6. Estimation of Macroseismic Intensity

6.1 Macroseismic Intensity deduced from the Building Damage

Y. Hisada and K. Meguro

During the 2001 Gujarat, India, earthquake, strong motion records were not available in the damaged area except Ahmedabad (see Fig. 6.1; Roorkee University, Dept. of Earthq. Engng, 2001). Thus, in order to estimate the strong motion, we carried out building damage surveys, and estimated a MSK intensities on the basis of European Macroseismic Scale 1998 (EMS98). For this purpose, the following five groups carried out the surveys to obtain the building damage data.

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Group 3: T. Toshinawa (Meisei Univ.)
Group 4: Y. Hayashi and S. Sawada (Kyoto Univ.) and S. Pareek (Nihon Univ.)
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EMS98 is a macroseismic scale proposed by the European Seismological Commission of IASPEI (International Association of Seismology and Physics of Earth’s Interior) in 1998, which was modified from the MSK scale (1964) to be applicable to various modern structures. Similar to the MSK scale, EMS98 defines the building vulnerability classes from A to F, as shown in Fig. 6.2. It also classifies building damage into Grade 1 to 5, as shown in Fig. 6.3. The intensity was deduced from the numbers of damaged buildings for various damage grades and vulnerability classes, as shown in Table 6.1.

We classified the vulnerability of the buildings in Gujarat as follows (see Fig. 6.2). First, the masonry houses are classified into Type 1 to 3. **Type 1** represents typical traditional houses, which are made of rubble stones with mud mortar and wooden roofs (see Photo 6.1). This type is

![Fig. 6.1 The Gujarat state and the epicenter of the Gujarat earthquake (USGS, 2001)](image)

![Fig. 6.2 Vulnerability classes according to building types by EMS98](image)
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Table 6.1 Relation between the MSK intensity and the numbers of damaged buildings for various vulnerability classes and damage grades (EMS98)

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Vulnerability Class A</th>
<th>Vulnerability Class B</th>
<th>Vulnerability Class C</th>
<th>Vulnerability Class D</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>a few</td>
<td>a few</td>
<td>a few</td>
<td>a few</td>
</tr>
<tr>
<td>G2</td>
<td>many</td>
<td>many</td>
<td>many</td>
<td>many</td>
</tr>
<tr>
<td>G3</td>
<td>a few</td>
<td>a few</td>
<td>a few</td>
<td>a few</td>
</tr>
<tr>
<td>G4</td>
<td>many</td>
<td>many</td>
<td>many</td>
<td>many</td>
</tr>
<tr>
<td>G5</td>
<td>many</td>
<td>many</td>
<td>many</td>
<td>many</td>
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</tbody>
</table>

11. Type 2 represents relatively new houses, which are made of simple stones or manufactured blocks with wooden roofs (see Photo 6.2), and are classified as vulnerability Class B (Fig.6.2). Type 3 are newer houses, whose walls are similar to type 2, but have RC roofs and/or RC floors (see Photo 6.3). They are classified as vulnerability Class C (Fig.6.2).

On the other hand, typical RC buildings in Gujarat are made of RC frames with un-reinforced concrete blocks. Since the earthquake resistant design code is not mandatory in India, they are classified as vulnerability Class C (see Fig. 6.2). However, during the survey, we found that the damage grades were clearly different between buildings with and without pilotis (see Photo 6.4 and 6.5). RC buildings with pilotis were found extremely weak, i.e.

Fig.6.3 Classification of damage grade for masonry (top) and RC (bottom) buildings by EMS98.
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Equivalent to Classes A to B. Actually, almost all damage in Ahmedabad was concentrated on the buildings with piloti. Therefore, we take into account these effects when we estimate macroseismic intensity.

During the survey, we used the intensity survey sheet shown in Fig. 6.4. The collected data were the date and time of the observation, the name of city or village, the location (latitude and longitude using GPS), the average damage grade and the approximate numbers of investigated buildings for each type, and additional comments. After the survey, we compiled all the data from the five survey groups, and estimated the intensity in each city or village using Table 6.1. The number of damaged buildings in each category in the table is classified into few (0-20 %), many (20-60 %) or most (60-100 %). Here, we assumed that the average damage grades correspond to the category “many” in Table 6.1, and estimated the corresponding MSK intensities.

