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Enhancement of Shear Capacity of the Vernacular Masonry Houses in Rural Areas of Nepal Using Horizontal Bands

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Abstract—*Stone Masonry with mud mortar is common for construction of vernacular houses in rural areas of Nepal. The April 25th, 2015 and May 12th, 2015 Gorkha earthquakes in Nepal caused a widespread damage to these houses as well as loss of almost 9000 lives. It has been recorded that 602,257 houses were fully damaged and 285,099 houses were partially damaged by the earthquake which lies mostly in this category in the rural areas. The failure patterns of these houses due to the earthquake show that they are mostly weak in shear. Hence, the present work is to study the shear strength capacity of stone masonry in mud mortar and then study the effect of introduction of horizontal bands on shear strength of these houses. The houses are modelled in 3muri software for the analysis with and without provision of horizontal bands. The results of the analysis show that shear capacity of the house has been increased significantly when horizontal bands were introduced. This technique will be very useful in reconstruction of safe houses and maintenance of partially damaged houses using the local materials in rural areas of Nepal.*

1. INTRODUCTION

The April 25th, 2015 and May 12th, 2015 Gorkha earthquakes in Nepal caused widespread damage to housing in the affected districts, as well as loss of life of almost 9000 people. The government of Nepal figures out 602,257 houses were fully damaged, and 285099 houses were partially damaged [6]. Around 95% of low strengthening masonry structures are complete damage and 67.7% are partially damaged due to the earthquake. Some photos of stone masonry buildings damaged by 2015 Earthquake in rural areas of Nepal is shown in Figure 1 below.

The building made with stone and brick masonry had suffered with extensive damages during the earthquake. Reconstruction of these houses considering the mitigation measures against probable earthquake is most important task and strengthening of some partially damaged houses.

The stone and adobe brick masonry building with mud mortar is the typical type of masonry houses widely constructed in rural area of Nepal. The recent earthquake has proven that they are very weak to take lateral loads. However, there is a need for low cost strengthening measures which can be included in the construction of new houses in the traditional forms and using local materials so that the rural population can afford to build safer houses. Construction of masonry building is only the means of housing for the rural area because in rural area construction of RCC building is not possible. The geography of Nepal makes access to industrially produced heavy construction materials such as concrete and steel prohibitively expensive and difficult or impossible to deliver to many of the rural mountainside sites in the country.

As the stone masonry building is very common in context of rural areas of Nepal and the stone masonry is in mud mortar or cement mortar, the structures are being reconstructed although they have showed their weaknesses in lateral loads. Hence, there is a need of enhancing lateral load capacity in the wall system of these building.

Figure 1: Photos of stone masonry buildings damaged by 2015 Earthquake in rural areas of Nepal.

This work is to study the enhancement of the shear capacity stone masonry rural houses using horizontal band like lintel bands. The main objective of this research work is to study the shear capacity of unreinforced masonry building and how to enhance the shear capacity of stone masonry buildings in cement mortar and mud mortar.

2. VERNACULAR BUILDINGS IN RURAL AREAS OF NEPAL

Stone masonry is one of the oldest and most common vernacular construction practices. Stone masonry construction varies widely around the world depending on the type of locally available materials, the level of artisan skills and tools, and economic constraints. In the past, stone masonry construction was used to build simple dwellings and also palaces, temples, and heritage landmark structures. It continues to be used for housing construction in developing countries and in areas where stone is a locally available and affordable building material as in rural areas of Nepal.

In many cases, earthquakes pose a major threat to these structures. The seismic vulnerability of stone masonry buildings is due to their heavy weight and, in most cases, the manner in which the walls have been built. Human and economic losses due to earthquakes are unacceptably high in areas where stone masonry has been used for house construction. Both old and new buildings of this construction type are at risk in earthquake-prone areas of the world. However, stone is one of the most widely used construction materials, and many stone masonry buildings have remained in use for centuries.

As such in the context of Nepal, the typical rural housing construction in the hills and mountains throughout Nepal is shown in Figure 2. It is a traditional construction practice followed for over 200 years. These buildings are basically loose-fitting, load-bearing structures constructed of un-coursed rubble stone walls in mud mortar, with timber floors and roofs. The recent earthquake showed they are extremely vulnerable to the effects of earthquakes due to their lack of structural integrity.

