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Multi-Hazard Risk Management for Heritage Buildings: Case Study Buranhpur Fort

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1 GENERAL PROFILE

This gateway of Southern India amid Satpura Ranges on the bank of river Tapti, relish footprint of dynasties from almost 150 BC. Physical structures shows evidence of layers of settlements drowned and vanished under debris and then rehabilitated over period of time. The imperial Fort located at the river bank is a seven storied structure, whose lower floors have become inaccessible due to centuries collection of mud heaps, which also gives ideas about the instability of these floors. Town has underground water supply system based on Persian Technology, which collects water from beneath the hills and tap into well like siphons distributing it through the city.

Morphologically, Buranhpur (Fig. 4) has peculiar character of walled town with the perkota wall covering circumference of 5.5 km holding 9 gates and 12 windows. Principal streets running cardinally along the principal axes culminate at city gates. There are secondary streets, and then narrow winding lanes approaching the cluster of houses through a community gate.

Table 1 : List of Historical Monuments in Buranhpur.

	Name	Year Of Construction	Period / Style	Location	Physical Status
1	Tomb of Nadir Shah	16th Century	Islamic Architecture	Buranhpur	Good
2	Raja's Chhatari	17th Century	Rajputana Style	Buranhpur	Good
3	Bibi Shahib's Masjid	1453	Islamic Architecture	Buranhpur	Good
4	Fort	1590	Farauqui Style	Buranhpur	Diapidated
5	Palace in the fort		Islamic Architecture	Buranhpur	Good
6	Hamam Khana		Mughal Architecture	Chowck Mohalla	Stabalised
7	Tomb of Shahnuma	16th Century		Asirgarh	Good
8	Mahadev Temple	16th Century		Buranhpur	Good
9	Idgah Front Wall	16th Century		Asirgarh	
10	Asirgarh Fort	9-12th Century		Asirgarh	
11	Khooni Bhandara	1615		Buranhpur	Dilapidated
12	Dome of Adil Shah	15th Century		Buranhpur	
13	Dome of Shah Nawaz Khan		Mughal Architecture		Good
14	Renuka Mata Mandir	1680		Buranhpur	Good

(a) (b)

Figure 1 : (a) View of Tapti river with Raj ghat, recently renovated (b) Tunnels of Khooni Bhandara, the Persian underground water supply system water was collected from satpura hills and distributed through tunnels against gravity by making use of siphon system.

2 NEED OF MANAGEMENT

Much of the damage that occurs during an earthquake is directly related to the building's existing condition and maintenance history. Well maintained buildings, even without added reinforcement, survive better than buildings weakened by lack of maintenance. The capacity of the structural system to resist earthquakes may be severely reduced if previous alterations or earthquakes have weakened structural connections or if materials have deteriorated from moisture, termite, or other damage. Furthermore, in unreinforced historic masonry buildings, deteriorated mortar joints can weaken entire walls. Cyclical maintenance, which reduces moisture penetration and erosion of materials, is therefore essential. Because damage can be cumulative, it is important to analyze the structural capacity of the building.

Over time, structural members can become loose and pose a major liability. Unreinforced historic masonry buildings typically have a friction-fit connection between horizontal and vertical structural members, and the shaking caused by an earthquake pulls them apart. With insufficient load bearing system of beams, joists, and rafters against the load bearing walls or support columns, they fail when seismic loads are added to it. The resulting structural inadequacy may cause a partial or complete building collapse, depending on the severity of the earthquake and the internal wall configuration.

Out of various historic monuments the city is dotted with the Imperial Fort with its perkota wall is found to be most vulnerable and susceptible to seismic damages due to following reasons:

1. The seven storied fort and palace has lost its Box action and the entity due to lost elements like floor slab of some units.
2. Sitting on edge of the hill with undulating adjoining land.
3. Random rubble masonry with mud mortar in thick walls lacks adequate through stones.
4. Lower floors are not properly accessible and engrossed in heaps of rubble.
5. Thick wall of the fort are likely for wythe separation under seismic forces.
6. Soil erosion on the bank of Tapti River has reduced strength of foundation over period of time.
7. Repair work already undertaken lacks coherence with original work.
8. The ad-hoc growth and encroachments supporting the perkota wall has added to its deterioration.

