IDENTIFYING EARTHQUAKE-UNSAFE SCHOOLS
AND
SETTING PRIORITIES TO MAKE THEM SAFE

A Case Study In Gujarat, India

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Funded by:

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GeoHazards International

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SUMMARY

After the January 26, 2001 Gujarat Earthquake, GeoHazards International (GHI) was concerned about the risk of school buildings in the largest Gujarat cities and asked the Volunteers for India Development and Empowerment (VIDE) and NGOs Kobe to help fund a study that would identify earthquake-unsafe school buildings in Ahmedabad, Baroda and Surat. VIDE and NGOs Kobe agreed to help. GHI worked with its Indian partner organization, SEEDS, to evaluate 153 schools: 42 in Ahmedabad, 58 in Baroda, and 53 in Surat. The schools included different structural types, served students from a variety of educational and economic levels, and were widely dispersed within each city.

GHI found that the earthquake risk of the schools in all three cities is significant, and recommends that the authorities responsible for these schools take steps to reduce the risk. GHI further recommends that these authorities initiate comprehensive school earthquake risk mitigation programs. GHI and SEEDS will meet with officials in these three cities to discuss these findings and follow-up actions. After this meeting, this report will be revised.

INTRODUCTION

Gujarat State is a highly earthquake-prone region in western India. Past earthquakes have devastated almost all parts of the state. Table 1 lists thirty-three significant earthquakes that struck the region since 893-894 A.D.

Figure 1 shows the location of Ahmedabad, Baroda and Surat, and the location of selected historic earthquake epicenters, their date of occurrence and number of fatalities. Figure 2 depicts the Seismic Zoning Map of India. The cities in this report lie in Zone 3 where, according to current Indian standards (IS: 1893-2002), peak ground accelerations of 0.16g and seismic intensities of VII MMI can reasonably be expected to occur once during the design life of a structure. The seismic zoning map is based on the likely intensity from likely earthquakes, and does not follow current worldwide fashion of specifying zones in terms of ground acceleration (a measure of earthquake shaking intensity) with a certain probability of being exceeded in a given number of years.

Table 1. Historical Earthquakes in Gujarat Region

Date	Location	Magnitude	Maximum MMI
893-894 A.D.	Debal-Bahmanabad, Pakistan [1, 2]	$M_W = 7.5$	
08-29-1636	Surat area, Gujarat [3]		III
02-1705	Bhavnagar-Gogha area, Gujarat [3]		XI
06-16-1819	Great Rann [4]	7.8	XI
08-13-1821	Kaira-Daman-Ahmedabad [5]	5.0	V
07-20-1828	Bhuj-Anjar area, Gujarat 5		VI
06-19-1845	Southwest of Lakhpat	6.3	VII
04-26-1848	South of Mount Abu [4]	6.0	VII
04-29-1864	Surat-Ahmedabad area [5]	5.0	VII
04-14-1872	Bhavnagar area, Gujarat [6]		
01-14-1903	Northeast of Kunria [4, 5]	6.0	VII
08-15-1906	North of Bakasar, Rajasthan [7]	$M_W = 6.2$	
07-12-1907	Tharpakar, Pakistan [5, 7]	$M_W = 5.6$	VI
04-21-1919	Near Bhavnagar [5]	5.5	VII
07-20-1935	Gulf of Khambat, Gujarat [5]		VII
06-1938	Jhinjuwada-Vadgam area, Gujarat [5]		VI
07-14-1938	Dhandhulka-Limbdi area, SW of Ahmedabad [5]		VI
07-19-1938	Dhandhulka-Limbdi area, SW of Ahmedabad [8]		VI
07-23-1938	Paliyad Earthquake, SW of Ahmedabad [9, 5]		VII
1940	Umia-Luna area, Gujarat [4]	$M_S = 5.8$	
10-31-1940	Northwest of Kathiawar, Jamnagar District [8]	6.0	VI
11-27-1945	Off the Makran coast, Pakistan [10]	$M_W = 8.0$	
06-14-1950	Tharad-Jhajham area, Gujarat [5]	5.6	V
07-21-1956	North of Anjar [4, 11]	$M_w = 6.0$	IX
09-01-1962	Khed Brahma-Vadali area, Gujarat [4]	$M_S = 5.0$	
03-23-1970	Bharuch District [4, 11]	$M_W = 5.4$	VII
03-26-1975	Arabian Sea [12]	$M_b = 5.2$	
08-24-1993	Arabian Sea [4]	$M_b = 4.9$	V
09-12-2000	Northeast of Bhavnagar [13]	$M_L = 3.8$	
01-26-2001	Near Bhachau [13]	$M_w = 7.6\text{-}7.7$	IX-XII
01-28-2001	Suvi-Rapar area, Gujarat [13]	$M_W = 5.8$	
02-08-2001	Suvi-Chobari area, Gujarat [13]	$M_L = 5.1$	
08-05-2003	Janan-Rapar area, Gujarat [13]	$M_L = 4.9$	

References

(1) Rajendran and Rajendran (2001)
(2) Rajendran and Rajendran (2002)
(3) Iyengar *et al.* (1999)
(4) Dasgupta *et al.* (2000)
(5) Rao and Rao (1984)
(6) Srivastava and Ramachandran (1985)
(7) Ambraseys (2000)
(8) Chandra (1977)
(9) Mathur (1998)
(10) Pacheco *et al*. (1992)
(11) Rajendran (2000)
(12) United States Geological Survey
(13) Institute Meteorological Department

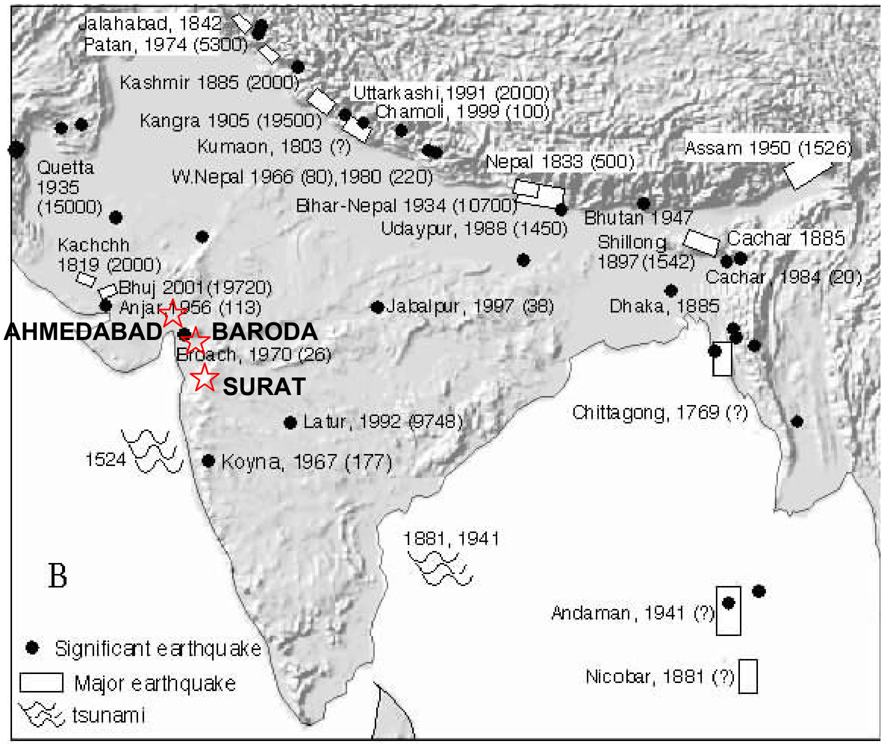


Figure 1. Location, year and number of fatalities for earthquakes in India in the last 200 years (Bilham and Gaur 2000)

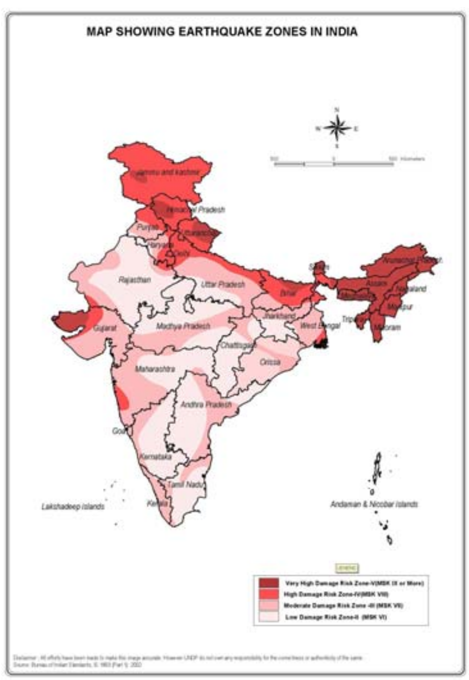


Figure 2. Seismic Zoning Map of India (www.mapsofindia.com)

The Bhuj Earthquake on January 26, 2001 caused significant damage to school buildings in Gujarat. Rai et al. (2002) concluded that school buildings in general are neglected and poorly constructed and maintained. The collapsed and seriously damaged school buildings in Bhuj demonstrated a high degree of vulnerability of these structures to earthquakes. This study classifies school buildings by degree of vulnerability and provides a method to assess and recommend priorities for earthquake risk mitigation actions. GHI believes that the high level of risk of the Gujarat schools detailed in this report justifies actions to reduce this risk to children before future earthquakes strike.

METHODOLOGY

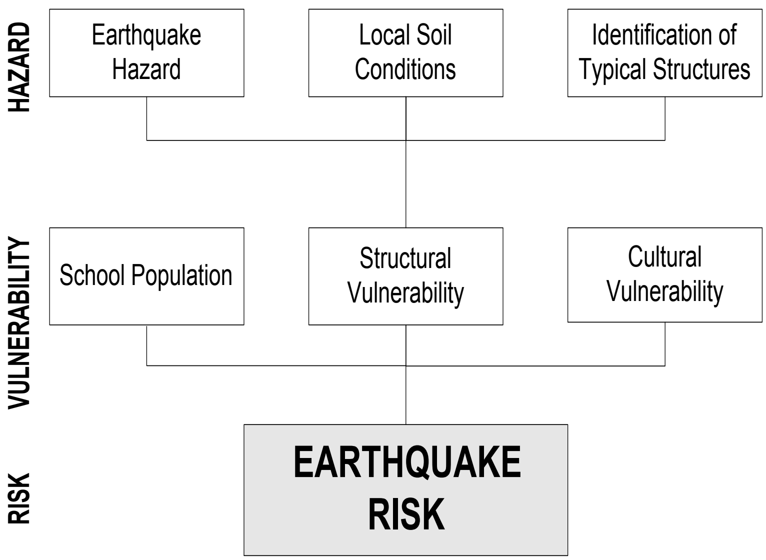


Figure 3. Method for assessing earthquake vulnerability

The method used by GHI to assess the earthquake risk to schools is diagramed in Figures 3 and 4. This method is particularly suitable when economic resources are scarce, the stock of school buildings is large, and priorities are needed to implement earthquake risk mitigation actions.

The first step is to describe the earthquake hazard affecting the geographic area of interest. All possible sources of seismic activity were identified and their potential to cause strong ground motions was described. Earthquake sources also were identified from pre-instrumental historical records.

The second step is to collect information on local soil conditions, because geological and soil conditions profoundly influence the shaking amplitude, frequency content, duration and damage. Buildings located on sites where ground motions are amplified are more likely to be damaged.

The third step is to identify typical structural systems (the lateral-force resisting system) found in school buildings in the area. Local construction and design practices, quality of typical construction materials, and observed past earthquake damage are documented. A small number of buildings are selected and studied to assess the vulnerability. The results from the sample buildings determine conclusions about the entire building stock.

Assessing selected school buildings accomplishes two essential tasks: 1) it identifies the structural lateral-force resisting system; and 2) it identifies features that can compromise the seismic performance of the building. The assessment is done from the building exterior. Trained inspectors record information on building type, size, number of students and hours of operation, as well as attributes that modify seismic performance. The inspector also sketches the floor plan and takes photographs of the buildings from different sides to record observed structural attributes and features that illustrate the structural type. The information is recorded on a form to assure consistency. Photographs allow additional study of the buildings without returning to the school site. Figure 4 illustrates these steps.

