Seismic Retrofitting Journey of Industrial Buildings

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SUMMARY:
This paper describes the collaborative project team set up by P&G and the journey of this team to implement seismic retrofitting on industrial buildings in Northern India. The journey starts at the point where seismic deficiencies were uncovered in existing facilities. P&G established and implemented a plan to create the project team to resolve the matter.
Multiple seismic retrofitting solutions were explored by the project team which included stiffening, strengthening, increasing ductility, mass reduction, base isolation, addition of supplementary damping, changes to building configuration, rebuilding on site or rebuilding on a new site as well as structural use of existing infill masonry walls were explored. The retrofit design evolution involved peer reviews, field testing, detailed understanding of factory production and operational requirements, cost and programme and technical implications of all the proposed options. The extremely limited local contractor experience in seismic retrofitting was understood from the beginning of the project and influenced approach and decision making throughout.
During construction, the project team evolved to incorporate new retrofitting skill sets to meet the demanding requirement of completing retrofitting while maintaining an operational facility. Key project review team members were continually involved to conduct reviews and technical assessments to ensure the seismic retrofit design was implemented in accordance with the design principles. Pro-active steps were taken to monitor construction quality and site safety to ensure the project was delivered in line with manufacturing time frames and required standards. Throughout this journey significant effort was invested in education about disaster risk reduction, educating sceptics to be more informed why it was necessary to undertake the retrofit and creating an environment where all parties had to make adjustments and compromises to achieve the P&G objective of having facilities that met basic earthquake life safety requirements.

Keywords: Retrofit, Incremental, Masonry, Leadership, Peer Review

1. BACKGROUND TO P&G's GLOBAL APPROACH TO EARTHQUAKE ENGINEERING

After experiencing losses from earthquakes in Southern California (1994), Kobe, Japan (1995), and Western Turkey (1999); the Procter & Gamble Company undertook a corporate program for assessment and mitigation of seismic risk to its owned facilities worldwide. P&G facilities and risk-management, along with seismic experts, defined a process to assess risk in buildings worldwide in regions of significant seismic hazard. The assessment process involved iterative steps of initial screenings to detailed evaluations, during which seismic vulnerability and loss estimates were prepared.

A necessary and challenging feature of the program was the preparation of a uniform assessment tool to be applied to all facilities internationally for both seismic hazard (i.e., probability of earthquake ground motions) as well as building vulnerability. Drawing on industry standards and guidelines, P&G developed a rating system that evaluated risk to life as well as risk to facility assets and potential business disruption. These ratings serve to determine where mitigation is required, analyse the cost-benefit relationship of different mitigation measures, and set priorities on mitigation expenditures.

Much of the risk assessment required on-site investigation of structural and non-structural conditions as well as advanced analysis. P&G was able to form teams comprised of international seismic experts and engineering firms local to the project sites. These collaborations proved successful by integrating specialized, state-of-the-art seismic expertise with specialized knowledge of local construction practices and capabilities. The remainder of this paper describes a journey P&G undertook to retrofit industrial buildings in India.

2. INTRODUCTION

In 2006 P&G acquired existing manufacturing capabilities for healthcare products in Baddi (Mapaex and Sarvottam), northern India as shown in Figure 1 and Figure 3. This change in ownership required P&G's global leadership to implement their global seismic safety standard that had been developed after the 1995 Kobe earthquake to achieve as a minimum the "Life Safety" requirement; "Buildings do not fall down and that people have a safe exit path in the event of a large earthquake". P&G desired performance point is shown in Figure 2.

