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Analytical Performance Investigation of Post-Tensioned Concrete Shear Wall

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Abstract —*This paper introduces a novel approach in building a hybrid type of shear wall- A combination of conventional reinforced concrete shear wall and a vertical unbonded posttensioning which provides a desirable selfcentering of shear wall and reduced rebar congestion in wall with considerable amount of energy dissipation through yielding of mild steel. In opposed to behaviour of cast in place reinforced concrete shear wall, which produces permanent interstorey drift after seismic event. To study the performance of cast in place unbonded posttensioned shear wall a finite element modelling done using SAP2000 program. First model was of conventional cast in place reinforced concrete shear wall with typical reinforcement ratio and detailing. Second model consist of a vertical unbonded posttensioned tendons replacing half of rebar. The both models was subjected to nonlinear time history analysis and static pushover analysis. Different global responses of both the shear walls are plotted and it is concluded from analysis that posttensioned wall performs well with reduced storey drift and self-centering capability as compared to conventional reinforced concrete shear wall*

Keywords- *Shear wall, Posttensioned, Unbonded posttensioning, Self-centering, Vertical posttensioning.*

I. INTRODUCTION

A post-tensioned concrete shear wall is a conventional concrete shear wall in which about 50% of the vertical reinforcement is replaced with an equivalent amount of high strength cable that is tensioned after the wall is constructed. The addition of the post-tensioned cables modifies the design, detailing, and behaviour of the wall as follows:

1. 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, the wall will self-centre.
2. The yielding of the mild reinforcing steel during a seismic event provides added damping to the structure improving its performance.
3. Increases the overall stiffness of the wall improving seismic performance.
4. Allows the engineer to set the performance level of the structure by controlling the drift limits via the amount of post-tensioning used.
5. Reduces mild steel congestion improving construction efficiency.

Factors affecting response of RC shear wall

The behaviour of shear walls is primarily affected by a combination of flexural, shear and axial deformations. Medium- to high-rise wall behaves mostly in a flexural manner, while low-rise walls are controlled mainly by the shear deformations. Some of these factors are:

1. The wall dimensions and its aspect ratio.
2. The axial load level applied on the wall (axial-flexure interaction).
3. The amount of wall reinforcement and the bond between the reinforcement and concrete.
4. The wall flexure capacity relative to the wall shear capacity.
5. The rigidity of wall foundation and the interface between the wall and its foundation.
6. Rocking of the wall about its foundation due to slippage of vertical reinforcement from the foundation (Rigid-body rotation).
7. The dimensions and reinforcement of the wall boundary columns if applicable.
8. The effect of the structural elements connected to the wall (e.g. coupling beams, moment resisting frame, etc.).

Therefore, modelling of RC shear walls should take into account the previous factors, especially for the axial-flexure interaction and the representation of the wall boundary conditions, in order to simulate the wall behaviour efficiently. The analytical model should be able to estimate the monotonic capacity of the wall, as well as its behaviour under reversed cyclic loading. The ideal numerical model should also be able to represent other phenomena like concrete cracking, stiffening in tension, opening and closing of cracks with recovery of stiffness, strength degradation with cyclic loading, confinement effects in compression, etc. In most cases, one or more of these factors are neglected in the analytical model for simplicity, if this approximation would not lead to a significant impact on the model accuracy in simulating different behaviours of RC walls. [1]

Behavior of PT-CIP walls

The behaviour of hybrid post-tensioned walls can be understood by considering the simplified model shown. The wall is idealized as a rigid cantilever supported by a rotational spring and damper assembly, exhibiting the cyclic lateral force-deformation response described by both the PT tendons and mild steel reinforcing provide flexural strength to PT-CIP walls. As the wall deforms inelastically, the mild steel provides energy dissipation and the tendons generate restoring forces and self-centering capacity. [3]

The response of a cantilevered PT-CIP wall can be represented by the superposition of two components of its behaviour.

