Static and Dynamic Behavior of Coupled Shear Wall

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***Abstract*-- The reinforced concrete wall primarily resists the lateral load genrated from wind and earthquake. Due to concentration of flexural stresses at the base of solid wall, it exhibits brittle failure like concrete crushing in boundary element and sliding shear at construction joints. In the coupled shear wall (CSW), the sructural walls are connected through the coupling beams. The inherent behavior of CSW reduces the moment in the walls due to the coupling action. In plastic stage, the hinges are formed at the end of coupling beam and then at base of the walls, which causes the dissipation of energy and redistribution of forces through out the structure. The coupling beams also save the structural walls from the excessive damage. Therefore the CSW is not only used for the newly constructed structure but also for the seismic rehabilitation of the existing structure.**

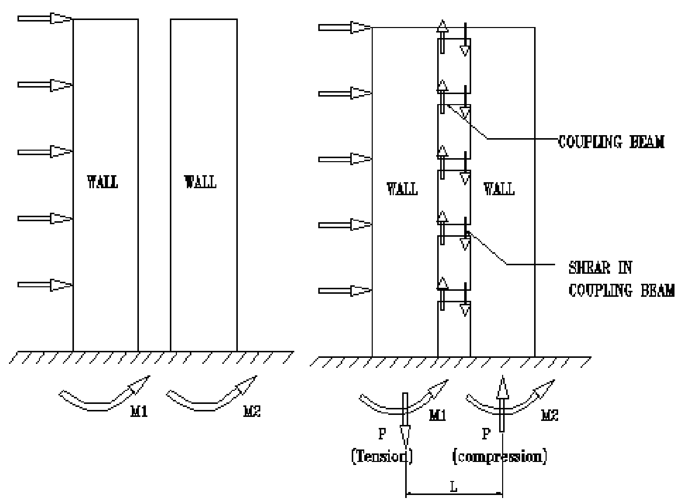
In the present work seismic behavior of multistoried CSW is discussed with parametric study. The parameters considered in the study are: number of story, length of wall, depth and span of coupling beam. The response of CSW is observed in terms of axial forces, shear and moments in walls and the coupling beams at various floors. An important index to quantify the efficiency of the CSW is the degree of coupling (DC). In this study DC is also evaluated for the different parameters. Time period of CSW is observed to compare the time period formula suggested by Indian Code IS 1893 (Part 1) : 2002. It is found that with suitable dimensions the DC can be kept constant through out building and strong column and weak beam concept can be simulated. It is also found that the time period formulae given in code should include dimensions of CSW for better estimation of seismic forces.

***Index Terms*-- Coupled shear wall, Degree of coupling, Earthquake, Coupling beam, Time period, Plastic stage, Hinges**

I. INTRODUCTION

The solid structural wall (Figure 1(a)) showed brittle failure under effect of lateral earthquake loads due to concentration of stresses at the base. For the remedial measure, the researchers had come up with new concept in which the structural walls are connected through the framing beams. These walls are categorized as coupled shear wall and the connecting framing beams are known as coupling beam. When the coupled shear walls are subjected to lateral loading, both of walls bend in flexure and coupling beam is displaced vertically in opposite direction to each other at the ends. The vertical displacement causes the double curvature bending of the beam which induces internal shear in the beam. The induced shear causes axial tension and compression at the center of gravity of the wall. The couple generated by the lever arm in between axial tension and compression force resists the external moment (Figure 1(b)). In a cantilever wall the total overturning moment, M_0 is resisted at the base in the form of flexural stresses. While in coupled shear walls the axial forces as well as moments in the walls resist overturning moment M_0. At any section the following equilibrium equation should be satisfied [1].

$$M_0 = M_1 + M_2 + P \times L \quad (1)$$



Moments in Structural Wall (b) Responses in CSW
Fig. 1. Comparison in Structural wall and CSW

