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Analysis of Reinforced Concrete Coupled Shear Wall Using Finite Element Method

Gummadi Amar
Assistant Professor, Dhanekula Institute of Engineering & Technology, Vijayawada, AP, India

Abstract
The growth of population density and shortage of land in urban areas are two major problems for all developing countries including India. In order to mitigate these two problems, the designers resort to high-rise buildings, which are rapidly increasing in number, with various architectural configurations and ingenious use of structural materials. An earthquake in India on January 26th, 2001 caused considerable damage to a large number of RCC high-rise buildings. This particular incident has shown that designers and structural engineers should ensure to offer adequate earthquake resistant provisions with regard to planning, design, and detailing in high rise buildings to withstand the effect of an earthquake to minimize disaster. As an earthquake resistant system, the use of shear walls is one of the potential options.
The main idea of taking this topic of “ANALYSIS OF REINFORCED CONCRETE COUPLED SHEAR WALL USING FINITE ELEMENT METHOD” is the challenging task in designing of Coupled shear wall manually by IS 13920 for a ten storey office building and also verifying and analyzing this same structure using ANSYS 12 software.

Keywords
Earthquake, Shear Wall, Coupled Shear Wall, Finite Element Method, Ansys 12.

I. Introduction

Shear walls are vertical elements of the horizontal force resisting system. Shear walls are constructed to counter the effects of lateral load acting on a structure. In residential construction, shear walls are straight external walls that typically form a box which provides all of the lateral support for the building. Lateral forces caused by wind, earthquake, and uneven settlement loads, in addition to the weight of structure and occupants; create powerful twisting (torsion) forces. These forces can literally tear (shear) a building apart. Shear walls are especially important in high-rise buildings subjected to lateral wind and seismic forces.

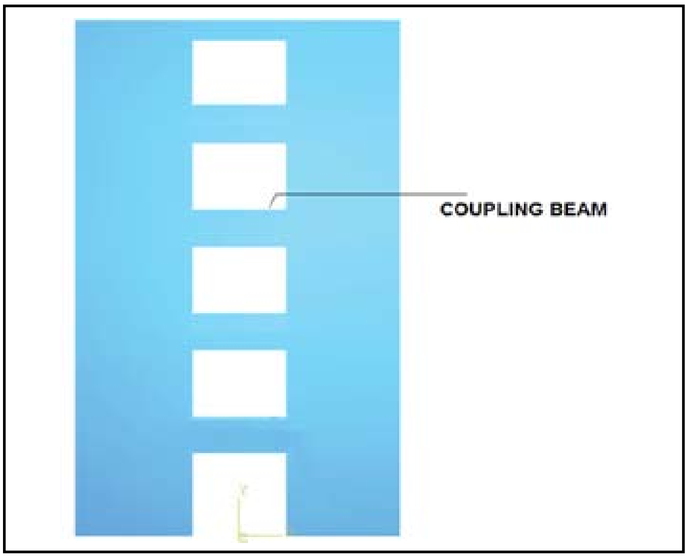

Fig. 1: Coupled Shear Wall

Architectural requirements lead to repeated openings from floor to floor – result is isolated walls connected by coupling beams. Coupled shear walls shall be connected by ductile coupling beams. Coupling beams must have large ductility as they are subjected to extensive inelastic deformations at their ends.
In coupling beams of small span-to-depth ratio, diagonal reinforcement is much more effective in controlling shear displacements and in preventing sliding shear failure as compared to conventional parallel reinforcement. Lateral stiffness and strength of system significantly influenced by design of coupling beams.

A ten storey building with plan dimensions as shown

Table 1: Dimensions of an Office Building

Parameters	Dimensions
Storey Height	3.1 m
Total Building Height (H)	3.1×10 = 31m
Floor Area	28.8 × 9.6 = 276.48 m^2
Depth Of Wall (L_w)	9.6 m
Length Of Coupling Beam (L_b)	1.6 m
Shear Wall And Slab Thickness	300 mm
Column And Beam Size	300 × 600 mm
Materials	M 30 & Fe 415
Number of Shear Walls	4

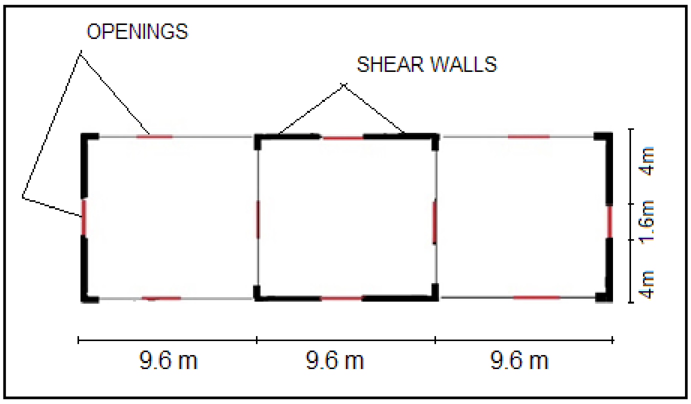

Fig. 2: Plan Area

II. Design Parameters (As Per Is 1893: 2002)

Building is situated in Delhi zone IV.
Zone factor (Z) = 0.24
Importance factor (I) = 1.5
Response reduction factor (R) = 3
Ductile shear wall with OMRF (R) = 3