Figure 2: Photos of typical stone masonry buildings in rural areas of Nepal.

There is no alternative option of construction materials for reconstruction of recently damaged buildings in rural areas of Nepal but the shear capacity of the building is a critical issue to resist future earthquake effects.

3. MODELLING OF MASONRY BUILDING

During Gorkha earthquake, many of the masonry building failed due to low shear resisting capacity. For future, to minimize the effect of the earthquake in rural areas of Nepal, this study has considered the analytical modelling of the housing model that has been prescribed by Department of Urban Development and Building Construction (DUDBC), Ministry of Urban Planning for reconstruction works. The study area is limited on study of increment of the shear capacity of masonry building by introduction of horizontal bands.

Material Properties

To predict a realistic picture of the masonry building for the modelling and analysis the properties of the masonry units and mortar is generally obtained from the experimental results. However, experimental determination of the material properties is not the scope of this study. Data obtained from test carried out by the previous researcher has been used to define material properties of masonry building as follows.

For Masonry wall [7]

Weight per unit volume (γ) =21.72 kN/m^3

Modulus of elasticity (E) =8168 MPa (for cement mortar 1:4)

Poisson ratio (ν) =0.25

Mean Compressive strength of masonry (fm)= 7 MPa

Modulus of elasticity (E) = 305 MPa (for lime/mud mortar) [2].

Weight per unit volume (γ) =17.60 kN/m^3 (for lime/mud mortar)

Concrete

Modulus of elasticity (E) = 5000$\sqrt{fck}$

Strength of concrete (fck) = 20MPa

Poisson's ratio = 0.2

Unit weight of concrete = 24 kN/m^3

Various factors such as dimension, joint width, material properties of brick units and mortar, arrangement of the units, quality of the workmanship etc. make the modelling of masonry structure very difficult. Further, it is difficult to ensure the optimized model without verifying the analysis result with some experimental values obtained from laboratory testing procedure. However, these are constraints in the local context. Possible solution to estimate the behaviour of the structure under earthquake is use of analytical techniques. Hence, models of a typical building have been prepared for analysis in 3muri Software. This software allows 3-dimensional modelling of whole unreinforced rubble masonry buildings in which: the bearing structure, both referring to vertical and horizontal loads, is identified, inside the construction, with walls and floors; the walls are the bearing elements, while the floors, apart from sharing vertical loads to the walls, are considered as planar stiffening elements, on which the horizontal actions distribution between the walls depends; the local flexural behaviour of the floors and the wall out-of-plane response are not computed because they are considered negligible with respect to the global building response, which is governed by their in-plane behaviour. The wall is modelled as a frame of non-linear element, which constitutive relationship is formulated to approximate the actual damage behaviour of masonry panels. The numerical models and analysis procedures, have been incorporated into the TREMURI program [3].

Description of model structure

The building selected for the analysis is stone masonry building where main structural elements are masonry walls constructed with stone as units and cement or mud mortar as binding mortar.

Figure 3: Sketch of a typical stone masonry building in rural areas of Nepal [1]

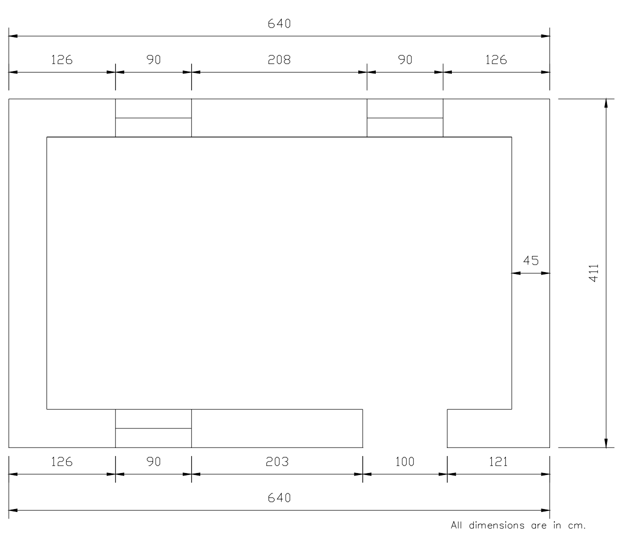

Figure 4 – Plan view of the typical stone masonry building in rural areas of Nepal

Generally, stone masonry building has wall thickness of 450 mm. The building is single or double storey. Typical rural buildings are of single storey with an attic floor. The main elements used for the construction of roof are corrugated galvanised iron sheet with timber used as purlin and rafter. The sketch of the building considered for the study is shown in Figure 3.

