Updating of GIS Building Inventory Data for Earthquake Damage Assessment Using High-Resolution Satellite Image – Application to Metro Manila, Philippines –

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Abstract: The GIS building inventory data in Metro Manila, Philippines is updated by using the satellite remote sensing data in order for the reliable earthquake damage assessment. The distribution of mid-rise and high-rise buildings is captured by the application of the building detection method using the high-resolution satellite images. The distribution of low-rise buildings is estimated from the land cover classification based on the time-series middle-resolution satellite images. The building damage due to a scenario earthquake is assessed by means of simplified procedure considering the seismic capacity of the buildings. The result shows that the damage of low-rise buildings is concentrated at lowland areas while the damage of high-rise buildings are slight to moderate at most of the areas.

1. INTRODUCTION

Influx of population to urban areas is a common problem faced by developing countries. The number of mega-cities, which are vulnerable to disasters, is increasing. The disaster mitigation activities in mega-cities should be strengthening immediately. The earthquake loss estimation is indispensable to efficient earthquake disaster mitigation planning. The GIS (Geographic Information System) building inventory data is a basic data to practice the reliable loss estimation. Due to the rapid growth in the urban area, the number of buildings has been swelling. Not only the number of low-rise buildings, but also that of high-rise buildings is increasing especially in developed commercial zones. However, the system for updating GIS data continuously is hardly established in developing countries. As a result, the number of buildings that are not included in the GIS data is increasing.

Satellite remote sensing can capture land cover information in urban areas widely and continuously. Recently, high-resolution satellite images (e.g., IKONOS, QuickBird) with the ground resolution 1m or less have been available at relatively low cost. Individual building in an urban area can be identified in the images. Therefore, the high-resolution satellite images are useful to grasp the distribution of mid-rise and high-rise buildings that are difficult to identify the individual location in middle-resolution satellite images (e.g., Lantsat, SPOT). In this paper, the method for automatic detection of newly constructed buildings from a high-resolution satellite image is applied in Metro Manila, Philippines in order to grasp the distribution of mid-rise and high-rise buildings. Combining the result together with the distribution of low-rise buildings estimated from the land cover classification based on the time-series Landsat images, the up-to-date building inventory data is constructed. The building damage assessment due to a scenario earthquake is conducted by means of simplified procedure based on the seismic capacity of the buildings and the computed ground motion.

2. SOCIAL CONDITION AND DATA SOURCES IN METRO MANILA

Metro Manila, the capital of Philippines, consists of seventeen cities and municipalities including Manila, Makati, Quezon and Marikina. The population concentration and the urban sprawl have been strongly observed. As shown in Fig. 1, about fifty years ago the urbanized area was less than $100km^2$ with a population of 1.6 million, but now is expanded to more than $600km^2$ with a population of 10 millions (Doi and Kim (1998)). In the downtown such as Manila, densely built-up area with low-rise and mid-rise buildings has been developed. In the commercial zones such as Makati and Ortigas, many high-rise buildings have been constructed. According with the sprawl of urbanized area, new commercial zones have been expanded.

In Metro Manila, the GIS base map was constructed based on the topographic map with a scale of 1/10,000 edited in 1987. In the base map, the footprints of the buildings and the congested housing areas are included. The building survey was conducted in the major commercial zones such as Makati, Manila, Ortigas and Quezon (Midorikawa *et al.* (2002)). The number of the buildings whose footprints are shown is about 280,000. In Metro Manila, the total number of the buildings is about 910,000 as of 1989 (Sarausad (1993)). The difference of the numbers suggests that about 630,000 buildings are located in the congested areas. Thus, assuming that the 630,000 low-rise buildings are uniformly distributed in the congested areas, they are added in the GIS data. However, the buildings that are newly constructed after 1989 are not included in the GIS data.

The satellite IKONOS color images with 1m ground resolution are used in this study in order to grasp the distribution of newly constructed mid-rise and high-rise buildings. These images are composed of 3 bands with visible (Red, Green, Blue) range and 1 band with near infrared (NIR) range. Figure 2 shows the coverage areas of the images. These images cover 75 percent of Metro Manila.