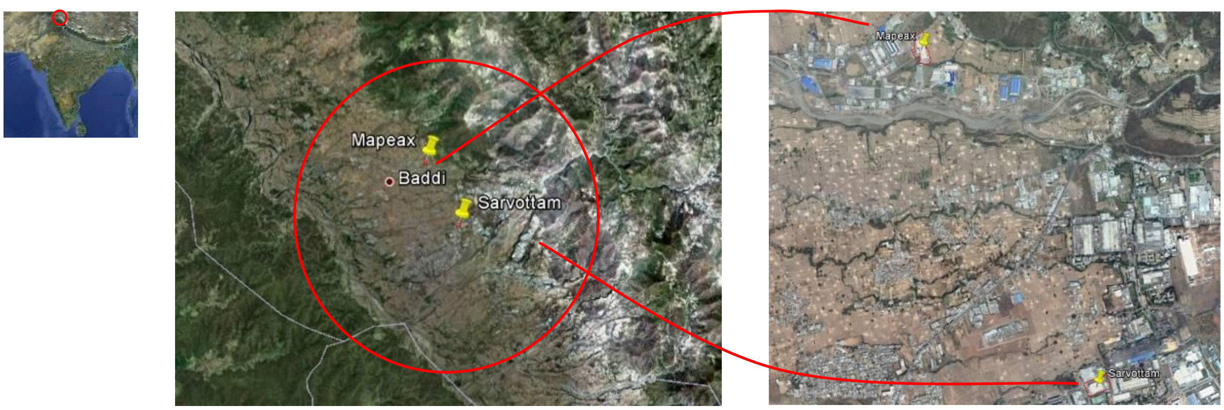

Figure 1 Project location in northern India that has undergone rapid industrialisation.

This is consistent with P&G values and policies: "Ensure our operations are safe for employees, neighbours and the environment surrounding our sites." And "This policy is assured by internally imposed standards of operation applied worldwide, which frequently go beyond the letter and the spirit of those laws and regulations that apply locally."

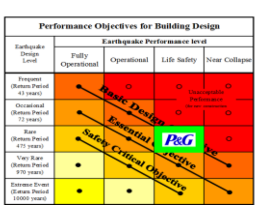

Figure 2. Seismic performance objective.

Figure 3. Sarvottam and Mapaex at the foothills of the Himalayas in Baddi, India.

P&G created a steering team to establish the seismic performance capability of the facilities. This team initiated:

1. A seismic hazard assessment desk study
2. An initial structural seismic assessment of the main new buildings

3. SEISMIC DESK STUDY

According to the Indian seismic code, IS 1893, Baddi has a seismic zone factor of IV (i.e. 0.24g) as shown in Figure 4.

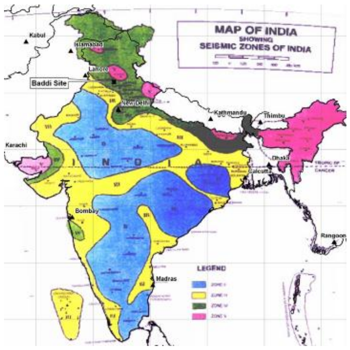

Figure 4. Indian Seismic hazard map in accordance with IS1893 (Part1): 2002 showing Baddi to be in zone IV.

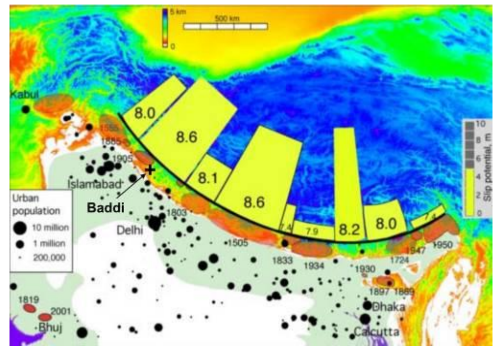

Figure 5. Potential earthquake magnitudes in northern India according to Bilham.

However the desk study quickly revealed that Baddi is in a very high seismic region as shown in Figure 5. Closer examination of the project location revealed that the site is located in a fault zone and surrounded by several active faults, at least one of which is highly active (slip rate > 5 mm/yr) and capable of generating large-magnitude (Mw > 7.0) earthquakes (Source Type A according to UBC 1997) as shown in Figure 6.

