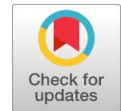# Seismic Vulnerability Assessment of Buildings in Surat City of western India

Abhijitsinh Parmar, Vikram M. Patel, A. P. Singh

Abstract: *In Surat city, the second largest city of Gujarat, 6930 buildings had been rapidly screened (RVS). RVS is known as a sidewalk evaluation, in which a skilled screener inspect a structure visually in order to recognize characteristics that influence the building's seismic output, for example the construction type, seismic zones, soil, and irregularities, etc. This study of RVS is based on the checklists in a RCC and Masonry Performa. Other significant structure information, including building occupancy and possible structural risks, are also collected during the screening. A performance score of the structure is calculated based on RVS values that correspond to these characteristics. In comparison with a cuts-off rating, the structure rating determines if a construction has possible vulnerabilities to be evaluated by a skilled engineer. We applied the Gaussian distribution methodology for cut off score in this study. The Gaussian distribution is also commonly called the normal distribution. Though, there are varied constructions practices, 74% constructions are RCC and 26% masonry structures. The performance results of surveyed buildings show that about 80 percent of both structures have high quality because they have a performance rating > 60. The survey's results also indicate that buildings practice have been changed from masonry to RCC after 2001 Bhuj earthquake (M7.7). Due to design, RCC buildings will have more shear capacity to tolerate the seismic shaking in comparison to the masonry buildings.*

Index Terms: *Rapid Visual Survey; Vulnerability assessment; seismic hazard; buildings; Performance score.*

I. INTRODUCTION

Surat is the district's administrative center. The town is situated at 284 kilometers south of Gandhinagar, the state capital, and the core at the mouth of the river at about 22 kilometers (14 mi) (fig. 1). Surat is the second largest town in Gujarat, after Ahmedabad, and its population reached 4.6 million at the 2011 census. Bhuj earthquake (M7.7) of 26 January 2001 caused more than 20,000 casualties. [1] [2] relatively low earthquake awareness and improper building methods are the main reason for these enormous deaths. The seismic codes of India are generally updated on the basis of technological advances and information acquired after earthquakes. Several new rules have been included and many old ones modified. Assuming that the involvement of Government Officers, Researchers and engineers will bring sufficient precautions to comply with the Indian Standards, the buildings being built are now expected to be earthquake resistant. What will the safety of structures for pre-code

modification happen in this regard? These buildings make up a significant proportion of the fragile system. Even if we have a very good system of catastrophe response, earthquake damage cannot be reduced without taking into account pre-code constructions. Moreover, it has to be checked that how the structure are constructed post code. A thorough evaluation of Gujarat's seismic risk is essential in this respect.
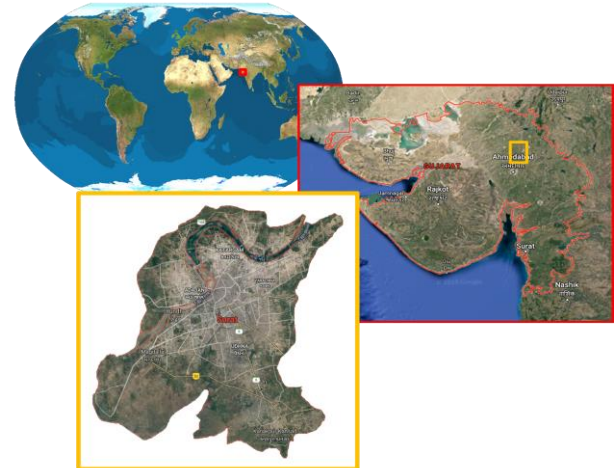

Fig. 1 Maps world map (b) Red inset shows location of Gujarat (c) Yellow inset shows location of Surat in Gujarat.

