

Intensity and isoseismal map of 25th November 2007 Delhi earthquake

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सार – दिल्ली में 25 नवम्बर 2007 (2312 यू. टी. सी.) M_L : 4.3 परिमाण का भूकंप आया जिसका अवकेन्द्र 28.55° उ./ 77.08° पू. तथा नाभीय गहराई 33.1 कि. मी. थी। इसका अधिकेन्द्र दिल्ली विश्वविद्यालय के लगभग 21 कि.मी. दक्षिण-पश्चिम में था। दिल्ली और इसके आसपास के क्षेत्रों में इसके झटके महसूस किए गए और इससे स्थानीय लोगों में भगदड़ मच गई। 27 नवम्बर 2007 से लगभग दस दिनों तक एक प्रश्नावली के माध्यम से दिल्ली और उसके आस-पास के क्षेत्रों के लगभग 1500 वर्ग कि.मी. के क्षेत्र के 89 स्थानों का दीर्घभूकम्पी सर्वेक्षण किया गया। दीर्घ भूकम्पी सर्वेक्षण के परिणामों से ArcGIS 9.1 के विश्लेषण उपकरण का उपयोग करके समभूकम्पीय मानचित्र के रूप में भूकम्प के प्रभावों के स्थानिक वितरण तैयार किए गए। समभूकम्पीय मानचित्र से पता चला कि दिल्ली के सबसे उत्तरी क्षेत्र को छोड़कर जहाँ भूकम्प की तीव्रता IV थी, दिल्ली के बाकी भागों में भूकम्प की तीव्रता एम. एम. आई. पैमाने पर V रही। क्षेत्र V, IV, III, II के लिए समभूकम्पीय मध्य त्रिज्या क्रमशः 29.13, 57.78, 83.63 और 100.75 कि. मी. रही। तीव्रता के दीर्घाकृत अधिकेन्द्रीय मार्ग के विन्यास से पता चला है कि दिल्ली – सरगोधा रिज के साथ-साथ प्रतिबल सुस्पष्ट था और इस रिज में होने वाली गतिविधियों के कारण भूकम्प आया।

ABSTRACT. An earthquake of magnitude M_L : 4.3 occurred on 25th November 2007 (2312 UTC) in Delhi with hypocenter at 28.56° N / 77.08° E and focal depth 33.1 km. The epicenter was at about 21 km SW of Delhi University. It was widely felt in and around Delhi and created panic among the local populace. A macroseismic survey was conducted in about ten days starting from 27th November, 2007 at 89 locations covering an area of about 1500 sq. km in Delhi and its neighborhood through a questionnaire. The results of the macroseismic survey allowed establishment of spatial distribution of the earthquake effects in the form of isoseismal map generated using geo-statistical analysis tool of ArcGIS 9.1. The isoseismal map shows that most parts of Delhi region experienced an intensity of V on MMI scale, except on northern most region of Delhi where intensity was found IV. The mean isoseismal radii for the zones V, IV, III and II are 29.13, 57.78, 83.63 and 100.75 km, respectively. The orientation of elongated epicentral track of intensity field shows that the stress release was pronounced along Delhi-Sargodha ridge and earthquake was attributed to activities of this ridge.

Key words – Intensity, Isoseismal, Earthquake, Macroseismic survey.

1. Introduction

Immediately on occurrence of an earthquake, hypocentral parameter (location, magnitude and depth) are disseminated by India Meteorological Department (IMD) to the authorities responsible for post earthquake disaster management and public. This information is very useful to initiate relief and rescue operation, but does not tell about the actual impact of earthquake at different area, which varies according to the distance from the hypocenter, intensity and soil condition. Seismic intensity is a qualitative method to measure earthquake ground shaking *viz.-a-viz.* its impact at a specific location

determined subjectively during post earthquake investigations and is traditionally used worldwide. Isoseismal (equal intensity) maps provide valuable information on distribution of earthquake shaking and are commonly used to characterize earthquake severity and seismic hazard.

The assessment of seismic intensity through macroseismic studies are especially helpful in seismically active regions where seismic instrumentation is distributed too sparsely in order to provide a reliable spatial coverage of effect of shaking and hazard due to an earthquake. Intensity data may provide a basis for interpreting or

extrapolating strong motion data and, in the absence of strong motion data, can help to identify regions in which ground motion is amplified due to site-specific geologic conditions. Isoseismal maps of recent earthquakes, whose epicenters, depths and other source parameters are determined with instrumental data, help calibrate analyses of intensities of historic, non-instrumentally recorded earthquakes to refine estimates of locations, size and other source parameters. It is, therefore, important to quantify the meaning of intensity levels when possible and to develop as clear criteria as possible for their assignment.

