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Seismic Strengthening of Re-entrant corner Masonry Building

Abishek Bhattarai
Department of Earthquake Engineering
Thapathali Campus
IOE, TU
Kathmandu, Nepal
bhattarai25abishek@gmail.com

***Abstract*— The seismic performance of the building is influenced by the presence of re-entrant corners in the structure. Re-entrant corner causes concentration of stresses and torsion related problem during a seismic event. This defect is more vulnerable in case of masonry building due to its brittle nature. This paper deals with the behavior of re-entrant corner irregularity in masonry building and strengthening measures for it. The objective of study is to compare the capacity of building in different cases of plan irregularities before and after retrofitting. An arbitrary L- Shaped masonry building is taken for analysis. Subsequent analysis of the structures after strengthening with the steel angle at the junction of re-entrant corner was also carried out. The results of analysis confirm the improvement of seismic capacity of the re-entrant corners of the building with slight reduction of story drift.**

Keywords—Re-entrant corner, masonry, steel angle, seismic strengthening

I. Introduction

The practice of construction of masonry building with the irregular configuration of re-entrant corner is frequent. Re-entrant corners are the most useful set of building shapes that enables the accommodation of large area in the compact form [1]. They are more useful in case of school buildings and other service-related buildings.

The buildings with the re-entrant corners are the serious form of irregularities that abruptly effect the strength and stiffness of the structure. So, it is necessary to understand the behavior of such deficiency of the building in order to make it seismic resistant.

The effect of re-entrant corner during a seismic event is associated with two problems:

- Local stress concentration at the re-entrant corner due to the differential movement of different wings [1]
- Torsional movement due to the relative separation of center of mass and center of stiffness of the building [1]

Unreinforced masonry is brittle in nature and hence it is very susceptible to damage during earthquake. In addition, presence of re-entrant corner makes it more disastrous. So, this paper study about the behavior of masonry building through numerical modeling and suggest for the strengthening measures to control the disastrous effect of re-entrant corner.

Basically, two types of failures are associated with the masonry structures In-plane and Out of plane failure

So, this paper study about the behavior of masonry building through numerical modeling and suggest for the strengthening measures to control the disastrous effect of re-entrant corner.

In order to do so following models are taken into consideration and analyzed in ETABS

Model M1: One story masonry building with re-entrant corner

Model M2: One story masonry building strengthened with steel angle at re-entrant corner

Model M3: Two story masonry building with re-entrant corner

Model M4: Two story masonry building strengthened with steel angle at re-entrant corners

II. Method of Analysis

Linear static analysis or seismic coefficient method is used for seismic analysis of the masonry building. IS 1893:2002 [7] code is used for calculating seismic coefficient of the building. The seismic analysis of structure is carried out by considering the peak values of ground acceleration as in case of equivalent static method. Code design practices use the concept of force-based design, in which individual components of the structure are designed for strength based on the results obtained from elastic analysis.

III. Structural Modeling Details

Altogether four masonry buildings are modeled which includes the models before and after retrofitting with the angle section. Plan area of building in each case of building are same.

TABLE I. MODELING DETAILS

Maximum dimension along X-axis (L)	6m
Maximum dimension along Y-axis (B)	10m
Projection of re-entrant along X-axis (l)	3m
Percentage projection of re-entrant along X-axis (l/L)	50%
Projection of re-entrant along Y-axis	5m
Percentage projection of re-entrant along Y-axis (b/B)	50%
Plan Area of re-entrant buildings	45 m^2
Number of stories	1 story buildings and 2 story building
Floor to floor height	3m
Slab thickness	125mm
Thickness of masonry wall	230mm
Dead load + live load	8 KN/m^2
Seismic zone	V
Importance factor	1
Soil type	Medium (Type- II)
Response Reduction Factor	1.5
Steel angle section	500mm x 500mm x 25mm, Fe-250 steel
Brick size	19cm x 9cm x 9cm modular brick
Crushing strength of brick	10 N/mm^2
Modulus of Elasticity of Brick Masonry	2200 N/mm^2
Mortar type	M1

IV. RESULT AND DISCUSSION

The Structural models of masonry buildings mentioned above are subjected to linear static analysis as per the recommendations of IS 1893:2002 [7] using ETABS. Also, the capacity of wall in axial, shear and bending is calculated by the aid of manual calculation using IS 1905:1987 [6]. The confinement of re-entrant corner with angle section in two layer (inner and outer side of the wall) contributes in increasing the load bearing capacity of attached walls. It also increases in-plane and out of plane stiffness of the attached walls which helps in minimizing the effect of over stressing of the walls at the re-entrant corners due to torsion. The result of analysis indicates that the increase in stiffness of the walls at re-entrant corner increases the story stiffness of the building which ultimately decreases the story drift.

