Seismic Strengthening Of Typical Stone Masonry Wall Using GI Wire Mesh

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Abstract— **This paper explores one of the methods of Strengthening existing low strength unreinforced stone masonry wall using GI wire meshing. Stone Masonry houses in mud mortar without any earthquake resistant features is the most common type of construction for economically weaker section. In this study, Stone masonry wall in mud mortar was modeled in SAP 2000 and analysis was done for the resultant stresses and its distribution along horizontal and vertical directions as per IS standards. we observe that the stresses occurred were beyond its permissible strength. So, GI wire meshing as a seismic strengthening measure was considered and designed, where new analysis showed improved performance. By the study, it has been inferred that GI wire mesh intervention significantly increases lateral strength and deformability of the seismically deficit low strength masonry structure. Lack of structural integrity is addressed and potential out of plane failure has been notably decreased. The basic focus of retrofitting was to enhance the integrity of the masonry building so that whole structure acts as box.**

Keywords— Seismic strengthening, Stone Masonry, Mud Mortar, GI wire mesh

I. INTRODUCTION

Construction of building in Nepal is largely dictated by the availability of construction materials and labor skills to the immediate locality. The community relies on the local craftsman for construction, although most of them have no formal training. These types of construction behavior do not incorporate seismic safety as seismic design is not part of overall practice. Locally available materials like Stone, rubbles, timber, adobe and mud are mostly used in rural construction. These types of earthen buildings has low seismic resistance causing huge devastation during earthquake. Majority of the buildings in the recent 2015 earthquake were damaged belonging to stone masonry, of which, severe problems of failure were seen in walls. Old, cultural and historical monuments, functionally changed and poorly designed buildings are the most for seismic strengthening. Earthquake damage patterns in Masonry buildings are:

- Corner separation
- Diagonal cracking
- Out of Plane Failure flexural failure
- In-Plane flexural failure
- Delamination of walls

The most common and dominant modes of failure are out-of-plane and In-Plane Failure of walls.

Out-of-plane failure: Out-of-plane failure of wall in un-reinforced masonry buildings are the most vulnerable caused collectively by inadequate anchorage of the wall into the roof diaphragm and limited tensile strength of masonry and mortar. The flexural wall will not resist any shear however, will be checked for out of plane forces with vertical loads. This action produces combined action of axial compression and bending forces. The relationship between the combined effects of axial load (P) and bending (M) can be related to the virtual eccentricity (e=M/P), and for linear elastic behavior it can be expressed as

$Fm = P/A + M/S$ Where,

Fm =allowable stress for combined compression and bending

A = area of section and,

S = sectional modulus

Some of the damage's patterns seen are like Horizontal cracks along the façade, Partial collapse of an external wall, Cracks at lintel and top of slender piers, Cracks at the level of the roof etc.

In-plane failure: In-plane failures of walls in un-reinforced masonry structures due to excessive bending or shear are most common and as example from double diagonal (X) shear cracking. It is assumed in Seismic design of masonry that the total base shear induced by an earthquake will be resisted by the in-plane shear wall and flexural wall will not resist any shear. Some of the damage patterns seen are like Vertical cracks on openings, Diagonal shear cracks on parapets and in doors and window lintels, Diagonal shear cracks in the masonry piers between openings, Crushing of corners of walls due to excessive compression stress, Horizontal flexure cracks on top and/or base of masonry piers etc.