Table 2: Lateral Force & Shear Calculations

Floor	Weight (Wi) (kN)	Height (m)	$W_i h_i^2$ (10^6)	Design Lateral Force (kN)	Shear (kN)
10	3184.94	31	3.06	498.51	498.51
9	3184.94	27.9	2.47	402.39	900.9
8	3184.94	24.8	1.95	317.67	1218.57
7	3184.94	21.7	1.49	242.73	1461.3
6	3184.94	18.6	1.10	179.2	1640.5
5	3184.94	15.5	0.76	123.73	1764.31
4	3184.94	12.4	0.48	78.19	1842.5
3	3184.94	9.3	0.27	43.98	1886.48
2	3184.94	6.2	0.12	19.54	1906.02
1	3184.94	3.1	0.03	4.98	1911

Fig. shows the bar chart with gradual increase in Lateral force from bottom floor to top floor.

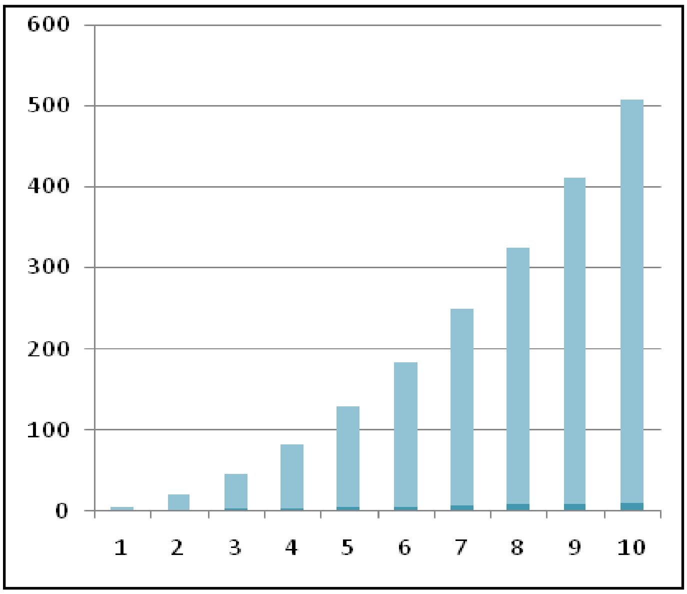

Fig. 3: Lateral Force on Each Storey

Fig. 4 shows bar chart with gradual decrease in shear from bottom floor to top floor.

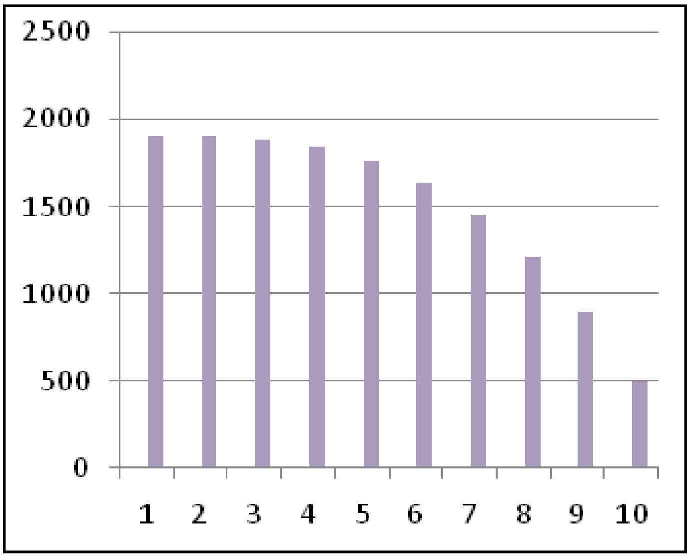

Fig. 4: Shear on Each Storey

III. Design of Ductile Coupled Shear Wall for Office Building

Bending moment and shear force:

Four shear walls are provided as given in the problem to resist the seismic forces in each direction.

The shear wall is assumed to be cantilever in calculations.

Factored shear force (V_u)	1433.25 kN
Factored bending moment (M_u)	34943.95 kN-m
Factored axial load	6000 kN
Moment of Resistance (M_u):	25203.94 kN-m.

Provide 22 # 20 mm diameter bars @ 400 mm c/c in the vertical direction in two layers.

