

Evaluation of Seismic Behaviour of RCC Building Using Coupled Shear wall

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Abstract - Shear walls are vertical members in the structure which provide stability to structure from lateral loads like wind and seismic loads. Many structures located in seismic zone are mostly constructed with shear walls to resist lateral load. But due to construction of shear walls, the problem of ventilation and opening for various purposes in shear wall is occurs. To avoid such problems coupled shear walls are used. Shear wall with an opening is called as coupled shear wall, it consist of two or more shear walls are connected by beam called as "coupling beam." In this paper ten storey, R.C. special moment resisting frame with solid and coupled shear walls providing at corner position with different configuration such as varying length and depth of coupling beam which results in changing sizes of opening in coupled shear wall have been analyzed for seismic zone IV as per IS 1893:2002, using equivalent static and response spectrum method. An ETAB 15 software is used to perform the analysis. Responses such as time period, storey displacement, storey drift, storey and base shear, overturning moment at base and acceleration have been evaluated. From the analysis it has been observed that, coupled shear wall behaviour depends on arrangement of reinforcement and size of coupling beam. Solid shear wall system are effective than coupled shear wall. The performance of coupled shear wall is good in minor size of opening which results into increase of length or depth of coupling beam.

Key Words: Earthquake, solid and coupled shear wall, coupling beam with conventional and diagonal reinforcement.

1. INTRODUCTION

Earthquake causes greatest damage to manmade structures and tremendous loss of life. Therefore, to withstand the effect of an earthquake, structural engineers and designers should give provisions for earthquake resistant structure with regards to planning, design, and detailing. To create earthquake resistant structures architects and structural engineers work on four aspects, namely seismic structural configuration, lateral strength, lateral stiffness, ductility and other aspects like aesthetics, form, functionality and comfort of building. In reinforced concrete building shear walls are used to resist earthquake force in high seismic zone due to its in-plane stiffness but these systems has some disadvantages such as when shear wall is constructed the problem of opening for door, window and ventilation occurs. So, use of Coupled shear wall i.e. shear wall with opening in

RCC building could be an alternative solution for shear wall to attain functional flexibility in architecture. Analysis of coupled shear wall is complex process but present day improve in technology allows for precise analysis and design of different systems. Shear wall behaviour depends on wall positioning in building frame, wall thickness, material used and length of wall. Hence the objective of this paper is to study the behaviour of RCC building with coupled shear wall by changing sizes of opening in coupled shear wall and compare its responses such as time period, storey displacement, storey drift, storey and base shear, overturning moment at base and acceleration with RCC building with solid shear wall.

2. COUPLED SHEAR WALL (CSW)

A coupled shear wall is combination of coupling beams and wall piers. In this, shear wall are divided into parts and connected by beam due to that opening is form in between walls. Coupled shear walls are built over the height of building with series of walls coupled by beam to accommodate opening for door, window, corridor and elevator well. The behaviour of coupled shear wall is greatly influenced by coupling system which depends on geometry and strength of coupling beam as compare with wall. The main parameter in coupled shear wall is stiffness ratio of coupling beam to wall pier, which depends on sizes of wall pier and coupling beam. The development of shear force in coupling beam results in formation of coupling action between wall piers. The lateral load resist by coupled shear wall through combination of flexure and frame action impart by wall piers and coupling beam respectively. The accumulation of shear in coupling beam results in developing axial force couple in coupling beam. An overturning moment is partially resist by couple which is form due to development of axial compression-tension forces across the wall rather than by the flexural action of the wall. Light coupling result in uncoupled wall and over coupling results in single wall with less or no energy dissipation by coupling beams such types of systems are avoided in coupled shear wall.