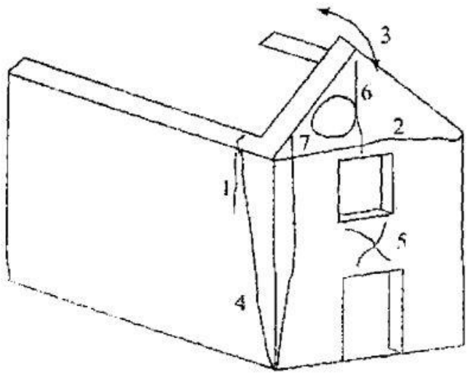

Fig. 1. In-Plane failure characterization (pasquale and Orsmi, 1999)

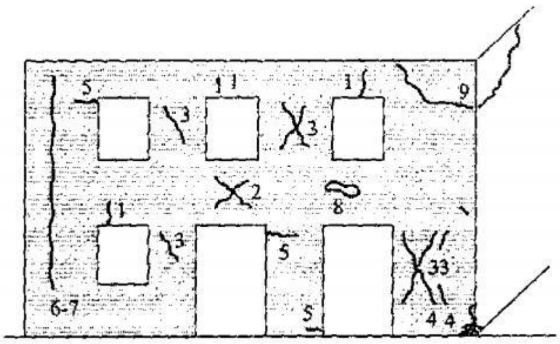

Fig. 2. Out -of-Plane failure characterization (zuccaro and Papa, 1999)

Some of the methods of retrofitting which can be implemented to resist the low to medium level of earthquake without collapse and able to delay the collapse during high seismic events so that occupants could escape are wall jacketing, bolting of walls, splint and bandage etc. This study focuses on seismic strengthening of wall against in-plane and out-of-plane failure using one of the simplest intervention techniques: wall-jacketing using GI mesh in cement mortar because of following advantage criteria.

- Retention of same structural system
- Minimum intervention to the existing structural system
- Improvement of integrity between the building component
- Easily implementable by local craftsmen
- Improvement of structural as well as non-structural components

GI Wire Meshing (Jacketing): To improve the lateral resistance in damaged masonry walls or where there is need of strengthen to the existing structure, the application of reinforced cement coating forming a jacket on one or both side of the wall is used. Ferro-cement or wire fabric like FRP materials is used as alternative of steel. In Strengthening of Stone masonry wall with wire mesh, process is done by removing of plaster from the damaged portion of the walls. Welded wire meshes or wire fabric is placed around the entire damaged region and Steel ties are inserted at regular intervals of 30 cm to 40 cm in order to tie the mesh with the wall and plastered by cement sand mortar of (20-40) mm thickness on the outer surface.

Some of the Caution need to take care of while designing by this method are:

- Additional thickness of concrete may add sufficient weight and overturning moment so we need to strengthen the foundation for increased bearing area.
- Special designing may require by the extremely high stress concentration and overturning forces, if only isolated wall meshing was done.
- Jacketing highly increases the stiffness of the masonry and caution must be taken not to produce tortional moments.

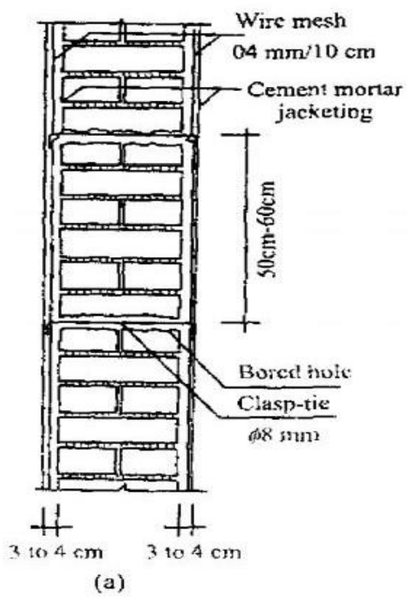

Fig. 3. Methods for jacketing (a) Use of wire mesh (UNDP, 1983)

II. METHODOLOGY

A typical style, single wall 14 in (350 mm) thick, 12 ft (3660mm) high and 12 ft (3660 mm) with opening (6 x 6) ft. (1830 x 1830) mm long is considered for the study.

Seismic Base Shear has been calculated as per IS,
Seismic Zoning Factor (Z =5),
Importance factor (I=1),
Response Reduction Factor (R=1.5),
Period,T= (0.09XH)/(D^0.5)=0.1722,

Similarly, other loads assigned in the wall are Dead load due to self-weight of slab and floor finish. The live load used is 1.5 KN/m2.