IS 1893 (Part1): 2002 does not include a provision for near-source factors which are clearly relevant in this instance.

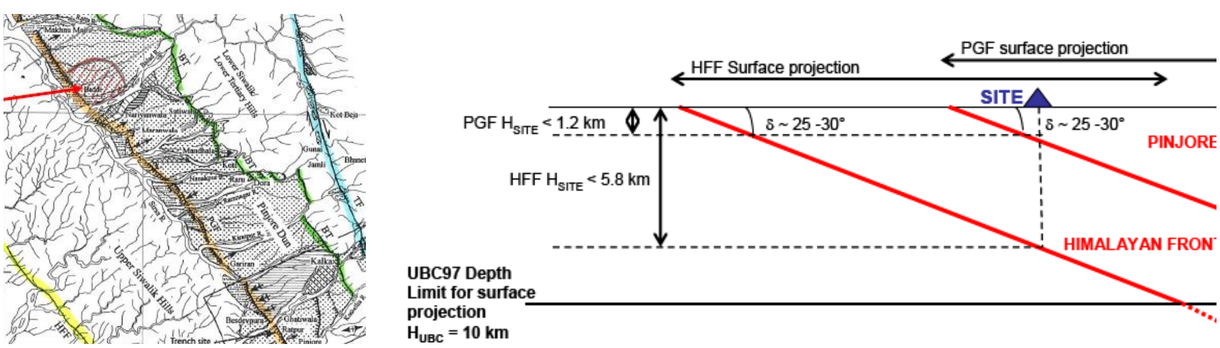

Figure 6. Map and schematic representation of known active faults in relation to the project sites.

Based on the available information, the recommended UBC (1997) Seismic Coefficients C_a and C_v have been determined as C_a=0.66 and C_v=1.28, based on a Zone Factor Z=0.40g, a Soil Profile Type S_D (stiff soil) and Near-Source Factors N_a=1.5 and N_v=2.0 (in the absence of performing a site specific probabilistic seismic hazard assessment). The project leadership agreed to adopt these parameters for the initial seismic assessment which is described in the next chapter.

3. INITIAL SEISMIC ASSESSMENT

The initial site visit and subsequent structural seismic assessment of the main buildings revealed that the buildings were substandard against P&Gs global seismic safety standard. The main findings were:

- Seismic movement joints had not been built
- Seismic detailing had not been built, with the steel fixers and common civil engineering construction practitioners in the region not being familiar with the concept of 135 degree hooks and closely spaced links etc...
- The diaphragm was not complete
- The existing RC columns and beams were deficient in flexure and shear with very limited deformation capacity.
- Steel to concrete connections were inadequate.
- Internal walls did not connect to the roof diaphragm.
- Large amounts of unreinforced masonry infill potentially posed a large risk.

Given that the new buildings were now being judged against P&Gs global standard it was decided not to explore if the original building had been in compliance with IS 1893. It was clear that significant works would be required such as the addition of reinforced concrete shear walls (and their foundations) and strengthening of the roof diaphragm as shown in Figure 7.

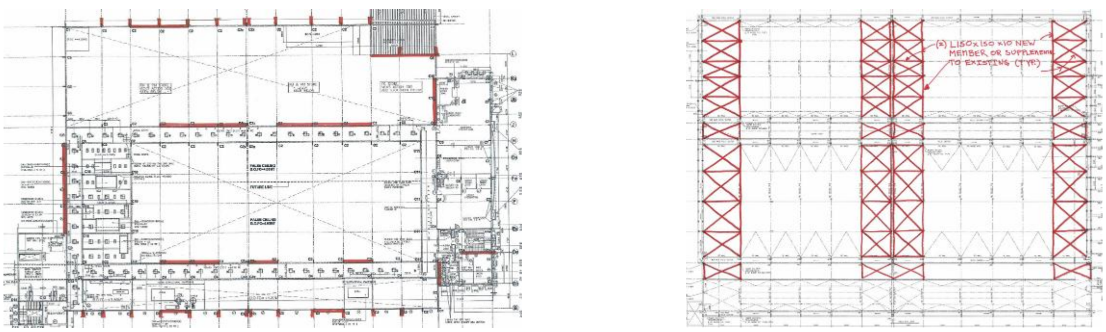

Figure 7. Concept sketches of the likely extent of the required retrofitting works.