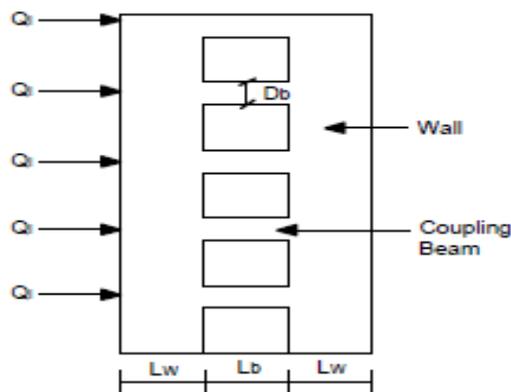


Fig-1: Coupled shear wall

2.1 COUPLING BEAM

The horizontal member below and above the opening which connects two walls together is called as coupling beam. The beam is called as coupling beam because coupling action develops in the wall piers due to generation of large amount of shear force in beam. The important function of coupling beam is dissipate energy generated during earthquake and behave in ductile manner. Coupling beam must be sufficiently strong, stiff and yields before the wall piers.

Types of reinforcement in coupling beams:

Based on the arrangement of reinforcement, coupling beams are classified into two types; they are coupling beams with conventional and diagonal reinforcements.

A. Coupling beam with conventional reinforcement

In this kind of beam, the arrangement of reinforcement is similar to reinforcement in normal beam, where longitudinal reinforcement is composed of steel that is placed both at the top and bottom of the beam in the longitudinal axis of the beam and the transverse reinforcement is composed of ties. But when compared to regular beams this kind of beams do possess a more amount of shear reinforcement.

B. Coupling beam with diagonal reinforcement

Due to diagonal arrangement of reinforcement, large amount of shear force is transformed into axial load. Diagonal reinforcement designed based on the assumption that the shear force can be resolved into diagonal compression and tension forces, intersecting each other at mid span where no moment is resisted.

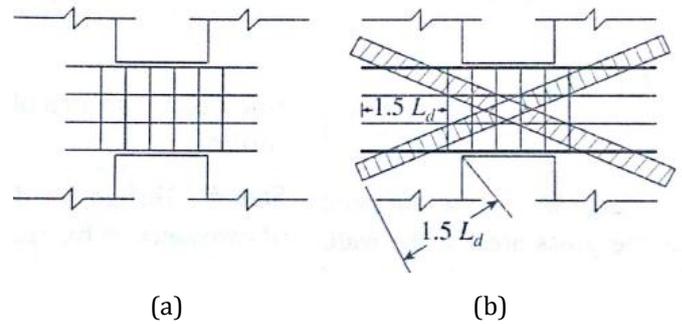


Fig-2: Reinforcement detail in RC coupling beam (a) Conventional reinforcement (b) Diagonal reinforcement

3. METHODS OF ANALYSIS

Equivalent static and response spectrum methods are used for analysis of structure.

3.1 Equivalent Static Method

This method is used to find out lateral force generated during earthquake. Here force depends upon the fundamental time period of the structure given by IS 1893:2002. It is suitable for building with regular distribution of mass and stiffness. In this method the base shear is calculated first and distributed with respect to the height of the building based on the formulae given below.

The total design horizontal force or base shear (\$V_b\$) along any principal direction is calculated as,

$$V_b = A_h \cdot W \tag{1}$$

Where, \$W\$ is the seismic weight of the building.

The horizontal seismic coefficient \$A_h\$ is given as,

$$A_h = \frac{Z I S_a}{2 R \xi} \tag{2}$$

Where, \$Z\$ = Zone factor

\$I\$ = Importance factor

\$R\$ = Response reduction factor

\$S_a/g\$ = Average response acceleration coefficient

Total base shear should be distributed along the height of building as,

$$Q_i = V_b (w_i h_i^2 / \sum w_i h_i^2) \tag{3}$$

Where, \$Q_i\$ = Design lateral force at floor \$i\$,

\$w_i\$ = Seismic weight of floor \$i\$,

h_i = height of floor i measured from base

3.2 Response Spectrum (RS) Method

It is representation of maximum response of idealized single degree freedom system having certain period and damping, during earthquake ground motion. The maximum response plotted against of undamped natural period and for various damping values and can be expressed in terms of maximum absolute acceleration, maximum relative velocity and maximum relative displacement.

Design lateral force at each floor in each mode is:

$$Q_{jk} = A_k \phi_{ik} P_k W_i \quad (4)$$

Where, A_k, ϕ_{ik}, P_k and W_i are calculated with the help of IS1893:2002.