Where M_0, M_1, M_2, P and L are total external moment resisted by CSW, moment resisted by wall 1 and 2, axial forces in walls and lever arm respectively. From numerous experimental and analytical studies, it is observed that the structural behavior of the coupled shear wall is greatly influenced by the behavior of their coupling system. The index of the coupling system is the degree of coupling. The following equation is given to define the degree of coupling [2].

$$\text{Degree of coupling} = \frac{P \times L}{M_0} \quad (2)$$

Based on the degree of coupling, the coupled shear walls are categorized as low coupling, intermediate coupling and high coupling. When the DC is low, the CSW will behave in flexural mode like isolated structural wall or braced frame and for high DC the CSW behaves in shear mode like rigid frame. The behavior of CSW is flexural-shear mode for the intermediate DC like wall-frame structure. Therefore the

CSW may be considered as the generic lateral load resisting structural system. The degree of coupling, forces in wall and the coupling beams depend on the sizes of wall and coupling beam. The CSW behavior is also influenced by the number of storey or height of the wall.

Understanding behaviour of CSW with variations in dimensions of shear wall and coupling beams is more useful from practical point of view. Therefore a parametric study is conducted to observe the behavior of CSW with above aspects.

II. Problem formulation for parametric study

The typical floor plan of coupled shear wall building is given in Fig. 2. The CSW shown in the building plan is considered for the parametric study. The parameters are depth and span of coupling beam, length of wall, and number of storey as shown in Fig. 3. Here the CSW is the primary lateral load resisting system. It will resist all the lateral loads generated by earthquake or wind. The problem formulation for 30-Storey CSW is given in Table 1. The same combinations of parameters have been considered in the problem formulation of 5, 10, 15, 20, and 25 storied CSW. The wall thicknesses and beam widths for different storied CSW are given in Table 2. The typical storey height is considered as 3.0 m.The CSW was modeled and analyzed by using shell elements in ETABS software[3]. Earthquake loads are calculated by using equivalent static approach for zone III, response reduction factor 4.0, importance factor 1.0 .Time period is calculated from the codal provisions given in IS 1893 (Part 1) : 2002 [4] , which is given in Equation (3).

$$T_a = \frac{0.09h}{\sqrt{d}} \quad (3)$$

Where h = Height of building in meter, d = Base dimension of the building at the plinth level along the considered direction of the lateral force, in meter.

III. Discussion on rsponses of CSW

Here the responses of 30 storied CSW in terms of axial forces in wall, moments in the wall and forces in coupling beams are discussed. For all other number of storey as mentioned in section II only the degree of coupling is presented in this paper.

A. Axial forces in the wall

When coupling beam depth is considered as parameter, the axial forces in CSW increases with increase in depth of coupling beam (Fig. 4(a)). It is observed that the axial forces decrease with increase in span of coupling beam (Fig. 4(b)). Similarly with increase in the length of wall the axial forces also decrease (Figure 4(c)). When the axial forces increase, the coupling action (i.e. $P \times L$) of CSW

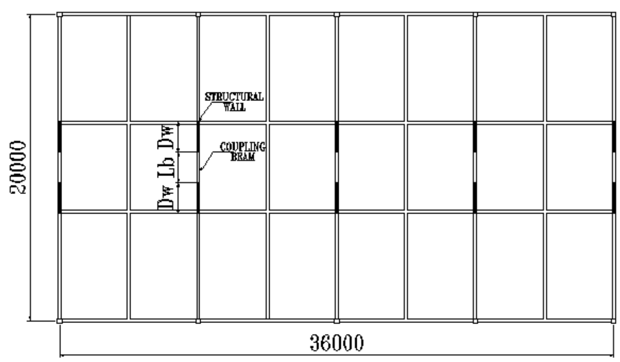


Fig. 2 Plan of a coupled shear wall building

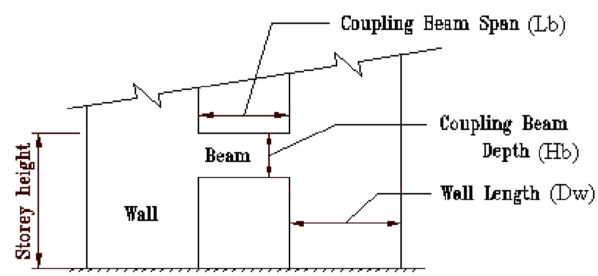


Fig. 3. Parameters in CSW (Elevation)

