Seismic protection and preservation of the Newari architecture in Nepal

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ABSTRACT: Traditional construction techniques in seismic areas have been characterized, for a long time, by a large variety of structural solutions based on the combined use of masonry and timber elements. Examples of this can be found also in Nepal, where the recent seismic event occurred on April 25th, 2015 has made the analysis of the traditional building technology very urgent. The interest for this comes from the consideration that the Newari vernacular architecture, developed in the Kathmandu valley, presents interesting earthquake-proof structural solutions, very different from the typical timber frame adopted in other nearby regions, like the Kashmir Dhajji-dewari. Through the analysis of the effects produced by the recent earthquake on vernacular structures in Nepal, this research aims at clarifying both the current state-of-the-art and the capabilities of the Newari architecture, which is nowadays subject to the risk of disappearing and needs therefore to be understood in order to preserve its identity and to improve restoration projects.

1 INTRODUCTION

The Nepalese culture is well represented in the Kathmandu Valley, in the heart of the Himalayas, where also the two main religions coexisting in the region are present. The aspects characterizing the Nepalese cultural heritage were clearly identified by Lévi (1905); all the Nepalese arts, including painting, sculpture and architecture, originate from the Indian culture and are directly linked to the two main Indian religions, Buddhism and Hinduism. The same applies to the most important architectural works, which often keep the original names. As they developed in time, however, they assumed new morphologies and a style not anymore reflecting the typical Indian origin (Bonapace & Sestini 2003).

Since 1979, the Kathmandu Valley was designated as a World Heritage Site by UNESCO and in 2003 was registered in the list of Cultural Heritage Sites in Danger. Despite these nominations, industrialization and commercialization have not stopped and an increasing number of historic buildings have been demolished, giving the way to the design of low quality construction. In addition, natural hazards and especially earthquakes have always characterized this region, producing damage at a large extent across the centuries (Maskey 2013).

Earthquakes, by nature, recur in time, so that both the original morphology and the time evolution of the most effective construction techniques are directly related to the level of the local seismic hazard. In areas affected by severe and frequent natural disasters special systems, therefore, are naturally developed; in order for this to happen, however, it is required that the memory of the natural event and the knowledge of the damage are not lost. The hazard consciousness, indeed, induces local society not to forget nor abandon traditional construction techniques, but rather to maintain and improve them.

In Nepal, the comparison between historical seismicity and seismic damage indicates, apparently, a lack of seismic consciousness, directly affecting the level of damage. Surprisingly, although since 2003 many efforts had been made for the protection of the cultural heritage, attempts to save them from earthquake disasters have not been sufficient.

The damage extent corresponding to recent seismic events has highlighted the need for the definition of a strategy to regulate both restoration interventions and new construction, in order to avoid the easy trend to demolish and reconstruct damaged historic buildings, monuments and temples into reinforced concrete structures, with a significant loss of historic value.

In the paper, this issue is discussed with reference to the Newari architecture, a meaningful example of the local building tradition that deserves protection and, at the same time, is seriously endangered by earthquakes.

2 THE APRIL 25TH, 2015 EARTHQUAKE

2.1 The seismic event

The M7.8 and M7.3 earthquakes that stroked Nepal in 2015 on April 25th and May 12th were followed by a series of M5-M6 aftershocks. During the first event,
Another important aspect, underlined by Romão et al. better (Romão et al. 2015). These observations areings performed poorly under the earthquake, while of bricks and mud mortar, proved very low resistance of villages, indeed, the surveyed masonry buildings, made structural behavior. Both in Kathmandu and in the vil-

ysis of the damage level and the interpretation of the construction typology, on the basis of both the anal-

tricts, i.e., 20% in Kathmandu and 40% in Bhaktapur. However, although the original design was inspired by seismic awareness, several modifications introduced over the time have negatively affected the earthquake behavior during the last seismic event.

2.2 Preliminary considerations on the earthquake effects

Due to the availability of both media reports and scientific field investigations it is possible to estimate a widely spread state of damage with several structural collapses, probably determined by both geometrical configurations and poor mechanical properties of the material as well; but according to Romão et al. (2015) the real situation is somehow more complex.

