HELLENIC OPEN UNIVERSITY

SeismiCON 2022

NUMERICAL MODELLING OF THE SEISMIC BEHAVIOUR OF PRESTRESSED CONCRETE COLUMNS

Dr.-Ing. Konstantinos G. Megalooikonomou

Ph.D. in Civil Engineering, University of Cyprus, Cyprus

Visiting Scholar, University of California Berkeley, USA

M.Sc. in Earthquake Engineering, ROSE School, University of Pavia, Italy

M.Eng. in Structural Engineering, Democritus University of Thrace , Greece

Member of the Hellenic Society of Earthquake Engineering (ETAM)

Member of the German Society of Earthquake Engineering and Structural Dynamics (DGEB)

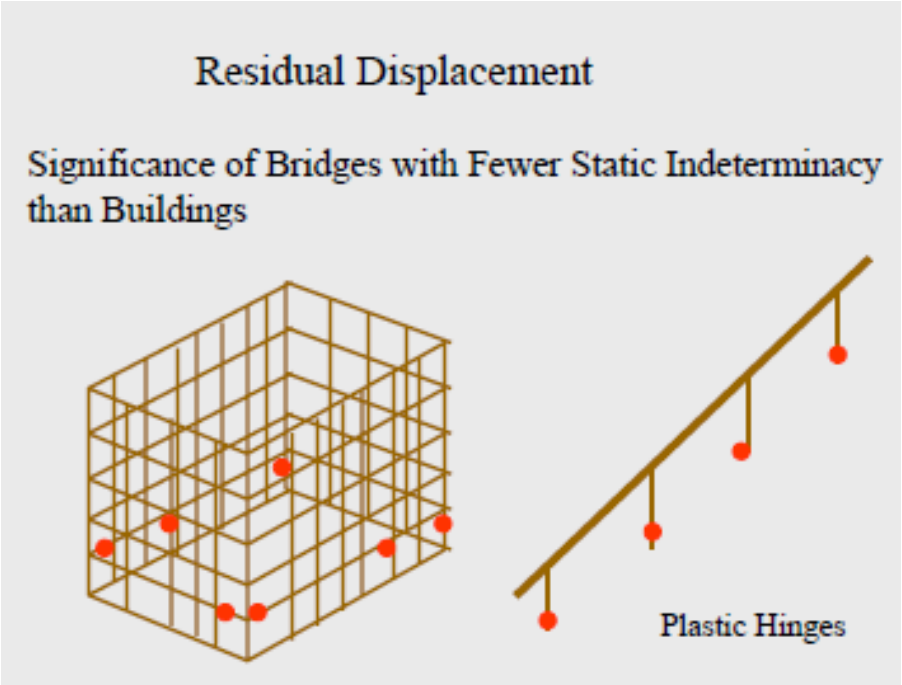
HELLENIC OPEN UNIVERSITY

Outline

- Introduction
- Experimental Study from the Literature
- Finite Element Model
- Correlation with Experimental Results
- Conclusions

Introduction

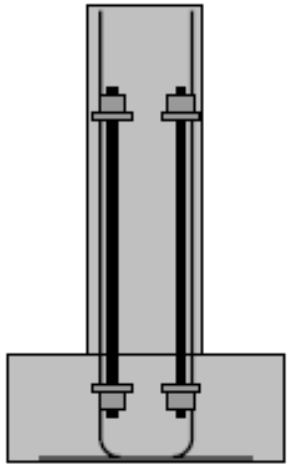
- A key technical problem that researchers and engineers are looking for its remedy, is the seismic performance and post-earthquake serviceability of buildings and bridges in earthquake-prone regions.
- Reinforced concrete columns' seismic design based on ductility demands upon columns' damage tends to produce large residual column deformation after a major earthquake event due to the formation of a plastic hinge.
- In addition, the restoring force remarkably decreases when longitudinal bars locally buckle in standard reinforced concrete columns.



Introduction

- A method to reduce residual displacements by incorporating an unbonded prestressing tendon at the centre of a reinforced concrete column was introduced by Sakai et al. (2004).
- A major advantage of unbonded tendons is that additional tensioning of the unbonded prestressing tendon is allowed during the life cycle of the prestressed concrete (PC) structure.