4. INITIAL RETROFIT DESIGN

P&G's global leadership reconfirmed their resolve to retrofit Mapaex and Sarvottom after having obtained an order of magnitude cost estimate for the envisaged works. Over the coming months the seismic design engineering team undertook detailed seismic analysis in accordance with the linear dynamic procedure of FEMA 356 using response spectrum analysis. The team created a project specific structural design basis that documented the known engineering properties and assumptions. This document was reviewed and agreed by all with updates to it when new information justified a change.

The initial task was to retrofit the buildings without removing the masonry infill walls. Attempts were made to account for the strength and stiffness of the masonry however the team did not have any engineering properties for the masonry. Therefore the benefits of the masonry were ignored. This resulted in a "heavy" retrofit with very many shear walls and extensive diaphragm work. This retrofit still required the masonry walls to be retrofitted for out of plane behaviour. The interruption to business and cost of the extensive works pushed the team to search for further solutions.

As part of this the team studied an option for replacing the heavy masonry walls with medium weight insulated wall panels. This reduced the seismic mass and allowed a reduction in the number of shear walls, foundation works and diaphragm strengthening works. The team was then able to source lighter weight insulated wall panels resulting in further project savings. However, replacing most of the infill walls with lightweight panels created many problems for the operational people, long construction shutdown, massive dust creation, the removal and reinstallation of the majority of manufacturing equipment, and would necessitate a near complete rewiring of all the hidden factory wiring among many other serious issues. Base isolation was considered briefly but would have required the construction of a second foundation and this option was rejected on cost and practicalities.

The option of the addition of viscous dampers was also investigated by the project team. However, because the existing reinforced concrete structure had a very low deformation capacity the project would have required many viscous dampers. In addition the dampers would have required to be connected between locations were there was significant differential movement. This then necessitated many stiff shear walls that were not directly connected to the reinforced concrete frame. Again, the solution became impractical and expensive with no tangible benefits over the already explored conventional retrofitting solutions.

5. PEER REVIEW

After the initial retrofit designs were completed, the project convened at IIT Kanpur for a peer review at one of India's main earthquake engineering universities. IITKs main reviewers were Professor Sudhir Jain and Dr. Durgesh Rai. P&Gs global senior leadership, their India operations leadership, Arup and the original designer of the building were in attendance during this review.

The peer review process reinforced the requirement that the buildings needed to be retrofitted. Having the senior leadership presence during the review ensured that informed decisions could be made to find ways to further improve the retrofit design to comply with P&G's structural seismic design safety standards for new buildings as well as business requirements.

The team agreed two lines of work to improve the project data:
1. undertake geophysical testing to validate the expectation that the actual in-situ soil class is better than D and could be changed at least to a C class which would result in a reduction in the size of the design spectra.
2. Reconsider making use of all the unreinforced masonry walls which required the team to:
   - Find evidence that reinforced concrete band beams were built inside the infill walls
   - Confirm that the masonry had been built up tight against the band beams or if there was a gap.
   - Undertake testing of masonry samples from the project to determine the masonry compressive strength, stiffness (brick and prism tests on brick samples taken from the field).
   - Conduct in situ masonry shove tests to determine as-built project specific masonry shear strength properties.

The review process gave further assurances to the project team that the reinforcement bars were likely of reasonable quality because IITK frequently tested reinforcement from the specific manufacturer.

