Analysis and Design of Vertical Post-Tensioned Precast Shear Wall

Rutuja Chavan
P.G Student, Department of Civil Engineering,
School of Mechanical and Building Sciences
VIT University, Chennai 600 127.
rchavan6317@gmail.com
contact- +917709958606

M. Ramesh Kannan
Professor, Department of Civil Engineering,
School of Mechanical and Building Sciences
VIT University, Chennai 600 127.
rameshkannan.m@vit.ac.in
contact- +919840393307

Abstract-This study aims to provide analysis and design of Vertical-Post-tensioned Precast Shear Wall as per IS 1343:2012. Instead of using conventional cast-in-situ Shear Walls, use of precast shear wall using post-tensioned tendons for flexural reinforcement observed only small amount of damage to the concrete material. This research focuses on the use of unbonded post-tensioning tendons for wall to wall connection in precast shear wall across the horizontal joint over the portion of its length. For this purpose a commercial (G+4) storied building with shear walls modelled in ETABS2016 to analyse the structure and to found the load coming on shear walls. Design of Precast Shear walls using post-tensioning tendons are done manually for each precast walls. The behaviour of vertical post-tensioned precast shear wall is captured by analysing the precast shear wall in SAP2000 software.

Keywords—*Vertical Post-tensioning; Precast Shear Wall; Behaviour of Shear Wall*

*****

.Nomenclature

A_w	Area of wall (mm^2)
L_w	Length of wall (mm)
t_w	Thickness of wall (mm)
X_u	Neutral axis depth (mm^2)
N_w	Axial force(KN)
M	Moment (KNm)
M_u	Moment capacity (KNm^1)
A_g	Gross c/s area of column,wall
A_h	Horizontal reinforcement area within spacing S_v
A_k	Area of concrete core of column (mm^2)
f_{ck}	Characteristic compressive strength
f_y	Yield stress of steel
Subscripts	
SW	Shear wall
PT	Post-tensioning

I. INTRODUCTION

The Shear Wall is a vertical cantilever member to counter the effects of lateral load acting on a structure (Fintel, 1995). Conventional Shear Walls are cost-effective way of providing lateral load resisting systems located in seismic regions (B. Erkmen and A. E. Schultz, 2007). Instead of using conventional cast-in-situ shear walls, the use of precast shear walls and rely on post-tensioned tendons for flexural reinforcement observed only small amount of damage to the concrete material (FJ Perez, 2004). This unbonded post-tensioned precast shear walls provides an excellent envelope for low rise commercial and industrial buildings.

Over the past earthquakes, it has been recognized that seismic performance of buildings using reinforced concrete shear walls was unsatisfactory as the primary lateral load resisting system (A.C. Tanyeri and J.P. Moehle, 2012). With the benefits of precast construction and practices, the use of precast shear wall panels has become an excellent lateral load resisting system. And the behaviour of precast shear walls under lateral load showed that use of unbonded post-tensioning across the horizontal joints of precast wall and allowing inelastic deformations to occur in the vertical joint connectors provides wide, stable hysteresis loops, which provides good inelastic energy dissipation without loss in self-centring behaviour (FJ Perez, 1998). The lateral load behaviour of this walls differs significantly from that of conventional cast-in-place reinforced concrete walls. As a result of unbonding, large nonlinear lateral drift can be achieved in precast shear wall without fracturing or yielding of post-tensioning tendons under moderate-to-severe earthquake (F.J. Perez et al., 2002). And using a combination of mild steel reinforcement and high strength post-tensioning tendons across horizontal joint for flexural resistance. The mild steel was designed to yield in compression and tension by providing inelastic energy dissipation. The PT tendons provided for self-centring ability and reduces permanent lateral displacement of wall due to large earthquakes. As compared to cast-in-situ reinforced concrete shear wall, the amount of mild steel reinforcement that would be needed for partially PT wall was smaller because of lateral strength of wall was provided by PT steel (Yahya C. Kurama, 2005). During cyclic loading the PT force may completely die out, while wall retains its self-centring characteristic. By comparing the analytical results with experimental results, indicates that proper design of end anchorages for Pt tendons, self-centring can be achieved even when the PT force dies out completely (B. Erkmen and A. E. Schultz, 2007). However, due to lack of energy dissipation these walls undergo large displacement under seismic load (Sause R et al., 2002). Therefore, to overcome this jointed wall system concept introduced, which consist of two or more walls designed with PT steel and connected to each other using special connectors placed along vertical joints (Nakaki SD et al., 1999). The proposed method accurately captures the elongation of PT tendons (Sriram Aaleti and Sri Sritharan, 2009).