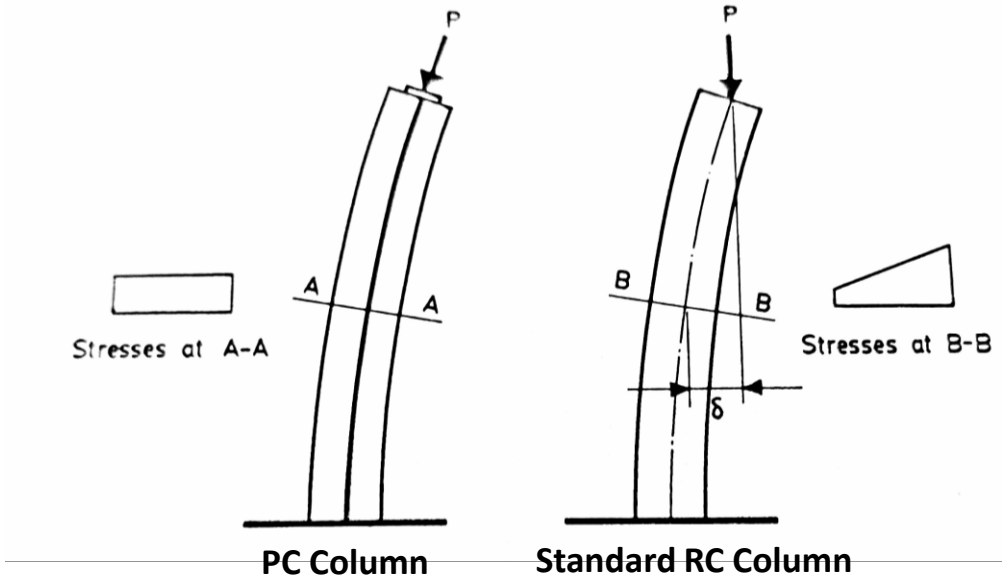
Advantage of Introducing Prestress Force



- Prestresssing bars are set so that they remain in elastic range under extreme excitation
- Prestressing bars enhance both flexural and shear capacity
- Residual displacement can be mitigated

Introduction

- In PC columns, under only the load of the prestressing force, the pressure line is coincident with the tendon profile even if the vertical member is given a small lateral displacement.
- Thus, at any section the pressure line is still coincident with the tendon position and a uniform stress distribution is obtained. Therefore, in PC vertical members no P- δ effects are induced by the prestressing force alone.



Experimental Study from the Literature

- Five specimens with a 360mm by 500mm cross-section were constructed and tested by Liu (2008) under cyclic lateral loading to investigate their force – displacement characteristics and failure modes. Among the test specimens there is a conventional reinforced concrete column (S1) and an unbonded post-tensioning prestressing cast-in-place column (S2).
- These specimens will be used as basis for the verification of the finite element model.