1) A non-linear elastic component representing the contribution of the axial load largely provided by the PT
2) An inelastic yielding component representing the contribution of the mild steel reinforcing

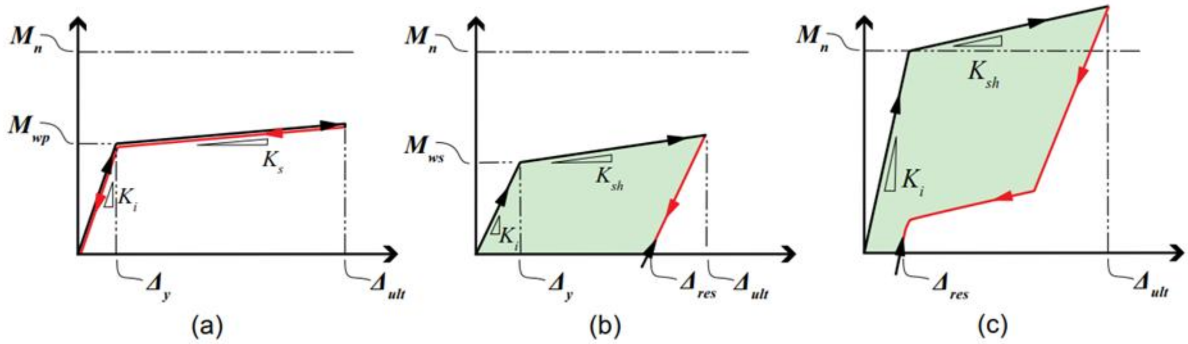

Figure 1 Response of a hybrid post-tensioned wall: (a) post-tensioned wall response; (b) mild-steel reinforced wall response; and (c) combined response [3]

Components of post-tensioned walls

While aspects of the seismic response of a hybrid PT-CIP wall are fundamentally different from a traditional reinforced concrete wall, the components of their construction are conventional and standardized, not requiring special manufacture. [3]

Concrete

The strength and workability of the concrete are always factors in specifying concrete. They are especially important in PT-CIP walls for several reasons. A mix with high long-term strength gain is essential to fully exploit the benefits that post-tensioning provides. PT walls develop relatively higher compressive forces at the boundary zones and rely on the shear strength of the walls to dependably develop their flexural capacity. This is more economically achieved by specifying concrete strengths at 56 or 84 days, rather at 28 days, as is common practice. This flexibility allows the substitution of cement with slower reactivity admixtures such as blast furnace slag or fly ash, which can improve the workability and consolidation properties of the mix while minimizing the cement content. Achieving adequate consolidation of the concrete matrix without deleterious voids is essential to developing the expected performance of the system. This is especially true at critical locations such as PT anchors, boundary zones, and large reinforcing bar terminations. These areas, where consolidation is most important, often become congested, increasing the potential for voids if not carefully detailed.

Post-Tensioning Tendons

Post-tensioning tendons are bundles of individual strands sharing a common anchorage. The strands themselves consist of seven helically wound high-strength wires, To keep the tendons isolated from the surrounding concrete, they can be individually sheathed in plastic ducts along their length or collectively grouped bare inside a common duct depending on construction methods and sequence.

Tendons are typically arranged such that all of the post-tensioning forces are concentric to both horizontal axes of the wall. In addition, it is advantageous to keep the tendons grouped closely in the middle of the wall to minimize strains resulting from large lateral drifts. Since the tendons are unbonded, the change in stress in the tendons can only occur by vertical deformation between anchors. This protects the tendons by distributing the extension along the full length of the tendon, thereby minimizing the strain on the strands.

Mild Steel Reinforcement

Mild steel reinforcement is an essential part of a PT-CIP wall. The imperative to make PT-CIP walls more compact in size will often lead to heavily reinforced boundary zones where the reinforcing is essential for both tension and compression. In addition, in order to preclude undesirable shear failure modes through capacity design principles, heavy horizontal reinforcing is to be expected, especially at the plastic hinge region.

Confinement Reinforcement

The element that is responsible for literally holding the whole wall together, and ensuring a ductile flexural response, is the confining reinforcement. Confinement at the boundary zones prevents premature crushing of the concrete and buckling of the longitudinal bars. Confinement between boundaries, in the body of the wall, helps to stabilize the diagonal compression struts that form the shear mechanism. Finally, local confinement at the tendon anchors is necessary

Figure 3 PT-CIP shear wall elevation

Figure 2 PT-CIP shear wall reinforcement to contain the splitting forces generated in the anchorage zone. Headed reinforcement is typically used at critical locations to provide superior confinement and facilitate constructability by minimizing congestion typically associated with overlapping layers of bent stirrups