Check for shear:

Factored shear force (Vu) = 1433.25 kN

Nominal shear stress $(\tau_v) = \frac{Vu}{tw\ dw} = 0.32\ N/mm^2$

Design shear stress $(\tau_c) = 0.42\ N/mm^2$

Nominal shear stress (τ_v) < Design shear stress (τ_c)

Provide minimum shear reinforcement in horizontal direction.

Provide 74 # 20 mm diameter bars @ 400 mm c/c in horizontal direction in two layers.

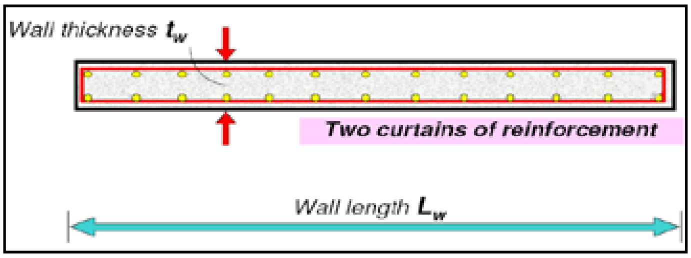

Fig. 5: Two Curtains of Reinforcement

Coupling Beam Reinforcement (Cl 9.5 of IS 13920:1993)

Provide 1#20 mm diameter in each diagonal of diagonal reinforcement in two layers.

Reinforcement Detailing:

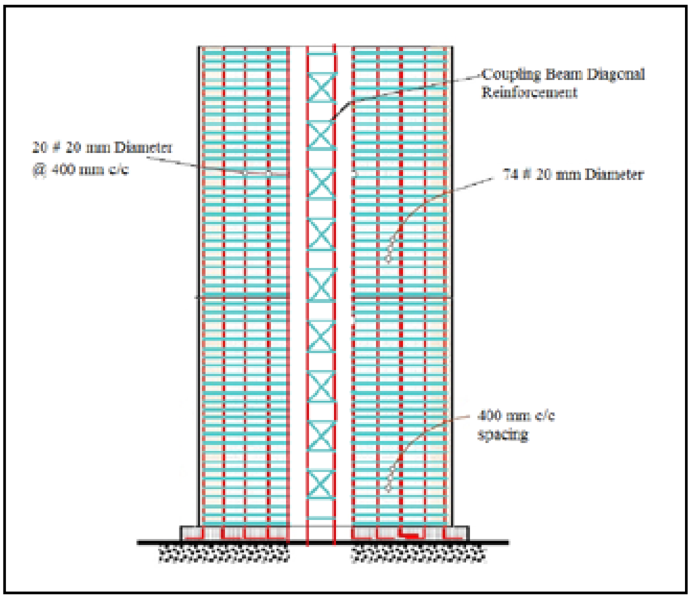

Fig. 6: Elevation Showing Reinforcement Detailing

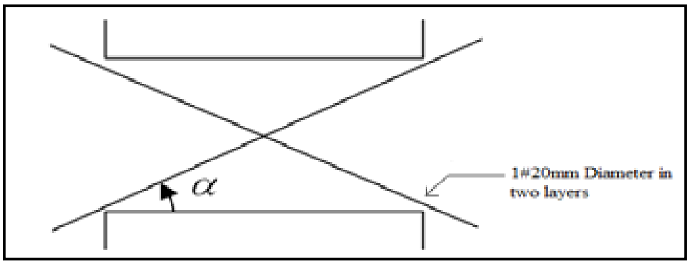

Fig. 7: Coupling Beam Reinforcement

IV. Analysis of Coupled Shear Wall by Finite Element Analysis (Ansys 12)

A. Element Types

The Shear wall was modelled in ANSYS 12 with Solid 65 and Link8 elements. The Solid 65 element was used to model the concrete. These elements have eight nodes with three degrees of freedom at each node- translations in the nodal x, y and z directions.

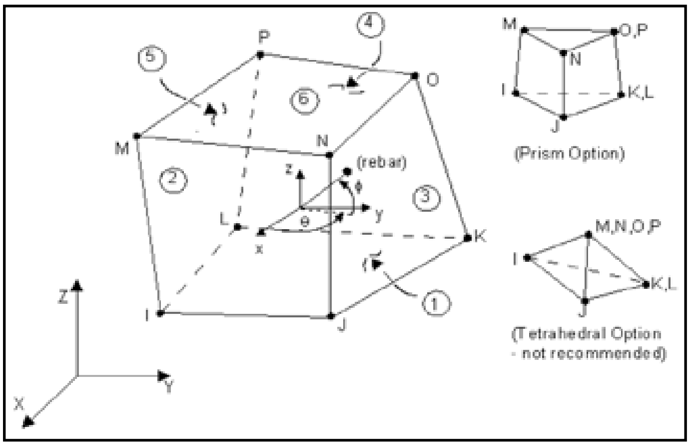

Fig. 8: Solid 65 Geometry

The Link8 element was used to model the reinforcement. This three- dimensional spar element has two nodes with three degrees of freedom at each node translations in the nodal x, y and z directions.