II. MATERIALS AND METHODS

The Vertical Post-tensioned Precast Shear Wall is designed to study the performance of Precast Shear Wall. Also it is intended to study flexural strength and self-centring ability of PT Shear Wall. For this purpose a Commercial (G+4) storied building is modelled in ETABS2016. All the loads are distributed to the shear walls and core walls through floor frame action. Frame with (G+4) storeys having M30 grade concrete, Fe500 steel is modelled and analysed in ETABS2016.

A. Modelling and Analysis

1) Geometric properties:
   a) Height of typical storey =3.5 m
   b) Length of building = 51 m
   c) Width of building = 21m
   d) Slab thickness = 125 mm
   e) Thickness of Shear wall = 300 mm
   f) Beam size: 300 X 400 mm
   g) Column size : 600 X 600 mm

2) Loads:
   a) Live Load
      Live load for shops, corridors and staircase=5 KN/m^2
      Load for Toilets = 2 KN/m^2
   b) Masonry Load
      External walls (0.3thk) =18.9 KN/m
      Internal walls (0.15thk) = 9.5 KN/m

3) Seismic Loading :
   The building comes under Zone-V using the IS 1893 (Part-I) -2002

4) Load Patterns:

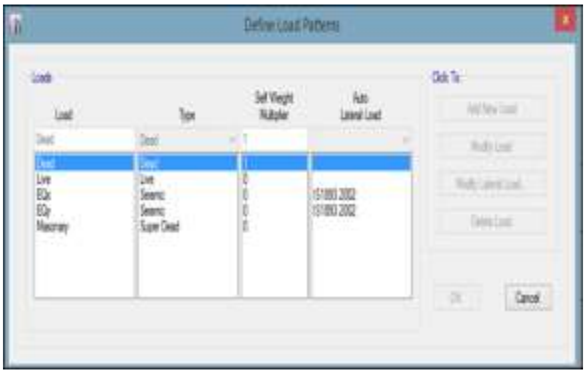

Figure 1.shows load patterns

5) Load Combinations:
   The load combination for concrete frame design, slab design and shear wall considered as per IS code.

6) Commercial (G+4) storey building model:

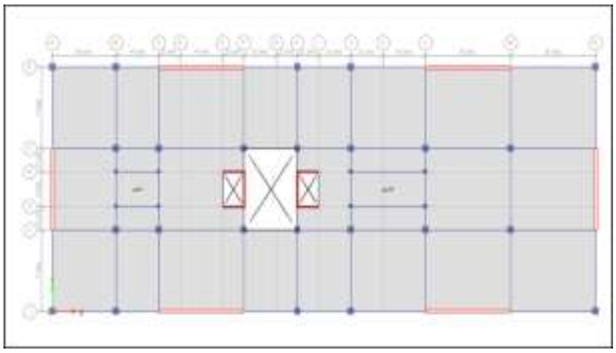

Figure 2.1 plan view of commercial building

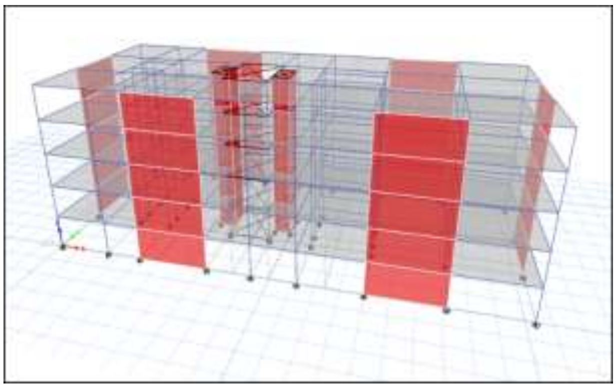

Figure 2.2. 3D view of G+4 storey building

Various load combinations are applied to the models. The building model then analysed and various results such as axial force, moments and shear force are taken as reference for designing of post-tensioned precast shear wall and conventional shear wall. Considering the maximum values of shear force, axial force and moment coming on shear wall. For Pier1 (7m) i) axial force = 4915 KN, Shear force=2966 kN, Moment 3-3 = 37060 kNm and for Pier2

(8m) ii) axial force = 9857 KN, Shear force=3891 kN, Moment 3-3 = 69909 kNm.

