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# Application of confined masonry in lieu of RC construction in newly expanding urban area of Nepal

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## ABSTRACT

Confined masonry (CM) technology has not been formalized in Nepal in regular construction. Despite the poor performance in last 2015 Gorkha earthquake, RC fame constructions with masonry infill that were designed and detailed poorly being in short to the required seismic resistance are still prominent in reconstruction. Moreover, the same construction is spread to new developed urban centers. In this study, confined masonry is investigated for its seismic resistance and cost effectiveness to compare with equivalent RC construction for low rise residential buildings. Two types of construction with similar configuration and occupancy area are evaluated in terms of base shear and deformation capacity. The limiting strength and deformation points are identified using pushover analysis. The study shows that CM technology offers better economic incentive in addition to enhanced performance in seismic loading pertinent to hazard defined by current National Building Code (NBC) of Nepal. A type-design confined masonry two-story building is also proposed for the reconstruction in semi-urban and rural areas where access to engineers who can perform detailed analysis for design is limited. The paper describes the method and results of comparative study that would justify the necessity CM technology in Nepal in regular housing construction as well as in in post-earthquake reconstruction.

Keywords: Confined masonry, Building Code, Non-ductile RC, Push-over analysis

## INTRODUCTION

The 2015 Gorkha (Nepal) Earthquake caused heavy damage to a large number of reinforced concrete (RC) residential buildings in Kathmandu and other urban centers although the peak ground acceleration was observed only about 1/3rd of the design earthquake [1]. Those buildings were affected with the damage ranging from cracks in the masonry infill walls and RC columns to complete collapse. It was believed that main causes of the damage to those RC buildings were related to inherent vulnerabilities of non-ductile RC construction arising from inadequate detailing of RC structural components, structural irregularities due to lack of systematic treatment of infill walls in design and poor construction quality. The damages in low-rise RC buildings, when occurred, were found to be concentrated mostly in columns, beam-column joints and infill walls of bottom stories. In conventional RC construction practiced in the country, the masonry walls are not considered to be the part of the lateral load resisting system as well as the irregularities they may create in the building system is often overlooked. High concentration of stress and increased ductility demand at certain points of the structure were likely the outcomes resulting into unwarranted damages in earthquake shaking.

A robust seismic code, its effective enforcement, a quality workmanship and material supply in construction are obviously the part of solution to the problem. It may, however, take long to effectively get this right at acceptable level. Further, there is already massive need for reconstruction with reinforced concrete housing in replacement of those damaged RC houses as well as other types that owner now wants to move from low strength masonry to RC in urban and semi-urban areas. More household are considering RC construction also in rural places that have road access to take standard construction material - steel, cement and aggregate [2].

A good alternative to this will be confined masonry (CM) construction. The material involved in the construction of building, the building envelop and the internal configuration as well as the housing functionality it offers to occupant is similar to that of frame construction with infill masonry. The major difference in the construction is limited to sequence of erecting masonry walls and beam columns. While in confined masonry construction, masonry walls are constructed first followed by the cast in-place RC tie-columns at the sides of walls and RC tie-beams on top of wall simultaneously with floor/ roof slab in each storey, RC frame with masonry infill has the RC frame of beam, column and slab constructed first followed by the construction of masonry walls in between the frame elements. Despite the same look of resulting structures from two process, they work differently in resisting the lateral load. The major differences come from the fact that masonry walls in CM construction are lead bearing and act as shear walls while in RC frame with infill, the walls are not load bearing.