4. MODELING AND ANALYSIS

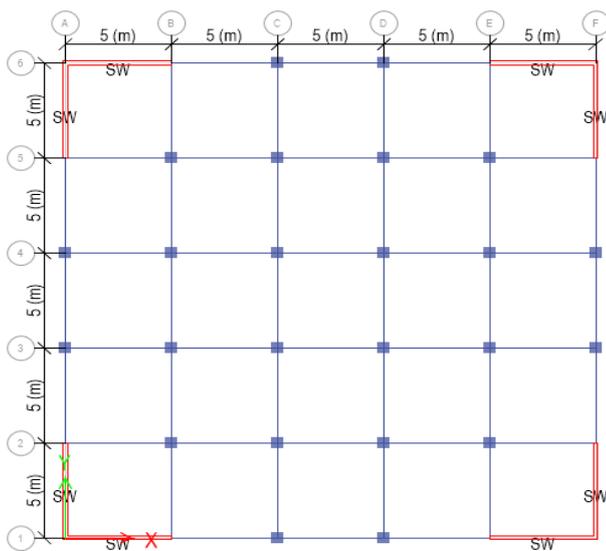


Fig-3: Plan of building

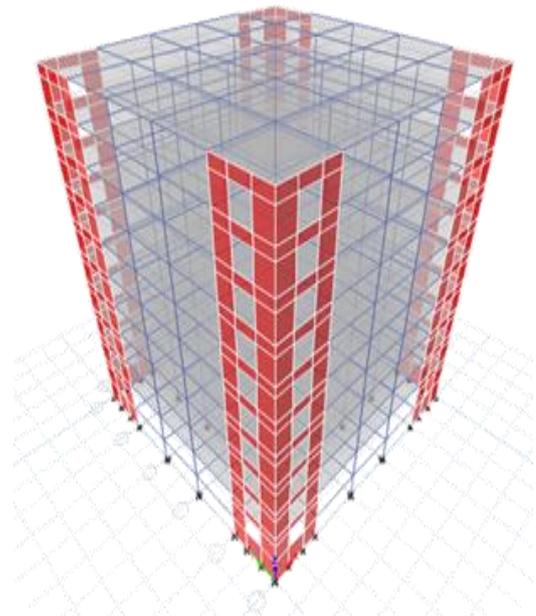


Fig- 4: 3 dimensional model of building with CSW

Table-1: Problem description

Structure	SMRF
No. of storeys	10
Storey height	3m
Seismic zone	IV
Soil type	Medium
Plinth level	2.5m
Material Properties	
Grade of concrete and steel	M30 and Fe415
Density of R.C.C and brick masonry	25KN/m ³ and 20KN/m ³
Member Properties	
Thickness of Slab	0.200 m
Beam size	0.45 x 0.23m
Column size	0.5m x 0.5m
Thickness of shear wall	0.23m
Thickness of external brick Wall	0.2m
Thickness of internal brick wall	0.15m
Loading	
Live load	3 KN/m ²
Earthquake load	As per IS1893-2002 (part-1)

- The dimensions are, length of solid shear wall $L_w = 5\text{m}$ in x and y direction.
- For coupling beam of length $L_b = 1.6\text{m}$, the length of wall piers $L_w = 1.7\text{m}$.
- For coupling beam of length $L_b = 1.8\text{m}$, the length of wall piers $L_w = 1.6\text{m}$.
- The depth coupling of beam D_b varies as 0.3m, 0.45m, 0.9m and 1.8m.

4.1 Models for Analysis

- **Model I:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.8/0.3=6$
- **Model II:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.6/0.3=5.33$
- **Model III:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.8/0.45=4$
- **Model IV:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.6/0.45=3.55$
- **Model V:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.8/0.9=2$
- **Model VI:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.6/0.9=1.77$
- **Model VII:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.8/1.8=1$
- **Model VIII:** Building with Coupled Shear wall (CSW) with coupling beam ratio, $L_b/D_b = 1.6/1.8=0.88$
- **Model IX:** Building with Solid Shear wall (SSW)

5. RESULTS AND DISCUSSION

From the analysis parameters such as time period, storey displacement, storey drift, storey and base shear, overturning moment at base and acceleration are obtained and compared. It shows that the results are same in x and y direction because of regular building.