3. FLOW OF UPDATING GIS BUILDING INVENTORY DATA

In order to assess the earthquake damage appropriately, it is necessary to grasp the up-to-date building distribution. Figure 3 shows the flow of updating GIS building inventory data employed in this study. The distribution of mid-rise and high-rise buildings is captured by the high-resolution satellite images, while the distribution of low-rise buildings is estimated from the middle-resolution satellite images.

Individual location and their height of mid-rise and high-rise buildings are detected from IKONOS images using the method proposed by the authors (Miura and Midorikawa (2003)). The locations of the newly constructed buildings are detected from the difference between the image and the GIS data. In this method, the edges are extracted from the image in order to detect the boundaries of the buildings. The shadow area, the vegetation area, the existing building area, the road area and the water area are extracted as “the known areas” from the image and the GIS data. After the elimination of the edges in the known areas, the image analysis is conducted for discriminating building edges from the others. Considering that edges of a building are always neighbored to their shadow, the edge pixels neighbored to the shadow pixels in the direction of the sun are identified as the building edges. The regions including the building edges are finally extracted in the analysis. The numbers of stories of the buildings are estimated using the shadow length observed in the image.

The up-to-date distribution of low-rise buildings is estimated from the land cover classification based on the time-series Landsat images by Yamazaki *et al.* (2003). They classified the built-up areas into the three categories according to the developing period. Considering that the newest built-up areas almost correspond with the distribution of the buildings that are constructed after the edit of the GIS data, we estimated the distribution and amount of the low-rise buildings. Combining the results of the analysis, the GIS building inventory data is updated.

4. DISTRIBUTION OF MID-RISE AND HIGH-RISE BUILDINGS

First, we examine the applicability of the proposed method (Miura and Midorikawa (2003)) to the data in Metro Manila. Figure 4 (a) shows a part of the IKONOS image acquired in 2001/9/28. The area covers recently developed commercial zone in the northeastern part of Makati. The high-rise buildings shown in the circles in Fig. 4(a) are newly constructed after the edit of GIS data.

We apply the method to the data shown in Fig. 4(a). Figure 4(b) shows the result of the analysis. The rectangles indicate the locations of correctly detected buildings. The triangles and the circles represent the location of mis-detected objects and un-detected buildings, respectively. All of the high-rise buildings shown in Fig. 4(a) are detected correctly. Figure 5 shows the result arranged according to the building size and the number of stories. A lot of low-rise buildings whose sizes are under 25m are observed in the image. Using the proposed method, it is difficult to detect such low-rise and small buildings individually. However, almost 90% of the mid-rise and high-rise buildings are detected successfully.

We estimate the numbers of stories using the shadow lengths observed in the image. The number of stories is calculated using the shadow length, the sun elevation and the average floor height set as 3.2m. The result shows that most of the buildings are estimated successfully within the error range of 2 stories.

The proposed method is applied to the whole area of the images shown in Fig. 2. Figure 6 shows the result of the analysis. The regions indicate the locations of detected buildings. About 2,600 newly constructed buildings are detected from the images. The numbers of stories of the buildings are estimated using their shadow lengths. The number of the mid-rise buildings (4-9F), that of the high-rise buildings (10-30F) and that of the super high-rise buildings (31F-) are 666, 202 and 24, respectively. In order to provide quantitative assessment of the analysis, the un-detected buildings are extracted by the visual interpretation with the images. The detection percentage of mid-rise and high-rise buildings is computed as shown in Table 1. The result shows that all the detection percentages are more than 90%. All the footprints of the newly constructed buildings are included in the GIS data.

