6. Estimation of Macroseismic Intensity

6.1 Macroseismic Intensity deduced from the Building Damage

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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 2: Y. Hisada (Kogakuin Unv.)
- Group 3: T. Toshinawa (Meisei Univ.)
- Group 4: Y. Hayashi and S. Sawada (Kyoto Univ.) and S. Pareek (Nihon Univ.)
- Group 5: K.Venkataramana (Kagoshima Univ.), D. K. Paul, and R. N. Dubey (Roorkee Univ.)

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

EMS98 is a macroseismic scale proposed by the European Seismological Commission of IASPEI (International Association of Seismoloy 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

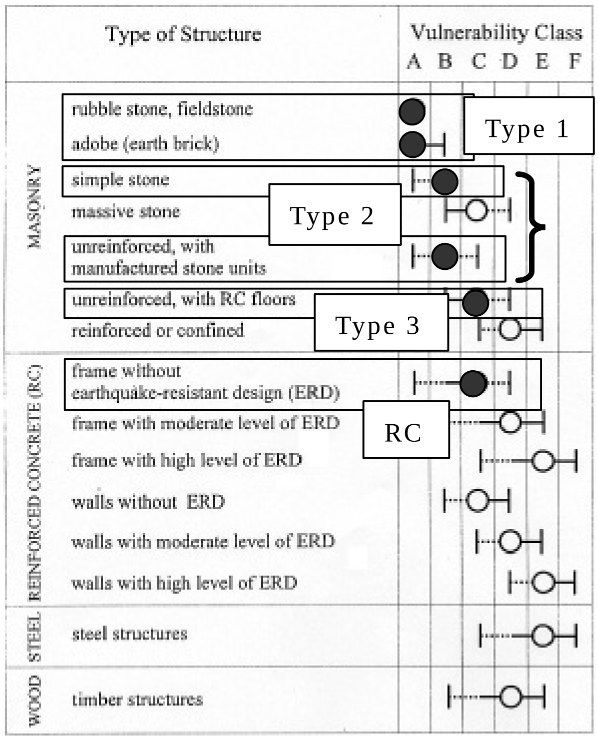


Fig.6.2 Vulnerability classes according to building types by EMS98

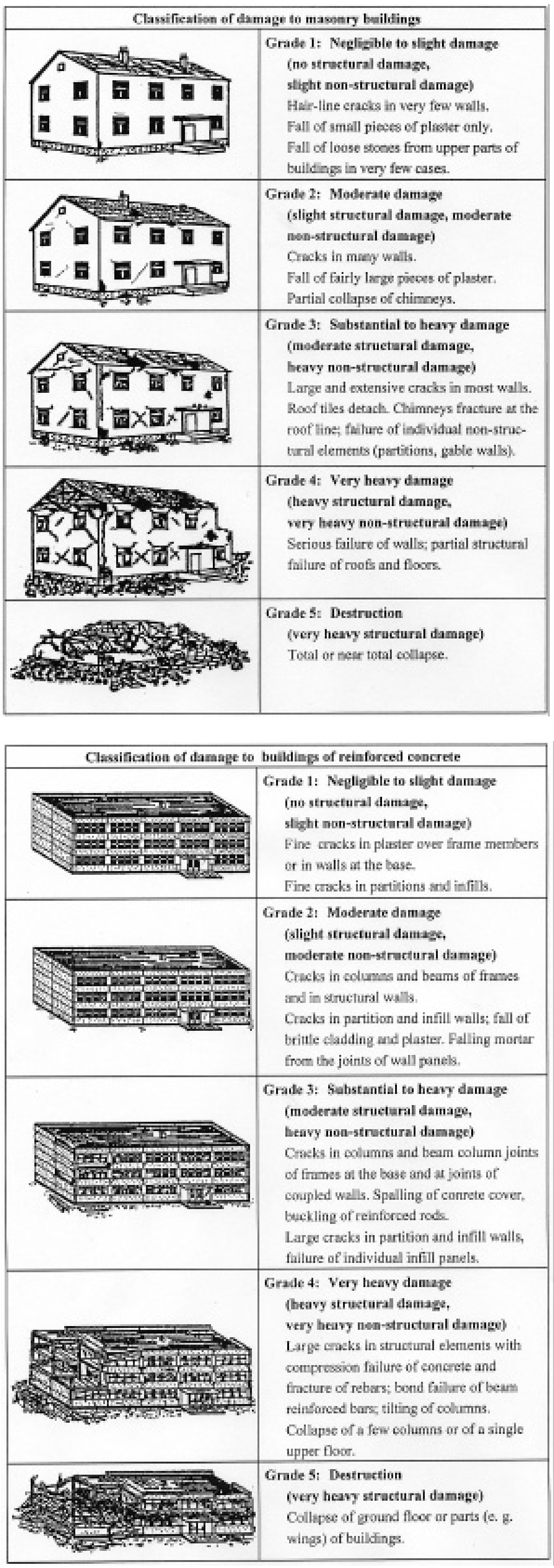


Fig.6.3 Classification of damage grade for masonry (top) and RC (bottom) buildings by EMS98

Table 6.1 Relation between the MSK intensity and the numbers of damaged buildings for various vulnerability classes and damage grades (EMS98)

Intensity	damage	Class A	Class B	Class C	Class D
V	G1	a few	a few		
VI	G1	**many**	**many**	a few	
	G2	a few	a few		
VII	G1				a few
	G2		**many**	a few	
	G3	**many**	a few		
	G4	a few			
VIII	G2			**many**	a few