TABLE 1. PROBLEM FORMULATION FOR 30-STOREY COUPLED SHEAR WALL

Prob. No.	H_b as Parameter			Prob. No.	L_b as Parameter			Prob. No.	D_w as Parameter		
	H_b, m	L_b, m	D_w ,m		H_b, m	L_b, m	D_w ,m		H_b, m	L_b, m	D_w ,m
1	0.50	1.0	3.0	6	0.5	1.00	3.0	11	0.5	1.0	2.0
2	0.75	1.0	3.0	7	0.5	1.50	3.0	12	0.5	1.0	3.0
3	1.00	1.0	3.0	8	0.5	2.00	3.0	13	0.5	1.0	4.0
4	1.25	1.0	3.0	9	0.5	2.50	3.0	14	0.5	1.0	5.0
5	1.50	1.0	3.0	10	0.5	3.00	3.0	15	0.5	1.0	6.0

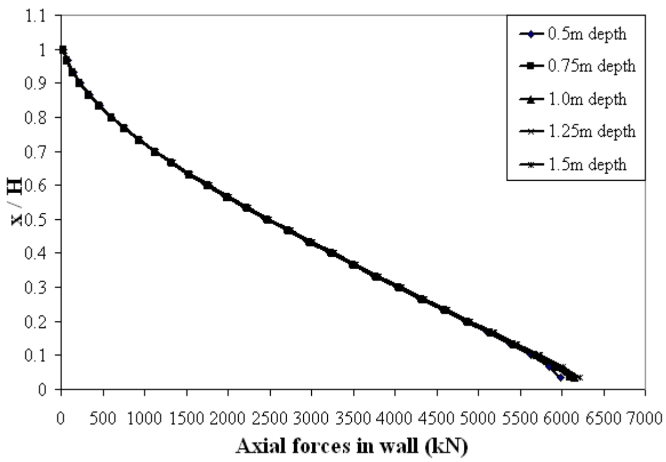
TABLE 2. WALL THICKNESS & BEAM WIDTH FOR DIFFERENT STOREY CSW

Storey No. of CSW	5	10	15	20	25	30
Wall Thickness/ Beam Width, m	0.2	0.25	0.3	0.3	0.35	0.35

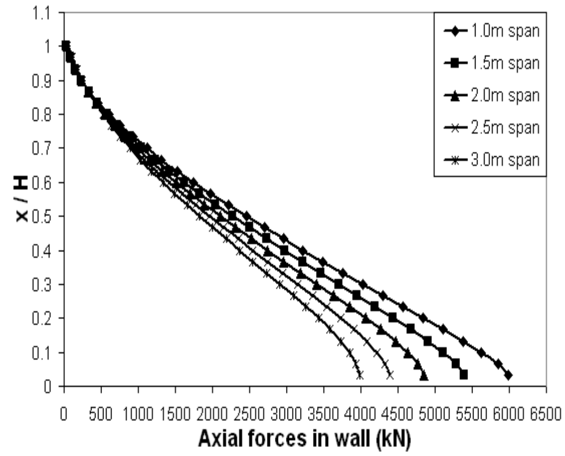
will be increased and the total moment to be resisted by the walls will be reduced.

