Study of Effect of Provision of Shear-wall in multi-Storey Buildings

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Abstract:- **The basic structural behavior of high rise structure is similar to that of cantilever coming out from ground. The lateral forces generated from wind and Earthquakes are critical in high rise structures. Therefore to resists these lateral forces, lateral load resisting structural systems are required. *Shear wall is one of the most effective lateral load resisting system which has been studied over here*.**

There are many ways to resist Earthquake forces; shear wall is one of them. Shear wall provides considerable amount of increase in stiffness of structure. Shear wall is having great ability to resist the Earthquake forces and by this it prevents complete collapse of building. It adds additional safety to the structure. It is not only provided to resist Earthquake forces but also to serve for other functional requirements. Number of storey have been increased gradually to study the following aspects in context of shear wall in these high rise structures:

- **Structural behavior**
- **Effectiveness**
- **Feasibility**
- **Economy**
- **Serviceability**

I. Introduction

Shear walls are specially designed structural walls incorporated in building to resist lateral force that are produced in plane of the wall due to wind, earthquake and other forces. This came into practice only as late as 1940. The recent times, reinforced concrete buildings have become common in India, particularly in towns and cities. Reinforced concrete consists of two primarily materials, namely concrete and reinforcing steel bars.(4) Concrete is made of sand, crushed stone and cement, all mixed with pre-determined amount of water. Concrete can be molded into any desired shape, and steel bars can be bent into many shapes.(4)

Most of the framed structure project vertically upward from the ground. The seismic ground motion results in distortions and internal forces in them.(5) Due to dynamic nature of the seismic ground motion these distortion undergo reversal effect.(4)

The deformed shaped and distribution of moment, will keep changing in magnitude and significantly increased shaking, the frame may yield forming plastic moment hinges at supports and joints.(5)

Columns and floors in a RC building are cast and the concrete hardens, vertical spaces between columns and floors are usually filled in with masonry walls to demarcate area into functional spaces.(4) Normally these masonry walls, also called infill walls, are not connected to surrounding RC columns and beams.(4) When columns receive horizontal forces at floor levels, they try to move in the horizontal direction, but masonry walls tend to resist this movement. Due to their heavy weight and thickness, these walls attract rather large horizontal forces.(4)

II. Shear wall as a column element

Any vertical element can either be column or shear wall. The nomenclatures depend upon the structural behavior of the member in that particular case.

A vertical "framing" member can be classified as column when, lateral load in that frame is resisted mostly by flexural deformations. If the lateral load is being resisted mainly by shear deformations, same element will be called as shear wall. When lateral forces are applied on a frame, columns stiffness comes into action to take care of this lateral force. When *cumulative* stiffness of all columns is still unable to take care of this lateral force .Now due to introduction of shear walls frame most of the lateral force is attracted by shear walls.

III. Current Codal Provision

Indian Concrete Code IS 456: 2000

Limit State Design Philosophy

The philosophy of limit state method of RC structures proposes that the structure should withstand safely all possible loads throughout its design life by satisfying certain specified acceptable limit states of collapse and serviceability. The possibility of a structure attaining one of its limit states is determined using inputs from probabilistic studies. The probable variations in material properties and loads are accounted for through appropriate partial safety factors based on inputs from statistical analysis.

Sections 35 and 36 of Indian Standard [IS 456:2000] discuss the limit states of collapse and serviceability for the design of reinforced concrete structures. The limit states of column include the limits for flexure, compression, torsion and shear, and the limit states of serviceability include the limits for deflection and cracking.

Flexural Design

The assumptions for flexural limit state design specify the limit states in terms of the maximum compressive strain in the extreme layer of concrete in bending and the minimum tensile strain in the extreme layer of steel in bending. While the limit states are sufficient for over-reinforced RC sections, the limit states for under-reinforced designed section are not addressed to.

Shear Design

Section 40 discusses the shear design provisions for RC sections. The nominal shear stress τ_v in a RC rectangular section of uniform depth is defined as

$$\tau_v = \frac{V_D}{bd} \qquad (1)$$

where V_D is the factored design shear force, b is breadth, and d is the effective depth of section. This nominal shear stress τ_v is required to be less than the maximum allowable shear stress $\tau_{c(max)}$ (in MPa) in concrete given be [SP – 24-1983]

$$\tau_{c(max)} = 0.83\sqrt{f'_c}\,, \qquad (2)$$

where f'_c is the cylinder strength of concrete.

