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 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.

Group 1: K. Meguro, F. Uehan, and P. K. Ramancharla (Univ. of Tokyo)
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.)

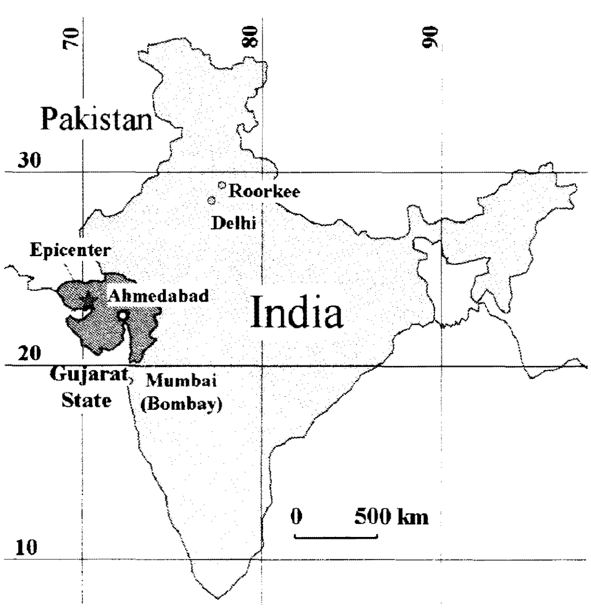


Fig 6.1. The Gujarat state and the epicenter of the Gujarat earthquake (USGS, 2001)

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

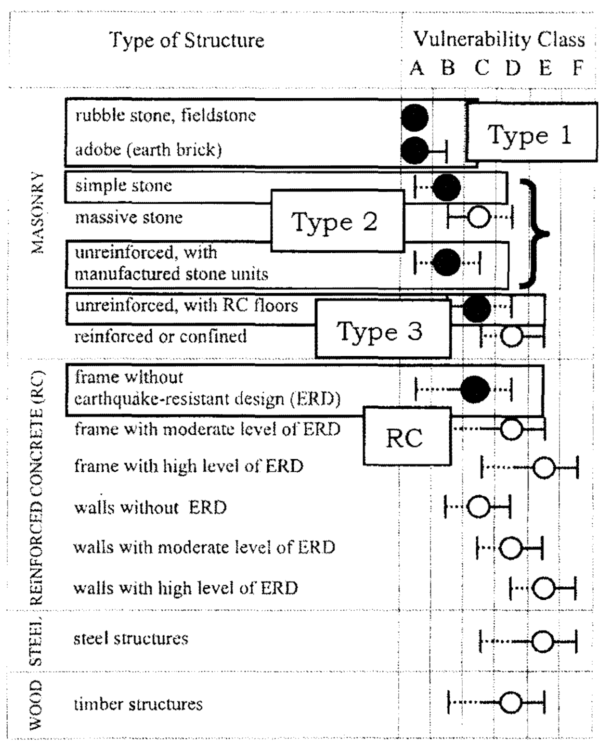


Fig 6.2. Vulnerability classes according to building types by EMS98

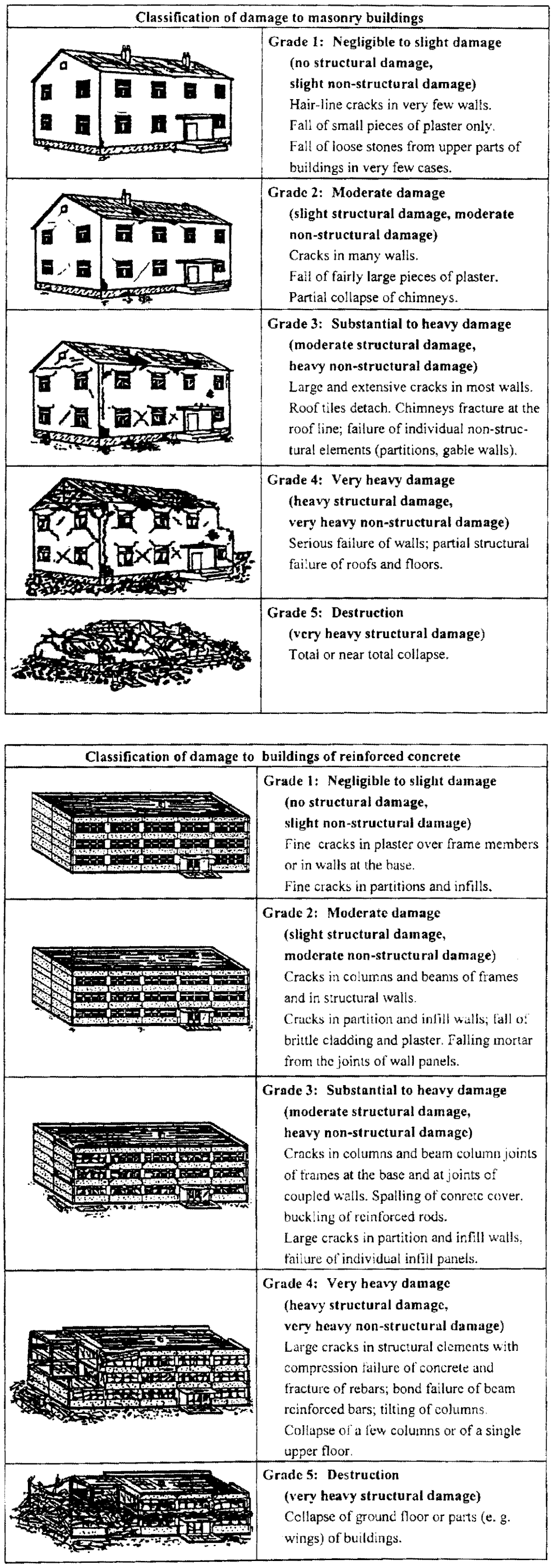


Fig 6.3. Classification of damage grade for masonry (top) and RC (bottom) buildings by EMS98

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.

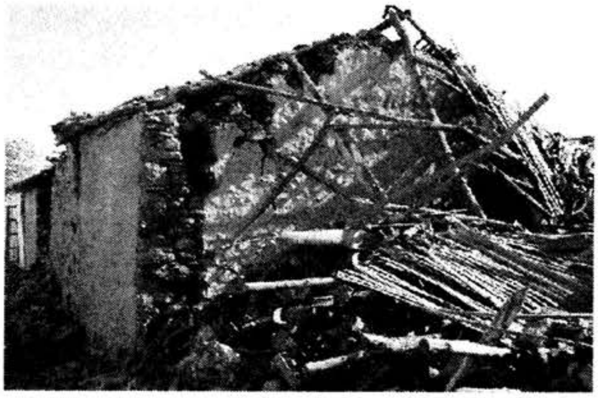


Photo 6.1. Type 1 masonry house (Class A)

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 villages between different groups, the

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.								Comments Picture ID
				Latitude			Longitude			Masonry *3)						RC	Num*2)	
				deg	min	sec	deg	min	sec	Type 1	Num*2)	Type 2	Num*2)	Type 3	Num*2)			
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