	G3		**many**	a few	
	G4	**many**	a few		
	G5	a few			
	G1				
IX	G2				**many**
	G3			**many**	a few
	G4		**many**	a few	
	G5	**many**	a few		
X	G2				
	G3				**many**
	G4		**most**	**many**	a few
	G5	**most**	**many**	a few	
11	G2				
	G3				
	G4			**most**	**many**
	G5		**most**	**many**	a few
12	G5	All	All	All	most

categorized as vulnerability Class A. **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.

Photo 6.1 Type 1 masonry house (Class A)

Photo 6.2 Type 2 masonry house (Class B)

Photo 6.3 Type 3 masonry house (Class C)

Photo 6.4 RC building without piloti (Class C)

Photo 6.5 RC building with piloti (originally classified as Class C, but in reality weaker than Class C)

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

MSK Intensity Survey Sheet for the 2001 Gujarat, India, Earthquake

Name of Investigator:

ID	Date	Time	Village or City Name	Location						Ave. Damage Grade & Apprx. Num. for Various Type of Build.								
				Latitude			Longitude			Masonry *3)						RC	Num *2)	Comments
				deg	min	sec	deg	min	sec	Type 1	Num *2)	Type 2	Num *2)	Type 3	Num *2)			Picture ID
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		

*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, 1+, 10+, 100+, …), (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