Indeed, comparing the 2011 census with the dam-

age report (NDRRP, 2015) it was possible to assume that most of the damage to the housing sector occurred outside the main cities, especially in rural areas where the total number of fully or partially damaged houses has been estimated to be between 85 and 100%, in contrast with the survey performed in the main districts, i.e., 20% in Kathmandu and 40% in Bhaktapur. Another important aspect, underlined by Romão et al. (2015), concerns the inquiry about the most vulnerable construction typology, on the basis of both the analysis of the damage level and the interpretation of the structural behavior. Both in Kathmandu and in the villages, indeed, the surveyed masonry buildings, made of bricks and mud mortar, proved very low resistance levels.

In general, the traditional and vernacular build-

ings performed poorly under the earthquake, while modern reinforced concrete structures reacted much better (Romão et al. 2015). These observations are

Based on preliminary data available from the Global Shelter Cluster (GSC, 2015), which shows that, for the fourteen districts declared “crisis-hit”, about 70% of the traditional masonry constructions collapsed or exhibited severe damage, whereas 87% of reinforced concrete structures presented a damage level from zero to moderate (Romão et al. 2015).

As a first point, in agreement with some comments by Langenbach(2015), the basic question is: how can the total absence of a “seismic culture” be justified? Considering, indeed, that the local seismic activity is characterized by an average value of 80 to 100 years for the return period of such events, the absence of an earthquake resistant tradition is difficult to explain.

2.3 Some notes on historical seismicity

Thanks to the availability of interesting works on this topic [Bilham 1995, Furukawa et al. 2012, Dixit et al. 2013, Gautam 2014] it is possible to summarize, for Nepal, historical seismicity focusing on the devastat-
ing earthquakes occurred in the past, which caused severe damage in the densely populated Kathmandu valley.

A part from the 1255 earthquake, which killed one third of the population in the Kathmandu valley, the first event belonging to recent history occurred in 1833 (M=7.7). One century later (1934) another event hit the area (M=8.1) with strong effects on both the population and the buildings: 4296 fatalities in the Kathmandu valley with 55,000 affected buildings and 12,397 severely damaged; in 1988 a less strong earthquake (M=6.5) caused 721 fatalities across the country with 66,382 collapsed buildings.

The last severe earthquake occurred only 27 years ago, but the lack of maintenance and the fast uncontrolled reconstruction have amplified the effects of the recent one.

Surya Acharya, a civil engineer at the National Society for Earthquake Technology (NSET) in Nepal described this trend as follows: “All the monuments were built with earthquake-safe technology 400 years ago, using timber, brick, stone or mud, and lime. Those buildings survived many big earthquakes – this one was not so big. Many of the historical structures even survived the last major earthquake here, in 1934, but materials weaken due to age and poor maintenance” (Langenbach 2015).

2.4 Lack of homogeneity

Gautam(2014) points out the effectiveness of the traditional unreinforced masonry Newari buildings, on the base of 42 structures surveyed in the city of Bhaktapur. The final conclusion, further remarked upon in a recent interview just after the earthquake (Langenbach 2015), states that “some excellent features regarding earth-

quake resistant constructions were introduced into the Newari [structural design] …[and this] may add up some milestones in developing resilient structures of modern time” [Gautam, 2014].
The inspections after the last earthquake, carried out by Gautam and reported by Langenbach (2015), seem to show that “there were only minor diagonal cracks and no collapsed house” in all the buildings in line with the Newari tradition.

From the above considerations and from post-earthquake inspections, the main issue, apparently, is the lack of homogeneity in the behavior of private dwellings in the Kathmandu Valley, described in §2.1. Some inspections, indeed, have highlighted the positive effects of a clear seismic consciousness; at the same time, however, the damage suffered by several buildings looks, in general, extremely serious. It is natural to wonder why this discrepancy is possible and why just a few of these buildings incorporate seismic resistant details.

First of all, it should be considered that nowadays masonry construction does not follow a single model, due mainly to the low quality of both design and execution, in charge to poor workmanship, with limited support from structural engineers and architects (Romão et al. 2015); this has surely contributed to increase the level of damage during the recent event.

