Seismic Strengthening
of the Nepalese Pagoda:
Progress Report

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INTRODUCTION

The history of earthquakes in Nepal suggests every hundred years a significant earthquake strikes. We know a little about the 1830's earthquake from written documents, and extensive photographic documents exist from the 1934 earthquake. Combined with extant structural damage, this historic data provides meaningful insight into the potential damage of a future earthquake in the Kathmandu Valley, which boasts the country's highest concentration of historical structures. However, this data cannot substitute for the vagaries of time and taste. After the last great earthquake of 1934, resources, craftsmen, and a willingness to recreate temples in traditional style could still be found among the local community. Today, people do not like old things, they prefer to build anew rather than preserve the old historic patina. If tomorrow something happens to these monuments, will anyone call for historically accurate rebuildings and repairs that respect the historical configurations and materials? If simple maintenance is a problem today, imagine how difficult rebuilding the monuments after a future earthquake might be. We thus need to consider seismic strengthening as a key feature in any comprehensive conservation scheme and preservation planning.

Current conservation practices in the Kathmandu Valley are typically limited to repair work or in some cases to the restoration structures, often by introducing modern materials. Even though there are numerous opportunities to improve structural quality or introduce reinforcements during these processes, thus far seismic strengthening is not a norm, nor do preservation guidelines in Nepal encourage it.

Considering the Nepal's location in a high-risk seismic zone (zone #5), the development of sensitive and effective strengthening measures for the retrofitting of the historic buildings and monuments is an urgent matter. Some protective work has been done, but until now no one has seriously taken up the challenge of reinforcing the Nepalese pagoda temples against the next earthquake, one which is sure to come.

This presentation is a work-in-progress report from Kathmandu about our international effort to design seismic retrofitting for three of Nepal's most prominent pagoda temples. These three temples stand at the entrance to the Kathmandu Royal Palace Complex and date originally to the 16th, 17th, and 18th centuries respectively. Our research has revealed that all of them suffered major damage in the last great earthquake of 1934. Given the specific construction history of each building - past rebuilding, intact materials, general configuration, etc. - we may develop diverse approaches for each of the design solutions.

We do not have all the answers yet, but we know which questions to ask:

1. Are these monuments going to fall in next earthquake?
2. What performance is our goal?
3. What structural analysis can be made?
4. How effective our past interventions? How can we improve them?
5. What information is still lacking to analyze improvements?

LEARNING FROM 1934 EARTHQUAKE; TYPE OF DAMAGES

Analyzing the 1934 earthquake photos, many monuments were not rebuilt and often those rebuilt were erected in unhistorical configurations with reduced details. Given the vast number of monuments destroyed by the quake, it is certainly understandable that only a portion was rebuilt however the architectural loss to the Valley continues to be felt today. As no photographic documentation of the earlier 1833 quake exists, we cannot imagine how much was lost and in what ways the cityscape changed configuration.

From the various photographs taken after the 1934 quake, we can observe different types of architectural damage. Certainly after such a huge earthquake damage, it was not possible to photograph each and every monument, however enough historical photographs of the major monuments were taken, thankfully, which explain the basic types of damage. This photographic evidence leads us to consider certain possibilities for taking future protective measures.

***Illustration. no. 1*. Kathmandu Darbar WHS. 1934 earthquake damage.**
Three tiered Narayan Temple with timber arcade on the lower level (left) completely collapsed up to the plinth; Jagannath Temple (2nd from left) partially damaged on the upper roof and wall on the ground level bulging outwards, this temple was completely dismantled and rebuilt; Indrapura Temple (3rd from left), upper tower completely collapsed and several cracks on the ground floor wall; Degu Taleju Temple (4th from left) and Vamsagopal Temple (right), only upper tower collapsed. Photo courtesy: Jharendra SJB Rana.

Partial damages

Monuments that escaped major damage often still suffered the collapse of their upper roof. The top tower of the temple or timber gallery or a timber overhang inclined windows on the upper level are all examples of building sections that typically collapsed. The top tower of the temple was always built above the timber beam, which does not have vertical continuity, so when the earthquake struck, the top tower most probably tipped over from the beam.

***Illustration. no. 2*. Nytapola (five tiered) Temple, Bhaktapur.**
On this temple only upper most roof collapsed, due to its taller overall proportion, which increases risk over smaller buildings. Thus perhaps buildings with high plinths are safer. Huge plinth might act as a shock absorber (?). There are several examples of temples surviving intact with the huge plinth. Photo courtesy: Jharendra SJB Rana.

***Illustration. no. 3*. 55 Windows Palace, Bhaktapur Darbar WHS.**
Photo before and after earthquake of Bhaktapur Royal Square. Most probably the upper level of the palace (2nd from left) was not able to hold the heavy load from the roof structure because here in this Palace, overhanging windows supported the massive roof structure. All three of the pagoda temples in the center completely collapsed and two stone temples (3rd from left and on the right) partially collapsed. Photo courtesy: Ganesh Photo Lab.