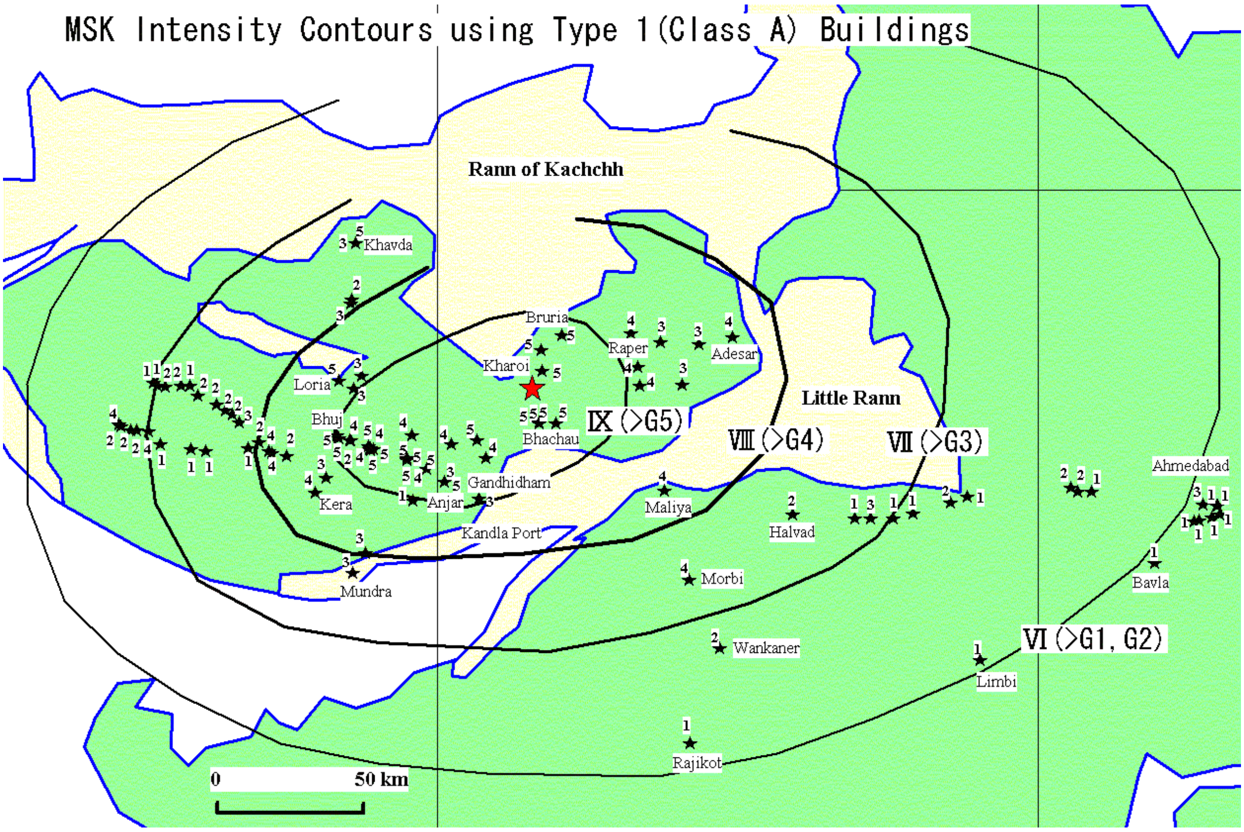


Fig.6.5 MSK intensity contours using the damage data of Type 1 buildings

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