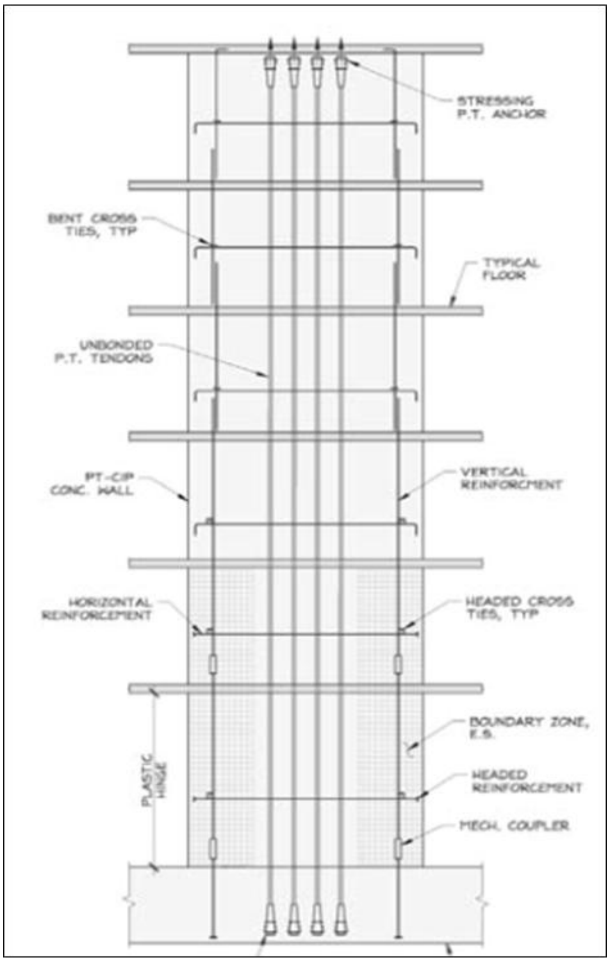

Figure 4 PT-CIP shear wall elevation

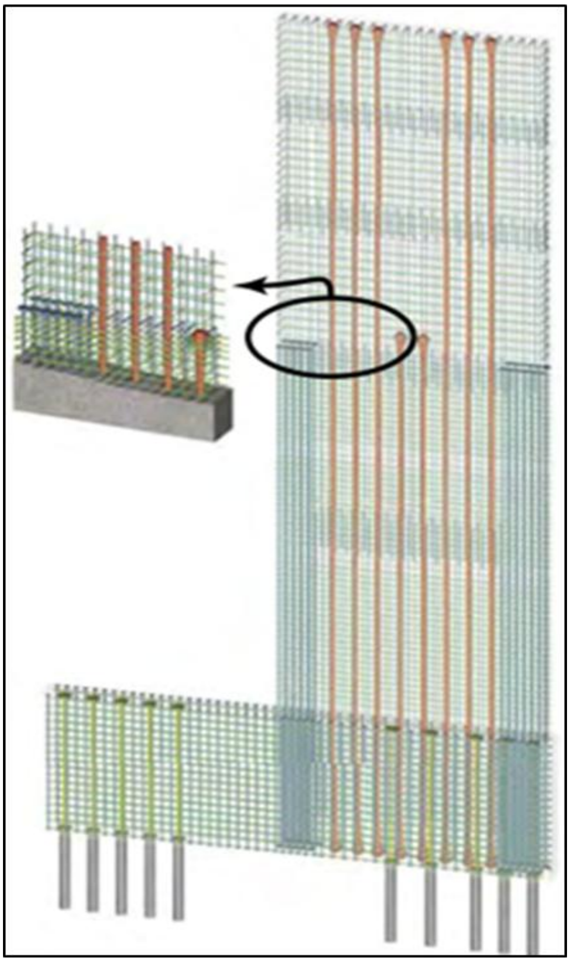

Figure 5 PT-CIP shear wall reinforcement

II. Aim

To model, analyse and investigate the performance of cast in place unbonded posttensioned concrete shear wall under different lateral loading

III. Methodology

Following methodology is adopted for the study

- Study the IS codes and theory of shear wall and PT
- Study the finite element modelling of RC and PT structures.
- Identification of research problem
- Modelling the RC and PT shear wall and analysing for lateral load
- Comparing the results obtained.