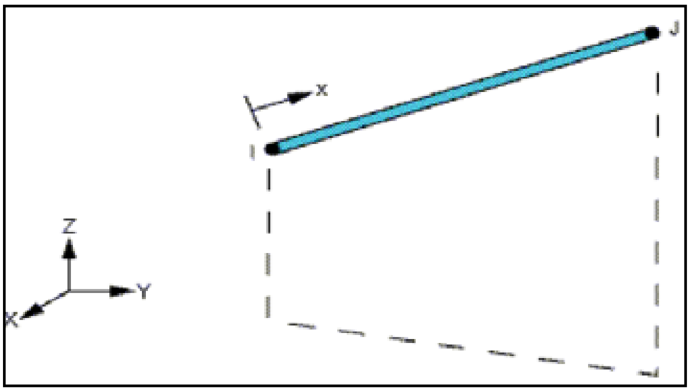

Fig. 9 Link 8 Geometry

B. Sectional Properties (Real Constants)

The real constants considered for Solid 65 element were volume ratio and orientation angles. Since there was no smeared reinforcement, the real constants (volume ratio and orientation angle) were set to zero. The real constants considered for Link8 element are cross sectional area and initial strain. Real constant set 1 is given for solid 65 and 2 for Link 8 element shown in Table 3.

Table 3: Sectional Properties

Real Constant Set	Element Type	Particulars of specimen	
2	Link 8	Cross sectional Area ()	3.14e-4
		Initial Strain	0

C. Material Properties

Table: 4 Material Properties

Material Model Number	Element type	Material Properties		
1	Solid 65	Linear Isotropic		
		EX	2.738e10 N/m²	
		PRXY	0.15	
		Multilinear isotropic		
			Strain	Stress
		Point 1	0.00036	14.21
		Point 2	0.0006	22.33
		Point 3	0.0013	39.91
		Concrete		
		Shear transfer Coefficient for open crack	0.2	
		Shear transfer coefficient for closed crack	0.9	
		Uniaxial tensile cracking stress	4.1e7 N/m²	
		Uniaxial crushing stress	-1	
2	Link 8	Linear Isotropic		
		EX	2.1e11 N/m²	
		PRXY	0.3	
		Bilinear Isotropic		
		Yield Stress	4.15e8 N/m²	
		Tangent Modulus	8.47e8 N/m²	

The concrete is modeled as Material Model Number 1 in the Solid65 element. The Concrete material model is shown in figure

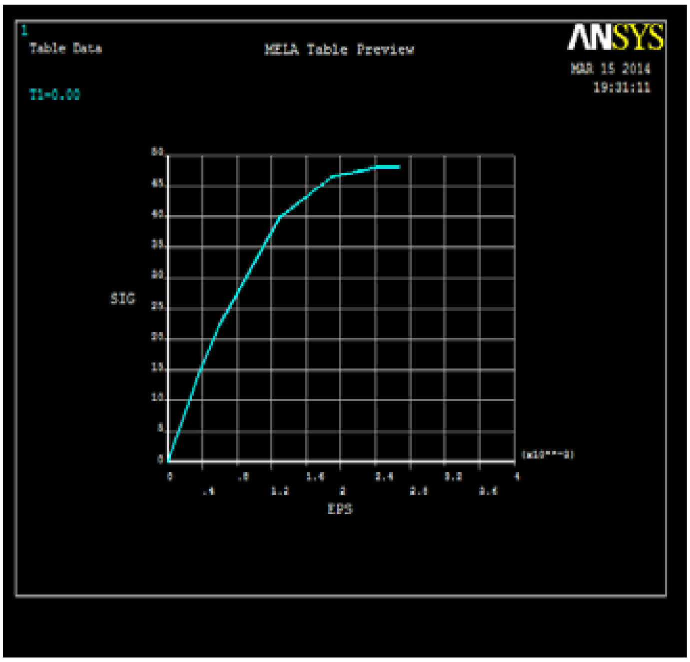

Fig. 10: Stress Vs Strain for Concrete

The reinforcement is modeled as Material Model Number 2. The reinforcement used is f_y=415 MPa steel. The reinforcement material model is shown in fig.

