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Effectiveness of GI Wire Mesh on Performance of Stone Masonry Buildings with Mud Mortar

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Abstract

Stone masonry houses with mud mortar are the most common type of houses found in hilly and mountainous regions of Nepal. These structures are highly vulnerable during earthquakes resulting maximum number of casualties. It is necessary to improve the seismic performance of existing and new SMM buildings. Therefore, a simple, affordable, replicable and economical method is introduced to increase the performance and servicabilityof these structures making such houses earthquake resistant. A typical SMM building is numerically modeled in ANSYS software with and without GI wire mesh. Pushover analysis is performed to determine the performance of both models. The capacity of building is evaluated in terms of base shear coefficient versus spectral displacement plot. The performance of the building is also determined by plotting the capacity curve and demand curve in the same graph using FEMA 356. The results show that the performance level of SMM building reinforced with GI wire mesh has increased from collapse prevention level to life safety level proving this technique to be effective in preventing collapse during earthquake and can save human lives.

Keywords

SMM, GI wire mesh, Pushover Analysis, Capacity Curve

1. Introduction

Nepal lies in the lap of Himalayas where the world's youngest mountains are growing a few centimeters each year due to the uplift caused by the northward push of the Indian tectonic plate against the Eurasian plate. As a result of this tectonic movement, earthquakes of large magnitude are recurring at a periodicity of 7 to 8 decades, thus situating Nepal in the most seismically active zone. In 1934, the Nepal-Bihar earthquake of 8.0 magnitude claimed 8,519 lives and 80,893 buildings were completely destroyed and a total of 126,355 houses were severely damaged. The 6.7 magnitude earthquake destroyed 7000 buildings and killed 721 people in 1988. The Gorkha Earthquake in 2015 killed 8,790 lives in total and more than 22,300 were injured. More than 500,000 residential buildings and 2,656 official buildings were collapsed completely and almost 200,000 residential buildings and 3,622 official buildings were partially damaged [1] .

Stone-masonry building is the most ancient, durable, and widespread building method devised by mankind. Stone masonry with mud mortar (SMM) is durable, fire resisting, thermal and sound insulating, uses locally available materials and local manpower. Also it is a technology inherited from our ancestors and resembles our civilization, tradition and culture. Thus, stone masonry is one of the most sustainable and environmental friendly construction materials and due attention should be provided for its promotion.

On the other hand, traditional stone masonry buildings have shown poor performance during earthquakes. More than 70% of the collapsed and damaged buildings in Gorkha earthquake were masonry structures and most of them were the stone masonry buildings. Since SMM buildings has no continuum, has limited elastic strength, lacks integrity and is not feasible to increase its capacity, so they are highly vulnerable in earthquake shaking. But we have no solution other than using locally available materials.

To replace all these buildings at once using modern materials is almost impossible, either due to conservation of cultural and historical values or because of socioeconomic reasons. Thus, enhancing the seismic performance of these buildings is the only viable option for safer construction practice. Various factors such as traditions, cultural and historical significance, transportation facilities, availability of materials, accessibility to technical skills, topographical landscape, geographical location, political decisions, socioeconomics and awareness of risks influence the applicability of each method. It is necessary to develop a restrengthening technique for rubble stone masonry, which is relatively cheap, easily adoptable, effective, durable and requiring less maintenance. Upgrading the capacity of low cost traditional housing is to limit the damage during normal earthquakes and to provide enough time to the occupants to escape in the event of large earthquakes.

SMM is still one of the most popular and feasible construction practice especially in hilly and mountain regions. GI wires are affordable and can be easily transported to these areas than other construction materials. The use of GI wire mesh in SMM increases the deformability (i.e. work done), slows down the initialization of damages and controls volume loss of structure. GI wire mesh jacketing can significantly increase the seismic performance of SMM buildings in terms of its energy dissipation and ductility.