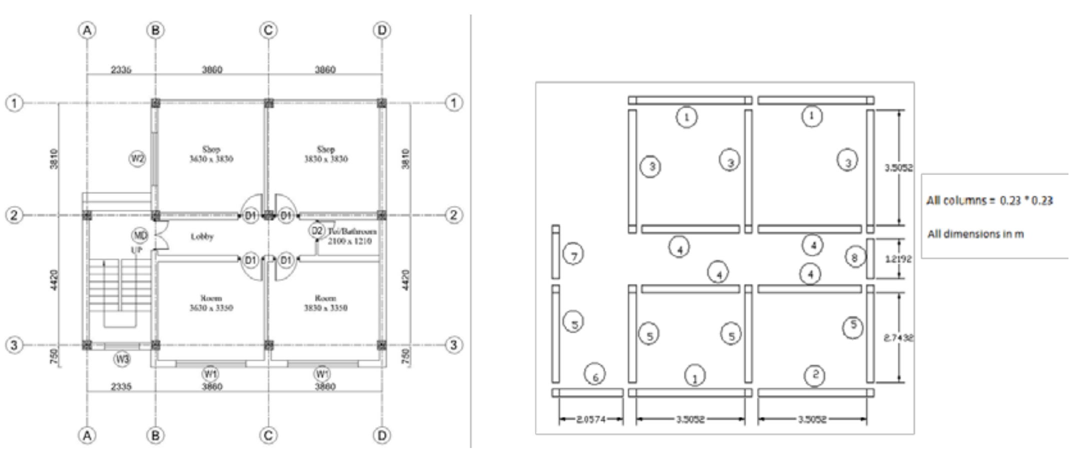
The confined masonry housing technology has been used in extensively in many parts of the world including in seismic region. Past earthquakes showed the effectiveness of the technology in earthquake resistance [3]. A comparative performance of confined masonry over adobe buildings was reported in post-earthquake reconnaissance reports of recent 2010 Chile earthquake [4,5]. There have been several initiatives at the global as well as at national levels in several countries promoting the technology for earthquake resistant housing alternatives [6]

However, this technology did not have consideration among engineering community, construction industry and in public in Nepal in the past. As confined masonry offers high seismic performance and yet serves as an economical solution, there is good potential in Nepal to use this technology in building construction practices including that in the post-earthquake reconstruction process. Common residential buildings in Nepal are constructed as low rise buildings of 3-4 story for which confined masonry construction method offers efficient and effective solution. This also applies in the context of post-earthquake reconstruction as rebuilding the damaged buildings requires comparatively less skilled manpower and structural detailing in comparison to RCC frame.

This study explores the suitability of the method looking at the equivalent properties of the confined masonry housing in resisting seismic load in comparison to conventional RC frame residential housing along with cost effectiveness. This study makes comparison between two houses – one actual residential home designed and built as per conventional RC frame with masonry infill construction and its potential confined masonry equivalent, in terms their seismic design parameters and adequacy to meet the hazard demands using linear analysis. The building also has open front for retail store, a common pracice prevalent in Kathmandu outskirt and other urban center of Nepal. A detailed cost estimate was made for both models to present the comparative cost. A more detailed nonlinear analysis was made to another set of RC building used for residential propose. Nonlinear pushover analysis of RC construction with infill and equivalent confined masonry was carried out and results are presented to show the compassion.

## LINEAR ANALYSIS

A simple regular residential building (Building 1) with four room floor plan was selected from the actual building permit inventory in the city office of Kathmandu. The building is three story with total 9m height (3m story height) with identical floor plans (Figure 1). It was originally designed and built as reinforced concrete frame with masonry infill is selected as the candidate for use of alterative confined masonry technology. The building columns are of 300mm x 300mm sizes and beams are of 230mm x 325mm including integral 125mm think slab. The building has regular plan and falls under the category of mandatory rule of thumb (MRT) for reinforced concrete design as per the Nepal national building code, NBC [7]. The concrete used in the building has compressive strength, $f'_c$ = 15MPa, steel strength, $f_y$ =4 15 MPa and brick compressive strength, $f'_b$ = 11.03MPa, mortar strength $f'_b$ = 1.58 MPa. The modulus of elasticity of the brick masonry is evaluated to be $E_m$ = 2300MPa following the work of Chaulagain et al. [8] The equivalent confined masonry layout is shown in Figure 1b where all the building enveloped and room side are kept same but tie columns and beams are reduced to 230mm x 230mm. These tie columns are placed at each intersection of walls and at the ends of openings.