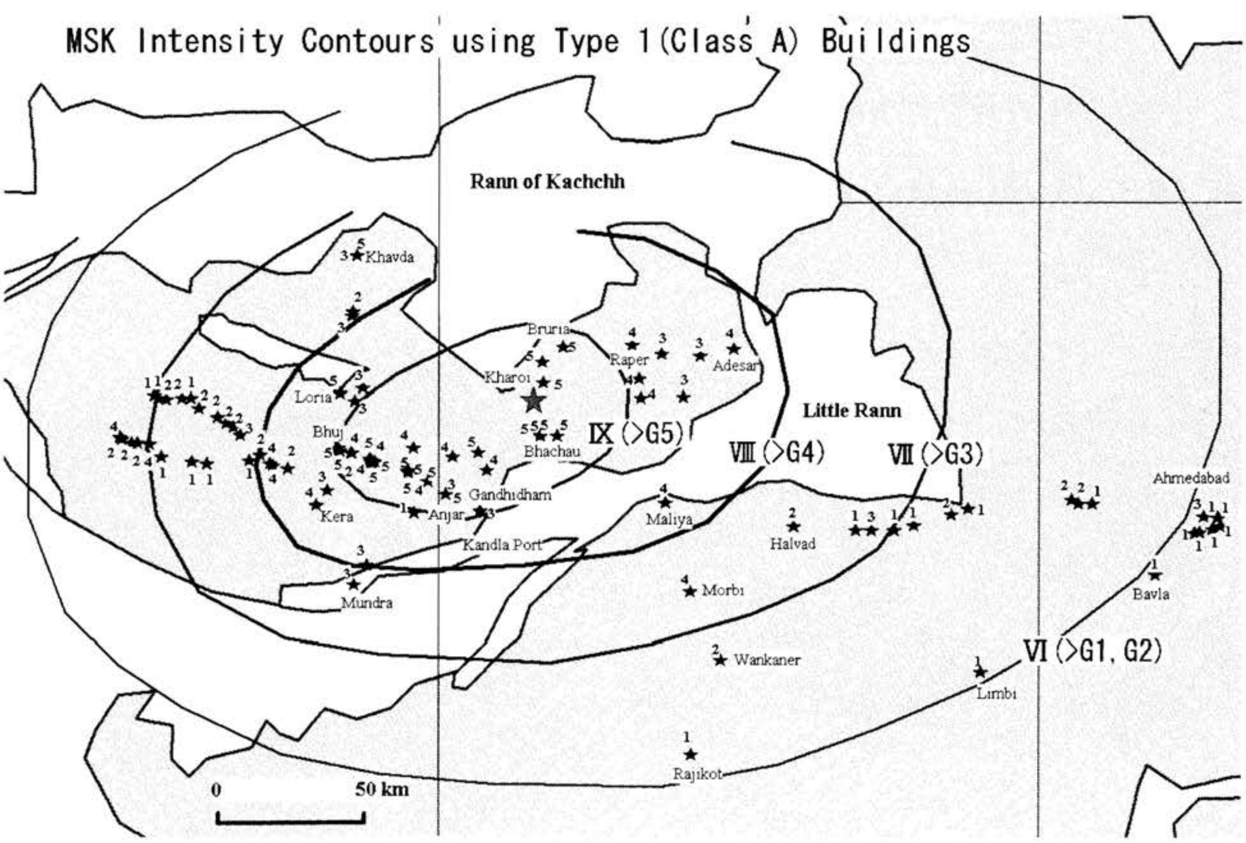


Fig 6.5. MSK intensity contours using the damage data of Type 1 buildings

villages/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 higher grades because they are probably