Figure 4 shows the typical plan of stone masonry building in rural areas of Nepal. This simple structure consists of one attic floor. The ground floor height is 300 cm. The height of roof from the attic floor is 150 cm. The windows are placed 90 cm above the floor. All the walls have 45 cm thickness. The slabs are considered flat and rigid. It is one directional regarding load transfer, direction from axis side wall to side wall. A dead load of 5kN/m^2 and a live load of 2 kN/m^2 are applied on them.

The objective of this paper is to make comparison of shear capacity of the building without and with provision of horizontal bands. For this, a typical stone masonry building has been taken for construction as widely constructed in rural areas of Nepal. Models of the buildings were prepared and analyzed with software, and the results are compared.

4. ANALYSIS AND RESULTS

Modelling of the stone masonry building is done in 3muri software for the analysis. TREMURI program has been widely used to determine the shear capacity of masonry buildings [4]. Results of the analysis are presented in this section in the following Tables and Figures.

Base Shear Calculation

The base shear along a principal direction is calculated using seismic coefficient method based on the Nepal Building Code NBC105:1994 [5].

$$Vb = Cd*W \qquad (1)$$

Where,

Cd = Design horizontal seismic coefficient

W = Seismic weight of building

$$Cd=CZIK \qquad (2)$$

Where,

Z =Seismic zone factor

I = Importance factor

K = Structural performance factor

Time period of the building is estimated as 0.1 second according to the code NBC105. Taking corresponding values from the code NBC105 (C=0.08, Z=1, I=1 and K=4), the horizontal seismic coefficient is estimated as 0.32. The total seismic weights of the building are estimated as 1068.67 kN (for cement mortar) and 911.61 kN (for mud mortar).

Then,

Base shear = 0.32*1068.67 = 341.97 kN. (for cement mortar)

Base shear = 0.32*911.61 = 291.71 kN. (for mud mortar)

Capacity Analysis

The capacity of the masonry building is determined in terms of the shear resistance of the building. The model has been run for two cases, first for without horizontal bands and the second for with horizontal bands at the lintel level. The horizontal bands are assumed as reinforced concrete bands with material properties as stated in the previous section. The size of the band is taken as 450 cm wide with 10 cm depth.

Figure 5 shows the 3D view of structural model without provision of horizontal band, with provision of horizontal band at both levels in 3Muri Software using Eurocode 8. The results of the analysis of the model for the cases without provision of horizontal band, with provision of horizontal band in level 1 and both levels are presented in Figure 6, Figure 7, Figure 8, and Figure 9 in X and Y directions. The results are also presented in Table 1 and Table 2. Y direction is the shorter dimension.

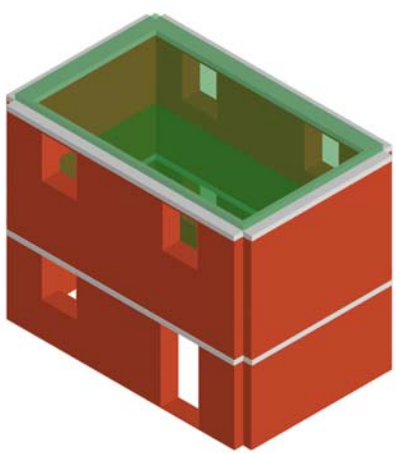

Figure 5: 3D view of structural model with provision of horizontal band at both levels in 3Muri Software

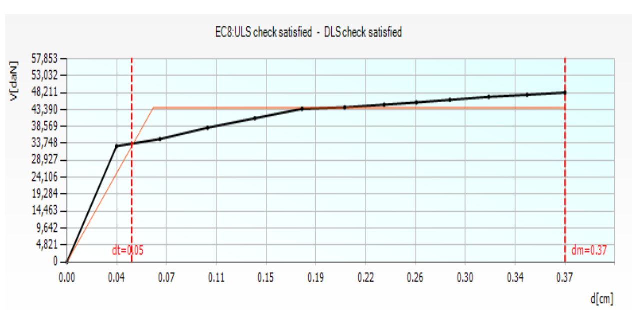

Figure 6: Capacity curve in X direction without provision of horizontal band, with provision of horizontal band at both levels for cement mortar stone masonry