6. DATA IMPROVEMENT

The additional downhole soil investigation tests completed resulted in the site soil class improving to soil type C. This resulted in a ten percent reduction in the seismic spectra.

Figure 8. Geophone preparation.

Figure 9. Five brick masonry prisms compression testing.

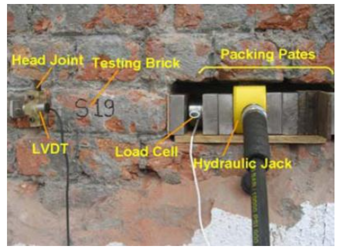

Figure 10. In situ shove test loading and instrumentation system.

Figure 11. Construction photos showing band beams.

The masonry tests, shown in Figure 9 to Figure 11 resulted in project specific properties, as shown in Table 1, to be used in reconsidering the use of the masonry structurally as part of the retrofit. These results provided the basis to reconsider the infill brick walls out of plane resistance in the whole analysis.

Table 1. Masonry test results summary (N/mm^2)

Expected masonry shear strength (Mapex)	$v_{me\ Mapex}$	0.55
Expected masonry shear strength (Sarvottam)	$v_{me\ Sarvottam}$	0.41
Compressive strength	f'_{me}	3.24
Young's Modulus	$E_{me} = 500\ f'_{me}$	1620

7. FINAL RETROFIT DESIGN

In the revaluation of the retrofit, the masonry stiffness and strength were evaluated by using guidance from FEMA 356, Al Chaar and Paulay & Priestley. Overall the number of required shear walls was able to be reduced. In close collaboration with the plants' operational management, the final locations of all the structural retrofitting items were agreed. As part of the design development process, P&G was also able to obtain a concession from their operational department to close the factory for a eight week period during which all internal foundation and shear wall construction work was to be undertaken. This is an important point as it recognises that in order to implement seismic retrofitting everybody has a contribution to make towards the necessary works.

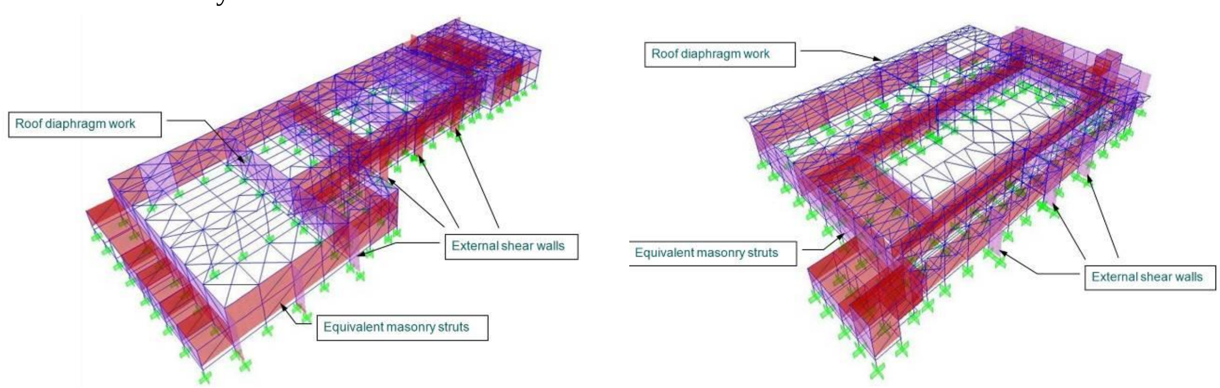

Figure 12. Final retrofit design analysis models for both facilities.

Where additional diaphragm bracing was required, it was provided in service corridors or externally to the main building in order to minimise impact on the function of the factory. Where possible, the reinforced concrete shear walls were designed to be external to the main buildings to further reduce the impact on production.

Detailed out of plane stability evaluation of the masonry revealed, with the presence of the intermediate support beams and with the masonry being built up tight against the beams, that with the help of arching action, the out of plane stability of the walls was likely. Therefore it was reasonable to take the view that the masonry would not pose an unreasonable risk to safety.

