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ASSESSMENT AND RESTORATION OF HERITAGE AND HISTORIC STRUCTURES AFFECTED BY THE BHUJ, INDIA EARTHQUAKE OF 2001

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Abstract. *This paper presents the results of a study of the assessment and restoration of heritage structures affected by the Bhuj earthquake of 2001. The paper examines the outcomes of assessments of heritage and historic structures that were carried out following the Bhuj earthquake not only in the epicentral area, but also in distant cities e.g. Ahmedabad and others. The monuments included in the study are the heritage and historic structures in Bhuj including the Ayna Mahal complex, Fuvara Mahal, and the city Gates in the old walled city. The paper presents an analysis of the design and construction process used for the restoration of the Gates of the old Walled City; and the Ayna Mahal complex in Bhuj. A practical assessment of the structural framing system of the Ayna Mahal; and its performance during the Bhuj earthquake is presented. The repair and restoration scheme developed by the Architect and Engineer for the restoration of the Ayna Mahal; and historic city gates is presented. The results presented in this paper will help focus attention on the urgently needed issues of protection, restoration and preservation of heritage structures during earthquakes not only in Gujarat but also in other parts of India.*

1 INTRODUCTION

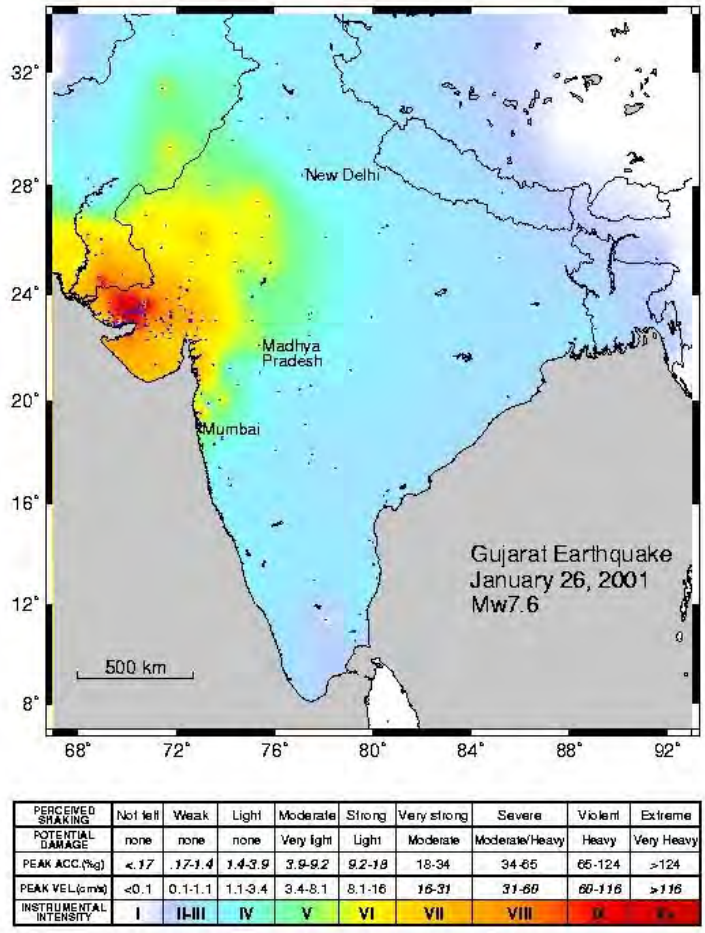
The rich cultural and architectural heritage of gujarat is at risk due to effects of rapid urbanization, aging, climatic factors and hazards such as wind storms, rains and flooding, and earthquakes. A study of the seismological history of Gujarat provides clear evidence of earthquake risk to heritage and historical structures in Gujarat, as well as different sectors of the infrastructure of villages, towns and cities in Gujarat. The catastrophic bhuj earthquake of 2001, was an eye opening experience for communities at large in the state of Gujarat as well as the rest of India. Unless we learn from the experience of past disasters not only in India but around the globe, and undertake efforts to restore, protect and preserve our heritage structures; our rich and precious architectural and cultural heritage will not survive and will be lost forever.