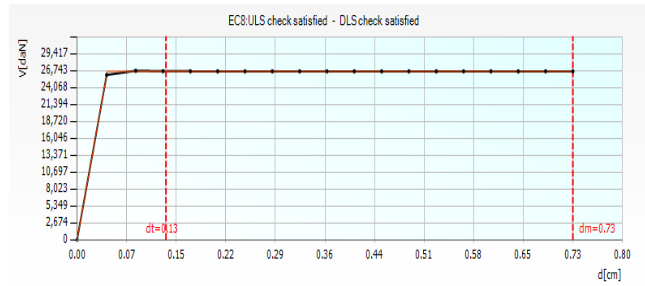

Figure 7: Capacity curve in Y direction without provision of horizontal band at both levels for cement mortar stone masonry

The increase in shear capacity of the stone masonry building in cement mortar due to provision of horizontal bands is shown in Table 1.

Table 1: Increase of shear capacity with provision of horizontal band at level 1 and both levels for cement mortar stone masonry.

Direction	Without band (kN)	With band at level 1 (kN)	With band at both levels (kN)	% of increase with band at level 1	% of increase with band at both levels
X	209.28	337.19	482.11	61	130
Y	173.85	235.96	266.59	36	53

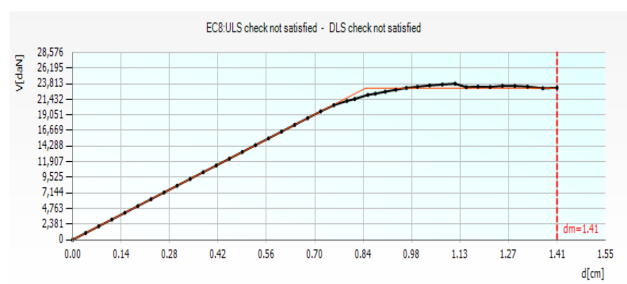

Figure 9: Capacity curve in Y direction without provision of horizontal band, with provision of horizontal band at both levels for mud mortar stone masonry

The increase in shear capacity of the stone masonry building in mud mortar due to provision of horizontal bands is shown in Table 2.

Table 2: Increase of shear capacity with provision of horizontal band at level 1 and both levels for mud mortar stone masonry.

Direction	Without band (kN)	With band at level 1 (kN)	With band at both levels (kN)	% of increase with band at level 1	% of increase with band at both levels
X	176.23	243.39	329.84	38	87
Y	163.04	188.63	231.85	16	42

The estimated base shear for cement mortar and mud mortar stone masonry is 341.97 kN and 291.71 kN respectively. These results of analysis in Table 1 and Table 2, shows that the shear capacity of stone masonry houses is far below the base shear. The shear capacity of stone masonry in mud mortar and even in cement stone masonry is critical as base shear in Y direction is 20% less than the base shear estimated when horizontal bands are not provided. The building has enough capacity in X direction. However, the effect of introduction of horizontal bands on shear capacity of the building has been found significantly as high as 130% in X direction 53 % in Y direction compared to the capacity without horizontal bands in cement masonry case. However, the results show that the shear capacity of the building in mud mortar stone masonry building can increase by 42% in Y direction and 87% in X direction.

5. CONCLUSIONS

The pushover curves show a good basis for estimation of shear capacity of stone masonry building of rural areas of Nepal without provision of horizontal band and with provision of horizontal bands at lintel levels. From the analysis of the typical building, the results showed that the shear capacity of the mud mortar stone masonry building can increase by 42% in Y (shorter dimension) direction and 87% in X direction of the building in mud mortar. Whereas in the same stone masonry building, the increase in shear capacity is more, 53% in Y direction and 130% in X direction in cement mortar.

This paper offers a solution to masonry capacity design with 3muri software. The outcomes of this study will be useful in re-construction of masonry building in rural area of Nepal damaged due to Gorkha earthquake enhancing shear capacity of the stone masonry buildings.

6. REFERENCES

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