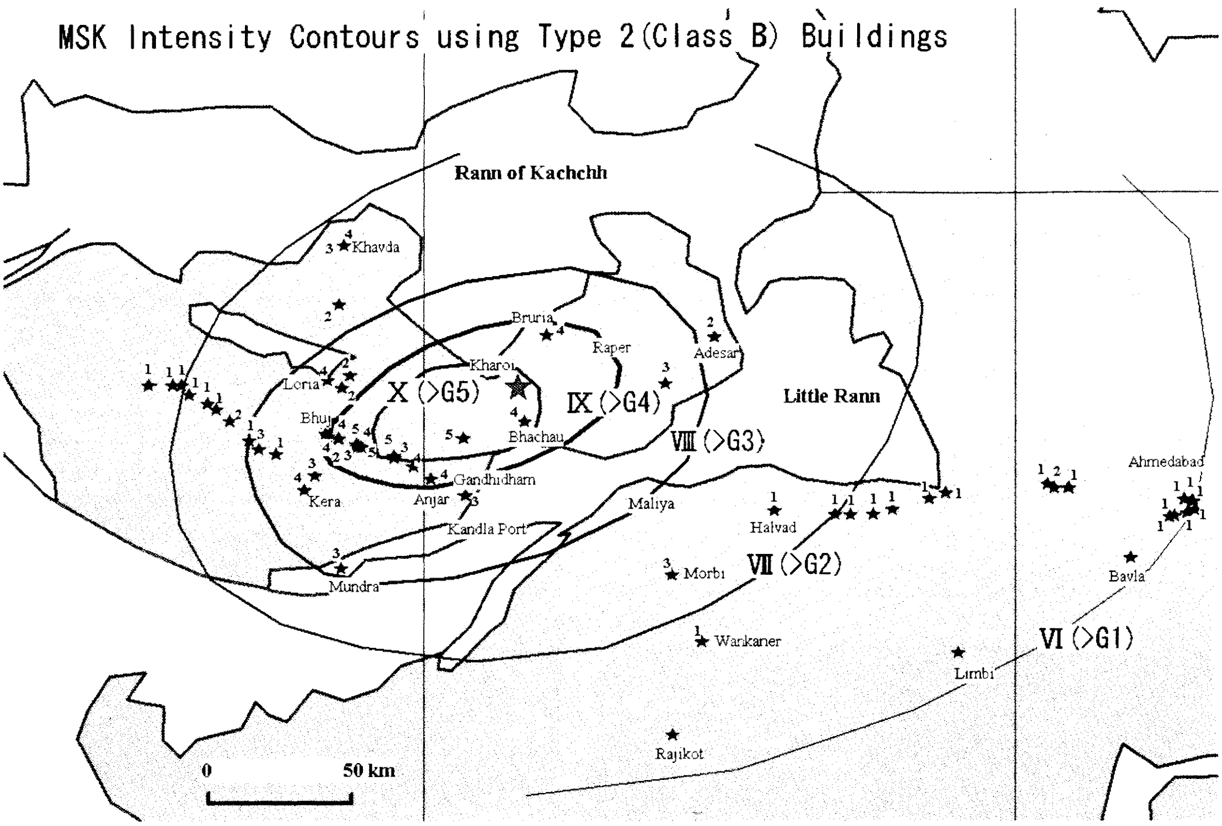


Fig 6.6. MSK intensity contours using the damage data of Type 2 buildings

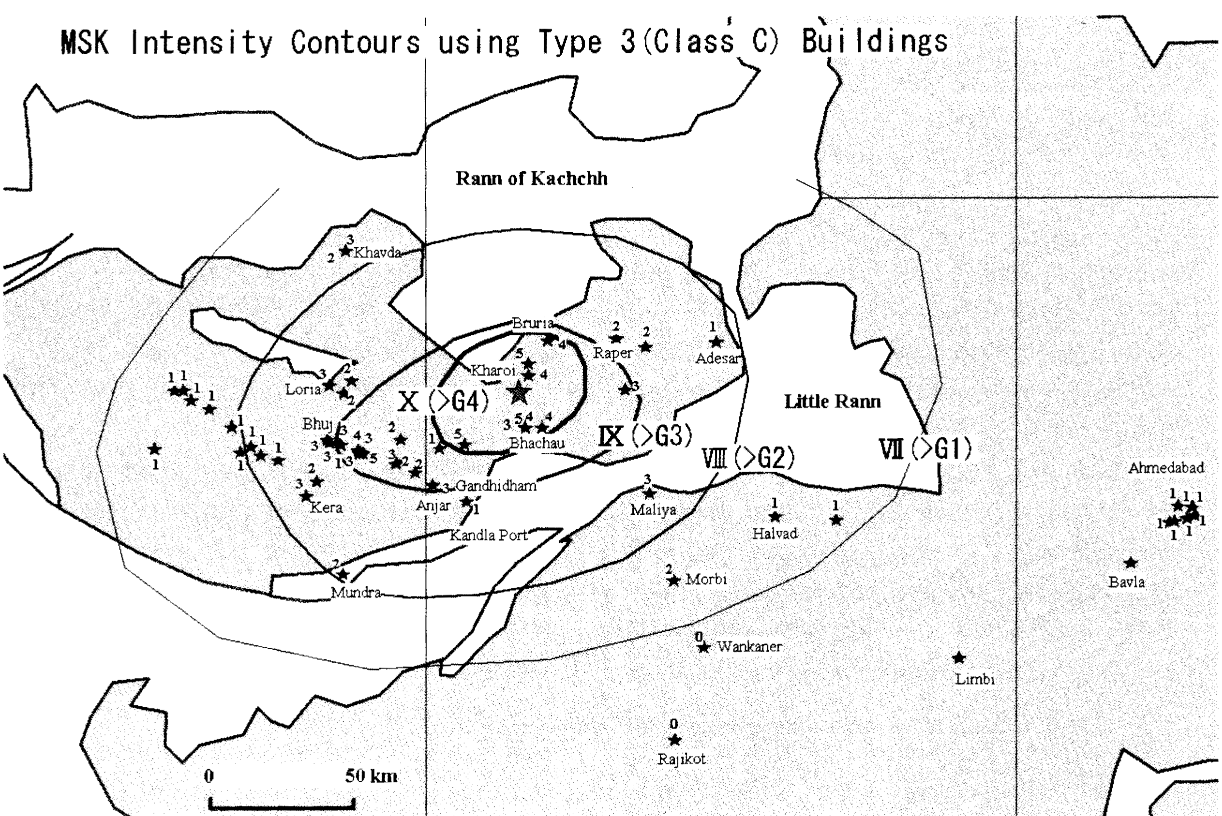


Fig 6.7. MSK intensity contours using the damage data of Type 3 buildings

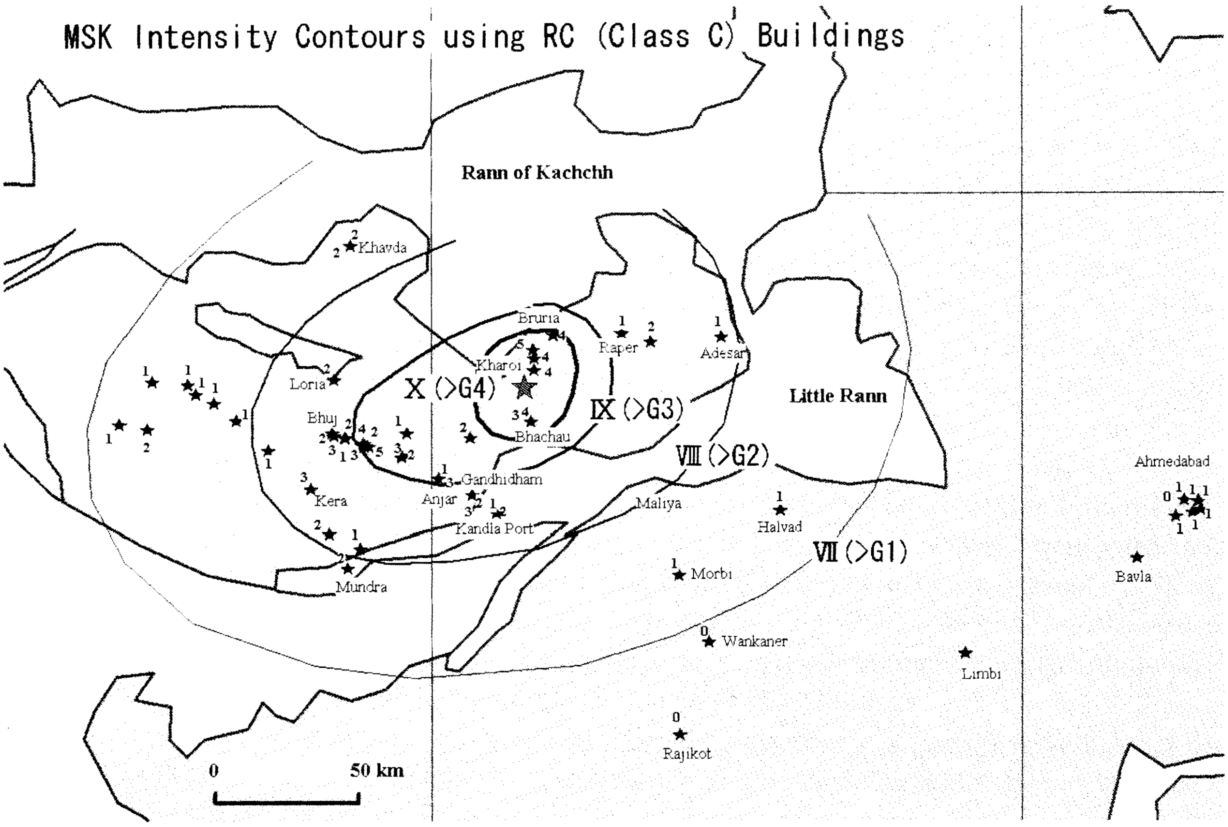


Fig 6.8. MSK intensity contours using the damage data of RC buildings

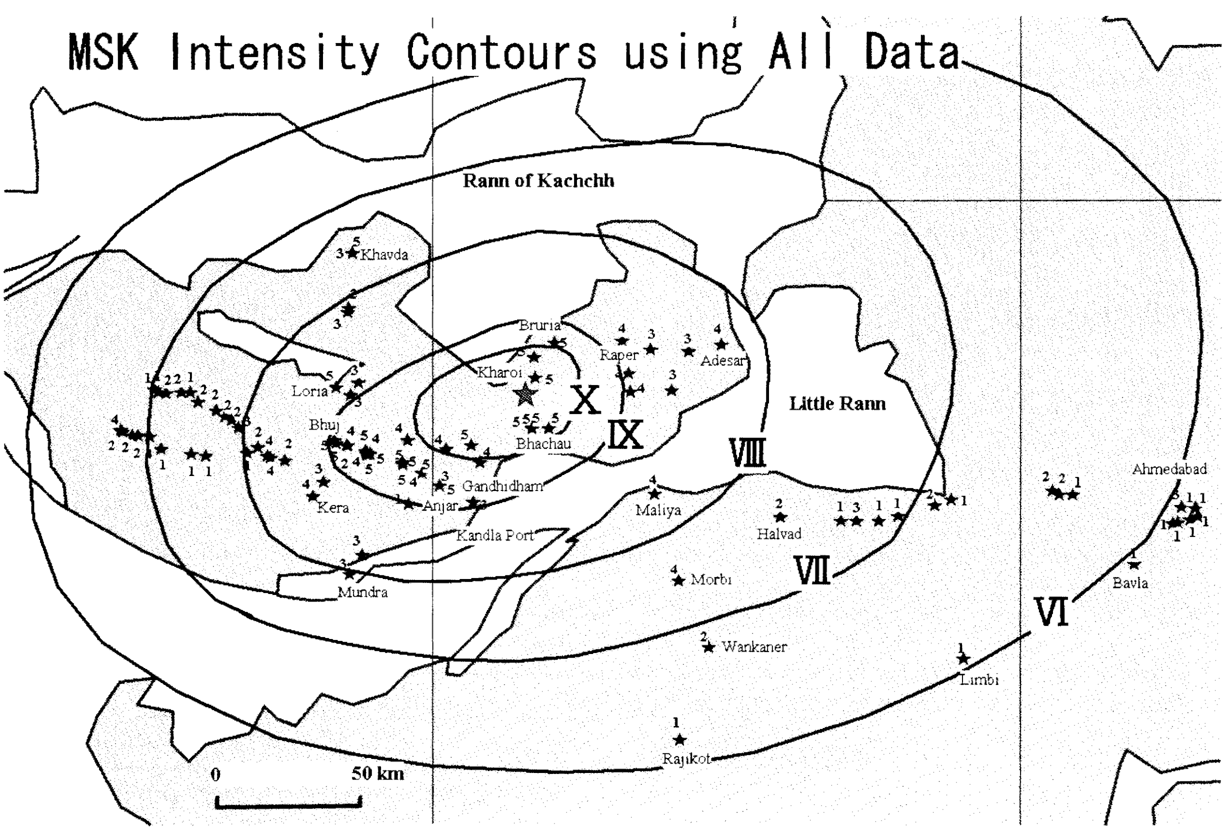
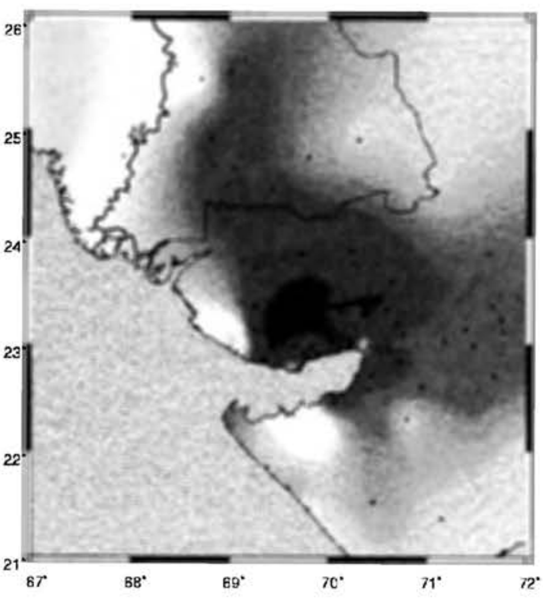


Fig 6.9. MSK intensity contours using all the data

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	[illegible]	[illegible]

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

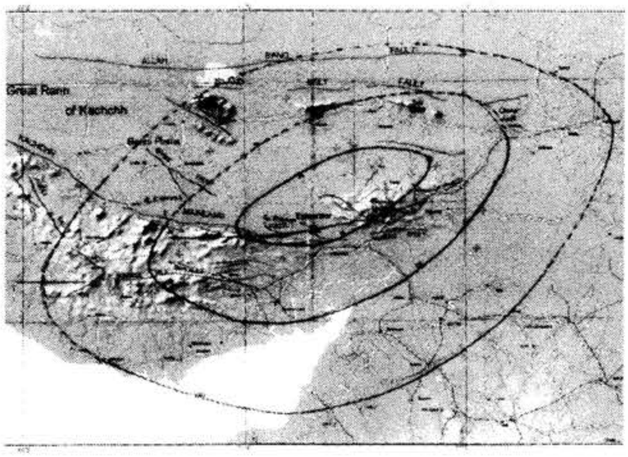


Fig 6.11 MSK intensity using field survey data (Narula and Chaubey, 2001)

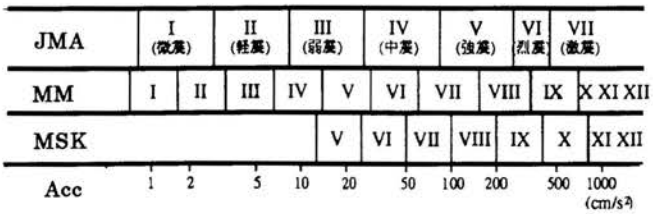


Fig 6.12. Comparison among the JMA, MM, and MSK intensities, and maximum acceleration

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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6.2 Estimation of MSK Seismic Intensity by Questionnaire Method

H. Murkami and V. Katta

In the 2001 Gujarat earthquake, only few strong motion records were observed, among which one in Ahmedabad was recorded by Roorkee University (2001). In the epicentral and most devastating disaster area of Kachchh district, no strong motion records were obtained. Estimation of strong motion parameters such as intensity is significant to evaluate attenuation characteristics and vulnerability relations. During our reconnaissance for damage survey during March 5th thru 10th, we conducted MSK seismic intensity survey by questionnaire method with great assistance by the members of the reconnaissance team consisted of Japanese and Indian engineers and scientists. In this section, survey method and results of the survey is described.