An earthquake of magnitude M_L : 4.3 occurred on 25th November 2007 with hypocenter location at 28.56° N / 77.08° E and focal depth about 33.1 km. The epicenter was located at about 21 km south west of Delhi University. IMD is operating a VSAT based Seismic Telemetry Network around Delhi with nine field stations within 80 km from Central Receiving Station at IMD, Lodi Road, New Delhi. This earthquake was widely felt in and around Delhi and created panic among the local populace. It did not cause fatalities or any major damage to the buildings. There were felt reports of earthquake from as far as upto 80 km from epicenter (Modipuram and Meerut area in the north east of Delhi). At Model Town (north Delhi) widening of cracks in walls of a few building were reported. Some people reported peculiar behavior of animals at Hasanpur (south east Delhi) locality. A few person reported felt direction as West to East in locations at Malka Ganj (North Delhi) and Patel Nagar (west central Delhi). A macroseismic survey was conducted to study the effect of this earthquake.

There are several seismic intensity scale for measuring severity of earthquake shaking. These are Rossi-Forel scale, European-Macroseismic scale (EMS-98), Shindo scale, MSK-64 scale etc. Most of these scales have twelve degrees of intensity, which are roughly equivalent to one another in values but vary in the degree of sophistication employed in their formulation. The Modified Mercalli Intensity (MMI) scale of Wood and Neumann (1931) is one of the widely used intensity scale world over. In general MMI depends on numerous factors, including the earthquake magnitude, epicentral distance, local soil condition and building characteristics etc. There are 12 levels in MMI scale marked by Roman numerals from I to XII, where Modified Mercalli Intensity XII refer to total damage, seismic waves seen on ground surface, line of sight and levels distorted and objects thrown upward into the air. It is established that the attenuation of intensities with distances varies in different tectonic domain (Bakun and McGarr, 2002). The macroseismic intensity surveys are being made based on pre formulated set of questions. Several such questionnaires are available in the literature in the form of personal interviews, postal,

telephonic and internet based surveys (Wood and Neumann, 1931; Dengler and Dewey 1998 and Wald *et al.*, 1999). In this study, intensity estimated is calibrated with MMI as basic methodology is based on Wald *et al.* (1999).

For present study a questionnaire consisting of 24 questions, based on Wald *et al.* (1999) was prepared. It is a simplified and easy to understand to a common man, each question addressing a specific aspect of earthquake impact with a numerical value assigned to the answer of each individual question of the questionnaires (Appendix 1). Four teams were deployed for field survey and collecting response from the inhabitants. The survey was completed in ten days time starting from 27th November 2007 covering entire NCT Delhi and adjoining areas from where earthquake was reported felt. The survey was conducted in the form of personal interviews in the community centers, residential colonies, villages and other places. A set of 50 questionnaires were also distributed to the employees of IMD, posted at HQ, New Delhi living in various places of Delhi and requested for participation. Data were analyzed and intensity map was generated using GIS tools.

2. Data and Methodology

The answers to the questions were analysed and numerically evaluated. The mean value for answers to each question was calculated from all the responses in the corresponding area. An area Weighted Sum Survey (WSS) was then calculated based on following equation.

$$\begin{aligned} \text{WSS} = & 5 \times [\text{Felt index} + \text{Shelf index}] + \text{Motion} \\ & \text{index} + \text{Reaction index} + 2 \times \text{Stand index} \\ & + \text{Hanging object index} + \text{Furniture index} \\ & + \text{Damage index} \end{aligned} \quad (1)$$

This equation was basically derived from community weighted sum (CWS) formula of Wald *et al.* (1999) with certain modifications to weight assigned to Hanging object index, Furniture index and Damage index. Due to this, the final value of these indices may vary slightly in case of damaging (big) earthquake as compared to the original equation of Wald *et al.* (1999).

Some of the questions in survey were not used directly in area intensity calculations but responses were collected for consistency in deciding intensity with standard MMI scale. These include questions on whether the observer was inside or outside, perceived duration of earthquake felt/shaking and type of structure in which observer was present during earthquake.