3 STATUS OF NATURAL DISASTER

As per the seismic zonation map Buranhpur comes in Zone III. The state suffers mainly from two major Natural Hazards, namely, floods and Earthquakes both of moderate frequency. Floods, although of high frequency, are rather of short duration. River Tapti and small river streams have also resulted in floods combined with releases from the reservoirs on these rivers in the upstream.

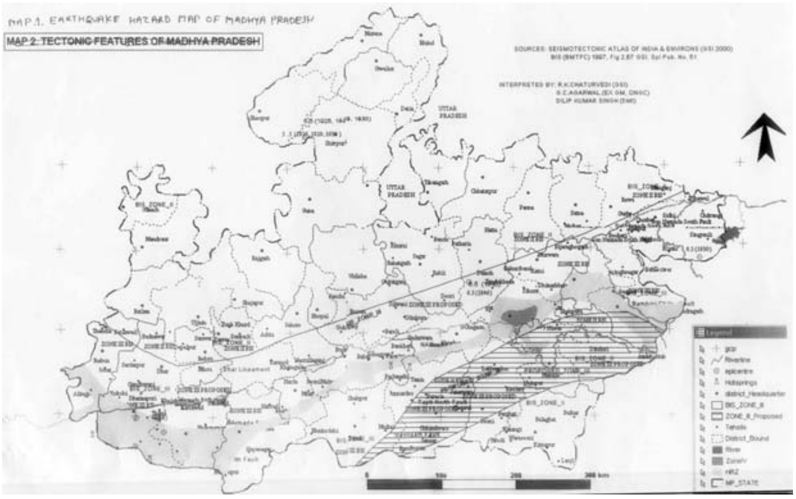

Figure 2 : Vulnerability status map of Madhya Pradesh

According to this qualification, zone III, which covers the central part of the state along Sonata - Tapti Valleys can get a maximum intensity of MM-VII. Classification as high risk depends on following factors:

1. The presence of several hot springs along SNSF, Tatpani fault, Tapti North Fault, etc, as brought out by G.S.I. is also indicative of high heat flow and geothermal energy along active faults where the surface water gets down to great depths and surfaces again as hot springs.
2. Repeat Earthquake: Historical records show that in close area around Jabalpur, 3 earthquakes of +5 magnitudes (1846, 1903, and 1997) and many more with lesser magnitude have been felt more or less at the same point, i.e. Lat.23 N, Lon.80 E.
3. Geological Survey of India has already identified active / neo tectonic faults which clearly show that SNSF happens to be seismically most active fault within CITZ, along which more severe earthquakes within M.P. can be expected in future.
4. Earthquakes experienced in near vicinity, mainly in Latur and Jabalpur. Where as Khandwa district Buranpur comes in, experienced seven earthquakes out of which two were of magnitude more than 6.0.

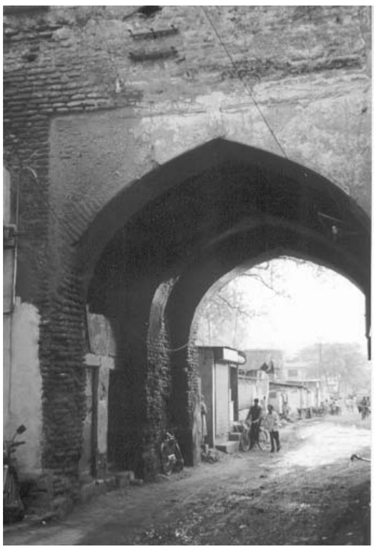

Figure 3 : Raj pura Gate Flooded almost every year. Dilapidated lower portions are visible.