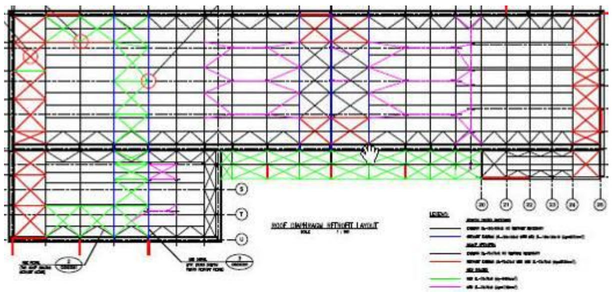

Figure 13. Shear walls and roof diaphragm work.

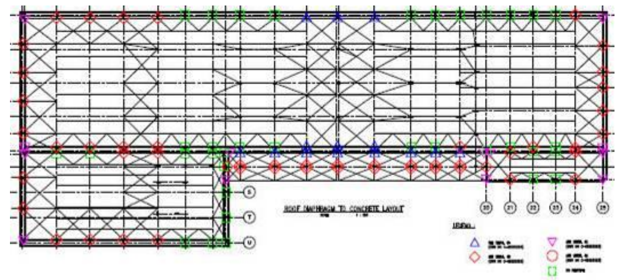

Figure 14. Connection for repair or strengthening.

A number of existing steel and concrete members needed bespoke strengthening due to local deficiencies.

8. PRE TENDER STEEL WORK SURVEY

After completion of the retrofit design, a visual survey of the steel was carried out, due to quality concerns of the existing steel work, in order to improve the projects knowledge prior to engaging with contractors. It is simpler to budget and plan for known problems rather than incurring unexpected time and cost increases. Typical findings from the steel work visual survey are shown in Figure 15. The survey findings were communicated to bidders during the tender process to ensure the bidders were fully aware of the required work which consisted of repairing as well as retrofitting.

Figure 15. Identification of typical steel work deficiencies.

9. TENDERING

Five shortlisted contractors were interviewed but only one had capabilities and interest in this complex retrofit project. The contractor was selected based on a review of their management processes, financial stability and experience of complex projects. Once sufficient managerial and technical capability had been demonstrated the contract was negotiated directly with the entire process taking approximately 2 months.

10. CONSTRUCTION

Like many construction sites a rigorous independent site inspection procedure contributed to significantly reducing defective work and where defective work was carried out to identify and rectify the defective work.

Much of the labour on site was from a rural background with limited formal training in construction. Achieving a reasonable level of construction quality was always a challenge. At one point the quality of the concrete became questionable and early core results indicated that the specified retrofit cube strength of 25MPa had not been achieved. Figure 16 shows the variability of concrete strength results. Final independent testing of cores by IITK confirmed that the achieved concrete quality was at best marginally adequate. To avoid breaking out concrete each shear wall was reassessed in terms of what the controlling concrete strength would be in order for concrete to be the strength controlling factor. This allowed us to conclude that there was adequate spare capacity in the retrofit design of the new shear walls to be able to still have adequate strength even with reduced concrete strengths.

