Structural Analysis of Historic Construction – D'Ayala & Fodde (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-46872-5

Structural assessment of earthen walls and techniques for onsite consolidation and conservation

Sandeep Sikka
Superstructures (Architects + Engineers), New York, USA

ABSTRACT: The areas of Spiti and Kinnaur district in the Western Himalayan region have experienced some significantly strong earthquakes in the last few decades. Recent seismic tremors have caused some serious structural damage to the buildings in the region especially to the un-reinforced historic adobe structures. The deformation and bulges resulted in the adobe structures, as a resistance to the seismic vibrations, are the vulnerable areas, most likely to collapse in an event of any future horizontal force. These historic structures, which were originally designed for arid climate, are now facing problem with increased precipitation and regular rainfall for the last few years. The paper puts forward various repair techniques carried out on the site to consolidate load-bearing walls with cracks and research data on upgraded component used for the protection or repair work for these building.

1 INTRODUCTION

The Spiti and Kinnaur region in the Northern Indian State of Himachal Pradesh has some remarkable ancient Buddhist temples made of Adobe. Constructed between the 10th and 15th century AD [1], these temples preserve some of the earliest artistic heritage of the Tibetan Buddhism in the form of mural paintings, polychromed clay sculptures and decorative wooden ceiling members. This arid region in the Western Himalayas have witnessed a gradual development of Buddhist temples architecture from simple single storey buildings constructed on a relatively flat land to a complex maze of multistory fortress on the mountain top, over a period of 500 years. Standing on a highly seismic zone and having survived for several centuries the buildings are undoubtedly a living evidence of highly engineered structures. These historically well-crafted temples structures originally designed for arid climates today lie susceptible to an annual precipitation of 200 mm–400 mm due to the globally changing climatic patterns. Recent seismic tremors have caused some serious structural damage to these un-reinforced historic adobe structures buildings. The deformation, bulges and cracks in the load bearing adobe wall, as a resistance to the seismic vibrations and moisture, are the vulnerable areas, most likely to collapse in an event of any future movement in the building. A detailed assessment of the condition of structures after the recent earthquakes with a methodology and results of much needed on-site research on reinforcement of structural components, followed by techniques and methods of repairs which was and can be carried out to stabilize and repair the two load bearing temple walls at the Nako temple complex in Kinnaur, have been discussed as a case study in his paper.

Figure 1. Nako Temple Complex, Himachal Pradesh, India.

2 NAKO TEMPLE COMPLEX

The great translator *Lotsawa Rinchen-Zangpo* (958–1055 A.D.) reportedly founded the historic Buddhist complex at Nako in the Northern Indian state of Himachal Pradesh. The Buddhist temple complex at Nako is an arrangement of four dedicated unicellular temples along a common courtyard. The site of the temple complex gradually slopes from the east to the north clockwise in the four directions with the northern edge lying at a difference of about 3 meters from the common courtyard of the complex. The

four temples in elevation rise to a height of about 5 to 6 meters from their respective entrance levels on the exterior. The two lower temples *Lotsawa Lhakhang* dedicated to the great translator *Rinchen-bzangpo* and *Karjung Lhakhang* 'the white temple' face east lie on a relatively flat ground are mentioned in this paper as above ground structures. The other two temple *Gongma Lhakhang* and the *Gya-pag-pai Lhakhang* facing west are mentioned as below ground or semi-subterranean structures because the ground level outside these temples is much higher than the interior floor level. This historic temple complex which houses invaluable artwork, murals, polychrome clay sculptures and decorative wooden ceilings, survived for more than 800 years, is showing alarming signs of deterioration.

Nako Temple Complex was nominated and included in the 100 most endangered sites of the world by WMF in 2001. Since then efforts have been made every year under Nako Preservation Project [2, 3] to protect and stabilize the structure and its artwork.

In the year 2006 and 2007 Institute of Conservation and Restoration, University of Applied Arts, Vienna, Austria carried out a conservation and research campaign [4] at the temple complex with limited funds from the University and Austrian Development Agency (ADA). The conservation project team mostly focused on the following tasks.

2.1 *Art work conservation*

Task 1: The restoration of damaged clay sculptures inside the *Lotsawa Lhakhang*,
Task 2: Stabilization and cleaning of wall paintings
Task 3: Stabilization and cleaning decorative wooden ceiling panels inside the *Gongma Lhakhang*.