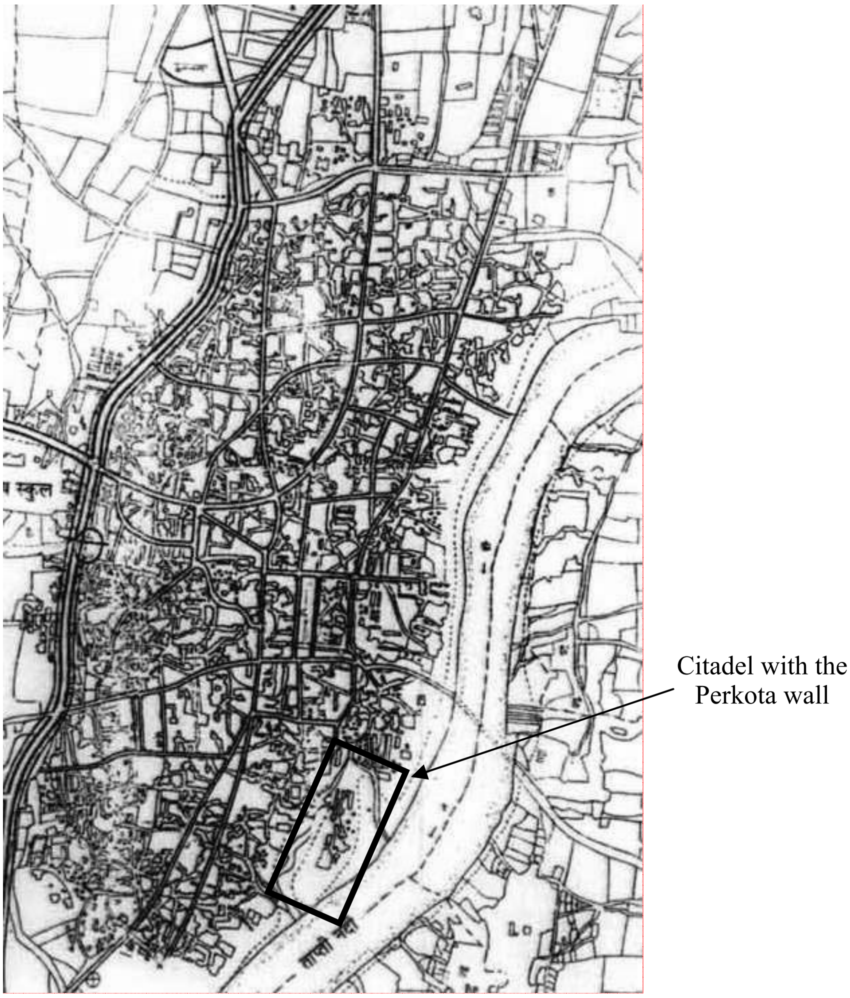

Figure 4 : Town Morphology.

4 RAPID VISUAL SCREENING (RVS)

This procedure is implemented without performing structural analysis and statistical calculations. It utilizes a scoring system. Rapid visual screening is the latest methodology adopted here for quick survey of buildings for structural stability from seismic as well as flood point of view. Appraisal of Built Environment have been done by visual screening of historical monuments, their significant heritage values, their precincts and the existing level of protection. Test data on the strength characteristics of random rubble and half-dressed stone masonry is not available. It is, however, qualitatively known that the compressive strength even while using clay mud as mortar will be enough to support three storeys but the tensile strength could only be near about zero. Sliding shear strength will only be due to frictiona1 resistance. Understanding the physical performance of different building elements is very necessary in lieu of the likely occurring damages. The main pattern of damages for historic buildings is enlisted as below:

1. Separation of walls at corners and T-junctions takes place even more easily than in brick buildings due to poorer connection between the walls.
2. Delamination and bulging of walls, that is, vertical separation of internal wythe and external wythe through the middle of wall thickness. This occurs due mainly to the absence of "through" or bond stones and weak mortar filling between the wythes. In half-dressed stone masonry, the surface stones are pyramidal in shape having more or less an edge contact one over the other, thus the stones have an unstable equilibrium and easily disturbed under shaking condition.
3. Crumbling and collapsing of bulged wythes after delamination under heavy weight of roofs/floors, leading to collapse of roof along with walls or causing large gaps in walls.

