A Technical Review on Unbonded Precast Post Tensioned Shear Wall

Umang B. Parekh¹ Dr. Rajul K. Gajjar²
¹Student ²Principal
¹²Department of Civil Engineering
¹L.D. College of Engineering, Ahmedabad ²Vishwakarma Government Engineering College, Chandkheda, Ahmedabad

Abstract—In developing India, use of post tensioning is limited to flat slab, beam & slab on ground. We are using RCC shear wall as a lateral load resisting system but till now effect of post-tensioning in shear wall is not studied. Understanding the behavior of shear wall with unbonded posttensioned tendon under lateral loading is necessary. In the past few decades, there has been significant progress in development of unbonded post tensioned precast shear wall system. However, such analysis relies on simplified methods and experimental data related to structural components, not of the complete systems. This paper presents a review of the available experimental and numerical studies on behavior of structural system with unbonded post tensioned shear wall, current approaches and identifies the research needs and usefulness of unbonded precast post tensioned shear wall system.

Key words: PT, RCC, unbonded

I. INTRODUCTION

Seismic loading is one of the most important load considered while designing the structure. For the improvement of structure there is increase in materials and technologies. One of the common system is used in designing structures are shear wall system. RCC shear wall has shown good performance in earthquake but two inherent limitations found in commonly used RCC walls are: (1) the required nonlinearity or softening of the wall is caused by damage (i.e., yielding of reinforcing steel and softening of concrete in compression); and (2) residual lateral drift after a major seismic event. Both these limitations can be addressed through the use of post tensioning. The post-earthquake residual lateral deformation of a structural can be controlled by use of posttensioning which provides a restoring force against the lateral load which enables the wall to rock back to its original upright position. Using precast concrete panels accelerates the construction process as they can be fabricated in workshops and easily erected on-site. Therefore, several analytical and experimental studies have been conducted in last decade or two to combine the two components of precast construction and post-tensioning to improve lateral load behavior of structural walls.

A. Unbonded Precast Post Tensioned Shear Wall System:

The precast Posttensioned concrete shear wall shown in Figure 1, is constructed by stacking rectangular precast wall panels along horizontal joints above the foundation and at the floor levels. Fiber reinforced non shrink dry pack grout is used at these joints for the alignment bearing of the wall panels and to allow for construction tolerance during erection. The term “hybrid” reflects that a combination of mild reinforcing steel and high strength unbonded post tensioning steel is used for lateral resistance across the joints. The PT force is provided by multi strand tendons placed inside ungrouted ducts to prevent bond between the steel and concrete through the wall panels. Thus, the PT tendons are connected to the structure only at the end anchorages.

Fig. 1: Elevation, Exaggerated Displaced Position, and Cross Section of Posttensioned Wall System

Under the application of lateral loads in to nonlinear range the primary mode of displacement in a well-designed posttensioned precast shear wall occurs through gap opening at the horizontal joint between the base panel and the foundation. The behavior results in reduced damage in the posttensioned shear wall system than the damage that would be expected in a conventional monolithic cast in place reinforced concrete wall system.

Upon unloading, the PT steel provides a vertical restoring force in addition to the gravity loads acting on the wall to close the gap at the base joint thus significantly reducing the residual i.e., permanent lateral displacements of the structure after a large earthquake. This results in a system with a large self-centering capability i.e. the wall returns essentially to its un-displaced position. The use of unbonded PT tendons reduces the strand strains as well as the tensile stresses transferred as the concrete as the tendons elongate under lateral loading thus, preventing or delaying the yielding of the strands and reducing the cracking of the concrete in the wall panels.

Further, the tendons are placed near the centerline, i.e. mid length of the wall to minimize the strand elongations and to keep the tendons outside of the critical confined concrete regions at the wall toes. To prevent significant gap opening at the upper panel to panel joints, a small amount of mild steel reinforcing bars, designed to remain linear elastic with short unbonded lengths, are placed at the panel ends as shown in Figure 1. Friction develops at the horizontal joints due to the PT force and gravity loads. The mild steel bars, together with the friction induced by
post tensioning and gravity, prevent significant sliding along the joints. The mild steel bars crossing the base joint referred to as the energy dissipating E.D. steel are designed to yield in tension and compression and provide energy dissipation through the gap opening closing behavior of the wall under reversed cyclic lateral loading. A predetermined length of these bars is unbonded at the base joint by wrapping the bars with plastic sleeves to limit the steel strains and prevent low cycle fatigue fracture. The E.D. bars should be designed and detailed to develop the maximum steel stresses and strains including strain hardening that are expected to occur during a large earthquake.

While the gap opening behavior designed at the base joint of posttensioned precast walls leads to less concrete cracking than would occur in a conventional monolithic cast-in-place reinforced concrete shear wall, localized compression damage should be expected at the toes of the base panel about which the wall rotates at the base. Under a large ground motion, the cover concrete at the wall toes will be damaged and possibly spall. This damage is deemed acceptable and should be repairable if necessary. However, excessive deterioration of the concrete is undesirable, and accordingly, confinement reinforcement in the form of closed hoops should be placed at the ends of the base panel to prevent compression failure of the core concrete. The grout placed at the base joint should also be made ductile by utilizing fibers within the grout mix design.