(1) Intensity survey by questionnaire method, review

In Japan, JMA (Japan Meteorological Agency) seismic intensity scale is broadly used and instrumental intensity is broadly recorded by JMA and National Fire Department and is immediately announced thru mass media and internet web pages, so that extent of probable damage distribution and needs for emergency response are evaluated by local and central governments. At the same time, questionnaire intensity survey was standardized by Ohta et al. (1979) and has been performed for the most damaging earthquakes in Japan for the last 15 years, and the results have been utilized for macro zoning and micro zoning.

On the other hand, in most of the other seismic prone countries, seismic intensity survey is conducted by seismologists and engineers for research purpose, and are not used for optimizing immediate and emergency response. Their survey method can be based on expert experience and knowledge in the macro seismic intensity scale definition. In India, Richter's scale (earthquake magnitude) is reported as soon as possible, though seismic intensity is the subject for seismological reconnaissance investigation.

The authors developed questionnaire method to estimate seismic intensity based on Modified Mercalli Intensity Scale of 12 levels and applied to some earthquakes in California and in the 1988 Nepal-India border region (Murakami et al., 1991). The questionnaire items of 34 questions and categories were edited based upon the definition of MM and MSK intensity scales. For each item category, corresponding seismic intensity was given. Fuzzy set theory was applied to the seismic intensity coefficient, because, likelihood of intensity suggested by each item category have some sort of fuzziness and not exact indicator. Membership function for fuzzy function were prepared for each item category as in Table 2 and Figure 13. As a membership function, Z functions are given for the smallest category for each question item, Pai functions are given for the intermediate categories, and S functions for the largest categories (Fig. 1).

Shiono and Koyama (2000) modified the intensity questionnaire method mentioned above so as to fit MSK intensity scale, which are commonly used in European and some Asian countries. They reexamined question items and the new questionnaire containsed 22 questions. Intensity evaluation method was based upon Murakami et al. (1991), though have been reexamined and updated. They made preliminary survey in the 1999 Kocaeli, Turkey earthquake and obtained some data in the 6 locations where strong motion records were observed.

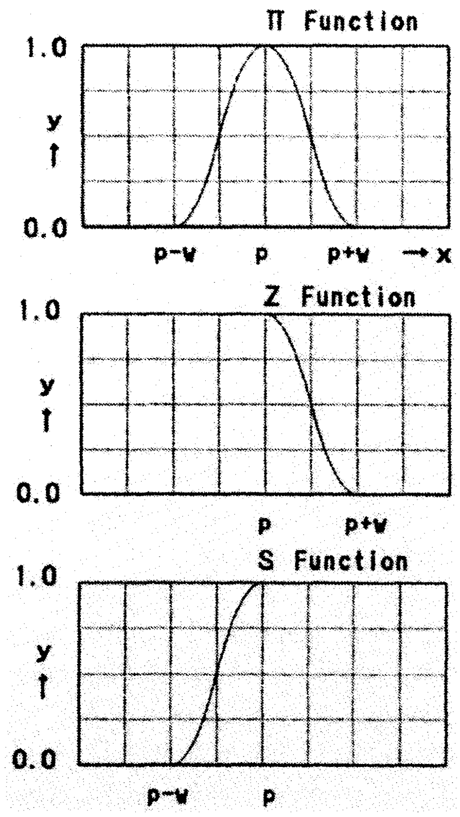

Figure 6.13. Schematic diagram showing the three types of membership functions, Pai, Z and S.

(2) Questionnaire survey

The English questionnaire as modified by Shiono and Koyama (2000) were used for the Gujarat earthquake reconnaissance. Two questions were newly added to ask entrapment of the occupants and occurrence of human casualty. The questionnaire is attached as an appendix. The English questionnaire was translated to Hindi version by Dr. Sanjay Pareek and then to Gujarati version by supporting staffs in Munbai. The three language versions of the intensity questionnaire were printed and brought in the field reconnaissance.

We made a plan to cover the longitudinal east-west direction along the presumed fault strike and the transverse north-south direction. The longitudinal axis starts Bhuj city, which is an administrative and economic center of the Kachchh district and extends to the east direction thru Bhachau with highest

Table 6.2. Parameters for intensity coefficient membership functions

Notes	Item	Category	Function	Peak	Width-Left	Width-Right
Feel eq	1	1	S	6	4	4
	1	2	Z	1	4	4
Shaking indoors	4	1	Z	4	3	3
	4	2	Pai	5	3	4
	4	3	Pai	7	4	3
	4	4	Pai	8	3	3
	4	5	S	9	3	3
Shaking	5	1	Z	2	3	3
	5	2	Pai	3	3	3
	5	3	Pai	4	3	3
	5	4	Pai	5	3	4
	5	5	S	7	4	3
Awaken	10	1	-	0	0	0
	10	2	Z	4	3	3
	10	3	Pai	5	3	3
	10	4	S	6	3	3
Frightened	11	1	Z	4	3	3
	11	2	Pai	5	3	3
	11	3	Pai	6	3	3
	11	4	Pai	7	3	3
	11	5	Pai	8	3	3
	11	6	S	9	3	3
Hanging objects	12	1	Z	3	3	3
	12	2	Pai	4	3	3
	12	3	Pai	5	3	3
	12	4	Pai	6	3	3
	12	5	Pai	7	3	3
	12	6	S	8	3	3
Furniture	13	1	Z	4	3	3
	13	2	Pai	5	3	3
	13	3	Pai	6	3	3
	13	4	Pai	7	3	3
	13	5	Pai	8	3	3
	13	6	S	9	3	3
Noises	14	1	Z	3	3	3
	14	2	Pai	4	3	3
	14	3	Pai	5	3	3
	14	4	S	6	3	3
Plaster	15	1	Z	6	2	2
	15	2	Pai	6.5	2	2
	15	3	Pai	7	2	2
	15	4	Pai	7.5	2	2
	15	5	Pai	8	2	2
	15	6	S	8.5	2	2
Outer walls	16	1	Z	6	3	3
	16	2	Pai	7	3	3
	16	3	Pai	8	3	3
	16	4	Pai	9	3	2
	16	5	Pai	9.5	2	3
	16	6	S	10.5	3	3
Chimneys	17	1	Z	6	3	3
	17	2	Pai	7	3	3
	17	3	S	8	3	3
Building damage	18	1	Z	7	3	3
	18	2	Pai	8	3	2
	18	3	Pai	8.5	2	2
	18	4	Pai	9	2	3
	18	5	Pai	10	3	3
	18	6	S	11	3	3
Roads	19	1	Z	6	3	3
	19	2	Pai	7	3	3
	19	3	Pai	8	3	4
	19	4	Pai	9.5	4	4
	19	5	Pai	11	4	3
	19	6	S	12	3	3
Ground deformati	20	1	Z	5	3	4
	20	2	Pai	6.5	4	4
	20	3	Pai	8	4	3
	20	4	Pai	9	3	3
	20	5	Pai	10	3	4
	20	6	Pai	11.5	4	4
	20	7	S	13	4	4

Table 6.3. MSK intensity estimation by questionnaire method.