The design shear strength V_u of an RC section is contributed by both concrete and the shear reinforcement, and is given by,

$$V_u = V_{uc} + V_{us} \qquad (3)$$

where the shear strength V_{uc} and V_{us} are contributed by concrete and steel respectively

$$V_{uc} = \tau_c bd\text{, and} \qquad (4)$$

$$V_{us} = 0.87 f_y A_{sv}\left(\frac{d}{s_v}\right), \qquad (5)$$

in which

$$\tau_c = \left(\frac{0.85\sqrt{0.8 f_{ck}}\left(\sqrt{1+5\beta}-1\right)}{6\beta}\right) \qquad (6)$$

$$\beta = \frac{0.8 f_{ck}}{6.89\, p_t} \geq 1 \qquad (7)$$

$$p_t = 100\,\frac{A_s}{bd} \qquad (8)$$

where τ_c is the design shear strength of concrete, f_y is the characteristic strength of stirrups not to be greater than 415 MPa, A_{sv} is the total cross sectional area of shear reinforcement, s_v is the spacing of the stirrups along the length of member, f_{ck} is the characteristic compressive strength of concrete, and p_t is the percentage of longitudinal reinforcement.

For sections under axial compression, the design shear strength of concrete is $\delta\tau_c$,, where

$$\delta = 1 + \frac{3P_u}{A_g f_{ck}} \leq 1.5, \tag{9}$$

where P_u is the axial compressive force in N, and A_g is the gross area of the concrete section (in mm^2). The minimum shear reinforcement specified is,

$$\frac{A_{sv}}{bs_v} \geq \frac{0.4}{0.87 f_y} \tag{10}$$

For RC walls with boundary elements as in buildings, the contribution of boundary elements in the total shear capacity of the wall section needs to be calculated as per Eq. – (2.3) [(19)]

Indian RC Ductile Detailing Code IS 13920: 1993

Section 9 specifies the design provisions of RC structural walls that are part of lateral force resisting system.

General Requirement

The general requirements of RC structural walls of Section 9.1 pertain to the dimensional constraints and sectional characteristics. These are the salient clauses:

1. A minimum thickness of wall specified is 150 mm to ensure the stability of the web under compressive load.
2. A minimum reinforcement is specified along both vertical and horizontal directions as 0.25% of the gross area of cross section. This reinforcement is required to be distributed uniformly in the plane of the wall.
3. Two curtains of reinforcement are to be provided along each of the horizontal and transverse direction in the web of the wall when the factored shear stress in the wall exceeds $0.25\sqrt{f_c}$ or wall thickness exceeds 200 mm.
4. A maximum diameter of reinforcement is specified at any location of wall is one-tenth of thickness at that location.
5. A maximum spacing of reinforcement in either direction is specified as the smaller of $l_w/5$, $3t_w$ and 450 mm, where l_w is the horizontal length of wall and t_w is the thickness of the web.

Flexural Design:-

Section 9.3 recommends the Moment of resistance M_{uv} of RC walls with uniformly distributed vertical steel to be calculated in the same way as is done for RC sections subjected to combined uniaxial bending M_u and axial compression P_u as per Indian Concrete Code, and provides the following expressions in terms of the length l_w and thickness t_w of the wall, material properties E_s, f_y and f_{ck} and percentage of vertical steel ρ.

$$\rho = \left(\frac{A_{st}}{t_w l_w}\right) \tag{11}$$

Parameter Φ, λ and β are calculated as

$$\Phi = \frac{0.87 f_y \rho}{f_{ck}} \tag{12}$$

$$\lambda = \frac{P_u}{f_{ck} t_w l_w} \tag{13}$$

$$\beta = \frac{0.87 f_y}{0.0035 E_s} \tag{14}$$

when the depth of neutral axis is above the balanced depth of neutral axis, i.e., $\frac{x_u}{l_w} \leq \frac{x^*_u}{l_w}$, then,

$$\frac{M_{uv}}{f_{ck} t_w l^2_w} = \Phi \left[\left(1+\frac{\lambda}{\phi}\right)\left(\frac{1}{2}-0.416\frac{x_u}{l_w}\right)-\left(\frac{x_u}{l_w}\right)^2\left(0.168+\frac{\beta^2}{3}\right)\right]$$

