Wangduephodrang Dzong Reconstruction Project – Aspects of cultural heritage and safety

By Andreas Galmarini, WaltGalmarini AG, Zürich and Nagtsho Dorji, Division for Conservation of Heritage Sites, Thimphu

Introduction

Wangdi Dzong was built in the 17th century by Zhabdrung Ngawang Namgyal and is situated at a strategically important intersection of the country’s main east-west axes with an important north-south axis. The Dzong’s position on the end of a ridge between the two rivers Punatsanchu and Danchu made it easy to defend and enabled a good view over the traffic on the axes. In the early days, the dzongpon of Wangdue Phodrang was the powerful ruler, after the dzongpons of Punakha and Thimphu.

Wangdi Dzong was an outstanding example of traditional Bhutanese building tradition and was accepted, together with the Dzongs of Punakha, Paro, Dagana and Trongsa for the tentative list of world heritage sites. The Dzong is composed of three courtyards in series with diminishing size. The total length is approximately 200m, the width of the largest courtyard 50m and the outer walls are up to 20m high. The main entrance is located in the first court yard that also hosts the county administration while the second and third are reserved for the clergy. The only free standing building within the Dzong structure is the Utse in the small third court yard. Most walls are made of traditional multi-leaved stone masonry with mud mortar, others of ekra and a few of rammed earth. In the roof structure, the floors and the partition walls wood dominates and the entire Dzong was covered with an extraordinarily beautiful shingle roof landscape.

Since its establishment, the Dzong has been extended, modified and repaired many times. It has also suffered major damage at more than one occasion. From historic documents, we know that the Dzong was repaired in 1837 after a fire and an earthquake in 1897. Tragically, the Dzong burned to the ground on 24 June 2012 following an electrical short circuit.
The Reconstruction Project
Immediately after the shocking loss, the debris was searched and surviving cultural assets salvaged. The ruins were documented and assessed for their stability. Unfortunately, the heat of the fire caused the stones of the wall surfaces towards the court yards to crack such that vast parts of the ruins had to be levelled.

The Division for Conservation of Heritage Sites (DCHS) under the Ministry of Home and Cultural Affairs spearheaded the documentation and the planning of the reconstruction. Financing was
secured through generous funding and sponsoring from His Majesty the King, the Government of India, and several other organisations and private persons. In 2014, a Steering Committee was constituted, Kinley Wangchuk was appointed as project director and the reconstruction work started.

Early on, DCHS realised the potential of this huge project to address the earthquake resilience of traditional Bhutanese structures – a known weak spot that has caused economical damage and loss of lives in the past. Therefore, in January 2015, DCHS organised a workshop on the subject with participation of local authorities and renowned international experts. Many of the fundamental concepts and approaches now under implementation were developed at this workshop. The workshop also led to the realisation that at the time there was not enough expert structural engineering capacity in the country to develop the specific interventions based on these concepts. The aim of developing interventions for Wangdi Dzong is therefore to make interventions applicable to Bhutanese traditional structures in general and to strengthen the capacity within DCHS in the field of structural engineering.

In mid 2016, the site management team has grown and up to 400 workers engaged in the reconstruction. The Kuenray at the far end of the Dong is the first part of the reconstruction to be completed. It was consecrated under the guidance of His Majesty the King on the 20. April 2016. The continued intensive interaction and collaboration of designers and site management has led to a good understanding of the challenges in different aspects, to a mutual trust and finally to the development and implementation of many innovative measures.
Challenges and Developments

Fire

Historically, fire has caused 80% of all major damages to Dzongs. The setting up of butter lamp houses outside of the main structures several years ago and the banning or at lease reducing of the number of butter lamps within the Dzongs has reduced this risk significantly. On the other hand the
electrification, often implemented or modified disregarding basic safety measures, is an increasing threat. The risk to the structure and its users can not only be reduced by reducing the potential fire possibilities but also by providing appropriate access for fire fighters / evacuation routes for users, by the installation of detection systems, fire fighting equipment and the provision of water on site and by structural measures delaying or restraining the spread of a fire. The Wangdi Dzong Reconstruction Project (WDRP) is fortunate to have Lars Mülli from the Gebäudeversicherung des Kantons Zürich, one of the brightest fire protection experts of Switzerland, as an advisor for these questions.

Multi-leaf walls
Structurally, the stone masonry walls, up to 3 m thick, form a major challenge. As the surface shall look nice the stones are neatly aligned. Handling and production processes result in a certain size of stone and in connection with the requirement for a nice surface to a rather uniform length of the stones measured from the wall face towards the inside. The volume between the two outer layers (leaves) of stones can be masoned more freely. This disposition leads to a weakness at the transition of the outer leaves to the inner one(s). Under extraordinary loadings such as under an earthquake, the weakness results in a separation of the wall into its leaves and often to a collapse of a leaf or the wall. As a countermeasure, we have developed a reinforced concrete element named “Fritz-Stone”. It consists of two heads that have the dimensions of a masonry stone connected by a thin central part holding them together. When used in the masonry, the Fritz-Stones run from face to face and connect the two outer leaves such that they cannot move apart at this point. The Fritz-Stones were first invented as a sketch, than calculated, verified and detailed in the office before they were produced on site in a test-series. The feedback from the site on the production, handling and implementation led to some modifications to the design before the Fritz-Stones as they now are used for the masonry were finalised.
Box effect