5. DISTRIBUTION OF LOW-RISE BUILDINGS

It is difficult to detect the individual location of low-rise buildings accurately using the proposed method. Yamazaki *et al.* (2003) revealed the distribution of built-up area in Metro Manila using time-series Landsat images (30m-resolution). They classified the built-up areas into the three categories according to the developing period (-1972, 1972-1992, 1992-). The older built-up areas before 1992 almost coincide with the building distribution of the existing GIS data. The built-up areas after 1992 correspond with the building distribution developed after the edit of the GIS data. We compare the number of the buildings of the existing data and the built-up areas. The number of the buildings in the existing data is about 910,000 while the number of pixels in the built-up areas before 1992 is about 330,000. Therefore, the number of buildings that are located in the one pixel is estimated at three. Considering that the number of pixels in the built-up areas after 1992 is about 130,000, the number of the buildings in the built-up area after 1992 is estimated at about 380,000. Assuming that the most of the estimated buildings consist of low-rise buildings and the low-rise buildings are uniformly distributed in the built-up areas, they are added in the GIS data. Combining the distribution of mid-rise and high-rise buildings and that of low-rise buildings, the building inventory data is updated. The total number of the buildings is estimated at about 1,290,000, which almost corresponds with the result of the recent survey by JICA *et al.* (2003).

6. ESTIMATION OF BUILDING DAMAGE

Using the updated GIS building inventory data, building damage assessment due to a scenario earthquake is conducted considering the seismic capacity of the buildings. The flow of building damage estimation is shown in Fig. 7. The ground motion due to a scenario earthquake was computed by the hybrid simulation method with the 3-D underground structure model and the soil response analysis using the surface soil profiles (Yamada *et al.* (2003)). The building response is evaluated by the capacity spectrum method. The buildings in Metro Manila are classified into several categories. The nonlinear response of the buildings is estimated from the capacity curves and the ground motion spectrum. The damage state for each building category is determined by the building response and the fragility curve. Multiplying the damage state of each building category and the updated building inventory data, the distribution of the building damage is computed.

The building types proposed by Vibrametrics, Inc. (2003a) are used in this study. They classified the buildings into three major categories; CHB (concrete hollow block), C1 (concrete moment frame building) and C2 (concrete shear wall building), and twenty detailed categories considering the possible height range and the design vintage for each structural type. Taking account of the height range and the typical design vintage, we classify the buildings into seven categories shown in Table 2. The capacity curves and the fragility curves proposed by Vibrametrics, Inc. (2003a, b) are used in the capacity spectrum method.

The West Valley Fault is selected as the source of a scenario earthquake because the fault is closer to the central part of Metro Manila. The computed peak ground velocity on the surface due to the scenario earthquake (M 6.7) is shown in Fig. 8 (a). The large ground motion is computed in the areas that are located on the thick soft soil such as Coastal lowland and Marikina valley.

The number of the damaged buildings is computed by multiplying the damage ratio and the number of the buildings. Figure 8 (b) shows the distribution of low-rise buildings (1-3F) with the complete or extensive damage level. The damage of low-rise buildings is concentrated in Coastal lowland and Marikina valley. The number of the damaged buildings is about 180,000, which corresponds with almost 15% of the low-rise buildings in Metro Manila.

The distribution of mid-rise buildings (4-7F) with the complete or extensive damage level is shown in Fig. 8 (c). The damage is concentrated in Manila. About 20% of mid-rise buildings are damaged because a lot of mid-rise buildings are located in Manila. The distributions of high-rise buildings with the moderate damage level are shown in Fig. 8 (d)-(f). The building damages for the higher types are relatively slight. Most of the high-rise buildings may suffer less than moderate damage level. One of the reasons is the spectral characteristic of ground motion. The magnitude of the scenario earthquake (6.7) is not large enough to generate the strong ground motion with longer period, which contributed to the response of higher buildings.

7. CONCLUSIONS

The GIS building inventory data in Metro Manila, Philippines is updated by using the satellite remote sensing data in order for the reliable earthquake damage assessment. The distribution of mid-rise and high-rise buildings is captured by the application of the building detection method using the IKONOS images. The distribution of the low-rise buildings is estimated from the land cover classification based on the time-series Landsat images. The building damage due to a scenario earthquake is assessed by means of simplified procedure considering the seismic capacity of the buildings. The result shows that the damage of low-rise buildings is concentrated at lowland areas while the damage of high-rise buildings are slight to moderate at most of the areas.