The other parameters adopted for wall modeling are:
Unit Weight = γ = 19 KN/m3
Poisson's Ratio = ν = 0.15
Modulus of Elasticity (E) =2076 N/mm2
Slenderness ratio (SR) = $\frac{3.66}{0.35}$ =10.45 = 10 taken and
Eccentricity of wall = 0
Height to width ratio of masonry unit < 0.75 (assumed).

The wall was modeled and analyzed using SAP 2000 and stress concentration and distribution was compared with allowable stresses of Shear, axial compression and tension. Then, Failure is addressed with the strengthening measure of wall jacketing by using GI wire meshing in cement sand mortar. Using layered shell design approach providing equivalent thickness of steel throughout the wall is now used for modelling and analysis of composite Section. Then resultant stresses induced after strengthening is now checked against permissible stresses for the composite section.

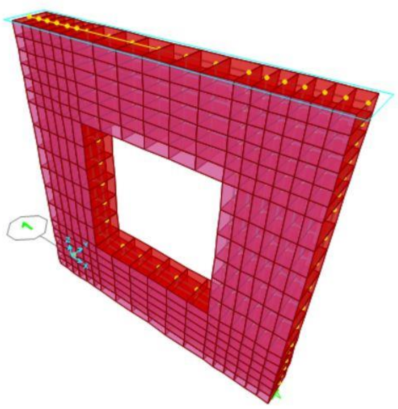

Fig. 4. 3D Model of wall in SAP2000

The permissible stresses check were calculated as per IS 1893: 2000. The permissible stresses for retrofitted section were deliberated as :

Permissible Compressive Strength ($F_{retrofittd\ wall}$)

$F_{retrofittd\ wall} = F_{wall} + F_{steel}$ (i)

$F_{wall\ only} = f_b \times K_s \times K_a \times K_p$ (ii)

$F_{steel} = f_s \times Ast$ provided (iii)

For L1 mud mortar and 40 Mpa Stone masonry

Basic Compressive strength (f_b) = 1.06 N/mm^2
Stress reduction factor (K_s) = 0.89
Area Reduction Factor (Ka) = 0.7 + 1.5 A =1 for A being greater than 0.2 m^2
Shape Modification Factor (K_p) =1

Similarly, permissible Shear Strength of retrofitted wall ($\tau_{c\ (retrofitted\ wall)}$) was computed as,

$\tau_{c\ (retrofitted\ wall)} = \tau_{c\ original\ wall\ only} + \tau_{c\ (steel)}$ (iv)

$\tau_{c\ original\ wall\ only} = 0.1 + f_d/6$ (v)

Where,
f_d = compressive stress due to dead load in N/mm^2
τ_c = permissible shear stress in N/mm^2
$\tau_{c\ (steel)}$ computed from Table 23 of IS 456:2000

III. Results and Discussion

The seismic analysis of the wall was carried out considering earthquake in x and y directions. The design forces for retrofitting were determined by considering combined effect of axial load and bending. The determination of steel for GI mesh in horizontal and vertical directions for resisting the resultant stresses.

TABLE I. RESULT COMPARISION TABLE

Parameters	Unit	Un Reinforced Model	Retrofitted Model	Remarks
Length	m	3.66	3.66	Wall Jacketing with GI wire mesh 3.5 mm @ 25 mm both ways with 50 mm thick M20 mortar all over the wall.
Height	m	3.66	3.66	
Thickness	m	0.35	0.45	
Permissible compressive stresses	N/mm²	0.94	2.94	Capacity has increased
Model S11	N/mm²	0.961	1.677	Axial Compression decreased
Model S22	N/mm²	1.021	1.852	Axial Compression decreased
Permissible Shear Stress	N/mm²	0.113	0.463	Shear Strength has increased.
Model S12	N/mm²	0.512	0.308	Shear Stress has decreased
Inter Story Drift	mm	0.617	0.201	Displacement has Decreased.
Base Shear	KN	20.8	28.2	Base shear capacity has Increased.