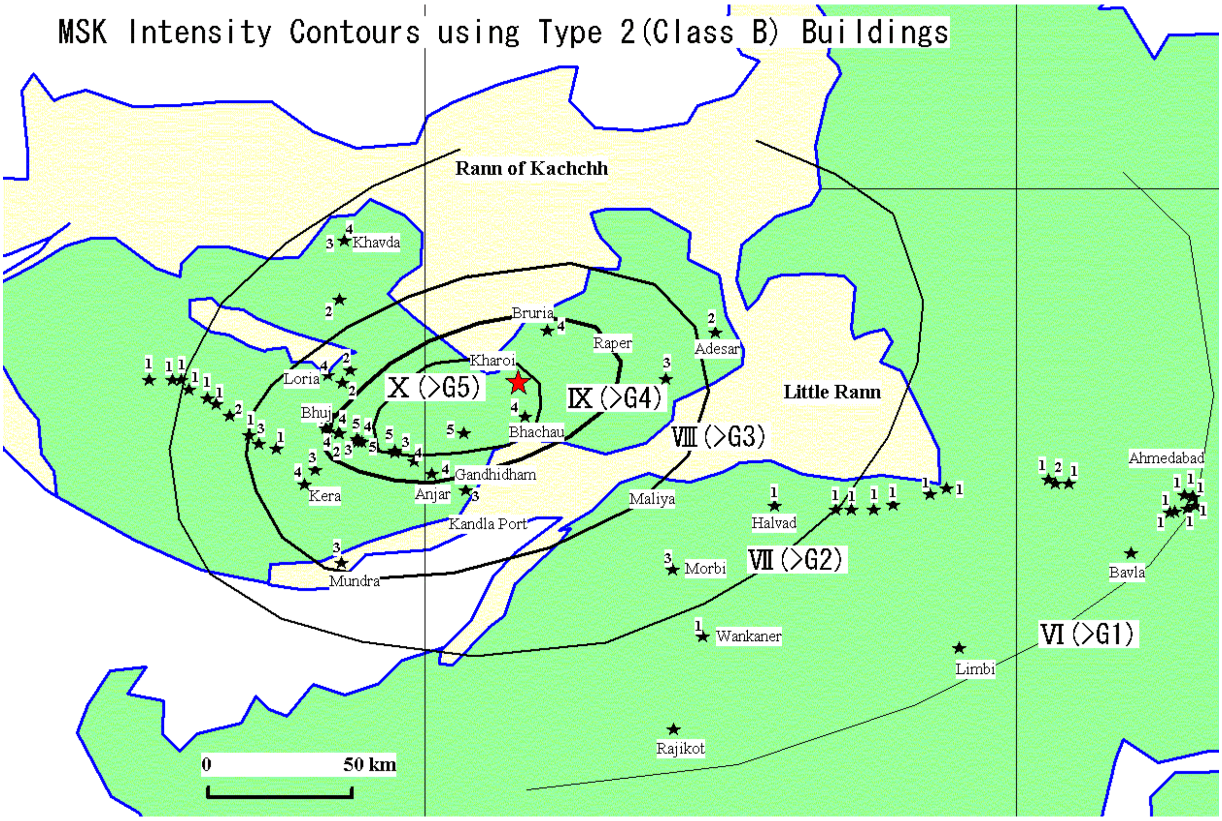


Fig.6.6 MSK intensity contours using the damage data of Type 2 buildings