(a) (b)

Figure 1: Floor plan of Building 1: (a) Original RC frame with infill (b) Equivalent confined masonry

### Wall Density Index

Prior to detail analysis of building with confined masonry model, it was first checked with simple wall density index for seismic safety adequacy check that is used for low rise confined masonry buildings following Meli et al.[3]. Evidence from past earthquakes shows that confined masonry buildings with adequate wall density were able to resist the effects of major earthquakes without collapse. The expression for the criterion is given by Eq.1 as:

$$d = \frac{A_w}{A_p} \geq \frac{A_h.n.w}{f_s} \quad (1)$$

Where d is wall density index, $A_w$ is sum of cross sectional area of all walls in one direction, $A_p$ is area of building floor plan, $A_h$ is horizontal seismic coefficient, n is number of floors, w is average weight of floor per unit area and $f_s$ is allowable shear stress for masonry wall. For seismic coefficient Ah = 0.1 in both directions, and allowable shear stress $f_s$ = 0.128Mpa, the wall density index ration comes as 9.2 and 6.57 in x and y directions respectively. The contribution of wall piers 7 and 8 as they have H/L ratio greater than 1.5 exceeding the limit suggested for wall density index calculation. As the required wall density index in both direction is only 2.71, it is concluded that the given building is adequate to be consider for confined masonry construction.

### Confined Masonry Analysis Using Spring Model

At first, a simplified model was developed using shear springs for individual walls, which were assembled for analysis in x and y directions. A total of eight different type of wall piers were identified based on the configurations. They were indicated in the Figure 1b. Compressive stresses, shear stresses, total shear resistance and shear demand in 1st story walls, which experience highest shear demand, were obtained as below in Table. It was found that that walls have adequate shear capacity.

Table 1. Check for shear resistance of walls using simplified method (spring model)

| X-direction walls | | | Y- direction walls | | |
|---|---|---|---|---|---|
| Wall No. | Shear force (kN) | Shear resistance (kN) | Wall No. | Shear force (kN) | Shear resistance(kN) |
| 1 | 86.44 | 343.49 | 3 | 115.85 | 343.49 |
| 2 | 28.81 | 114.50 | 5 | 120.89 | 358.42 |
| 4 | 115.26 | 457.99 | 7 | 3.92 | 11.63 |
| 6 | 14.07 | 55.91 | 8 | 3.92 | 11.63 |

### Confined Masonry Analysis Using Wide Column Model

Considering the similarity of confined masonry between RC frames with masonry infill, it is reasonable to apply wide column method, also known as equivalent frame model, for confined masonry that is more close to RC frame from modelling aspect. The major difference is that the contribution of masonry wall is directly taken into consideration in deriving the sectional properties of the equivalent frame in confined masonry .In RC frame with infill, the masonry wall is considered only as compression bracing strut. The wide column modelling of confined masonry provides a tool to designers to analyze the building in a way they usually do otherwise for regular frame buildings in commercial software like SAP2000 [9].

All walls in confined masonry were modelled as frame elements, located at the centers of the wall segments where transformed section used including the properties of tie columns. The reinforced concrete material is transformed to equivalent masonry properties using the ratio of modulus of elasticity of two properties. At wall junctions, rigid beam elements were introduced to ensure that the forces are transferred correctly to the wall axis [10]. At the junctions of openings and walls at slab level, flexible beam elements were introduced. A linear lateral load analysis of the building was carried out using commercial software SAP2000. Comparison of the shear demands obtained from wide column (WC) model with that from spring model (SP) as presented in Table 2 shows they are very close which provide confidence in consistency and reliability of the models.