The GI wire mesh system establishes a continuous cage of reinforcement around each and every wall. This reinforcement system is cheap, easy to transport, highly thermal resistant, durable, can be accommodated and tightly fitted in any shape of wall and is based on simple techniques. The wall strengthened with gabion wire mesh is expected to deform, but not collapse and kill people. Therefore, the life safety performance level is achieved.

1.1 Need of Study

The mountains and hilly regions of our country have typical two storied stone masonry buildings in mud mortar in massive numbers. But these structures are highly vulnerable during earthquake shaking. Considering the road access, local economy and material availability we cannot replace the existing structures with structurally sound buildings. So, it is necessary to increase the seismic performance of these existing or new SMM buildings and effectively reduce damage during an earthquake both economically and easily.

Also, most of the houses constructed after Gorkha earthquake by technical and economic assistance of National Reconstruction Authority (NRA) are two roomed single story SMM buildings with attic. These houses can't meet the day to day requirement of people because of its small sizes, so there is high probability of horizontal and vertical expansion of buildings after NRA terminates the work. This signifies the necessity of introducing new technique to overcome the problems encountered during vertical expansion.

For this GI wire jacketing can be a better option to enhance the capacity of buildings because of its low cost, easy transportation, construction technique and especially of its ductile property. The seismic capacity of the models with and without gabion wire mesh will be determined and compared.

2. Methodology

2.1 Selection of Building

A double storey two roomed SMM building of size 9.5m*4.5m was selected. This size represents about 65% of SMM typology houses built after Gorkha Earthquake. Fig 1 and Fig 2 represents the plan of ground floor and first floor respectively. Total height of the building was 3.9m in which ground floor height was 2.1m and first floor height was 1.8m.

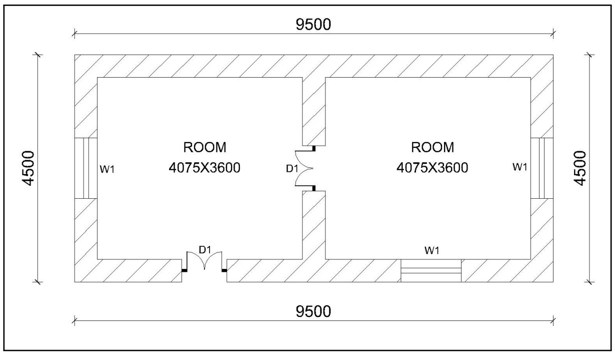

Figure 1: Plan of Ground floor of the model

The sizes of doors were 900mm*1800mm (D1) and 900mm*1500mm (D2) in ground and first floor respectively. The sizes of windows were taken as 1200mm*1200mm (W1) in the ground floor, 1200mm*1050mm (W2) and 1050mm*900mm (W3) in the first floor respectively. Flexible floor was considered throughout the study. The main load bearing element of the building was masonry wall of thickness 450mm. The floor beam size was taken as 80mm*140mm at 500mm centre to centre. This building was named Model 1 (M1). Similarly, Model

2 (M2) was the stone masonry building (SMM) with the same description as of M1 structure strengthened by wrapping with a regular square mesh of size 150mm*150mm using 2mm diameter GI wire on both sides of the walls.

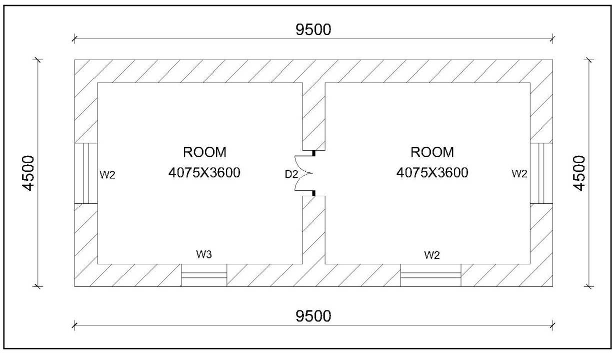

Figure 2: Plan of First floor of the model

2.2 Material Properties

The mechanical properties of SMM was taken from the experimental results performed by Build Change (2019) on Nepalese SMM walls to characterize various elastic and non-linear material properties as listed in Table 1.