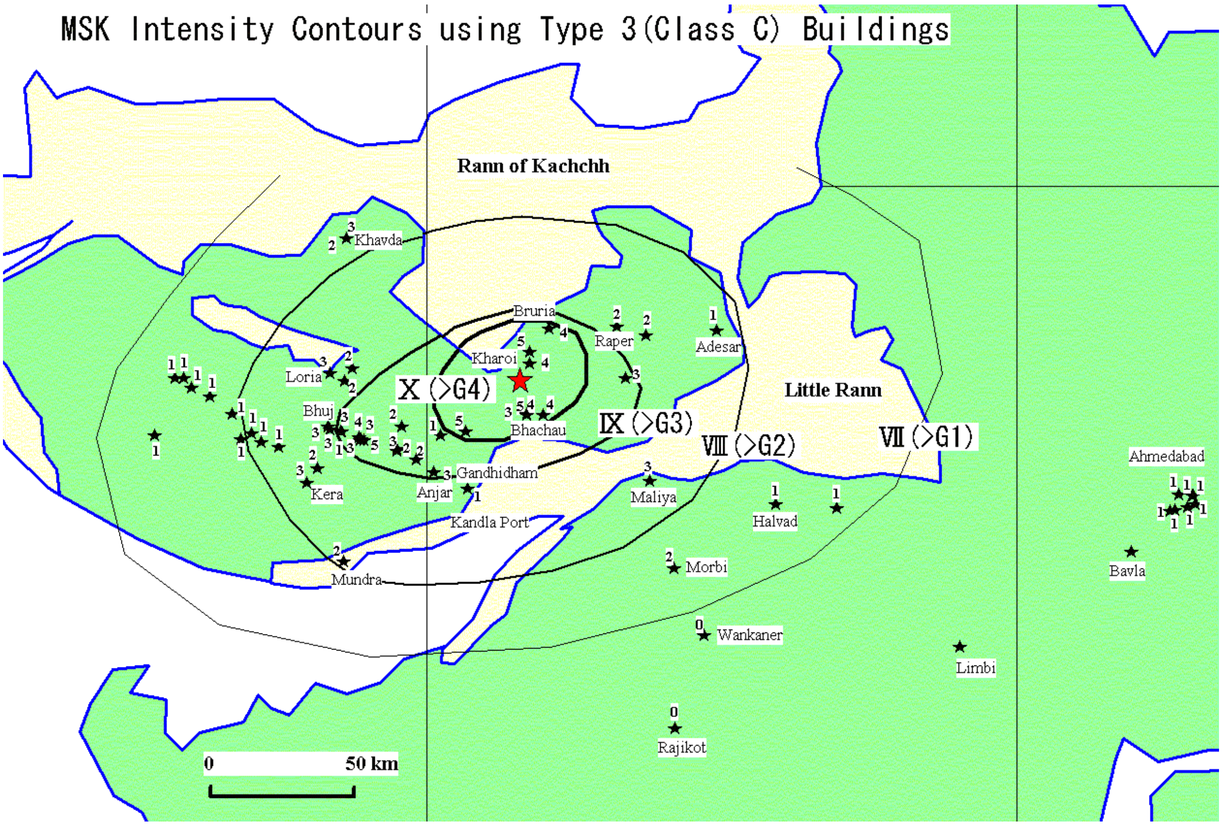


Fig.6.7 MSK intensity contours using the damage data of Type 3 buildings

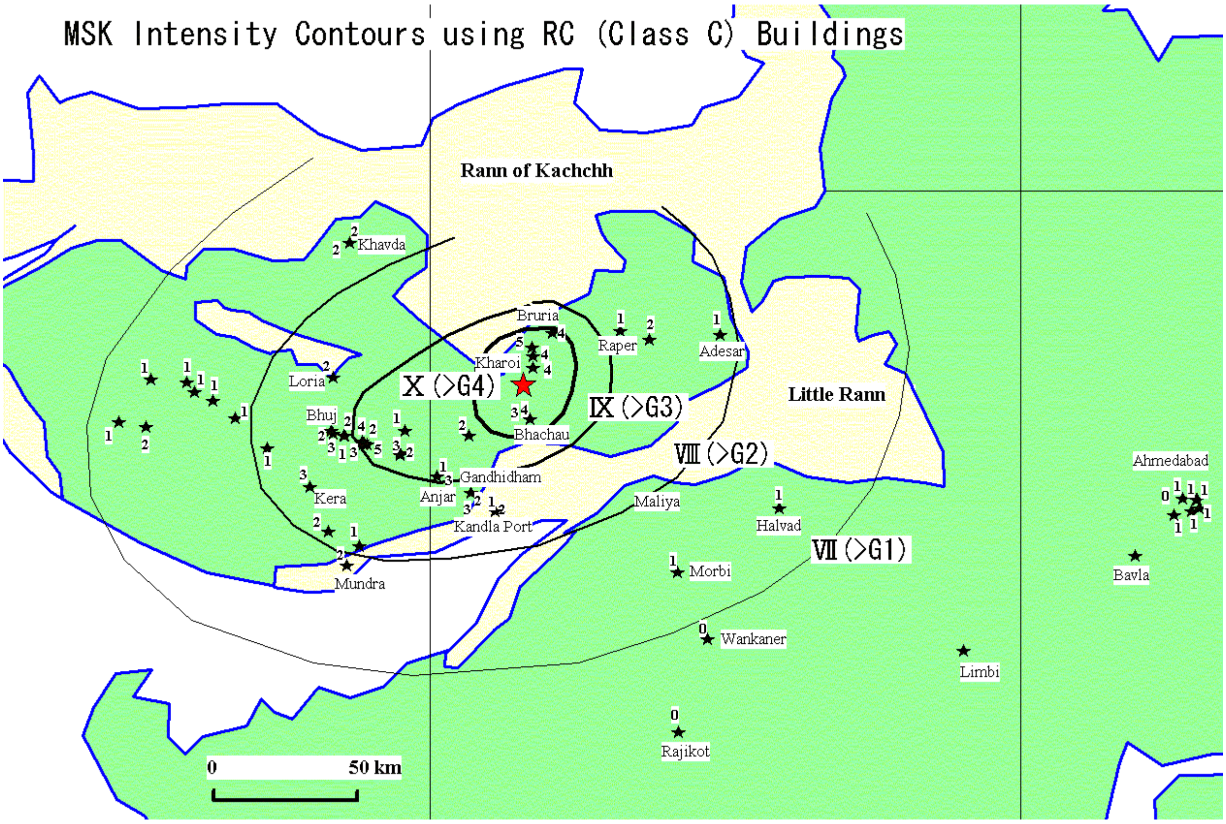