(15)

where

$$\frac{x_u}{l_w} = \frac{\phi+\lambda}{2\phi+0.36}, \text{ and} \qquad (16)$$

$$\frac{x^*_u}{l_w} = \frac{0.0035}{0.0035+\frac{0.87 f_y}{E_s}} \qquad (17)$$

when the depth of neutral axis is below the balanced depth of neutral axis, i.e., $\frac{x^*_u}{l_w} < \frac{x_u}{l_w} < 1$, then

$$\frac{M_{uv}}{f_{ck} t_w l^2_w} = \left[0.36+\phi\left(1-\frac{\beta}{2}-\frac{1}{2\beta}\right)\right]\left(\frac{x_u}{l_w}\right)-\alpha_2\left(\frac{x_u}{l_w}\right)^2-\alpha_3-\left(\frac{\lambda}{2}\right), \qquad (18)$$

$$\alpha_2 = 0.15+\frac{\phi}{2}\left(1-\beta-\frac{\beta^2}{2}-\frac{1}{3\beta}\right)$$

and (19)

$$\alpha_3 = \frac{\phi}{6\beta}\left(\frac{1}{\left(\frac{x_u}{l_w}\right)}-3\right) \qquad (20)$$

where $\frac{x_u}{l_w}$ is obtained by solving,

$$\left[0.36+\phi\left(1-\frac{\beta}{2}-\frac{1}{2\beta}\right)\right]\left(\frac{x_u}{l_w}\right)^2+\left(\frac{\phi}{\beta}-\lambda\right)\left(\frac{x_u}{l_w}\right)-\phi/5\beta=0 \qquad (21)$$

In the derivation of above expressions, the vertical steel is represented by an equivalent steel plate along the length of the section, and the design stress-strain curves for concrete is as per IS: 456 whereas that for steel is assumed to be bi-linear.

To economize the wall design, the cracked flexural strength of the wall is prescribed to be more than uncracked flexural strength. Also for walls without boundary elements, extra vertical steel needs to be concentrated at the boundary region to provide additional flexural capacity.

Shear Design

Section 9.2 discusses the shear design provisions for RC structural walls. Relevant clauses are:

1.The design shear capacity V_{uw} of the wall section is given by,

$$V_u = \tau_c t_w d_w + 0.87 f_y A_h \left(\frac{d_w}{s_v}\right) \qquad (22)$$

where the first term on the right hand side is the contribution of concrete and the second term is the contribution of steel. In Eq. (22) *Ah* is the total area of horizontal shear reinforcement, and s_v is the vertical spacing of horizontal shear reinforcement along the height of the wall. The shear strength of concrete τ_c is calculated using Eq. (6). The design shear capacity of the wall section is based on the capacity of web portion only. Thus, for walls with boundary elements, the contribution of boundary element is not addressed.

1.The nominal shear stress τ_v in the section is calculated as,

$$\tau_v = \frac{V_D}{t_w d_w} \qquad (23)$$

where d_w is the effective depth of wall section to be taken as $0.8 l_w$ for rectangular sections. The nominal shear stress should be less than the maximum possible shear stress τ_{cmax} as in Eq. (2)

2.If the design vertical steel comes out to be less than the design horizontal steel, then the code requires that the vertical steel be increased at least equal to horizontal steel.

Design of Boundary Element(2):-

1.Boundary elements are to be provided if the maximum compressive stress in the section, due to factored gravity and factored seismic loading, exceeds $0.2f_{ck}$. Such boundary elements are to be continued along the length of the wall until the section where the compressive stress reduces below $0.15f_{ck}$. The compressive stress is to be calculated using linear elastic model and gross section properties.