	Location	Latitude, N	Longitude, E	No of questionnaire data	No of effective data	Q_MSK1 #1 mean	Q_MSK1 stdev	Vulnerability Class #5	Adjustment	Q_MSK2 #2 (mean+adjustment)	Epic dist, km from USGS 23.40degN 70.32degE
1	Dhrangdra	22.983	71.467	7	7	7.17	1.40	A	−1.0	6.2	133.9
2	Dhaneti	23.254	69.915	3	3	11.40	0.40	C	0.0	11.4	44.5
3	Ambapar	23.226	70.048	5	5	8.40	1.93	C	0.0	8.4	33.8
4	Taper	23.239	70.131	2	2	8.90	0.14	A	−1.0	7.9	26.2
5	Chitrod	23.405	70.675	2	2	8.50	1.56	A	−1.0	7.5	36.4
6	Adesar	23.554	70.982	11	11	8.65	2.18	B	−0.5	8.2	69.9
7	Pragpar	23.539	70.743	9	9	7.60	1.17	B	−0.5	7.1	46.0
8	Rapar	23.567	70.646	10	10	7.60	1.19	C	0.0	7.6	38.1
9	Khedoi	23.055	69.919	11	11	7.62	0.98	A	−1.0	6.6	55.9
10	Gundala	22.896	69.762	14	12	8.90	2.49	B	−0.5	8.4	79.7
11	Bharaper	23.125	69.629	5	5	9.64	1.48	A	−1.0	8.6	77.0
12	Kera	23.080	69.594	3	3	7.47	0.90	B	−0.5	7.0	82.3
13	Mundra	22.835	69.717	9	9	7.64	1.91	C	0.0	7.6	87.7
14	Loria	23.420	69.673	3	3	8.87	0.12	C	0.0	8.9	66.3
15	Bherandiala	23.656	69.713	6	6	8.40	0.40	A	−1.0	7.4	68.4
16	Ahmedabad	23.024	72.585	4	4	6.40	0.65	C	0.0	6.4	235.8
17	Bhuj #4	23.247	69.673	2	2	7.20	0.57	B	−0.5	6.7	68.4
18	Rasdiya	23.402	69.094	5	5	7.36	1.13	A	−1.0	6.4	125.6
19	Samatra	23.152	69.964	5	5	7.72	1.45	C	0.0	7.7	45.6
20	Nakhtrana	23.348	69.266	17	16	7.05	1.06	B	−0.5	6.6	108.2
21	Devpan	23.318	69.317	16	9	7.59	2.68	A	−1.0	6.6	103.2
22	Halvad	23.015	71.185	9	9	7.78	2.06	A	−1.0	6.8	98.3
23	Paladi	23.011	72.565	6	5	6.12	0.18	C	0.0	6.1	234.1
24	Ambawadi	23.022	72.545	2	2	5.00	0.85	B	−0.5	4.5	231.8
25	Morbi	22.813	70.838	7	7	10.63	1.24	B	−0.5	10.1	83.5
26	Rajkot	22.317	70.842	4	4	7.85	1.11	B	−0.5	7.4	130.5
27	Limbdi	22.500	71.865	8	7	8.43	2.28	B	−0.5	7.9	186.8
28	Maliya	23.086	70.757	30	27	8.58	1.47	B	−0.5	8.1	56.6
	Total			215	200	8.11	1.81			7.5	

#1: Q_MSK1 Intensity without adjustment by dwelling vulnerability class.
#2: Q_MSK2 Intensity with adjustment by dwelling vulnerability class.
#4: Seismological station in Northern suberb of Bhuj city.
#5: Vulnerability class A if Q6= 1) field stone, or 2) adobe. B if Q6= 3) solid brick, 4) hollow brick or 5) cut stone.
C if Q6=6) wood and masonry (half-timbered), 7) large block (prefab), or 8) RC.

devastation and to Rapar and Adesar, and to the west direction thru Nakhtrana. The transverse axis extends to the north direction to Great Rann of Katchch and few populated locations such as Berandiala, and to the south direction to Mundra.

The field survey was conducted from March 3rd thru 10th while damage investigations and seismic intensity evaluation based on macro seismic intensity scale was conducted. Counterparts from Roorkee University or reconnaissance team members dispatched from Japan who can speak Hindi explained the purpose of survey to local residents and asked those to answer the questionnaire. From 28 locations, 215 questionnaires were collected, among which 200 were effective data. The list of survey locations and the result of the survey with estimated average intensity are shown in Table 6.3.

The question item 18 asks extents of building damage. The seismic intensity corresponding to the damage level depends on the vulnerability classes of buildings. In the standard evaluation procedure, vulnerability class B of the MSK intensity scale, that is, ordinary brick masonry or half timber dwellings is assumed. When the building type are regarded different, simple modification is applied adding adjustment coefficient I_adj and Q_MSK2 is obtained.

Vulnerability Class A: Rubble stone or adobe masonry. adjustment= -1.0.

Vulnerability Class B: Ordinary brick, hollow brick, or cut stone masonry. adjustment=-0.5.
Vulnerability Class C: RC masonry or timber structures. adjustment=0.0.

Table 6.3 indicates survey locations (latitude and longitude) as well as estimated MSK questionnaire intensity (means and standard deviations). According to the average vulnerability class, adjustment coefficients are given and Q_MSK2 (mean+adjustment) depicts tentative estimation results. Figure 6.14 shows distribution of estimated questionnaire intensity along with intensity isoseismals estimateb yb building damage in Section 6.1, in the map of Gujarat. Figure 6.15 shows relation of epicentral distance and estimated intensity. The scattering is large, though attenuation tendency can be observed. Wide variation of intensity in the distance from 20km to 70km may be explained by finite size of fault plane. Yagi and Kikuchi (2001) estimated the earthquake fault as L=70km and W=30km with EW strike direction. Sato et al. (2001) estimated aftershock area as 40km EW and 40km NS zones.

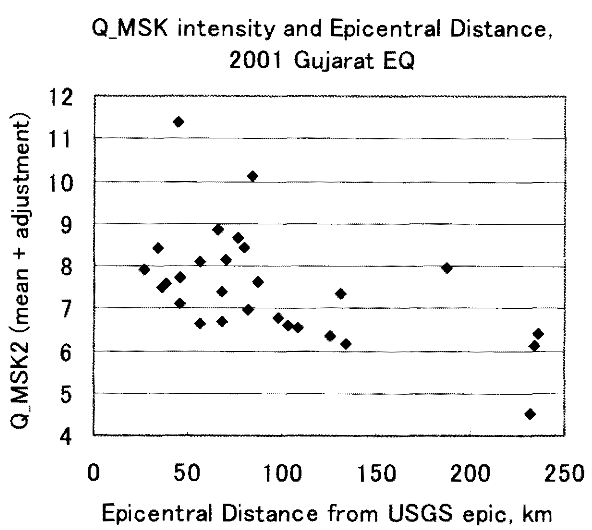

Figure 6.15. Estimated intensity (Q_MSK2) vs. epicentral distance.

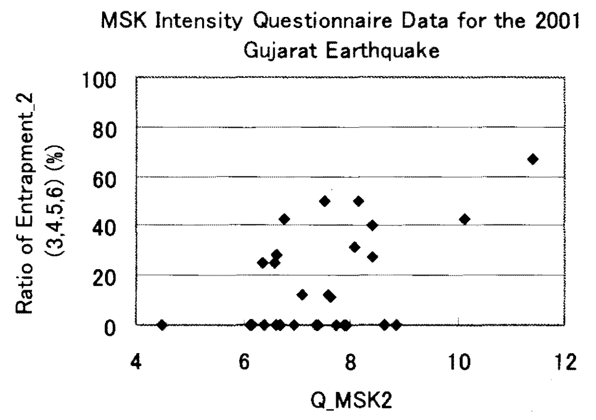

Figure 6.16. Ratio of entrapment and estimated intensity (Q_MSK2).

Figure 6.16 indicates the relation of ratio of entrapment (Question 21) and seismic intensity estimated. Again the scattering is still very large and further examination of intensity estimation method is necessary.

MSK seismic intensity survey was conducted by use of the questionnaire method and intensity was estimated based on modified method by Shiono and Koyama (2000). Types of dominant vulnerability classes in each location, that corresponds to building types, were considered and intensity estimation was modified. Using the estimated MSK intensity, seismic intensity distribution were depicted in the macro seismic zoning map and the relation of intensity to the epicentral distance were examined. The cause of scattering in intensity estimation will be reexamined further to reach more reliable intensity estimation.

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Photo 6.8. Damage of masonry dwellings in Loria, Q_MSK2=8.9.

Photo 6.9. Intensity questionnaire survey in Dhaneti.

Photo 6.10. Damage in Adeser, Q_MSK2=8.2.

Photo 6.11. Damage of masonry building in Mundra, Q_MSK2=7.6.