In the latest years, the threat of earthquake activity in India has been quickly growing and the nation has miserably struggled to ensure earthquake-resistant construction in higher earthquake zones. The seismic risk in India has been expanding quickly in the late years and nation has fizzled pitiably in guaranteeing tremor safe developments in high seismic districts Six direct seismic tremors have occurred in the last two decades: M6.4 (Bihar-Nepal fringe, 1988), M6.6 (Uttarkashi, Uttaranchal, 1991), M6.3 (Latur, Maharastra, 1993), M6.0 (Jabalpur, Madhya Pradesh, 1997), M6.8 (Chamoli, Uttaranchal, 1999), M7.7 (Bhuj, Gujarat, 2001) and M 7.2 (Muzzafarabad, Kashmir, 2005). [3], [4], [5] More than 2 lac causalities were measured in India but if similar type earthquake take place in developed countries like USA, Japan, etc., such causalities will not take place. In Bhuj 2001 earthquake most of public affected directly or indirectly. More than 20,000 people died due to 2001 Bhuj earthquake out of that 782 people in Ahmedabad and 18 people dies in Surat city. [6], [7] Even the Ahmedabad and Surat city is about 250 and 350 km, respectively away from the epicentral region of Bhuj earthquake. One Building Harekrishna collapsed in Varachha area and many building got moderate to Severe damaged. [6] Narmada fault which can generate Magnitude 7.0 earthquake is 80 kilometer away from Surat City which affect city very severely [8]. Extensive research of the Surat region of Gujarat is essential in this regard.

Bhuj earthquake continued its intense post-shock activities [2], [3]. Since March 2008, 14 aftershocks having Magnitude between 5.0-5.8, around 200 aftershocks having magnitude between 4.0-–4.9, around 1600 aftershocks having magnitude between 3.0- 3.9, and several thousand aftershocks with magnitude < 3 have been recorded. Regional seismicity with Mw 5.0 earthquakes and related series of foreshocks and post-shock [9]. Surat, which is approx 350 km from seismically-active sites in Kutch, gets unforeseen casualties from the 2001 Bhuj flood in Mw 7.7 and is in the seismic area III under IS 1893:2002 (Fig. 1). Surat is classified vulnerable to an earthquake and since the beginning of time has been hit several occasions (1684, 1856, 1871, 1935, 2008, 2013, 2016 and 2018) (Fig. 2). Cambay, Rann of Kutch, and Narmada-Tapti regions have been recognized as one of Peninsular India's most seismic active regions. [10] Mainly historic earthquakes have been located in Peninsular India close to the weak rifting zones. [10]
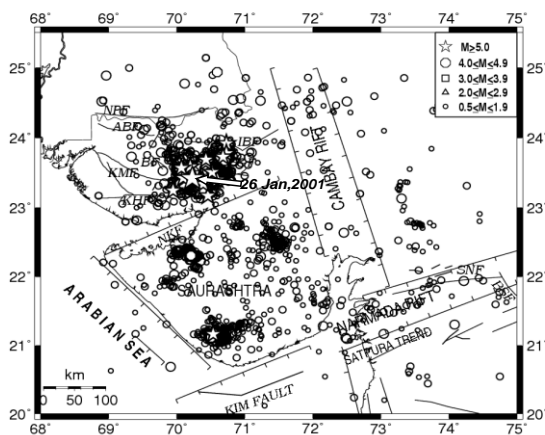

Fig. 1 Showing Bhuj 2001 earthquake (biggest star) and aftershocks occurred in Gujarat during 2001 to Dec-2015. The solid lines indicate the major faults (Source: ISR)

II. METHODOLOGY

The Many methodologies are developed to assess the damaged structures and to find the vulnerability of structure. Rapid visual survey is one the most popular method which allows the surveyor to evaluate large number of building in short time without conducting any destructive practical. It evaluates possibilities of damage or damage percentage by just visual inspection and it hardly take 30 minutes for each building. The screening depends on geometric seismic hazard and weakness score. The results rely on the typical stage of the earthquake in the region and the resistant design and level of the construction practice of the city. The assessment depends on a couple of factors of structures. The factors of the structures are tallness of building, diaphragm effect, pounding effect, plan and mass asymmetry, short column, large cantilever members, soil conditions, falling hazard, quality of building material, and so on. The execution results of the structures have been found on the assumption of the earlier stated parameters. The recipe is provided as the performance rating

$$PS= (BS) + \Sigma [(VSM) \times (VS)]$$

If VSM stands for the Vulnerability Score Modifiers and VS is the Vulnerability Score multiplied by VSM to find out the real modifier for the BS or Basic Score. [11]