2.2 *Structural conservation*

Task 4: Structural assessment and stabilization of load bearing wall at *Gya-pag-pai Lhakhang* and *Karjung Lhakhang*.

This paper is concerned with the structural issues and describes the research and repairs for structural conservation work carried out on the two temples (*Gya-pag-pai Lhakhang* – Semi subterranean structure and *Karjung Lhakhang* – Above ground structure) to accomplish Task 4.

3 ARCHITECTURE OF BUDDHIST TEMPLE COMPLEX AT NAKO: MATERIALS AND METHOD OF CONSTRUCTION

The design of Buddhist temples are simple, rectangular geometric spaces with carefully designed structural members unveil an outcome of years of trials, wisdom and extreme climatic conditions and natural disasters. The walls of these historic structures are made of (Adobe) a sun-dried large sized mud brick laid in mud mortar with the foundation in rubble stone masonry, generally rests on a stable solid ground[1]. The thickness of the walls varies from 2½ feet to about three feet. Vertical measurements shows that sometimes the outer faces of the walls are slanted so that the wall thickness is wider at the base and gradually tapers to the top, providing extra stability to these tall and flexible structures. Due to the cold climatic conditions for most time of the year, the openings in the walls of these temples are minimum possible and contribute to less than 5% of the total wall surface in a rectangular space and are located at the center of the wall. Besides the wooden doorframes such punctures in the walls are reinforced with thick vertical and horizontal tensile wooden members connected to each other with flexible joint. Series of wooden lintels laid next to each other along the thickness of the walls are anchored deep and extend into the masonry on both sides of the openings like additional horizontal tie members. The load bearing walls of the temples are reinforced with a wooden framework of horizontal wall ties, with a cross section of 6 to 8″ in width and 4 to 5″ in height, as ring beams around the building, installed externally and internally flushed with the surface of the wall. The ring beams tie the entire structure together with each beam running at a distance of approximately 1½ or 2 meters to the other. The exterior horizontal wall ties were joined to each other at the corner externally with wooden vertical ties, now missing in most of the temples. The arrangement thus prevents any outward movement during any seismic vibration and these wall ties, along with the wooden lintels disrupt structural cracks that could otherwise extend the full height of the wall eventually causing total collapse. Strength of the adobe and the mortar joints vary all along the wall hence differential loading. The horizontal ties therefore redistribute the load evenly through out the wall. In addition to these horizontal members, the load-bearing walls of the temples in Nako are reinforced at the corners with buttresses at the corners. These buttresses were added later to support the masonry, after the building was struck by an earthquake separation of corner walls. The buttresses are random rubble stones stacked one over the other against the corners of the building forming a pyramid. The roofs of the temples are flat and are made of mud laid in various layers and compacted. About 7 inches of compacted mud rest on 2 inches thick rectangular wooden panels or a mesh of willow twigs, with a layer of local shrubs or birch bark sandwiched between the two for waterproofing. These

[1] Trial holes dug in the past next to the outer wall revealed that the foundations generally rests on either rocky outcrops or solid ground.

are in turn supported over wooden rafters and beams, which are further supported directly on load bearing mud walls and wooden columns.

4 STRUCTURAL ASSESSMENT

4.1 *Methodology of diagnosis*

With budget limitations, inaccessibility to testing laboratory, investigation equipments and limited time frame, the investigation methods selected for the structural assessment of two temples were primarily:

- Visual inspection
- Study of previous data on documentation of wall sections, strength and properties of masonry components from published and unpublished reports [2, 3, 5, 6, 8]
- Load calculation through study models.

Figure 2. Horizontal crack in the load bearing wall of the semi-subterranean structure.

4.2 *Semi-subterranean structure*

The temple of *Gya-Pag-Pai*, which is, mentioned as semi-subterranean structures because the ground level outside the building is higher than the inner floor level was affected the most and has been under enormous structural stress after the earthquake of 1975. A detailed documentation of the walls in the past [3, 4] has revealed that there is tremendous movement in the upper portion of the load bearing walls. The lateral outwards horizontal movements in walls have resulted in large-scale bulges and cracks in the masonry. Increased moisture due to recent changes in the climate has further caused enormous seepage into the interiors and has also disturbed the structural integrity of the temples. The roof of *Gya-Pag-Pai* due to the shortage of funds has been covered temporarily, by the locals, with corrugated galvanized iron sheets. The focus of the structural work, as mentioned in the task 4, was to assess and address immediate threat to the structures. Survey of temple walls and measurement of moisture inside the masonry through conductivity meter revealed that there is large-scale ingress of water and moisture from the surrounding ground.