Table 2. Comparison of shear demand derived from spring model (SP) and wide column (WC) model

| X-direction walls | | | Y- direction walls | | |
|---|---|---|---|---|---|
| Wall | SP model Vx ( kN) | WC model Vy ( kN) | Wall | SP model Vx ( kN) | WC model Vy ( kN) |
| 1 | 86.44 | 106.11 | 3 | 115.85 | 109.91 |
| 2 | 28.81 | 29.90 | 5 | 120.89 | 110.48 |
| 4 | 115.26 | 85.25 | 7 | 3.92 | 10.90 |
| 6 | 14.07 | 17.43 | 8 | 3.92 | 5.13 |

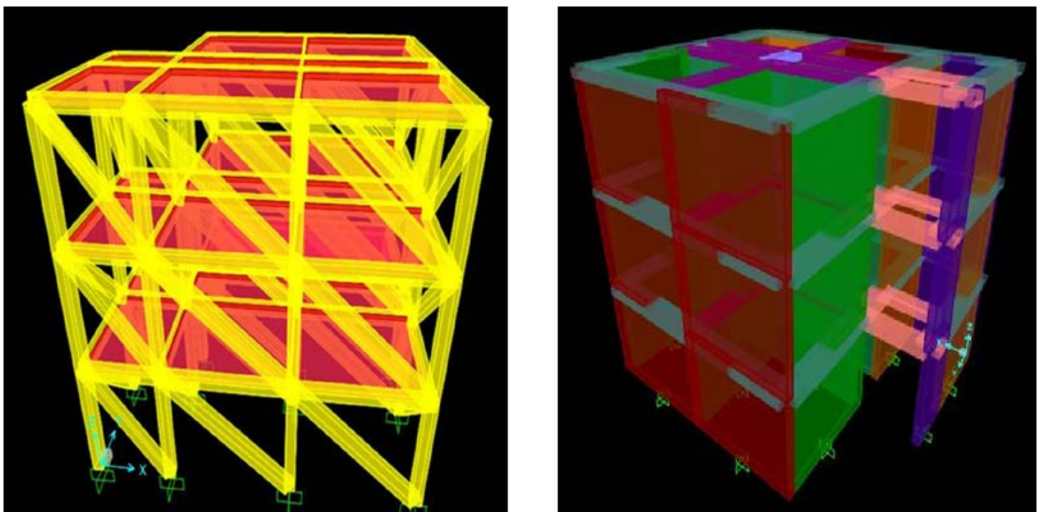
**Analysis of RC frame with masonry infill**

The reinforced concrete frame model of building was analyzed using frame elements for beams columns, shell element for slabs and compression only strut for infill masonry walls. The wide of equivalent compression strut for the model is obtained using method suggested by IS code[11]:

$$W_{ds} = 0.175(\alpha h)^{-0.4} L_{ds} \tag{2}$$

$$\alpha = \left( \frac{E_m t \sin 2\theta}{4 E_f I_c h} \right)^{\frac{1}{4}} \tag{3}$$

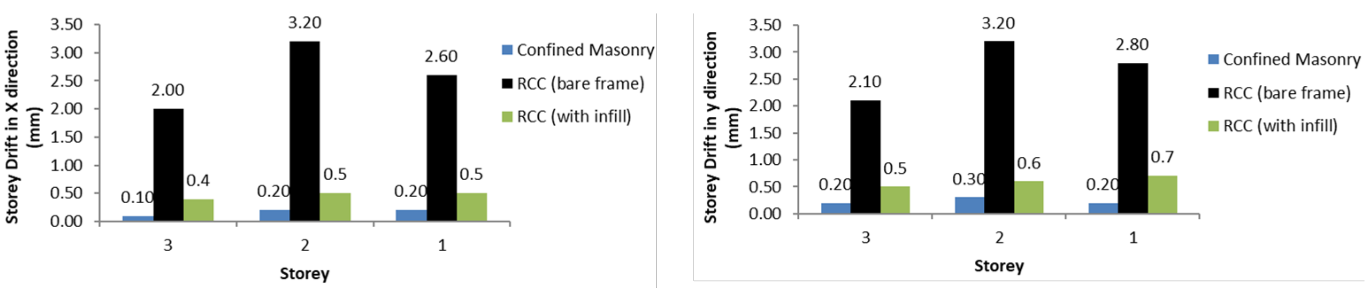
Where, $E_m$ = modulus of elasticity of masonry, t = thickness of masonry wall, θ =inclination of diagonal strut to horizontal, $E_f$ = modulus of elasticity of reinforced concrete, $I_c$ = moment of inertia adjoining column, h = height of wall and $L_{ds}$ = diagonal length of infill wall. In addition, a bare frame model of the building neglecting the effect of infill in the analysis is also carried out. This is most commonly used model in the practice in Nepal for frame building even that with masonry infills. Snapshots of SAP model of RC frame infill with strut elements and wide column model of the building are presented in Figure 2.