B. Moment in the wall

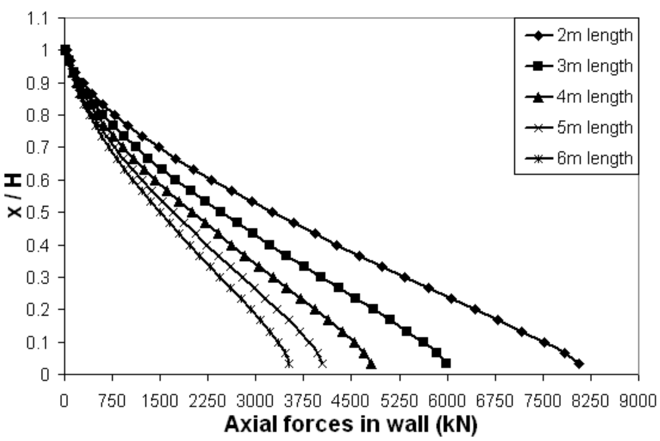
With increase in the depth of coupling beam, the moment in walls decreases (Fig. 4(d)). The reason for reduction of moment in wall is the net external moment reduces due to the coupling action. When coupling beam span is the parameter, the moment in walls reduces at the upper storey and increases at the lower storey (Fig. 4(e)) with increase in span. With the increase in wall length the moment in wall increases (Fig. 4(f)).