Complete collapse

The buildings that collapsed completely often had a timber arcade gallery on the ground level. But it is not true in all cases. In fact, we can not say there were typical damages to particular types of the buildings.

Illustration. no. 4. Degu Taleju Temple, Patan Darbar WHS.
Top: This large building with huge wall thickness collapsed completely. Even a thick wall structure was not able to hold the upper massive structure in this temple. Photo courtesy: Jharendra SJB Rana. Bottom: Contemporary view after reconstruction.

ANALYSIS OF TYPICAL WEAKNESS OF THE HISTORIC STRUCTURE

Before any intervention, it is critical to find the problems or weaknesses of the existing historic construction technique. From our research on the old buildings over last ten years and documentation from 1934 earthquake, we observe following:

1. Wall structure was always built in mud mortar with three layers. Outer and inner face layers were not well connected with the middle core wall. Normally the middle core was filled with rubbles and mud, which make wall very poor to hold the heavy load from the main structure. The quality of the bricks was always good on the exterior surface, but normally for interior walls inferior bricks were used. In many places, fired bricks were used only for the exterior while for interior and middle fill, simply sun-dried bricks and rubbles were used.

Illustration. no. 5. A detail section of three-layered wall structure in traditional buildings.

2. Lack of vertical structural continuity is created by the upper temple levels resting on the timber beams rather than directly on the wall structure below. The beam, with upper temple level and wall structure below, thus lacks any rigid continuity.

Illustration. no. 6. Section of typical temple structure.
The upper most tower rests above the two principal and two secondary timber beams.

3. A timber arcade, or ambulatory, at the base level (a variation of the pagoda type temple) creates looseness with the timber columns, which hold the huge wall and roof structure above. Timber columns on the base level stand on the base stone with a small pin inserted on the stone base, which means no rigid connection either vertically or horizontally. The top of the timber column's pin goes through the beam and again the heavy wall just sits above the timber beam. In the worst case found, this whole structure rests on the column only.

Illustration. no. 7. Kwalkhu Sattal (resthouse), Patan.
Whole upper front masonry wall structure rests on the timber arcade structure.

4. A huge overhanging roof structure with tremendous load supported by the struts is another weak point of the temple structure. Diagonal rafters sits on the wall plate above the wall and the outer part sits on the purlin, supported by the couple of timber pegs. The only rigid connection is eaves board at the edge, which are not quite strong to absorb heavy tremor and with no vertical rigidity, sit loosely.

Illustration no. 8. Detail of the temple roof overhang.
All the rafters are giving force to the purlin, which is supported by struts, and does not have rigid connection in between struts with purlin and main wall of the temple.

5. Except these major structural defects, there are still many small details that lack rigid connections, such as connection in between the timber members, historical timber joineries, etc.

Many technologies were developed for modern steel and reinforced concrete construction, which can be expected to resist earthquake tremors without threatening lives. However, research or technology has not been developed yet to enhance the resistance of historic buildings to tremors, at least not in Nepal. As well, no research has been carried out on traditional construction technology and materials.

OVERVIEW OF 10 YEARS RESEARCH / SEISMIC STRATEGY

No one has made any kind of research or calculation of the loads or bearing capacity of historic structure for reinforcement. Normally, most of the conservation projects are done in a very simple way, just repairs as the building used to be, or reconstruction with modern materials without considering seismic effects. UNESCO project Hanuman Dhoka Restoration Project and German project Bhaktapur Development Project in early 70s are the first two major foreign projects in Nepal to have established as the norm reinforced cement concrete (r.c.c.) ring beam. After that, it became as a restoration standard in Nepal to insert r.c.c. ring beams in restoration projects.

Illustration. no. 9. Seismic characteristics of the pagoda temple.

After considering the seismic characteristics of the pagoda temple, we introduced many kinds of small-scale reinforcements in various places in the historic buildings. However, all of these solutions were not made with load bearing calculation, but rather by feeling while working closely with traditional buildings. As we understand from speaking with several structural engineers, it is much more difficult to make perfect calculations for historic buildings as it is modern cement concrete structures. This is because of the three layered loose wall structure, heavy load from the upper tower, huge plinth base (which to date nobody has open to learn more about the details) etc. And no guidelines or even strategies exist for seismic retrofitting of historical buildings in Nepal. Here is a review of reinforcements, which we have employed in our past projects these last 10 years in co-ordination with local engineers and volunteer earthquake engineers from United States.

Illustration. no. 10. Section of typical temple showing reinforcement/ seismic improvement areas.

Kathmandu Royal Palace is the first project in Nepal that has allowed for involvement of world-class seismic experts to make the necessary analysis and recommend protective measures for historic buildings. Unfortunately, no such technicians or seismic engineer in work Nepal, specializing in seismic retrofitting for historic buildings. For the first time, two leading seismic experts of the world to work on our three temples for two weeks: Robert Silman, a New York based structural engineer and Randolph Langenbach, an architect and seismic specialist. We reviewed all the retrofittings and reinforcements we had done in past 10 years. All of these were small scale, however this time we think that the Royal Palace needs something which can reinforce on the larger scale. The smaller interventions help, but more intervention is urgently needed.