Fig. 6.5 shows the estimated intensity contours using only the damage data of buildings Type 1 (Class A). Although we see some differences in grade in the same
6. Estimation of Macroseismic Intensity

<table>
<thead>
<tr>
<th>ID</th>
<th>Date</th>
<th>Time or City Name</th>
<th>Location</th>
<th>Ave. Damage Grade &amp; Apprx. Num. for Various Type of Build.</th>
<th>Masonry Type 1</th>
<th>Masonry Type 2</th>
<th>Masonry Type 3</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Avg. Damage Grade: 1 (G1: Negligible to Slight), 2 (G2: Moderate), 3 (G3: Substantial to Heavy), 4 (G4: Very Heavy), and 5 (G5: Destruction)</td>
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<td>1</td>
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</tr>
</tbody>
</table>

*1) Majority (Average) Damage Grade: 1 (G1: Negligible to Slight), 2 (G2: Moderate), 3 (G3: Substantial to Heavy), 4 (G4: Very Heavy), and 5 (G5: Destruction)

*2) Approximate Number of buildings you watched in the village or city (ex: 1: log-scale number, 1v, 10v, 100v, ...), (ex 2: : majority, : minority, : few)

*3) Masonry Type 1: Buildings in rubble stone, fieldstone and/or adobe (usually with mud mortar)
Masonry Type 2: Buildings in simple stone, brick or concrete block (usually with cement mortar)
Masonry Type 3: Buildings in Type 1 or 2 with lintel band and/or RC floors

Fig. 6.4 MSK intensity sheet based on EMS98

Fig. 6.5 MSK intensity contours using the damage data of Type 1 buildings

Villages between different groups, the villages/cities with the highest damages (G5) are concentrated around the epicentral area, and the areas with smaller grades scatter into circumferences. In Figs. 6.5 to 6.8, we used thicker lines in the contours with
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Fig. 6.6  MSK intensity contours using the damage data of Type 2 buildings

Fig. 6.7  MSK intensity contours using the damage data of Type 3 buildings
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Fig. 6.8 MSK intensity contours using the damage data of RC buildings

Fig. 6.9 MSK intensity contours using all the data
higher grades because they are probably more reliable; damage grades G4 and G5 are easily detected visually, but this is not the case of G1 and G2. Similarly, Figs. 6.6, 6.7, and 6.8 show the estimated intensity contours using only the Type 2 (Class B), Type 3 (Class C), and RC (Class C or less for structures with piloth) data, respectively. The similarity of contours suggests the overall reliability of the data. Finally, Fig. 6.9 shows the integrated intensity contours using all the data from Figs. 6.5 to 6.8.

We shall compare our intensity map shown in Fig. 6.9 with the other existing intensity maps. Fig. 10 shows a MM intensity map by Martin and Hough (2001), which was estimated using media information. Although there are similarities between both maps, there are also distinctive differences. In particular, the map of Martin and Hough (2001) shows the highest intensity around Bhuj, rather than around the epicentral area. This is probably because of media biases. The damage information is usually exaggerated at bigger cities. On the other hand, Fig. 6.11 shows a MSK intensity map by Narula and Chaubey (2001) on the basis of field survey data. There are similarities between both MSK maps, such as elongating contours along the northeast to southwest axis. However, there are also differences such as the location of the region with intensity 10. For instance, the map of Narula and Chaubey (2001) locates Bhachau out of intensity 10 area and Raper is in. Our proposal map suggests exactly opposite. Photo 6.6 and 6.7 show typical damages to RC buildings in Bhachau and Raper, respectively. Almost all RC buildings in Bhachau suffered severe damage, while only moderate damage in RC buildings were observed in Raper. Therefore, we believe that our intensity map represents more realistically the macroseismic intensity in the epicentral area.
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Finally, Fig. 6.12 shows a comparison of the JMA, MM, and MSK intensities, and maximum accelerations. We can estimate the JMA magnitude using the empirical relation (Chronological Scientific Tables, 1996)

\[ M = \log(S_5) + 3.2, \]

where \( S_5 \) is the area with intensity larger than JMA intensity 5. In our proposed intensity map (Fig. 6.9), the area corresponding to JMA intensity 5 or higher is about 21,500 km\(^2\). Thus, we obtain \( M \approx 7.5 \), which is close to \( M_w = 7.6 \) reported by USGS. This agreement also supports the validity of our results.

**Acknowledgement**

This building damage survey was possible with the collaboration of Drs. F. Uehan, and P. K. Ramamcharla (Univ. of Tokyo), T. Toshinawa (Meisei Univ.), Y. Hayashi and S. Sawada (Kyoto Univ.), K. Venkataramana (Kagoshima Univ.), H. Murakami (Yamaguchi Univ.), S. Pareek, (Nihon Univ.), D. K. Paul, R. N. Dubey, and A. Kumar (Roorkee Univ.).

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