(a) (b)

Figure 2. SAP model of the study building: (a) RC frame with masonry infill by equivalent strut (b) confined masonry wide column model

Story drift of the buildings in each floors in x-direction are presented in Figure 3. It is observed that confined masonry provides good control of the drift compared to its RC frame counterpart, particularly with conventional bare frame model. Even compared to frame model with equivalent compression strut, the confined masonry drifts are mostly less than half. This shows the effect of shear wall behavior of the confined masonry.




(a) (b)

Figure 3. Story drifts obtained in different models: (a) X-direction (b) y-direction

**Comparison of Material quantity and costing between RC frame with infill and confined masonry**

As this study also explores economic feasibility of the confined masonry construction against the RC frame building counterpart, bill of quantity and cost estimates were developing following specification and guidelines of the Government of Nepal [12]. Table 3 shows the bill of quantity for the core structural engineering works of the study building (Building 1) excluding floor finishing, plastering and painting works, electrical and sanitation works, HVAC etc. The comparison shows that concrete works in confined masonry is about 30 percent less than that for reinforced concrete frame construction. Similarly, steel reinforcement quantity in confined masonry is 44 percent less. The brick masonry work in the confined masonry is only 14% higher than that in RC frame construction. This all leads confined masonry total of 14% cheaper than equivalent RC frame construction for the same building envelop and floor are and functionality based on 2018 unit rate construction provided by the Government of Nepal [12]. The approximate cost of core structural works for RC frame building is CA$48,000 and the cost of confined masonry construction comes to CA$41,000.

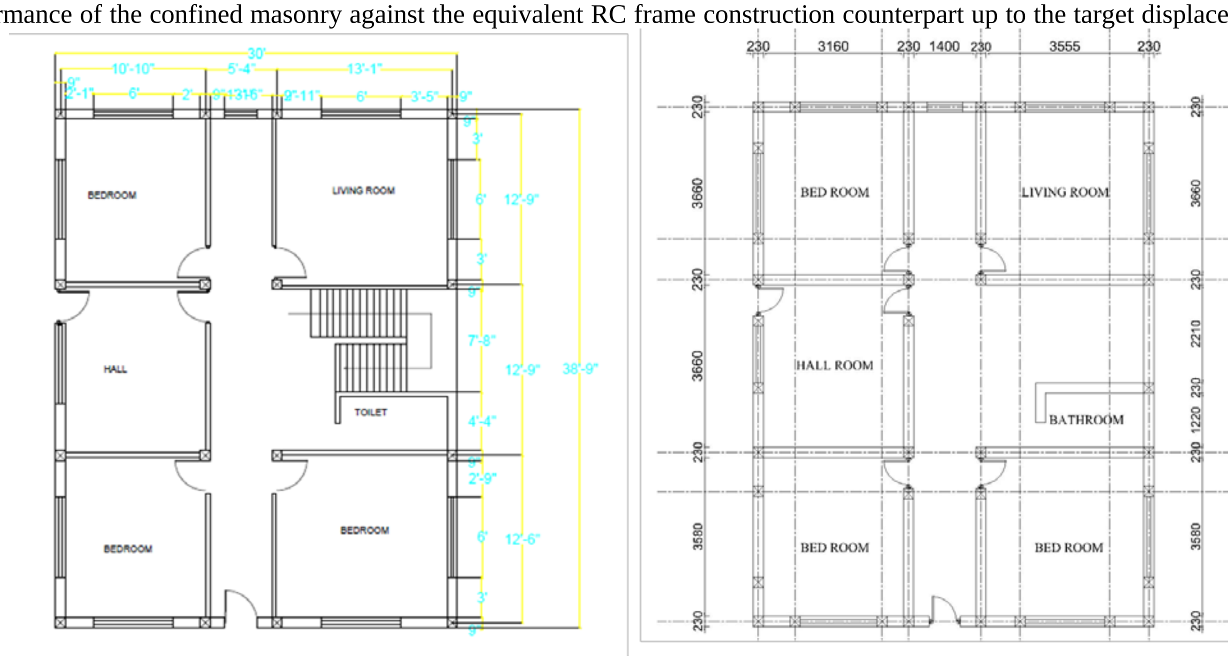
Table 3. Quantity variation in key items of RCC and CM construction