IV. Modelling Details and Analysis

To investigate the behaviour of reinforced concrete shear, wall and posttensioned concrete shear wall a single rectangular isolated wall is considered with the typical geometry and materials.

The concrete used is M30 and rebar of fe415 and Indian tendon of yield stress of 1689 N/mm2. The loads considered are live load of 2.5 kN per square meter and dead load of 5.5 kN per square meter (Slabs, Beams, Columns, Walls). The typical tributary area of 250 square meter is considered.

The walls are subjected to both dynamic nonlinear time history analysis and a pushover analysis for time history analysis the earthquake data from Elcentro earthquake is referred. For the pushover analysis the displacement control is exercised (31m/250=0.124m).

As the main interest is to study nonlinear behaviour of the walls in longitudinal direction of the wall the shear deformations are considered elastic

To simulate the interaction of rigid floor interaction with the wall at floor level the diaphragm constraints are assigned at each floor joints

To get the earthquake lateral forces 25% live load is considered along with the full dead load of the structure

To model the shear wall nonlinear-layered shell element is used and specified the rebar layer thickness as specified in table below.

Table 1 Wall modelling Input data

Wall Parameters	Parameter details
Number of storeys	10.00
Height(in meter)	31.00
Length(in meter)	6.00
Width(in meter)	0.30
Height/Length	5.17
Boundry Element up to storey	4.00
Boundry Element Height(in meter)	12.40
Boundry Element Length(in meter)	1.20
Boundry Element % R/F	3.00
% Reinforcement in between Boundry element	0.40
% Reinforcement above Boundry element	0.30