Table 1: Material properties for Stone masonary in mud mortar [Build Change (2019)]

Material Properties	Value
Unit weight	2200Kg/m^3
Young's modulus	65.1MPa
Shear modulus	22.4Mpa
Poisson's ratio	0.2
Compressive strength	2.4MPa
Tensile strength	0.02Mpa
Cohesion	0.013
Coefficient of friction	0.4

Similarly, hard timber of density 801kg/m^3 with compressive strength of 71Mpa was taken [2].

The modulus of elasticity and tensile strength for 2mm diameter GI wire mesh was taken as 69000Mpa and 435Mpa respectively and modulus of elasticity for SMM with GI wire mesh was 1.47Mpa [3].

2.3 Numerical Modeling

For finite element analysis, a macro model of the proposed building was prepared using ANSYS software. The 3D geometry of the building was constructed using spaceclaim platform in ANSYS. Timber joist were provided in the interface of ground floor and first floor for flooring purpose. The floor and roof has been avoided in the model for its visual clarity but their load were calculated and assigned on the wall as distributed mass. This is named as model M1. For convenience in discretization and efficiency in solving, the model was splited where two walls from different planes intersected as shown in Fig 3 and mesh was generated for the entire structure as shown in Fig 4.

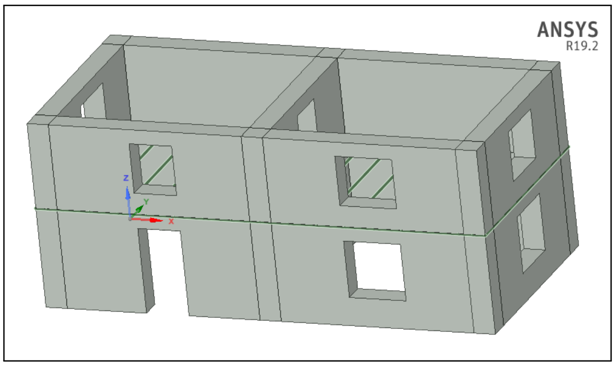

Figure 3: 3D view of model M1

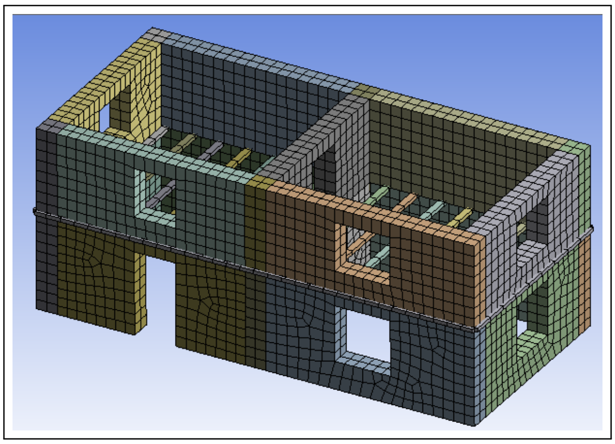

Figure 4: Model M1 after meshing

Since masonry being brittle material, solid65 element was used for modeling the building which has capabilities to undergo crushing on compression and cracking on tension[4]. In this study, ANSYS non-linear concrete model based on William-Warnke failure criteria was used.

The monotonic lateral loading was applied in the form of inertial load. The static structural analysis consists in the application of self-weight in a first step and after deformation and stresses were produced by this section a lateral load is applied in second step. Gravity loads and acceleration were assigned with stepping and sub stepping in longitudinal and transverse directions respectively with boundary conditions and solved for convergence keeping the base of model fixed to determine the roof displacement for pushover analysis.

After analysis of Model M1, using 2mm GI wire, a regular square mesh of size 150mm*150mm is prepared around the SMM model named model M2 as shown in Fig 5.