2 HISTORICAL BACKGROUND

History of the Bhuj and Kutch areas of Gujarat dates back to the Harappan civilization (2900 -1900 B.C.), the conquest by Alexander in 325 B.C., followed by rule of Darius, in 521 B.C. - 485 B.C., further down to rule by Samudragupta's son from 4th century A.D., and then down to rule by the Solanki dynasty in the 11th century, and on the way to annexation by the British in 1816 and finally the merger with independent India in 1947. A more complete historical background of Bhuj and the Kutch area of Gujarat has been presented by EERI [1]. Adjoining the area of Kutch in the south-west of the state of Gujarat lies the region called Saurashtra which literally means "a hundred nations", that includes districts of Rajkot, Jamnagar, Jamnagar, Amreli, and Porbandar. This region was made up of a number of small kingdoms with the result that this area is full of a rich cultural heritage and beautiful heritage structures. These heritage structures in this area suffered widespread damage during the 2001 Bhuj earthquake.

3 PERFORMANCE OF HERITAGE STRUCTURES DURING THE 2001 BHUJ EARTHQUAKE

The 2001 Bhuj earthquake caused widespread devastation and damage to the rich cultural and architectural heritage of Bhuj and the Kutch region of Gujarat. A Modified Mercalli Intensity shaking map for the affected region during the 2001 Bhuj earthquake is presented in Figure 1. A detailed study of the performance of heritage structures during the 2001 Bhuj earthquake was reported by EERI [1], based on a detailed condition assessment of heritage and historical structures carried out by INTACH [2] and EERI reconnaissance teams. According to the detailed EERI report [1], it was reported that there were close to 15000 heritage structures spread over 250 towns in the Kutch region, out which 10,000 were very badly damaged or destroyed. The EERI / INTACH damage survey of heritage structures covered the districts of Kutch; Jamnagar, Junagarh and Rajkot; and Mehsana, Surendranagar and Ahmedabad. Such a history of earthquake risk demands an urgent call for ongoing action to plan for protection, restoration of heritage and historical structures. Initial damage surveys of heritage and historical structures were carried out and reported by EERI [1], INTACH [2], and UNESCO [3] and others.



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

Figure 1: Distribution of Modified Mercalli Intensities in India and the neighboring areas for the M_w 7.6 Bhuj earthquake. (Source: http://pasadena.wr.usgs.gov/office/hough/bhuj/bhuj-intensity.doc)

4 AINA MAHAL – PALACE OF MIRRORS

Basically this beautiful heritage structure consists of a huge two story mansion, built in 1761 A.D. by Rao Lakhpat Ji. The first floor had three main rooms - the Audience Hall, the Ayna Mahal and apartments. The Ayna Mahal was used as pleasure palace where the kings wrote poetry and watched performances by dancing girls for entertainment. There are three main parts of this complex, the Fuvara Mahal, Hira Mahal and Ayna Mahal. The Ayna Mahal and Hira Mahal are located on the first floor next to south side of the Fuvara Mahal. The innovative designs of that time incorporated really creative approaches to achieve a comfortable living environment and create dazzling patterns of ambient lighting effects through use of complex geometrical patterns of mirrors (mica pieces) integrated with the interior finishes.

4.1 STRUCTURAL SYSTEM

The floors and roofs of the Aina Mahal were originally made of composite lime concrete overlaying 101.6 mm stone slabs supported on timber beams and columns. The thickness of the lime concrete and stone slabs was about 304 mm. The masonry wall enclosure is

constructed with Bella Stone with lime and cement mortar. Bella stone is essentially dressed sand stone and is available in 228.6 mm x 228.6 x 457.2 mm size

5 FUVARA MAHAL (PALACE OF FOUNTAINS)

Fuvara Mahal was actually a music hall where "Vraj haveli sangeet" used to be performed. This first floor hall was 15 meters square, with a central area that originally had pools and fountains; and a 2.4 meter open walkway that wraps around the perimeter of this hall. This open walkway is enclosed by 450 mm thick masonry exterior walls on one side and a grid of wooden columns, on the interior side, that supports the two-way truss framing above. The perimeter masonry walls are 3 meters above the floor level and are capped by a roof slab 2.4 meters wide spanning the perimeter walkway.