Fig. 3 (a & b): A sample of RVS form filled for performance scores of the existing Frame buildings in the Surat city. Similar format applied for all Frame buildings

Fig. 4 (a & b): A sample of RVS form filled for performance scores of the existing masonry buildings in the Surat city. Similar format applied for all masonry buildings
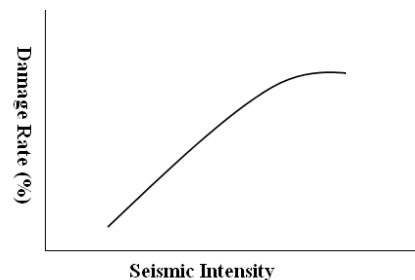

Fig. 5: Concept of damage (Fragility) function

III. RESULTS AND DISCUSSIONS

From Figures 3 & 4 shows the general distribution of RVS scores of the buildings. It is clearly seen that the scores are predominantly ranging between 60 through 120 both for masonry and concrete structures. There are also small portion of structures that are in range less than 30. On visual observation itself, we may conclude that these structures will surely collapse in the event of moderate earthquake. On the other hand there are a few buildings which have scores range over 110. Also from the visual observation it can be concluded that these buildings will not damaged severely. Further analysis of data revealed us some important observations.
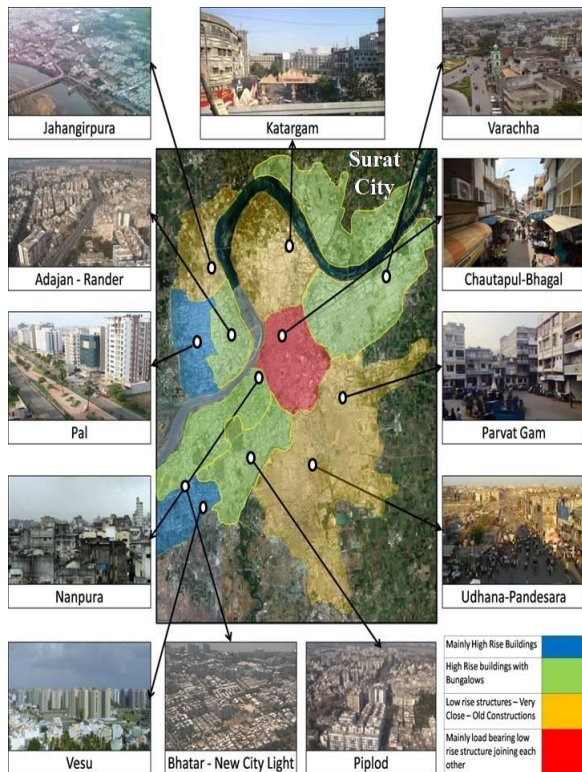
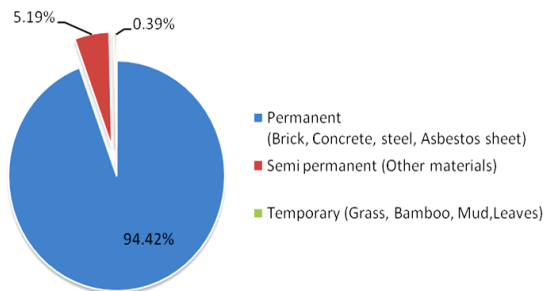**Fig 7: Zoning of Surat city based upon building type**

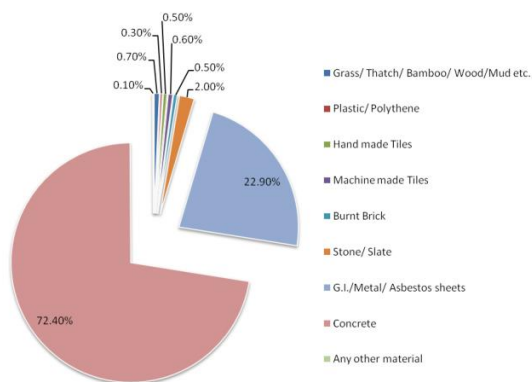**Fig. 7 : Categorized the existing buildings based on based on Material in Surat city**