An equation to get a Community Internet Intensity (CII) from CWS (which is similar to WSS) was derived

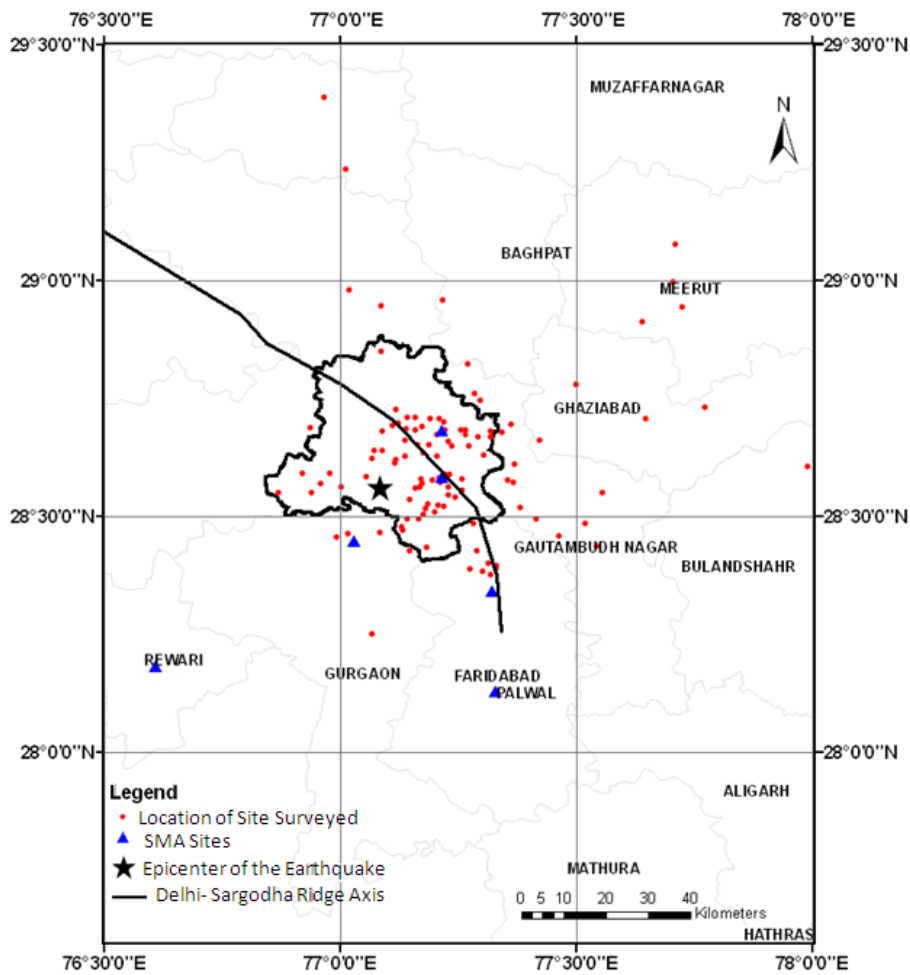


Fig. 1. Location of sites surveyed

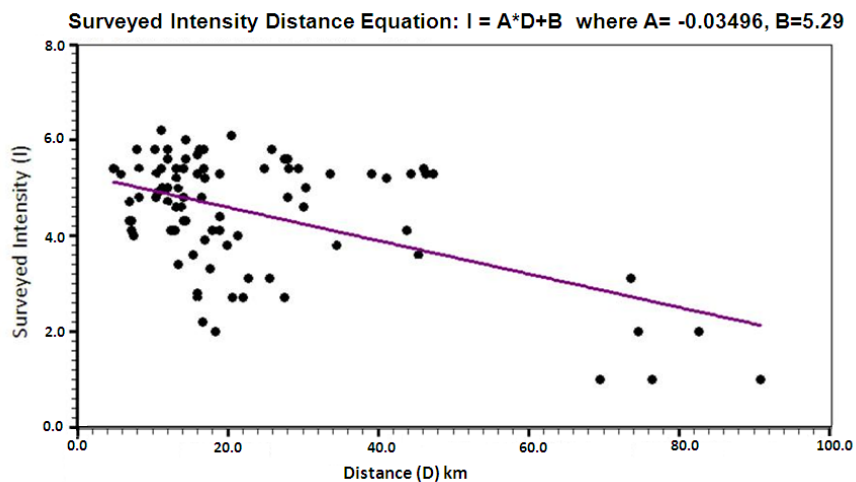


Fig. 2. Surveyed Intensity - distance relationship for the Delhi earthquake of 25th November 2007

by Wald *et al.*, 1999 based on past earthquake records. We may use the same relationship to get Surveyed Intensity (SI) from WSS as

$$\begin{aligned} \text{SI} &= 3.4 \log(\text{WSS}) - 4.38 \text{ for } \text{WSS} \geq 6.53 \\ &= 2 \text{ for } \text{WSS} < 6.53 \text{ and felt} \\ &= 1 \text{ for } \text{WSS} < 6.53 \text{ and not felt} \end{aligned} \quad (2)$$

The SI values were computed to two decimal places and then rounded off to integer values for comparison with Roman numerals assigned to MMI values. As an example the WSS and SI estimate for Lodi Road area is shown in Appendix 2.