5.1 DRAMATIC ROOF FRAMING SYSTEM

It consists of an array of interior timber columns extending about 3.2 meters above the top of the exterior walls and the walkway roof slab, to support a timber truss system carrying a flat roof over the central part of the Fuvara Mahal as shown in Figure 2.

Figure 2: Fuvara Mahal, timber truss system and clerestory

The truss configuration with vertical sides with large openings form a clerestory. This unusual roof truss configuration appears more like a knee-brace type lateral bracing system for the upper part of the roof structure, as there are no horizontal ties defining the truss system, even though partial horizontal restraint is provided by the roof slabs spanning the perimeter walkway, acting as a perimeter ring beam. The wooden trusses use bolted metal-strap connections, which suggests that they possibly represent repairs carried out after one of the earlier earthquakes e.g. the 1819 Gujarat earthquake.

6 DESIGN FOR ENVIRONMENTAL COMFORT

The builders of these beautiful heritage buildings incorporated innovative natural means combining evaporative cooling; pools of water and fountains, high ceilings, clerestory's, and cross-ventilation to achieve environmental comfort in the scorching heat of the arid Bhuj – Kutch region of Gujarat.

7 CONDITION ASESSMENT

According to the excellent detailed field survey of heritage buildings in Gujarat carried out in 2001 under the sponsorship of INTACH, the existing condition was very well documented [4]. It was discovered that a 2.5 meter long section of the exterior masonry wall had collapsed; the interior columns in the central part of Fuvara Mahal on the north side were found to be tilting 5.0 – 7.5 degrees northwards (outward). It was reported that both the north and south walls were tilting outward by about 3 degrees, in the northerly direction. Some of the timber columns had tilting of the order of 2% and the corner columns on the structural grid were totally vertical. It was reported that one member of a truss had buckled and slightly split, but other that no sign of structural failure was observed in the timber framing system. Furthermore it was reported that there was significant sagging of the roof slab over the central portion of the roof.

8 RESTORATION

8.1 Ayna Mahal

The restoration work of Ayna Mahal in Bhuj started around April 2009, eight years after the 2001 earthquake, and took eight months to complete according to the project architect. The restoration work generally involved the bracing of the damaged and unstable components and materials; removal of loose materials; and replacement of damaged components. The restoration work was carried out in the following sequence:

8.1.1 Restoration of stone columns and arched corridors

The arched corridor and the stone columns on the west side of the entry steps to the Ayna Mahal had collapsed during the 2001 Bhuj earthquake, as shown in Figure 3.

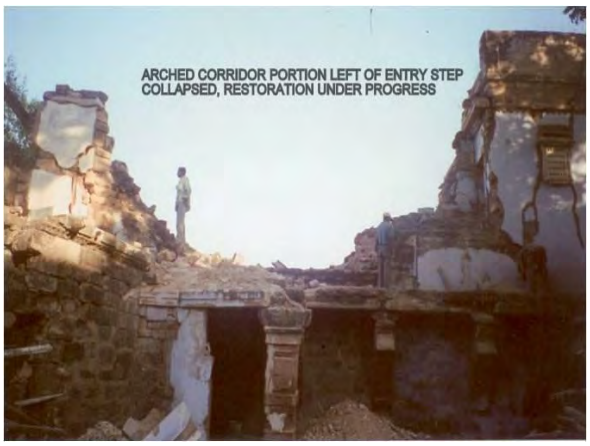


Figure 3: Ayna Mahal, collapsed arched corridor west of entry steps, restoration in progress.

The repair work started with the restoration of these stone columns and the corridor arches as shown in Figure 4.

Figure 4: Ayna Mahal, arched corridor restoration in progress.

The distortion and damage of a typical corridor stone arch, including the numbering of the stone pieces making up the arch, and the temporary shoring used during the restoration process is shown in Figure 5.