| S.N. | Item | RC frame with infill | Confined masonry | Difference (%) |
|---|---|---|---|---|
| 1 | Concrete works ( $m^3$) | 82.97 | 57.95 | -30.16 |
| 2 | Steel reinforcements (kg) | 8058.79 | 4502.74 | -44.13 |
| 3 | Brick work  ($m^3$) | 97.21 | 111.28 | 14.47 |

**NONLINEAR ANALYSIS**

Structural Analysis was carried out in another reinforced concrete frame building (Building 2) designed and constructed meeting the requirement of Nepal's National Building Code (NBC). This building is also selected from the actual inventory in the city office. It has larger floor area than Building 1 and does have open front. The actual floor plan as submitted to the city office was shown in Figure 4a and modified equivalent confined masonry is shown in Figure 4b. The building is 2-storey high and has similar floor configuration at both story levels. Material properties are similar to that of Building 1.  Column in this building were 230mm x 230mm and beam were 230mm x 300mm including integral slab of 130mm. all brick walls are 230mm thick.

The nonlinear static pushover analysis was carryout to the building models to understand the behavior of the confined masonry in nonlinear range. More importantly, it was to check the adequacy of the construction in terms seismic resistance following nonlinear path up to the target displacement dictated by the demand from seismic hazard. A comparison was made on the performance of the confined masonry against the equivalent RC frame construction counterpart up to the target displacement level.




(a) (b)

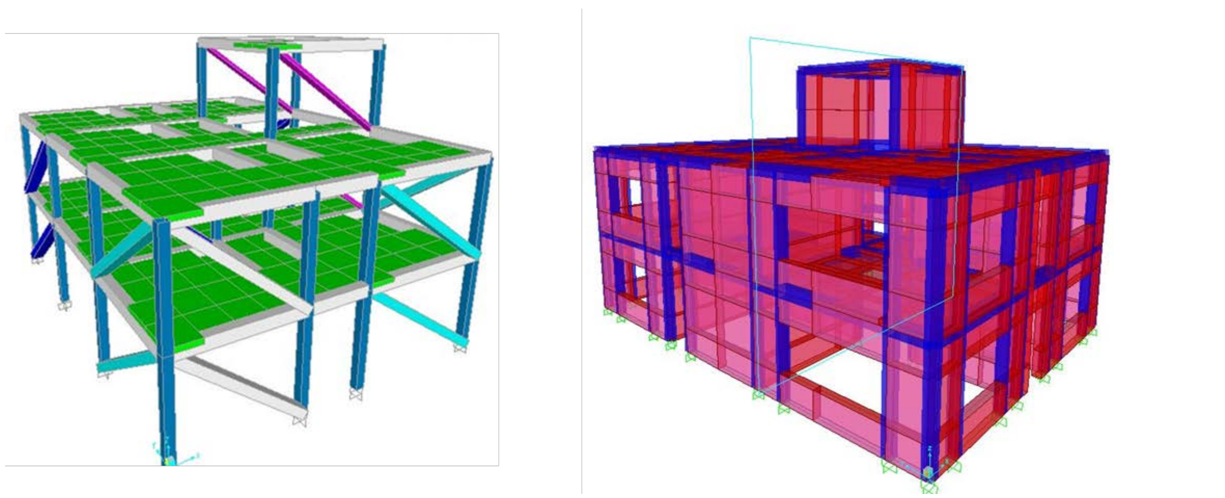
Figure 4: Floor plan of Building 2: (a) Original RC frame with infill (b) Equivalent confined masonry

