbreaks in Metropolitan Manila in the year 2002 is 4,265, namely 20.00 incidents per 10,000 households. The usual fire outbreak ratio in Metropolitan Manila is 1.53 (=20.00/13.06) times higher than Kobe.

b. Fire Outbreak Ratio due to 1995 Kobe Earthquake

Most of the fire due to the earthquake occurs from residential buildings. Some fire may occur from chemical facilities or flammable liquid/gas stations but the number is small. Therefore, the correlation of fire outbreak ratio with residential building damage ratio is high. Figure 2.5.3 shows the relation between fire outbreaks and building damage by 1995 Kobe Earthquake. The correlation of these factors is very high.

The relation of Figure 13.5.3 was applied to Metropolitan Manila and the difference of usual fire outbreak ratio was used for compensation. In the case of Model 08, the number of fire incidents just after the earthquake in Metropolitan Manila was estimated as around 500.

It is not sure that the relation between fire outbreaks and building damage in Metropolitan Manila is same to the case in Kobe. There may occur more fire than in Kobe considering that many fire occur by electricity leakage or short-circuit after the earthquake. On the contrary, considering that many heating equipment was used in Kobe because Kobe Earthquake occurred in winter, the number of fire outbreaks may be smaller.

The estimated number of fire outbreaks in Metropolitan Manila in this section may not be exact value but the approximate number. However, it should be noted that some hundreds of fire are expected to occur just after the earthquake. This number of fire outbreaks is far beyond the capacity of fire fighting.

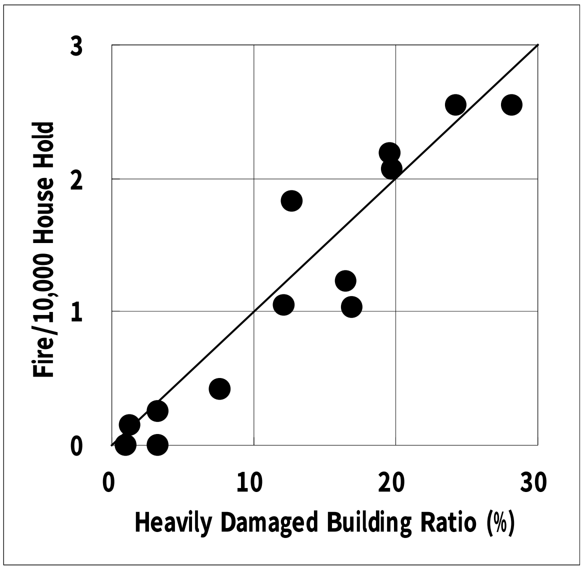


**Figure 13.5.3 Relation between Fire Outbreaks and Building Damage by Kobe Earthquake**

Source : Report on the Hanshin-Awaji Earthquake Disaster

## 13.5.3 Fire Spread Possibility

The fire-spread possibility is greatly affected by the effect of fire brigade. In the case of huge earthquake, such as Model 08, much more fire than the capacity of fire brigade occurs at the same time, therefore, most fire will not be interfered. This assumption will be supported from the fact that hydrant may not be used because of the water pipe damage.

The fire spreading possibility and burnt out ratio without fire fighting activity is affected by building density and ratio of flammable buildings. Figure 13.5.4 shows the result of the numerical simulation on the relation between “flammable area ratio” and “burnt area ratio” by the Japanese Ministry of Construction (1982). The definition is as follows:

$$\text{Flammable Area Ratio} = \left(1 - \frac{\text{Area of Open Space}}{\text{Total Area}}\right) \times \left(\frac{\text{Floor Area of Flammable Buildings}}{\text{Floor Area of All Buildings}}\right)$$

$$\text{Burnt Area Ratio} = \frac{\text{Burnt Floor Area}}{\text{Floor Area of Flammable Buildings}}$$

Open Space : Park, Water Related, Grassland, Road, Educational etc.

Flammable Buildings : Wood, Half Concrete and Half Wood, Floor $<= 10\text{m}^2$

The burnt area ratio becomes higher in proportion to a rise of flammable area ratio. The wind speed also affects to the result. If the wind speed is higher, larger area will be burnt out. If the flammable area ratio is less than 30%, burnt area ratio will be 0%. This means that if fire may occur in the area with flammable area ratio less than 30%, it never spread to other buildings.

Figure 13.5.5 shows the possible area of fire spreading, namely the area with flammable area ratio greater than 30%. The 796 grids are estimated as possible area of fire spreading, namely 30% of Metropolitan Manila. If a fire occurs in these grids and it can't be distinguished, the fire may spread. The burnt area will be affected by the flammable area ratio and wind speed. The large LPG/gasoline plants are also shown in the figure. In worst scenario, these plants in possible fire spreading area may explode because of fire spreading even if the facility itself may not become fire source.

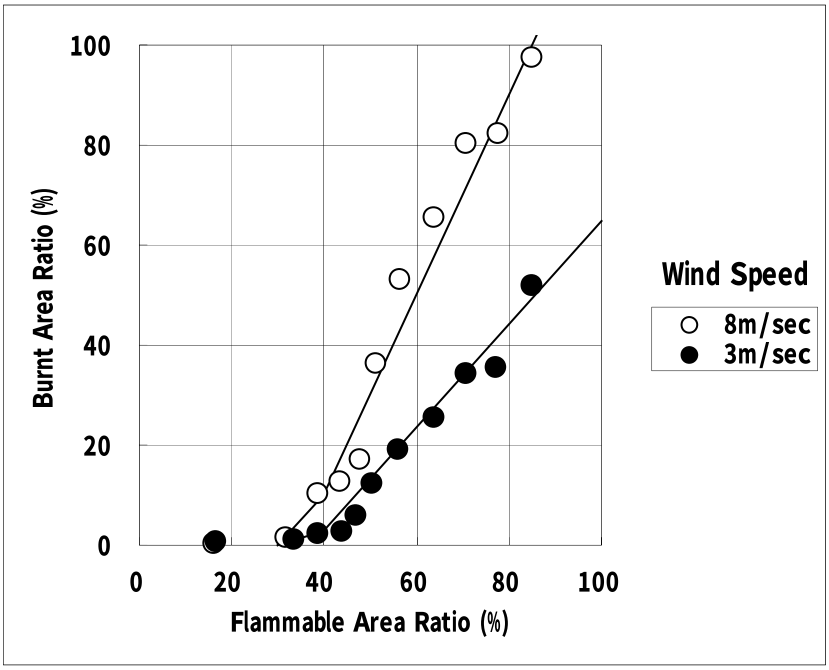


**Figure 13.5.4 Relation between Burnt Area Ratio and Flammable Area Ratio**

Source : Japan Ministry Construction (1982)

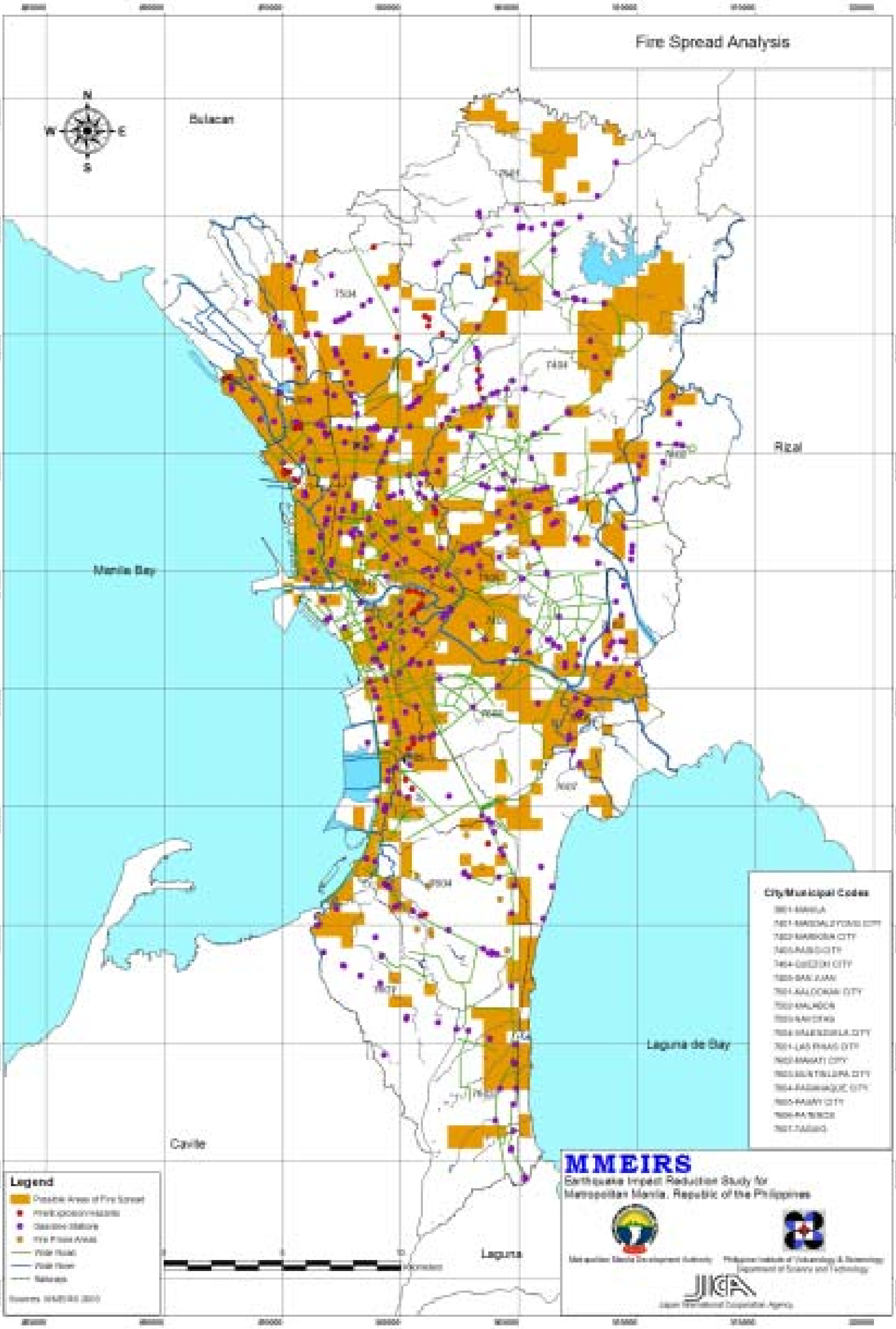


**Figure 13.5.5 Possible Area of Fire Spreading**

### 13.5.4 Damage Estimation

The damage by fire was estimated with following assumption. The estimated damage means the maximum possible number. The building damage by Model 08 was used in calculating human casualties.

a. Number of Burnt Out Building

- All the grids of possible fire spreading suffer fire
- No effective fire fighting activities
- Fire continue till putting out by it self
- Burnt out building number can be estimated with Figure 13.5.4

b. Death Toll

- Estimate based on the following experience in Kobe
- The trapped people in collapsed flammable buildings will be burnt to death
- All the people living in 70% of heavily damaged flammable buildings in burnt out area will escape or rescued
- Half of the people living in 30% of heavily damaged flammable buildings in burnt out area will escape or rescued, the rest half will be killed by fire

The summary of estimated damage is shown in Table 13.5.1. The damage by LGU is shown in Table 13.5.2 and the distribution of burnt out buildings is shown from Figure 13.5.6 to Figure 13.5.7.

The damage is severe in Manila. Almost all area in Manila except Intramuros may suffer fire. All the living area in Navotas will suffer fire and 25% of buildings may be burnt out at worst.