A. Basic Equations

Extreme Fibre Compressive Stresses,

$$f = \frac{P}{A_w} + \frac{6M}{t_w * (l_w)^2} \qquad (1)$$

Moment of resistance of middle part of wall,

For, $\frac{\chi_u}{l_w} < \frac{\chi_u}{l_w}^*$

$$\frac{M_{uv}}{f_{ck} * (l_w)^2 * t_w} = \phi\left[\left(1 + \frac{\lambda}{\phi}\right) * \left(0.5 - 0.416\frac{\chi_u}{l_w}\right) - \left(\frac{\chi_u}{l_w}\right)^2 * \left(0.168 + \frac{\beta^2}{3}\right)\right] \qquad (2)$$

For, $\frac{\chi_u}{l_w}^* \leq \frac{\chi_u}{l_w} \leq 1.0$

$$\frac{M_{uv}}{f_{ck} * (l_w)^2 * t_w} = \alpha_1\left(\frac{\chi_u}{l_w}\right) - \alpha_2\left(\frac{\chi_u}{l_w}\right)^2 - \alpha_3 - \frac{\lambda}{2} \qquad (3)$$

Where,

$$\alpha_1 = \left[0.36 + \phi\left(1 - \frac{\beta}{2} - \frac{1}{2\beta}\right)\right]$$

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

$$\alpha_3 = \frac{\Phi}{6\beta}\left(\frac{1}{\chi_u/l_w} - 1\right)$$

Axial load carrying capacity of boundary element,

$$P_u = 0.4 * f_{ck} * A_c + 0.67 * f_y * A_{sc} \qquad (4)$$

The special confining reinforcement is provided in boundary elements in region lo,

$$A_{sh} = 0.18 * S * h * \frac{f_{ck}}{f_y}\left(\frac{A_g}{A_k} - 1\right) \qquad (5)$$

The design initial stress for the post-tensioning steel, f_{pi} is assumed

Let, $f_{pi} = 0.55 * f_{pu}$

Area of post-tensioning steel,

$$A_p = \frac{2M_u}{(\beta_m + 1) * (l_w - a_c) * f_{pi}} - \frac{N_{wd}}{f_{pi}} \qquad (6)$$

Where, a_c = length of concrete rectangular compression stress block

$$a_c = \frac{N_{wd} + A_p * f_{pi}}{0.85 * f_c{}' * t_w} \qquad (7)$$

B. Design and Analysis

1) Design of Post-tensioning Precast Shear Wall and Conventional Shear Wall :

Table 1.1 Reinforcement details of Precast Shear Wall for Pier1 and Pier2

	Member	Size(mm)	Main Steel	Lateral steel
Pier1	Web part of wall	300thk	#10 of 15.24 mm Ø	8mm bar @ 100mm spacing
	Boundary element	500*900	# 10 of 25 mm Ø	8mm bar @ 75mm spacing
Pier2	Web part of wall	300thk	# 12 of 15.24mm Ø	8mm bar @ 75mm spacing
	Boundary element	500*900	#16 of 25 mm Ø	8mm bar @ 90mm spacing

Table 1.2 Reinforcement details of Conventional Shear Wall for Pier1 and Pier2

	Member	Size(mm)	Main Steel	Lateral steel
Pier1	Web part of wall	300thk	10 mm @ 200mm c/c	8mm bar @ 100mm spacing
	Boundary element	500*900	#10 of 25mm Ø	8mm bar @ 75mm spacing
Pier2	Web part of wall	300thk	12 mm @ 180mm c/c	8mm bar @ 75mm spacing
	Boundary element	500*900	#18 of 32mm Ø	8mm bar @ 90mm spacing

2) Analysis of Post-tensioning Precast Shear Wall :

The analysis of Post-tensioning Precast Shear wall is done using SAP2000 software. From analysis of wall we can see that predominantly horizontal crack pattern develop in the lower hinging region after few cycles of deformations. In below figure we can see the maximum stresses developed in the lower region of wall.