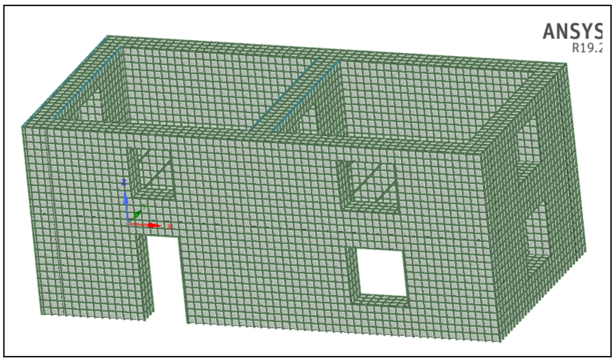

Figure 5: 3D view of model M2

This GI wire mesh created a jacket for both inner and outer surface of the wall. For the connection, contacts were created between wall and wall,wall and timber joist, wall and wire and between wire and wire. This contact between wall and wire can be practically achieved in field by providing thin cement sand plaster on both sides of the wall or by providing GI wire ties across walls at spacing of 300 cm both horizontally and vertically.

After the model M2 is prepared, similar procedure as stated earlier is performed for pushover analysis.

3. Results and Discussion

Static nonlinear analysis of the selected buildings was carried out along longitudinal (X) direction and transverse (Y) direction. Gravity was applied in a first loading step and then incremental seismic forces proportional to mass of the structure was introduced until the analysis stopped due to the collapse of the model. The capacity curve was defined making reference to different control points. Response spectrum was taken from IS 1893 (part I):2016 for 5% damping and converted to demand spectra [5]. Finally, that value of roof drift at the intersection point of capacity curve and demand curve termed as performance point was determined [6].