5.1. Time Period

The time taken for each complete cycle of oscillation (i.e., one back and forth motion) is called natural period of building. The first (longest) modal time period of vibration is called as fundamental natural period. It is observed that with increase in span of coupling beam,

time period is increases and decreases with increase in depth of coupling beam.

Table-2: Time period of building

Type	Time Period (s)
CSW, $L_b/D_b=1.8/0.3=6$	1.174
CSW, $L_b/D_b=1.6/0.3=5.33$	1.135
CSW, $L_b/D_b=1.8/0.45=4$	1.099
CSW, $L_b/D_b=1.6/0.45=3.55$	1.068
CSW, $L_b/D_b=1.8/0.9=2$	1.002
CSW, $L_b/D_b=1.6/0.9=1.77$	0.985
CSW, $L_b/D_b=1.8/1.8=1$	0.952
CSW, $L_b/D_b=1.6/1.8=0.88$	0.943
Solid shear wall (SSW)	0.89

5.2 Scale Factor

The design spectrum of IS 1893 is actually the MCE level spectrum which must be reduced by dividing this value by factor 2R, in which R is response reduction factor. In the first run, the value scale factor should be $I_g/2R$ in which I is importance factor. After the first run, check the base shear which develops in the model and if this value is less than code prescribed minimum, then increase the scale factor of first run such that the resultant base shear matches the code specification.

Table-3: Scale factor

Type	Scale factor
CSW, $L_b/D_b=1.8/0.3=6$	1023
CSW, $L_b/D_b=1.6/0.3=5.33$	1024
CSW, $L_b/D_b=1.8/0.45=4$	1027
CSW, $L_b/D_b=1.6/0.45=3.55$	1029
CSW, $L_b/D_b=1.8/0.9=2$	1043
CSW, $L_b/D_b=1.6/0.9=1.77$	1044
CSW, $L_b/D_b=1.8/1.8=1$	1046
CSW, $L_b/D_b=1.6/1.8=0.88$	1048
Solid shear wall (SSW)	1059

5.3 Storey displacement

The magnitude of lateral displacement indicates the damage state and vulnerability of the building. With increase in span of coupling beam, displacement is increases and decreases with increase in depth of coupling beam. For less than 2 span to depth ratio of

coupling beam in coupled shear wall only 6% variation in displacement as compare with solid shear wall. The displacement obtain for 0.9m and 1.8m depth of coupling beam are nearly equal. Because for 1.8m depth of coupling beam the reinforcement are arranged diagonally which helps to reduce the displacement in structure.