**Table 13.5.1 Summary of Fire Damage**

| Wind Speed | | Burnt Area | Maximum Possible Burnt Out Building | | Maximum Possible Death Toll by Model 08 | |
|---|---|---|---|---|---|---|
| 3m/sec | (10.8km/hour) | 798 ha | 42,100 | (3.2%) | 7,900 | (0.1%) |
| 8m/sec | (28.8km/hour) | 1710 ha | 97,800 | (7.4%) | 18,300 | (0.2%) |

## Table 13.5.2 Fire Damage by LGU

| LGU Code | Name | Area (ha) | Building Number | Population | Maxumum Possible Burnt Out Area (ha) | | Maximum Possible Burnt Out Building | | | | Maximum Possible Casualty Damage by Model 08 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Number (x 1,000) | | Ratio | | Death (x 1,000) | | Ratio | |
| | | | | | 3 m/sec | 8 m/sec | 3 m/sec | 8 m/sec | 3 m/sec | 8 m/sec | 3 m/sec | 8 m/sec | 3 m/sec | 8 m/sec |
| 390 | Manila | 4,144 | 168,528 | 1,581,082 | 216 | 450 | 13.7 | 31.0 | 8.1% | 18.4% | 3.0 | 6.8 | 0.2% | 0.4% |
| 741 | Mandaluyong | 1,111 | 32,942 | 278,474 | 33 | 70 | 1.7 | 4.0 | 5.1% | 12.2% | 0.3 | 0.7 | 0.1% | 0.2% |
| 742 | Marikina | 2,273 | 53,422 | 391,170 | 4 | 9 | 0.1 | 0.4 | 0.3% | 0.8% | 0.0 | 0.1 | 0.0% | 0.0% |
| 743 | Pasig | 3,200 | 72,143 | 505,058 | 35 | 74 | 2.2 | 5.0 | 3.1% | 6.9% | 0.7 | 1.6 | 0.1% | 0.3% |
| 744 | Quezon | 16,595 | 302,818 | 2,173,831 | 115 | 259 | 4.9 | 12.3 | 1.6% | 4.1% | 0.6 | 1.4 | 0.0% | 0.1% |
| 745 | San Juan | 590 | 11,793 | 117,680 | 21 | 43 | 0.5 | 1.3 | 4.6% | 10.8% | 0.1 | 0.2 | 0.1% | 0.2% |
| 751 | Valenzuela | 4,468 | 62,778 | 485,433 | 8 | 22 | 0.2 | 0.7 | 0.3% | 1.1% | 0.0 | 0.0 | 0.0% | 0.0% |
| 752 | Kalookan | 5,332 | 168,480 | 1,177,604 | 56 | 120 | 3.5 | 8.2 | 2.1% | 4.8% | 0.3 | 0.6 | 0.0% | 0.1% |
| 753 | Malabon | 1,602 | 51,694 | 338,855 | 54 | 114 | 3.2 | 7.3 | 6.1% | 14.1% | 0.3 | 0.7 | 0.1% | 0.2% |
| 754 | Navotas | 1,099 | 35,124 | 230,403 | 48 | 97 | 3.9 | 8.6 | 11.2% | 24.4% | 0.6 | 1.4 | 0.3% | 0.6% |
| 761 | Las Pinas | 3,239 | 73,919 | 472,780 | 18 | 38 | 0.8 | 1.7 | 1.0% | 2.3% | 0.1 | 0.2 | 0.0% | 0.0% |
| 762 | Makati | 3,208 | 50,381 | 471,379 | 53 | 116 | 2.0 | 4.9 | 4.0% | 9.7% | 0.7 | 1.6 | 0.1% | 0.3% |
| 763 | Muntinlupa | 3,827 | 55,522 | 379,310 | 35 | 78 | 0.8 | 2.0 | 1.4% | 3.6% | 0.2 | 0.6 | 0.1% | 0.2% |
| 764 | Paranaque | 4,578 | 72,230 | 449,811 | 39 | 82 | 1.5 | 3.5 | 2.1% | 4.8% | 0.2 | 0.6 | 0.1% | 0.1% |
| 765 | Pasay | 1,785 | 39,968 | 354,908 | 50 | 103 | 2.5 | 5.8 | 6.4% | 14.4% | 0.7 | 1.5 | 0.2% | 0.4% |
| 766 | Pateros | 196 | 8,726 | 57,407 | 3 | 7 | 0.2 | 0.5 | 1.8% | 5.4% | 0.0 | 0.1 | 0.1% | 0.2% |
| 767 | Taguig | 2,763 | 65,428 | 467,375 | 12 | 28 | 0.3 | 0.8 | 0.5% | 1.3% | 0.1 | 0.2 | 0.0% | 0.0% |
| | Total | 60,010 | 1,325,896 | 9,932,560 | 798 | 1,710 | 42.1 | 97.8 | 3.2% | 7.4% | 7.9 | 18.3 | 0.1% | 0.2% |

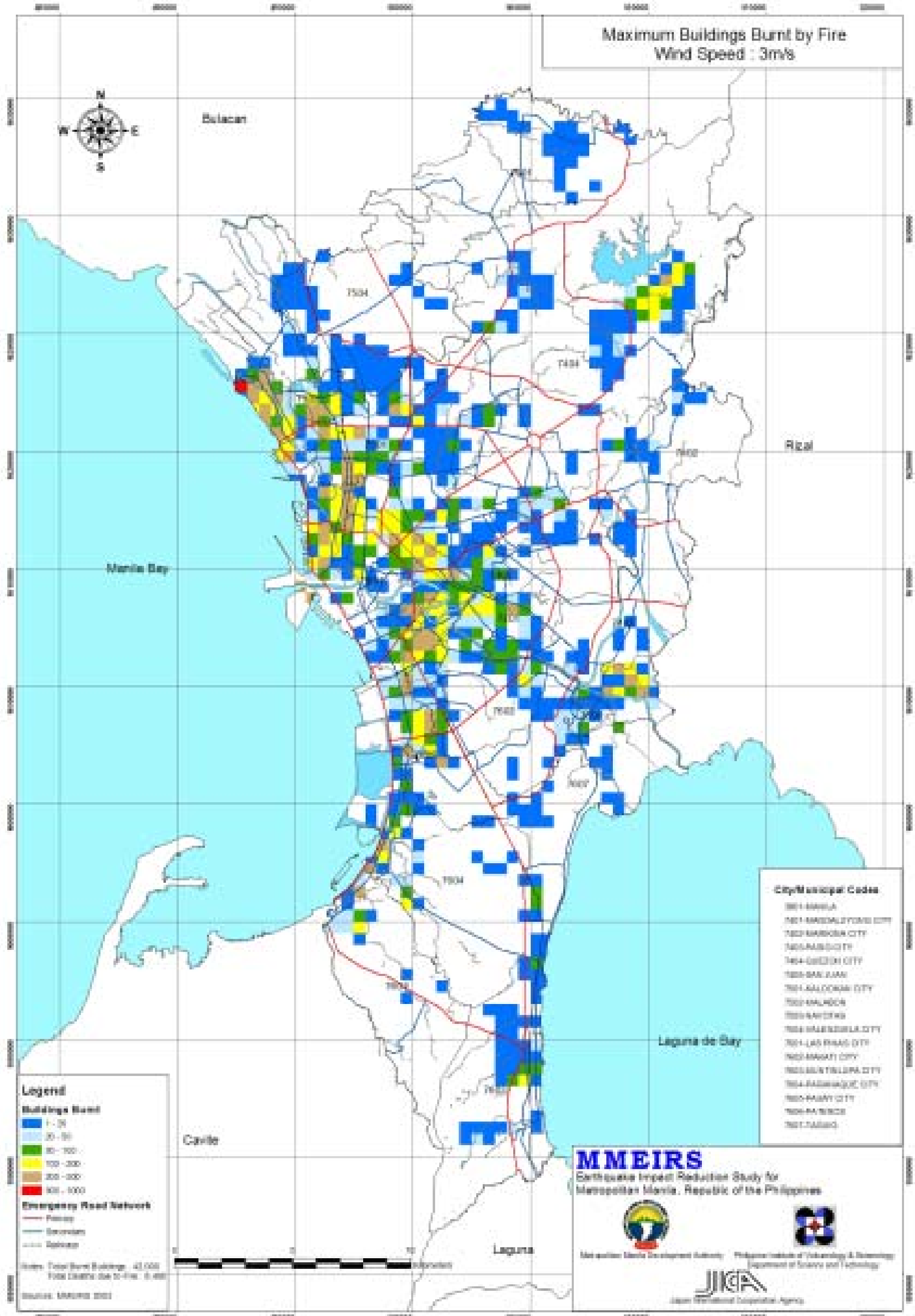


**Figure 13.5.6 Maximum Burnt Buildings by Fire : Wind Speed 3m/sec**

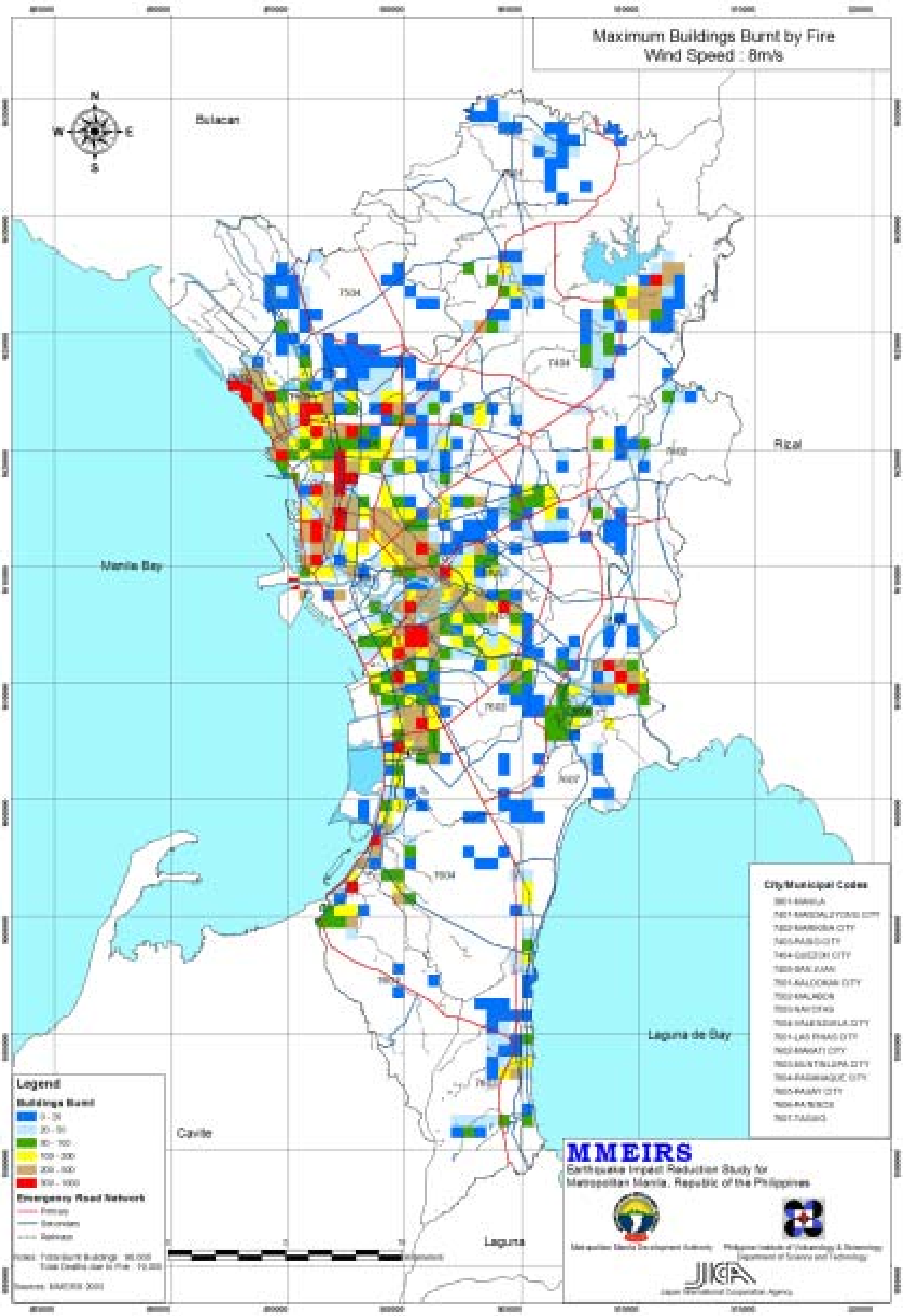


**Figure 13.5.7 Maximum Burnt Buildings by Fire : Wind Speed 8m/sec**

## 13.6 Lifelines

The damage of lifeline facilities seldom affects human lives in distinction from residential buildings. But the lifelines are indispensable for modernized urban life and the damage of lifeline facilities strongly affect the society. It is the characteristics of lifeline damages that they have an effect to each other. For example, electricity failure cause water cut off.

The following 3 types of lifelines are considered in this section:

a. Water Supply Pipeline

b. Electric Power Supply Cable

c. Telecommunication Cable

Lifeline facilities are to be classified into two major categories, nodes and links. Nodes include facilities such as substations and purification plants. Links include facilities such as pipes or cables for supply and distribution purposes. A statistical approach for damage estimation of links, i.e., distribution pipes and lines, is applied in this study

Damages to node facilities are not estimated in this study, because such structures are different with respect to purpose and location and a statistical approach is not applicable for the analysis. Separate detailed surveys are required for the damage estimation of node facilities.