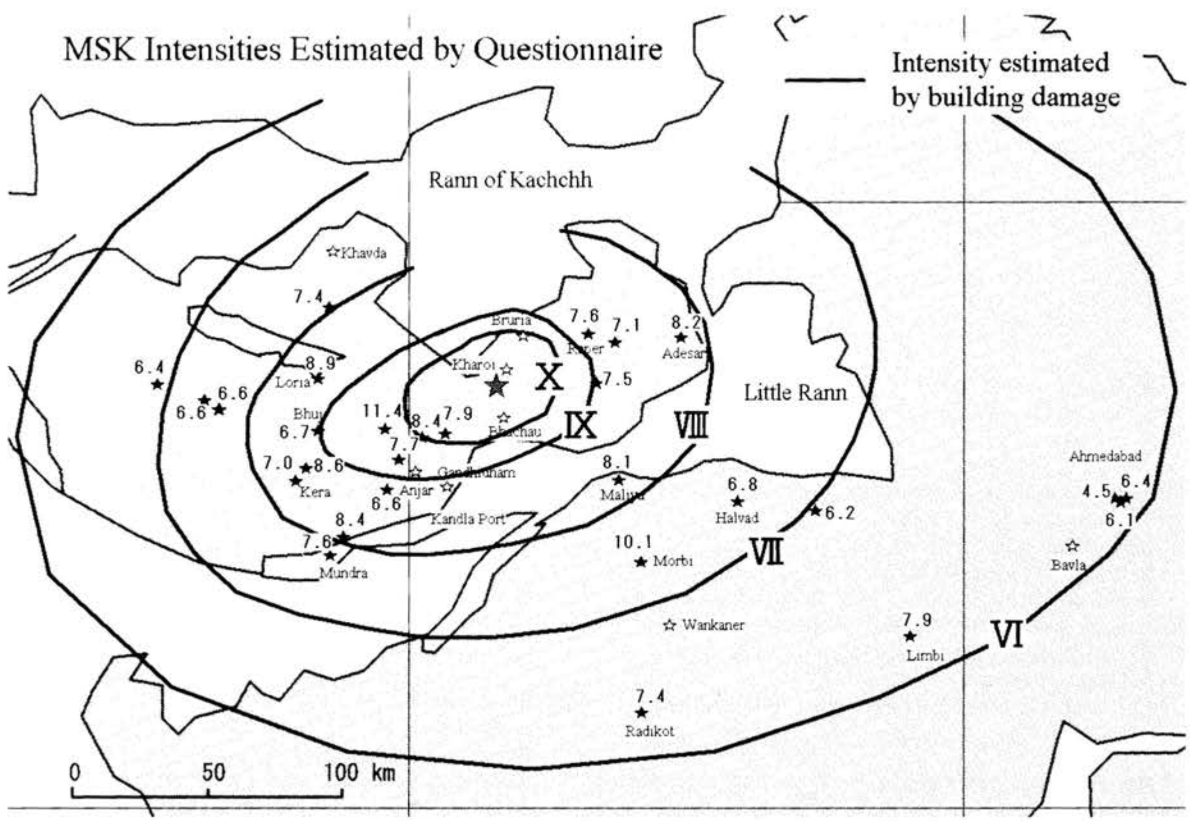

Figure 6.14. MSK intensities (Q_MSK2) estimated by the questionnaire method.

Attachment:

Seismic Intensity Questionnaire Survey Form

1. Did you feel the earthquake?
   1) Yes.
   2) No.

2. Where were you when the earthquake occurred?
   Address:
   ( )
   City/Town/Village:
   ( )
   District:
   ( )
   Postcode: ( )

3. Were you indoors or outdoors when the earthquake occurred?
   1) Indoors
   2) Outdoors
   3) In a vehicle

If you DID NOT FEEL the earthquake, please go to Question No. 23, skipping the questions from 4 to 22.

4. How did you notice the shaking? [indoors]
   1) I was not certain whether or not it was an earthquake. [4]
   2) I realized at once it was an earthquake. [5]
   3) I felt it difficult to stand. [7]
   4) I was not able to stand. [8]
   5) I was thrown down. [-9]

5. How did you feel the ground shaking?
   1) As slightly as one hardly felt. [-2]
   2) As a light truck passing by. [3]
   3) As a heavily loaded truck passing by. [4]
   4) As a heavy object falling inside the building. [5]
   5) As something exploding in the building. [7-]

6. What was the main material of the building?
   1) field stone
   2) adobe
   3) solid brick
   4) hollow brick
   5) cut stone
   6) wood and masonry (half-timbered structure)
   7) large block (including prefabricated type of structure)
   8) reinforced concrete

7. How old was the building? ( ) years

8. How many stories did the building have?
   ( ) stories

9. On which floor of the building did you feel the earthquake?
   1) Ground floor.
   2) First floor
   3) Second floor
   4) Third floor
   5) ( )th floor

10. Did you awake to the earthquake?
    1) I cannot answer, because I was not sleeping.
    2) No. [-4]
    3) Yes, but I did not realize why I awoke. [5]
    4) Yes, and I realized that an earthquake occurred. [6-]

11. Were you frightened?
    1) No. [-4]
    2) A little, but I felt safe even staying in the building. [5]
    3) Quite, but I felt it safe even staying in the building. [6]
    4) Almost scared. [7]
    5) Scared and did not know what I should do. [8]
    6) Panicked. [9-]

12. What happened to hanging objects, such as pictures on the wall and lights?
    1) Nothing. [-3]
    2) Slight swinging without noises. [4]
    3) Considerable swinging with banging noises, and some swung out of place. [5]
    4) Partly damaged or fallen. [6]
    5) Mostly damaged or fallen. [7]
    6) Practically every hanging object were damaged or fell. [8-]

13. What happened to furniture?
    1) Nothing. [-4]
    2) Slight shake. [5]
    3) Considerable shake. [6]
    4) Heavy furniture partly moved. [7]
    5) Heavy furniture mostly moved and partly overturned. [8]
    6) Mostly overturned, and considerable damage occurred. [9-]

14. What kind of noises did you hear during the earthquake?
    1) Nothing. [-3]
    2) Rattle of windows, doors, and dishes and/or creak of walls and floors. [4]
    3) Banging of doors and windows and/or creak from every part of the building. [5]
    4) Banging, creaking, and crushing noises filled in the building. [6-]

15. What happened to the plaster?
    1) Nothing. [-0]
    2) Fine cracks formed, and/or small pieces of plaster fell. [-6.5]
    3) Large pieces of plaster fell here and there. [7]
    4) Large pieces of plaster fell everywhere. [7.5]
    5) The whole faces of plaster fell here and there. [8]
    6) The whole faces of plaster fell everywhere. [8.5-]

16. What happened to the outer walls?
    1) Nothing. [-6]
    2) Small cracks. [7]
    3) Large and deep cracks. [8]
    4) Gaps. [9]
    5) Collapse in a single face and/or corner. [9.5]
    6) Collapse in two or more faces and/or corners. [10.5-]

17. What happened to the chimneys?
    1) Nothing. [-6]
    2) Cracks formed in chimneys, and/or parts of chimneys fell. [7]
    3) Chimneys fell. [8-]

18. What was the damage to the building?
    1) Nothing. [-7]
    2) Damage in the outer walls and roofs, but the building kept its inner space. [8]
    3) Collapse in the outer walls, but the building kept its inner space. [8.5]
    4) One story partially crushed. [9]
    5) One story fully crushed. [10]
    6) Two or more stories crushed. [11-]

19. What happened to the roads?
    1) Nothing. [-6]
    2) Slight damage, but motor vehicles were able to go at normal speed. [7]
    3) Moderate damage, and motor vehicles often had to slow down. [8]
    4) Heavy damage, and motor vehicles always had to go slowly. [9.5]
    5) Motor vehicles were not able to go, but bicycles were able to go. [11]
    6) Only walkers were able to go. [12-]

20. What was the ground deformation?
    1) Nothing. [-5]
    2) Narrow cracks. [6.5]
    3) Cracks as wide as your toe might enter. [8]
    4) Cracks as wide as your foot might enter. [9]
    5) Cracks as wide as your body might enter. [10]
    6) In addition to wide cracks, vertical and/or horizontal deformation. [11.5]
    7) Many extensive vertical and/or horizontal deformation. [13-]

21. Were you or your families trapped in the building?
    1) No.
    2) Yes. Family member can get you or your family out.
    3) Yes. Relatives or neighbors could rescue you or your family.
    4) Yes. Rescue teams, police, military, etc. could rescue one
    5) Yes. One could not be rescued.
    6) Others (   )

22. Were you or your families injured due to the earthquake?
    1) No.
    2) Yes, lightly injured.
    3) Yes, treated by a doctor.
    4) Yes, hospitalized.
    5) Deceased.

23. Are you male or female?
    1) male
    2) female

24. How old are you?
    (   ) years

COMMENTS

Thank you very much for answering the questionnaire

6.3 Ground Condition Estimated from Microtremor Observations

Sumio SAWADA, Fumiaki UEHAN, Yasuhiro HAYASHI and Hiroshi ARAI

Microtremor on ground surface was measured by three teams in many cities and villages in order to estimate the ground condition. The members and instruments of the teams are shown as follows;

Team A: Dr Arai
(Velocity meter with natural freq. of 2 sec.)