2. The boundary element is to be designed as a short column for an axial compression P equal to the sum of the factored gravity load P_g and the additional compressive force P_e induced by the seismic force, given by

$$P_e = \frac{M_u - M_{uv}}{C_w}$$

where M_u is the factored design moment on the entire wall section, M_{uv} is the moment of resistance provided by vertical reinforcement along the length, and C_w is the horizontal center to center distance between the boundary elements.

3.If the gravity load adds to the strength of the wall, its load factor shall be taken as 0.8.

4.The percentage of vertical reinforcement in boundary elements shall not be less than 0.8 percent, nor grater than 6 percent. In order to avoid congestion, the practical upper limit would be 4 percent.

5.To sustain repeated cycles of inelastic strains without large degradation of strength, special confining reinforcement is to be provided along the full height of the boundary element.

6.If boundary elements are not provided, special confining reinforcement is to be provided throughout the entire wall .

IV. Use of software: STRAP

Structural Analysis Program - "STRAP" is a special purpose computer program, which satisfies all the needs of structural engineer of various fields. The need for special purpose program has never been more evident, as, structural engineer put static and dynamic analysis into practice and use the greater computer power available today to create large, more complex analytical models.

V. Case study

A symmetrical building as shown in figure below has been taken. Case-0 is a building with out shear wall and Case-1 is building with shear wall where shear walls are provided at outer periphery. In Case-1 shear walls are provided as a column element.

Stiffness Calculation:-

i.e. (i) Horizontal frame of CASE-1:-

2 frame of with shear wall = 0.75∑k

3 frame with out shear wall =0.25∑k

So, Stiffness of 1 frame with shear wall = 4.5 Stiffness of frame with out

(ii) Vertical frame of CASE-1:-

2 frame of with shear wall = 0.75∑k

7 frame with out shear wall =0.25∑k

So, Stiffness of 1 frame with shear wall = 10.5 Stiffness of frame with out shear wall

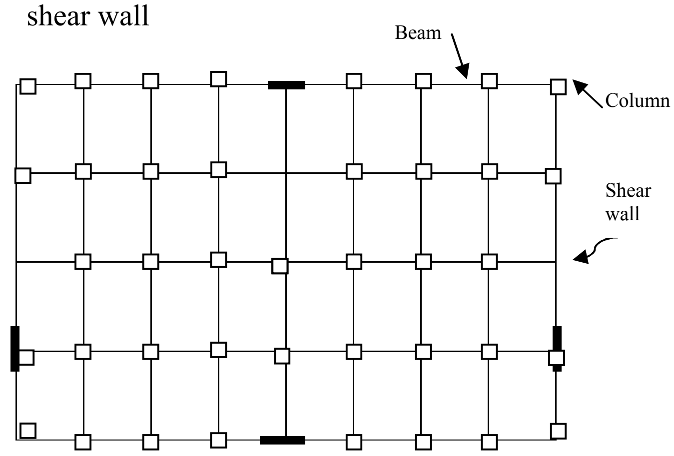

Figure:01 Layout plan of Case-1

Beam size:- 230mm x 420mm

Case-0 is with out shear wall and Case-1 has shear walls. Beam and Column sizes in both the Cases were same initially. But after analysis results sizes of column Case-0 has been changed

NO. OF STOREY	EQ AND WIND	EQ ONLY	WIND ONLY	BEAM	COLUMN	TOTAL COST
5	YES			19.45	79.04	98.49
		YES		19.67	79.04	98.71
			YES	13.58	81.76	95.34
10	YES			32.32	146.6	178.92
		YES		32.53	146.56	179.09
			YES	25.37	151.22	176.59
15	YES			52.27	360.31	412.58
		YES		48.75	359.18	407.93
			YES	41.6	368.74	410.34
20	YES			71.84	433.71	505.55
		YES		65.37	408.83	474.2
			YES	59.01	406.5	465.51
25	YES			89.23	643	732.23
		YES		62.6	661.58	724.18
			YES	72.2	660.49	732.69