### 13.6.1 Water Supply Pipeline

#### 1) Damage Estimation Method

The damage to water pipes in Kobe city in the 1995 Kobe Earthquake is one of the most well known damage examples, and the relation of damage and seismic motion in Kobe and the surrounding area are well studied. Figure 13.6.1 shows the relation between the damage of water supply pipelines and the ground motion in Kobe and other cities compiled by Tokyo (1997). As for the ground motion, PGV (Peak Ground Velocity) is used. This figure also shows that pipeline damage is strongly affected by liquefaction because liquefied soil provides buoyancy to pipeline. The damage function for water supply pipelines were established by Tokyo (1997) and shown in Figure 13.6.1.

The water distribution pipeline damage due to 1990 Luzon Earthquake was reported in several cities, but quantitative damage statistics is almost nothing. The number of damage points and water pipeline length in Agoo and Baguio, written in Philippines Earthquake Reconnaissance Report (1991), is the only available data. Agoo was affected by liquefaction. The damage in these two cities is also plotted in Figure 13.6.1. The PGV in these cities was estimated from the seismic intensity by AIJ (1992) using the empirical formula by Trifunac and Brady (1975). The damage in Agoo is explained by the damage function by Tokyo (1997). The damage ratio in Baguio is higher than the experience in Japan. Many landslides occurred in Baguio due to the Luzon Earthquake and many water pipelines were reported to be destroyed by landslides. This may be the reason of higher damage ratio than Japan. Based on these considerations, the damage function, shown in Figure 13.6.1, was used for damage estimation.

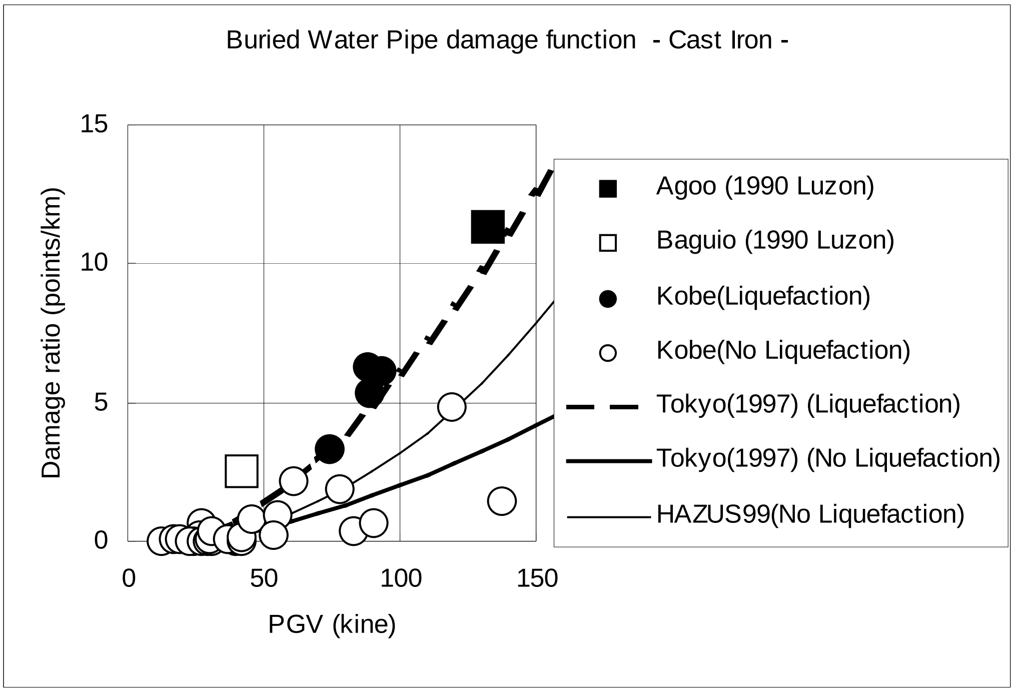


**Figure 13.6.1 Damage Function of Water Supply Pipeline**

The damage function for Metropolitan Manila is formulated as follows:

Rm(PGV) = R(PGV) x Cl x Cp x Cd

where

Rm(PGV): damage ratio (points/km)

PGV: Peak Ground Velocity (kine = cm/sec)

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

Cl: liquefaction coefficient

| | |
|---|---|
| for $P_L = 0$ | 1.0 |
| for $0 < P_L \leq 5$ | 1.2 |
| for $5 < P_L \leq 15$ | 1.5 |
| for $15 < P_L$ | 3.0 |

Cp x Cd : pipeline material and diameter coefficient

| | | |
|---|---|---|
| for Ductile Iron | $\phi \leq 75$ | 0.6 |
| | $100 \leq \phi \leq 450$ | 0.33 |
| | $500 \leq \phi \leq 900$ | 0.09 |
| | $1000 \leq \phi$ | 0.045 |
| for Cast Iron and Galvanozed Iron | | |
| | $\phi \leq 75$ | 1.7 |
| | $100 \leq \phi \leq 250$ | 1.2 |

| | | |
|---|---|---|
| | $300 \leq \phi \leq 900$ | 0.4 |
| | $1000 \leq \phi$ | 0.15 |
| for Steel | $\phi \leq 75$ | 0.84 |
| | $100 \leq \phi \leq 250$ | 0.42 |
| | $300 \leq \phi$ | 0.24 |
| for PVC and Fiber Reinforced Plastic | | |
| | $\phi \leq 75$ | 1.5 |
| | $100 \leq \phi$ | 1.2 |
| for Asbestos and Concrete | | |
| | $\phi \leq 75$ | 6.9 |
| | $100 \leq \phi \leq 250$ | 2.7 |
| | $300 \leq \phi$ | 1.2 |
| for Polyethylene and HDPE | | 0.0 |

**2) Estimated Damage**

The damage estimation definition is shown in Table 13.6.1. The damage in each 500m grid is calculated and shown in Figure 13.6.2 to Figure 13.6.3. The summary of damage is shown in Table 13.6.2.

The water distribution pipelines in Metropolitan Manila extend 4,614 km. The distribution of water pipelines is not uniform. There is no water service in eastern LGU, such as Taguig and Muntinlupa. Only little water pipelines exist along WVF, which is the source fault of Model 08. Therefore, the around 4,000 damage points by Model 08 concentrate to western area in Metropolitan Manila and very little in the area of high seismic intensity zone. The damage will become much larger than estimated in this study if water service will reach to eastern area.

**Table 13.6.1 Definition of Water Pipeline Damage Estimation**

| Object | Distribution Pipes |
|---|---|
| Content of Damage | Break of pipes or joints<br>Pull out of joints |
| Amount of Damage | Number of damage points |

**Table 13.6.2 Summary of Water Pipeline Damage**

| Model | Damage Points |
|---|---|
| 08 | 4,000 |
| 13 | 0 |
| 18 | 200 |

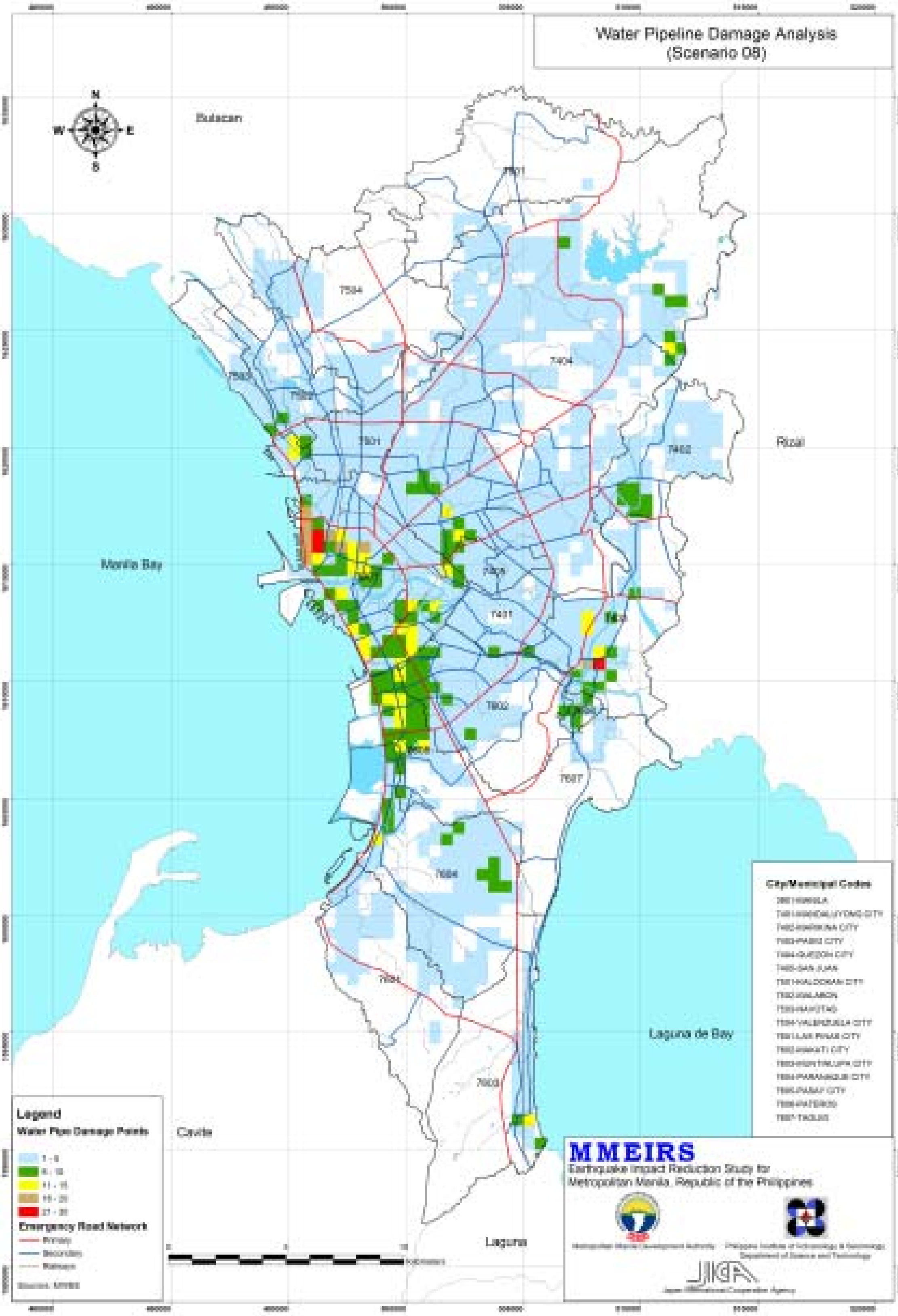


**Figure 13.6.2 Distribution of Water Pipe Damage : Model 08**

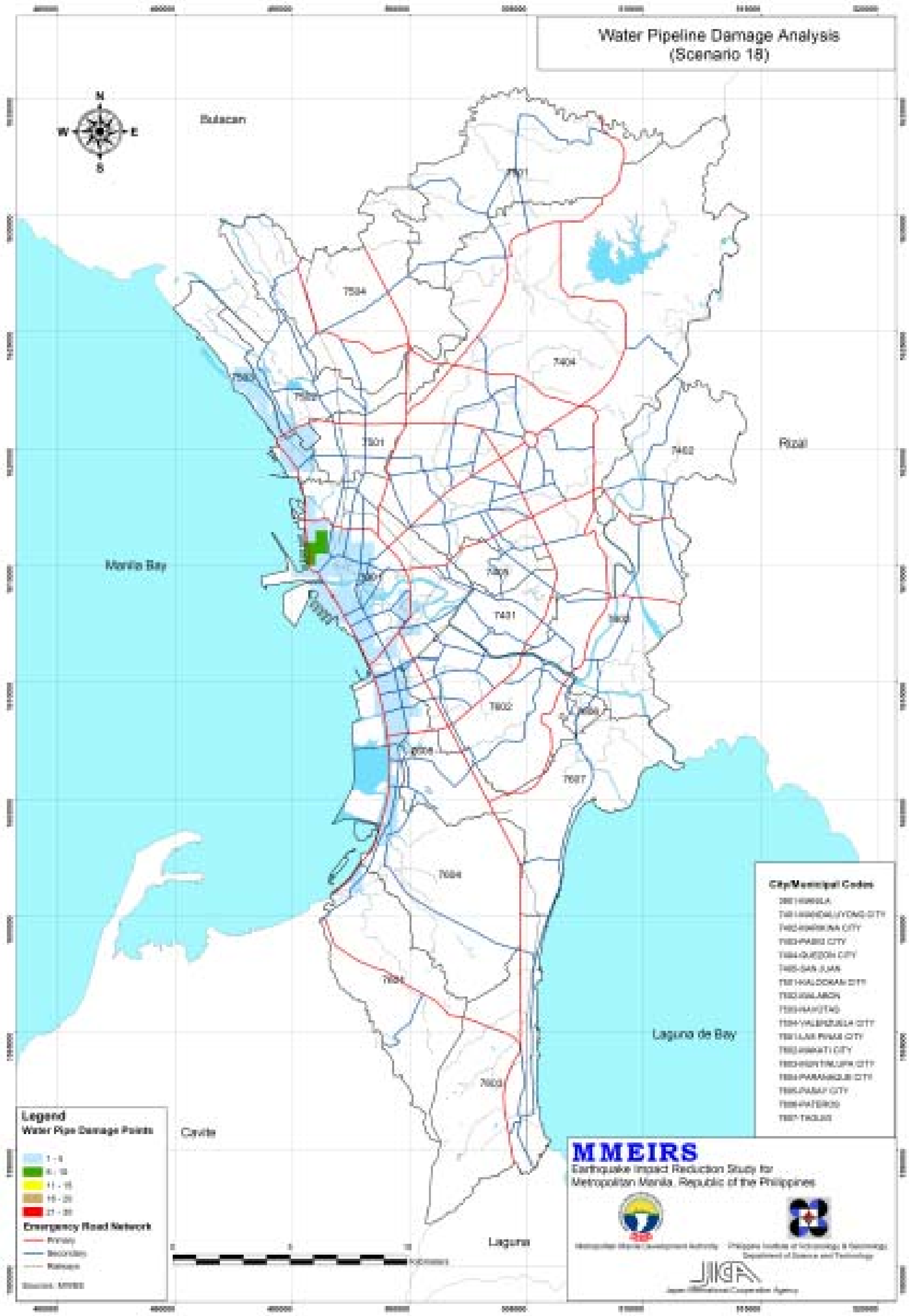


**Figure 13.6.3 Distribution of Water Pipe Damage : Model 18**

## 13.6.2 Electric Power Supply Cable

### 1) Damage Estimation Method

The electric power supply cable will be damaged by several causes due to earthquake. The electric pole may be broken by vibration or tilt by liquefaction. Collapsed buildings may pull down the electric pole and cables may be burnt by fire.