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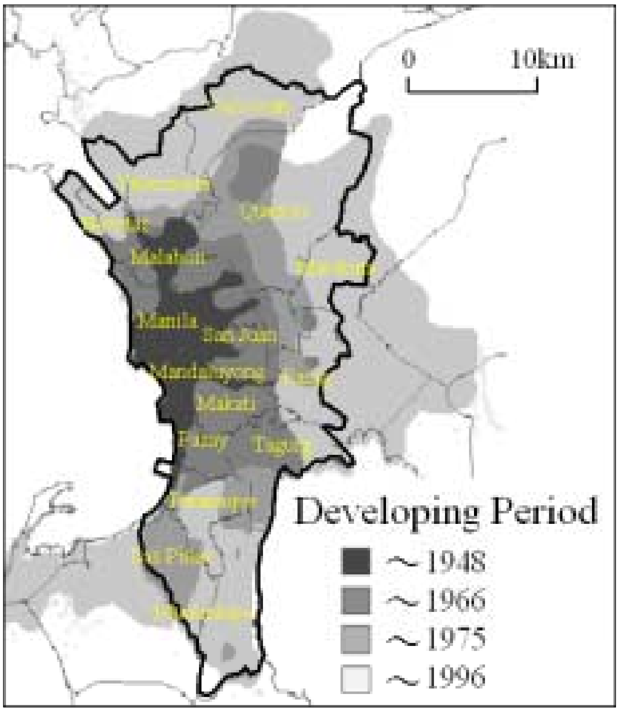