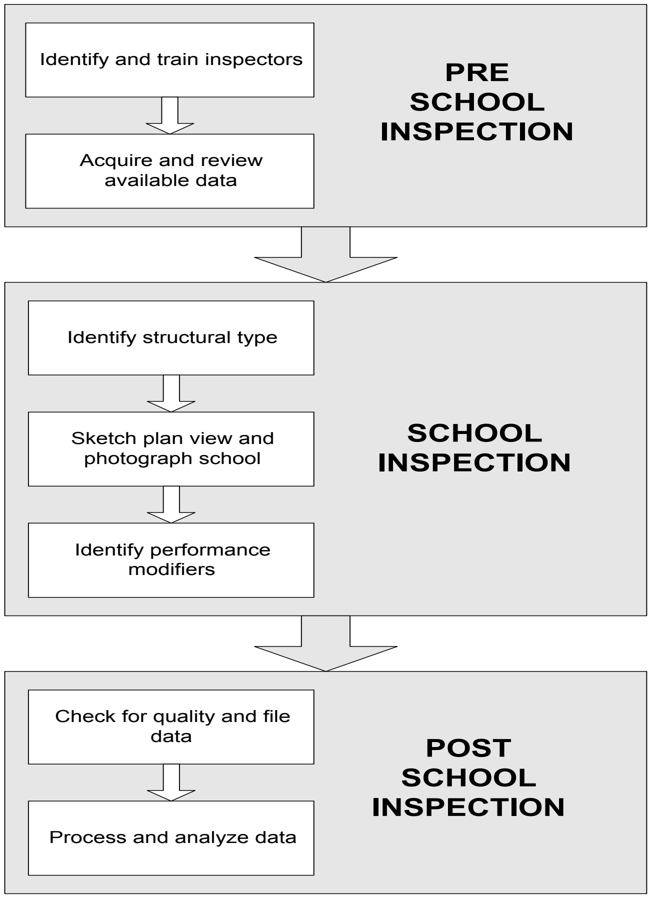


Figure 4. Stages of the visual inspection

The *school population* is the number of students and school staff in the buildings and schools. This is critical information for describing the seismic threat and setting priorities. Overpopulated schools complicate implementation of earthquake preparedness actions and compromise student safety in other ways. Proper evacuation of a school (that is, evacuation without jeopardizing the lives of students and teachers) is more challenging to manage as the number of students increases. Larger populations require greater access to stairs, aisles and escape routes. The risk to students increases if these accommodations are not provided. Increased student density also results in increased loads on the structure, and if these loads were not considered when the structure was designed, the building can be unsafe even without the occurrence of an earthquake.

The *structural vulnerability* is estimated for each building surveyed using the European Macroseismic Scale 1998 (EMS 1998) (See Appendix I). According to this scale "if two groups of buildings are subjected to exactly the same earthquake shaking, and one group performs better than the other, then … it can be stated that the buildings that were less damaged are more earthquake-resistant, and vice versa." The European Macroseismic Scale includes six classes of structural vulnerability (A, B, C, D, E, and F). The first three classes A, B, and C represent the most vulnerable building types (buildings most likely not to withstand shaking); and classes D, E and F represent building types with less structural vulnerability (buildings most likely to withstand shaking). Judgment is used to assign the structural vulnerability class to the school building based on the structural features identified during the assessment phase.

The *cultural vulnerability* is related to the degree of earthquake risk awareness, preparedness and response capabilities of the school community. School occupants who are prepared and trained to respond to earthquakes are less vulnerable than occupants who lack earthquake risk awareness and training. The higher the level of education and the greater the awareness of earthquake risk, the lower the cultural vulnerability.

The *earthquake risk* of a building is related to the aggregation of the hazard and school population, structural and cultural vulnerabilities. Different degrees of earthquake risk are defined by correlating ranges of school population with the classes of structural vulnerability and different levels of cultural vulnerability for each building. For two buildings with the same structural and cultural vulnerabilities, the one with the larger population would present greater earthquake risk than the one with a smaller population. For two buildings with the same degree cultural vulnerability and school population, the one with greater structural vulnerability would present greater earthquake risk than the building having lesser structural vulnerability. For two schools with the same school population and structural vulnerabilities, the one with higher level of cultural vulnerability would present greater earthquake risk than the school with lower level of cultural vulnerability. For two schools with the same school population, and same level of structural and cultural vulnerabilities, the one with higher earthquake hazard would present greater earthquake risk than the school with lower earthquake hazard. However, in the present study, earthquake hazard and cultural vulnerability are not distinguishing factors because all three cities are located in Zone 3, and have, it is assumed, equal hazard.

Historic performance is the basis for estimating the structural and cultural vulnerabilities, and for establishing the degrees of earthquake risk. The different degrees of earthquake risk should affect priorities for risk reduction actions. These actions could include reducing the structural vulnerability strengthening or replacement of vulnerable buildings, reducing school population (relocation of students to other buildings or assigning the use of existing buildings in ways that expose fewer people to the risk), and reducing cultural vulnerability (training and education of school occupants on earthquake risk).

SCHOOL BUILDING TYPES

GHI identified four typical school building types in Ahmedabad, Baroda, and Surat. Two types (Figure 5) dominated: reinforced concrete frame buildings and unreinforced masonry buildings. Very few wood and steel structures were identified because this region does not have many buildings with these structural systems. Therefore, this report will address only reinforced concrete frame and masonry structures.

Concrete Frame Buildings

Concrete frames are the most common structural systems in the region and in the entire country (Jain et al. 2002). A typical system consists of a three-dimensional reinforced concrete frame resting on isolated footings with cast-in-situ reinforced concrete slab floors and unreinforced masonry walls or panels in the area between the frames. Tie beams connecting the footings, and plinth beams connecting columns at the ground story level usually are not present. A typical cross section of columns is 0.23 x 0.45m. The length of the Indian standard burnt clay brick unit, whose dimensions are 0.23 x 0.115 x 0.076m, determines these dimensions. The orientation of columns is decided more by architectural and geometric considerations than by structural principles, or the need to provide lateral resistance to earthquake forces. Floor slabs are usually 0.12m thick, and beam dimensions vary from 0.23 x 0.40m to 0.23 x 0.75m. Masonry infill walls use cement mortar, but sometimes mud mortar is used, and there is no reinforcement (Jain et al. 2002).

Unreinforced Masonry Buildings

A typical masonry building is made with burnt clay bricks joined by cement or mud mortar, and sometimes confined by reinforced concrete columns and beams. Cast-in-situ reinforced concrete slabs at levels form the floors. The quality of the brick units is poor and highly variable, even within the same batch. Common wall thickness is 0.23m. However, some one-and-a-half brick walls (0.345m) and some half-brick length thick walls (0.115m) were seen. Proper structural connections between the walls and the roofs, as well as between the walls and foundations are often missing.

Figure 5 illustrates the study sample of school buildings according to building type for the three cities. In Ahmedabad 75 percent of the school buildings are concrete frame, 23 percent masonry, and 2 percent wood. In Baroda 55 percent of the school buildings are concrete frame, and 45 percent masonry. In Surat 75 percent of the school buildings are concrete frame, 18 percent masonry, 5 percent wood, and 2 percent steel.

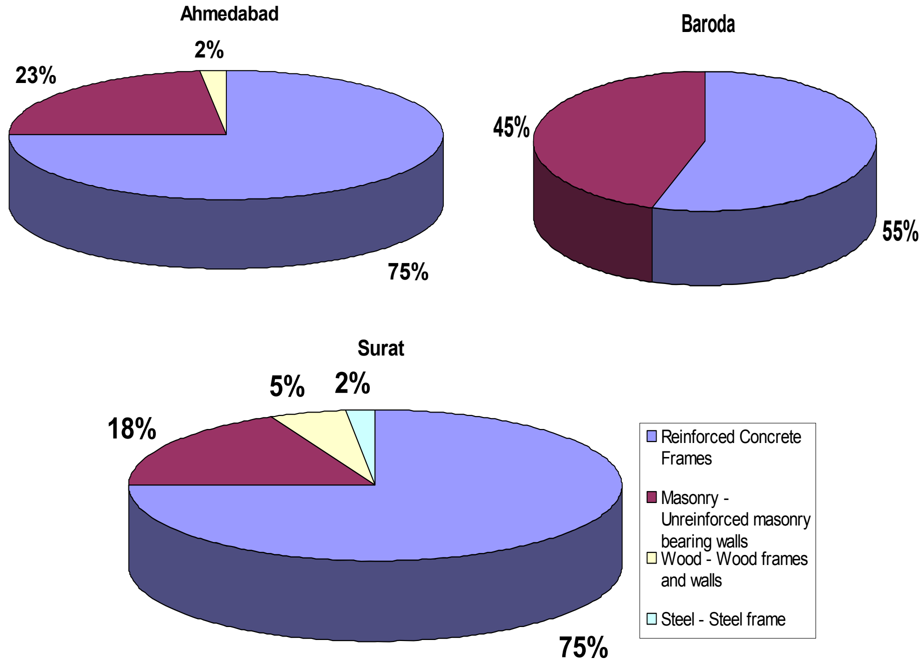


Figure 5. School building types in Ahmedabad (above, left), Baroda (above, right) and Surat (below)

Figure 6 displays the distribution of concrete frame and masonry school buildings according to four ranges of age; i.e., older than 40 years (>40), between 40 and 15 years (15-40), between 15 and 5 years (5-15), and under 5 years old (<5). Ahmedabad has the greatest proportion of older concrete frame school buildings (>40 and 15-40); 28 percent are over 40 years old and 67 percent are between 40 and 15 years old. Surat has the greatest proportion of the older masonry structures, where 50 percent of the masonry buildings are over 40 years old, and 40 percent between 15 and 40 years old.

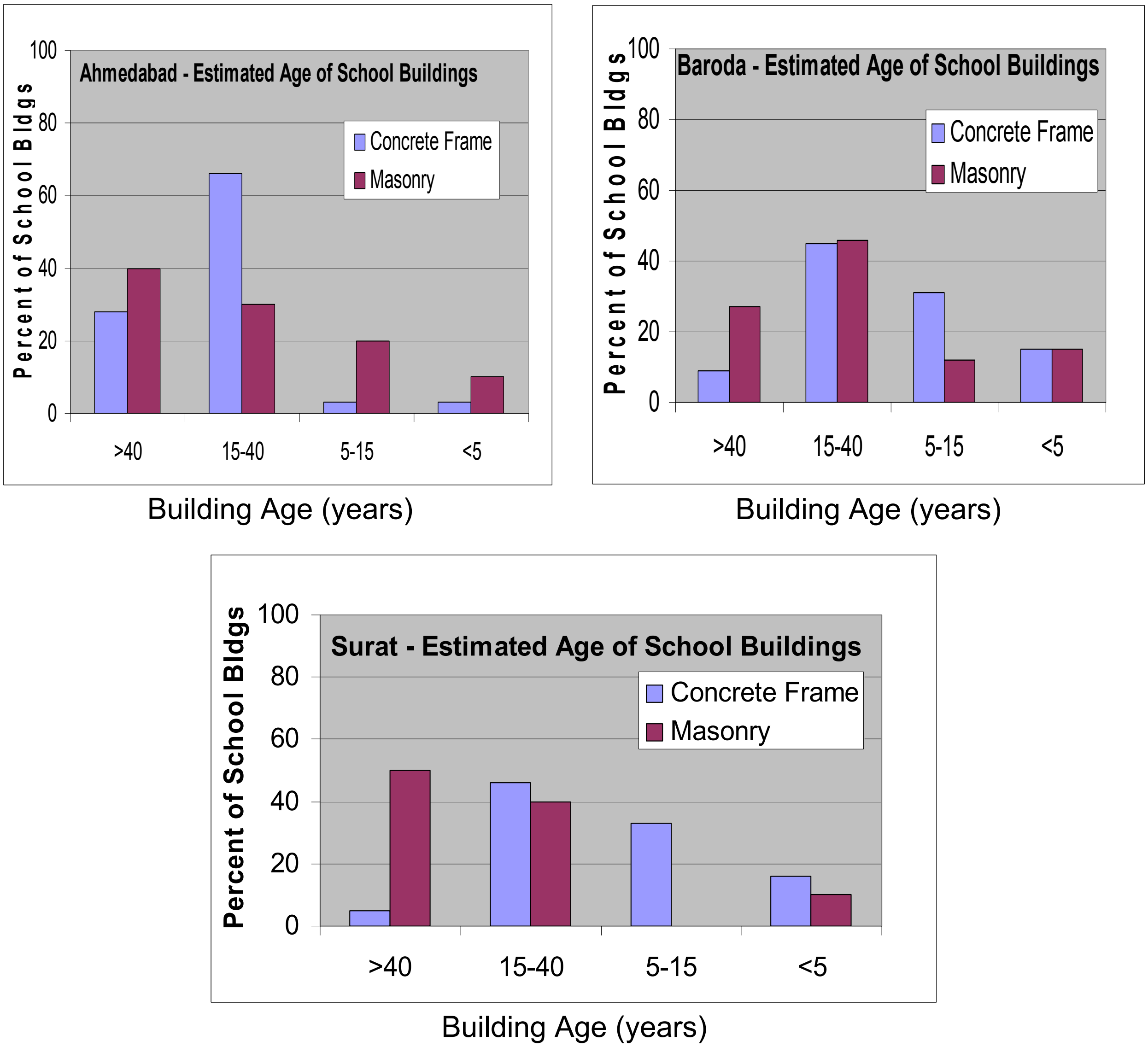


Figure 6. Distribution of concrete frame and masonry school buildings according to 4 ranges of age (40+, 40-, 15-, and 5- years old) for Ahmedabad (above, left), Baroda (above, right) and Surat (below)

Figure 7 displays the distribution of school buildings according to number of stories observed in the three cities. Masonry school buildings are predominantly 1- or 2-story structures, and concrete frame buildings are usually 3-story structures. In Ahmedabad, 90 percent of the masonry school buildings are 1- or 2-stories and 10 percent are 3-stories; 65 percent of the concrete frame buildings are 3-stories, 22 percent are 1- or 2-stories, and a few are higher than 3 stories. In Baroda, all masonry school buildings are 1- or 2-stories; 45 percent of the concrete frame buildings are 3-stories, 34 percent are 4-stories, and around 20 percent are 1- or 2-stories. In Surat, 80 percent of the masonry buildings are 1- or 2-stories and 20 percent are 3-stories; about 60 percent of the concrete frame buildings are 3-stories, 30 percent are 4-stories, and a few are 6-story structures.