The information about electric power supply facility damage due to earthquake in the Philippines is not available. Therefore, the damage was estimated based on the experience in Japan. The damage was calculated on the supposition that the structure and condition of electric power supply facilities are same to Japan, so the damage amount in this study is primitive.

Figure 13.6.4 is the relation between electric power supply cable damage ratio and seismic intensity due to 1995 Kobe earthquake by Tokyo (1997). The damage of electric power supply cable is limited to the damage that will bring electric power cut off. The effect of liquefaction is shown in Table 13.6.3. The damage was calculated using the damage function by Tokyo (1997).

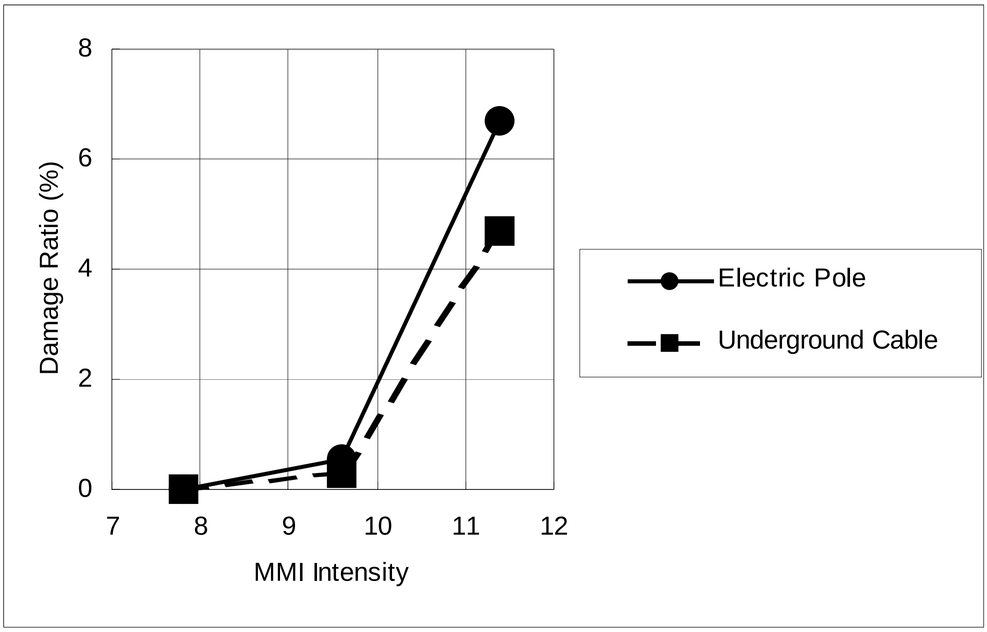


**Figure 13.6.4 Damage Function of Electric Power Supply Cable**

**Table 13.6.3 Liquefaction Coefficient for Damage Estimation**

| Liquefaction Potential | Overhead Cable | Under-ground Cable |
|---|---|---|
| $P_L = 0$ | 1.0 | 1.0 |
| $0 < P_L \leq 5$ | 1.1 | 1.2 |
| $5 < P_L \leq 15$ | 1.3 | 1.5 |
| $15 < P_L$ | 2.1 | 3.0 |

### 2) Estimated Damage

The damage estimation definition is shown in Table 13.6.4. The damage in each 500m grid is calculated and shown in Figure 13.6.5 to Figure 13.6.6. The summary of damage is shown in Table 13.6.5.

The electric power supply cables in Metropolitan Manila extend 4,862 km. By Model 08, 31km will be damaged and bring power cut off. The electric power supply cables distribute in all Metropolitan Manila, therefore damage will be severe in high seismic intensity area. The electric power is supplied to each buildings stepping down the 34.5kV line to 220V line using the transformer on the pole. The damage to the transformer and 220V line are not calculated in this study. The total length of 220V line may be several times to 34.5kV line, so many damages are expected to this part.

**Table 13.6.4 Definition of Electric Power Supply Cable Damage Estimation**

| | |
|---|---|
| Object | Transmission, Distribution line (230kV, 115kV, 34.5kV) |
| Content of Damage | Collapse, lean of pole<br>Cut of cables |
| Amount of Damage | Length of cables to be replaced |

**Table 13.6.5 Summary of Electric Power Supply Cable Damage**

| Model | Damage Length (km) |
|---|---|
| 08 | 30 |
| 13 | 0 |
| 18 | 4 |

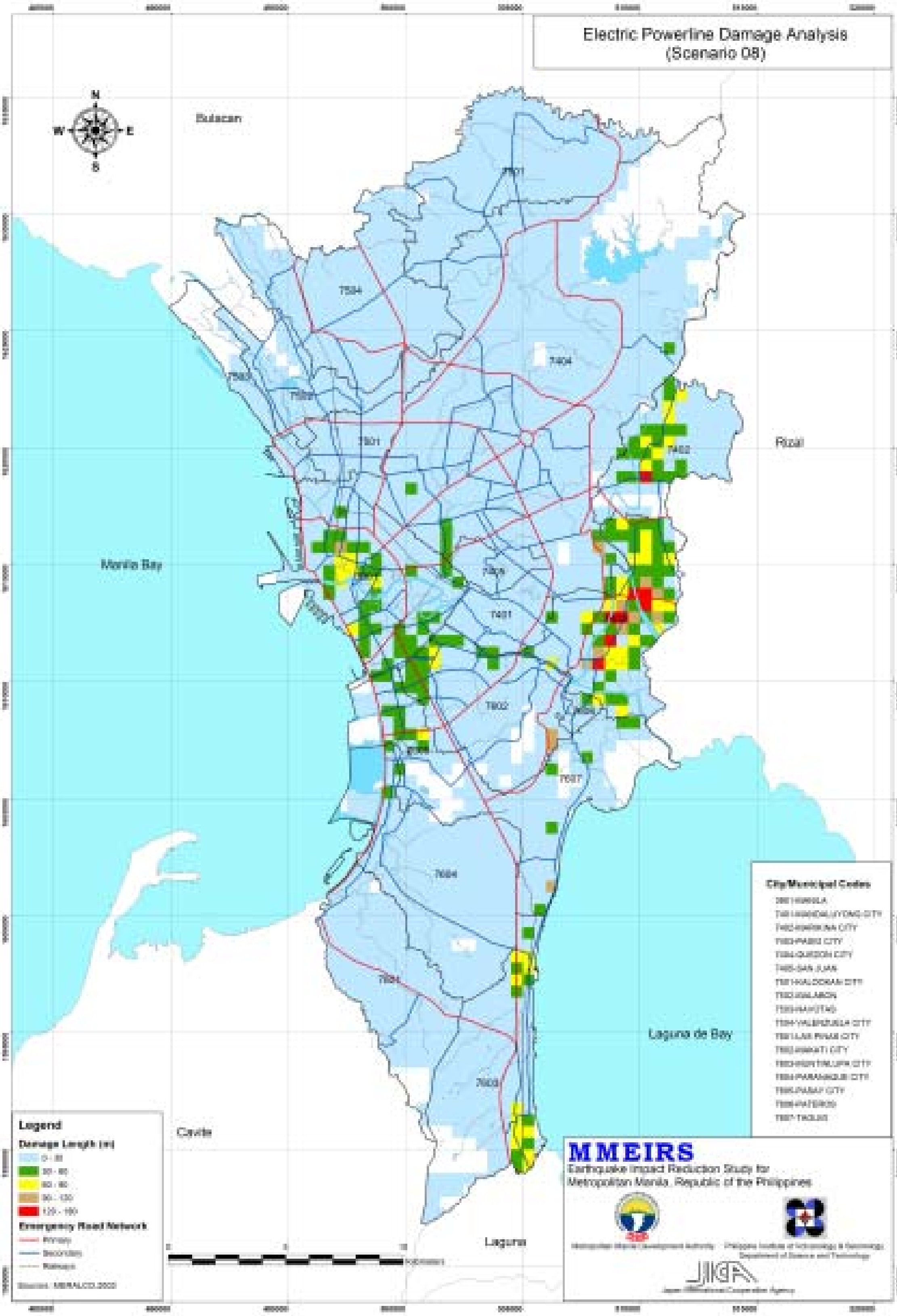


**Figure 13.6.5 Distribution of Electricity Cable Damage : Model 08**

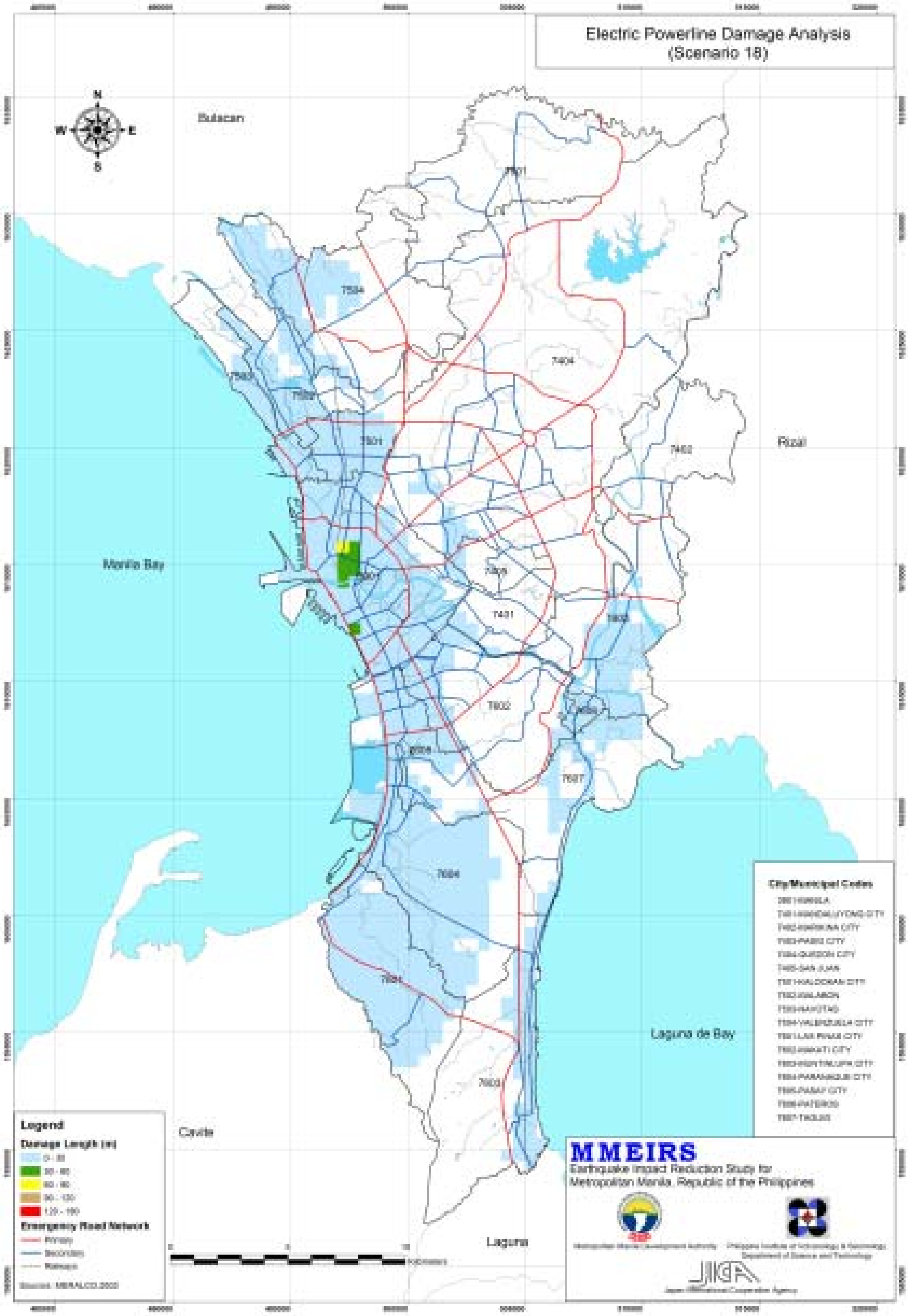


**Figure 13.6.6 Distribution of Electricity Cable Damage : Model 18**

## 13.6.3 Telecommunication Cable

For telecommunication cable, only a statistical table is available. The length of cable in each 500m grid was estimated based on the building distribution.