Due to inadequate length of the wooden spouts added recently on the adjacent building's roof and in absence of any proper drainage facility from the roof of the *Gya-Pag-Pai*, the rainwater and water from the melting snow drain next to the load bearing walls at the rear of the temple. Consequently the water seeps into the building walls and foundation causing enormous damage to the water-soluble un-reinforced masonry. In addition to this the site of the temple complex slopes down along the east-west direction and consequently the excess water draining from the village on the higher level towards the rear of the temple contributes excessive moisture to the ground adjacent to the load-bearing wall. As a result the soil outside the building swells after gaining moisture, which exerts horizontal pressure on the load bearing walls. The rear wall of the *Gya-Pag-Pai Lhakhang* is unable to resist the horizontal shear stress along the floor level outside, resulting in a major horizontal structural crack. (See figure 2).

Due to inadequate drainage the excessive moisture accumulated outside, gradually seeps into the wall causing serious damage to the masonry, plaster and painted surface inside. Problems of salts and other agents of chemical, environmental and biological decay followed water seepage causing severe damage to the 800-year-old structure. The compacted mud flooring of this semi subterranean structure was replaced with impermeable cement concrete flooring in the year 1996 AD, has aggravated the problem of moisture many times. The Cement concrete flooring prevents the effective evaporation of water rising from the ground that eventually evaporates from the walls. Constant drying and wetting of the painted area causes deterioration and loss of binding strength. The interior plaster decomposed into a powdery mass, has started leaving the surface, revealing the masonry below. There is also a drastic change in the humidity and level of moisture content in the walls after the insertion of cement flooring that have not only affected the strength of the plaster but has also affected the strength of the mud blocks. Another intervention made recently to the structure was cladding of the base of porous earthen walls with impermeable stone slabs on the exterior, with intension to avoid basal erosion from water and wind, resulted in accumulation of moisture inside the masonry. The moist adobe walls with horizontal structural cracks and deteriorated base are not only vulnerable to any seismic vibrations but are also a major threat to human life and artwork stored inside the building in an event of collapse.

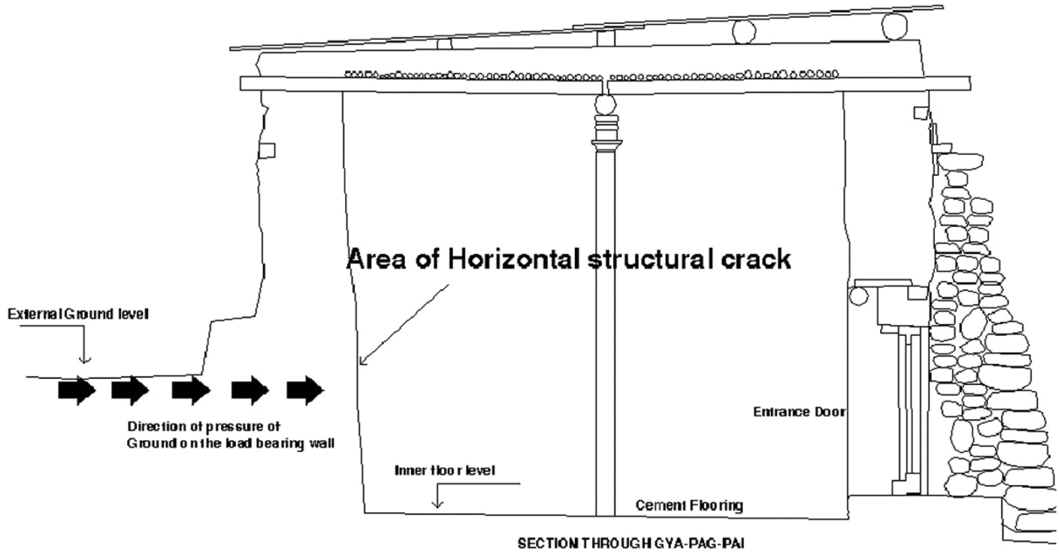

Figure 3. Thrust created by the expanding ground due to moisture gain next to the wall results in a horizontal crack.