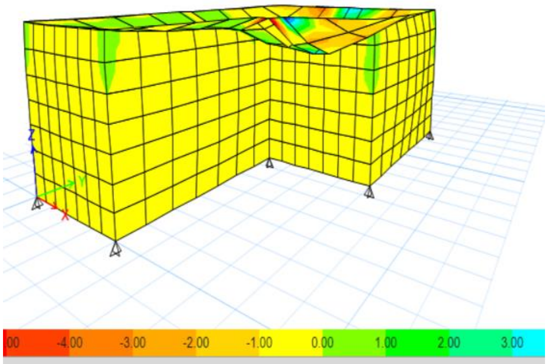

Fig. 1. Induced axilal stress at re-entrant corner for M1

A. *Capacity of wall before retrofitting*

Basic Compressive stress (f_b) = 0.96 N/mm^2, from table 8 of IS 1905:1987

Permissible compressive stress (F_a) = $f_b * k_s * k_a * k_p$

k_s =Stress reduction factor (function of slenderness ratio and eccentricity of wall)

k_a = Area reduction factor

k_p = Shape modification factor

Permissible shear strength of masonry (F_v) = 0.1 + f_d /6

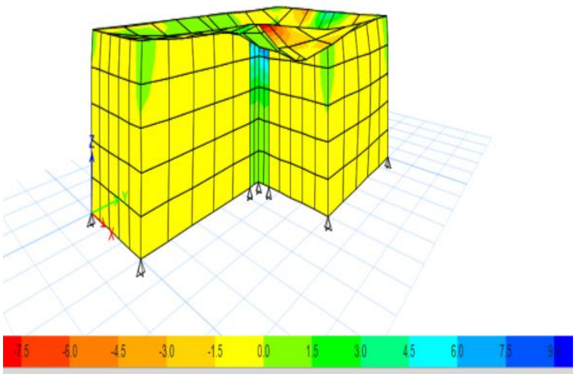

Fig. 2. Induced axilal stress at re-entrant corner for M2

B. *Capacity of wall after retrofitting*

$F_a = F_{wall} + (F_{steel})_c$

$(F_{steel})_c$ = Direct compressive strength of steel

$F_b = F_{bd}$ =Bending strength of steel

$(F_{steel})_c$, F_{bd} are adopted from IS 800:2007

TABLE II. MAXIMUM STRESSES IN RE-ENTRANT CORNER

Model	Maximum stresses in re-entrant corner		
	Compressive	Tension	Shear
M1	0.87	0.34	0.15
M2	5.83	4.22	1.04
M3	0.64	0.43	0.11
M4	4.35	2.89	0.62

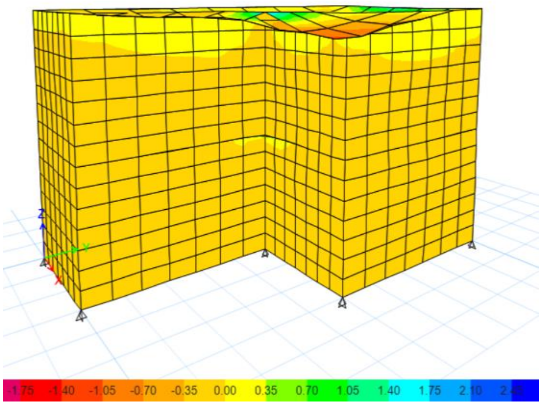

Fig. 3. Induced axilal stress at re-entrant corner for M3

TABLE III. CAPACITY OF WALL AT RE-ENTRANT CORNER

Model	Capacity		
	Compressive	Tension	Shear
M1	0.749	-	0.12
M2	15.6	14.88	8.93
M3	0.749	-	0.12
M4	15.6	14.88	8.93