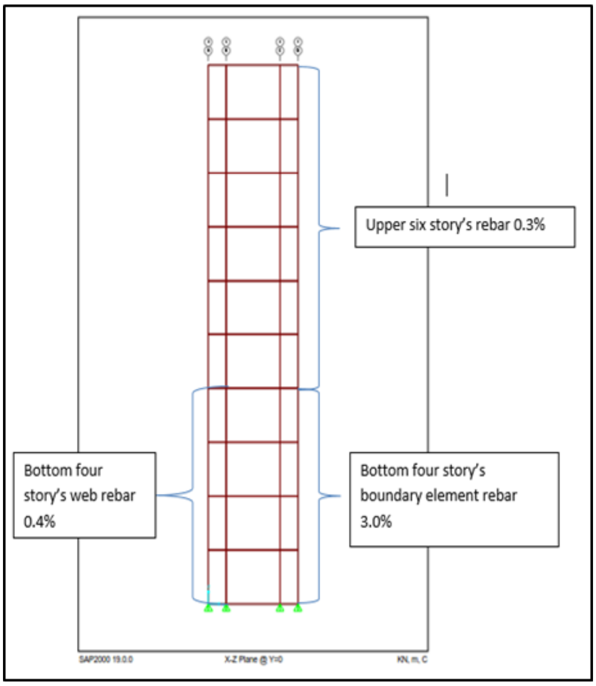

Figure 4 Percentage of Steel in Shear Wall

Analysis result graphs for Reinforced concrete wall

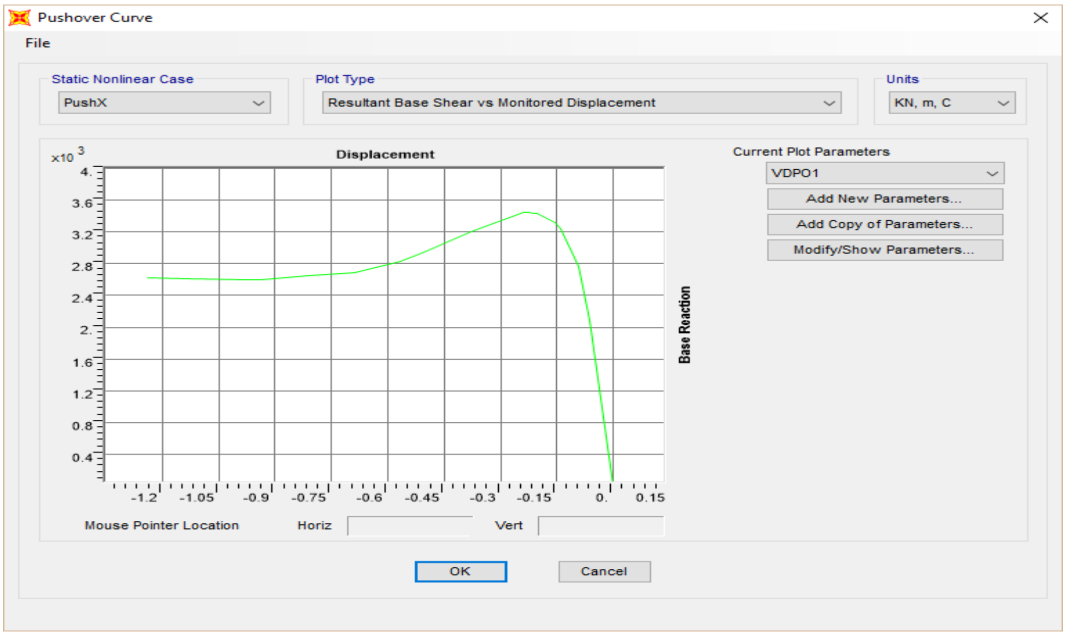

Figure 6 Displacement Vs Base Reaction

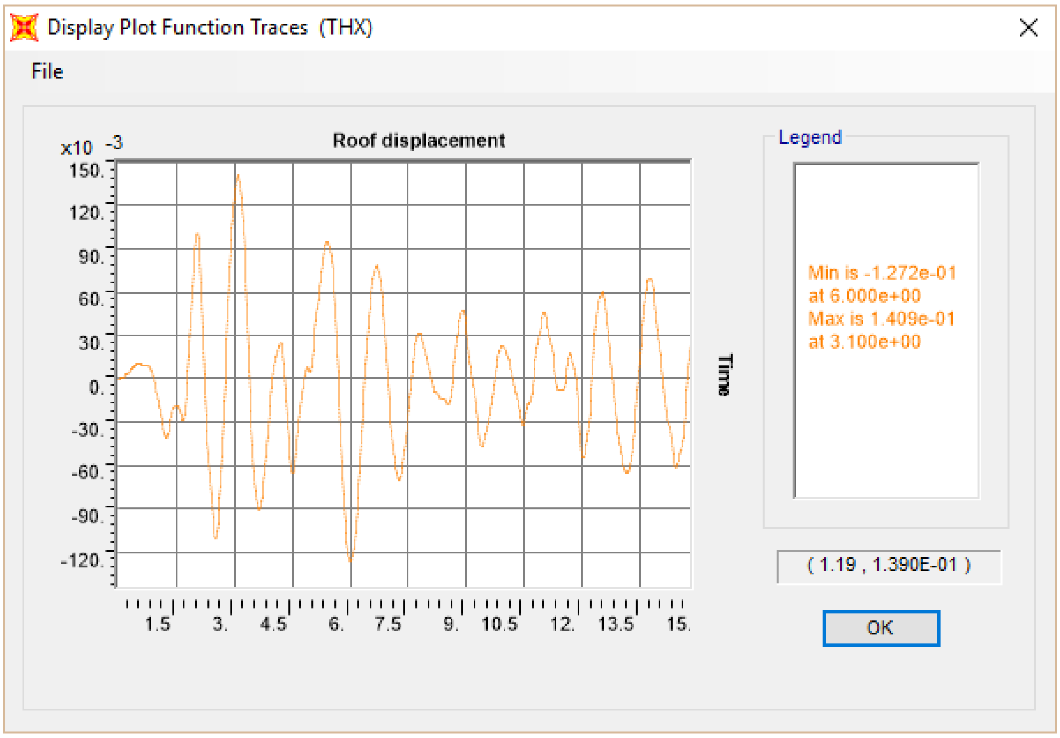

Figure 7 Percentage Roof Displacement Vs Time

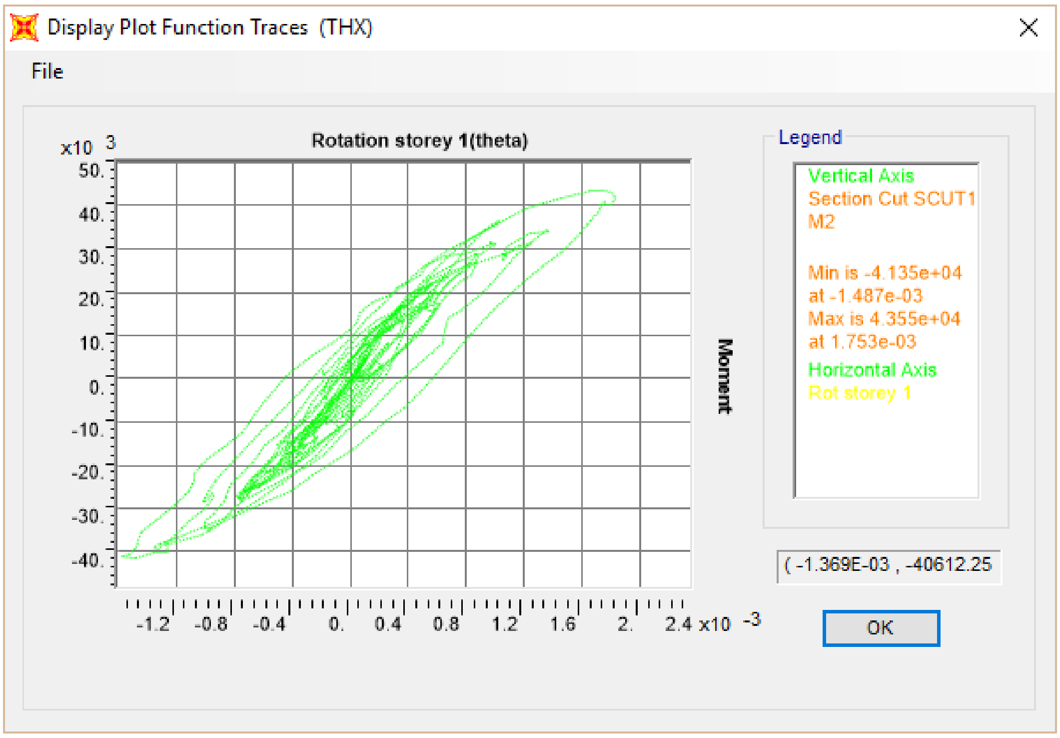

Figure 8 Rotation 1st storey Vs Moment

Analysis result graphs for Post-tensioned concrete wall

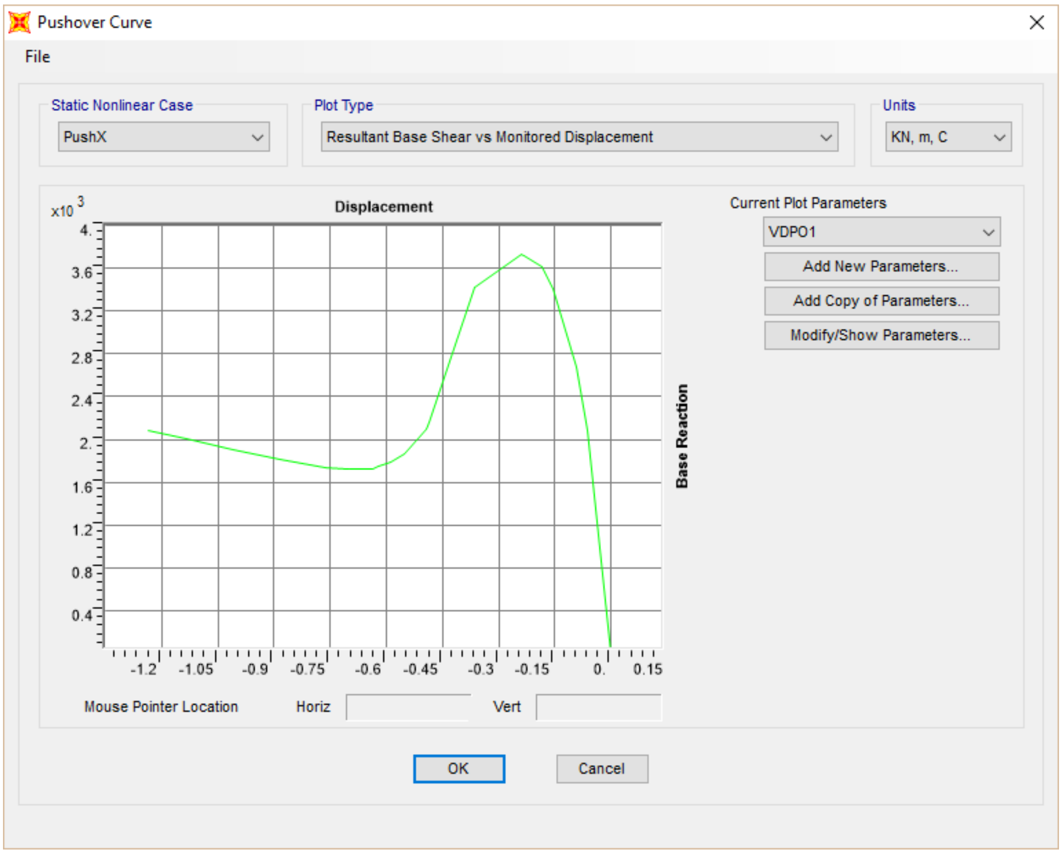

Figure 9 Displacement Vs Base Reaction

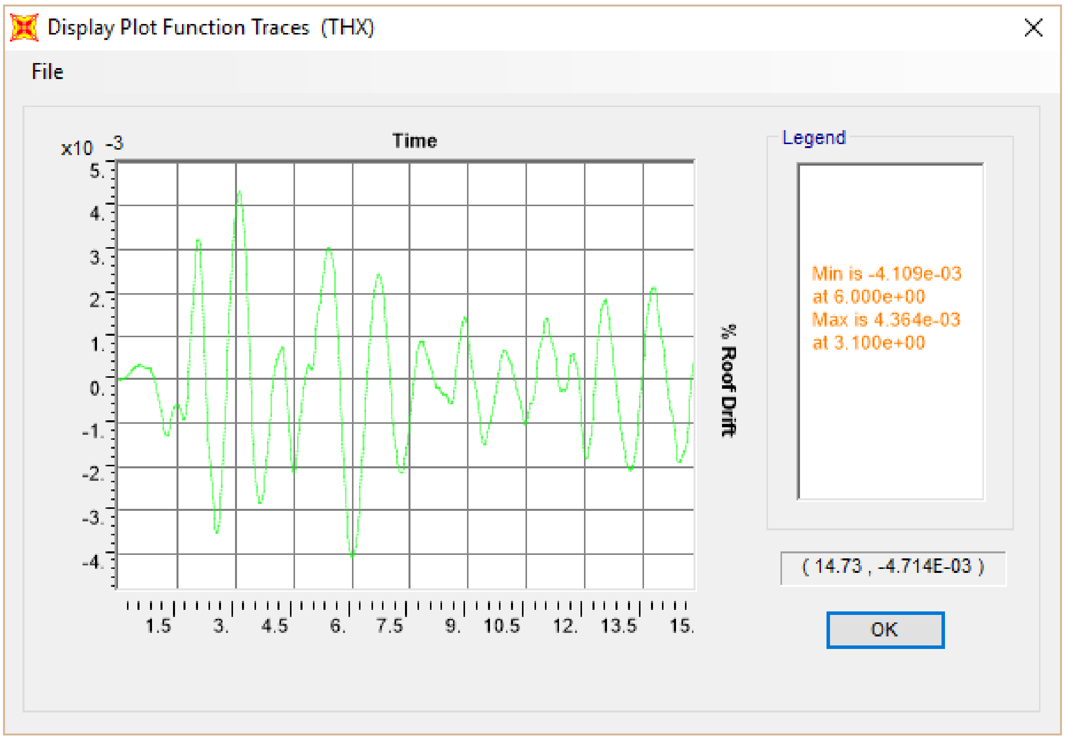

Figure 10 Percentage Roof Displacement Vs Time

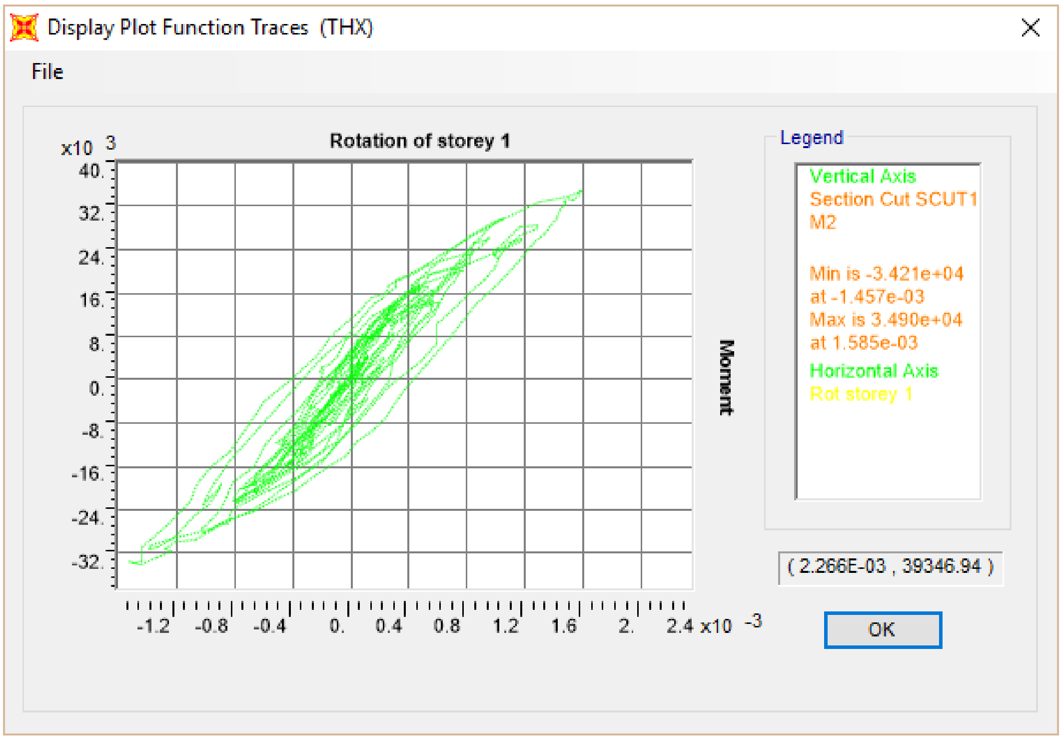

Figure 11 Rotation 1st storey Vs Moment

V. Comparison of Results

The comparison of the analysis graphs for Reinforced concrete shear wall and Post-tensioned concrete shear wall shows that,