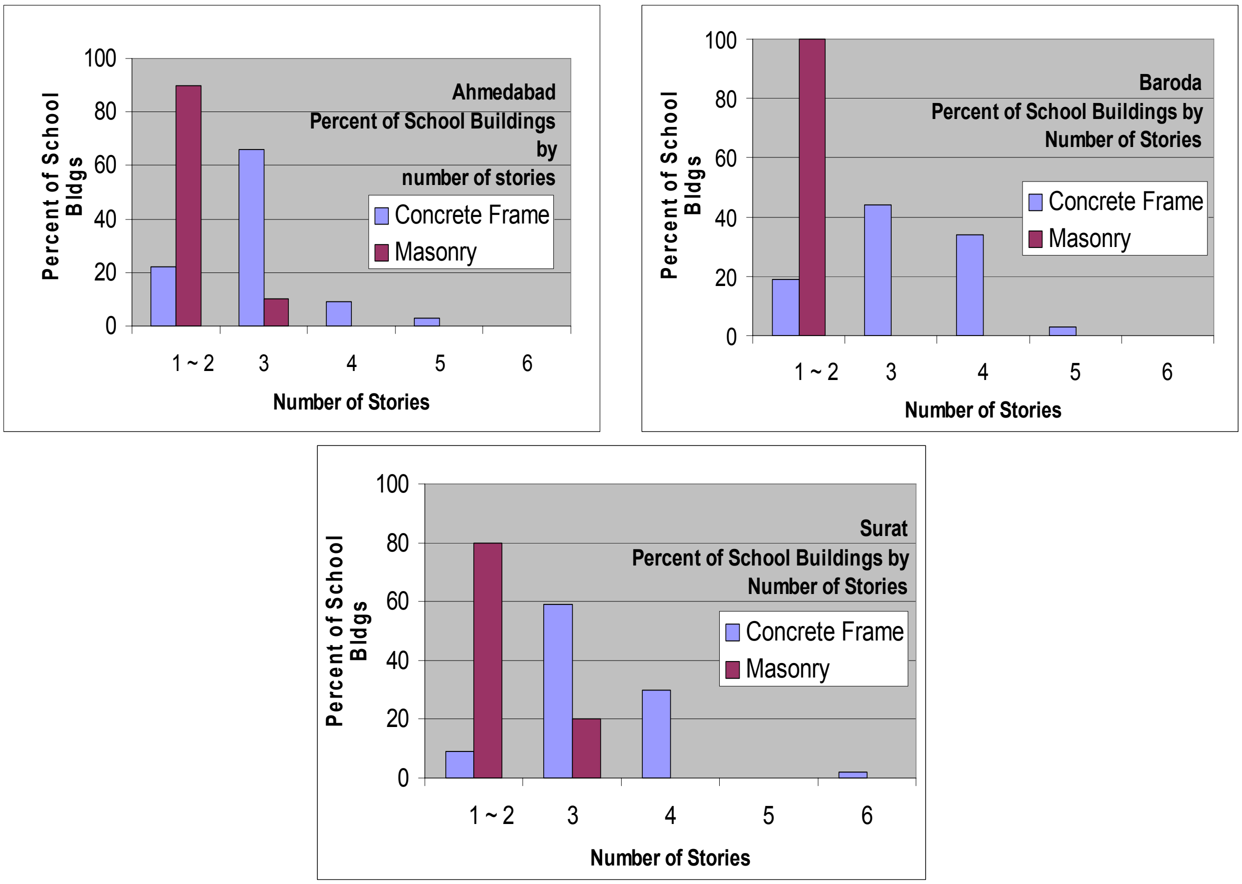


Figure 7. Percent of school buildings by number of stories for Ahmedabad (above, left), Baroda (above, right) and Surat (below)

VISUAL ASSESSMENT

The visual assessment inventories school buildings and identifies those that are potentially seismically vulnerable. It requires minimally trained inspectors (who need not be civil engineers or architects) and a digital camera. Figure 8 shows typical structures in the three cities.

(a)Ahmedabad. Concrete frame (left) and masonry (right) school buildings

(b) Baroda. Concrete frame (left) and masonry (Right) school buildings

(c) Surat. Concrete frame (left) and masonry (right) school buildings

Fig. 8 Typical school buildings in Ahmedabad, Baroda, and Surat

The visual assessment method uses a data collection form that consists of four sections: basic information, emergency preparedness and response, structural deficiencies, and condition of the school building (See Appendix II).

- The *basic information* section includes building age, number of stories, plan dimension, total height, structural type, roof type, roof cover, soil type, a sketch of the school layout, and photos.
- The *emergency preparedness and response* section includes information on fire fighting provisions, staff and personnel training, awareness programs, emergency plan, escape routes, and evacuation drills.
- The *structural deficiencies* section includes vertical irregularity, soft story, torsion, plan irregularity, façade hazards, short column and lack of lateral rigidity (See Glossary in Appendix II).
- The *structural condition* section includes information of observed distress in structural elements such as cracking and deterioration in reinforced concrete columns, slabs and beams, stairs and walls.

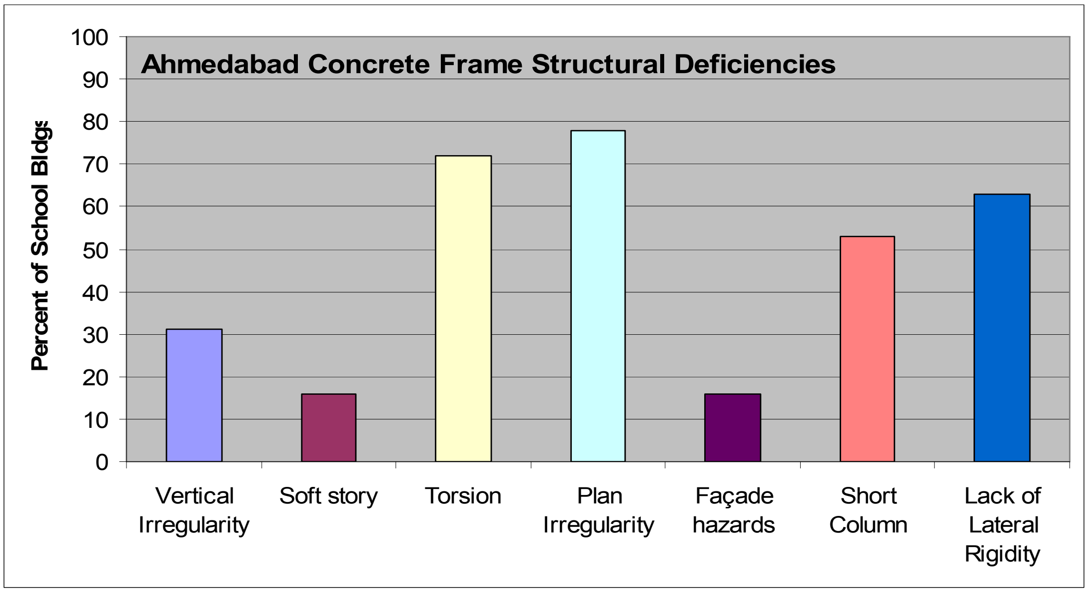
Note that the identified structural deficiencies and condition could affect the expected seismic performance of the buildings.

Below are the results of the visual assessment of concrete frame and masonry schools in Ahmedabad, Baroda and Surat.

AHMEDABAD

Concrete Frame School Buildings

Figure 9 summarizes the findings of the visual assessment of school buildings in Ahmedabad. Plan irregularity (78 percent), torsion (72 percent), lack of lateral rigidity (63 percent) and short columns (53 percent) are the most frequent features that adversely affect seismic performance of concrete frame school buildings. Structure condition is reflected by buildings with cracking in beams and slabs (97 percent), cracking in walls (91 percent), spalling of concrete and steel corrosion (74 percent), and cracking in column/beam connections (69 percent).



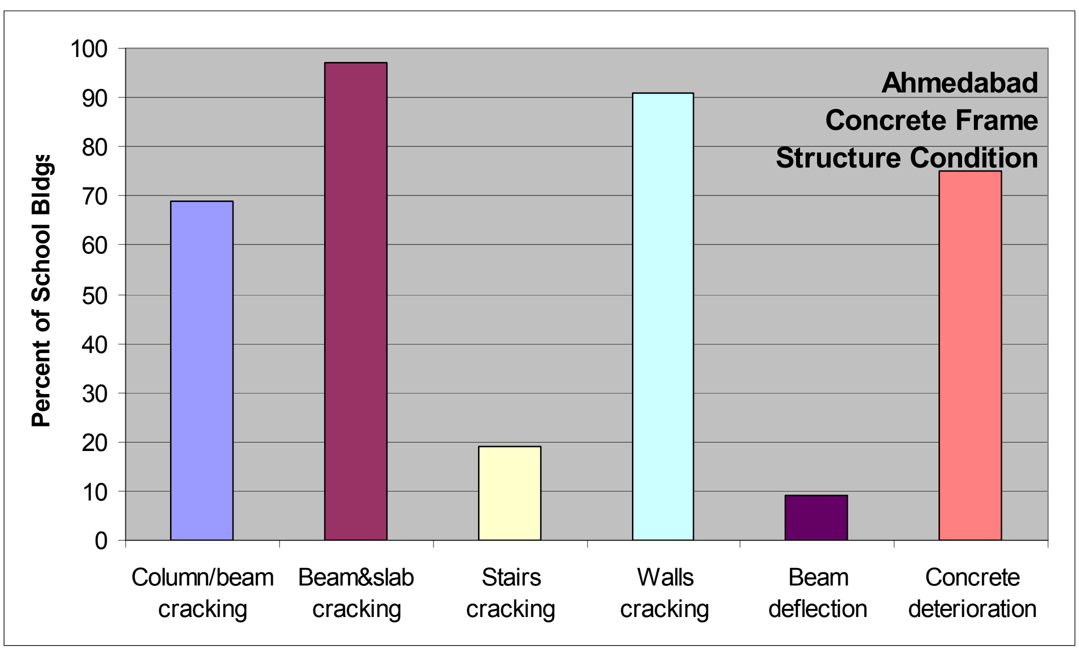
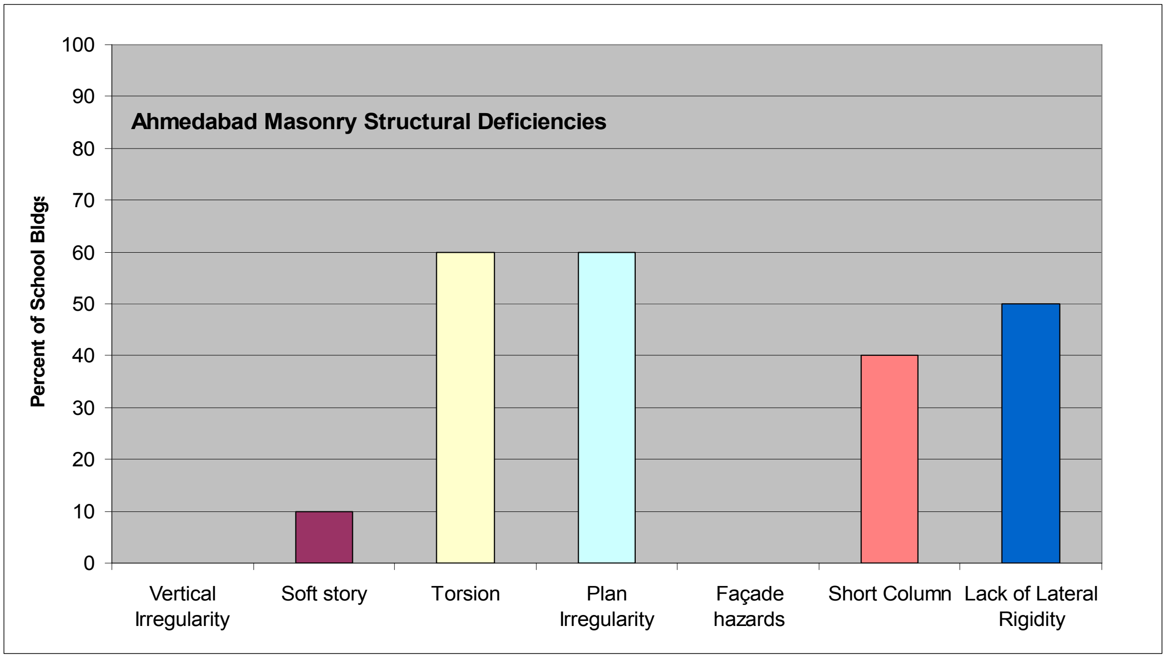


Figure 9. Frequency of concrete frame structural deficiencies and condition for Ahmedabad

Masonry School Buildings

Figure 10 summarizes the results of the visual assessment of masonry school buildings in Ahmedabad. Plan irregularity (60 percent), torsion (60 percent), lack of lateral rigidity (50 percent) and short columns (40 percent) are the most common features that adversely affect seismic behavior. Structural condition is reflected by buildings with cracking in walls and beams and slabs (90 percent), cracking in column/beam connections (80 percent), and concrete deterioration (60 percent).