### 1) Damage Estimation Method

The damage function for electric power cable was used for telecommunication cable damage estimation. The damage was calculated on the supposition that the structure and condition of telecommunication cables are same to Japan, so the damage amount in this study is primitive.

### 2) Estimated Damage

The damage estimation definition is shown in Table 13.6.6. The damage in each 500m grid is calculated and shown in Figure 13.6.7 to Figure 13.6.8. The summary of damage is shown in Table 13.6.7.

The telecommunication cables in Metropolitan Manila extend 14,105 km. By Model 08, 95km will be damaged and bring cut off.

**Table 13.6.6 Definition of Telecommunication Cable Damage Estimation**

| | |
|---|---|
| Object | Primary, Secondary line (Overhead, Under-ground) |
| Content of Damage | Collapse, lean of pole<br>Cut of cables |
| Amount of Damage | Length of cables to be replaced |

**Table 13.6.7 Summary of Telecommunication Cable Damage**

| Model | Damage Length (km) |
|---|---|
| 08 | 95 |
| 13 | 0 |
| 18 | 11 |

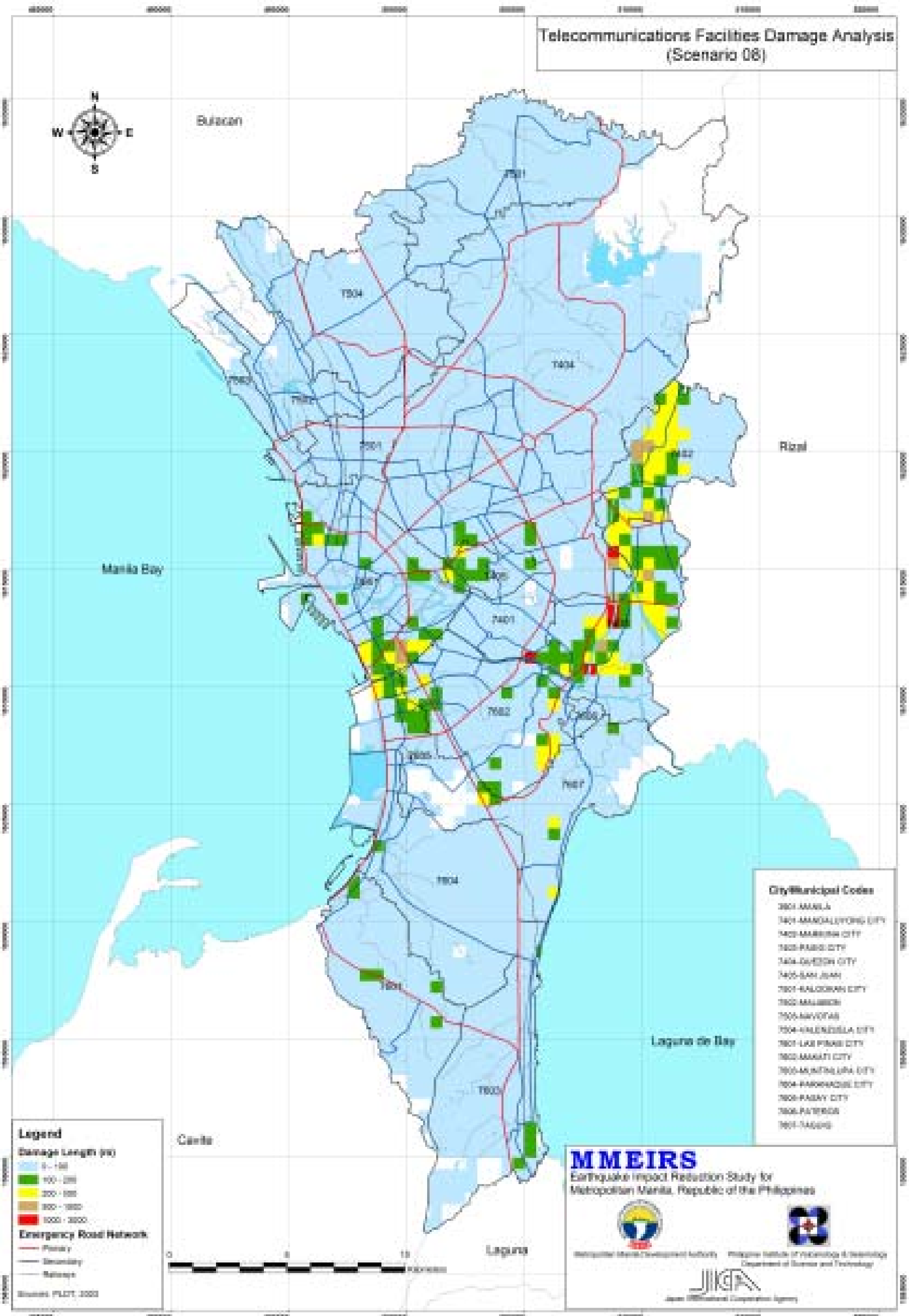


**Figure 13.6.7 Distribution of Telecommunication Cable Damage : Model 08**

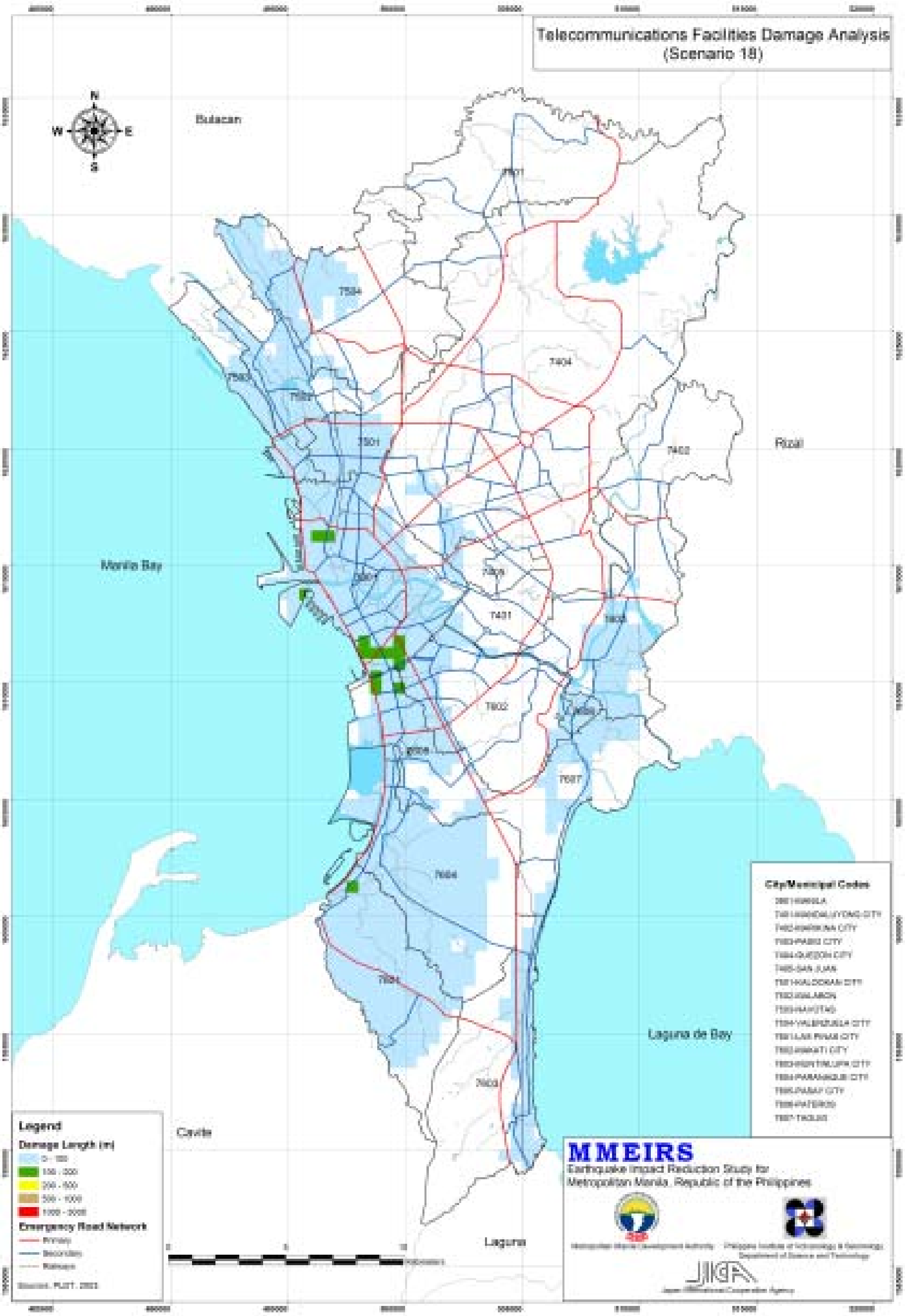


**Figure 13.6.8 Distribution of Telecommunication Cable Damage : Model 18**

## 13.7 Bridges and Flyovers

If a large earthquake occurs, many activities such as rescue and relief, transporting emergency goods and food have to be undertaken and therefore securing road network is indispensable. In this regards, bridge collapse will create serious problem to maintain road network and damage estimation of bridges are evaluated in the Study.

In parallel to the Study, another JICA study “The Study on the Improvement of Existing Bridges along Pasig River and Marikina River in the Republic of the Philippines” (referred as the JICA Bridge Study) is implemented and the Bridge Study evaluated 17 bridges crossing Pasig River and Marikina River and focuses mainly current damaged situation in detail from structural engineering viewpoint. The Earthquake Study used statistical evaluation method based on the actual situation of damage in the past, however, observation of each bridge regarding deterioration and cracks to each bridge is not considered. Therefore, for the specified 17 bridges, it is ideal to take the result of the Bridge Study. The result of the Bridge Study will be shown in the later section.

### 13.7.1 Bridge Damage Estimation

**1) Method**

Failure of bridge structure can give an extensive malfunction even though each failure is limited to particular point in line of road system. Contribution of road system in reconstruction term of the city is very large; when the bridges are safe, but if some of the bridges of road are destructed, repairing of bridge need very long term. This is the reason why the destruction of the bridges should be prevented as much as possible. Purpose of this section is to point out specific bridges that should be noticed in order to mitigate malfunction. This is so called “First screening”.

Considering that, the falling-off of the girder can give the most serious effect to the road system. Therefore, a methodology that is proposed by Kubo/Katayama (hereafter referred to as Katayama’s method) is selected in this study because that methodology is very effective for evaluate the bridges on the viewpoint of falling-off of the girder. Schema of this evaluation system is shown in Figure 13.7.1. As shown in Figure 13.7.1, almost necessary data can be obtained by observing the bridges in site except a few items.

In Katayama’s method, 10 items, which are likely to affect the falling-off probability of the girder, are studied. Each items consist of a few categories, they can be selected without complex calculations. Score chart for bridges/flyovers stability analysis is shown in Table 13.7.1. The category-score is given to each category as a weighting factor. The category score, which is modified by taking account of bridges in Metropolitan Manila, is shown in this table.