Team B: Mr. Uehan, Prof. Meguro, Mr. Ramancharla
(same as Team A)

Team C: Prof. Hayashi, Prof. Sawada, Dr. Pareek.
(Kudo's type accelerometer)

Table 6.4 Microtremor Observation site in kachchh region

Team	Location	Longitude	Latitude
A	Bhachau	70.34533	23.0289
A	Kandla	70.21983	23.00383
A	Gandhidham	70.13166	23.06283
A	Anjar	70.03000	23.10466
A	Bhuj-0	69.66033	23.23883
A	Bhuj-1	69.65050	23.23200
B	Bhuj_oldtown	69.668972	23.255861
B	Bhuj	69.666333	23.248683
B	Anjar_oldtown	70.029416	23.110916
B	Anjar	70.03075	23.11175
B	Bhachau	70.205516	23.014066
B	Tuna port	70.074361	23.009388
B	Kandla port	70.21625	23.007816
B	Nakhatrana_0	69.265722	23.347944
B	Nakhatrana_1	69.269694	23.345027
B	Devper	69.3407	23.295
B	Samatra	69.497633	23.19115
C	Bhuj_Airport	69.676842	23.280726
C	Anjar	70.025452	23.111853
C	Kandla port	70.219718	23.004618
C	Bhachau_0	70.340292	23.293691
C	Bhachau_L	70.336987	23.288767
C	Malia	70.757187	23.086074

The observation sites in Kachchh region are listed in Table 6.4 and those locations are shown in Figure 6.17. As the teams acted independently, some sites are located in the same city. The results of microtremor observation in Ahmedabad are discussed later.

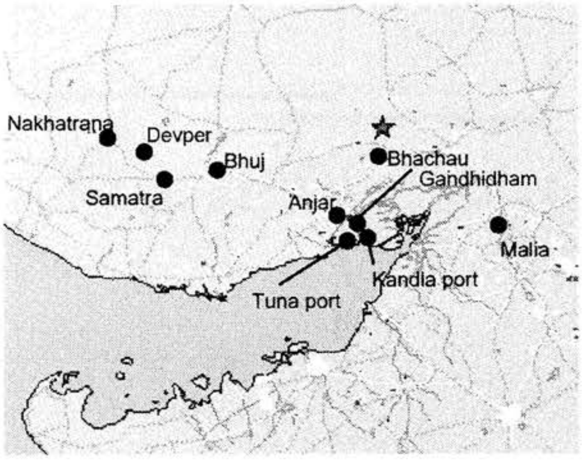

Figure 6.17 Location of microtremor observation sites in Kachchh region.

Typical example of observation condition is shown in Photo 6.12. Spectral ratio of Horizontal to Vertical (H/V spectrum) is used for indicating basic natural period of the ground in the noisy environment as shown in the photo.

Photo 6.12. Typical circumstances around microtremor observation site.

The differences of the results between teams are firstly examined. Two or three teams observed at Bhuj, Anjar, Bhachau and Kandla, as listed in Table 6.4. The H/V spectra resulted by the teams at those cities are shown in Figures 6.18–6.21. As the instrument used by team C was accelerometer, it is plotted in the frequency

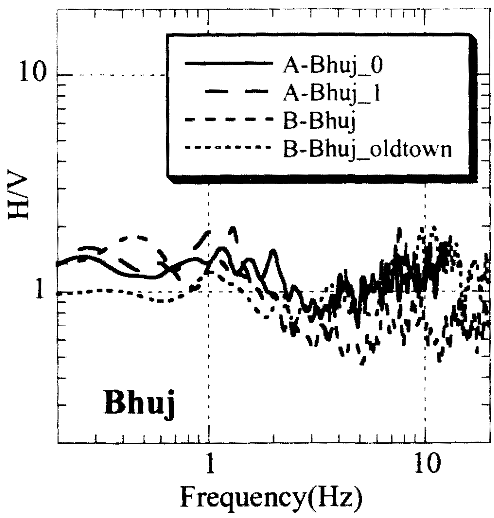

Figure 6.18. H/V spectra at Bhuj.

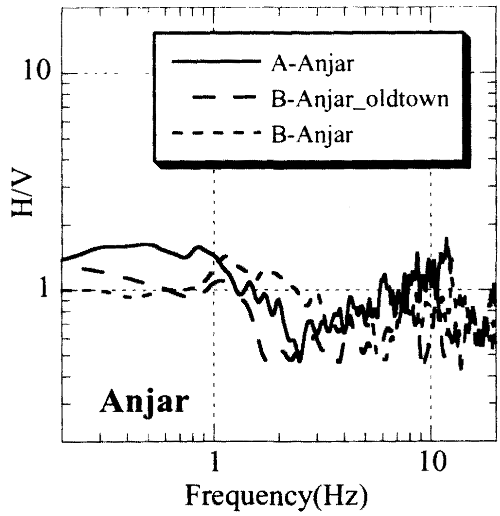

Figure 6.19. H/V spectra at Anjar.

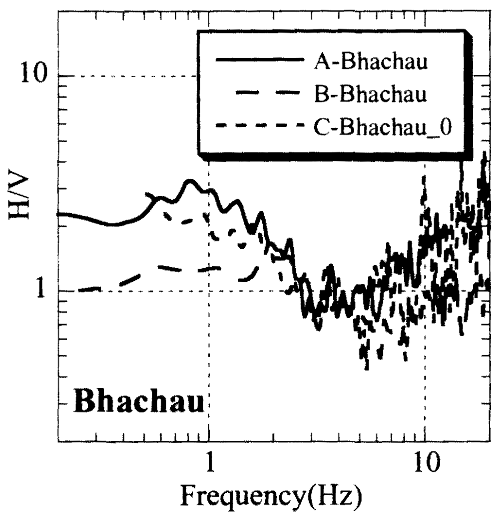

Figure 6.20. H/V spectra at Bhachau.

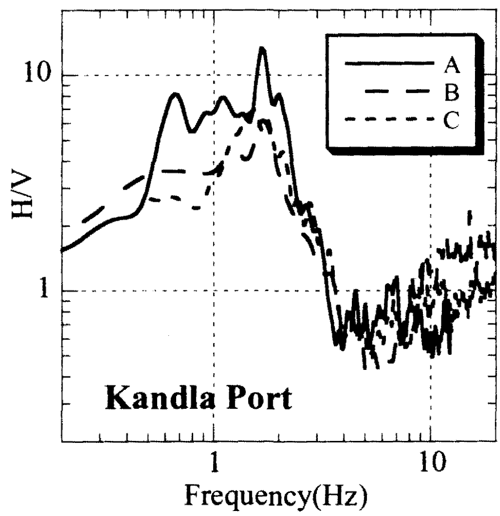

Figure 6.21. H/V spectra at Kandla.

range over 0.5Hz. Although the locations of the observation in the city are not same, the results in the city are similar. This means that the difference of instrument is not significant and we can discuss the results of three teams without any correction. Figures 6.18–6.21 can be considered as showing the typical H/V spectral characteristics of ground at the cities.

The ground conditions in Kachchh region are discussed. Figures 6.18 and 19 show that Bhuj and Anjar are built on hard ground. On the contrary the ground at Kandla port has soft and thick surface layer as shown in Figure 6.21. H/V spectra obtained in two cities near Kandla port are shown in Figure 6.22. It is shown that Tuna port has the similar ground while Gandhidham has a quite different ground from Kandla port. Team C measured microtremor on ground surface at many sites in Gandhidham. Those results are shown in the section 7.2.

H/V spectra at Bhachau have two peaks, one is in high-frequency range around 10 Hz and the other around 1Hz, as shown in Figure 6.20. The former peak suggests the thin surface layer and the later implies the

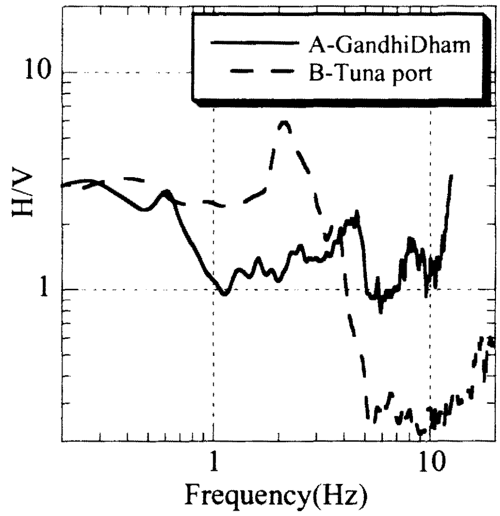

Figure 6.22 H/V spectra near Kandla port.