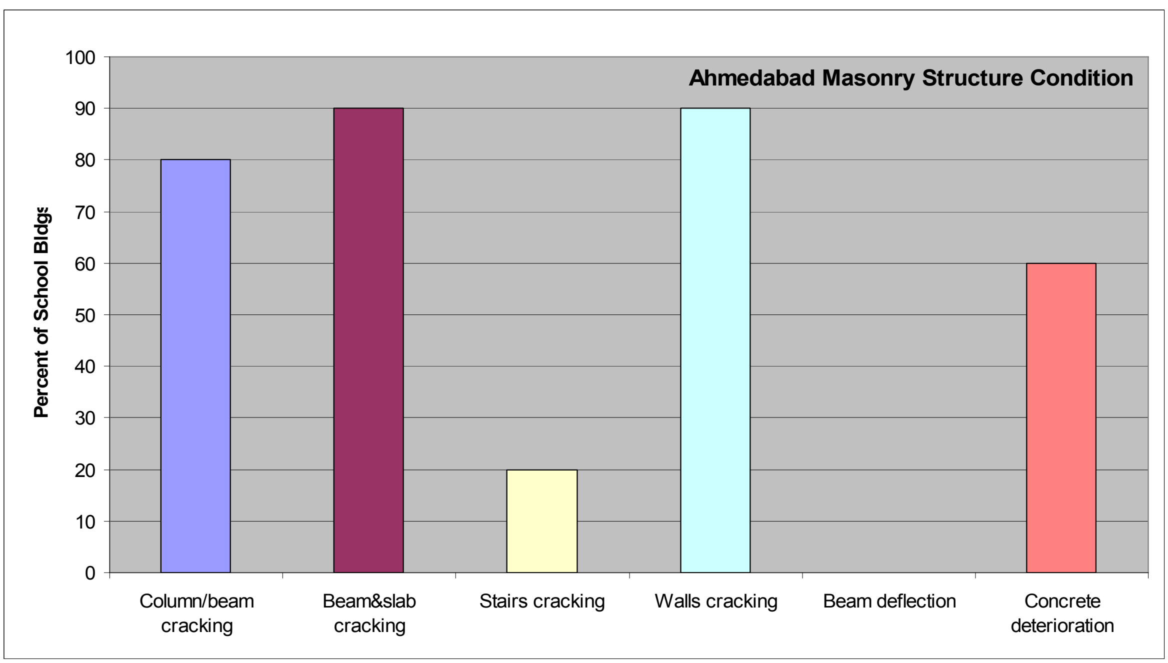
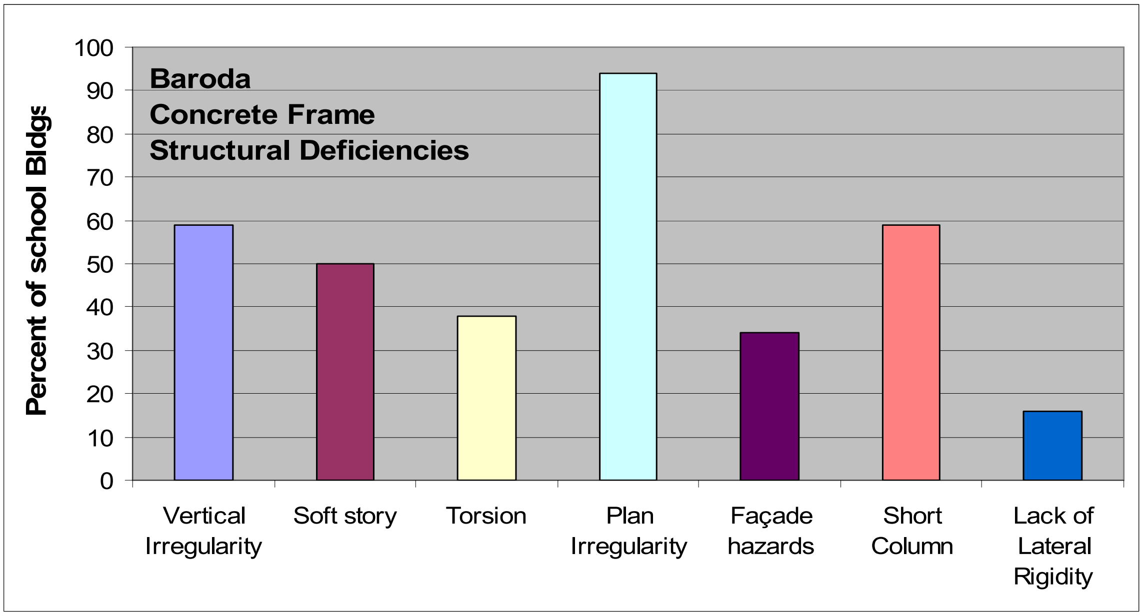


Figure 10. Frequency of masonry structural deficiencies and condition for Ahmedabad

BARODA

Concrete Frame School Buildings

Figure 11 summarizes the results of the visual assessment for concrete frame school buildings in Baroda. Plan irregularity (93 percent), short columns (58 percent), vertical irregularity (58 percent) and soft story (50 percent) are the most frequent features that adversely affect seismic performance. Façade hazards were found in more than 30 percent of the school buildings. Structure condition is reflected in cracking in beams and slabs (56 percent), cracking in walls (50 percent), reinforced concrete deterioration such as spalling of concrete and steel corrosion (40 percent), and cracking in column/beam junctions (38 percent).



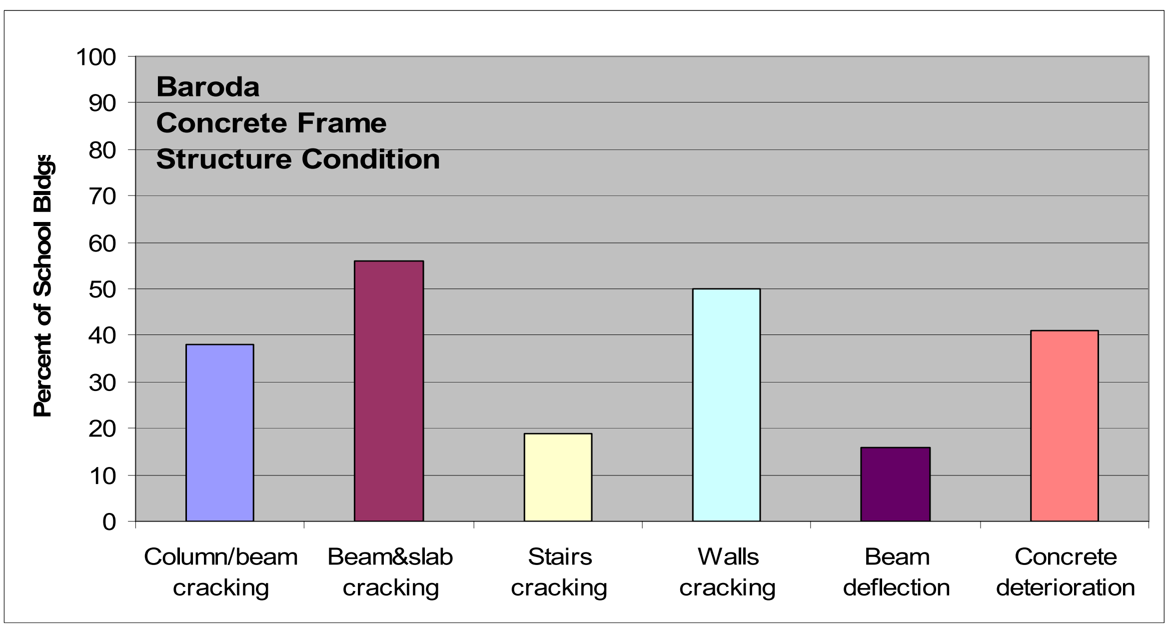
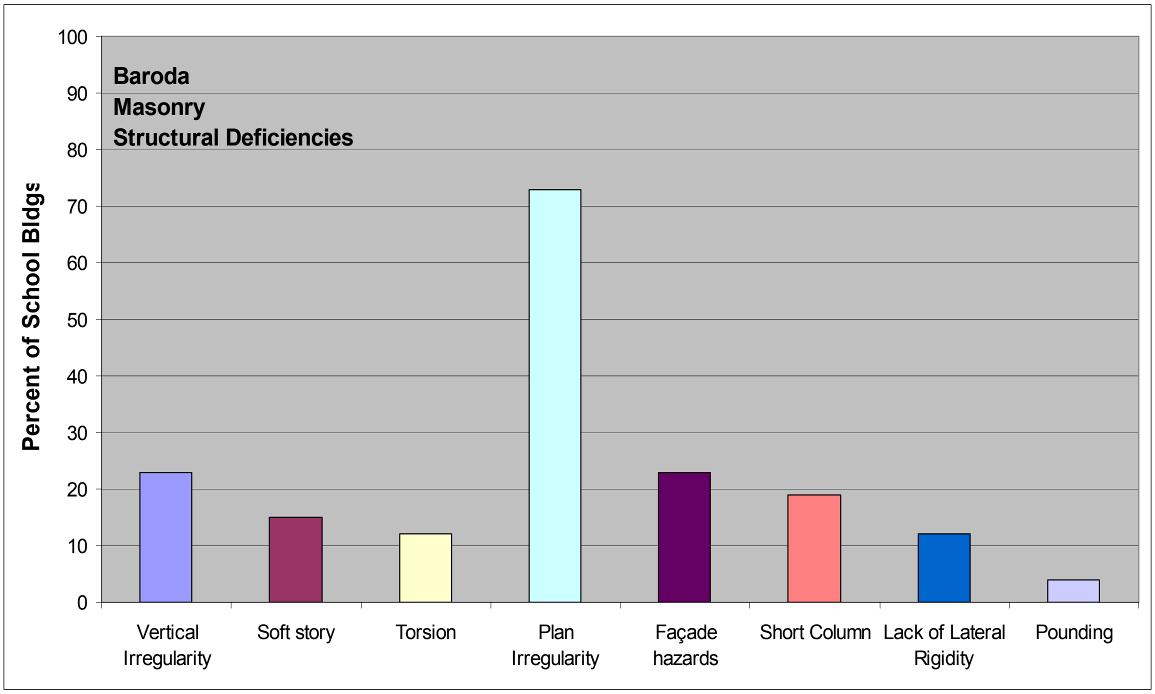


Figure 11. Frequency of concrete frame structural deficiencies and condition for Baroda

Masonry School Buildings

Figure 12 summarizes the findings of the visual assessment of masonry school buildings in Baroda. Plan irregularity is by far the leading deficiency (74 percent), followed by façade hazards (23 percent), vertical irregularity (22 percent) and short columns (19 percent). The structural condition is manifested by 58 percent of buildings with cracking in beams and slabs, 50 percent cracking in walls, and 31 percent concrete deterioration.