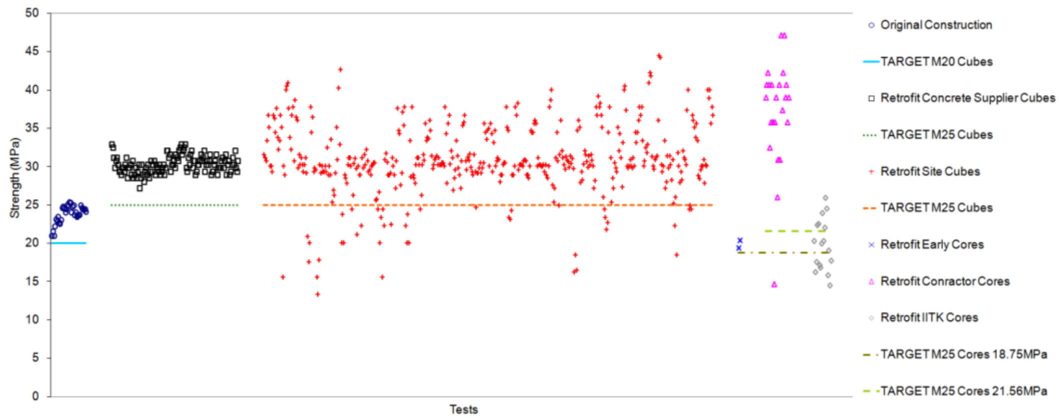

Figure 16. Highly variable concrete strength results during the project time line.

11. HEALTH AND SAFETY

The project delivery team recognised early on that the labour force background was from rural India with limited safety training or standards. Therefore pro active measures were taken during construction to enhance the contractor’s health and safety performance. P&G deployed their own health and safety manager for the entire construction duration. This approach resulted in a safe site with no significant incidents despite working in a live operating facility with much work at height. The following Heath and Safety measures were key parts of the Health and Safety plan.

1. Enforcement of a clear responsibility structure
2. Review of the contractors health and safety standards and then enhancing them throughout the project:
    - Training system
    - Introducing a dedicated safety team.
    - Permit system.
    - Behaviour observation system.
    - Inspection system.
    - Developing project specific safety plan and methodology
    - Introducing safe working rules for working at height or hot working.

- Incident reporting and follow up system.
- Clear sign posting of dangers and risks.
- Daily coordination with the operations team
- Having an agreed emergency management system in place
- Weekly and monthly safety meetings
- Results tracking and reporting system

3. Documentation & Record keeping so that all were aware of the
4. Reward system to motivate the workers for safe performance.
5. Safety was celebrated at all possible opportunities and senior leaderships attendance at these events.
6. Education and raising awareness by having the workforce analyze incidents and near misses and present in team settings with recommendations to improve safety continuously.

Figure 17. Tool box meetings, multi lingual safety signs, clip on when working at height and hazard identification

12. CONCLUSION

The conclusion from this project is that a successful seismic retrofit project in an existing operational facility involves complex planning, technical expertise, agility, health and safety focus and strong management commitment. Constraints of the location mean that these items can need additional focus. The process of completing a successful retrotfit project demonstrated these valuable lessons:

1. Leadership commitment at the highest level is needed.
2. Desk studies to be undertaken at the very beginning as they will influence the project direction.
3. The chosen solution does not have to involve innovation or undertaking expensive research but does involve being well informed and supporting decisions by good quality data.
4. Involving many aspects of the business is recommended to create understanding and then coorporation to carry out such retrofit works.
5. The project team should include all appropriate skills and experiences mix for the required task.
6. Recognition of the particular project location challenges and opportunities should be considered in the planning and execution of the retrofit works.
7. The current Indian seismic hazard map in IS 1893(Part1):2002 needs to be used with caution and maybe un-conservative in a number of locations such as in Baddi.
8. In locations such as Baddi, significant investment is required to train masons, carpenters, shutterers, steel fixers in seismic detailing and basic construction quality and that this needs close monitoring
9. Basic construction site health and safety is not always developed to international standards and special measures should be taken to address this.
10. Supervision engineers will benefit from seismic retrofit training to control site quality and to ensure design intentions are actually built as intended.
11. Creating a neutral review platform by involving independent local experts such as IITK in this instance helps convince local business leadership of the need to carry though with such projects.
12. Professional collaboration and peer reviews among consultants and experts.

13. Early checking and training of the contractor should be undertaken at the start of the project to create maximum benefit.
14. In certain locations, consider specifying required material properties to give margin against potential material and construction quality deficiencies.
15. Make health and safety a priority from owner and contractor, and using an experienced health and safety manager can provide clear benefits.

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