II. LITERATURE REVIEW

A. Yahya Kurama, Richard Sause, Stephan Pessiki, Le-Wu Lu (1999) [1]:

An analytical investigation has been carried out to investigate the behavior of precast post tensioned wall system under lateral loading. The behavior of unbonded post-tensioned precast walls is governed by behavior along the horizontal joints. Figure 2 shows the two types of behavior that can occur along the joints, namely gap opening and shear slip. In the case of gap opening, the posttensioning force and the axial force due to gravity load provide a restoring force that tends to close the gaps upon unloading. In the case of shear slip, however, there is no restoring force to reverse the slip. Thus, it is difficult to control the magnitude of the shear slip displacements which may occur during an earthquake, and, shear slip should be prevented by design and detailing. The behavior of walls which are designed to have gap opening along the horizontal joints, but not shear slip.

Fig. 2: Behavior along Horizontal Joints: (A) Gap Opening; And (B) Shear Slip

To investigate the behavior of unbonded post-tensioned precast walls under earthquake load, six story prototype walls were designed and more than 200 nonlinear dynamic time-history analyses of these walls were conducted using a series of ground motions. Figure 5 shows the dynamic response of one of the prototype walls under the Hollister ground motion (from the 1989 Loma Prieta earthquake) scaled to a peak acceleration of 1.0 g to represent a (severe) survival level ground motion (the dynamic analysis was conducted with a viscous damping ratio of 3 percent). Figure 3 shows the analytical model for a six-story unbonded post-tensioned precast wall which is developed using the DRAIN-2DX

Fig. 3: Analytical Wall Model: (A) Wall; And (B) Model.

This research has shown that unbonded post-tensioned precast walls—provide a feasible alternative to conventional reinforced concrete walls in seismic regions. One advantage of these walls over conventional walls is their ability to soften and undergo large nonlinear lateral displacements with little damage. Unbonded post-tensioned precast walls can be designed to resist design level ground motions with little damage, and to resist survival level ground motions with damage, but without collapse.


The study investigates the seismic response of five prototype walls with the primary objective of evaluating the approach that was used in the seismic design of the walls. This design approach is described in detail in Kurama. Nonlinear dynamic time-history analyses are used to investigate the seismic response characteristics of the walls for different site seismicity, site soil characteristics, and wall properties. The walls were designed for a set of six-story office building structures (Table 1) that consist of four structures for regions with high seismicity (referred to as Structures SH1, SH2, SH3, and SH4) and one structure for a region with moderate seismicity (referred to as Structure SM2).

<table>
<thead>
<tr>
<th>Structure</th>
<th>Wall</th>
<th>Seismicity</th>
<th>Soil</th>
<th>No. of walls</th>
<th>T1, s</th>
<th>Seismic design</th>
</tr>
</thead>
<tbody>
<tr>
<td>SH1</td>
<td>WH1</td>
<td>High</td>
<td>Medium</td>
<td>10</td>
<td>0.65</td>
<td>Proposed approach 1 , 2</td>
</tr>
</tbody>
</table>
Table 1: Prototype Structures and Walls

<table>
<thead>
<tr>
<th>Wall Type</th>
<th>Variation</th>
<th>Shear Slip Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH1</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>WH2</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>WH3</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>WH4</td>
<td>1.00</td>
<td></td>
</tr>
</tbody>
</table>

Shear slip along the horizontal joints of the walls should be prevented. This requires the estimation of the maximum base-shear demand and the minimum shear-slip capacity under the survival-level ground motion.

The amount of the PT force, and the initial stress and eccentricity of the PT bars, are among the most important design parameters affecting the seismic behavior of the walls. Shear slip is more likely to occur in walls with a smaller amount of PT force and in walls with a larger amount of eccentricity of the PT bars. A decrease in the amount of PT force also results in larger gap-opening lengths along the horizontal joints in the upper floors of the walls, indicating the possibility of undesirable gap-opening behavior under service-level ground motions and a lack of adequate integrity of the system under survival-level ground motions.

C. Brian J. Smith, Yahya C. Kurama, and Michael J. McGinnis (2011) [3]

This paper presents the measured lateral load behavior of a 0.40-scale hybrid precast concrete wall test specimen in comparison with design and analytical predictions. The hybrid precast wall system investigated in the paper utilizes a combination of mild (i.e., Grade 400) steel and high-strength unbonded posttensioning (PT) steel for lateral resistance across horizontal joints. A seismic design procedure that conforms to ACI 318 and ACI ITG-5.2 was used for the design of the test specimen based on ACI ITG-5.1. Overall, the wall system performed as designed; however, failure occurred prematurely due to lower than specified concrete strength and poor placement of the confinement hoops at the wall toes.