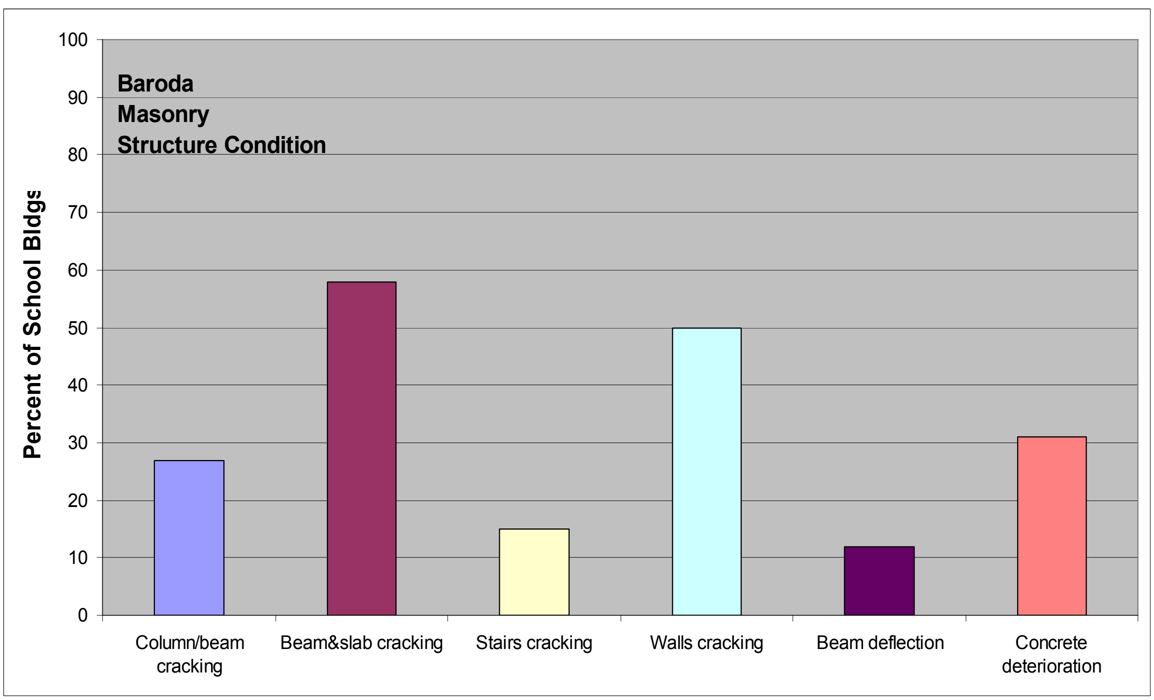
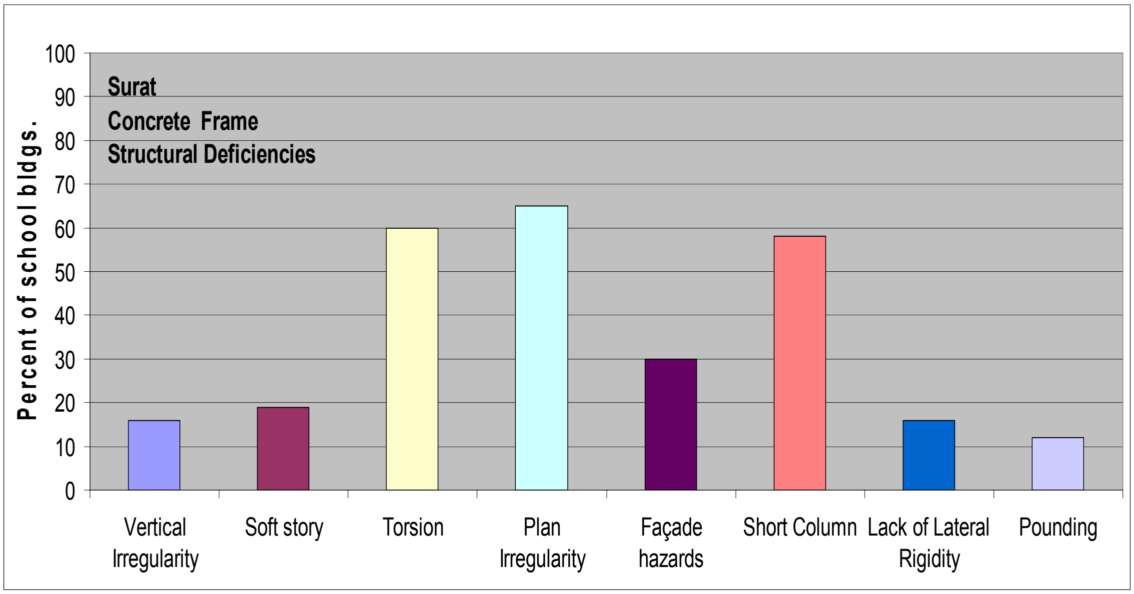


Figure 12. Frequency of masonry structural deficiencies and condition for Baroda

SURAT

Concrete Frame School Buildings

Figure 13 summarizes the findings for concrete frame school buildings in Surat. It clearly shows that plan irregularity (65 percent), torsion (60 percent) and short columns (58 percent) are the leading structural deficiencies that may adversely affect the seismic behavior of these school buildings. Around 30 percent of schools have façade hazards. The structural condition indicates that around 38 percent of the schools show concrete deterioration, 30 percent cracks in walls and 23 percent cracks in beams and slabs.



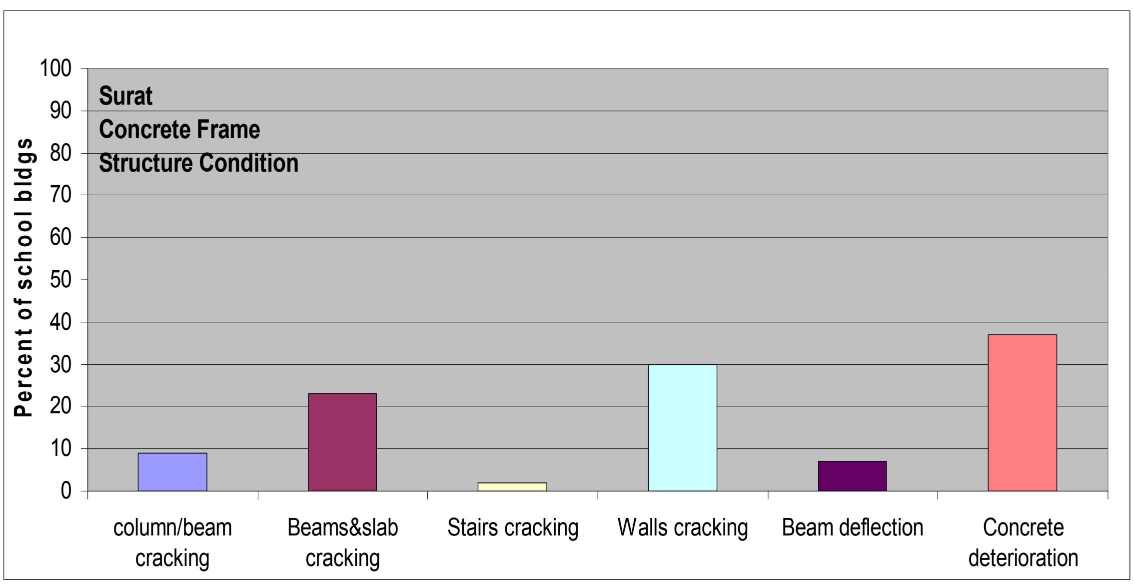
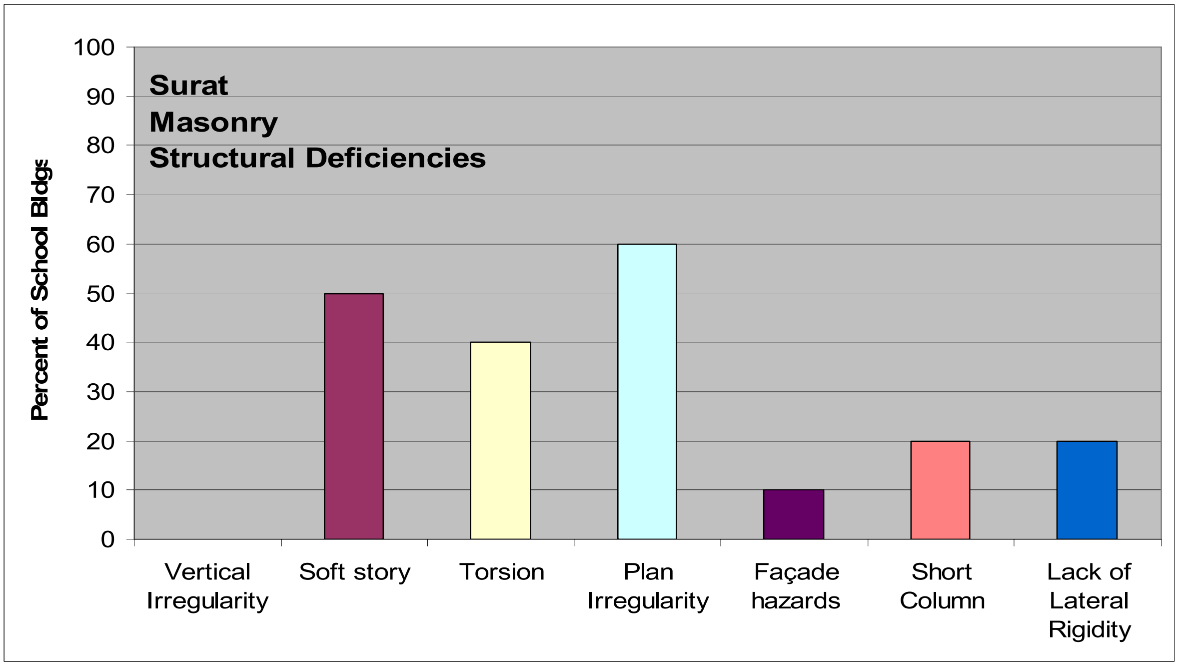


Figure 13. Frequency of concrete frame structural deficiencies and condition for Surat

Masonry School Buildings

Figure 14 summarizes the findings of the visual assessment of masonry school buildings in Surat. It shows that plan irregularity (60 percent), soft story (50 percent) and torsion (40 percent) are the most frequently observed structural deficiencies. Structural condition is indicated by wall cracks in 40 percent of the schools, concrete deterioration in 30 percent and beam deflection in 20 percent.



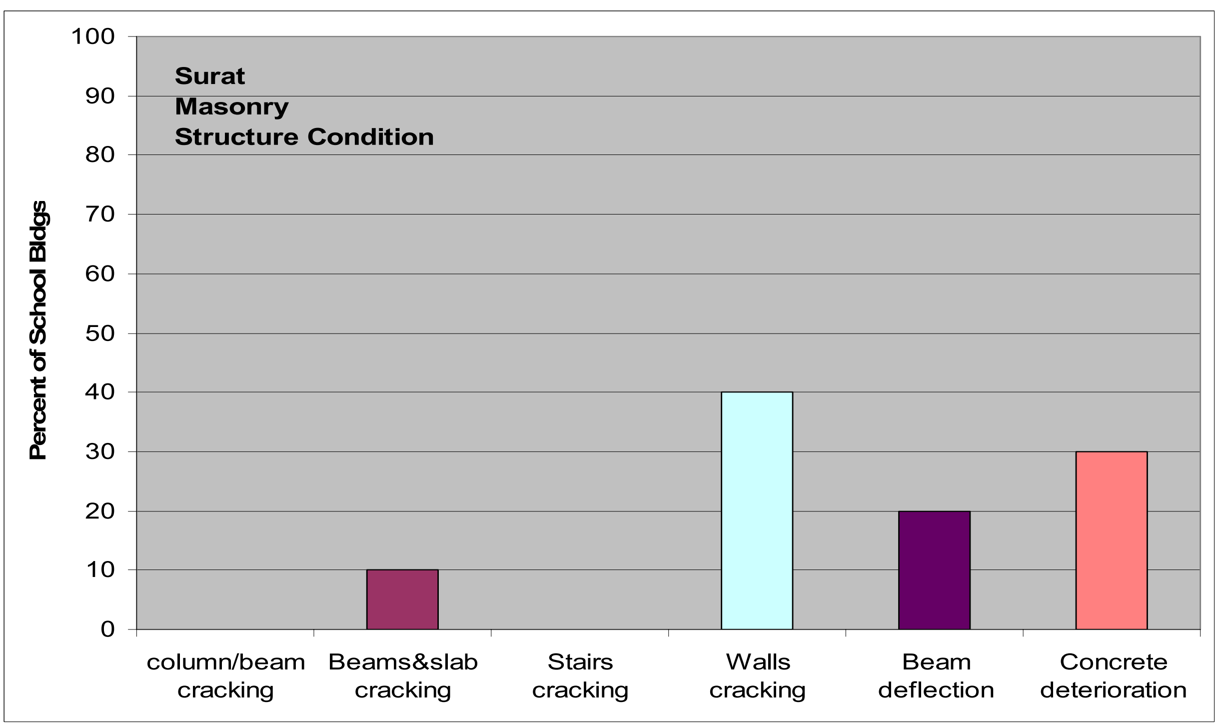


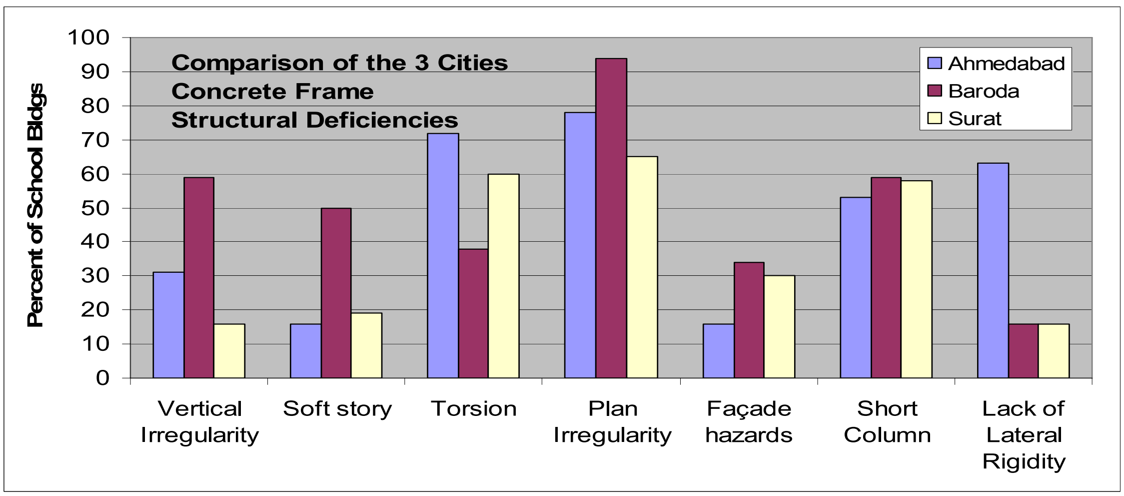
Figure 14. Frequency of Masonry structural deficiencies and condition for Surat