Another frequently observed failure type is the separations of the walls in their corners leading sometimes even to the falling out of an entire wall. This was addressed by the use of a double layer of soffit boards rotated with +/- 45° towards the joists, of nails and long screws to enable the floors to transfer loads from one wall to another. A similar system was already use some years ago for the Punakha Bazzam. In addition, a steel element connecting the floor to the walls called Wangdue Latch and a ladder beam for the horizontal transfer of loads in the plane of the walls were devised.

Utse

While some of the buildings are constructed using pure traditional methods others are fully engineered and some are constructed using elements such as the Fritz Stone but without specific engineering. One of the buildings fully engineered is the Utse located in the narrow third courtyard. The Utse was to be reconstructed with walls higher than the original one and an even higher roof. At the same time, the outer dimensions at its base had to be kept within the original footprint such that people can still pass around in the future. With these constraints, the measured described above alone were not yet sufficient to increase the earthquake resistance to an acceptable level. After considering different options, the design and construction of a base isolation was proposed. As this concept was a first not only for Bhutan in the entire region His Majesty personally was consulted and agreed to its implementation.

A base isolation typically consists of two foundations and a set of bearings. The upper foundation collects the forces from the structure above and leads them to the bearings where they are transferred to the lower foundation that distributes them again to the subsoil. In an earthquake the subsoil together with the lower raft moves while the upper foundation and the structure above moves significantly less which reduces the forces in the structure. Usually, the same bearings are used for the control of the horizontal movement and the transfer of the
vertical forces. In the case of the Utse this set-up was not suitable due to the enormous weight of the masonry walls that are 17 m high and up to 1.8 m thick at the base and 0.9 m at the top. Therefore, we separated the functions and designed two types of bearings: the first type is responsible to the transfer of the vertical loads and consists of two steel plates that are cast in the upper and lower foundation and a sliding surface with minimal friction (stainless steel on Teflon) in-between. The second type again has two steel plates but here, a stack of 8 sheets of polyurethane and 7 thin sheets of steel is glued in-between. Despite a design that reduced the complexity of steel work to a bare minimum the sourcing in India turned out to be unsuccessful. Luckily, two Swiss companies stepped in: Angst+Pfister AG supplied their polyurethane sheets for free and Tuchschmid AG took over the steel work to a discounted rate. Helvetas organised the transport.

PICTURE: Bearings and the site management team.

As the reinforced concrete works necessary for the foundation of the Utse were outside of the core competences of the WDRP workers, the project was supported by the Punatshangchu Hydropower Project Authority and the works were supervised by Fritz Baumgartner, a Swiss architect living in Bhutan for more than 25 years. In February 2016, all 18 bearings arrived on site in perfect condition and in May 2016 the foundation of the Utse was completed.

Materials/RiTS

It is known that the seismicity in Bhutan has not yet been investigated and analysed to an extent that trustworthy design values for structural engineering are available. The work with the structural design of Wangdi Dzong has furthermore revealed severe deficiencies in the knowledge of the technical properties of the traditional building materials. Neither rammed earth nor the stone masonry with mud mortar or the timber have been tested sufficiently to derive engineering properties and there are no suitable laboratories in the country to do so. Therefore, for Wangdi Dzong assumptions and best guesses of these properties have to be used. The construction laboratory at ETH Zürich has voluntarily carried out a small series of initial tests on mud samples to reduce the uncertainty on some of the assumptions.
Nevertheless, the issue remains critical and a large hindrance to the development of the country and the safety of its inhabitants. When people lose faith into their structures and the only alternative at hand is the Indian developed reinforced concrete frame structures with masonry infill the building culture of Bhutan will invariably change and with the building culture also its intangible culture. On this background the concept of a Royal Institute of Traditional Structures (RITS) was born and an plan for its mission and organisation as well as for a small laboratory building and equipment developed. Because in particular masonry is a composite structure (both the properties of the mortar and the stones but also their geometry and arrangement influence the behaviour) and can only be understood testing actual wall samples, the basic most universal testing machine alone is not sufficient, but a small reaction floor and wall including a set of hydraulic jacks is required for a meaningful lab. Despite His Majesty has commanded the setting up of such an organisation and laboratory, the process is slowed down by the hesitance of both the government and development organisations to allocate the necessary funding for such a long term project over other opportunities that give more rapid success. This is disappointing because it is the safety of the Bhutanese and the Bhutanese culture that suffer but there is nothing to do but keep on pushing.

**Situation on Site**

At the time of writing the Kuenray and the foundation of the Utse were completed and works on site focus on the first court yard where the sourcing of good quality stones and of sufficient wood of good quality is a worry. There are up to 400 people working on site and in the carpentry workshop in Samtang. The design focusses on the upper part of the Utse and the Shabkhors of the third courtyard.