4.3 *Above ground structures*

Of all the temples in Nako the condition of above Ground Temple Structure *Karjung Lhakhang* is the worst. During the earthquake of 1975AD, the walls of the Karjung have developed major, vertical and diagonal structural cracks on all sides of the building resulting in overall destabilization of the structure.

Outward movement in the walls due to excessive load from the roof and thrust due to seismic vibrations, have caused separation at the corners, resulting in vertical cracks. This above ground structure is temporarily covered with galvanized iron sheet above the damaged roof with no proper gutters, leader or roof drainage system to canalize the water. Consequently water from rain and melting snow draining along the slope of the sheets, eventually runs along the exterior surface of the wall eroding the plaster and the masonry forming large crevasses. These crevasses thus formed are the most vulnerable areas in an event if a seismic vibration or building movement in the future. Diagnostic investigation through visual inspection revealed that is large-scale damage to the upper portion of the outer Wythe of wall partly due to the earthquake and partly due to water seepage that had been repaired by the local craftsmen with big stone pieces. The mud blocks at the upper portion of the wall have deteriorated due to the ingress of water, resulting in the loss of strength. These mud blocks below are unable to take the load of big stones resulting in an outward bulge. These areas have now become major threat to the rest of the wall below and over all stability of the structure.

5 MITIGATION AND REMEDIAL MEASURES

On-site visual inspection of the load-bearing wall of the two 12th-century Buddhist temples at Nako reveled some intersecting conditions, which required judicious research for development of components for repairs to avoid further deterioration of masonry and eventual collapse.

5.1 *Methodology for development of remedial measures*

The methodology of repairing semi-subterranean and above ground structures requires detail understanding of its materials, its chemical and physical characteristic, their present condition and future behaviour and vulnerability to during any seismic event, unforeseen loading and exposure to moisture. Due to remoteness of the temple complex, limited funds and inaccessibility to lab and issue of sustainability of repairs, mentioned previously, it was decided to find locally available materials for repairs. Another reason for choosing local materials was to maintain the character of the building.

5.1.1 *Experimental program for improvement of Adobe block*

For the production of adobe for the repair of the external Wythe of the structural walls, it is essential to study their behaviour and strength against the increased load and the changing climatic conditions. To improve the strength of the adobe and their resistance to water, it

Figure 4. The samples were tested for their Flexural Strength through an apparatus designed specifically for testing the adobe in the field; using compressed earth block units of 7 kg.

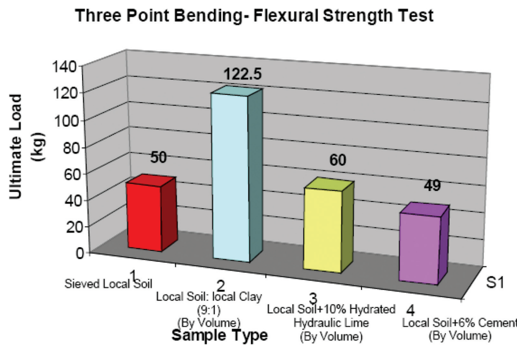

Figure 5. Results of strength test conducted on four samples of adobe on site.

was decided to conduct an experiment with various samples of adobe made with the locally available soil with additives and stabilizers to impart extra strength and resistance against moisture.

5.1.2 *On-site strength test*

An apparatus designed specifically for measuring the strength of the adobe in the field was used for determining the 3-point flexural strength (See figure 4). The 3-point loading was applied using series of compressed earth blocks each weighing 7Kg. The particle size analysis (see figure 7) of the local soil and clay indicated that the percentage of sand content in the soil was far more than the required quantity. Therefore to increase the strength it is essential to increase the quantity of the binder in appropriate proportion. The mix thus prepared with various binders like cement, lime and locally available clay for extra strength were then put to test. Four kinds of adobe samples were then prepared with relatively dry mixes, wet compacted inside the moulds and were left to dry for four weeks.