A total of 209 responses were collected from 89 locations, of which 206 responses were used for intensity estimation and remaining 3 were rejected due to incompleteness. The locations of surveyed points are shown in Fig. 1.

3. Results and discussion

In order to visualize intensity contour map using GIS tools, the estimated intensities are also required at spatial grid boundary points. A linear relationship (Eqn. 3) was estimated between intensity computed and epicentral distance to facilitate estimation of intensity at boundary grid points. This linear fit of intensity *versus* epicentral distance is shown in Fig. 2.

$$\text{SI} = 5.29 - 0.03496 D \quad (3)$$

Where, D is the distance in km.

This relationship was used for estimation of intensities at 22 spatial grid points. Thus, SI was determined at 89 surveyed locations and extrapolated at 22 boundary points using Eqn. (3). Further, in this study, all the responses for damage index were value zero, no response of maximum value for furniture index and only one response for hanging object index with maximum value. Thus, variation in computation of WSS due to this value could be 0.00485, which is negligible. The SI value estimated from Eqn. (2) vary from 6.2 to 1.0. At three locations SI was estimated ≥ 6.0 (6.2, 6.1 and 6.0 at Satbari village, New Usmanpur and Hasanpur at an epicentral distance of 11.2, 20.5 and 14.4 km respectively). It was observed that estimated SI value was same at certain locations with different epicentral distance. For example, SI value 5.4 was estimated at 11 locations, including Delhi Cantt. and R. K. Puram localities at a epicentral distance ranging from 4.9 to 8.2 km. This shows effect of local geology which is varying in the region.

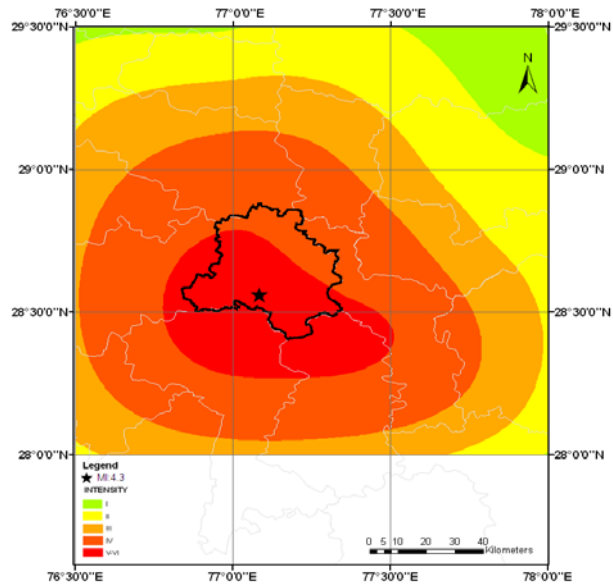


Fig. 3. Isoseismal map for 25th November 2007 Delhi earthquake

Based on estimated SI, the MMI were determined as intensity VI ($5.5 < \text{SI} \leq 6.5$) at 14 locations, intensity V ($4.5 < \text{SI} \leq 5.5$) at 39 locations, Intensity IV ($3.5 < \text{SI} \leq 4.5$) at 19 locations, intensity III ($2.5 < \text{SI} \leq 3.5$) at 10 locations, intensity II ($1.5 < \text{SI} \leq 2.5$) at 4 locations and intensity I ($0.5 < \text{SI} \leq 1.5$) at 3 locations in the dataset. The areas with MMI values V and VI are mapped as single zone V, since the surveyed points do not spatially resolves two intensities.

The isoseismal map of 25th November 2007, Delhi earthquake was developed using geo-statistical analysis tool with local polynomial interpolation method (Fig. 3). The mean and root mean square error in interpolation of intensity data using local polynomial is -0.0007946 and 0.905 respectively. The mean isoseismal radii for the zones V, IV, III and II are 29.13, 57.78, 83.63 and 100.75 km, respectively.