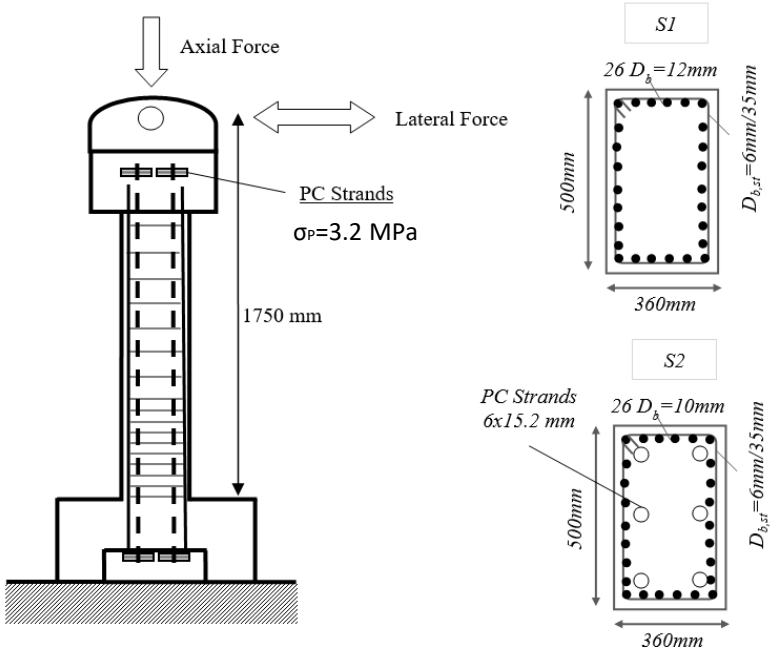
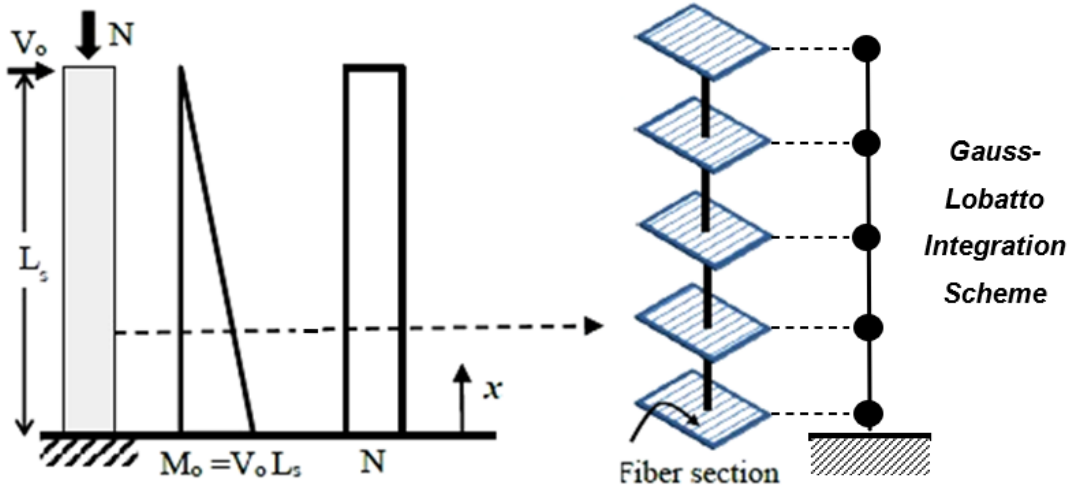


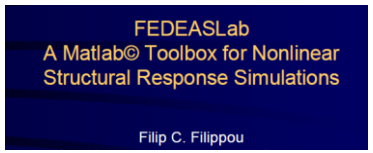
Table 1. Details of specimens by Liu (2008)

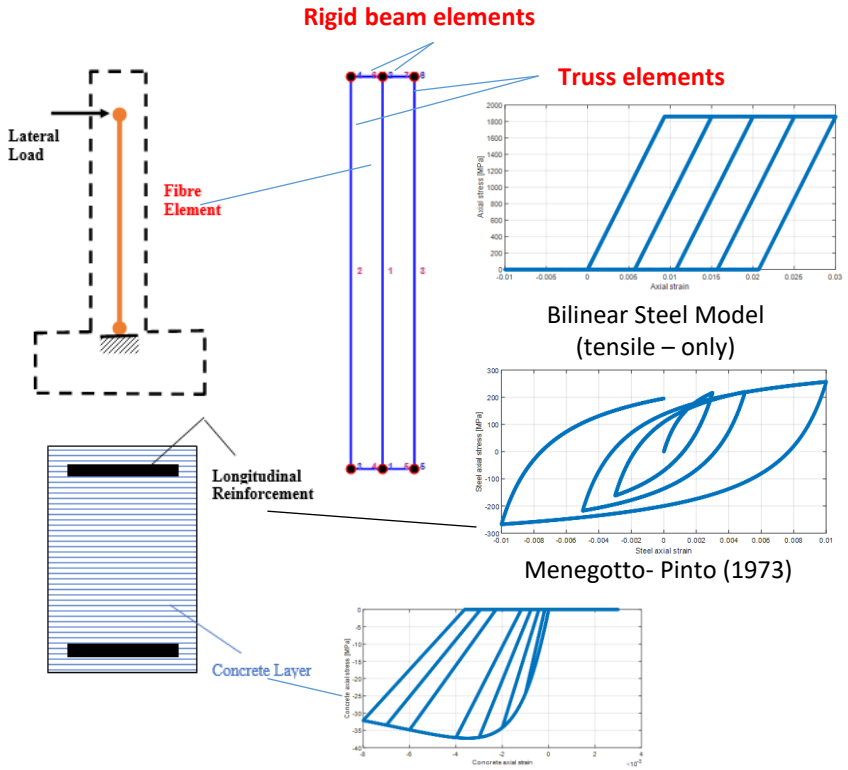
Specimen	Longitudinal Rebar	Prestressing Tendon	Transverse Reinforcement	
			Hoops	Volumetric Ratio
S1	26D12	-	D6@35mm	1.08%
S2	26D10	6x7D5	D6@35mm	1.08%