Figure 5: Ayna Mahal, arched corridor restoration in progress. Showing distortion of corridor arch and numbering of stones making up the arch.

The process of restoration of the corridor arch including the temporary masonry work for shaping the corridor arches being restored, is presented in Figure 6.

Figure 6: Ayna Mahal, arched corridor restoration in progress

8.2 Fuvara Mahal

It appears that one of the main causes of the observed damage and failures in this whole complex was the effect of very heavy roofs and floors; possible amplification of ground motions toward the upper parts of buildings resulting in very large inertial forces that the existing lateral force resisting systems could not resist. An innovative solution to help reduce the dead weight of the floors and roof system, was developed and implemented by the project architect. It consisted of replacing the stone slabs and overlay of thick lime concrete (total thickness of 304.8 mm); with 50.8 mm thick thermocol sheets and topped with 30.8 mm thick IPS floor (Indian Pattern Stone) cement plaster floor finish. During this restoration process the stone slabs and the lime concrete over the wooden gratings and wooden planks, were removed as shown in Figure 7.

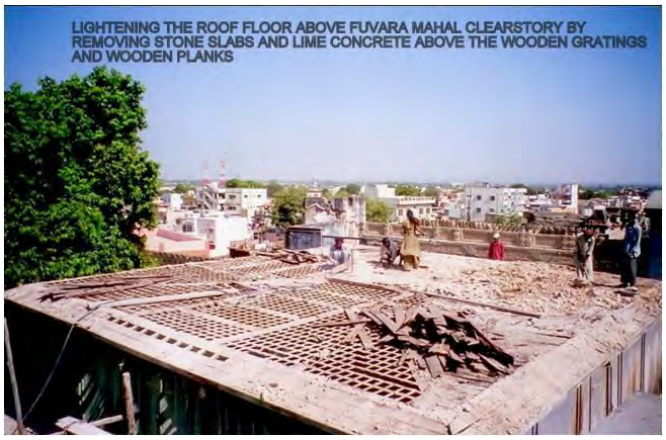


Figure 7: Lightening of roof / floor above Fuvara Mahal clerestory by removing stone slabs and lime concrete above the wooden grating and planks.

The preparation for the new layer of ferrocement, and thermocol sheets above the wooden grating is as presented in Figure 8.

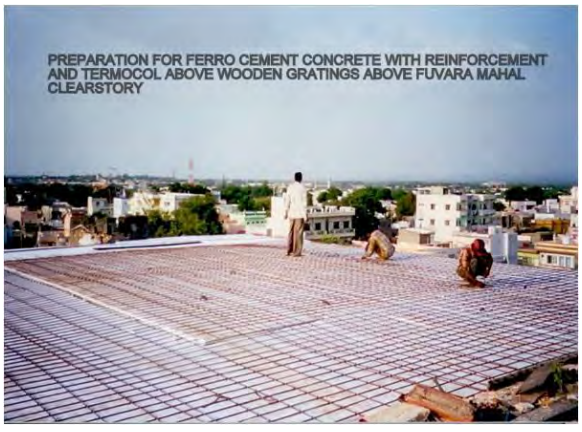


Figure 8: Lightening of roof / floor above Fuvara Mahal clerestory by removing stone slabs and lime concrete above the wooden grating and planks.

This innovative solution was able to achieve a 60-70% reduction in the dead weight of the floor / roof framing system, in the restoration process, and thus help reduce the earthquake forces that the structure will have to resist during future earthquakes.

8.2.1 Restoration of Clerestory and wood framework

The clerestory portion of Fuvara Mahal suffered extensive damage during the 2001 Bhuj earthquake. This part of Fuvara Mahal underwent significant distortion possibly due to torsional response, as shown in Figure 9.

Figure 9: Fuvara Mahal, distortion of clerestory portion

The restoration process of the Fuvara Mahal clerestory ceiling and replacement of damaged wood members is as shown in Figure 10 and Figure 11

Figure 10: Fuvara Mahal Clerestory Ceiling, restoration of buckled truss members in progress.

