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Mechanical behaviour of different type of shear band connections being used in reconstruction housing in Nepal

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HIGHLIGHTS

- The use of shear bands in masonry structures.
- Experimental approach to determine the mechanical behaviour of different materials used as shear bands.
- Reconstruction housing in Nepal.

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ABSTRACT

Masonry structures are common in most of the under developed and developing countries in South-East Asia and Nepal is one of those nations which suffered from tremendous loss during earthquake in 2015. These types of structures are strengthened using various traditional and modern techniques, but the sustainability of the approach is obtained when local building culture is taken into consideration. The use of shear bands in masonry structures has been implemented in different nations for several centuries. It is also recommended by Government of Nepal (GoN) through design catalogues for the reconstruction of earthquake resistant buildings. These techniques proved to enhance the seismic performance of the structure but the influence of using different materials and of their configuration in term of dissipation of energy are not quantified. This research work focuses on an experimental approach to determine the mechanical behaviour of different materials (concrete, timber, or bamboo) when used as shear bands. Significant differences were highlighted in the seismic performance behaviour and energy dissipation of shear bands according to the materials, the contact surface areas and the junctions between elements. These results are analyzed in light of the substantial differences in material and labour costs at local levels in each earthquake-affected district. This article covers the experimental research conducted on shear bands and its links with on-site reconstruction activities.

1. Introduction

Every year, various natural disasters activities take away lives and properties among which earthquake is one of the most significant phenomena occurring due to continuous tectonic movement and accumulation of huge energy in the earth. Nepal is a developing country with almost one-quarter of the population below poverty line and the residential buildings do not meet the minimum standards in most cases [23]. On 25th April 2015, an earthquake occurred at Barpak (Gorkha district), scaling 7.8 Mw on Richter scale with hypocentre depth of approximately 8.2 km. The main shock was followed by two major aftershocks 6.7 Mw on 26th April and 7.3 Mw on 12th May 2015 causing tremendous losses of human life and properties in highly urbanized areas. The total number of partial and completely collapsed buildings were 302,774 and 775,782 respectively [16]. 98% of the damaged and collapsed buildings were private houses. The topography of Nepal varies moving from south towards north and so are local building cultures, regarding the house types and the practices associated to them in particular. The houses present in the hilly region of Nepal are mainly made up of partially dressed stones [12,13] with mud or cement mortar and sometimes even dry stone masonry. These type of unreinforced masonry structures are quite common in most of

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the under developed and developing countries in South-East Asia. Such structures can be strengthened using several choices of materials and technique. The strengthening and retrofitting of masonry structures using modern composite materials has become quite common in developed countries [6,15] and turns out to be efficient regarding the structure stiffness and weight [14], as well as regarding its reversibility [20]. However, in order to increase people's resilience to disasters on the long run, it is necessary to promote rebuilding techniques that cope with inhabitants' empowerment, with the possibility of a self-upgradeability of houses, and with a large-scale reproducibility of the design suggested. Bearing in mind these three pillars, both traditional techniques and modern materials should be integrated, according to their adaptation to local contexts [9,19].

Seismic activities occur all over the world, but the extent of damage varies. The reason behind this variation is the respect of seismic safety rules during the construction works and the building lifespan, on the one hand, and people's understanding of the building behaviour and their respect of the safety measures during seismic activity, on the other hand. When local seismic activity is important, inhabitants and local professionals usually developed "local seismic cultures" over time [8]. Hence, in order to develop seismic strategies that cope with local conditions, studying historical buildings and traditional construction practices, the material used, and the cultural values related to it is of high importance. These specific building cultures are being lost with the import of international standards, which are not always relevant in the context of the country and often not sustainable. Decontextualized guidelines usually do not cope with local financial and professional capacities and resulting low quality works [8]. Hence, international standards, if needed, have to be customized to the context of intervention for an effective implementation and even more, so that they are not counterproductive.