5.1.2.1 Results and discussion

It was observed that the addition of 10% local clay or 10% lime as a binder significantly increases the strength of the adobe. Further tests with varied proportion of clay and lime can be tested before the manufacture of adobe for conservation work. The stabilizers and additives, which perform well for increasing the strength, may or may not perform well against water erosion. To generate a solution for the stabilization of the adobe with appropriate stabilizing materials against the increased precipitation, a scientific study of the samples of the various adobe formulated from the local soil and clay with different stabilizers were tested on site for their resistance against moisture. These blocks were then tested on site for their performance against general weather conditions and water. The final mix design should also impart strength, as they have to take the load of the roof at the same time.

Table 1. Composition and weight of sample adobe blocks.

Sample no.	Composition of blocks	Wt. (Kg.)
S1	Sieved local soil	23
SC	Sieved local soil mixed with 10% local Clay (9:1)	23
SL	10% Hydrated Hydraulic Lime and sieved local soil	24
SCC	6% Cement and local sieved soil (compressed)	7

5.1.3 *On site erosion test*

The water through a spray gun of pressure 50 K pa was thrown directly at the centre of each sample at a distance of 600 mm.

Each sample was exposed to equal water pressure for about 180 seconds. It was studied that the spray jet used in this test has flow rates much higher than the combined effect of rain and wind documented in this region. The test indicates the resistance of adobe to the direct effects of fine spray of water. The erosion was carefully measured perpendicular from the original surface to the eroded pit with a measuring scale.

5.1.3.1 Results and discussion

Addition of local clay 10% by volume increases the resistance of adobe against water erosion. Addition of chopped straw also significantly increases the cohesion and resistance to water.

5.2 *Experimental program for development of stabilized sacrificial external wall plaster*

To generate a solution for the stabilization of the locally available soil with appropriate stabilizing materials against the changing climatic conditions, a scientific study and technical examination was carried out at Nako of the samples of the various plasters mixes formulated from the local soil and clay with different

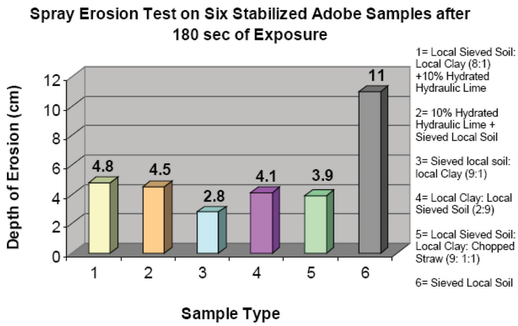

Figure 6. Result of spray erosion test conducted on six stabilized adobe samples.

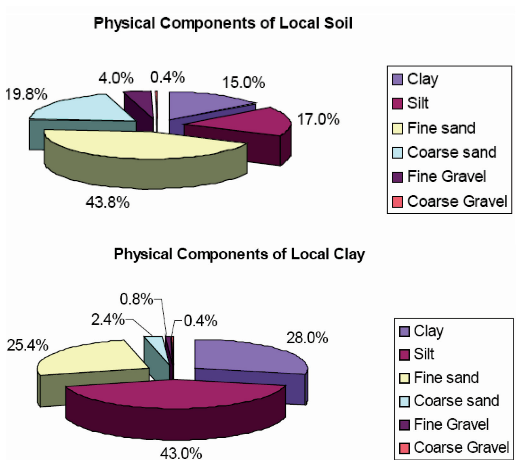

Figure 7. Particle size analysis of local soil and local clay.

stabilizers. It was also studied that the additives for stabilization of plaster cause no adverse effects on the historic structure as they render a coat of water proofing layer externally and at the same time keep the walls porous.

These mixes were then tested on site for their performance against general weather conditions and water. The mix finally designed should also impart strength by consolidation to the otherwise fragile surface of the historic monasteries.

To determine the exact mix of the stabilizer the first step undertaken was to understand the composition of the local soil and clay and their behaviour.

The data obtained from the laboratory analysis of the local soil samples helped in understanding the physical nature and behaviour of the existing soil and the local clay in the Nako Temple Complex, Kinnaur. The following results thus obtained can be read.