4. Outward overturning of stone walls after separation at corners due to inertia of roofs and floors and their own inertia when the roofs were incapable of acting as horizontal diaphragms. This particularly happened when the roof consisted of round poles, reed matting and clay covering.

Frequently, such stone masonry, under MSK VII or higher intensifies, are completely shattered and razed to the ground, the walls reduced to only heaps of rubble.

Geo-technical Appraisal of Heritage buildings includes:

1. General Buildings Survey with details of services as existing.
2. Auger boreholes (5 m – 9 m) to study soil profiles and binding capacity of mortar.
3. Building Technology - Retaining wall dry sandstone and sand infill to strengthen base and prevent soil erosion.
4. To identify building attributes that modify the seismic performance expected from primary lateral load resisting system for average expected ground shaking levels.

5 RETROFITTING FOR RISK REDUCTION

Retrofitting technologies should be coherent with the original structures, maintaining their original character as much as possible. The lateral strength and ductility are the most significant factors that govern the seismic capacity of a building. The purpose of retrofitting is to upgrade the strength and ductility of buildings by:

- Upgrading the ultimate lateral strength of structures by addition of shear walls, insertion of new slabs etc.
- Increase ductility of structures by inducing continuous ductile members, maintaining integrity of structures.
- Increase both ultimate strength and ductility.
- Reducing the seismic forces affecting the building by dampening vibrations or isolating the building base from ground.

Principle of Retrofitting is based to obtain desired level of seismic performances for most serious life safety concerns rectifying the deficiencies that could lead to serious causalities or total building collapse. It could be bracing and tying the most vulnerable elements like parapets, chimneys, projecting ornamentation insertion of special binding elements to connect old and new elements or reinforcing routes of exit. The possibility of reduction of dead loads and shifting of heavy loads from upper storey to lower one must be explored.

Retrofit techniques: Retrofit techniques can be categories into Global and Local Level. Global retrofit is required when entire load resisting system is deficient. The local retrofit is used when it is established that limited structural members are deficient. The techniques employed for global and local retrofit in state of art are explained as follows:

1. Addition of Shear Walls: Shear walls can be added extending from base to the roof to add both strength and stiffness to the building. The process of introducing shear walls should not spoil symmetry of structures and should be integrally connected to existing structures. It also should take into account the modified loads on foundation due to addition of shear walls.
2. Infill walls: Provisions of infill walls changes the basis ratio of solids and voids which are a pertinent character of heritage buildings, together with increase in loading on foundation due to these structural modifications. It’s better to avoid infill walls for heritage structures.
3. Insertion of new slabs: A rigid slab inserted into existing walls plays an important role in existing mechanism of the buildings. The slabs have to be properly connected to the walls through appropriate keys. Re-strengthening connection of slab to the walls is another approach to enhance its role and integrate the buildings for box-action. Inserting a small RC band into existing walls and band has to be keyed at least at every 3.0 m.
4. Strengthening walls with wire mesh: Two steel meshes (welded wire fabric with an elementary mesh of approximately 50 × 50 mm) are placed on both sides of wall and connected by passing steel each 500-700 mm apart). A 20-40 mm thick cement mortar or micro concrete layer is then applied on the two networks thus giving rise to two interconnected vertical plates. This system can also improve connection of orthogonal walls.