COMPARISON OF THE THREE CITIES

Concrete Frame School Buildings

Figure 15 compares observed structural deficiencies and conditions for the three cities. Plan irregularity is the most common structural deficiency in the three cities; this defect affects over 90 percent of school buildings in Baroda, almost 80 percent in Ahmedabad, and over 60 percent in Surat. Short columns are found consistently in the three cities at an average of 55 percent of schools. Schools in Baroda have the highest proportion of buildings with vertical irregularities and soft stories. School buildings in Ahmedabad have the largest proportion of buildings with torsional and lateral rigidity deficiencies. School buildings in Surat have the largest proportion of torsion problems.

The condition of concrete frame building in Ahmedabad is worse than buildings in Baroda and Surat. The poor condition of concrete frame school buildings in Ahmedabad should be considered when prioritizing mitigation actions.



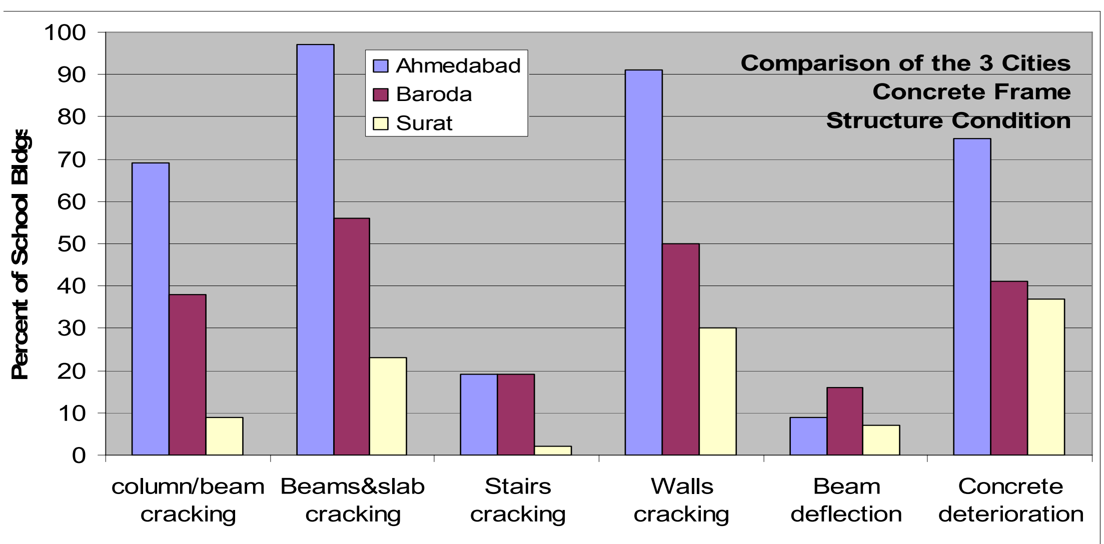
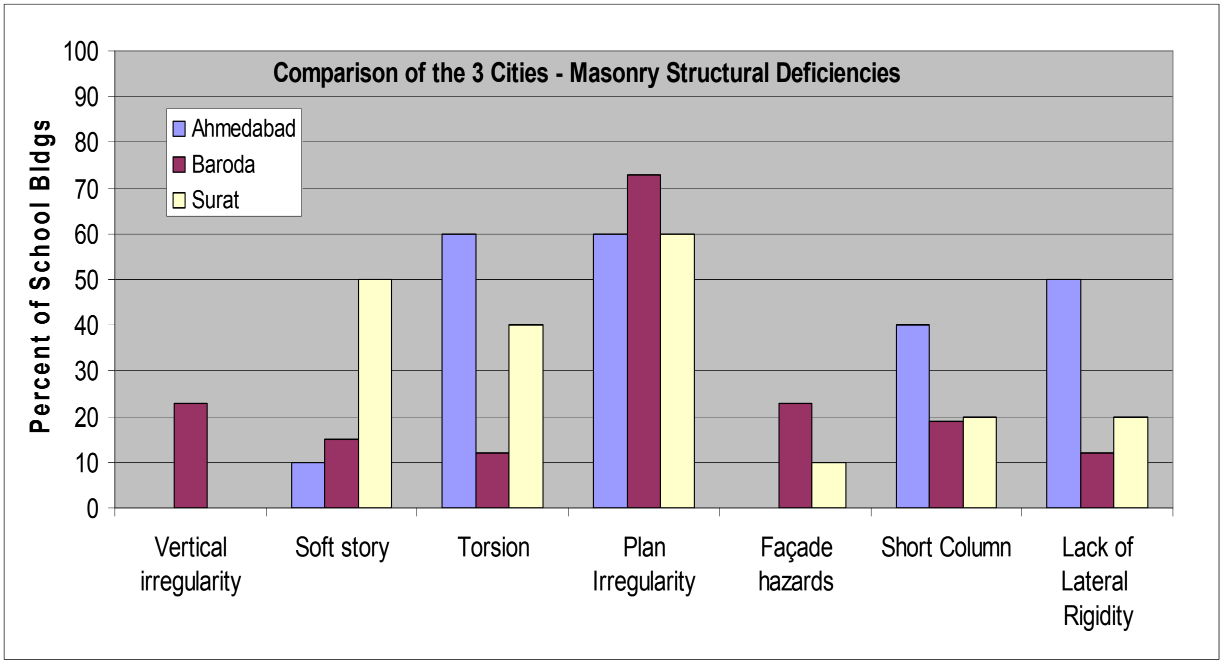


Figure 15. Frequency of performance modification factors for concrete frame buildings

Masonry School Buildings

Figure 16 indicates that plan irregularity is the most common structural deficiency found in masonry school buildings in all three cities. School buildings in Ahmedabad have the greatest proportion of torsion, short column and lateral rigidity deficiencies. School buildings in Surat have the greatest proportion of soft story deficiencies, and school buildings in Baroda have the greatest proportion of plan irregularity and façade hazards deficiencies. Masonry school buildings in Ahmedabad have the poorest condition.



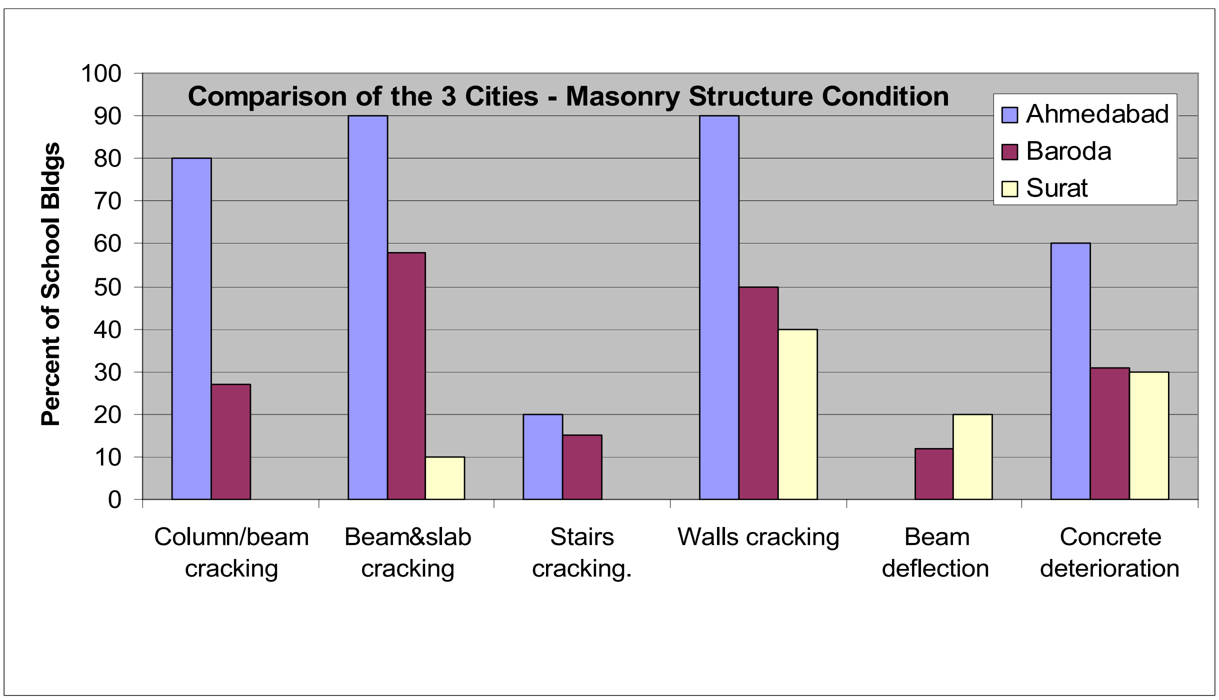


Figure 16. Frequency of performance modification factors for Masonry buildings

It is evident that school buildings in Ahmedabad, Baroda and Surat lack basic earthquake-resistant structural design concepts and sound construction practices. Poor quality of construction materials and the absence of proper structure maintenance compromise the seismic performance of the buildings.

STRUCTURAL VULNERABILITY

GHI used the European Macroseismic Scale (1998) guidelines to estimate the structural vulnerability of the school buildings. These guidelines provide five classes of structural vulnerability in increasing order from poorest (Class A) to best expected behavior (Class F). Class A behavior corresponds to adobe masonry or rubble stone masonry (poorest expected behavior or high structural vulnerability). Class F behavior corresponds to a structure with a high level of earthquake-resistant design (best expected behavior or less structural vulnerability). The structural vulnerability class is determined by the visual assessment (the building type and age, structural deficiencies and condition) and earthquake damage patterns observed in India (Jain et al. 2002, Mistry et al. 2001, Eidinger 2001).

Concrete Frame School Buildings

The structural vulnerability for concrete frame school buildings ranges from class B to D. Table 2 indicates that in Ahmedabad 84 percent of the school buildings are grouped into class B, and 16 percent into class C. In Baroda, 41 percent of the school buildings are grouped into class B, 53 percent into class C, and 6 percent into class D. In Surat, 35 percent of the school buildings are grouped into class B, 56 percent class C, and 9 percent class D. Concrete frame school buildings in Ahmedabad have the worst classifications, while school buildings in Baroda and Surat have almost the same level of structural vulnerability.

Table 2. Structural vulnerability classification for concrete frame school buildings in the three cities

Structural Vulnerability Class	Ahmedabad (percent)	Baroda (percent)	Surat (percent)
D	0	6	9
C	16	53	56
B	84	41	35

Masonry School Buildings

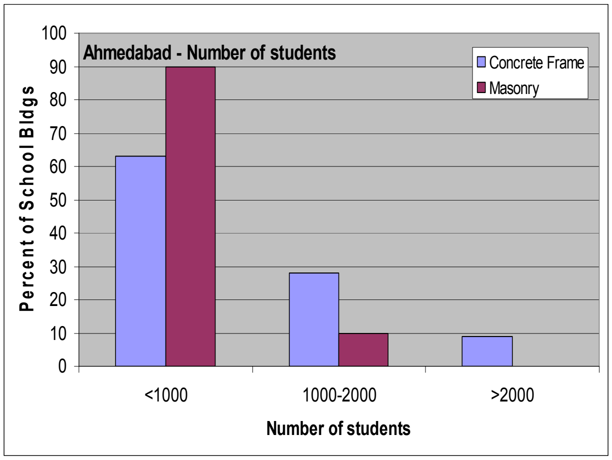
The structural vulnerability classes for masonry buildings ranges from A to C (Table 3), which are lower than the classes for concrete frame buildings. Masonry school buildings in Ahmedabad are rated the worst with 70 percent of school buildings falling in class A (the poorest behavior), 20 percent in class B, and only 10 percent in class C. Table 3 indicates that 60 percent of the masonry school buildings in Surat fall in class A, 30 percent in class B and just 10 percent in class C.