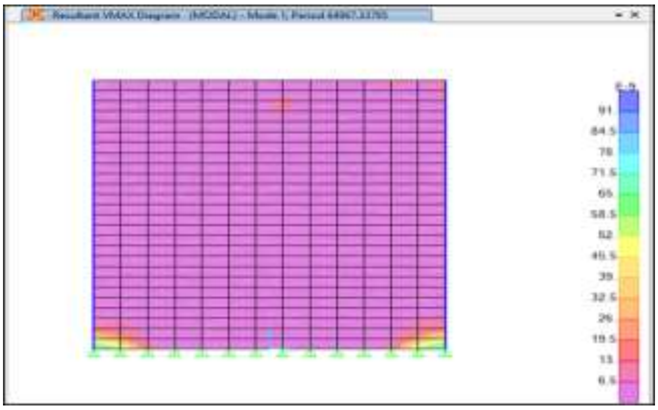

Figure 3.shows maximum stresses in wall at lower region

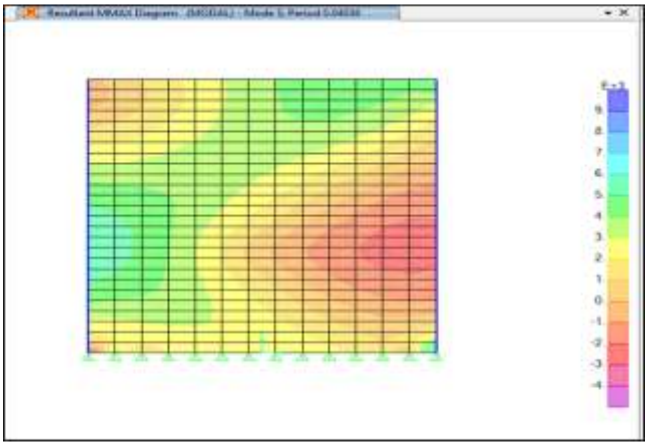

Figure 4.shows behaviour of Precast Shear Wall

Above figure shows that the behaviour of Post-tensioning Precast Shear wall. It indicates that due to adequate anchorage of wall foundation, the wall is capable of undergoing large deformations and prevent from overturning of the wall at base.

III. RESULTS AND DISCUSSION

1) Material Analysis:

Table 2.1 Quantity of material required for Precast and Conventional Shear Wall

	Quantity of Material required	
	Precast SW	Conventional SW
Total Concrete required (m^3) =	44.62	44.48
Total Steel required (kg) =	2896.98	4024.15

From above table it is observed that the quantity of Steel required for Precast Shear wall is very less than the Conventional Shear wall and the quantity of concrete required for both shear walls are approximately same.

2) Moment and Load carrying capacity of precast and conventional shear wall :

Table 2.2 Moment and Load carrying capacity of Precast Shear Wall

	Precast SW	**Conventional SW**
Total maximum moment on shear wall (KNm)	69909	69909
Moment carried by web part of wall, Mu (KNm)	32284	22590
Load carrying capacity of boundary elements, Pu(KN)	7977	10195

From the design calculations of shear wall it is observed that the moment carrying capacity of Post-tensioned Precast Shear Wall is larger than the Conventional Shear Wall.

3) Manual analysis of Precast Shear wall :

a) Rotation at wall base:

The rotation at wall base estimated as, $Ø = 1.418*10^{-6}$ and roof drift calculated for post-tensioned shear wall is $\Delta_{\boldsymbol{d}}$= 0.22%**.** Hence, ok.The roof drift estimated from manual analysis is within the allowable roof drift (025% to 0.15%).

b) Concrete confinement :

The required strain capacity of the confined concrete estimated as: $\varepsilon_{cu} = 0.0026$. Since the ultimate strain capacity demand, $\varepsilon_{cu} = 0.0213$ is sufficiently close to the demand$\varepsilon_{cu} = 0.0026$.

c) Yielding of post-tensioning steel:

Additional elongation, u_{py} of post-tensioning steel from f_{pi} to f_{py} is estimated as: $u_{py} = 28.61\ mm$.