Figure 11: Fuvara Mahal Clerestory Ceiling, restoration in progress

8.2.2 Discovered arches

During the process of repair and restoration of Fuvara Mahal, beautiful arches were discovered in the north façade of Fuvara Mahal. They were found to be embedded inside the masonry walls. The design team decided to incorporate the beautiful decorative arches as part of the finished window openings as shown in Figure 12. The restoration of the discovered arches in progress is presented in Figure 13.

Figure 12: Fuvara Mahal, discovered arches after restoration

Figure 13: Fuvara Mahal North Façade, discovered arches under restoration

8.3 Darbar Hall and Chori Mandap

The process of laying ferrocement concrete over thermocol sheets above Chori Mandap at second floor as presented in Figure 14. A view of Darbar hall structure and roof after restoration is presented in Figure 15.

Figure 14: Ferrocement Concrete, overlay on thermocol sheets above Chori Mandap second floor.

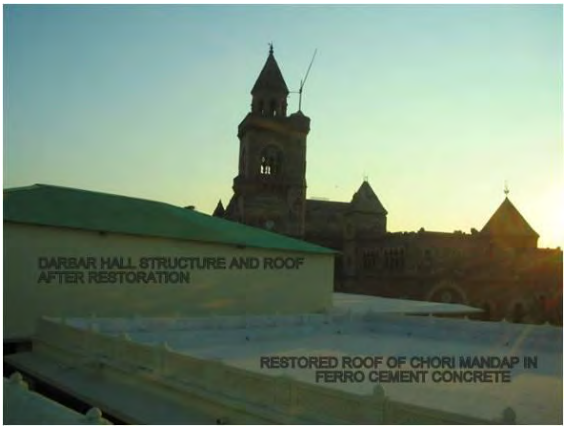


Figure 15: Darbar Hall structure and roof after restoration. Chori Mandap restored roof with ferrocement overlay.

9 COST OF CONSERVATION

The total cost of the restoration of Ayna Mahal, Fuvara Mahal, Hira Mahal, Darbar Hall and Chori Mandap was approximately Rs. 28 lakhs (one lakh=100,000). Efforts are underway to analyze the available data to determine restoration costs on a per square me-

ter basis for different types of restorations developed and implemented in the heritage structures in Bhuj.

10 OLD CITY GATES

The walled city of Bhuj that was founded in 1510, was surrounded by the fort which had five major gates, and 10.6 meter high walls and towers. Only small remnants of the old fort wall are to be found in the city of Bhuj, as the rest of the fort wall has fallen off due to the cumulative damage caused by earthquakes, urbanization and expansion of the city over the years. During the 2001 Bhuj earthquake, the Bhid Gate, the Sarpat Gate and Patwadi Gate, some of the beautiful symbols of the city's rich heritage, were severely damaged. The damage suffered by the Sarpat gate, built in 1740, is shown in Figure 16 and Figure 17.

Figure 16: Old City Sarpat Gate, damaged condition before restoration

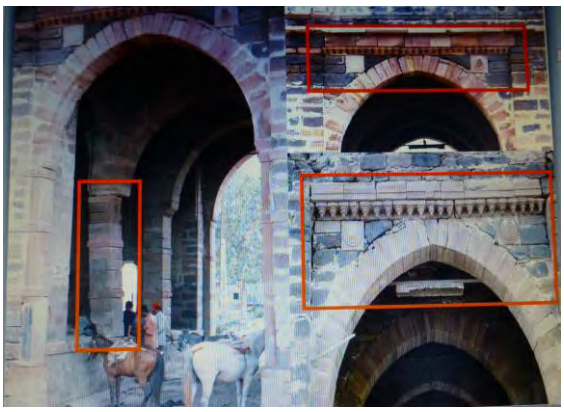


Figure 17: Old City Sarpat Gate, condition before restoration showing displaced column and shifted arch segments.