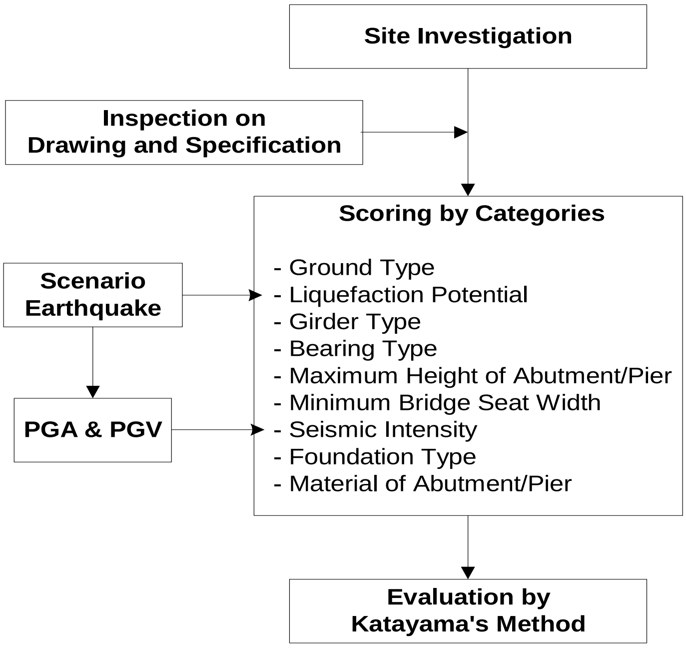


**Figure 13.7.1 Flowchart of Stability Analysis of bridges/flyovers**

**Table 13.7.1 Score Chart for Stability Analysis of Bridges/Flyovers**

| Item | Category | Category Score |
|---|---|---|
| Ground type | Stiff | 0.5 |
| | Medium | 1.0 |
| | Soft | 1.5 |
| | Very Soft | 1.8 |
| Probability of Liquefaction | Nothing | 1.0 |
| | Fear | 1.5 |
| | Having | 2.0 |
| Girder Type | Arch or Rigid Frame | 1.0 |
| | Continuous | 2.0 |
| | Simple | 3.0 |
| Bearing Type | with Specific Device (prevent falling-off of the girder) | 0.6 |
| | Bearing (with clear design concept) | 1.0 |
| | exist two bearing that can move axial direction | 1.15 |
| Max. Height of Abut./Pier | less than 5 m | 1.0 |
| | 5 to 10 m | 1.35 |
| | more than 10m | 1.7 |
| Number of Span | 1 span | 1.0 |
| | 2 spans or more | 1.75 |
| Min. Bridge Seat Width | Wide | 0.8 |
| | Narrow | 1.2 |
| JMA seismic intensity scale | 5 (4.5 to less than 5.0) | 1.0 |
| | 5.5 (5.0 to less than 5.5) | 1.7 |
| | 6.0 (5.5 to less than 6.0) | 2.4 |
| | 6.5 (6.0 to less than 6.5) | 3.0 |
| | 7.0 (6.5 and more than 6.5) | 3.5 |
| Foundation Type | Spread | 1.0 |
| | Pile | 0.9 |
| Material of Abut./Pier | Plain Concrete or others | 1.4 |
| | Reinforced Concrete | 1.0 |

The evaluated result can be given by substituting the data to the following equation;

$$y_i = \prod_{j=1}^{N} \prod_{k=1}^{M_j} X_{jk}^{\delta_j(jk)}$$

where,

$y_i$ : Predictors of damage degrees of $i$ -th bridges

$N$ : Number of all items

$M_j$ : Number of categories of $j$ -th item

$\delta_i(jk)$ : dummy variable

$\delta_i(jk)=1$ : when the characteristics of the $i$ -th bridge correspond to the category $k$ in the item

$\delta_i(jk)=0$ : otherwise

$X_{jk}$ : category-score for $k$ -th category of the $j$ -th item

$\prod_{j=1}^{N} \cdot$ : multiplication sign from $j$ -th value to $N$ -th value

If practical expression is needed, above-mentioned procedure means followings;

"Select the value of particular category for each item, and multiply the scores one another".

The seismic intensity scale in this context means the scale that is defined by JMA "the seismological observatory Japan", not correspond to MMI. The JMA intensity is selected because Katayama's method is based on this scale originally.

The analysis that is based on 30 sample of damaged bridges that are observed at 3 earthquake in Japan, (1923 Kanto, 1948 Fukui, 1964 Niigata) results following critical value.

The fall-off samples and the not falling-off samples were differentiated in the grade point value of 30 to 35.

All samples of falling-off and samples on the edge of fall-off differentiated in the grade point value of 26.

Therefore, the boundary value of Predictors of damage degrees for this study was set as follows;

**Table 13.7.2 Definition of Damage Degree of Bridges and Flyovers**

| | Class of damage degree | Boundary value of damage degrees |
|---|---|---|
| (A) | Large probability of falling-off | 30 and more than 30 |
| (B) | Moderate probability | 26 to less than 30 |
| (C) | Less probability | less than 26 |

## 2) Result of stability analysis

Total of 189 bridges and 38 flyovers exists in Metropolitan Manila were evaluated in the Study. As a result, 7 bridges are evaluated as large probability of falling-off and 2 bridges are evaluated as moderate probability of falling-off. Summary of result is shown as Table 13.7.3. Detailed list of bridges, which are evaluated as large or moderate probability of falling-off, are shown as Table 13.7.4 and result is illustrated as Figure 13.7.2.

| | | Existing Bridges and Flyovers in MM | | Inventory data available (No. of bridges for damage estimation) | | Bridge Damage (No of Bridges) | | | Bridge Damage (Ratio) | | | Flyover Damage (No of Flyovers) | | | Flyover Damage (Ratio) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LGU | LGU Code | No. of Bridges | No. of Flyovers | No. of Bridges | No. of Flyovers | SE8 | SE13 | SE18 | SE8 | SE13 | SE18 | SE8 | SE13 | SE18 | SE8 | SE13 | SE18 |
| Manila | 3901 | 63 | 17 | 56 | 3 | 4 | 0 | 2 | 7 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mandaluyong City | 7401 | 3 | 7 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Marikina City | 7402 | 6 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasig City | 7403 | 10 | 2 | 9 | 0 | 4 | 0 | 0 | 44 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Quezon City | 7404 | 45 | 11 | 41 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| San Juan | 7405 | 3 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kalookan City | 7501 | 8 | 1 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Malabon | 7502 | 12 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Navotas | 7503 | 7 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Valenzuela City | 7504 | 22 | 3 | 20 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Las Pinas City | 7601 | 6 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Makati City | 7602 | 5 | 28 | 4 | 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Muntinlupa City | 7603 | 11 | 1 | 7 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Paranaque City | 7604 | 5 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasay City | 7605 | 3 | 4 | 3 | 1 | 1 | 0 | 0 | 33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pateros | 7606 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Taguig | 7607 | 5 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| MM: Total | | **214** | **80** | **189** | **38** | **9** | **0** | **2** | **5** | **0** | **1** | **0** | **0** | **0** | **0** | **0** | **0** |
| | | **294** | | **227** | | | | | | | | | | | | | |

**Table 13.7.3 Summary of Bridge Stability Analysis**

**Table 13.7.4　　Bridges Evaluated as Large or Moderate Probability of Fall-off**

| Code No. of Bridge/Flyover: Main Code | Name of Bridge/Flyover | Name of Road, River, Flyover: Road | Name of Road, River, Flyover: River or Road | Const. Year (AD) | Number of Lanes (Total) | Bridge Width (m) | Bridge Length (m) | Ground Type: Stiff | Ground Type: Medium | Ground Type: Soft | Ground Type: Very Soft | Liquefaction Potential: Nothing | Liquefaction Potential: Fear | Liquefaction Potential: Having | Girder Type: Arch or Rigid Frame | Girder Type: Continuous Girder | Girder Type: Simple Girder | Type of Bearing: With specific device | Type of Bearing: Bearing (with clear design concept) | Type of Bearing: Movable | Max. Height of Abut./Pier: less than 5 m | Max. Height of Abut./Pier: 5 to 10 m | Max. Height of Abut./Pier: More than 10m | Material of Abut./Pier: Reinforced Concrete | Material of Abut./Pier: Plain Concrete / Others | Number of Spans: 1 span | Number of Spans: 2 or more spans | Foundation type: Pile | Foundation type: Spread | Bridge Seat Width: Wide | Bridge Seat Width: Narrow | Earthquake Intensity Scale (MMI) | Score | Damage class |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NC-5M-S602 | S. Padilla | S. Padilla | Estero de Magdalena | unknow | 2 | 6.95 | 12.50 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 5.4 | 36.3 | A |
| NC-NM-C302 | C.M. Recto 2 | Claro M. Recto | Estero De Magdalena | unknow | 3 | 10.90 | 15.80 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 5.4 | 31.1 | A |
| NC-NM-D201 | Roxas | Del Pan | Pasig | unknow | 6 | 30.00 | unknown | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 5.4 | 31.3 | A |
| NC-2M-A201 | Airport Road Bridge | Airport Road | Parañaque | 1980 | 2 | 12.24 | 40.80 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 5.5 | 26.1 | B |
| NC-1M-E201 | Alfonso Sandoval | Eagle | Marikina | unknow | 2 | 6.70 | 90.10 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 5.2 | 55.1 | A |
| NC-1M-S304 | Vargas Bridge | Pasig Boulevard Extension | Marikina | unknow | 2 | 7.42 | 99.85 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 5.1 | 34.0 | A |
| NC-1M-O102 | Ortigas | Ortigas | Mangahan Floodway | 1970 | 2 | 7.42 | unknown | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 5.2 | 51.0 | A |
| NC-NM-H101 | Balut I | Honorio Lopez Blvd | Estero Sunog Apog | unknow | 6 | 22.10 | unknown | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 5.0 | 37.8 | A |
| NC-1M-M401 | Modesto Bridge | Modesto Road | Marikina River | unknow | 2 | 8.60 | 60.86 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 5.6 | 26.1 | B |

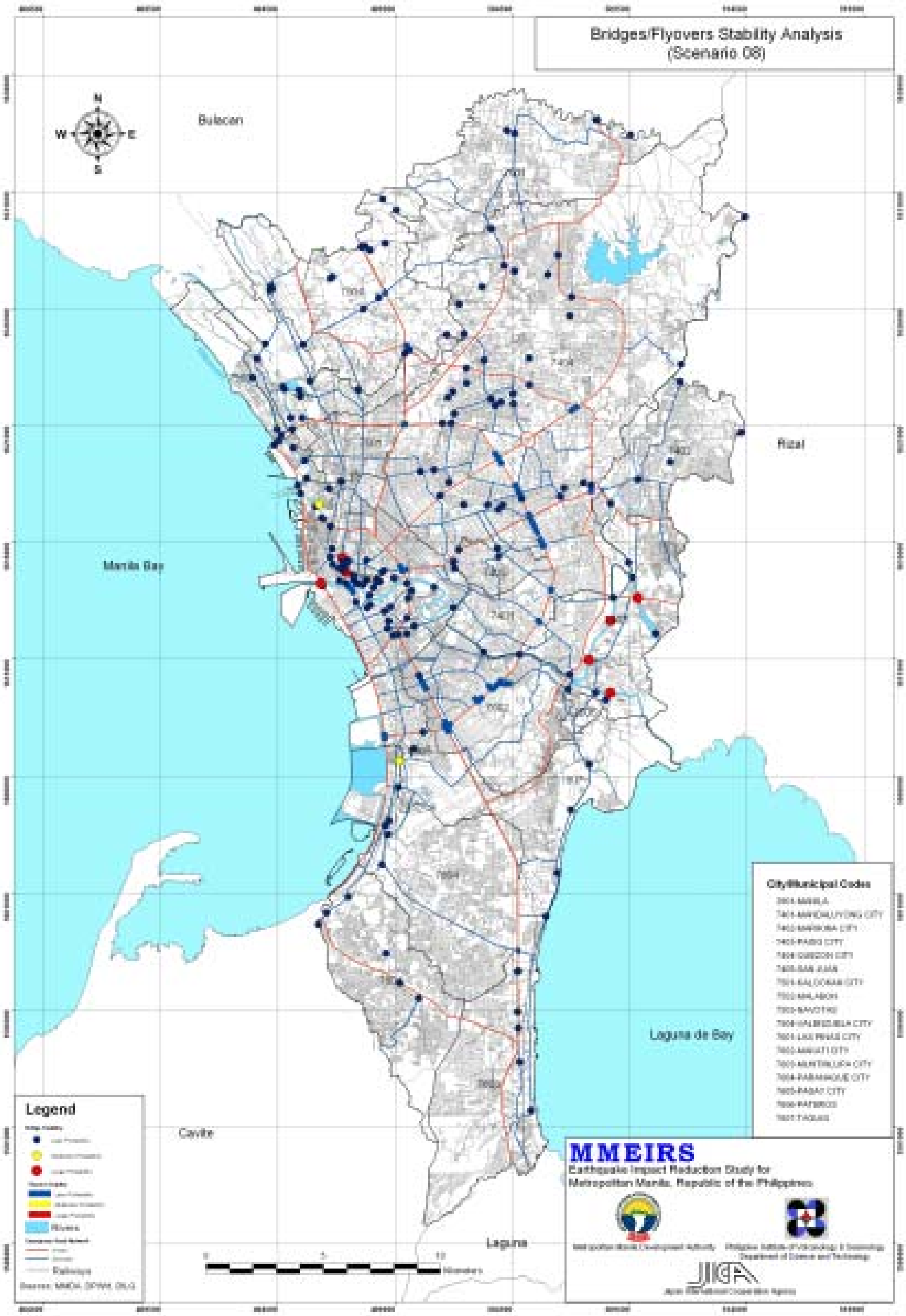


**Figure 13.7.2 Result of Bridges and Flyovers Stability Analysis**

As mentioned before, Katayama's method can evaluate vulnerability reflecting both qualitative characteristics and quantitative characteristics of the bridges. For instance "configuration of girder type", "bearing", "foundation", and "material of pier/abutment" represent qualitative characteristics.