Table.01 Total Cost of Case-0

NO. OF STOREY	EQ AND WIND	EQ ONLY	WIND ONLY	BEAM (LACS)	COLUMN (LACS)	SHEAR WALL (LACS)	TOTAL COST (LACS)
5	YES			18.12	71.89	5.05	95.07
		YES		18.06	71.89	2.73	92.69
			YES	13.98	71.89	2.65	88.52
10	YES			33.88	132.29	5.82	171.99
		YES		34.12	132.29	5.58	172.00
			YES	27.57	132.29	5.51	165.37
15	YES			54.44	237.7	9.75	301.89
		YES		51.42	238.12	8.13	297.67
			YES	44.38	245.12	9.22	298.72
20	YES			71.99	365.27	15.02	452.28
		YES		58.98	367.04	14.29	440.31
			YES	60.27	377.5	14.21	451.98
25	YES			86.16	583.05	20.55	689.76
		YES		86.88	583.1	18.97	688.95
			YES	76.40ss	598.27	19.7	694.37

Table-2 Total Cost of Case-1

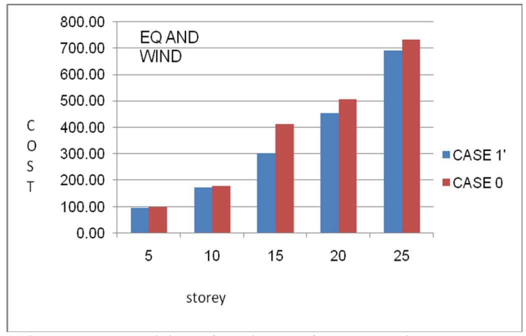

Chart.01 Comparision of total cost of Case-0 and Case-1(EQ and Wind)

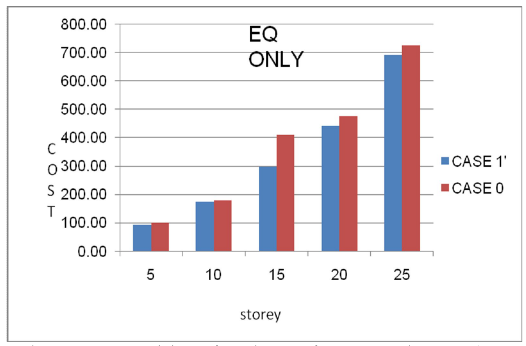

Chart.02 Comparision of total cost of Case-0 and Case-1(EQ only)

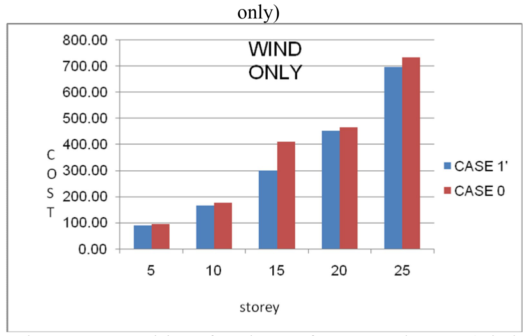

Chart.03 Comparision of total cost of Case-0 and Case-1(wind only)

VI. Conclusion

Rectangular shear wall can carry force in their own plane, but it can not resist forces in perpendicular direction, so it is always advisable to provide a bar – bell type structural wall i.e. shear wall with boundary element which can resist forces in its own plane as well as in perpendicular plane. This fact was also confirmed. Boundary element attracts large amount of forces, hence, it is very much important to have a proper design and detailing of boundary element so as to make sure that wall acts as a single unit.

Total cost of building with out shear wall in comparison of building with shear wall on outer periphery is higher. In Case-1 four shear walls are provided on outer periphery and in Case-0 there are no Shear walls. As per the results total cost of Case-0 is high in comparison of Case-1.

VII. References

1. P. C. VERGHESE, "Advanced Reinforced Concrete design"
2. IS 13920: 1993 " Ductile Detailing of Reinforced Concrete Structures subjected to Seismic forces – Code of Practice"
3. IS 1893 – 2002 (pt 1) "Criteria for Earthquake Resistant Design of Structures".
4. C V R MURTY, "Learning Earthquake Design And Construction" Indian Concrete Journal Volume- 77,April-2002.
5. SHARONL WOOD, "Shear Strength of Low Rise Reinforced Concrete Walls" ACI (Structural Journal) Vol-87, NO-1 JAN-FEB-1990.
6. http://www.nicee.org
7. http://www.eng-tips.com