IV. CONCLUSIONS

This paper reports on the analytically observed lateral load behaviour of Vertical Post-tensioned Precast Shear Wall. The conclusions drawn from this research are as follows:

1. The proposed method accurately captures the behaviour of Post-tensioning Precast Shear Wall, which is critical importance for the design of systems incorporating

post-tensioning.

2. The proposed equations seems adequate for estimating area of post-tensioning reinforcement and although simple for calculation purpose.
3. From comparison of Vertical Post-tensioned Precast Shear Wall and Conventional Shear Wall shows that the moment carrying capacity of web part of the wall is more in Post-tensioning of precast walls than conventional shear wall. This post-tensioning prevents the wall from overturning. Due to post-tensioning the wall has excellent self-centring capacity.
4. And from comparison it also seen that the post-tensioning precast wall requires lesser steel than the conventional shear wall.
5. From manual analysis of precast shear wall it is observed that required strain capacity of the confined concrete is sufficiently closer to the ultimate strain capacity. Hence, design of concrete confinement is satisfied. And it is also observed that yielding of post-tensioning reinforcement expected to occur before crushing of concrete confinement.

REFERENCES

[1] N. Janardhana Reddy, D. GosePeera, and T.Anil Kumar Reddy (2013), “Seismic analysis of multi-storied building with shear walls using Etabs-2013”, IJSR.

[2] A.C. Tanyeri and J.P Moehle (2012), “Seismic performance and modelling of post-tensioned, precast concrete shear walls”, 15 WCEE.

[3] Sriram Aaleti and Sri Sritharan (2009), “A simplified analysis method for characterizing unbonded post-tensioned precast wall systems”, Engineering Structures.

[4] B. Erkmen and A. E. Schultz (2007), “Self-centring behaviourof unbonded precast concrete shear walls”, Earthquake Resistant Engineering Structures VI.

[5] Can Bora, Michael G. Oliva, Suzanne Dow Nakaki (2007), “Development of a precast concrete shear-wall system requiring special code acceptance”, PCI Journal.

[6] Yahya C. Kurama (2005), “Seismic design of partially post-tensioned precast concrete walls”, PCI Journal.

[7] P. C. Varghese (2005), “Advanced reinforced concrete design”, Prentice-Hall of India Private Limited, New Delhi-110 001.

[8] D. J. Thomas and S. Sritharan (2004) , “An evaluation of seismic design guidelines proposed for precast jointed wall systems”, ISU-ERI-AMES report ERI-04643.

[9] F. J. Perez, R. Sause, S. Pessiki and L.W.Lu (2002), “Lateral load behaviour of unbonded post-tensioned precast concrete walls”, Advances in building technology, Volume 1.

[10] Kurama Y, Pessiki S, Sause R, Lu LW (2002), “ Seismic response evaluation of unbounded post tensioned precast walls”, ACI Struct J.

[11] Kim S. Elliott (2002), “Precast Concrete Structures”, Butterworth-Heinemann.

[12] TEK (2002),“ Post-tensioned concrete masonary wall design”, NCMA TEK

[13] Nakaki SD, Stanton JF, Sritharan S (1999), “ An overview of the PRESSS five-story precast test building”, PCI Journal

[14] Felipe de Jesus Perez (1998), “Lateral load behaviour and design of unbonded post-tensioned precast concrete walls with ductile vertical joint connectors”, Theses and Dissertations.

[15] Fintel M. (1995), “Performance of building with shear walls in earthquakes of last thirty years”, PCI Journal, Precast/Prestressed Concrete Institute 40:3, 62-80.

[16] PCI Design Handbook, 6th edition.

[17] KhajaRasoolThagaragunta and M. Helen Santhi, “Analysis and Design of a G+7 storeyed precast building”, Civil Engineering Systems and Sustainable Innovations.