The plasticity index indicated a low cohesive strength when plotted against the quantity of clay present in the soil sample. To increase the binding properties and inter-particular binding strength of the local soil it is required that their elementary properties are modified so that their particles remain firmly united and unaffected by moisture variation. Addition of lime will certainly change its chemical properties in which the clay of the soil reacts with lime to form a relatively strong binder. This hypothesis was then tested on site at Nako temple complex with other locally available stabilizers into different plaster samples. The samples were then monitored for two weeks and finally tested and documented for their durability against water pressure.

5.2.1 *Composition and application of plaster samples*

It was decided that the plaster samples should be applied and tested on the ancillary structure of the Temple Complex before any trials with the historic fabric.

The wall surface selected for application was even, completely dry and faced no problem of seepage or dampness. The surface received adequate sunlight, natural rain and wind. It was also exposed to the temperature variations throughout the day. The first step towards surface preparation for the application of the plaster included scraping with a wire brush to create undulations on the surface, so that the new plaster can adhere to the wall. The following step involved wetting of the wall surface properly with water spray at a very low pressure before application. This was done to avoid suction of water into the wall from the new plaster mix. The various plaster mixes were then prepared in a mixing tray with a trowel taking into consideration the percentage of water the minimum of which should be able to stick to trowel and spread evenly on the wall surface. Fifteen samples of the plaster mixes (<6 mm thick) with different local materials were then applied each on Feet Square of area of the wall. These fifteen plaster samples [7] were monitored for two weeks and then tried against the wet erosion test. The water through a spray gun of pressure 50 Kpa was thrown directly at the centre of each sample at a distance of 600 mm. After starting from the bottommost plaster sample; each sample was exposed to equal water pressure. It was observed that the spray jet used in this test has flow rates much higher than the rain obtained in this region. The process of erosion was carefully documented for the failure of plaster samples against continuous spray for three minutes. It was observed that the finer particles (comprising the soil) washed out of the plaster mixes creating initial pits on the surface and finally resulting in absolute failure. The plaster samples with lime as a binder and a stabilizer could resist water pressure for a longer time. Permeability of the water into the plaster was also tested on site, simply by digging the wet plaster and measuring

Figure 8. Fifteen plaster samples tested on-site for water erosion.

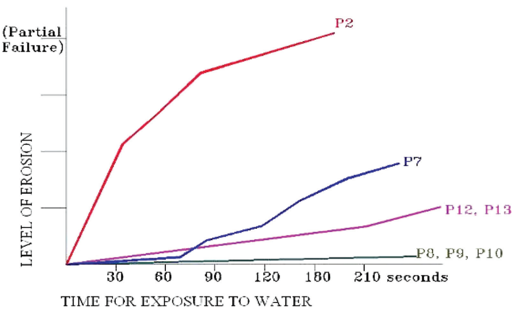

Figure 9. Results of water spray erosion test.

the depth of water penetration till the substrate. It was found that the plaster mixes stabilized with lime had a penetration of water <6 mm into the surface.

5.2.2 *Results and discussion*

The results obtained from the above mentioned tests could be interpolated and studied in the following graph. The intention of the exercise was to generate a sustainable solution against the changing climatic conditions that can be used as a sacrificial coat for structural adobe walls.

The selected mixes as shown in the graph (P8, P9, P10) after the tests are not only stable against moisture but at the same time porous enough to facilitate evaporation of moisture which is trapped behind so that the internal painted surface on the other side is not affected. The strategies thus derived after interpretation of the above results for the surface protection of these historic earth structures against the changing climate are not only practical and economical, but at the same time address the re-strengthening of thousand years old local traditions.

Figure 10. Eight feet deep drain dug at a distance of 2 meter from the walls of semi subterranean structures.

5.3 *Structural stabilization of load bearing wall for semi subterranean structures*

With budgetary constrains it was not possible to consolidate the masonry walls and replace appropriate roof from *Gya-pag-pai* therefore it was decided to address the structural and water seepage problems in mentioned in task 4, by providing appropriate drainage system both for the existing roofs and for the surrounding ground. With the help of the local craftsmen and the village community who shared their experience, opinion and labour happily with the conservators, it was possible to design a state of the art drainage system for the two historic structures. The drainage system, which was similar to a French drain commonly, used for effective drainage of historic buildings in most part of the world was designed and detailed carefully with local materials and technology. A detailed sketch explaining the section of the drainage is illustrated below (Fig. 14).