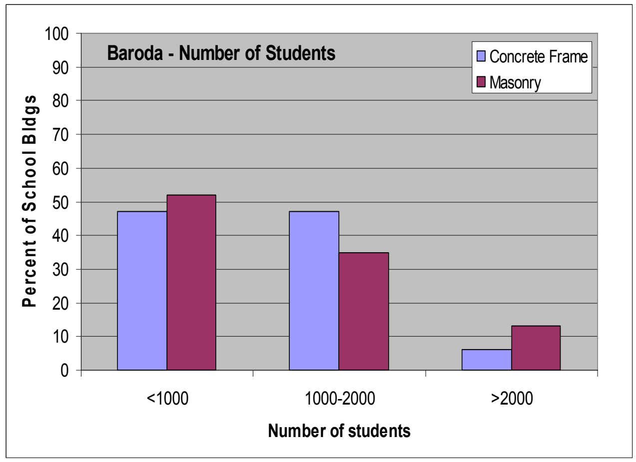
Table 3. Structural vulnerability classification for masonry school buildings in the three cities

Structural Vulnerability Class	Ahmedabad (percent)	Baroda (percent)	Surat (percent)
C	10	13	10
B	20	48	30
A	70	39	60

SCHOOL POPULATION

Three ranges in the number of school occupants are defined, and the percent of schools for each range are shown in Figure 17. The ranges are under 1000 people, between 1000 and 2000, and over 2000 people. These ranges are equivalent to low, medium and high levels of school population. Large school populations generally imply overpopulation, and high occupancy density.





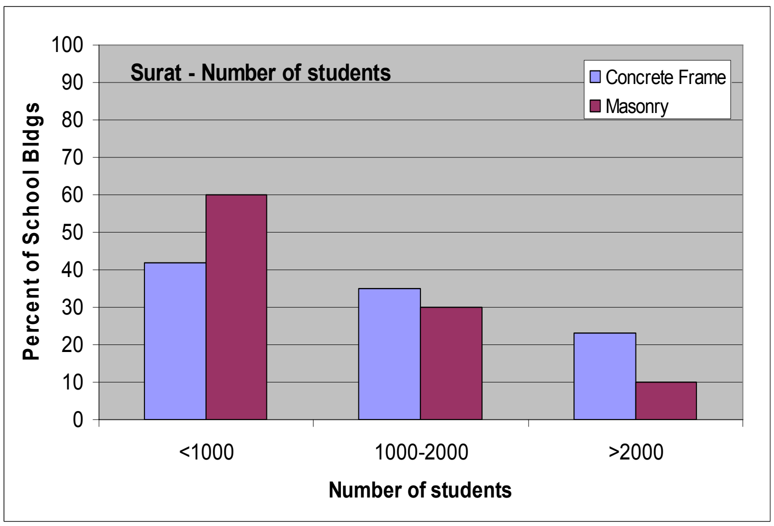


Figure 17. Distribution of school buildings according to number of students for Ahmedabad, Baroda and Surat.

CULTURAL VULNERABILITY

Cultural vulnerability is associated with the level of awareness of earthquake risk and preparedness and training of the school community. During the survey of schools, inspectors collected data on emergency preparedness and response, the existence of awareness programs, school community training, emergency plans, fire fighting provisions, signage of escape routes, and whether evacuation drills are held. The result of the surveys indicates an absence of awareness, preparedness and training on earthquake risk in the school communities. Because all schools rank high in cultural vulnerability, cultural vulnerability does not affect the relative levels of earthquake risk of the schools.

EARTHQUAKE RISK

The earthquake risk of the school buildings is described by aggregating the structural and the number of people; cultural vulnerability and earthquake hazard are the same for all schools. All cities have the same level of earthquake hazard so hazard does not affect relative levels of risk. Tables 4-9 show four different degrees of earthquake risk for concrete frame and masonry structures in Ahmedabad, Baroda and Surat respectively. Very High risk buildings show the highest structural vulnerability and largest school population, and at the other end of the scale Low risk buildings show the lowest structural vulnerability and smallest school population. Two intermediate classes are defined to reflect intermediate conditions of structural and school population; i.e., High risk and Medium risk buildings.

These degrees of earthquake risk can be used as the basis for establishing priorities for designing and implementing structural intervention and other earthquake risk mitigation actions. Because the building stock is large and existing resources are limited, all schools cannot be addressed from the very beginning of an earthquake risk mitigation plan. GHI recommends that programs to reduce structural vulnerability should start by addressing the Very High risk schools first, followed by the High risk ones, then by the Medium risk and finally the Low risk schools. GHI also recommends that all classes should begin programs to reduce cultural vulnerability.

Tables 4 and 5 show the different degrees of earthquake vulnerability for concrete frame and masonry schools in Ahmedabad respectively. Six percent of the concrete frame buildings and 70 percent of the masonry school buildings are classified as Very High risk; 81 percent of the concrete frame buildings and 20 percent of the masonry buildings are classified as High risk school buildings.

Table 4. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame school buildings in Ahmedabad

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	0 *0* *Low risk*	0 *0* *Medium risk*	0 *0* *Medium risk*
C	13 *4* *Medium risk*	0 *0* *Medium risk*	3 *18* *High risk*
B	50 *25* *High risk*	28 *37* *High risk*	6 *16* *Very High risk*

** Percent of population with respect to total school population in concrete frame school buildings*

Table 5. Percents of buildings and percents of school population for each level of earthquake risk for masonry school buildings in Ahmedabad

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
C	10 *7* *Medium risk*	0 *0* *Medium risk*	0 *0* *High risk*
B	10 *17* *High risk*	10 *29* *High risk*	0 *0* *Very High risk*
A	70 *47* *Very High risk*	0 *0* *Very High risk*	0 *0* *Very High risk*

** Percent of students with respect to total school population in masonry school buildings*

Tables 6 and 7 show the different degrees of earthquake risk of concrete frame and masonry schools in Baroda. Three percent of the concrete frame buildings are Very High risk, 38 percent High risk, 56 percent Medium risk, and 3 percent Low risk buildings (Table 3). Of the masonry schools, 44 percent are Very High risk, 43 percent are High risk, and 13 percent Medium risk.

Table 6. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame school buildings in Baroda

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	3 *1* *Low risk*	0 *0* *Medium risk*	3 *11* *Medium risk*
C	28 *14* *Medium risk*	25 *33* *Medium risk*	0 *0* *High risk*
B	16 *8* *High risk*	22 *26* *High risk*	3 *7* *Very High risk*

** Percent of students with respect to total school population in concrete frame school buildings*

Table 7. Percents of buildings and percents of school population for each level of earthquake risk for masonry school buildings in Baroda

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
C	9 *2* *Medium risk*	4 *4* *Medium risk*	0 *0* *High risk*
B	21 *11* *High risk*	22 *27* *High risk*	4 *9* *Very High risk*
A	22 *10* *Very High risk*	9 *11* *Very High risk*	9 *26* *Very High risk*

** Percent of students with respect to total school population in masonry school buildings*

The degrees of earthquake vulnerability in concrete frame and masonry buildings in Surat are shown on Tables 8 and 9. Very High risk buildings include 35 percent of the concrete frame buildings and 60 percent of the masonry buildings, and High risk buildings encompass 31 percent of the concrete frame buildings and 30 percent of the masonry buildings.

Table 8. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame school buildings in Surat

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	2 *1* *Low risk*	7 *7* *Medium risk*	0 *0* *Medium risk*
C	23 *7* *Medium risk*	16 *15* *Medium risk*	16 *32* *High risk*
B	17 *6* *High risk*	12 *13* *High risk*	7 *19* *Very High risk*

** Percent of students with respect to total school population in concrete frame school buildings*

Table 9. Percents of buildings and percents of school population for each level of earthquake risk for masonry school buildings in Surat

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
C	10 *8* *Medium risk*	0 *0* *Medium risk*	0 *0* *High risk*
B	20 *4* *High risk*	10 *19* *High risk*	0 *0* *Very High risk*
A	30 *18* *Very High risk*	20 *27* *Very High risk*	10 *24* *Very High risk*

** Percent of students with respect to total school population in masonry school buildings*

SUMMARY

Table 10 shows the proportions of school buildings with respect to the entire number of concrete frame and masonry schools in Ahmedabad for each class of structural vulnerability and school population. Proportions of buildings and proportions of school population are calculated with respect to the total number of concrete frame plus masonry school buildings.

Table 10. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame and masonry school buildings in Ahmedabad

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	0 *0* *Low risk*	0 *0* *Medium risk*	0 *0* *Medium risk*
C	12 *5* *Medium risk*	0 *0* *Medium risk*	2 *15* *High risk*
B	40 *24* *High risk*	24 *35* *High risk*	5 *14* *Very High risk*
A	17 *7* *Very High risk*	0 *0* *Very High risk*	0 *0* *Very High risk*

** Percent of students with respect to total population in concrete frame and masonry school buildings*

Table 11 shows the proportions of school buildings with respect to the entire number of concrete frame and masonry schools in Baroda for each class of structural vulnerability and school population. Proportions of buildings and proportions of school population are calculated with respect to the total number of concrete frame plus masonry school buildings.

Table 11. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame and masonry school buildings in Baroda

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	2 *0.5* *Low risk*	0 *0* *Medium risk*	2 *7* *Medium risk*
C	20 *9* *Medium risk*	16 *22* *Medium risk*	0 *0* *High risk*
B	18 *10* *High risk*	21 *25.5* *High risk*	4 *8* *Very High risk*
A	9 *4* *Very High risk*	4 *4* *Very High risk*	4 *10* *Very High risk*

** Percent of students with respect to total population in concrete frame and masonry school buildings*

Table 12 shows the proportions of school buildings with respect to the entire number of concrete frame and masonry schools in Surat for each class of structural vulnerability and school population. Proportions of buildings and proportions of school population are calculated with respect to the total number of concrete frame plus masonry school buildings.

Table 12. Percents of buildings and percents of school population for each level of earthquake risk for concrete frame and masonry school buildings in Surat

Structural Vulnerability Class	School Population		
	0 – 1000 occupants Percent of buildings Percent of population* Level of risk	**1000 – 2000 occupants** Percent of buildings Percent of population* Level of risk	**> 2000 occupants** Percent of buildings Percent of population* Level of risk
D	2 *1* *Low risk*	6 *6* *Medium risk*	0 *0* *Medium risk*
C	22 *7* *Medium risk*	13 *13* *Medium risk*	13 *29* *High risk*
B	17 *5* *High risk*	9 *14* *High risk*	6 *16* *Very High risk*
A	6 *2* *Very High risk*	4 *4* *Very High risk*	2 *3* *Very High risk*

** Percent of students with respect to total population in concrete frame and masonry*

CONCLUSIONS AND RECOMMENDATIONS

GHI estimated the earthquake risk of school buildings of Ahmedabad, Baroda and Surat by examining a sample of school buildings distributed across each city. The buildings represent the most prevalent structural types. The students in these schools come from a variety of economic levels. The structural vulnerability of the school buildings was estimated by making visual evaluations of structures. Earthquake risk is defined as the product of earthquake hazard and the aggregation of the structural, school population and cultural (level of awareness and training) vulnerabilities.

Observable building features known to affect seismic performance were recorded. The visual inspection of school buildings revealed poor structural design concepts, poor quality construction materials, and poor structural maintenance. Two types of structural systems were most common: reinforced concrete frames with unreinforced masonry infill walls (concrete frame) and unconfined oven-dried brick masonry (masonry). These structures are highly vulnerable to earthquake shaking.

All schools have a high degree of cultural vulnerability, meaning an absence of earthquake risk awareness, training, and preparedness among students and faculty. Together, the structural vulnerability of the school buildings and the number of students in each school determine the earthquake risk of the school buildings. This study grouped the buildings in one of four categories of risk. This ranking of risk was used to set priorities for the development and implementation of earthquake risk mitigation programs in the school system.

CONCLUSIONS

The results of this study lead GHI to draw the following conclusions:

Earthquake Risk

- Ahmedabad has the greatest stock of Very High and High earthquake risk school buildings. Baroda and Surat have similar earthquake risk and show approximately the same percentage of school buildings in each of the earthquake vulnerability categories.

Structural Vulnerability

- Plan irregularity is the most common structural deficiency found in reinforced concrete frame and masonry school buildings. Short columns are the most common cause of vulnerability. Torsion, lack of lateral rigidity and vertical irregularity are the other leading structural deficiencies.
- Ahmedabad school buildings are in worse condition than those in Baroda and Surat.

School Population

- Almost the same proportion of students, about 25 percent, occupies the Very High earthquake risk school buildings in the three cities. About three quarters of school population in Ahmedabad, half of the school population in Surat and 40 percent of the school population in Baroda occupy High earthquake risk school buildings.