Fig.1 Urban development in Metro Manila

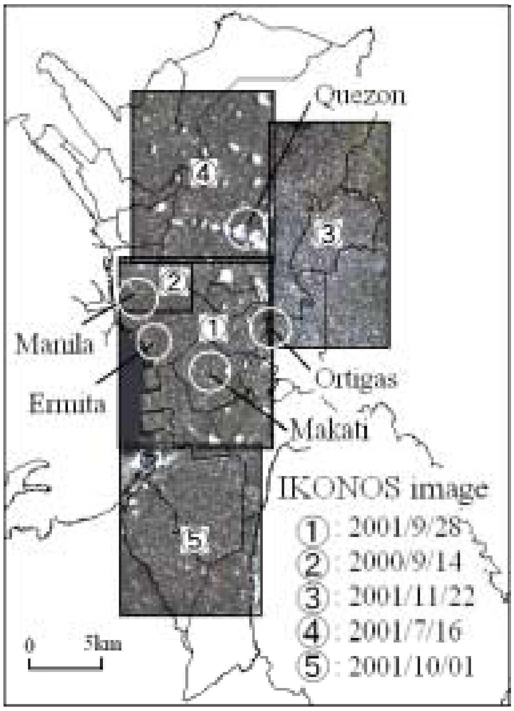

Fig.2 Coverage area of IKONOS images

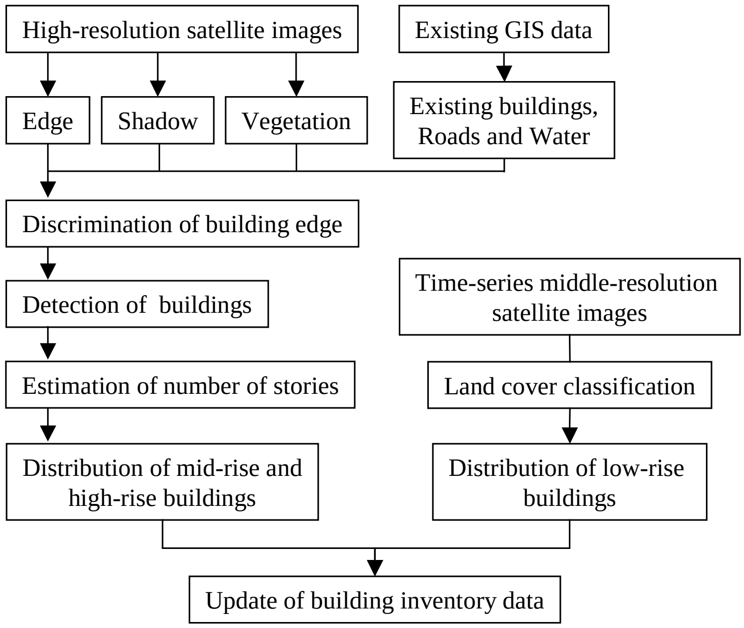

Fig.3 Flow of updating GIS building inventory data

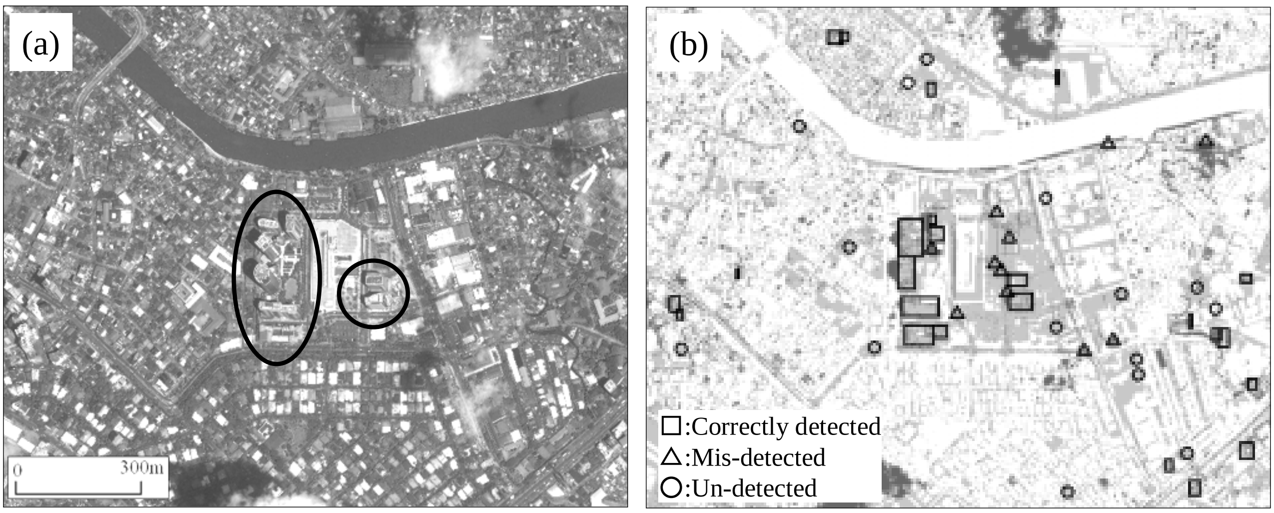

Fig.4 (a) IKONOS image in the developed commercial zone
(b) Result of the image analysis