- Permanent (Brick, Concrete, steel, Asbestos sheet)
- Semi permanent (Other materials)
- Temporary (Grass, Bamboo, Mud,Leaves)

Fig. 8 : Categorized the buildings based on Material of Roof

- Grass/ Thatch/ Bamboo/ Wood/Mud etc.
- Plastic/ Polythene
- Hand made Tiles
- Machine made Tiles
- Burnt Brick
- Stone/ Slate
- G.I./Metal/ Asbestos sheets
- Concrete
- Any other material
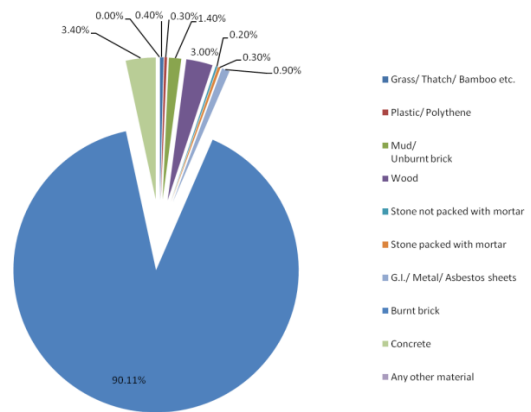
Fig. 9 : Categorized the buildings based upon Material of Wall

- Grass/ Thatch/ Bamboo etc.
- Plastic/ Polythene
- Mud/ Unburnt brick
- Wood
- Stone not packed with mortar
- Stone packed with mortar
- G.I./ Metal/ Asbestos sheets
- Burnt brick
- Concrete
- Any other material
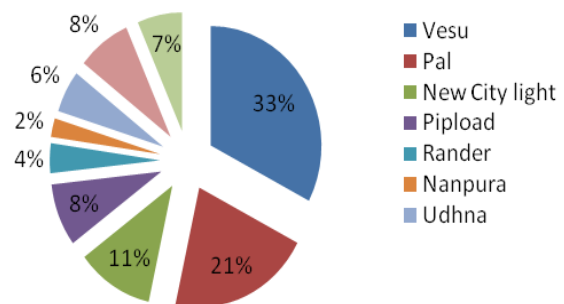
Fig. 10 : Percentage of High Rise buildings Zone Wise

- Vesu
- Pal
- New City light
- Pipload
- Rander
- Nanpura
- Udhna

We have initially estimated some statistical parameters namely mean median and mode range of huge data sets for masonry and RCC types of buildings in Surat city to describe properties of Normal (Gaussian) distributions. Usually conclusions can be drawn based on the scores, it can be said that the buildings with higher performance scores perform better compared to lower performance scores shall get damaged. However the buildings which are in the middle range of performance score is large in number and drawing meaningful conclusion is a difficult task because of non-availability of standard results for the Indian conditions.
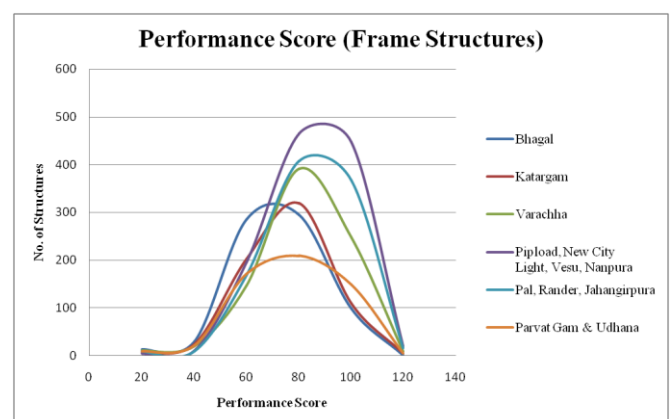