3.1 Capacity Assessment

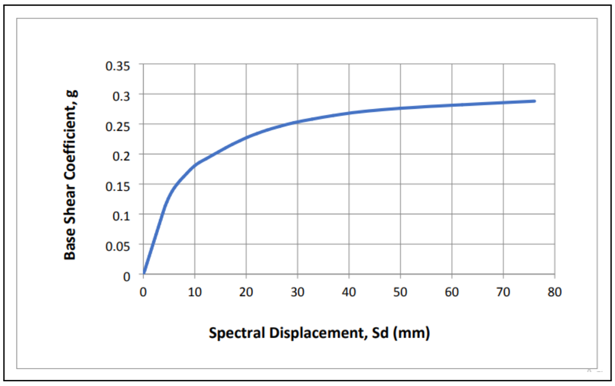

Figure 6: Capacity curve for model M1 along X-direction

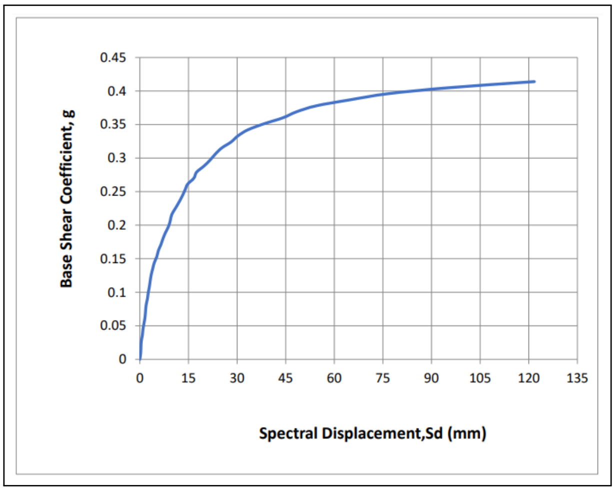

Figure 7: Capacity curve for model M2 along X-direction

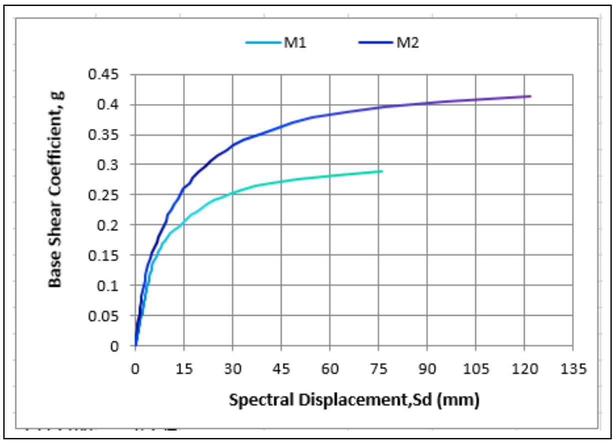

Figure 8: Comparison of capacity curve for model M1 and M2 along X-direction

Along X-direction, the first horizontal branch of the capacity curve was seen at the base shear coefficient of

0.138g for M1 and 0.261g for M2. The ultimate state was reached at the base shear coefficient of 0.288g at a displacement of 76 mm for model M1 as shown in Fig 6. Similarly, the ultimate state was reached at the base shear coefficient of 0.414g at a displacement of 121.7 mm for model M2 as shown in Fig 7. Hence the capacity of building reinforced with GI wire mesh increased by 30.45% and displacement increased by 37.55% as shown in Fig 8.

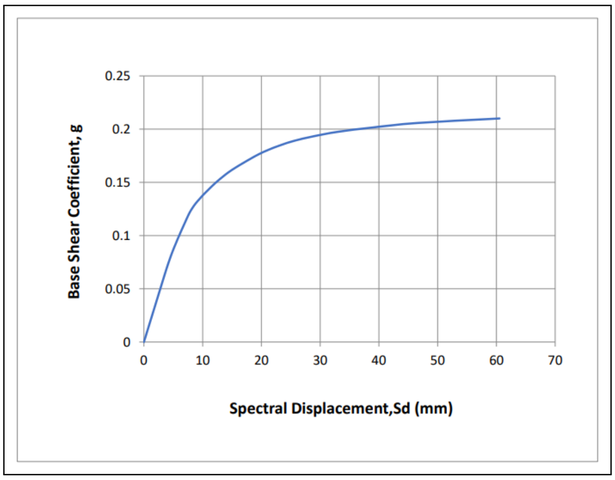

Figure 9: Capacity curve for model M1 along Y-direction

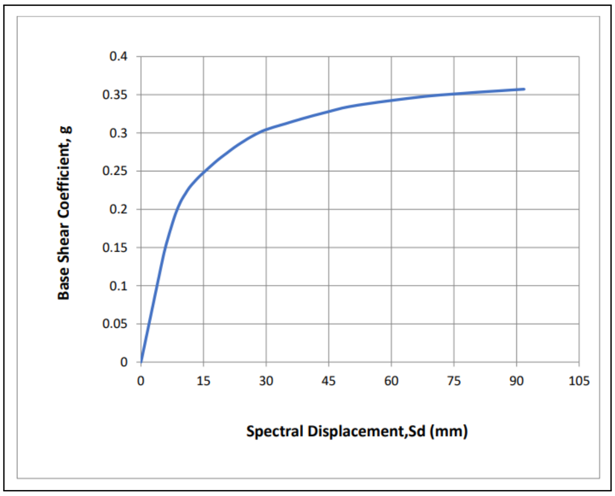

Figure 10: Capacity curve for model M2 along Y-direction

Similarly, along Y-direction, the first horizontal branch of the capacity curve was seen at the base shear coefficient of 0.126g for M1 and 0.22g for M2. The ultimate state was reached at the base shear coefficient of 0.21g at a displacement of 60.5 mm for model M1 as shown in Fig 9. Similarly, the ultimate state was reached at the base shear coefficient of 0.357g at a displacement of 91.8 mm for model M2 as shown in Fig 10. Hence the capacity of building reinforced with GI wire mesh increased by 41.24% and displacement increased by 34.1% as in Fig11.