5. Supplemental Damping services: The supplemental damping services such as addition of viscous damper frictional dampers in diagonals of bays of frame substantially reduce the earthquake response by dissipation of energy. The viscous dampers have been used for retrofit of four storeys, non-ductile concrete structures. (Miyamato and school 1996)
6. Seismic Base – Isolation: The concept of seismic base isolation is based on decoupling of structures and foundation. The isolation bearing decreases the frequency of overall building isolation system to 0.5 Hz. This low frequency system does not permit transmission of high frequency earthquake motion to structure. This approach has recently used for retrofiting and renovation of San-fransisco courthouse - a monument of state registry requiring intervention only at foundation level. Instead of Traditional approach of resisting the forces of Earthquake imposes on a structure, this is to avoid these forces by isolation of structure from the ground motion. For simpler buildings base isolation can be achieved by reducing different coefficient of friction between the structure and its foundation or by placing a flexible connection between the two. One of the suggested technique is to place two layers of good quality plastic between the structures and its foundation so that plastic layers may slide over each other. Use of rubber pads is the other technique, which absorbs the shocks, dampening their resultant forces on the superstructure

Local Retrofit Methods: As we have already discussed, beams and column jacketing from one or more sides by reinforced concrete, steel and composite using fiberglass, FRP, carbon fiber etc. The local retrofit methods employed for beam column joints include- low viscous epoxy resin and non shrink high strength mortar. Others are bonded steel plates and corrugated steel jacketing.

6 MONITORING SEISMIC DEFICIENCIES

As fault lines likely to follow contour of slopes with probability of liquefaction foremost is the stability of foundation, which needs to be assured before undertaking any ambitious plans. Buranhpur is most vulnerable from this aspect being surrounded by mountains all around and imperial fort being located on river bank. A checklist is stated with its inherent benefits to achieve an optimal level of seismic resistance through seismic upgradation. The structural strength should be effective along both the axes.

	Characteristics	Achieved Benefits
1	Low height to base ratio	Minimize tendency to overturn
2	Equal Floor heights	Equalises column wall stiffness
3	Symmetrical plan shape	Reduce Torsion
4	Uniform sections and elevation	Eliminate stress concentration
5	Seismic resisting elements at perimeter	Maximum Torsional Resistance
6	Redundancy (Deformability)	Toleration of failure of some members
7	Ductile detailing	Dissipate energy to prevent Collapse

An addendum to above a checklist as mentioned below helps in analysis of structural strength before deciding the content and extent of modifications. This is not an exhaustive list but illustrates most of the measures to reduce life safety risk which can be adopted for incremental upgradation of seismic performance of age old structures. But care should be taken to integrate these changes with the visual appearance and historical character of the building.

1. Inertial forces are the product of mass and acceleration. Newton's $F = m \times a$. Acceleration (a) is the change of velocity in certain direction over time and it is a function of earthquake. Mass on the other hand is a function of the building. An increase in mass is increase in forces; henceforth reducing heavy dead loads are desirable.
2. Asymmetry in plan and elevation reduces eccentricity between center of mass and center of lateral rigidity and also lead to torsion subjecting peripheral structural elements to severe stress and strains. Asymmetry also leads to stress concentration at typical points instead of uniform distribution.
3. Check the integrity of vertical tension members which can transfer the loads from roofs down to the foundation.