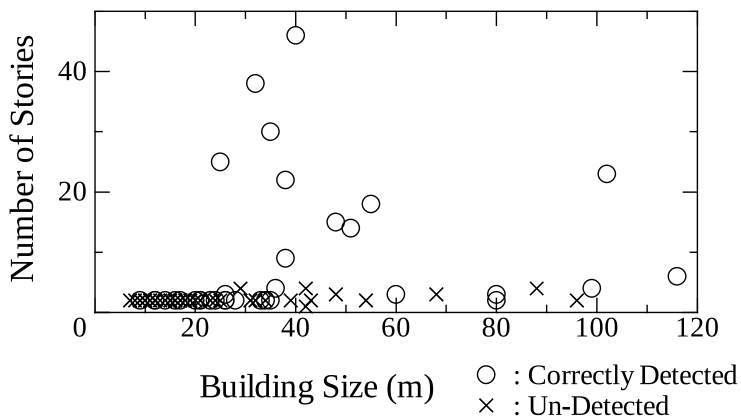

Fig.5 Relationship between building size and number of stories

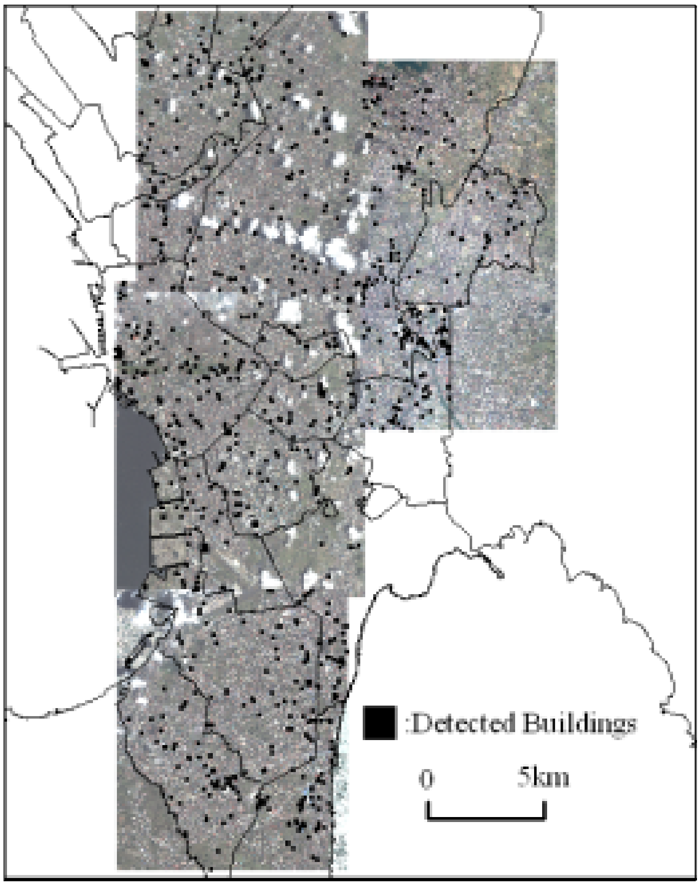

Fig.6 Locations of detected buildings

Table 1 Detection percentage of the analysis

The number of stories	Detected	Un-detected	Detection percentage
4-9	666	74	90%
10-30	202	7	97%
31-	24	0	100%

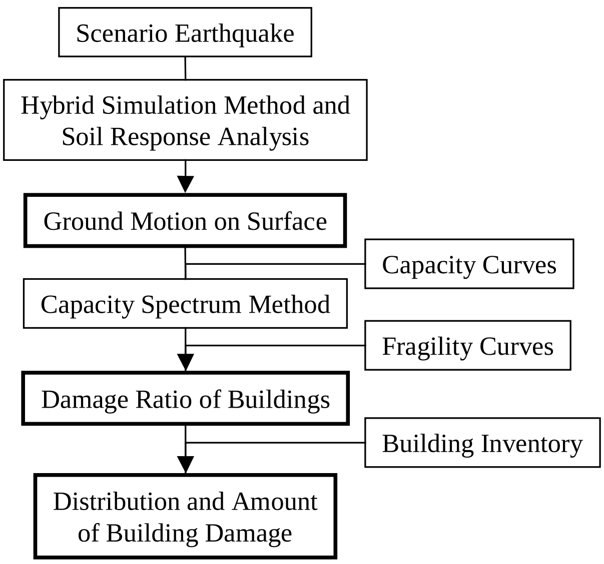

Fig.7 Flow of building damage estimation

Table 2 Building types used in this study

Building Type	Structural Type	Number of Stories	Design Vintage
CHB	Concrete Hollow Block	1-3	Sub-Type 3
C1L	Concrete Moment Frame Building	1-3	Sub-Type 3
C1M		4-7	Sub-Type 3
C1H		8-15	Sub-Type 2
C2V	Concrete Shear Wall Building	16-25	Sub-Type 1
C2E		26-35	Sub-Type 1
C2S		36-	Sub-Type 1

Sub-Type1 : Constructed after 1992
Sub-Type 2: Constructed from 1972-1991
Sub-Type 3 : Constructed before 1971