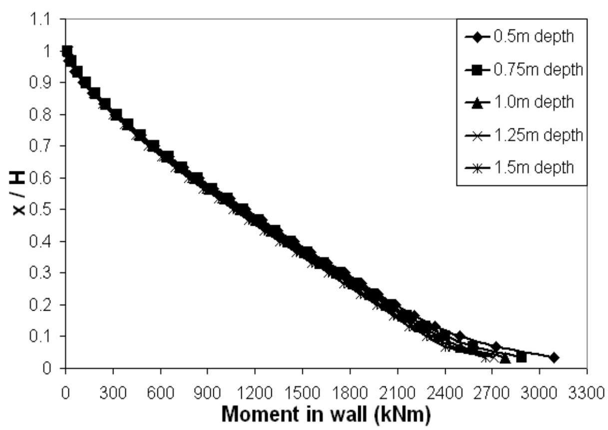
(a) Effect of Coupling Beam depth



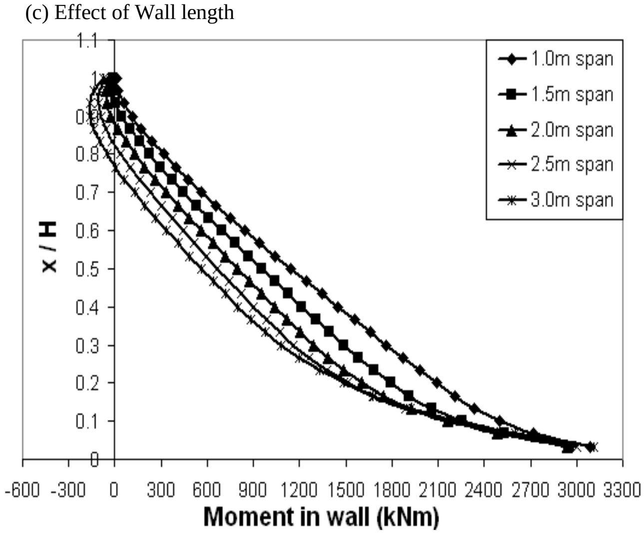
(b) Effect of Coupling Beam span

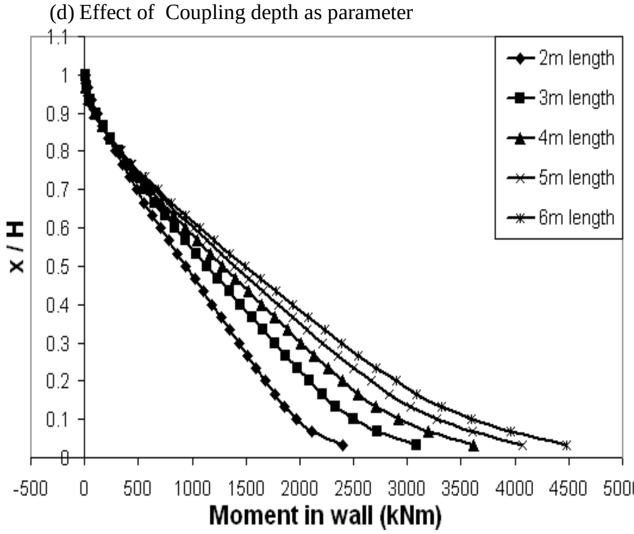


(c) Effect of Wall length



(d) Effect of Coupling depth as parameter





(e) Effect of Coupling Beam span

(f) Effect of Wall length

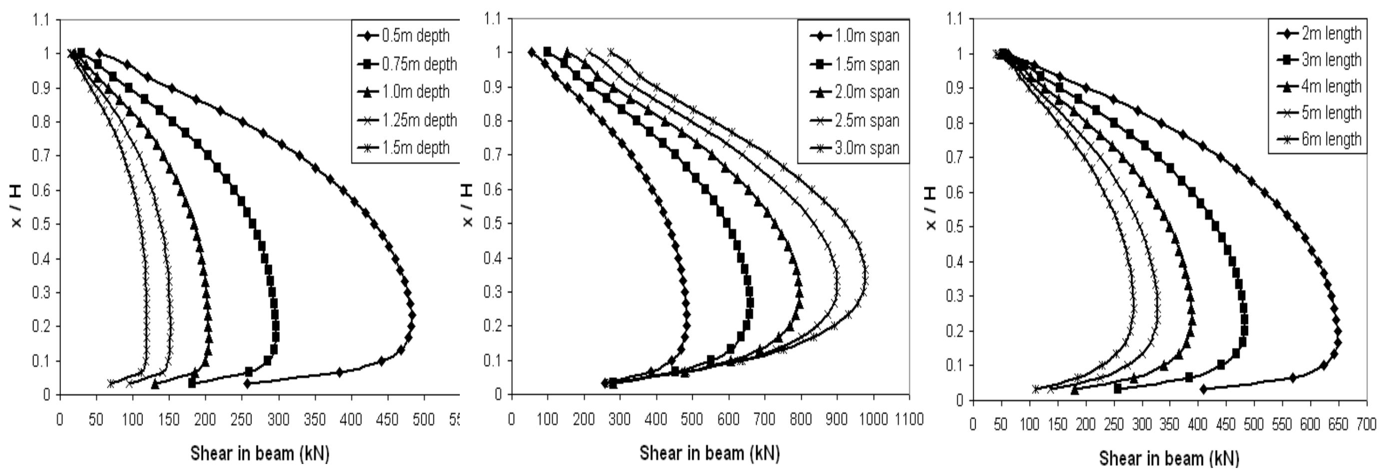
Fig 4. Effects of different parameters on Forces in Wall

C. Shear in the coupling beam

The shear in the coupling beam is critical in compared to the moment as per the experimental data [1]. Here the shear in coupling beam decreases with the increase in depth of coupling beam (Fig. 5(a)). The shear in the coupling beam increases with the increase in span of coupling beam (Fig. 5(b)). When wall length is the parameter, shear in coupling beam decreases with increase in wall length (Fig. 5(c)). Another thing to be noted here is that the shear in coupling beam is critical not at the ground floor of CSW but it is at the intermediate storey.