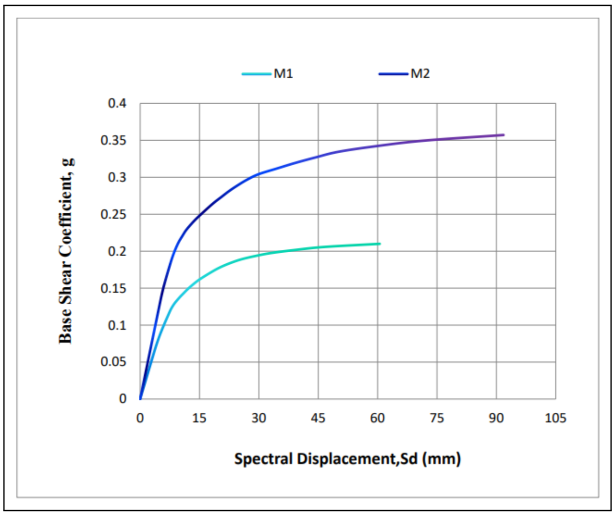

Figure 11: Comparison of capacity curve for model M1 and M2 along Y-direction

3.2 Performance Assessment

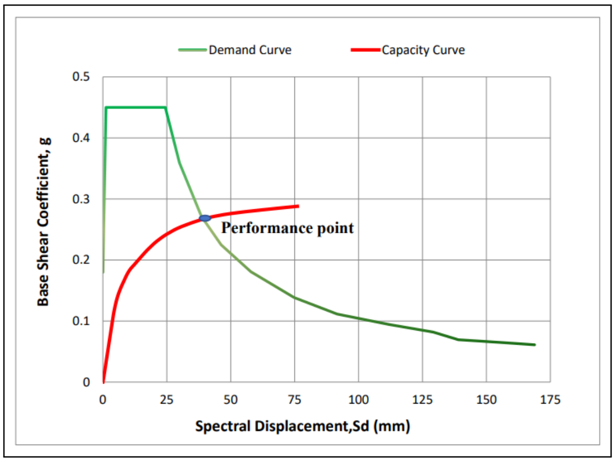

Figure 12: Determination of performance level for model M1 along X- direction

Along X-direction, the performance point in terms of storey drift was found to be 0.89% (i.e. 40 mm displacement) for model M1 and 0.71% (i.e. 32 mm displacement) for model M2. This value clearly showed the performance of URM lied near collapse prevention as shown in Fig 12. But after reinforcing the building with GI wires, the performance increased and life safety was achieved as shown in Fig 13.