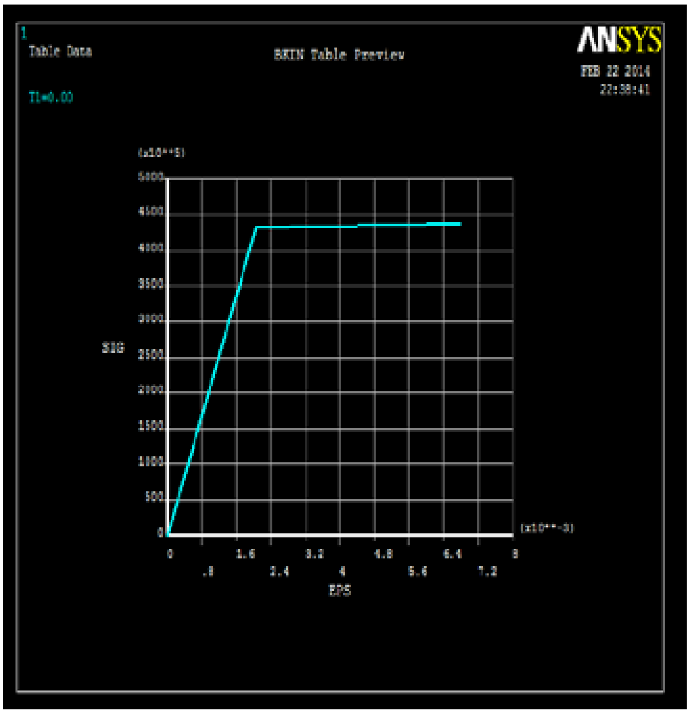

Fig. 11: Stress Vs Strain for Steel

D. Analytical Nonlinear Model

In ANSYS, the finite element models can be carried either using command prompt line input or the Graphical User Interface (GUI). For the present study, the shear wall concrete model was modelled using Graphical User Interface and Reinforcement was modelled by Command prompt line input data.

The shear wall is modeled as a volume. All the nodes at the ground level are fixed and the displacement into the wall is prevented. To obtain good results from the Solid65 element it is important to mesh the model properly. The analytical model of the meshed wall is shown in fig. 12

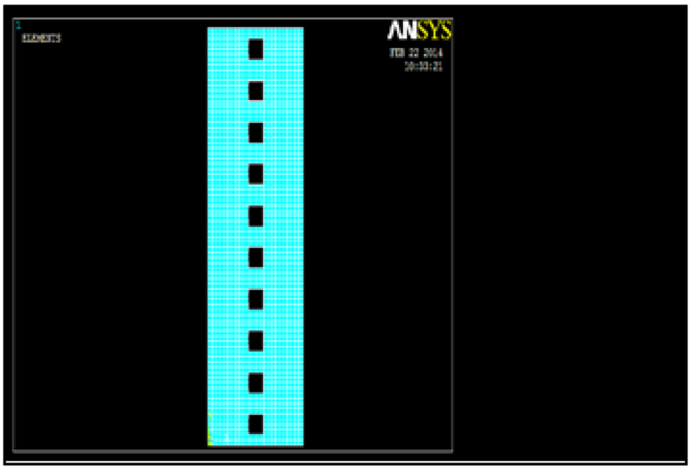

Fig. 12: Meshed Model of Shear Wall

Fig. 13: Element Numbers

Table 3: Main Characteristics of the FEM Model In ANSYS

No.	Finite element model	ANSYS shear wall model
1	Dimension of model	3D
2	Total number of concrete elements	5760
3	Total number of reinforcement elements	5760
4	Cracking and crushing of elements	YES
5	Yielding of concrete and reinforcement	YES

Reinforcement was modelled by Command prompt line input data.

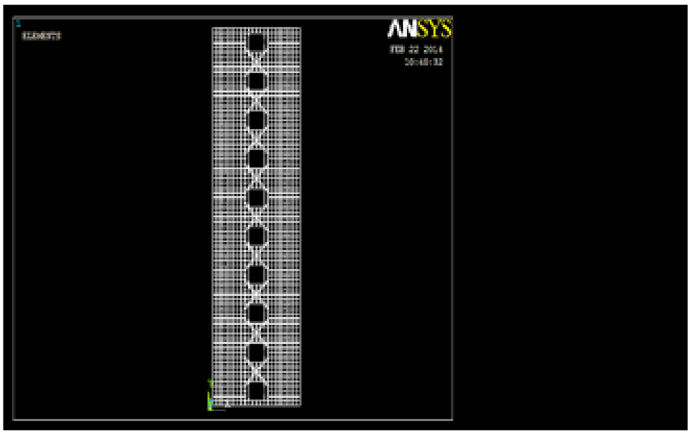

Fig. 14: Reinforcement Model In Ansys

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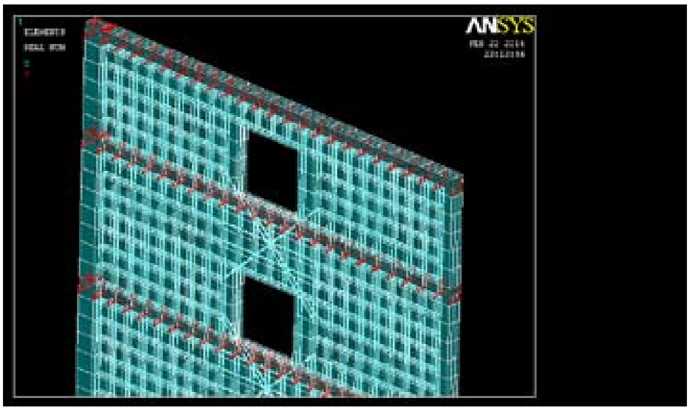