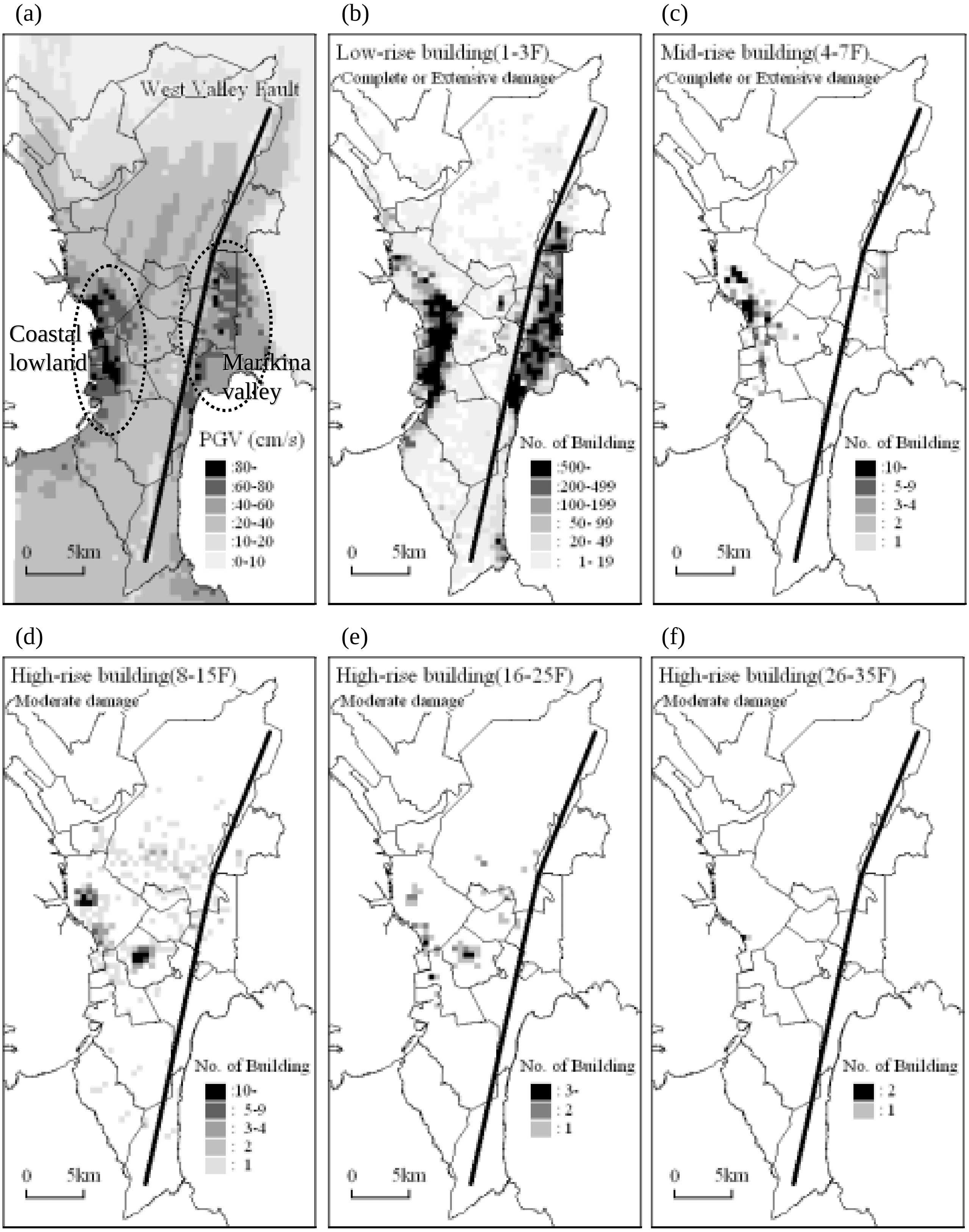

Fig.8 (a) Peak ground velocity on surface
(b) Distribution of low-rise building with complete or extensive damage
(c) Distribution of mid-rise building (4-7F) with complete or extensive damage
(d) Distribution of high-rise building (8-15F) with moderate damage
(e) Distribution of high-rise building (16-25F) with moderate damage
(f) Distribution of high-rise building (26-35F) with moderate damage