Nevertheless, the design procedure was able to result in a structure that achieved the required lateral strength and energy dissipation as well as the required performance of the mild steel and PT steel reinforcement.


In this study, a three-dimensional earthquake simulation test on a full-scale, four-story, prestressed concrete building was conducted using the E-Defense shaking table facility. The seismic force-resisting system of the test building comprised two post-tensioned (PT) frames in one direction and two unbonded PT precast walls in the other direction. The test building was subjected to several earthquake ground motions, ranging from serviceability level to near collapse. Input ground motions were scaled JMA-Kobe and JR Takatori records from 1995 Kobe earthquake. Excitation was applied in two horizontal and vertical directions simultaneously.

Important engineering parameters such as fundamental vibration period, stiffness, hysteresis shape, maximum base shear, and maximum roof drifts are adequately simulated using the analytical model. There are, however, some discrepancies in variation of these responses with time.
Each wall consists of three precast concrete panels, post-tensioned to the foundation with unbonded high strength PT steel. Energy dissipation is provided by two sets of mild reinforcing (ED) bars. The wall selected is 20 ft. long, 14 in thick and 45 ft. tall (cross-sectional aspect ratio \(hw/lw=240/14=17.1\), overall aspect ratio \(hw/lw=45/20=2.25\)). Specified compressive strength of unconfined concrete \((f'_c)\) is 6 ksi while yield \((f_y)\) and ultimate \((f_u)\) strength of ED bars is 60 ksi and 90 ksi, respectively. Yield \((f_{py})\) and ultimate \((f_{pu})\) strength of PT steel is 232 ksi and 272 ksi.

Nonlinear response history analyses were carried out for each building using the MCE records presented above. Analyses were also performed for the MCE records uniformly scaled down by factors of 0.20, 0.40, 0.56, 0.67, and 0.80 in order to compare performance of the three buildings over a range of earthquake levels.

F. Cost Analysis:

Initial construction costs based on material usage, including structural and nonstructural components, are provided in Table 2 for the three buildings. Using the analysis results and the Performance Assessment Calculation Tool (PACT) developed as part of FEMA P-58, the performance of each building in terms of repair cost was assessed. The assessment tool requires quantities for all structural components and vulnerable nonstructural components (e.g. curtain walls, partitions, ceilings) and contents (e.g. electrical equipment) to be defined, and then uses structural analysis results together with embedded fragility and consequence functions for the different components, to calculate direct (repair cost) and indirect (unsafe placarding) losses resulting from building damage due to earthquakes.

<table>
<thead>
<tr>
<th></th>
<th>SMF</th>
<th>RC</th>
<th>UPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Construction Cost</td>
<td>$33,245,000</td>
<td>$32,473,000</td>
<td>$32,449,000</td>
</tr>
</tbody>
</table>

Table 2: Initial Construction Cost

<table>
<thead>
<tr>
<th></th>
<th>SMF</th>
<th>RC</th>
<th>UPT</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBE</td>
<td>$21,57,000</td>
<td>$12,30,000</td>
<td>$13,76,000</td>
</tr>
<tr>
<td>MCE</td>
<td>$33,245,000</td>
<td>$18,31,000</td>
<td>$17,83,000</td>
</tr>
</tbody>
</table>

Table 3: Median Repair Cost

UPT wall has been shown to be a reliable and cost-effective option for the lateral-force resisting system of the 3-story case study building. Initial construction cost and economic losses under MCE were shown to be similar to a conventional RC wall of equal strength and smaller than the SMF building cost. Finally, provided that acceleration-sensitive nonstructural components are protected, economic losses in the UPT building can be further reduced, resulting in a nearly damage-free building that is operational after an MCE event.

III. RESEARCH NEEDS

From present review, it can be noted that use of unbonded post tensioning in shear wall improves the lateral load behavior of structures. Despite these advantages, as compared with monolithic cast-in-place reinforced concrete structural systems, the use of precast concrete shear walls and moment-resisting frames for lateral resistance in seismic regions has been limited. This is primarily due to the uncertainty about the performance of precast structures under earthquake loading, as well as a relatively small
amount of research to support precast concrete seismic design and construction practices.

IV. CONCLUSIONS

The authors concluded with their own experimental data and analytical data. The following gives few of the conclusion related to posttensioned shear wall.

1) The primary failures are because of the gap opening in precast post tensioned shear wall.
2) The amount of the PT force, and the initial stress and eccentricity of the PT bars, are among the most important design parameters affecting the seismic behavior of the walls.
3) The yielding of the mild reinforcing steel during a seismic event provides added damping to the structure improving its performance.
4) Increases the overall stiffness of the wall improving seismic performance.
5) Allows the engineer to set the performance level of the structure by controlling the drift limits via the amount of post-tensioning used.
6) Reduces mild steel congestion improving construction efficiency.
7) Allows the mild steel reinforcing to yield during a seismic event yet has sufficient restoring force to bring the wall back to plumb following the seismic event. Simply put, the wall will self-center.

REFERENCES