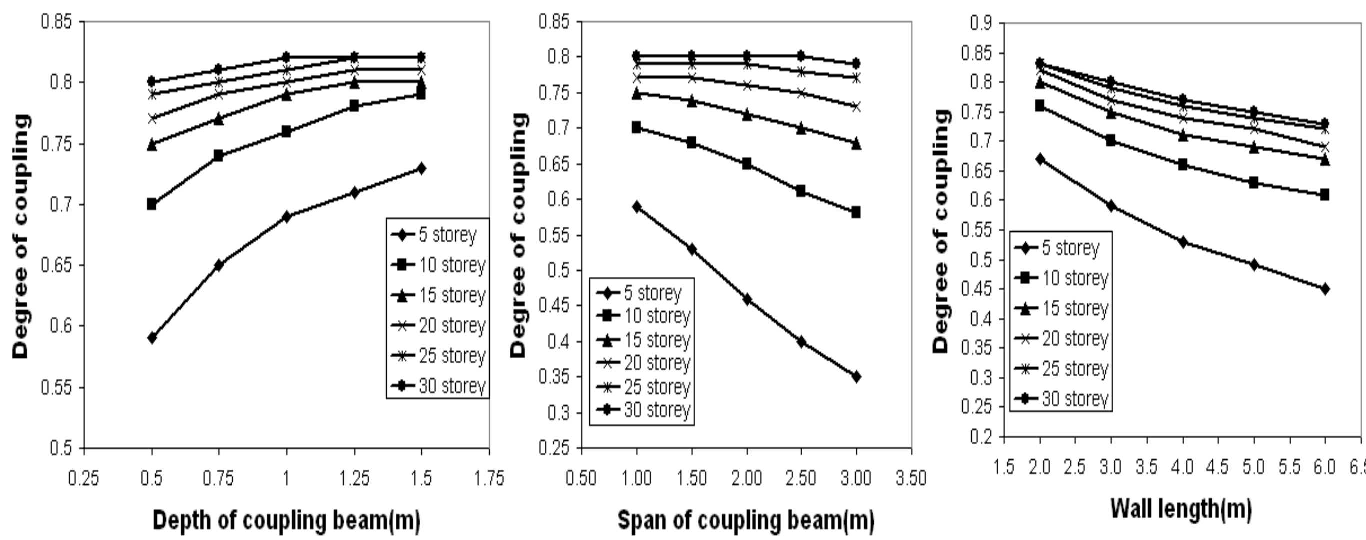
D. Degree of Coupling

The behavior of CSW is greatly influenced by the degree of coupling. Here DC is studied at the ground and top floor of CSW. As the depth of coupling beam increases the DC increases at the ground floor (Fig. 6(a)) but DC is decreased at the top floor (Fig. 7(a)). When the span of coupling beam is increased, the DC is decreased at the ground floor (Fig. 6(b)) and increased at the top floor (Fig. 7(b)). With the increase in wall length the DC is decreased at the ground floor (Fig. 6(c)) but at the top floor DC is increased (Fig. 7(c)). For the higher number of storey as in case of 30-storey building, with increase in depth of coupling beam, the increase in DC isn't significant at the ground floor of CSW. Similarly in case of span of coupling beam and wall length as parameter, the DC is not significantly affected with increase in the size of coupling beam and wall. For practical implementation of the CSW concept, DC can be kept uniform throughout the all storey with appropriate proportioning of wall and coupling beam.



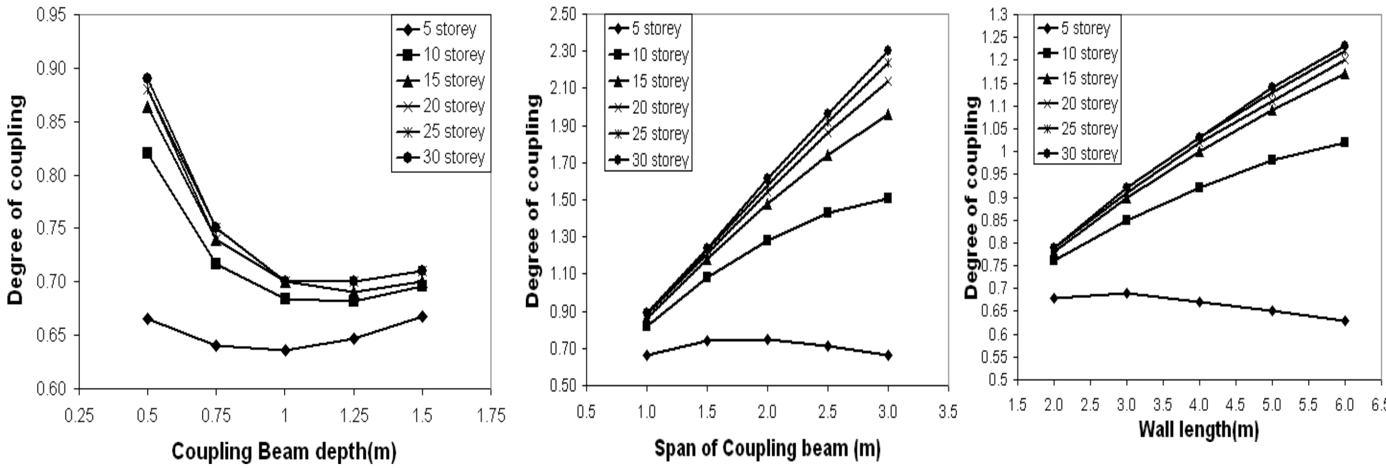
(a) Effect of Coupling Beam depth (b) Effect of Coupling Beam span (c) Effect of Wall length