It is reported that "configuration of girder type" can be effective factor to find the beginning point of falling–off of the girder in the report of many earthquake disaster especially "Kobe Earthquake".

As mentioned above the main purpose of Katayama's method is to differentiate the probability that the girder of the bridge fall-off. Other types of damage must be discussed using another method. i.e. damage of expansion joint failure of the girder and the crack of the pier

However it is effective to point out the bridges that have high risk, using this method as a first screening.

The statistical analysis of this method does not include the sample damaged by the ground surface displacement under the condition of faulting or landslide caused by faulting. Another discussion must be carried out if obvious evidence that indicate the possibility of faulting.

### 3) Coordination with Bridge Study

At present, in parallel to this seismic study, "The Study on the Improvement of Existing Bridges along Pasig River and Marikina River in the Republic of the Philippines" (hereinafter referred to as "Bridge Study")is under implementation. The main objective of the study is to conduct a study on the improvement of existing 17 bridges along Pasig River and Marikina River, and implement structural analysis referencing as built drawing, measurement, damage, material, reconstruction drawing, and ground survey, and evaluate difference between present required seismic resistant and the level of seismic resistance based on engineering judgment. As oppose to this, in this study, data on bridge measurement, structure, ground condition, estimated peak ground acceleration and etc. are utilized and damage estimation method, based on past damage to bridges, is used and evaluated. Comparison between both study is summarized as shown in Table 13.7.5.

**Table 13.7.5 Comparison of Seismic Resistance Evaluation of Bridges**

| Item \ Study | MMEIRS | Bridge Study |
|---|---|---|
| Objective | To prioritize order to strengthening existing bridges all over Metro Manila | To conduct a study on the improvement of bridges along Pasig River and Marikina River |
| Study Target | All the bridges in Metro Manila | 17 bridges along Pasig River and Marikina River |
| Survey Item | ・ Measurement<br>・ Structure<br>・ Ground Condition<br>・ PGA, etc. | ・ As Built Drawing<br>・ Measurement<br>・ Damage Survey<br>・ Material Survey<br>・ Reconstruction Drawing<br>・ Boring Investigation, etc. |
| Analysis Method | Statistical Damage Estimation based on past damage on bridges (Katayama Method) | Implement detail analysis in each bridge and evaluate seismic resistance with engineering judgment |
| Detail of Analysis | Depth of detail level is rather low to cover all bridges in Metro Manila | Depth of detail level is very high since detailed information is collected in each bridge and undertook dynamic analysis. |

Because of difference in analysis method as mentioned above, there are differences in the result of damage estimation caused by earthquake occurrence. For 17 bridges surveyed in the bridge study, difference of evaluation is shown in Table 13.7.6.

**Table 13.7.6 Comparison of Result of Damage Estimation**

| NO | Bridge Study Reference No. | MMEIRS Bridge Code | Bridge Name | Const. year | Result of Bridge Survey | Result of MMEIRS | Difference |
|---|---|---|---|---|---|---|---|
| | | | | | Vulnerability | Class of Damage Degree | |
| 1 | Pa1.1 | NC-NM-D201 | Delpan Bridge - Upstream | 1965 | Moderate | A | Less |
| | Pa1.2 | NC-NM-D201 | Delpan Bridge - Downstream | 1988 | Moderate | | |
| 2 | Pa2 | NC-NM-J301 | Jones Bridge | 1948 | High | C | Large |
| 3 | Pa3 | NC-NM-M201 | McArthur Bridge | 1948 | High | C | Large |
| 4 | Pa4 | NC-SM-Q101 | Quezon Bridge | 1946 | Moderate | C | Less |
| 5 | Pa5 | NC-SM-A201 | Ayala Bridge | 1935/1950 | High | C | Large |
| 6 | Pa6 | NC-NM-N102 | Nagtahan Bridge | 1966 | High | C | Large |
| 7 | Pa7 | NC-NM-P201 | Pandacan Bridge | 1997 | Low | C | None |
| 8 | Pa8 | NC-SM-N101 | Lambingan Bridge | 1979 | Moderate | C | Less |
| 9 | Pa9 | NC-2M-M101 | Makati-Mandaluyong Bridge | 1986 | Moderate | C | Less |
| 10 | Pa10.1 | NC-1M-E105 | Guadalupe Bridge (Central) | 1962 | Moderate | C | Large |
| | Pa10.2 | NC-1M-E105 | Guadalupe Bridge (Both Sides) | 1979 | High | | |
| 11 | Pa11 | NC-2M-C201 | C-5 Bridge | 1998 | Moderate | C | Less |
| 12 | Pa12 | NC-1M-P101 | Bambang Bridge | 1991 | Low | C | None |
| 13 | Ma1.1 | NC-1M-S304 | Vargas Bridge - Upstream | 1992 | Low | A | Large |
| | Ma1.2 | NC-1M-S304 | Vargas Bridge - Downstream | 1973 | Moderate | | |
| 14 | Ma2 | NC-1M-O101 | Rosario Bridge | 1952 | Moderate | C | Less |
| 15 | Ma3 | NC-1M-M301 | Marcos Bridge | 1978 | Moderate | C | Less |
| 16 | Ma4 | NC-2M-A102 | Marikina Bridge | 1980 | Moderate | C | Less |
| 17 | Ma5 | NC-QC-S301 | San Jose Bridge | 1980 | High | C | Large |

Definition of Vulnerability

- Low Vulnerability: When exposure to shaking from large earthquake should not cause collapse of all or part of the bridge. Where possible, damage that does occur should be readily detectable and accessible for inspection.
- Moderate Vulnerability: Total collapse of the bridge is not expected but damages to bridges would take time and difficult to restore.
- High Vulnerability: Probability of collapse under large earthquake could not be overruled, restoration to capacity under present code requirements will be very costly and impractical.

Class of Damage Degree

A ： Large probability of falling-off
B ： Moderate probability of falling-off
C ： Less probability of falling-off

Trigger factor of these differences is difference in scale of input seismic excitation. Moreover, in this study, detailed survey in each bridge was not investigated and visual survey to check cracks or deterioration on structure is not considered in this study. In the bridge study, compare to this study, detailed investigation on each bridge were undertaken and it is necessary to reflect the result of the bridge study to this study. However, changing the result intentionally which was analyzed using statistical method will create confusion on the result, therefore, result of damage estimation in this study will remain as it is. At the same time, as a final result of damage estimation in this study, as shown in the table below, result will be interpreted as result of overall estimation.

**Table 13.7.7 Overall Evaluation in the Study**

| NO | Bridge Study Reference No. | MMEIRS Bridge Code | Bridge Name | Result of Bridge Survey | Result of MMEIRS | Result of Overall Evaluation |
|---|---|---|---|---|---|---|
| | | | | Vulnerability | Class of Damage Degree | |
| 1 | Pa1.1 | NC-NM-D201 | Delpan Bridge - Upstream | Moderate | A | Risk level is high in MMEIRS. In this area, seismic intensity level and liquefaction potential is very high and these reasons cause high risk in this bridge. Further detail survey will be necessary. |
| | Pa1.2 | NC-NM-D201 | Delpan Bridge - Downstream | Moderate | | |
| 2 | Pa2 | NC-NM-J301 | Jones Bridge | High | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**High**". |
| 3 | Pa3 | NC-NM-M201 | McArthur Bridge | High | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**High**". |
| 4 | Pa4 | NC-SM-Q101 | Quezon Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 5 | Pa5 | NC-SM-A201 | Ayala Bridge | High | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**High**". |
| 6 | Pa6 | NC-NM-N102 | Nagtahan Bridge | High | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**High**". |
| 7 | Pa7 | NC-NM-P201 | Pandacan Bridge | Low | C | No Change |
| 8 | Pa8 | NC-SM-N101 | Lambingan Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 9 | Pa9 | NC-2M-M101 | Makati-Mandaluyong Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 10 | Pa10.1 | NC-1M-E105 | Guadalupe Bridge (Central) | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**High**". |
| | Pa10.2 | NC-1M-E105 | Guadalupe Bridge (Both Sides) | High | | |
| 11 | Pa11 | NC-2M-C201 | C-5 Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 12 | Pa12 | NC-1M-P101 | Bambang Bridge | Low | C | No Change |
| 13 | Ma1.1 | NC-1M-S304 | Vargas Bridge - Upstream | Low | A | Risk level is high in MMEIRS. In this area, seismic intensity level and liquefaction potential is very high and these reasons cause high risk in this bridge. Further detail survey will be necessary. |
| | Ma1.2 | NC-1M-S304 | Vargas Bridge - Downstream | Moderate | | |
| 14 | Ma2 | NC-1M-O101 | Rosario Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 15 | Ma3 | NC-1M-M301 | Marcos Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level is changed to "**Moderate**". |
| 16 | Ma4 | NC-2M-A102 | Marikina Bridge | Moderate | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level are changed to "**Moderate**". |
| 17 | Ma5 | NC-QC-S301 | San Jose Bridge | High | C | Risk level is low in MMEIRS, however, physical damage can be observed and risk level are changed to "**High**". |

#### 4) Controversial points of each bridge

The number of the bridges that is evaluated, as "Large probability" is 7, and evaluated as "Moderate probability" is 2. Therefore, detail explanation for each bridge is needed and each of them will be described as follows. Detailed investigation of each bridge is necessary for strengthening measures against possible earthquake.

**(1) Alfonso Sandoval Bridge (NC-1M-E201)**

The evaluated result of this bridge is 55.1, which is the highest score among others. The reason why this bridge possesses the high score is that this bridge is composed of simple girders with slant and spaces between girders, and seat width is rather small. In addition, this bridge is located in the area with very soft ground, high liquefaction potential, and high Seismic Intensity.

**(2) Ortigas Bridge (NC-1M-O102)**

The evaluated result of this bridge is 51.0. The reason why this bridge possesses the high score is that this bridge is composed of simple girders with many spans and that pier is comparatively high. In addition, this bridge is located in the area with high liquefaction potential, and high Seismic Intensity.

### (3) Balut I Bridge (NC-NM-H101)


The evaluated result of this bridge is 37.8. The reason why this bridge possesses the high score is that this bridge is composed of simple girders with little seat width. In addition, this bridge is located in the area with soft ground, high liquefaction potential, and high Seismic Intensity. These 3 items related to natural condition affects very much to this bridge.

### (4) S. Padilla Bridge (NC-SM-S602)

The evaluated result of this bridge is 36.3. The picture can not be observed well on this structure, however, collision of columns can be observed. This bridge has simple girders and ground condition is very bad with high liquefaction potential.

**(5) Vargas Bridge (NC-1M-S304)**


The evaluated result of this bridge is 34.0. Downstream and Upstream structure of this bridge is different. Girder type of Downstream is Steel Plate with simple girders and Upstream is PC Gerber Girder. The reason why this bridge possesses the high score is that this bridge is composed of simple girders (Downstream) and Gerber girder, which both of structure is weak against earthquake. Also this bridge is located in the area with high liquefaction potential and high seismic intensity. However, this bridge is rather good if any falling off device are added to survive from strong earthquake motion.

**(6) Roxas Bridge (NC-NM-D201)**


The evaluated result of this bridge is 31.3. This bridge also has different structure in Downstream and Upstream. However, both of girder type is PC Gerber box girder. According to the past earthquakes, Gerber bridges are very weak against earthquake and this bridge has small seat width. In addition, this bridge is located in the area with high liquefaction potential, and high Seismic Intensity.