Roof displacement for Reinforced concrete shear wall is 140mm whereas for Post-tensioned concrete shear wall it is 135mm which is the result of increased stiffness of the wall due to addition of posttensioned tendons. As a result of same the percentage roof drift for Reinforced concrete shear wall is more as compared to posttensioned concrete shear wall

The Strain of story 1 is 0.0018 for reinforced concrete shear wall whereas for posttensioned concrete shear wall it is 0.0014 resulting in less stresses in concrete.

The hysteresis plot of rotation of story one (θ) versus the moment at the top of story one shows somewhat narrow pinching behaviour for posttensioned concrete shear wall. Which is the indication of desirable self-centering behaviour of the posttensioned concrete shear wall.

The static pushover curve for reinforced concrete shear wall and posttensioned concrete shear wall shows posttensioned wall behave more stiff and it can offer more base reaction for same displacement but further there is sudden steep slope of curve. On the other hand, reinforced concrete shear wall is less stiff but after reaching maximum base reaction curve become less steep as compared to posttensioned concrete shear wall curve.

From the layer stresses for concrete layer it shows that the distribution of stresses for reinforced concrete shear wall and posttensioned shear wall is considerably different

VI. Conclusion

Presented above is a discussion of the behaviour of post-tensioned cast-in-place concrete walls. This discussion provides the basis for the development of a novel and promising lateral force resisting system, with these notable characteristics:

Self-centering capacity that minimizes or eliminates post-earthquake deformations: PT CIP walls have the potential to sustain no permanent structural damage in moderate earthquakes and significantly reduce post occupancy structural repair costs after major earthquakes.

Mode shaping capacity that eliminates large soft story drifts: PT-CIP walls can offer increased protection of gravity and architectural systems that will serve to reduce economic losses during a seismic event.

Economically feasible construction: PT walls combine two established means of concrete construction technology into a single technology well suited for seismic applications. This combination results in greatly reduced barriers to adoption of the technology by engineers, owners, contractors and building officials.

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