Fig.6.8 MSK intensity contours using the damage data of RC buildings

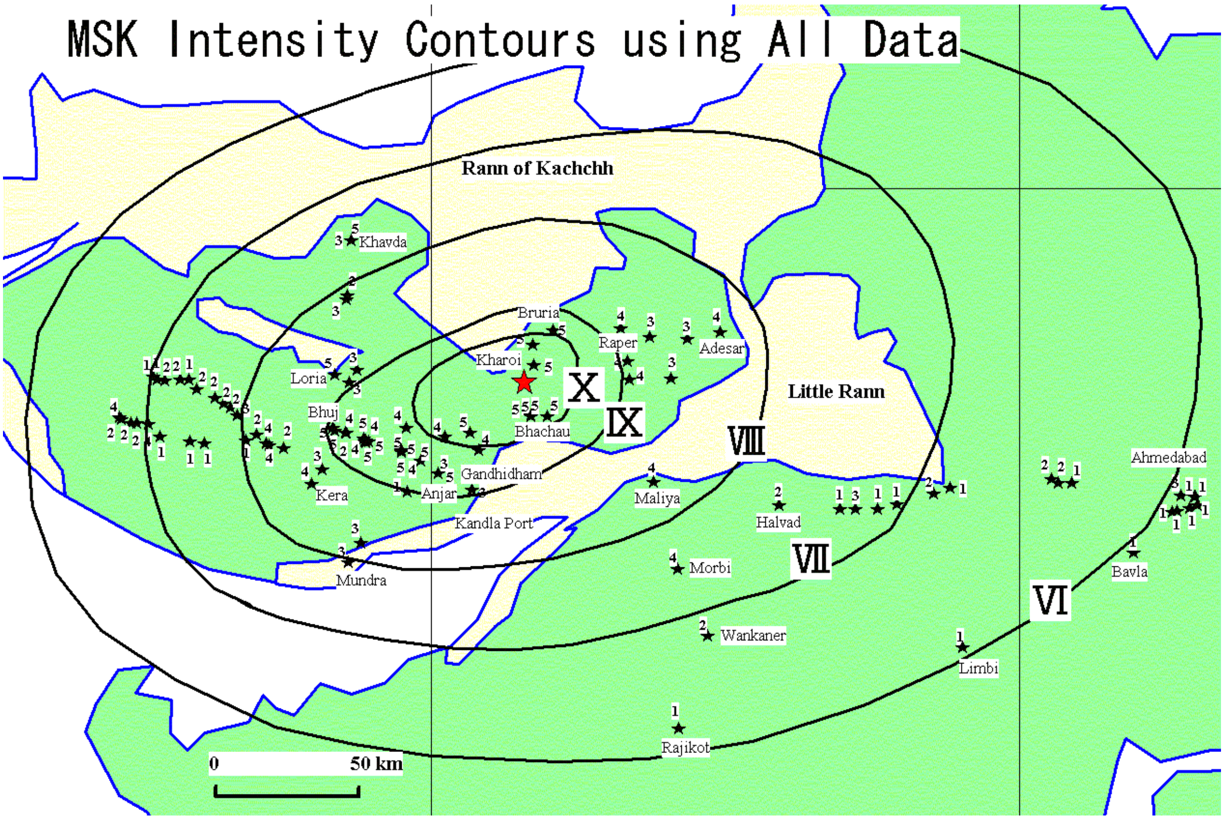
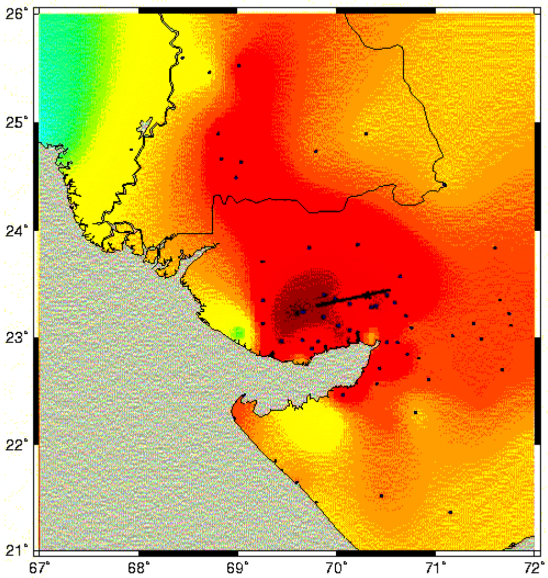