The most of the VI intensity sites are around south and south west of the epicenter covering areas in south west Delhi region (Chhabaa village, Dinadarpur, etc.), and south of Delhi (Asola) and Faridabad (Badkhal lake village).

The maximum intensity V–VI was estimated for a length of about 80 km along elongated track in WNW–ESE direction with mean isoseismal radii of about 29.13 km. The orientation of the elongated track is closely

TABLE 1
Comparison of intensity estimated from SI and PGA

| S. No. | Sites | PGA (gal) | | | PGA (gal) | SI (MMI) | MMI estimated from Trifunac and Brady (1975) |
|--------|--------------|-----------|--------|--------|-----------|----------|--|
| | | Z / V | N-S | E-W | | | |
| 1. | Guragon* | 81.34 | 74.48 | 37.24 | 68.60 | 5.7(VI) | 6 |
| 2. | Ballabhgarh* | 48.02 | 31.36 | 28.42 | 38.96 | 5.4(V) | 5 |
| 3. | Palwal* | 15.68 | 15.68 | - | 15.68 | 4(IV) | 4 |
| 4. | Rewari* | 23.52 | 4.90 | 3.92 | 13.97 | 3(III) | 4 |
| 5. | Lodi Road | 13.17 | 8.918 | 13.17 | 12.11 | 5(V) | 4 |
| 6. | Ridge | 16.85 | 13.044 | 15.758 | 15.63 | 3.3(III) | 4 |

PGA = $\frac{1}{2}$ [PGA (H) + PGA (V)] where PGA (H) = $\frac{1}{2}$ [PGA (N-S) + PGA (E-W)]

* Source: IIT Roorkee (Department of Earthquake Engineering)

parallel to Delhi-Sargodha ridge. This reflects that this earthquake was because of tectonic movement along this ridge. The fault plane solution shows that orientation of the strike (N115° E) of one of the nodal plane (Prakash, 2009), conforms trend of isoseismal as well as Delhi-Sargodha ridge.

Strong motion records at six sites namely; Lodi Road, Ridge, Gurgaon, Ballabhgarh, Rewari and Palwal were available. The MMI value at these locations were estimated from Trifunac and Brady (1975) relationship $MMI = (\log(PGA) - 0.014) / 0.3$. The MMI values obtained from Trifunac and Brady (1975) relationship and from SI are in good agreement as shown in Table 1.

4. Conclusion

The intensity map generated in this study shows meizoseismal area elongated WNW-ESE direction in the vicinity of Delhi Sargodha Ridge. This trend shows that this earthquake was due to tectonic activity along this ridge and fault plane solution also conform this. The methodology may be useful for generation of intensity map for earthquake magnitude less than five. However, the questionnaire and equation for estimation of weighted sum survey require further study to generalize this for any earthquake.

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Earthquake Risk Evaluation Center

Seismic Intensity Questionnaire Survey Form for the Earthquake on 25th November 2007, 23:12 UTC (26th Nov 2007 0442 IST)

1. Did you feel the earthquake? [Felt index]
(1) Yes [1] (2) No [0]
2. If Yes
(1) Duration of felt the event () Sec./Mint.
(2) () No. of Jolts felt
(3) () Direction from which it felt.
3. Where were you when the earthquake occurred?
Address:.....
City/Town/Village:Road:.....
District:..... Pin code.....
4. 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. 22, skipping the questions from 5 to 21.
5. Was it difficult to stand or walk [Stand index]
(1) Yes [1]
(2) No [0]
6. How did you feel the ground shaking? [Motion index]
(1) No felt [0]
(2) As slightly as one hardly felt. [1]
(3) As a light truck passing by. [2]
(4) As a heavily loaded truck passing by. [3]
(5) As a heavy object falling inside the building. [4]
(6) As something exploding in the building. [5]
7. 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
8. How old was the building? () years
9. How many stories did the building have?() stories
10. 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
11. Did you awake to the earthquake?
(1) I cannot answer, because I was not sleeping.
(2) Yes, but I did not realize why I awoke.
(3) Yes, and I realized that an earthquake occurred.
12. Were you frightened? [Reaction index]
(1) No [0]
(2) A little, but I felt safe even staying in the building [1]
(3) Quite, but I felt it safe even staying in the building [2]
(4) Almost scared [3]
(5) Scared and did not know what I should do [4]
(6) Panicked [5]