Fig. 15: Concrete And Reinforcement Model in Ansys

E. Loading and Boundary Conditions

All the nodes at the ground level are fixed and the displacement into the wall is prevented. Lateral Loads are applied on each storey of the building calculated as per IS 1893: 2002 and uniformly distributed load is applied on each floor.

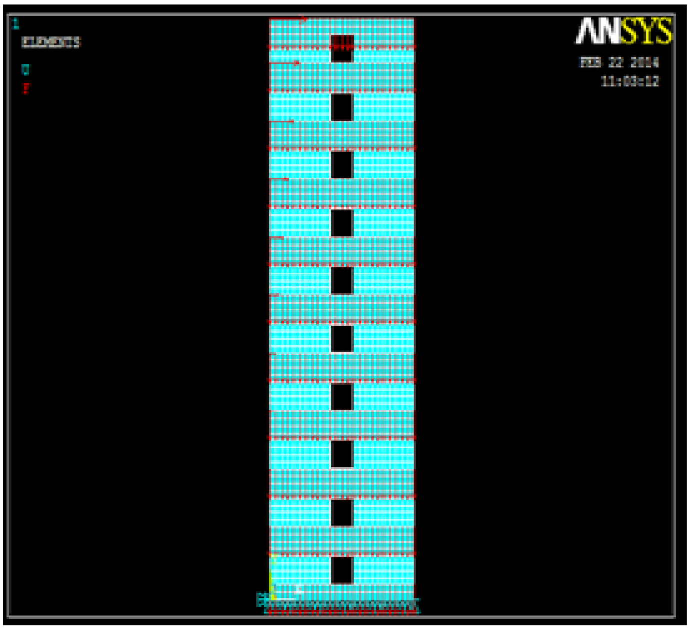

Fig. 16: Loading Conditions and Fixed Boundary Condition

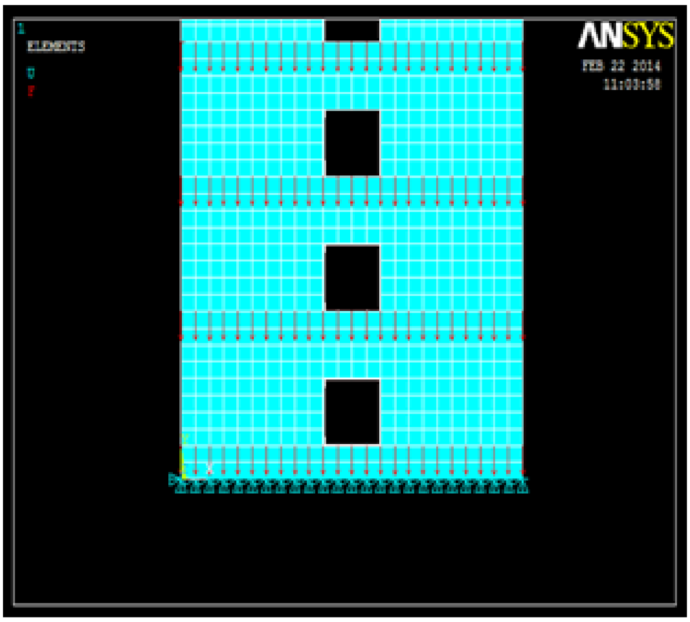

Fig. 17: Fixed Boundary Condition at Bottom

V. Results and Discussion

Results from finite element analysis of coupled shear wall under structural loading. The maximum deformation were observed for the top surface of shear wall and its gradually reduced towards the bottom. Von mises stress contour was observed that the maximum stress is at bottom of shear wall.

A. Displacement in ANSYS

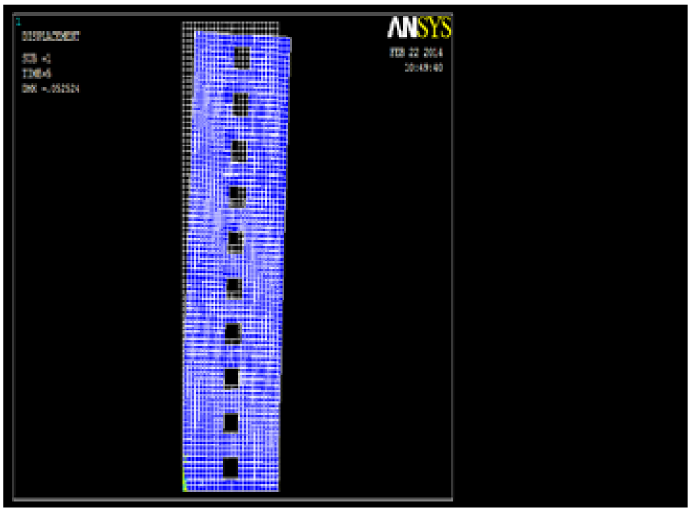

Fig. 18: Displacement in Ansys

The maximum lateral displacement at top storey due to lateral load is 52.52mm.