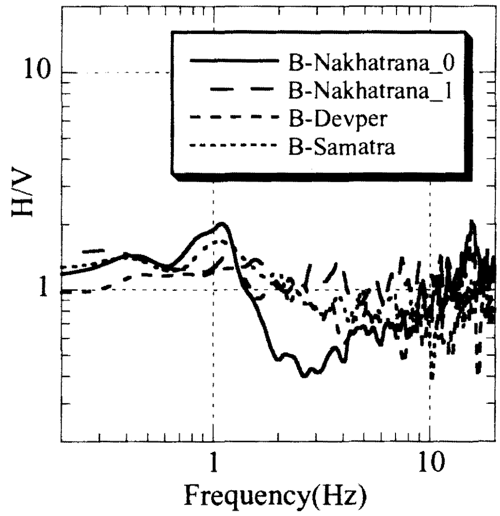

Figure 6.24 H/V spectra near Bhuj.

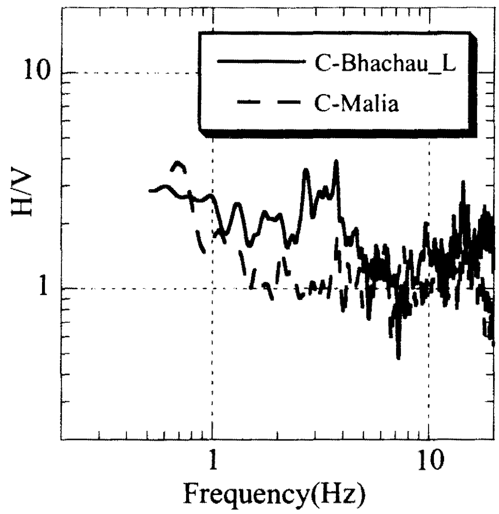

Figure 6.23 H/V spectra near Bhachau.

complex deep ground structure. As Bhachau is located on the slope of low hill, it may affect the shape of the H/V spectra. The result at the lowland (near riverbed) in Bhachau is shown in Figure 6.23. Significant peaks at 2-3 Hz are shown and imply thicker and soft surface layer. The figure also shows the spectrum at Malia. Though heavy damage occurred in the village during the earthquake as similar as Bhachau, the ground condition at Malia is considered as good as Bhuj. The results at the several villages near Bhuj are shown in Figure 6.24. All spectra have similar shapes with Bhuj except B-Nakhatrana_0.

Many cities in Kachchh region are built on hard ground, keeping distance from soft ground such as riverbed. It is concluded that site effects on seismic ground motion at the cities in Kachchh region were not large except of Kandla Port and Tuna Port, just along the Gulf of Kachchh.

Lastly the H/V spectra observed in Ahmadabad are discussed. Table 6.5 and Figure 6.25 shows the microtremor observation sites in Ahmadabad.

Table 6.5 Microtremor observation sites in Ahmadabad

Team	Site No.	Longitude	Latitude
A	0	72.52833	23.03000
A	1	72.55666	23.01650
B	0	72.526194	23.031972
B	1	72.560833	23.003250
B	2	72.552555	23.009361
B	3	72.545766	23.028833
B	4	72.549233	23.044333
B	5	72.569766	23.047566
B	6	72.600316	23.040833
B	6’	72.59555	23.039916
B	7	72.610055	23.031138
B	8	72.607116	23.01325
B	9	72.59165	23.0016
B	10	72.5797	23.00355
B	11	72.585166	23.02445
C	1	72.554663	23.015367
C	2	72.567688	23.008380
C	3	72.595031	23.000243
C	4	72.587681	23.038368
C	5	72.56814	23.043992

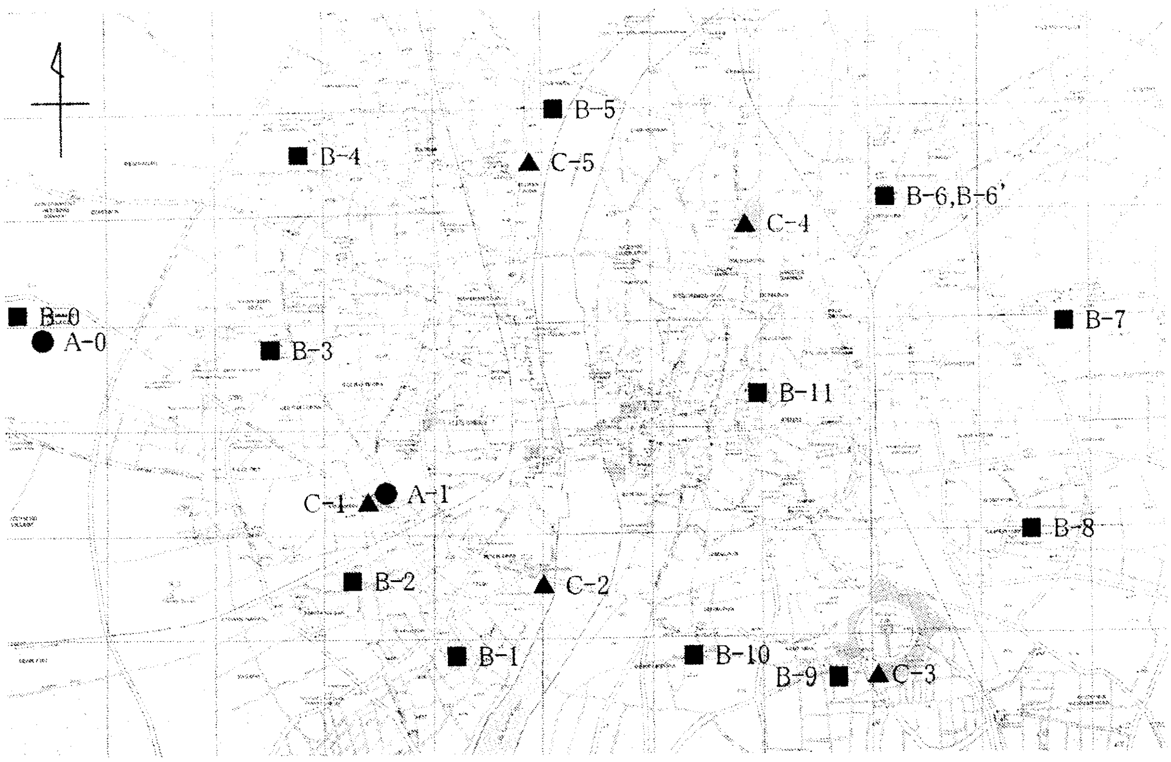

Figure 6.25 Location of microtremor observation site in Ahmadabad

The observation condition in Ahmadabad was very bad because of the noises caused by automobiles. The results of Ahmadabad from three teams compare worse than those of Kachchh region. Only the H/V spectra from team B are shown in this section.

Some damages occurred at the south region while slight damages at the north region of Ahmadabad. In order to examine the difference of south and north region of the city, the selected H/V spectra are shown in Figure 6.26. The spectral shapes in high frequency range over 1 Hz are similar while the levels in low frequency range are different. The peak around 0.5 Hz of B-9 site may imply the presence of thick sediment over the bedrock.

Significant damage occurred in Ahmadabad in spite of long epicentral distance more than 300 km. This is similar to the situation of Mexico city during Michoacan earthquake in 1985. It is a natural conclusion that site effects due to ground structure around Ahmadabad are one of the primary factors of the damages in Ahmadabad. The microtremor observations done by the three teams can not show the enough evidence of significant effect on amplification of seismic ground motion due to ground structure. Detailed surveys of ground structures are necessary to know what affected the seismic ground motion during the earthquake in Ahmadabad.

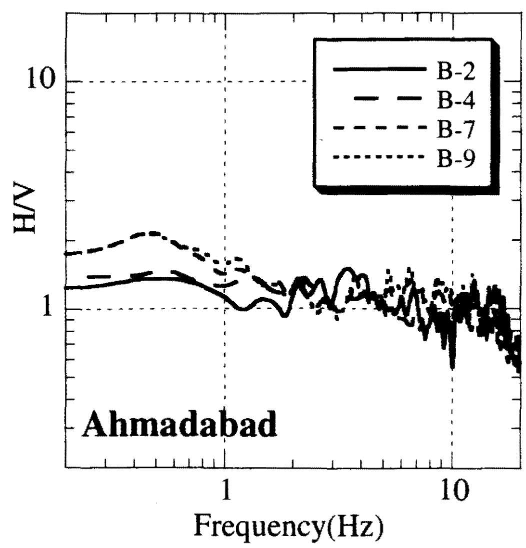

Figure 6.26 H/V spectra in Ahmadabad