Fig.6.9 MSK intensity contours using all the data

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 piloti) 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.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Fig.6.10 MM intensity using media data (Martin and Hough, 2001),

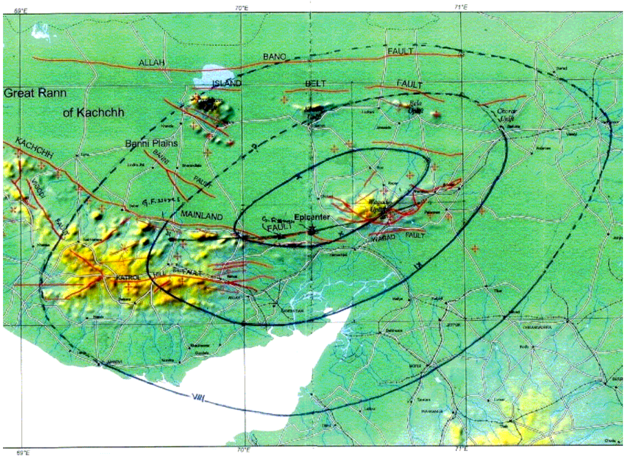


Fig.6.11 MSK intensity using field survey data (Narula and Chaubey, 2001)

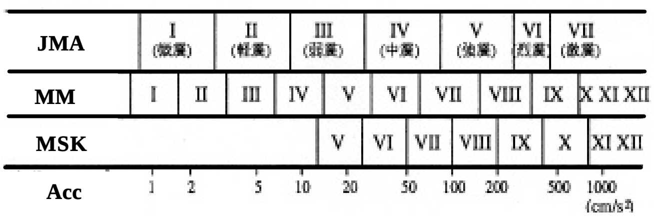


Fig.6.12 Comparison among the JMA, MM, and MSK intensities, and maximum acceleration

Photo 6.6 Damage to a RC building in Bhachau

Photo 6.7 Damage to a RC building in Raper

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 7.5, which is close to Mw=7.6 reported by USGS. This agreement also supports the validity of our results.

Acknowlegement

This building damage survey was possible with the collaboration of Drs. F. Uehan, and P. K. Ramancharla (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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