Fig. 5. Forces in Coupling Beam considering different parameters



(a) Effect of Coupling Beam depth (b) Effect of Coupling Beam span (c) Effect of Wall length

Fig. 6. Degree of Coupling at Ground Floor of CSW



(a)Coupling Beam depth as parameter (b)Coupling Beam span as parameter (c)Wall length as parameter

Fig.7. Degree of Coupling at Top Floor of CSW

IV. DISCUSSION ON TIME PERIOD OF CSW BUILDING

For the estimation of time period of coupled shear wall building different formulae are specified by various codes and the researchers. Goel and Chopra [5] had studied the time period of concrete shear wall building. They observed that the codal formulae provides period that are generally shorter than measured period and the current code formulae for estimating the natural time period of concrete shear wall buildings are grossly inadequate. Wallace and Moehle [2] proposed formula for the estimation of fundamental periods of structural wall buildings as given below.

$$T_{wallace} = 6.2 \frac{h_w}{\left(2D_w + L_b\right)} n \sqrt{\frac{w h_s}{g E_c p}} \quad (4)$$

Where n = number of stories; w = unit floor weight including tributary wall weight; h_s = mean storey height; p = ratio of wall area to floor plan (area for the walls aligned in the direction the period is calculated); g = acceleration due to gravity; and E_c = concrete modulus of elasticity. Wang [6] concluded in his analytical study on time period of coupled shear wall building that the results from SAP2000, Wallace & Moehle formula and his proposed method is in agreement. The parametric study on CSW building and CSW is carried out for the Problem No. 1 (Table 1) with varying number of storey, which is given in Table 3. The time period from ETABS results are closer to the time period obtained from Wallace & Moehle's formula. But there is a significant difference in time periods between the codal formula and Wallace & Moehle's formula as well as ETABS results (Table 3).

TABLE 3. TIME PERIOD OF CSW BUILDING AND CSW

No. of Storey		5 storey	10 storey	15 storey	20 storey	25 storey	30 storey
Time period of CSW Building, Second	IS 1893 (Part 1) : 2002	0.302	0.604	0.906	1.207	1.509	1.811
	Wallace & Moehle's formula	0.17	0.639	1.338	2.403	3.798	5.542
Time period of CSW, Second	ETABS Results	0.262	0.715	1.356	2.311	3.316	4.71

V. CONCLUSIONS

The Coupled Shear Wall (CSW) is behaving in ductile manner compared to solid shear wall as a lateral load resisting system, particularly during the seismic event. The following points can be concluded from the study.

1. The coupling action in CSW reduces the moment to be resisted by the individual walls.
2. In the well proportioning of wall and coupling beam, the coupling beam can protect the walls from excessive damage. So a global failure can be avoided to some extent.
3. The higher depth and lower span of coupling beam and lower length of wall at the lower storey gives higher degree of coupling (DC). Lesser depth and higher span of coupling beam and higher length of wall provides the higher DC in upper storey. With the variation of sizes of coupling beam and wall a uniform DC can be achieved for the more efficient behavior of CSW.
4. The time period formula given in Indian Standard need to be modified for the CSW building by incorporating the sizes of wall and coupling beam.

VI. REFERENCES

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