4. Additional tension members at grade, lintel and plate level to tie walls so that they may move in unison. Addition of concrete bond beams at the top of unreinforced masonry.
5. Creation of a crumple link between the segments of large or irregular buildings, so that structure will not hammer one another when they oscillate in different direction and frequencies. A physical separation by 3-4 cm above plinth level will prevent hammering effects between blocks. The gap lie expansion joint can be filled with a weak material which crush and crumble easily during an earthquake shaking.
6. Lateral load resisting elements like shear walls and braced frames when added to existing structure, required to be placed on the both axes of building.
7. Use of through wooden planks (coating to make it insects proof) may prevent separation of internal and external wythes.
8. Floor slabs which have lost their entity no more behave as a diaphragm (horizontal members) to transfer the load to the shear walls – In the fort where Floor slabs are missing or broken, extra strengthening of shear walls will be required to share the load
9. Openings should be 1.2 m away from the corner and should not be more than half of the total length between the supports.
10. Both tensile and shear strength are accountable for seismic resistance of masonry walls. Mud or very lean mortars are undesirable. A mortar mix (cement sand 1:4, lime cinder = 1:3 minimum or richer mortar is desirable).
11. For cantilever structures and ornamentation, seismic coefficient of about five times require as required for designing of main structures. (where seismic factor is generally taken as 2)
12. Maximum length of masonry walls between two consecutive vertical members (cross walls or buttress) should be 8-10 times of the thickness of wall.
13. Slenderness Ratio (height/depth) is important in free standing structure like the perkota wall which acts as vertical cantilevers.
14. Bracing and squinches supporting the roof or domes reduces the effective wall length subjected to lateral forces thus reducing slenderness ratio.
15. Baffled walls or additional piers increase lateral stability of structures.
16. Strong column weak beams should be aimed to prevent total collapse of structures and life safety of occupants.
17. Bondage of horizontal elements to vertical members should be ensured.
18. Bamboo coated with tar can be used in place of steel for reinforcement.
19. Adequate connection between old and new construction have to be ensured by shear keys or dowels. China has adopted a extensive plan of Pilasters right to the top of buildings with shear keys and especially designed dowels.
20. Historical buildings analyzed from these perspectives have more risk of disintegration of its parts. Pilaster can add the shear strength, but the RCC band on both inner side and outside concrete layer on mesh can enhance the box action.

7 URBAN HISTORIC ENVIRONMENT

Development and management for historic precinct requires certain management measures for effective implementation process. Foremost is involvement of community and their awareness about prevailing risk and significance value of heritage. Implementation process for a partnership based management model for urban historic environment pertaining to seismic hazard could be framed on following guidelines:

1. Awareness Raising: Dissemination of information about vulnerability of the monuments from existing hazard and prevailing risk. Awareness for existing cultural heritage and ways to maintain it.
2. Presentation of the partnership model and identifying the key actors in local government departments- public works, social development, welfare, education and health, civil society organization, NGO’s and CBO’s.
3. Participatory Assessment: Holding a community workshop in which information can be reviewed taking a snap shot of the situation at a particular moment. Major challenge involved here is to check fragmentation of information and address the inconsistencies and gaps in information.

4. Formation of partnership based management unit with well defined priority of activities, to generate awareness for cultural heritage and development of infrastructure for environmental management based on degree of need and feasibility.
5. Institutionalization of the model: Creation of local Government agency for management of urban historic environment and to supervise the implementation of model and role of key representatives in it. The major barriers are to check the overlap roles of various bodies.
6. At least know the risk: Informing the community of any vulnerable structure is the first step of creating awareness.

8 ADAPTIVE MANAGEMENT

New seismic retrofit systems, whether hidden or exposed, should respect the character and integrity of the historic building and be visually compatible with it in design. Evaluate odd-shaped buildings and consider the reinforcement of corners and connections instead of infilling openings with new construction. Altering the basic configuration and appearance of primary facades of buildings is damaging to those qualities that make the building architecturally significant. Adequate maintenance ensures that existing historic materials remain in good condition and are not weakened by rot, rust, decay or other moisture problems. Without exception, historic buildings should be well maintained and an evacuation plan needs to be developed.

Recent earthquakes have shown that historic buildings retrofitted to withstand earthquakes survive better than those that have not been upgraded. Even simple efforts, such as bracing parapets, tying buildings to foundations, and anchoring brick walls at the highest, or roof level, have been extremely effective. It has also been proven that well maintained buildings have faired better than those in poor condition during and after an earthquake. Thus, maintenance and seismic retrofit are two critical components for the protection of historic buildings in areas of seismic activity. It makes no sense to retrofit a building, and then leave the improvements, such as braced parapets or metal bolts with plates, to deteriorate due to lack of maintenance.

Damage to historic buildings after an earthquake can be as great as the initial damage from the earthquake itself. The ability to act quickly to shore up and stabilize a building and to begin its sensitive rehabilitation is imperative. Communities without earthquake hazard reduction plans in place put their historic buildings-as well as the safety and economic well-being of their residents at risk. Hence what we require is not a retrofitting plan but a plan for adaptive seismic management.

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