According to Romão et al. (2015), from the late 18th century meaningful changes in the lifestyle started to take place, resulting into significant modifications in the structural design: adding new stories to existing houses, restoring buildings without any care for the materials, changing the building function while using the same structure, creating new openings at the ground floor for commercial purposes, reducing the size of the family and the external decorations depend on the size of the family and on the caste. However, the principles governing the use of space are the same for all social groups (Korn 2014). One of the earliest descriptions of the Newari houses dates back to 200 years ago when Father Giuseppe, a Christian monk, visited Nepal: “The houses are constructed of bricks, and are three or four stories high; their apartments are not lofty; they have doors and windows of wood, well worked and arranged with full regularity.” (Korn 2014).

As reported by Parajuli (1986), the traditional building technology was originally developed for a two story building (the Bahal type). From the 17th century, an additional story was added and today 3-5 stories are built, without any modification of the construction details (foundations, materials, structural layout, etc.).

The main characteristic of these buildings is in the symmetry that inspired the architectural design, and which is clearly visible in the façade organized with respect to the central axis of a main window or door. Other windows are paired around this central axis, and the central window of each floor is emphasized by its size and detailed carving.

Where the ground floor is not used as a shop-front or a workshop, this section of the façade remains rather simple, with a low narrow door and perhaps one or two small windows on either side. Any irregularity in the ground floor façade, due to a door or a row of columns, usually is not repeated in the upper stories that are arranged, independently, in a symmetric configuration.

A critical factor determining the use of different rooms in the house is its vertical configuration. The size of the house and the external decorations depend on the size of the family and on the caste. However, the principles governing the use of space are the same for all social groups (Korn 2014).

A central wall (duaga) normally divides the ground floor, chhyadi, into two narrow rooms; the front room usually is used as a shop or workshop. A row of twin columns frequently replaces the entire front wall, opening the ground floor to the street. The back rooms

3 THE NEWARI

3.1 Description

The Nepalese architecture, otherwise known as the Newari style, has been influenced over the centuries by three main factors: environment, materials and craft activities.

This style is very different from those present in other Asian countries with similar cultures, traditions and religions. Surely, a distinguishing factor of this Newari style is the way in which the two main materials, wood and brick, are used.

The main material, which creates a connection between this architecture and the environment, is the clay soil of the Kathmandu Valley. This soil is excavated from a dry lake, which is now used for the fabrication of bricks (Bonapace & Sestini 2003).

Several authors have proposed typological classifications of the Nepalese architecture; in this, they make reference to the main monuments but give no consideration to the Newari houses. As already mentioned, the architectural works which define the cultural heritage of the country were clearly identified by Lévi not earlier than in 1905.

While religious buildings are well documented, indeed, the historical information concerning private dwellings is non-existent (Korn 2014). One of the earliest descriptions of the Newari houses dates back to 200 years ago when Father Giuseppe, a Christian monk, visited Nepal: “The houses are constructed of bricks, and are three or four stories high; their apartments are not lofty; they have doors and windows of wood, well worked and arranged with full regularity.” (Korn 2014).

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A central wall (duaga) normally divides the ground floor, chhyadi, into two narrow rooms; the front room usually is used as a shop or workshop. A row of twin columns frequently replaces the entire front wall, opening the ground floor to the street. The back rooms
are used as storage or workshops, and are opened onto the courtyard. The central wall, for structural reasons, is seldom replaced by columns.

Where the ground floor is used as a stable or store-room, only small windows are present and the same general access is used.

The access to the upper stories is given by a narrow staircase. A trap door, in the form of two heavy planks, closes off the stairwell, normally at each floor level and this was probably the result of earlier defense requirements.

Originally the ground floor was never used as a living area, also because it offered no protection against dampness. The floor is either tiled with bricks or covered with a layer of clay. Shops only have a well ventilated timber floor. The actual living space and sleeping areas of the family start at the first floor (*mata*, middle section).

Depending on the size of the house, the two rooms created by the central wall are further divided by either solid or light timber partitions to form sleeping quarters for family members, or for married sons, who remain in the parental home with their own families (Korn 2014).

The main living area of a typical Newari house is at the second floor (called *chwata* that means upper layer). A row of twin columns takes the place of the central wall, so that the room becomes a rather low hall (Fig. 1). Windows at the front and rear walls, particularly the large *sajhya*, are the only light and ventilation sources. The relatively good lighting also makes this floor the favorite location for different types of work (i.e., weaving looms, one of the most common of household implements in Newari homes, are set up near these large windows).