13. What happened to hanging objects, such as pictures on the wall and lights? [Hanging object index]
- (1) Nothing. [0]
 - (2) Slight swinging without noises. [1]
 - (3) Considerable swinging with banging noises and some swung out of place. [2]
 - (4) Partly damaged or fallen. [3]
14. What happened to furniture? [Furniture index]
- (1) Nothing. [0]
 - (2) Slight shake. [1]
 - (3) Considerable shake. [2]
 - (4) Heavy furniture partly moved. [3]
 - (5) Heavy furniture mostly moved and partly overturned. [4]
15. What kind of noises did you hear during the earthquake? [Shelf index]
- (1) Nothing. [0]
 - (2) Rattle of windows, doors, and dishes and/or creak of walls and floors. [1]
 - (3) Banging of doors and windows and/or creak from every part of the building. [2]
 - (4) Banging, creaking, and crushing noises filled in the building. [3]
16. What happened to the plaster? [Damage1 index]
- (1) Nothing. [0]
 - (2) Fine cracks formed, and/or small pieces of plaster fell. [1]
 - (3) Large pieces of plaster fell here and there. [2]
 - (4) Large pieces of plaster fell everywhere. [2.5]
 - (5) The whole faces of plaster fell here and there. [2.75]
 - (6) The whole faces of plaster fell everywhere. [3]
17. What happened to the outer walls? [Damage2 index]
- (1) Nothing. [0]
 - (2) Small cracks. [1]
 - (3) Large and deep cracks. [1.5]
 - (4) Gaps. [2]
 - (5) Collapse in a single face and/or corner. [2.5]
 - (6) Collapse in two or more faces and/or corners. [3]
18. What happened to the chimneys? [Damage3 index]
- (1) Nothing. [0]
 - (2) Cracks formed in chimneys, and/or parts of chimneys fell. [1]
 - (3) Chimneys fell. [2]
19. What was the damage to the building? [Damage4 index]
- (1) Nothing. [0]
 - (2) Damage in the outer walls and roofs, but the building kept its inner space. [1]
 - (3) Collapse in the outer walls, but the building kept its inner space. [1.5]
 - (4) One story partially crushed. [2]
 - (5) One story fully crushed. [2.5]
 - (6) Two or more stories crushed. [3]
20. Were you or your families trapped in the building?
- (1) No.
 - (2) Yes. Family member could 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 ()
21. 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.
22. Are you male or female?
- (1) Male
 - (2) Female
23. How old are you?
- () years
24. Any other Information?

APPENDIX-2

Locality: Lodi Road Area (IMD Residential Complex)
 Latitude: 28.58725 °N Longitude: 77.22245 °E

| Index | Q.N. | No. of response | | | | | | | | | | | | | | | | | | | Sum | Average |
|-------|------|-----------------|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|-----|-----------|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | | |
| F | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | | | | | | 14 | 1 |
| S | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | | 0 | 0 |
| M | 6 | 3 | 4 | 5 | 4 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | - | | | | | | 41 | 2.92857 |
| R | 12 | 3 | 2 | 0 | 3 | 0 | 0 | 5 | 0 | 0 | 2 | 3 | 4 | 0 | 1 | | | | | | 23 | 1.642857 |
| H | 13 | 0 | 2 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 1 | 0 | 2 | 0 | | | | | | 10 | 0.7142857 |
| FU | 14 | 2 | 0 | 1 | 0 | 0 | 0 | 3 | 0 | 1 | 1 | 1 | 1 | 2 | 1 | | | | | | 13 | 0.92857 |
| SH | 15 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | | | | | | 13 | 0.92857 |
| D | 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 |
| | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 |
| | 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 |
| | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | | | | 0 | 0 |

Table for Intensity Calculation

| Index | Question | Avg. values |
|---------------------------|--|-------------|
| Felt Index | F 1 | 1 |
| Motion Index | M 6 | 2.92857 |
| Reaction Index | R 12 | 1.642857 |
| Stand Index | S 5 | 0 |
| Shelf Index | SH 15 | 0.92857 |
| Hanging Objects Index | H 13 | 0.7142857 |
| Furniture Index | FU 14 | 0.92857 |
| Damage Index | D 16+17+18+19 | 0 |
| Calculation for Intensity | | |
| Weighted Sum Survey | $WSS = 5[F+SH]+M+R+2[S]+H+FU+D$ | 15.857 |
| Surveyed Intensity | $SI = 3.4 \ln(WSS) - 4.38$, for $WSS \geq 6.53$ $= 2$ for $WSS < 6.53$ and Felt $= 1$ for $WSS < 6.53$ and Not felt | 5.01 MMI V |