Before reinforcing the building we should consider what is the goal? Is it to reduce risk and of what? What are the performance criteria – a reduction in loss of life, to avoid the collapse, damage, and cracks? So many goals came up during our discussions among experts with different vision that we are led to ask the question, are we ready to sacrifice some of the historic configurations for the realization of other important goals?

Key alternatives for the conservation designer include:

1. Rebuilding historical structures in modern or traditional materials to achieve structural improvements
2. Following more conservative schemes to maintain historical structure while adding new additional reinforcements, though this is again the choice of modern versus historical materials
3. Rebuilding historic structure in modern or traditional material with new unhistorical configuration to achieve seismic effects:

   - Such as with an upper tower resting above the timber beam transferring the huge load from the tower to the beam, it is possible to reduce the load by reducing the wall thickness of the tower.

   - Roof load is one of the weak parts in the traditional buildings with huge mud bed beneath the roof tiles, supported with timber carved struts. It is also possible to reduce weight by reducing the mud thickness on the interior and still keep them historic from the exterior.

   - Our traditional architecture is mainly decorated from exterior while the interior is normally not open to the visitor. We are therefore ready if necessary to add layers from inside.

These are philosophical questions for ongoing discussions and debates, even when the changes do not alter the historic form of the monuments and no untrained eye would notice.

Meanwhile, for any calculations to reinforce against the sure-to-come earthquake, the collection of much more data is necessary. Properly designed seismic improvements to the historic buildings cannot be made without such scientific research. As the global value of historic buildings is much greater than that of new construction, increases in scientifically correct reinforcement to these historic structures should be a high priority. The first major challenge is to assess and improve the strength of historical materials for calculation. There is no data available on liquefaction to categorize soil conditions. No one thus far has attempted to test the strength of mud mortar, even though it is commonly used in the historic buildings. As for the foundation and massive plinth, these yield even more mysteries to uncover.

For the first time in Nepal, we are undertaking a comprehensive program to reinforce three temples in the Kathmandu Royal Square. We feel now, after working ten years in this field, that to only do repair or small-scale reinforcement is not sufficient to keep these vulnerable but extraordinary masterpieces from next earthquake or other hazards. More technical solutions carried out in the most scientific way are necessary, after which we would feel much more secure than we do today. This innovative work will be the model for future restorations for other monuments, here and elsewhere in the region. We are therefore not only designing with these three temples in mind but also looking to identify general techniques because so many buildings we come across are similar. Our efforts at the Kathmandu Royal Square will surely help us to design other structures as well.

Joining us in this project, Robert Silman is designing a 3D-computer model to test earthquake effects in different directions, thus taking our work to a new level. Where we have applied our basic theory on small-scale interventions, which has meant mainly tying together timber structure and link to the wall, results are good, but Silman correctly argues these interventions still needs some larger scale work. Following our r.c.c. ring beam practice, we experimented with several other retrofittings, such as timber ring beam, back up frame structure, steel beams etc. This two-week visit by the two seismic experts greatly enhanced our outlook on the matter and took our work to the next level of protective architectural science. The biggest jump was made in our plans to reinforce foundations, which up to date had not been introduced in Nepal, except at Chyaslin Mandap of Bhaktapur, though even there it was not retrofitting reconstruction at this sophisticated level.

We can now summarize this approach or working method:

1. To identify the performance criteria - should the goal of the retrofitting be protection against loss of life, collapse, substantial damage, and /or minor damage such as cracks?
2. To identify the structurally weak areas of the pagoda typology and traditional building technology
3. Examination of the role of modern technology in relation to the historical. Specifically, how much historic fabric and/or configuration should be sacrificed in order to improve earthquake performance?

We do not have the perfect answer for everything, but something we can answer from previous questions:

1. Are monuments in the Valley going to fall in next earthquake?
   Looking at the three temples in Kathmandu Royal Square, Robert Silman is certain as they stand now they will fall in next earthquake (similar to 1934 earthquake).
2. What performance is our goal?
   Collapse, damage or minor cracks. Because we want to maximally preserve the historic fabric and as not many people live in the temple, some damage would be acceptable. In Jagannath Temple, in 1934, there was huge damage, but not collapse, which gives us something relevant to study and document before reconstruction.
3. What structural analysis can be made?
   Load path analysis, Shear load analysis, Computer modeling.
4. How effective are our past interventions? How can we improve them?
   They obviously help in small earthquakes, but for larger quakes we need interventions in the foundations.
5. What do we still not know in order to fully analyze and make improvements?
   With better knowledge of mud mortar, detail of liquefaction, etc. we will be able to design seismic improvement more accurately.