Cultural Vulnerability

- School officials, parents, and students in all three cities lack awareness of earthquake risk, preparedness and training.

RECOMMENDATIONS

Because of the large proportion of schools with Very High and High earthquake risk in Ahmedabad, Surat and Baroda, GHI believes an aggressive school seismic safety program to reduce this risk is needed in these cities. GHI recommends that those responsible for school earthquake safety develop an earthquake risk mitigation program to address first the Very High earthquake risk school buildings, then the High earthquake risk school buildings, and lastly the Medium and Low earthquake risk school buildings.

GHI believes that the earthquake risk in other cities in Gujarat would be similar to that in Ahmedabad, Baroda and Surat, and therefore recommends that those responsible for the school seismic safety of other cities in Gujarat carry out similar measures.

Earthquake risk mitigation programs should adopt a combination of the following strategies:

Reduce the structural vulnerability

- Evaluate the Very High and High earthquake vulnerability school buildings to decide whether to retrofit or replace them.
- Retrofit or replace vulnerable schools.
- Design and implement education and training programs for engineers, architects and other professionals involved in the design, construction and supervision process of school buildings to avoid the structural deficiencies identified in the present study.
- Design and implement a maintenance program to prevent buildings from deteriorating and compromising a basic level of earthquake safety.

Reduce the cultural vulnerability

- Develop a program to educate school officials, parents and students about earthquake risk and steps to take to reduce the risk.
- Develop preparedness plans and hold evacuation drills.

Reduce the number of students in dangerous school buildings

- Decrease the number of students in Very High and High earthquake risk buildings.

Make sure new schools are safe

- Use current building codes
- Engage trained masons
- Inspect construction process

GHI believes that the method used in this study is a rapid, inexpensive and reliable way to characterize the relative earthquake vulnerability and exposure among school buildings in India, and that it could be used to conduct a broader study in the most earthquake-prone regions of India.

AKNOWLEDGEMENTS

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APPENDIX I

European Macroseismic Scale (Taken from the World Housing Encyclopedia, EERI)

"The term vulnerability is used in this document to express differences in the way that buildings respond to earthquake shaking. If two groups of buildings are subjected to exactly the same earthquake shaking, and one group performs better than the other, then it can be said that the buildings that were less damaged had lower earthquake vulnerability than the ones that were more damaged, or it can be stated that the buildings that were less damaged are more earthquake-resistant, and vice versa." (an excerpt from the publication *European Macroseismic Scale 1998 (EMS1998)*, prepared by the European Seismological Commission, Cahiers du Centre European de Geodynamique et de Seismologie, Vol.15, Luxembourg 1998). Note, therefore, that the use of word vulnerability in this document is not necessarily the same as other uses and definitions of the same word.

Classification of all structural types included in this document into six (6) classes of decreasing vulnerability (A, B, C, D, E, and F) is largely based on a similar classification presented in the EMS1998.

The first three classes A, B, and C, represent the most vulnerable (i.e. least earthquake-resistant or most prone to be damaged) building types; e.g. Class A- adobe masonry (Types 3 and 5 in Table 13 or rubble stone masonry (Type 1 in the table on the next page); class B- typical brick masonry building (Type 7); Class C- reinforced concrete frame structure without seismic provisions (Type 13).

Classes D and E are intended to represent building types characterized with the reduced vulnerability (i.e. increased earthquake-resistance) as a result of inherent structural features and also special seismic design provisions; well-built timber, reinforced concrete and steel structures, as well as confined and reinforced masonry structures generally fall into vulnerability classes D and E.

Class F is intended to represent the vulnerability of a structure with a high level of earthquake-resistant design.

Table 13. Guidelines for Seismic Vulnerability of Construction Types
(based on European Macroseismic Scale 1998)

Material	Type of Load-Bearing Structure	*No*	*Subtypes*	Vulnerability Class					
				A	B	C	D	E	F
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	•					
		2	Massive stone masonry (in lime/cement mortar)		|-	•	-|		
	Earthen/Mud/ Adobe/Rammed Earthen Walls	3	Mud walls	•					
		4	Mud walls with horizontal wood elements	|-	•	-|			
		5	Adobe block walls	•					
		6	Rammed earth/Pise construction						
	Clay brick/block masonry walls	7	Unreinforced brick masonry in mud mortar	|-	•	-|			
		8	Unreinforced brick masonry in mud mortar with vertical posts						
		9	Unreinforced brick masonry in cement mortar with reinforced concrete floor/roof slabs		|-	•	-|		
		10	Confined brick/block masonry with concrete posts/tie columns and beams			|-	•	-|	
	Concrete block masonry	11	Unreinforced in lime/cement mortar (various floor/roof systems)						
		12	Reinforced, in cement mortar (various floor/roof systems)			|-	•	-|	
Structural concrete	Moment resisting frame	13	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	|-	-	•	-|		
		14	Designed with seismic features (various ages)			|-	-	•	-|
		15	Frame with unreinforced masonry infill walls						
		16	Flat slab structure		|-	•	-|		
		17	Precast frame structure						
		18	Frame with concrete shear walls-dual system						
	Shear wall structure	19	Walls cast in-situ				|-	•	-|
		20	Precast wall panel structure		|-	•	-|		
Steel	Moment-resisting frame	21	With brick masonry partitions						
		22	With cast in-situ concrete walls						
		23	With lightweight partitions						
	Braced frame	24					|-	•	-|
Wooden structures	Load-bearing timber frame	25	Thatch		|-	•	-|		
		26	Post and beam frame			|-	•	-|	
		27	Walls with bamboo/reed mesh and post (Wattle and Daub)						
		28	Frame with (stone/brick) masonry infill						
		29	Frame with plywood/gypsum board sheathing						
		30	Frame with stud walls				|-	•	-|

LEGEND:

• = Expected Seismic vulnerability class

|- = Lower Bound

-| = Upper Bound

APPENDIX II

GLOSSARY

Façade Hazards: These are nonstructural falling elements such as chimneys, parapets, cornices, veneers, overhangs and heavy cladding. These elements can pose life-safety hazards during earthquakes if not adequately anchored to the building.

Lack of lateral rigidity: Buildings with good lateral-load resistance in one direction but not in the other.

Plan irregularity: Shape of building plan that makes the building more susceptible to earthquake damage. Examples of plan irregularity include buildings with re-entrant corners, where damage is likely to occur. Buildings with re-entrant corners include those with long wings that are E, L, T, or + shaped.

Short column: Height of column shortened by balcony parapets or walls. When columns are shortened, the effect is to make them less ductile and consequently more vulnerable to earthquake damage.

Soft story: A soft story exists if the stiffness of one story is dramatically less than that of most of the other stories. Examples are shear walls or infill walls not continuous to the foundation.

Torsion: Buildings with major stiffness eccentricities in the lateral-force-resisting system, which may cause torsion (twisting) around a vertical axis.

Vertical irregularity: When a building is irregularly shaped in elevation, it is more vulnerable to earthquake damage. Examples of vertical irregularity include buildings with setbacks, hillside buildings, and buildings with soft stories.

DATA COLLECTION FORM SAMPLE

CITY	**AHMEDABAD**	
FORM NO.	**13**	
SURVEYED BY	**M/S**	
DATE	**20/01/04**	

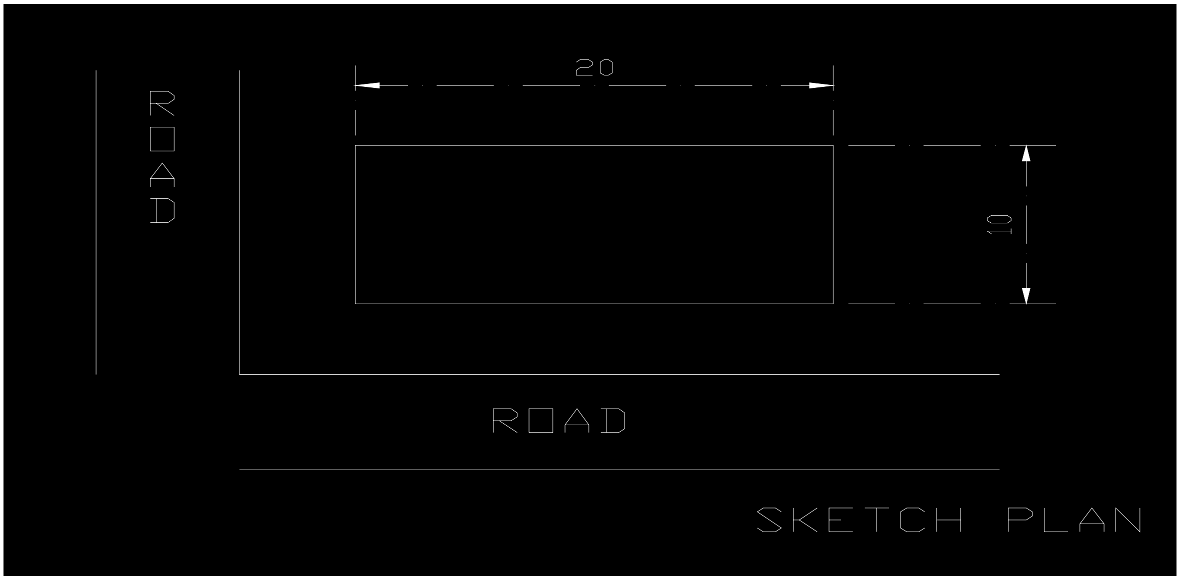
SCHOOL	**BHAVIN VIDHYAMANDIR**	
ADDRESS	**20 RAMDEV SOCIETY NARANPURA**	
TEL NO.	**7473252**	
ZONE		
MANAGING AUTHORITY	**TRUST**	(TRUST / PRIVATE /MUNCIPAL / STATE GOVT. / CENTRAL GOVT. / OTHERS)
EDUCATIONAL LEVEL	**SECONDARY**	(PRE PRIMARY / PRIMARY / SECONDARY / SENIOR SECONDARY)
ECONOMIC STATUS OF STUDENTS	**MIDDLE**	
MEDIUM OF INSTRUCTION	**GUJARATI**	
NO. OF CLASSROOMS	**9**	

POPULATION DATA

SHIFT DETAILS	TIME		BOYS	GIRLS	TOTAL
	FROM	TO			
8TH - 12TH	7:00	12:00			130
1ST - 7TH	12:00	5:30			105
					235

SAFETY CONDITIONS

FIRE FIGHTING PROVISION	**0**	['1' FOR 'YES' , '0' FOR 'NO']
STAFF/PERSONNEL TRAINING	**0**	
AWARENESS PROGRAMMES	**0**	
EMERGENCY PLAN	**0**	
ESCAPE ROUTE	**0**	
EVACUATION DRILLS	**0**	



FRONT VIEW OF THE SCHOOL BUILDING (F.F. AND S.F.)

BUILDING 1

I BASIC INFORMATION

BUILDING AGE	15-40 YEARS	(<1 YEAR / 1-5 YEARS / 5-10 YEARS / 15-40 YEARS / >40 YEARS)
NO. OF STOREYS	G+2	
DIMENSIONS	20M X 10M	
TOTAL HEIGHT	5-10 METERS	(<5 METERS / 5-10 METERS / 10-15 METERS / >15 METERS)
STRUCTURAL TYPE	concrete frame WITH INFILL	(concrete frame / concrete frame WITH INFILL / CONFINED BRICK MASORARY / UNCONFINED BRICK MASORARY / WOODEN)
ROOF TYPE	concrete SLAB	(concrete SLAB / STEEL FRAME / WOODEN FRAME)
ROOF COVERING	concrete SLAB	(concrete SLAB / TILES / SHEETING)
SOIL	REGULAR HARD SOIL	(SOFT / FILL / HARD SOIL)
DOES BUILDING HAVE ANY EXTENSION ?	1	("1" FOR 'YES', "0" FOR 'NO')

II	STRUCTURAL DEFICIENCIES		Gr. Floor	FIRST FLOOR	OTHER FLOORS
	HEIGHT RISK		0	0	0
	VERTICAL IRREGULARITY		0	0	0
	SOFT STORY		0	1	1
	TORSION		0	0	0
	PLAN IRREGULARITY		0	0	0
	POUNDING		0	0	0
	FAÇADE HAZARDS		0	0	0
	SHORT COLUMN		0	0	0
	BEAM C/S>COLUMN		0	0	0
	UNSUPPORTED COLUMN		0	0	0
	LATERAL RESISTANCE CAPACITY		0	0	0
	PLINTH BEAMS MISSING?		0		
III	**NOTICEABLE DISTRESSES**				
	COLUMNS				
	CRACKING IN COLUMN-BEAM JUNCTION		0	0	0
	CRUSHING		0	0	0
	SLABS AND BEAMS				
	SHEAR CRACKS		0	0	0
	DEFLECTION IN BEAMS		0	0	0