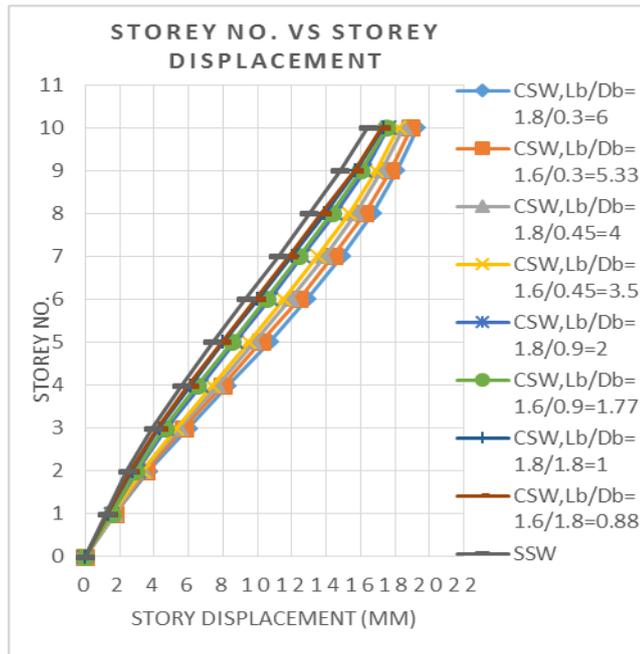


Chart-1: Storey displacement by static method

Table-4: Maximum displacement and drift

Type	Maximum Displacement (mm)		Maximum Drift (mm)		
	Static Method	RS Method	Static Method	RS Method	
CSW, L _b /D _b	1.8/0.3=6	19.28	13.70	0.79	0.582
	1.6/0.3=5.33	18.86	13.42	0.76	0.559
	1.8/0.45=4	18.45	13.07	0.725	0.527
	1.6/0.45=3.5	18.15	12.92	0.707	0.512
	1.8/0.9=2	17.63	12.52	0.669	0.475
	1.6/0.9=1.77	17.46	12.41	0.663	0.469
	1.8/1.8=1	17.3	12.27	0.659	0.466
	1.6/1.8=0.88	17.18	12.21	0.655	0.464
Solid shear wall (SSW)	16.4	11.75	0.628	0.447	

5.4 Storey drift

It is the displacement of one level relative to the other level above or below. With increase in span of coupling beam, storey drift is increases and decreases with increase in depth of coupling beam. For less than 2 span to depth ratio of coupling beam in coupled shear wall only 6% variation in storey drift as compare with solid shear wall. Thus, for smaller span to depth ratio of coupling beam, the behaviour of coupled shear wall is nearly similar to solid shear wall. The drift obtain for 0.9m and 1.8m depth of coupling beam are nearly equal. Because for 1.8m depth of coupling the reinforcement arranged diagonally which helps to reduce drift in structure.

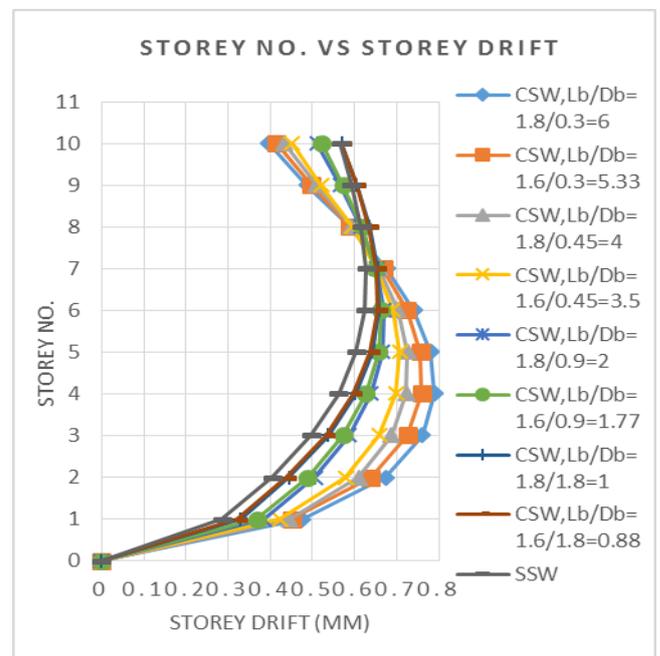


Chart-2: Storey drift by static method

5.5 Storey and Base shear

Storey shear is the sum of design lateral forces at all levels above the storey under consideration and base shear is the total design lateral force at the base of a structure. As opening size increases, the size of coupling beam decreases and due to that base shear is decreases. Building with solid shear wall has higher base shear than coupled shear wall because due to formation of opening in coupled shear wall, the weight of structure decreases.