**Nonlinear model of RC frame with masonry infill and confined masonry**

Beams were modelled as frame elements with reinforcement using section designer in SAP. The force deformation curve is for the beam is used from the model by Mehmet Inel (2006)[13]. For the beam of size 230mm x 300mm for $f'_c$ = 15MPa and $f_y$ = 415MPa with non-ductile detailing, the plastic hinge length is 0.265m, the ultimate rotational capacity at major drop in moment resistance, $\theta_p / \theta_y = 2.41$, and loss of residual strength is considered to be $1.5\theta_p / \theta_y$. For columns of 230mm x230mm size, the plastic hinge length is 0.249m, the ultimate rotational capacity, $\theta_p / \theta_y = 2.15$. Diagonal compression strut were used to model the masonry infill following the model suggested by IS 1893: 2016. Deformation controlled axial P hinges are assigned at the centre of the compression strut. Slabs were modelled as non-linear layered shell element where non-linearity is limited to in-plane. Thickness of concrete is reduced by 25% to reduce out-of-plane stiffness and to include effect of cracking. Tie - beams and tie-columns are modeled as frame elements but the end connections were made pin-ended so that but they can only transmit axial force, not the flexure and cannot resist flexure. The masonry panel is modeled as shell layered section. Acceptance criteria for frame elements in RC frame with infill and confined masonry model are presented in Table 4. The SAP models of the RC frame with infill represented by compression strut and confined masonry are illustrated in Figure 5.

Table 4: Acceptance criteria for the nonlinear hinge in RC frame and confined masonry

| Acceptance level | RC frame with masonry infill | | Confined masonry | |
|---|---|---|---|---|
| | Beam | Column | Tie-beam | Tie-column |
| Immediate occupancy (IO) 10%.$\theta_p/\theta_y$ | 0.241 | 0.2154 | 0.2632 | 0.3382 |
| Life safety (LS) 60%.$\theta_p/\theta_y$ | 1.4461 | 1.2924 | 1.5795 | 2.0295 |
| Collapse prevention(CP) 90%.$\theta_p/\theta_y$ | 2.1691 | 1.9386 | 2.3692 | 3.0442 |



(a) (b)

Figure 5. SAP models of Building 2: (a) RC frame with masonry infill (b) confined masonry

The criteria for different level of acceptance moment curvature relation input for calculation of hinges and acceptance criteria. Displacement controlled load was applied in both model up to the target displacement level, $\delta_T$. The target displacement is calculated for RC frame with masonry infill based on FEMA model[14].

$$\delta_T = C_0 C_1 C_2 S_a \frac{T_{eff}^2}{4\pi^2} \tag{4}$$

The elastic period of the building was found to be $T_i$= 0.23s. From the initial pushover it was found that load displacement curve can be idealized as elastic-plastic resulting to $T_{eff}$ = $T_i$. Other parameters in Eq.(4) are obtained as in the Table 5. As the target displace for the building is found to be 43mm, both models were pushed up to this displacement. The push over curve for the RC frame building with infill and confined masonry is shown in Figure 6.

In RC frame building, there are a total of 20 hinges exceeding the immediate occupancy and two hinges exceeding the life safety and one hinge at collapse prevention. The first hinge crossing the life safety occurred at upper joint of the column, it would go to undesirable state with further increase of load. There were 39 points crossing the immediate occupancy in confined masonry but one of them were in life safety risk. The first yield point in the RC frame was at the displacement of 24mm with $V_y$ = 3000kN. The yielding of confined masonry, however, happened earlier at the displacement of 22mm with $V_y$ = 3300kN. The overall behavior of the confined masonry is found to be robust and more ductile compared to its RC frame with masonry infill counterpart. Figure 7 shows hinge formation in the in one of the y-direction frame of the RC frame building with masonry infill.