A drain 2.5 meters wide placed exactly 1.5 meters away from the buildings was dug along the load bearing walls of the two semi-subterranean temples.

The depth of the drain was kept 8 feet (about 2.4 meters) that was decided according to the internal floor level. The bottom surface of the drain was kept at least 2' below the internal floor level of the temples so that all the water is drained out without any possible danger of seepage into the surrounding area.

The perforated terra cotta pipe laid at the bottom of the drain is protected with steel bars laid across and

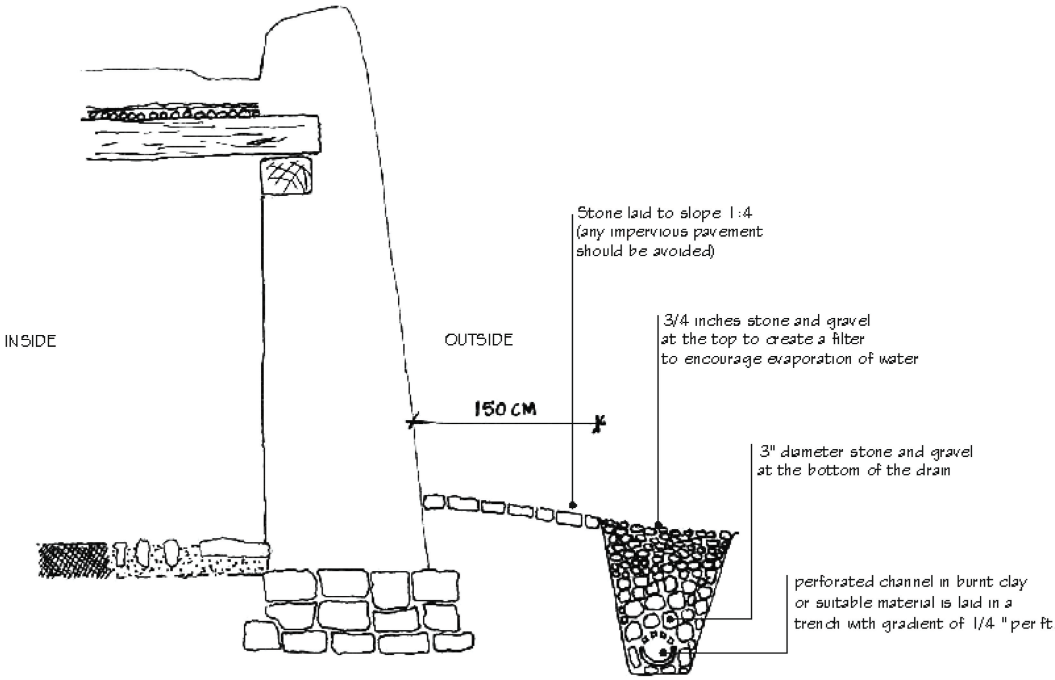

Figure 11. Perforated clay pipe laid at the bottom of the drain sloped away from the site.

above the pipe. The drain was then covered with stones of descending size till the ground level for effective evaporation. The drainage had outlet points for effective cleaning and the slope of the drain was designed as per levels of the surrounding site to effectively drain water away from the building complex. This state of the art inception of the drainage system was tested and monitored for a year for its effectiveness by checking the moisture levels in the ground outside the building and also inside the masonry. Repairs to the horizontal cracks will proceed as the moisture subsides.

5.4 *Stitching of diagonal and vertical cracks in above ground structures*

The cracks and crevasses developed in the*Karjung Lhakhang* are the areas of the potential weakness in the load bearing walls need to be repaired and stabilized to provide structural continuity. The crevasses are mostly along the cracks and in such case stitching would be a sympathetic alternative to strengthen and retain most of the original masonry.

Stitching adobe buildings have been developed, discussed and published before by many professionals. Techniques of stitching a crack in the load bearing wall with mural paintings on the inner face in a highly seismic zone is certainly a challenge and have not been tried or been discussed before.