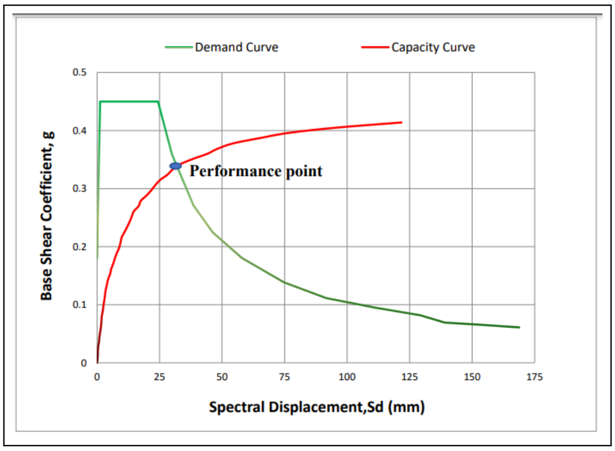

Figure 13: Determination of performance level for model M2 along X- direction

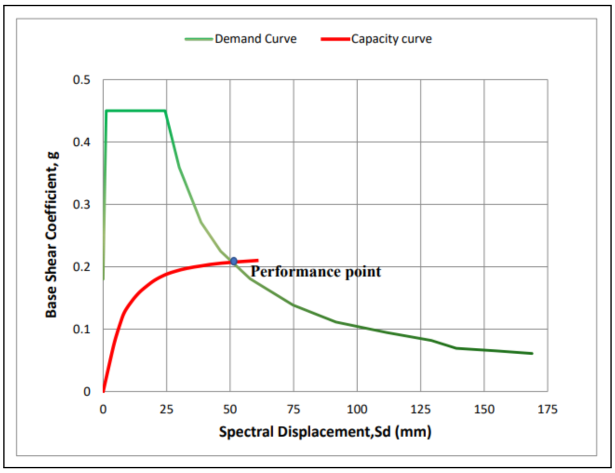

Figure 14: Determination of performance level for model M1 along Y- direction

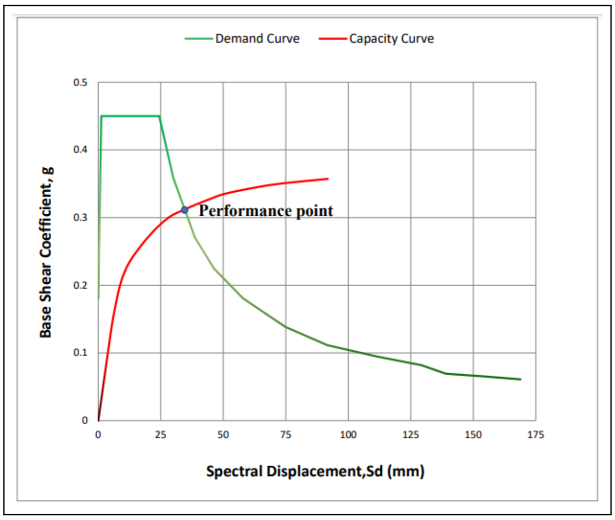

Figure 15: Determination of performance level for model M2 along Y- direction

Similarly, along Y direction, the performance point in terms of storey drift was found to be 1.26% (i.e. 56.8mm displacement) for model M1 and 0.85% (i.e. 38.1mm displacement) for model M2. This value clearly showed that the performance of unreinforced masonry lied near of collapse prevention as shown in Fig 14. But after reinforcing with GI wires, performance of building was increased allowing larger deformation and life safety was achieved as shown in Fig 15.

The results of model M1 and M2 along X and Y direction shows that the GI wire renforcement system allows controlled damage maintaining overall stability of the building and the confining property introduced prevents stones falling from localised damaged portion of the wall allowing larger deformation.

Also, the performance level of the building has increased from collapse prevention level to life safety level along both directions. This is due to the reason that GI wire mesh provides structural integrity to the building and during the earthquake; box action is imparted and prevents from collapse. This result suggests that GI wire reinforcing system can be effective in restrengthening or retrofitting stone masonary buildings with ease.

4. Conclusion

After the pushover analysis of two macro-models in ANSYS and interpreting the results, following conclusions can be drawn:

1. The SMM model is highly vulnerable to lateral loading because of the lack of effective connections between walls at corners and insufficient out-of-plane and in-plane strength. Without appropriate reinforcing system, these structures are highly vulnerable during strong earthquakes resulting high number of casualties.
2. Providing GI wire mesh jacketing on both sides of the wall can contribute to enhance the seismic capacity of SMM largely. Even during severe rocking and sliding of the masonry along multiple bedding planes, the containment mesh was able to hold the masonry together and helped self-centering of the building structures [7]. The capacity of model M2 is increased by 30.45% and 41.24% along X-direction and Y-direction respectively. This is because the

wire mesh provides structural integrity to the building; slows down the initialization of damage and controls volume loss confining cracks and damages to local areas. It increases the ductility of the building allowing larger deformation and avoiding immediate collapse which meets our first objective of increasing the seismic performance of SMM buildings.

3. A GI wire of 2 mm diameter having square mesh of 150 mm opening size is adequate to strengthen a two storey SMM building which satisfies our final objective of using GI wire mesh as a reinforcement system for existing SMM buildings as well as in new construction.

Because of randomness and variations in the properties of stone, mud mortar and workmanship, these findings will not be sufficient to be generalized to all types of random masonry construction [8]. However, the improvement achieved using galvanized wire mesh will be applicable to all types of walling.

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