Fig. 11 : Performance scores of surveyed frame structures in Surat city
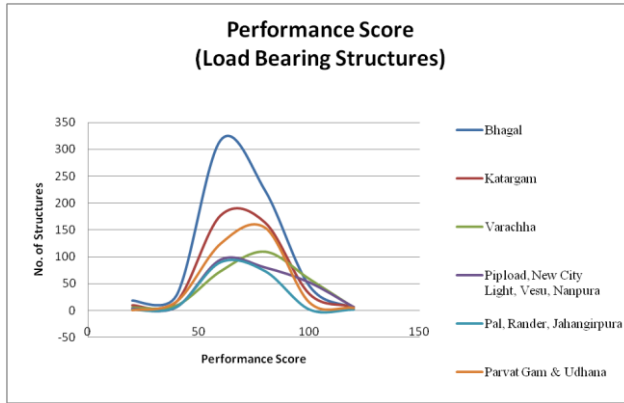
Fig. 12 : Performance scores of surveyed load bearing structures in Surat city

To overcome the above difficulty, it is proposed to do the preliminary assessment of selected buildings. For this purpose existing 6930 buildings falling in the range of mean plus or minus standard deviation are selected. In addition, up to 100 buildings with scores less than mean minus twice the standard deviation and greater than mean plus twice standard deviation were selected. Later detailed analysis required on selected few buildings to standardize the RVS score. The RVS scores will then be calibrated after detailed analyses and the buildings will then the divided into a few categories of performance factors indicating their vulnerability. After standardization of the performance scores, the fragility curves will be prepared. The fragility curve is the graph between seismic intensity and damage rate. This relation estimates losses for various building classifications and earthquake intensities. The concept of the fragility curve is shown in Fig (5). Based on survey data, it is observed that a variety of building types exist, mainly RCC frame structure and load bearing structures used in Surat City. Based on Rapid Visual Survey, Surat city divided into four zones or several namely, mainly high rise buildings; High rise buildings and tenements mixed Low rise buildings, Old constructions; Mainly Load bearing structures and mostly joining to each other. On the other hand, newly developed areas like Pal, Vesu, New city light (see Fig. 6 for location) having mainly high rise structure a mostly having more than G+7 structures. But based on RVS, we found that mostly all the building have parking at ground floor level which they all have soft storey at ground floor level which makes them more vulnerable to earthquake. After the year 2001, each building has been built so that it can withstand small seismic vibration rates. Adajan, Rander, Varachha, Nanpura, Chaupati areas (see Fig. 6 for location) have mixed structures like High rise structures and tenements and bungalows. 30-35% buildings are constructed before 2001 earthquake so they might have low shear capacity to tolerate low level of seismic shaking. 40%-45% tenements & bungalows have plan asymmetry which can lead to torsional effect during earthquake. Morabhagal, Udhana, Jahangirpura, Parvat gam areas having (see Fig. 6 for location) mainly low rise buildings or having less than 5 storeys. 60-65% buildings are constructed before 2001. Bhagal, Chawk, katargam, Chautapul (see Fig. 6 for location) are having mostly load bearing structures and old construction. In market area mostly load bearing structure are joining to each other and many of them are very old structures which have less earthquake resisting capacity. If higher magnitude earthquake took place, these areas are most vulnerable. Figs. 7-9 describe materials used in buildings

which affects to RVS scores of building. Mainly high rise buildings are constructed in Vesu, Pal and City Light area (Fig. 10). Generally, conclusions can be drawn based on the scores (Fig. 11 & 12). It is possible to say that structures with bigger scores perform superior to lesser scores. From the Fig. 11 & 12 the buildings which are in the middle range of performance score are large in number which concludes non-availability of standard results in Surat city.

IV. CONCLUSIONS AND REMARKS

Gujarat resides in one of the world's most seismically sensitive areas and there is also an inextricable risk of potential terrible and moderate earthquakes. Rapid Visual Survey has been conducted on 6930 buildings in Surat city. The performance results show that around 80% of Masonry and RCC structures have excellent quality as the output of these structures is above 60. The Average performance score of surveyed buildings is 67.81. However some low-scoring structures can be at risk from potential earthquakes. Preliminary analyzes of structures and thorough evaluation process for 30 structures are also suggested for the calibration of RVS results.