The third story (*pyeta*, fourth layer), constitutes an unusual addition to the basic Newari house, which normally includes the ground floor, the first floor (middle layer) and the second floor (upper layer). The fourth floor is often used as a single open-space for family and only in few cases it was subdivided into small rooms.

From a structural point of view, the main construction details, identified as being the main features providing an earthquake-resistant performance to the Newari houses, as reported by Dixit at al. (2004) and Romão et al. (2015) are:

1. the symmetric configuration (most of the traditional buildings are rectangular in shape);
2. the small length to depth ratio (in most of the buildings equal to 1.5 or less);
3. the symmetrical location of small openings;
4. the reduced inter-story height (less than 2.5 m) and the limited number of stories (usually up to three stories);
5. the presence of timber bands;
6. the vertical post at corners that acts as vertical tensile reinforcement;
7. the timber corner stitch;
8. the timber pegs (*chokus*, Fig. 2);
9. the boxing of openings by timber frames (Fig. 3);
10. the use of timber wedges, carpentry joints (dovetailing, etc.).

It is possible to state that all the above listed timber elements enhance the seismic behavior of the Newari house (Gautam 2014).

The vertical posts at corners provide an effective protection against tensile cracks. In some cases, this kind of elements provide some redundancy in the system that is very effective to withstand earthquake forces. The corner stitch, in addition to timber bands, can be found in the connection between orthogonal walls and protects from separation at the corner, enhancing a box behavior of the structure. Moreover, the timber pegs, which are frequent in this kind of traditional building, allow for a proper connection
of all timber elements, increasing resistance both at the floor and roof level, as observed in other seismic prone areas (Sorrentino et al. 2012). The carved timber framed openings, either all around or along the edges of the masonry wall, provided strength to the windows. Indeed, through the use of timber wedges, carpentry joints provide energy dissipation. As a conclusion, the use of timber appears to be a relevant element in the Newari typology; it is even more crucial, indeed, in the close Kashmir area, where the Dhajji-dewari houses are built with unfired mud bricks. The term Dhajji-dewari comes from Persian and literally means “patch-quilt wall”, identifying a type of construction that consists of a timber braced frame with masonry infill. It can be described as a half-timber, brick type construction and resembles the traditional well known solutions developed in Europe and, in detail, within the Mediterranean basin. Buildings of this type have much thinner walls and are therefore much lighter. The Dhajji-dewari construction provides an efficient and economical use of materials. According to Lagenbach (2009), in the Dhajji-dewari buildings the use of wood is kept to a minimum, but the wood still enables the 1/2 brick thick walls to resist out of plane collapse; at the same time, it restrains both in plane displacements and cracking of the infill masonry.

3.2 The main damage due to the earthquake

Following the earthquake that struck Nepal on April 25th, 2015, a preliminary assessment of the main failure mechanisms was performed on some Newari buildings through a visual inspection. To this purpose, meaningful photographs have been collected and analyzed; some of them were directly taken in situ by the authors.

The failure mechanisms collected in Table 1 highlight the recurrent seismic behavior of this building typology.

Following D’Ayala (2006), who analyzed the seismic vulnerability of the Newari buildings in Lalitpur (Kathmandu Valley), the most vulnerable mechanisms have been identified as D, F and M. According to the classification given in the aforementioned work (Figs. 4–8), the most common mechanism corresponds to the soft-story situation, or dalan (mechanism type M), followed by the overturning of the façade (mechanisms type D and A, respectively).

The dalan mechanism is associated with a high vulnerability class and, according to D’Ayala, is triggered by low levels of horizontal acceleration, typically lower than 0.1 g.

This kind of seismic behavior is probably due to the presence, at the ground level, of a twin row of
timber columns, replacing the entire front masonry wall for commercial purposes (i.e., to give access from the street to the inner shopping area).

Moreover, it is possible to note that façades presenting a high vulnerability level are affected by either the dalan mechanism or by the façade overturning (A and D) when they are poorly connected to party walls. As reported by D’Ayala, this kind of façades usually don’t have visible timber at the roof level, and hence do not benefit from the restraining action exerted by the horizontal structural elements.

Therefore, in agreement with Parajuli (1986), it is possible to conclude that traditional buildings presented damage patterns which are repetitive in nature. These occur because of noticeable deficiencies extending from the foundation to the roof and because of changes in the production process of building materials in recent times.