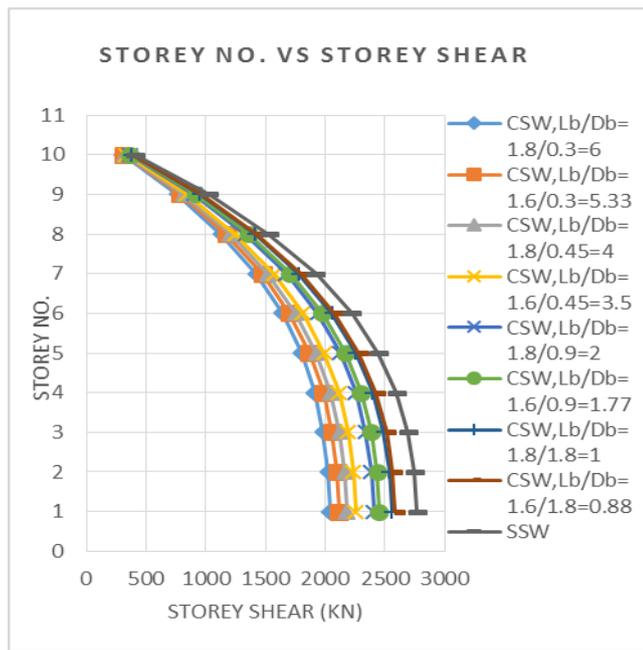


Chart-3: Storey shear by static method

Table-5: Base shear and overturning moment at base

Type		Base Shear (kN)		Overturning moment at base (kN.m)	
		Static Method	RS Method	Static Method	RS Method
CSW, L _b /D _b	1.8/0.3=6	2043	1738	50332	36551
	1.6/0.3=5.3	2120	1802	52235	38005
	1.8/0.45=4	2186	1850	53875	39030
	1.6/0.45=3.5	2257	1918	55623	40532
	1.8/0.9=2	2409	2048	59362	43190
	1.6/0.9=1.77	2457	2088	60531	44101
	1.8/1.8=1	2561	2176	63098	45918
	1.6/1.8=0.88	2589	2201	63782	46503
	Solid shear wall (SSW)	2776	2360	68338	50212

5.6 Overturning moment at base

It is observed that RCC building with solid shear wall gives higher overturning moment at base than RCC building with coupled shear wall. As sizes of opening increases the span to depth ratio of coupling beam decreases, which leads to decrease the overturning moment. RCC building with coupled shear wall gives lesser overturning moment at base because during

earthquake, structure is subjected to lateral load due that shear forces are developed in coupling beam and these forces are transferred to wall in the form of axial load which helps to resist overturning moment.

5.7 Acceleration

Table-6: Acceleration by response spectrum

Type	Acceleration (mm/s ²)
CSW, L _b /D _b =1.8/0.3=6	592
CSW, L _b /D _b =1.6/0.3=5.33	609.4
CSW, L _b /D _b =1.8/0.45=4	615
CSW, L _b /D _b =1.6/0.45=3.55	636.78
CSW, L _b /D _b =1.8/0.9=2	680
CSW, L _b /D _b =1.6/0.9=1.77	693.68
CSW, L _b /D _b =1.8/1.8=1	733
CSW, L _b /D _b =1.6/1.8=0.88	740.81
Solid shear wall (SSW)	786.18

From table it is observed that acceleration is maximum for building with solid shear wall and it decrease with increase in span to depth ratio of coupling beam in coupled shear wall. With decrease in depth of coupling beam the sizes of opening increase due to that weight of structure decreases which results in decrease in acceleration. Acceleration is maximum at top floor because for whole structure mass is constant and within same time period structure move more distance at top floor as compare with bottom floor.

6. CONCLUSIONS

Numerical study on 10 storey RCC building with solid and coupled shear wall is carried under earthquake load. To know behaviour of RCC building with coupled shear wall the comparison is made with solid shear wall using response quantities and performance criteria. The response obtained by response spectrum method gives lesser values than static method.

1. RCC building with coupled shear wall having span to depth ratio of coupling beam less than 2 gives only 6% more displacement and drift as compared with solid shear wall.
2. For larger span of coupling beam, time period, displacement and drift are increases but base shear is decreases.

3. Increase in depth of coupling beam results in decrease of time period, displacement and storey drift but increase in base shear.
4. Overturning moment at base is less in building with coupled shear wall as compare with building with solid shear wall.
5. Acceleration obtained by response spectrum method for building with solid shear wall is maximum and it decreases with increase in span to depth ratio of coupling beam for building with coupled shear wall.
6. RCC building with solid shear wall gives superior performance against time period, displacement and drift except overturning moment as compared to RCC building with coupled shear wall.
7. Coupling beam with higher depth contain diagonal arrangement of reinforcement gives superior performance. Thus, the sizes of opening affects on behaviour of RCC building with coupled shear wall.

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