V. RECOMMENDATION

• Implementation of the building code regulations for multi-storied structures needs to be given a high priority.
• With appropriate shear strengthening, structural details especially closer the beam-column joints must be enhanced.
• Quality control measures must be put in place for all new buildings. Ductility based design of structures must be incorporated.
• The efficiency must be improved of the low-level constructions constructed using local materials.
• Studies are needed to explore and enhance the efficiency of the above structures. The level of performance of low-rise structures built non-engineered in the existing city must be enhanced. This thing could contribute to a significant reduction in the number of deaths and damages in upcoming earthquakes.
• Almost all the high rise buildings having soft storey as ground level must be strengthened or stiffness of soft storey must be increased by various techniques.

ACKNOWLEDGMENT

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REFERENCES

1. Rastogi, B. K., Gupta, H. K., Mandal, P., Satyanarayana, H. V. S., Kousalya, M., Raghavan, R., & Satyamurty, C. (2001). The deadliest stable continental region earthquake occurred near Bhuj on 26 January 2001. Journal of Seismology, 5(4): 609-615

2. Singh, A. P., Mishra, O. P., Rastogi, B. K., & Kumar, S. (2013). Crustal heterogeneities beneath the 2011 Talala, Saurashtra earthquake, Gujarat, India source zone: seismological evidence for neo-tectonics. Journal of Asian Earth Sciences, 62: 672-684.

3. Singh, A. P., Mishra, O. P., Yadav, R. B. S., & Kumar, D. (2012). A new insight into crustal heterogeneity beneath the 2001 Bhuj earthquake region of Northwest India and its implications for rupture initiations. Journal of Asian Earth Sciences, 48: 31-42.

4. Ramancharla, P. K., Chenna, R., Goud, S. S., Sreerama, A. K., Vignesh, G., Sattar, B., ... & Babu, K. (2014). Rapid Visual Screening for Seismic Evaluation of Existing Buildings in Himachal Pradesh. Technical Report No. 01-2014, Volume-I

5. Jain, S. K. (2016). Earthquake safety in India: achievements, challenges and opportunities. Bulletin of Earthquake Engineering, 14(5): 1337-1436.

6. ASC :: 26 January 2001, M7.7 Bhuj Earthquake/Gujarat Earthquake (Gujarat), India

7. Sinvhal, A., Bose, P. R., Prakash, V., Bose, A., Saraf, A. K., & Sinvhal, H. (2003). Isoseismals for the Kutch earthquake of 26th January 2001. Journal of Earth System Science, 112(3): 375-383.

8. Chopra, S., Kumar, D., Rastogi, B. K., Choudhury, P., & Yadav, R. B. S. (2012). Deterministic seismic scenario for Gujarat region, India. Natural hazards, 60(2): 517-540.

9. Thaker, T. P., Rao, K. S., & Gupta, K. K. (2010, December). "Seismic hazard analysis for Surat City and its surrounding region, Gujarat. In Indian Geotechnical Conference (pp. 163-166).

10. Jaiswal, K., & Sinha, R. (2008). Spatial-temporal variability of seismic hazard in peninsular India. Journal of earth system science, 117(2): 707-718.

11. Srikanth, T., Singh, A. P., Kumar, S., Ramancharla, P. K., & Rastogi, B. K. (2011). Rapid Visual Survey of Existing Buildings in Gandhidham and Adipur Cities, Kachchh, Gujarat. European Journal of Scientific Research, 41(3): 336-353.

12. J. Visuvasam, J. Simon, R. Chandrasekar, "Seismic Vulnerability Assessment of Existing Residential Building at Vellore", International Journal of Civil Engineering and Technology (IJCIET), Volume 8, Issue 4, April 2017, pp. 604–610.

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Dr. Vikram M Patel is working as a Professor and Principal at AIIE. He has several years of experience in teaching, research and consultancy in the field of Infrastructure Engineering, Structural Engineering, Earthquake Engineering and Tsunami Engineering. Prof. Patel is member of Board of Studies at GTU, SP University, Visnagar and Ganpat University, Mehsana. Dr. Vikram M Patel has received the Pedagogical Innovation Award from GTU Innovation Council. He has also received Certificate of Appreciation from Director General, Institute of Seismological Research & ISES for Outstanding Work in Engineering Seismology and Tsunami Engineering. He has received Golden Educationist of India Award for outstanding achievement in the field of education from IIEM, New Delhi.

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