**(7) C.M. Recto 2 Bridge (NC-NM-C302)**

The evaluated result of this bridge is 31.1. The reason why this bridge possesses the high score is that it is in the area with very soft ground, high liquefaction potential, and Seismic Intensity is high. These 3 items related to natural condition affects very much to this bridge. In addition, since bridge is illegally occupied, any maintenance or inspection of bridge can be undertaken.

**(8) Airport Road Bridge (NC-2M-A201)**

The evaluated result of this bridge is 26.1. The reason why this bridge possesses the high score is that it is composed of simple girders with small seat width and fixed girder area. In addition, this bridge is located in the area with soft ground, high liquefaction potential, and high Seismic Intensity. These 3 items related to natural condition affects very much to this bridge.

**(9) Modesta Bridge (NC-1M-M401)**

The evaluated result of this bridge is 26.1. The reason why this bridge possesses the high score is that this bridge is composed of simple girders and that piers are comparatively high. However, compare to the other high score bridges, this bridge is located in the area with medium stiffness ground, medium liquefaction potential, but high Seismic Intensity. With small effort like adding fall prevention material will help avoiding fall of superstructure.

## 13.8 Transportation

### 13.8.1 Port

The North Port, Container Terminal and South Port are the three main ports in Metropolitan Manila that large ships can use. These ports are facing to Manila Bay. Most of the damage of ports and harbors due to past earthquakes were caused by liquefaction. In many cases, pier sank or tilted and cargo-handling machine will be damaged.

The liquefaction potential of three ports due to scenario earthquakes are summarized in Table 13.8.1. In all models, the pier of the port will be damaged by liquefaction and function of the ports will be lost.

**Table 13.8.1 Liquefaction Potential of Ports**

| Model | North Port | Container Terminal | South Port |
|---|---|---|---|
| 08 | Relatively High | Relatively High | High |
| 13 | Relatively High | Relatively High | Relatively High |
| 18 | Relatively High | Relatively High | High |

### 13.8.2 Airport

Ninoy Aquino International Airport is the only one airport in Metropolitan Manila. There are no experiences of severe damage to the international airport, where large passenger airplane can use, due to the earthquake. This may be explained by the fact that the facilities of the international airport are strongly built to support the heavy weight aircraft. However, in some cases, airport was closed for several days because of the crack of runway, damage to control tower or collapse of landing support system. In this section, the effect of scenario earthquake to the airport was estimated from the relation between damage experience and earthquake motion.

The recent earthquake damages to the airport are summarized in Table 13.8.2. The damage situation was classified from 0 to 2 and the relation with PGA was shown in Table 13.8.2. This figure shows that the airport may be closed for several days if PGA is larger than 300 gal (=0.3g).

The PGA at Ninoy Aquino International Airport by scenario earthquakes is shown in Table 13.8.3. There is high possibility of more than several days' closure of the airport by Model 08. Model 18 may also bring closure of the airport.

**Table 13.8.2 Damage to Airports by Earthquake**

| Earthquake | Airport | Damage Grade | Damage | Observed or Estimated Acceleration |
|---|---|---|---|---|
| 1989 Loma Prieta Earthquake (USA) | San Francisco Airport (International) | 1 | - Hair crack of runway<br>- Non-structure damage of terminal<br>- Fall of ceilings in control tower<br>- Windowpanes of control tower collapsed<br>- Airport was closed in 13 hours | 323 gal |
| 1993 Kushiro-oki Earthquake (Japan) | Kushiro Airport (International) | 1 | - Minor crack of slope | 520 gal |
| 1993 Hokkaido Nansei-oki Earthquake (Japan) | Okushiri Airport (Commuter) | 2 | - 20m crack in runway<br>- Airport was closed for 4 days<br>- Damage to landing instruction lights | 392 gal |
| 1995 Kobe Earthquake (Japan) | Kansai Airport (International) | 0 | - No damage | 169 gal |
| 2000 Tottori-ken Seibu Earthquake (Japan) | Yonago Airport (Local) | 2 | - Crack of runway<br>- Airport was closed for 5 days | 546 gal |
| 2001 Geiyo Earthquake (Japan) | Hiroshima Airport (Local) | 0 | - No damage | 298 gal |
| | Nishi Hiroshima Airport (Commuter) | 1 | - Minor damage | 298 gal |
| | Matsuyama Airport (Local) | 1 | - Minor damage | 298 gal |
| 2001 Seattle Earthquake (USA) | Seattle Seatac Airport (International) | 1 | - Damage to control tower | 194 gal |
| | King County Airport (in Bowing factory) | 2 | - Major crack of runway | 267 gal |

Note
Damage Grade 0 : No Damage
Damage Grade 1 : Minor Damage, Airport will not closed more than 1 day
Damage Grade 2 : Major Damage, Airport will be close for several days

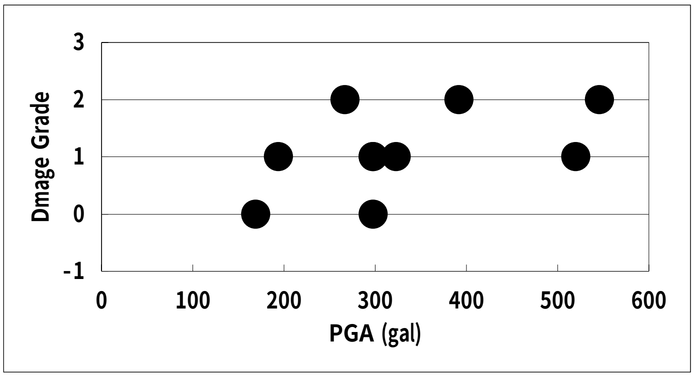


**Figure 13.8.1 Damage Grade to Airport and PGA**

**Table 13.8.3 Acceleration at Airport by Scenario Earthquake**

| Model | Acceleration |
|---|---|
| 08 | 500 - 700 gal |
| 13 | 100 - 200 gal |
| 18 | 300 - 400 gal |

## 13.9 Angat Dam

Detail analysis of Angat Dam is out of scope of the Study. Here stability and problems to the Dam is reviewed.

### 13.9.1 Review of Existing Report

Stability of Angat Dam and related facilities are discussed in "Study of Angat Dam Rehabilitation Project, JICA, 1989" (hereinafter called as "Dam Study"). Summary and recommendation of the Dam Study are shown in Table 13.9.1 and Table 13.9.2.

**Table 13.9.1 Summary of the Existing Report**

| Consideration Item | Result | Prioritization of Countermeasure |
|---|---|---|
| Capability of Discharge for Flood Way | If water level in the reservoir can be limited up to elev. 212.0 meter in a flood season, the flood way can control discharge for every flood. | — |
| Stability of Dam and Dike | -There is no damage, which should describe.<br>-In case of ordinary term, the dam and dike is stable.<br>-In case of earthquake term, there is a possibility of occurrence of surface failure. However, the dam and the dike itself is stable. | It is not necessary to repair immediately. |
| Landslide in Former Batch Plant | A landslide happened in the batch plant, where is reclaimed ground, when the dam was constructed. There is a possibility of recurrence of the landslide. | It is necessary to conduct countermeasure for landslide immediately. |
| Leak from Dike | Total amount of leakage water for a year is 261,000 cubic meters. It loses 56,100KWh as electric energy. Cost of a countermeasure for leakage water is expensive comparison with cost of losing electric energy. It is uncertain the countermeasure for leakage water. | It is not necessary to repair immediately. |
| Leak from Iron Pipe | Leakage point on iron pipe is two places, which are a part of branch and starting point. Total amount of leakage water is 0.7 cubic meter per second. | It is necessary to repair as soon as possible. |

Source: Study of Angat Dam Rehabilitation Project, JICA, 1989

**Table 13.9.2 Recommendations on the Existing Report**

| Recommendation Item | Content |
|---|---|
| Repairing Construction | - To conduct a countermeasure against the landslide in the former batch plant<br>- To Conduct a countermeasure against the leakage water from the dike.<br>- To conduct a countermeasure against the leakage water from the iron pipes. |
| Manage of the Dam | To get rid of grass and bushes on the dam and the dike. |
| Monitoring | - Amount of the leakage water.<br>- When an earthquake, which ground acceleration is more than 70 gal, to inspect of the dam and the dike and survey the slope gradient. |

Source: Study of Angat Dam Rehabilitation Project, JICA, 1989

The report concludes that 1) performance of the dam during the earthquake is stable and 2) when earthquake of peak ground acceleration exceeds 70 gal, inspection is required. The report was compiled in 1989. One year after 1990 North Luzon Earthquake occurred and importance of seismic activities near Metropolitan Manila is focused.

In this Study (MMEIRS), estimated peak ground acceleration is far bigger and the contents of those conclusion and recommendation shall be re-considered.

### 13.9.2 Location of West Valley Fault System and Angat Dam

Recent PHIVOLCS research clarified that extension of West Valley Fault System (WVFS) reached to Angat Dam Area (Figure 13.9.1). Surface fault trace transect just east of the Dam and also Angat Reservoirs.

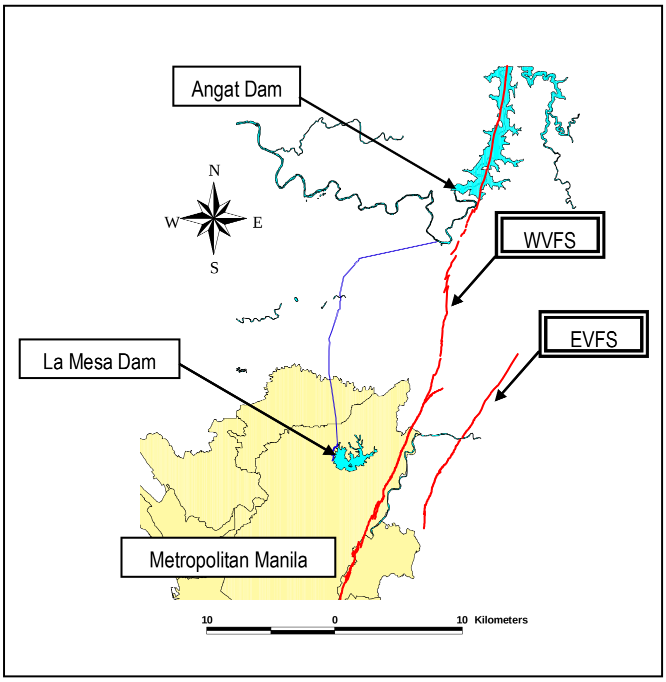


**Figure 13.9.1 Location of the Angat Dam and West Valley Fault System**

In earthquake scenario setting, WVFS extends north to La Mesa Dam in Model 08, earthquake of magnitude 7.2. On the other hand, WVFS extends north to Angat Dam in Model 09, earthquake of magnitude 7.4. Possibility of occurrence Model 09 earthquake is lower to that of Model 08, but there is no way to determine actual fault trace during earthquake. Peak Ground Acceleration is estimated as over 1g (1000 gal) along the fault for the two models. This means existence of the WVFS is substantially important to stability evaluation of Dam facilities.

### 13.9.3 Earthquake Effect

**1) Dam Stability**

Such a huge earthquake is not considered in designing of dam facilities. Ground motion directly affects dam stability. The worst case is collapse of dam itself. Another is large deformation of the dam. These lead to at first flooding and secondary shortage of water resources. Vibrate

**2) Flooding in Downstream Area**

There live over 500 thousands people in downstream area of Angat Dam (Table 13.9.3). Some of these people will suffer from flooding. It is sudden phenomenon and there is no time for evacuation. This leads to another human loss.

**Table 13.9.3 Population and Number of Households in the Downstream Basin of the Angat Dam**

| City/Municipality | Population | Number of Households |
|---|---|---|
| Norzagaray | 76,978 | 15,912 |
| Angat | 46,033 | 9,483 |
| San Rafael | 69,770 | 14,639 |
| Bustos | 47,091 | 9,799 |
| Baliuag | 119,675 | 25,050 |
| Plaridel | 80,481 | 16,596 |
| Pulilan | 68,188 | 13,948 |
| Total | 508,216 | 105,427 |

Source; Census 2000

**3) Water Supply**

Angat Reservoir is only one waterworks source to Metropolitan Manila. The water is transmitted to La Mesa Reservoir, secondary reservoir. Capacity of La Mesa Reservoirs is seven days water supply in regular condition. Once Angat Dam facilities are damaged and water supply stooped, this lead directly affect to shortage of drinking water, medical care, sanitary environment and so on.

**4) Electric Power Supply**

Another important function of Angat Dam is electric power generation. Once water lost and power generator facilities are damaged, this leads to shortage of electric power supply for a long time.

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