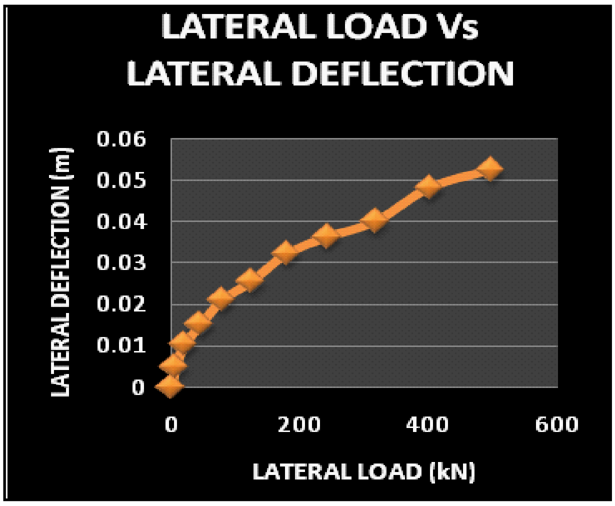

Fig. 19: Lateral Load Vs Lateral Deflection

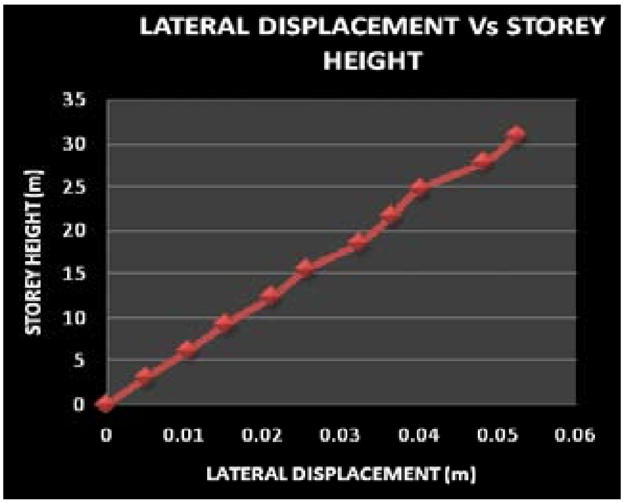

Fig. 20: Lateral Displacement Vs Storey Height

B. Von Mises Stress Contour

Von mises stress contour was observed that the maximum stress is at bottom of shear wall.

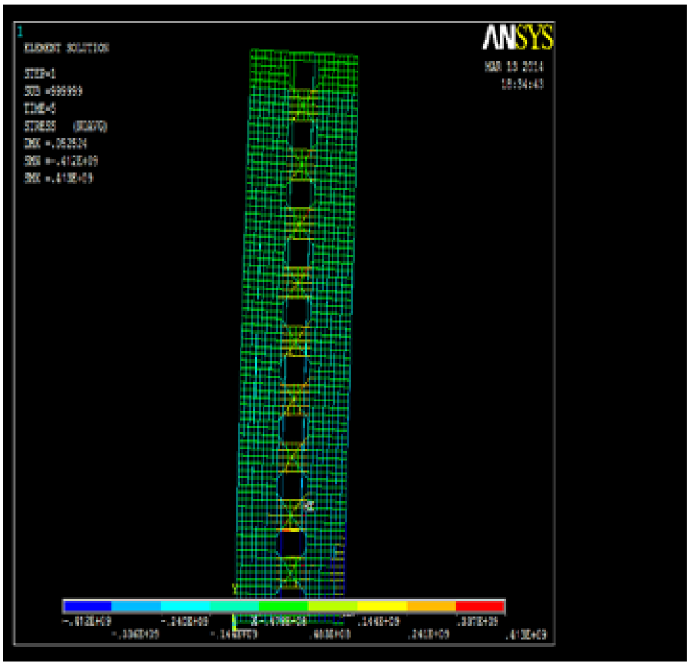

Fig. 21: Von Mises Stress in Steel

The Maximum Von mises Stress Intensity obtained is 413 MPa. The yield strength of steel is 415 MPa.