As part of the research and development of a sustainable strategy for repair at Nako, it was decided to

Figure 12. The structural cracks have been raked and the masonry is reinforced again with thin slate tiles.

do an example as trial with local material and techniques that could be monitored for its effectiveness on the bases of its performance. Severely weather portion of the load-bearing wall at the rear of this above ground structure was selected for making repairs. The surface of the wall which is about 2′–6″ thick was chased to a depth of about 1′–3″ into the wall, with a pointed Slater Hammer about 10 to 20 cms on both side of the cracks on the weathered surface to form a space for resting the stitch material. Generally masons or conservators tend to widen the crack to effectively rest the repair material. The wider cracks require substantial material to hold on to the parent masonry to provide enough flexibility as well as a strong adhesion to react appropriately to any building movement.

Hence, widening of crack was avoided and the stitch material was inserted into the masonry by making small slits into the adobe blocks in zigzag manner alternately to bridge the crack to achieve extra strength.

Study of ancient adobe blocks at Nako temple complex indicate the use of varied size of course aggregates and slate stones to gain extra reinforcement and strength. Thin Slate tiles are locally available, lightweight and have been use extensively for the construction of traditional houses. It is well known, learnt and documented by several locals and professional in the Himalayan region that if the slates tiles are well laid horizontally in layers inside a masonry wall, performs well during an earthquake. According to the survey conducted in 2003 the stone masonry structures with such horizontal band of slate tiles were affected less during earthquakes of 1975 in the region as compared to similar stone masonry structures without such band. Slates tile and local fiber reinforced lime-stabilized mud-mortar as filler was therefore selected as stitch material for cracks. The tiles were laid into the slits horizontally and voids in-between were then filled with mortar. This was repeated up to the top of the crack. Addition of fibers in the mortar mix reduced shrinkage and created better cohesion. The stitched portion of the wall was then rendered with lime stabilized mud plaster discussed above. A stabilized soil with lime and jaggery grout previously tested in the lab for its performance was injected from the inner painted surface to fill up rest of the void along the remaining width of the wall.

5.5 *Removal and replacement of outer Wythe of wall*

With diminishing knowledge of traditional mud bricks and repair techniques and sudden earthquake of 1975 resulted in some serious interventions in terms of masonry repairs. Most of the upper courses of the masonry near the roof, externally, have been replaced with big stone blocks that have eventually detached or are budging outwards due to excessive load on the walls. Replacement of stone with improved adobe blocks, tested through onsite research, discussed above, will be used for structural repairs to the outer Wythe of the *Karjung Lhakhang's* load bearing wall.

Finally drain pipes and gutters were designed and installed at the roof level of all the temples. The corrugated sheets covering the roof were fitted with gutters molded with flat galvanized sheets. It is proposed to remove the cement flooring inside the temple to relive the masonry and flooring from trapped moisture.

6 CONCLUSION

There are no ready-made answers, no ideal material and no ideal solution to the complex problems these earth structures are facing. For sustainable repair and conservation of these historical construction there is a need to understand the structure, materials and causes of damage in order to employ the appropriate remediation. With limited budget, inaccessibility to laboratory and treatment materials and distance from the civilization, in the middle of the high Himalayan Mountains more than 3500 feet above sea level, it was essential to find locally available materials and develop sustainable repair and maintenance techniques to through on site research which can be carried out as an when required by the local craftsmen to stabilize 800 year old structures against further seismic vibrations and changing climate.

REFERENCES

1. Luczanits, C. 2004. Buddhist sculptures in clay. Early Western Himalayan Art, late 10th to early 13th centuries. Chicago: Serindia Publications.
2. Khosla, R. 2003–2005. Report on Nako Preservation Project, Phases-I, II, III and IV. RKDS: New Delhi (Unpublished).
3. http://athene.gis.univie.ac.at/project/nako
4. http://www.dieangewandte.at/konservierung/stories/story Reader$66
5. Sikka, S. 2003. Research report on Conservation of historic earthen structures in the Western Himalayas-Museum of archaeology and anthropology. University of Cambridge: England (Unpublished).
6. Sikka, S. 2002. Conservation of earth structures in the Western Himalayas- MA Dissertation Bournemouth University: England (Unpublished).
7. Sikka, S. 2003. A research on Stabilization of Plaster Samples for conservation of historic earthen structures in the Western Himalayas. Terra 2003, 9th international conference on the study and conservation of earthen architecture. Preprints Yazd.
8. Bogin, S. (2005). A technical study of the early Buddhist wall paintings at Nako, Himachal Pradesh, India. Zeitschrift für Kunsttechnologie und Konservierung. 19(2): 199–229.