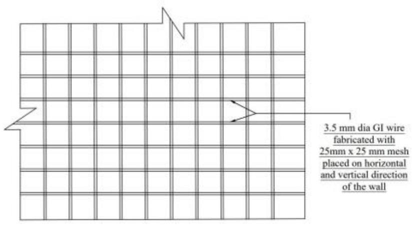

Fig. 5. Detailing of GI wire mesh

1. The allowable compressive strength of the wall with retrofitting is 2.94 N/mm² compared to 0.94 N/mm² of unreinforced Stone Masonry which is significantly higher by nearly 3.2 times its original strength.
2. The permissible shear stress capacity of the wall increases significantly from 0.113 N/mm² to 0.463 N/mm² by about 4 times its original shear strength.
3. The inter story drift of the wall has decreased after the reinforcing input.
4. The overall stresses are now distributed rather than in localized form.

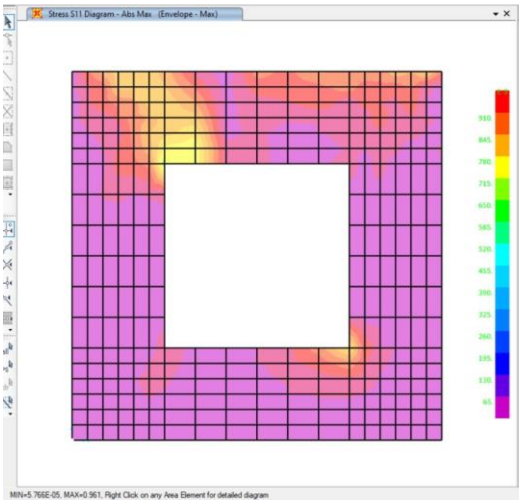

Fig. 6. Axial Stress Distribution S11 in Unreinforced Model

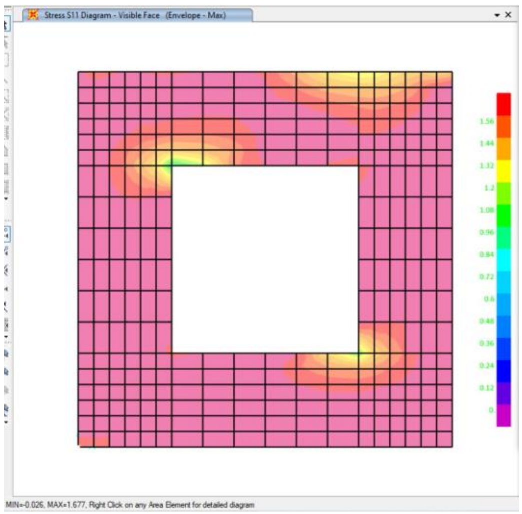

Fig. 7. Axial Stress Distribution S11 in Retrofitted Model

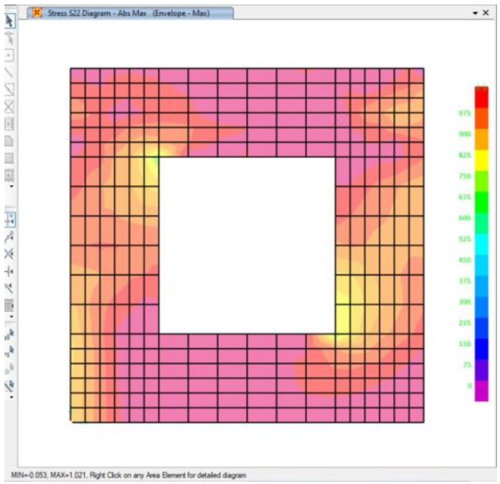

Fig. 8. Axial Stress Distribution S22 in Unreinforced Model

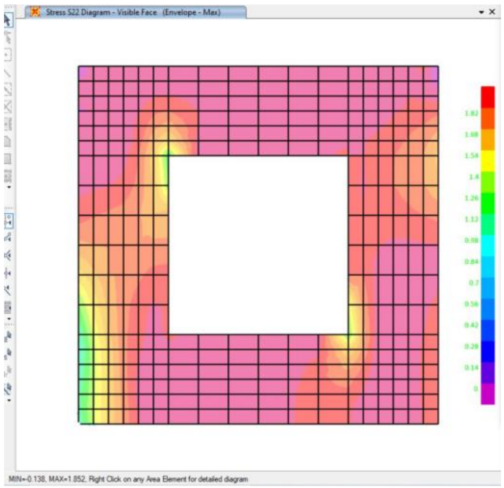

Fig. 9. Axial Stress Distribution S22 in Retrofitted Model

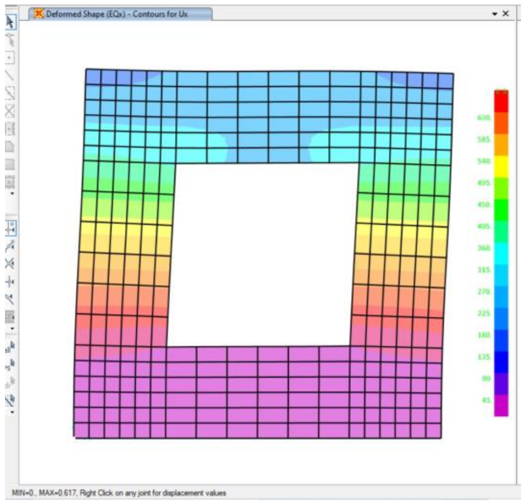

Fig. 10. Deformed Shape of Unreinforced Model

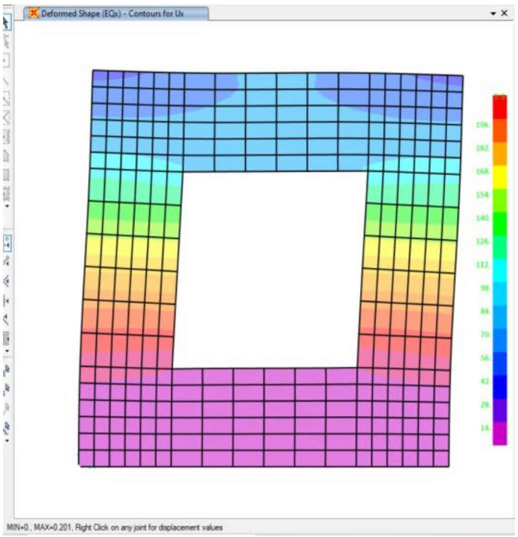

Fig. 11. Deformed Shape of Retrofitted Model

Constraints:

1. We modelled the reinforcing properties as a thin layered equivalent steel section which may perform different behavior than the actual wire mesh.
2. Basic compressive stress of Stone masonry is assumed by taking crushing Strength of masonry unit as 40 Mpa and L1 grade of mud mortar.
3. Height to width ratio of masonry unit is assumed to be less than 0.75.
4. Eccentricity of wall is assumed to be zero in manual calculation.

IV. CONCLUSIONS

Recent Earthquake have caused extensive damage to stone masonry buildings and such devastation after earthquake has underlined the need of retrofitting. Strengthening of Stone masonry wall with GI wire meshing has been most common type of construction technique in Nepal. This method of retrofitting is considerably effective method of minimizing hazard due to adoptability by local craftsman and owner and low complication.

It is inferred that:

i. Jacketing Scheme of strengthening can restore the strength even more than the original system.
ii. GI wire mesh not only increases the lateral resistance of the wall but also increase its shear and flexural capacities of the model.
iii. Structural integrity of the whole structure is increased due to confinement with GI wire mesh in terms of in-plane and out-of-plane forces.
iv. In-plane strength of stone masonry walls reduced due to opening or any other reasons may be increased by employing the technique of GI wire meshing.

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