C. Crack Pattern

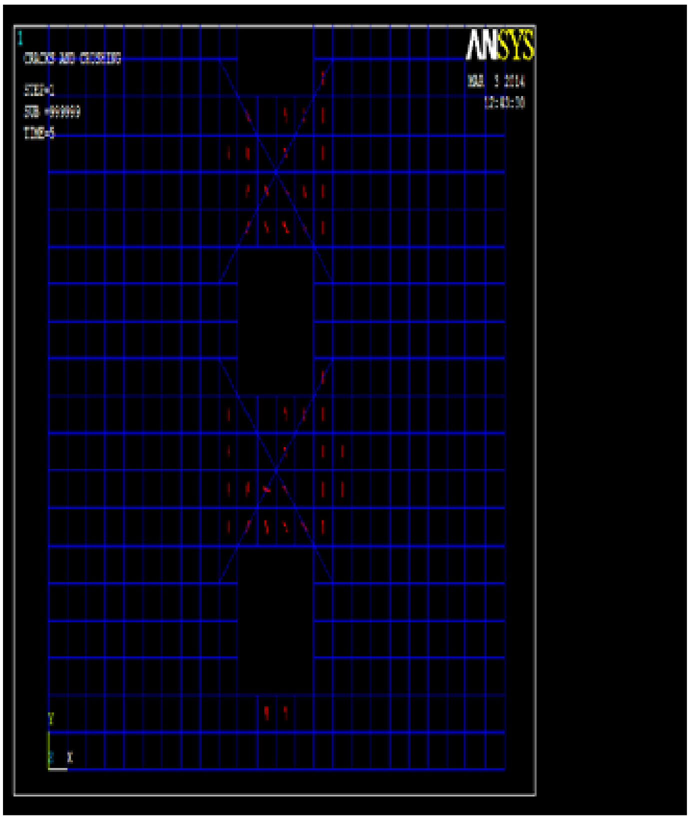

Fig. 22: Crack Pattern

The first crack appeared at element number 108 and 110.The diagonal cracks represent the tension cracks, straight cracks represent flexural cracks.

VI. Scope for Future Work

Shear walls are considered to be a gift to the future construction industry. Scope of shear walls in construction field is immense. It's since their arrival in market there topic was always a topic of interest. Shear walls are the structures usually build to balance lateral loads acting on the structure. Where the lateral loads are most predominantly wind and earth quake loads. And predominantly earthquake loads are more intense in their effect on the building structures. Earthquakes are becoming more intense due to the key reason that is ground water displacement. Hence in order to overcome the diverse effects of earthquake it's always best to save ourselves from future disasters.

Several other subjects related to this research have been identified that it needs further investigation. Experimental and analytical research works needed later are summarized below.

- More research works should be done to find a better way to simulate the behavior of coupled shear walls under cyclic loads. So that the ductility, the crack development, the failure region, etc. of this system can be studied in detail.
- Comparison of analytical results with that of the experimental results should be studied.
- More types of shear walls and material sets should be studied as well as laboratory tests to backup the numerical results.
- Architectural aspects i.e., effective location of shear walls in a building should be studied.

VII. Conclusion

- The finite element model of coupled shear wall constructed in ANSYS 12 using elements SOLID 65 and LINK 8 in this study could capture the non – linear response of this system under earthquake loading.
- The maximum lateral displacement at the top storey due to lateral loads was in control and in limitations. The check calculated is safe.
- Shear wall is very effective to resist horizontal forces coming from earthquake and wind forces etc. in multistory structure if it is properly oriented it will reduce torsional effect and storey deflection.
- The dedicated element employed a crack model to allow for concrete cracking with the option of modeling the reinforcement in a distributed or discrete manner.

References

[1] S.K. Duggal in his,"Earth quake resistant design of structures", pp. 301, 8.12 about Shear walls.

[2] S.K. Duggal in his,"Earth quake resistant design of structures", pp. 305, 8.14.1 (case: 1, case: 2) about flexural strength.

[3] IS 456:2000

As per clause 32, design for wall describes, design of horizontal shear in clause 32.4 given details of how shear wall have to be constructed.

IS 1893:2002 (part 1), Criteria of Earth Quake resistant design of structures page 24, clause 7.7 gives the Estimation of earth quake loads.

In IS: 13920:1993 it gives the ductile detailing of shear wall as per clause 9, where 9.1 gives general requirements.

9.2 shear strength

9.3 give flexural strength

9.5 gives coupled shear wall

9.6 give openings in shear walls.

Ductile detailing, as per the code IS: 13920:1993 is considered very important as the ductile detailing gives the amount of

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reinforcement required and the alignment of bars.
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Gummadi Amar received his B.Tech degree in Civil Engineering from V.R.Siddhartha Engineering College, Vijayawada, India, in 2012, and the M.E degree in Structural Engineering from Sathyabama Univeristy,Chennai,India, in 2014. His research interests include Earthquake Resistant Structural Design (Masonry, RC and Steel), Fatigue and Fracture in Steel. He was an assistant Professor at Dhanekula Engineering College.