The damage consisted of collapse of the stone masonry work on each side of the arched gate; and the parapet and spandrels above the arch; displacement of supporting columns; and shifting of the gateway arch segments. This type of damage was possibly caused by very heavy self-weight of masonry and earth-fill above the arched gates; and amplification of ground accelerations resulting in very large seismic forces on the stone

masonry arched gates. The arches in the arched gates did not collapse, but did show clear signs of yielding, with some of the arch stones being noticeably displaced from their normal positions as shown in Figure 17.

10.1 Structural System

The structural system for the old city gates basically consisted of four parallel stone arches spanning approximately 3.05 meters, spaced 3.05 meters apart; with five or six parallel arches perpendicular to the plane of the main arches spaced approximately 3.05 meters apart.

10.2 Restoration:

The general process of restoration of the historic Bhid Gate is shown in Figure 18, including scaffolding, and false masonry work to shape and support the arched gate while the restoration work is in progress. A view of the old city Bhid Gate after restoration is shown in the top picture in Figure 18.

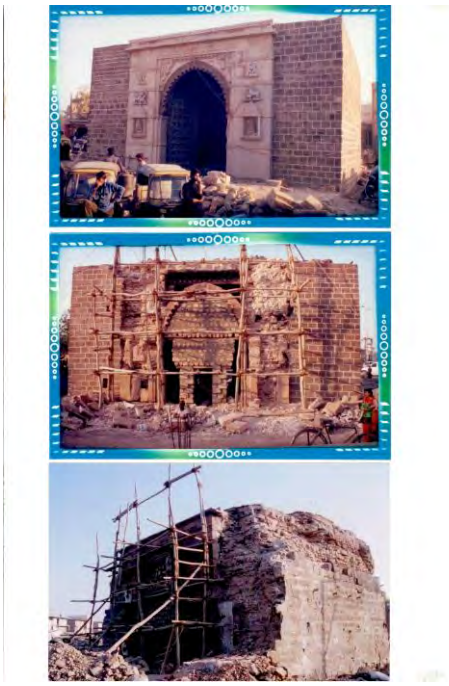


Figure 18: Old City Bhid Gate, restoration of arched gate in progress - Bottom two pictures

10.3 Cost of Restoration

The cost of the restoration of the old city gates are as follows:
Bhid Gate……..Rs.13 lakhs
Sarpat Gate….. Rs. 11 lakhs
Patwadi Gate.…Rs. 7 lakhs

11 CONCLUSIONS

This paper has attempted to focus attention on the status of the restoration of heritage structures in the city of Bhuj that were severely damaged by the 2001 Bhuj, India earthquake. The main focus of this paper is to share the experiences from assessment and restoration of the Ayna Mahal complex, Fuvara Mahal, and Old City Gates in the city of Bhuj in the state of Gujarat. Innovative local techniques using locally available materials were developed and implemented for the restoration of these heritage structures in Bhuj, that were devastated by the 2001 Bhuj earthquake. During the assessment process, no detailed structural analyses were carried out for studying the earthquake resistance of the heritage buildings in the Ayna Mahal Complex and the Old City Gates. Efforts have now been initiated to carry out such studies to better understand the issues of lateral stability and behavior of such heritage and historic structures in Bhuj, during earthquakes. Based on the experience of assessment and restoration of the heritage and historic structures in Bhuj, it can be concluded that the protection, restoration and preservation of the heritage structures in Gujarat is a very important issue and global collaborative efforts are urgently needed to protect this rich heritage from effects of aging, earthquakes, rapid urbanization, and climate factors, among others.

REFERENCES

[1] EERI, “Heritage Structures” - Bhuj, India Earthquake of January 26, 2001, Earthquake Engineering Research Institute, Oakland, California

[2] INTACH, Indian National Trust for Art and Cultural Heritage, New Delhi 2001

[3] UNESCO Mission to Gujarat, India for the Conservation of Earthquake-Damaged Cultural Properties, March 2001(http://www.conservationtech.com/india-UNESCO/UNESCO-report.htm)

[4] Booth, Edmund, and Vadavada, Rabindra., Earthquake of January 26, 2001 and its affects on Architectural Heritage of Kutch & Saurashtra, Prepared for INTACH, New Delhi, May 2001