The analysis reported by Suwal (2014), indeed, shows that the production of building materials has changed from quality to quantity. For example, bricks now used are neither well seasoned nor well burnt. Additionally, mud mortar is rarely used nowadays.

Because of changes in the construction materials, buildings erected at later time are characterized by a lower number of dhalin (joist), and by nila (beam) with smaller cross section and larger spacing, compared to the dwellings of earlier periods.

Moreover, as asserted by Romão et al. (2015), this aspect is probably related to the several changes that occurred in the way of life in Nepal. Most of all, the need of new houses to accommodate more numerous families, led to a height increase in the buildings. The additional stories were built also over the historical Newari dwellings and this fact implied a change in the opening arrangement and size (in order to satisfy the needs of new houses) and, hence, in the bearing capacity of the structure too.

Concluding, this preliminary analysis highlighted that a proper use of timber lacing in masonry can play an effective connection role (also in the presence of soft soil conditions, as in the Katmandu valley) (Langenbach 2015) and in reducing the earthquake effects.

A favorable contribution is also provided by the timber frames around the openings, which deeply characterize this building typology both from the architectural and the structural points of view.

4 A PROJECT FOR RECONSTRUCTION

The Nepalese government is seeking for new strategies in favor of the post-earthquake reconstruction issue. At present, a strong debate has been raised about the way to rebuild the collapsed Newari residential buildings: either recurring to earthquake resistant masonry (modifying historical masonry) or to reinforced concrete.

Therefore, Nepalese architects and engineers are developing some new building layouts for residential purposes, in accordance with the standard provided by the Nepalese Building Code, in order to rebuild easily and quickly, while preserving the main typological characteristics of the Newari house. Among the proposed projects, one deserves special interest (Fig. 9), as it preserves the original principles of the aforementioned historical buildings: symmetry in plan and in the window arrangement; low height (one story); double leaf masonry (ma appa bricks in the external leaf and dachi appa in the internal one), double timber frame around the openings; timber roof structure; timber pegs for connecting joists to walls.

What is of interest, indeed, are the presence of timber bands (tag and bhatar) that are more common in public palaces and temples rather than in private residential buildings, and the systematic use of pegs.

A finite element model of the reconstruction project is presented in Table 2. Planar shell elements have been used for masonry (elastic modulus: 1020 MPa), while timber elements have been modeled with beam elements (elastic modulus: 12500 MPa). The modal analysis highlights the symmetric behavior of the structure and the role of the peculiar timber roof design. It is interesting to note that while the first two modes are translational in the Y (longitudinal) and X (transversal) directions, the 3rd and the 4th modes are mainly rotational. The higher ones, such as the 5th and the 6th, are roto-translational modes.

For a comprehensive understanding of the timber elements role inside the structure, the analyses were performed with three models:

a. model with timber framed openings and horizontal bands;

b. model without timber horizontal bands;

c. model without timber framed openings.

As shown in Table 3, the presence of both bands and window frames leads to a stiffer structure that, in fact, is characterized by shorter periods. The model without double timber framed openings (c) is more flexible than in case (b), where the horizontal bands are absent. This aspect demonstrates that the timber window details play a positive role in the global seismic behavior of the structure.

In Figure 10, the response spectrum recorded during the April 25th 2015 earthquake is reported. The absence of window frames leads to a more flexible
structure, subject to higher spectral accelerations. This positive effect adds to the one against crack formation, already mentioned with reference to observed performances.

5 CONCLUSIONS

The 2015 Nepal earthquake highlighted a special case of timber reinforced masonry, corresponding to the Newari tradition, a building typology deeply charactering the local architectural heritage.

The analysis of literature works, in connection also with damage surveys, has shown the potentials of this system as a seismic resistant solution; in addition, with reference to the design of new houses, a preliminary numerical analysis has confirmed the effectiveness of some structural details inspired by the tradition. All this has indicated the need for a deeper analysis, extended to typical ancient buildings several stories high; specifically, analyses should highlight, in addition to the global seismic response, the effectiveness of a couple of meaningful details, associated to the timber frames around openings and to the roof structure, respectively. The interest in this kind of analysis is clearly related to the need of understanding the real resources of this structural system for preservation purposes; also, it is of interest to compare the Nepalese tradition in the use of timber as masonry reinforcement to corresponding well known traditions, which have provided, over the time, different interesting solutions.

REFERENCES