Table 5: Target displacement parameters for the RC building with masonry infill

| Parameter | Value | Note |
|---|---|---|
| C0 | 1.2 | Triangular load pattern |
| C1 | 1.0 | Ratio of inelastic to elastic displacement is assumed to be 1 as ductility for the system is very limited |
| C2 | 1.1 | The effective of hysteric curve is depend on performance level and structural framing (FEMA356). For life safety criteria it is taken as 1.1 |
| Sa/g | 2.5 | Based on IS code for equivalent elastic linear system |

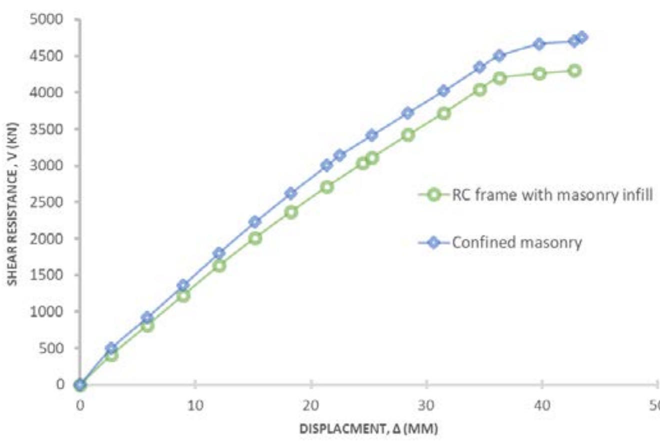



Figure 6. Static non-linear push over curve for RC frame infill and confined masonry models of Building 2

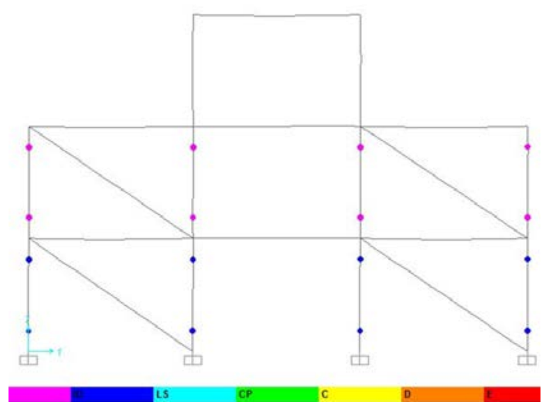



Figure 7. Hinge formation in the frame of RC buildings with infill

## CONCLUSION

This study is a first step to look into the use of alternative design and construction of conventional RC frame residential low rise buildings through confined masonry design and modelling. As the engineering community, construction industry and general public in Nepal are still reluctant to adopt the confined masonry as viable and effective construction method to replace the RC frame, this study provides a first level simple check whether the proposed method is easy to follow and whether it meets the requirement set by the building codes. It also presented the cost associated with the new technology in comparison to the conventional RC construction. The analysis and description of the study is purposefully made simplest possible so that it can be easily understood by regular engineer and building contractor that they don't feel in need of sophisticated analysis to perform the engineering works. Two different actual building were studied so as to have typical representation of low-rise residential construction prevalent in the country. The result shows that confined masonry analysis and design can be simply established with ease and the performance of the building under same lateral loading is better than that of RC frame with masonry infill counterpart. Even from this simple study it is found that the displacement is significantly controlled, shear stress at the critical level is well below the design demand, even lower than RC from infill. The nonlinear analysis shows better ductile behavior of the confined masonry. More importantly, the cost of construction is reduced by 14%. All these results indicate higher performance, better efficiency and economic incentive to use confine masonry in the reconstruction phase of urban housing in the post-earthquake reconstruction program of Nepal. It is also prudent to introduce the technology in regular construction of low rise residential building that uses concrete, steel and brick masonry as major construction materials.

## ACKNOWLEDGMENTS

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