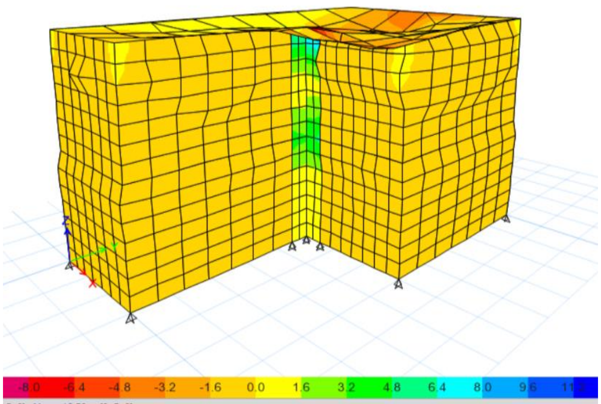

Fig. 4. Induced axilal stress at re-entrant corner for M4

C. Calculation of eccentricity of wall

The stiffness of the wall is

$K_{wall} = E_m t / [4^* (h/d)^3 + 3 (h/d)]$

$K_{retrofit} = K_{composite} + K_{wall}$

TABLE IV. STIFFNESS OF RE-ENTRANT WALL

Model	Stiffness of Re-entrant wall			
	storey 1		storey2	
	X-direction wall	Y-direction wall	X-direction wall	Y-direction wall
M1	72285	189940		
M2	83622	201277		
M3	72285	189940	72285	189940
M4	83622	201277	83622	201277

TABLE V. MAXIMUM DEFLECTION OF WALL

Model	Maximum Deflection in wall			
	Story 1		Story 2	
	U_x	U_y	U_x	U_y
M1	0.117	0.066		
M2	0.118	0.067		
M3	0.318	0.174	0.659	0.342
M4	0.186	0.201	0.432	0.426

Due to the confinement of cross walls by steel angle at re-entrant corner, in plane wall helps in stability of outplane wall

$K_{out\ of\ plane} = m * K_{inplane}$

Here, m is the coefficient of distribution of in-plane stiffness to out plane stiffness.

TABLE VI. STOREY STIFFNESS

Model	Story Stiffness			
	story 1		Story 2	
	Stiff X	Stiff Y	Stiff X	Stiff Y
M1	834494.283	1444298.51		
M2	835940.33	1455522.742		
M3	794745.709	1345360.439	512940.002	1027635.556
M4	841136.526	1463822.57	83622	201277

TABLE VII. STOREY DRIFT

Model	Storey Drift			
	Storey1		Storey2	
	Drift X	Drift Y	Drift X	Drift Y
M1	0.117	0.067		
M2	0.116	0.066		
M3	0.325	0.175	0.348	0.169
M4	0.313	0.176	0.32	0.171

- Stress induced in the re-entrant corner of the wall is more in a single-story building than in two story building because of the vertical stability provided by the upper story against lateral and torsional stress
- There is a significant increase in the permissible strength of the wall at re-entrant corner after strengthening because of confinement of overstressed brittle corner with high strength and ductile steel angle
- Stiffness of the walls increased to a considerable amount which ultimately helps in decreasing the deflection of wall after strengthening

- There was slight increase in the story stiffness of the building

Limitations of the study

- It is better recommended for the use of dynamic analysis rather than static analysis
- Vulnerability transfer to other corners after strengthening of re-entrant corner is not considered
- The effect of abrupt change in capacity of the wall at the junction of wall and steel angle is not considered
- The effect of re-entrant corner is even more vulnerable in case of openings which is not considered

V. CONCLUSION

The seismic performance of re-entrant corner masonry building is increased by the confinement of steel angle in the re-entrant corner.

- The induced compressive stress of the wall after retrofitting is increased to near about 6-7 times while the capacity has increased to about 20 times. This enormous increase in capacity of wall at re-entrant corner is due to the addition of high strength steel angle.
- The lateral stiffness of the re-entrant wall is increased at the range of 5-15 % while the story stiffness is increased to less than 1% which clearly indicates the mechanism of local retrofitting of the walls
- Thre is considerable reduction in the deflection of wall but very slight decrease in the storey drift

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