1.1. Need for scientific results

Following 2015 Nepali earthquakes, there is a high need for starting reconstruction works, which would be safe for upcoming similar events making proper decisions based on social, cultural, political, and environmental factors. To achieve this goal, the GoN published a design catalogue detailing earthquake resistance guidelines [7]. It includes different types of buildings, most of them with shear bands from various materials, for example timber, bamboo, or concrete. However, people started modifying these technical recommendations during reconstruction works without having proper knowledge on the shear bands sensitivity to these modifications. For example, during field surveys by CRAterre and 3SR in 2016 and 2017, several technical issues were observed such as the use of unseasoned timber, reinforcement bars being not properly positioned in concrete shear bands. These changes were mostly for economic reasons, but also because of a lack of properly trained masons. Hence, to find out the physical behaviour of those shear bands more experimental research work is necessary.

The mechanical impact of the shear bands has not been evaluated in the past. This is challenging as shear bands work in masonry wall and could have different impacts in depend of the masonry materials but also on the shear bands materials. The main hypothesis of the objective of a shear bands is to increase the masonry capacity to dissipated energy before collapse. This is provided by the localization of the energy dissipation at its interface between masonry which is softer that the interface between brick/stone masonries. Then, shear bands slide on the masonry and the masonry stay as a monolithic element. This paper presents the first investigation of the impact of a shear wall. It focuses to analyze the capacity to dissipate energy in regards of the material use for shear bands with the development of an experimental device to shear the interface in a quasi-static cyclic loading.

2. Shear band

Timber shear bands have been used for several centuries, and behaved very well during major earthquakes as observed in Europe (Balkanic countries, Greece), Asia (Turkey, Pakistan, India, Nepal, Bhutan), and Latin America (Chile, Bolivia) [10]. Moreover, during experimental tests, timber reinforced masonry wallets had better resistance to deformation than unreinforced masonry when subjected to compression followed by diagonal compression loading [22]. The integration of horizontal wooden elements not only improves their structural behaviour but also helps to reduce the risk of collapse due to differential settlements of the ground or the delamination of a masonry wall [11]. By varying the properties of the horizontal insertions (their shape and thickness) as well as their vertical spacing, it was possible to double the compressive strength of blocks (10 cm*10 cm*30 cm) and increase their deformation limit as observed from an experiment performed by Lehmann et al. at ENAC-EPFL under the supervision of Hofmann [10].

Horizontal reinforcement in walls can be used as horizontal bands or ring beams, cross-sections of bands, dowels at corners and junctions along with vertical reinforcement in the wall. As an alternative to the steel reinforcing bar, wooden planks of rectangular sections may be used where timber is available and more economical [1]. The seismic band should always be continuous and remain in the same level without any dip or change in height [2].

Among the different types of horizontal wood insertion adopted by vernacular buildings for providing extra resistance to seismic force, the ladder shaped, made up of longitudinal brackets connected by cross ties members, is the most common. The presence of transverse timber ties prevents the delamination of a vertical layer of the wall [22]. Transverse timber locking system plays an important role in the case of double layer masonry wall structure as they are very sensitive to delamination and having shear band at different level helps to reduce effective height thickness ratio and hence get low slenderness ratio. With lower slenderness ratio, the arc effect is limited to a shorter length which prevents excessive deformation out of plane [18].

The shear band is a member that is used for providing seismic resistance to the low strength masonry structures at different horizontal level using various material as shown in Fig. 1 (left). The horizontal continuous beam or band at each level acts as a belt, and the building vibrates monolithically preventing chances of out-of-plane failure by restricting the bending deflection, and corner separation as the structure is held together by horizontal band. The shear band at roof level also help in proper connection of roof with the wall and provide support during the seismic action.

Similarly, the use of horizontal shear band helps to prevent the in-plane shear crack propagation as shown in Fig. 1 (right). In this way, the crack is limited within the two-shear bands layer that prevents the complete failure of the wall. The sliding behaviour of those shear bands leading to dissipation of energy due to frictional behaviour at the interface layer can been observed. These bands also help to check the horizontal alignment of wall level at a different level during construction.

2.1. Shear band in Nepal

Nepal had experience many strong earthquakes in the past among which the highest recorded earthquake was 8.4 Mw in the year 1934 CE when around 126,000 houses had repairable extent of damage and approximately 81,000 collapsed [17]. After