Finite Element Model

- To conduct the analysis of the specimens by Liu (2008) that demonstrated a flexurally dominant response, a computer code was developed and implemented in the MatLab [Mathworks (2018)] toolbox FEDEAS lab 'Finite Elements for Design Evaluation and Analysis of Structures' [Filippou and Constantinides (2004)].
- This study models unbonded prestressing tendons with bilinear cyclic nonlinear truss elements exhibiting only tensile behaviour in collaboration with nonlinear force-based fibre frame element with proper nonlinear cyclic constitutive laws for concrete and common steel reinforcement.

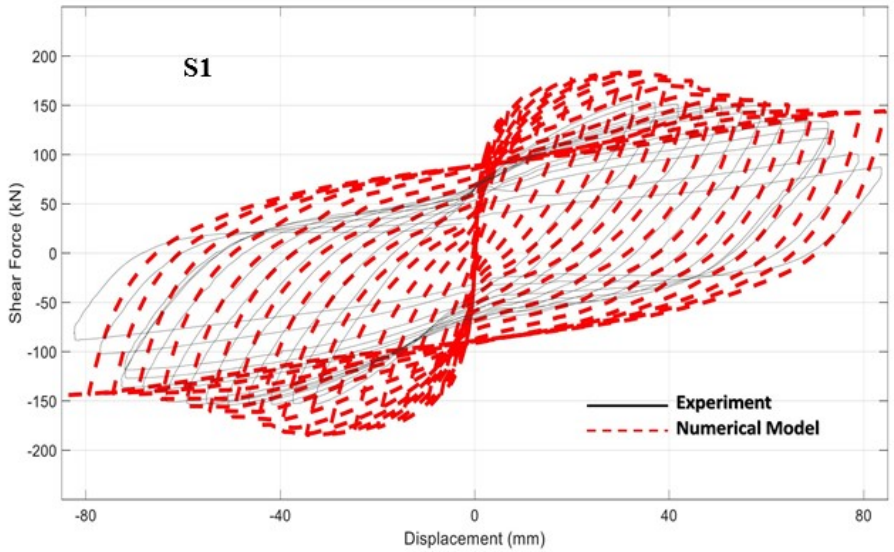


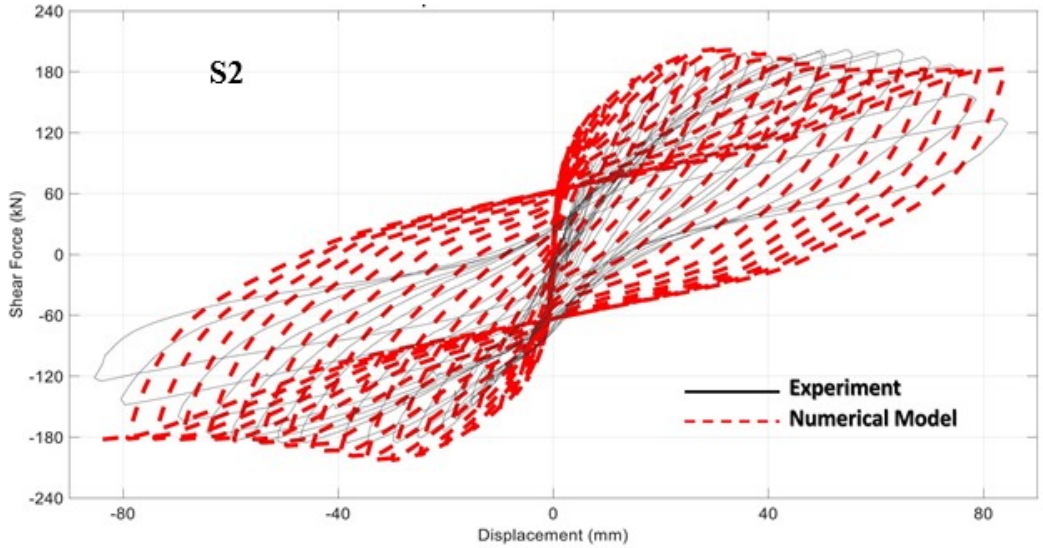




Correlation with Experimental Results

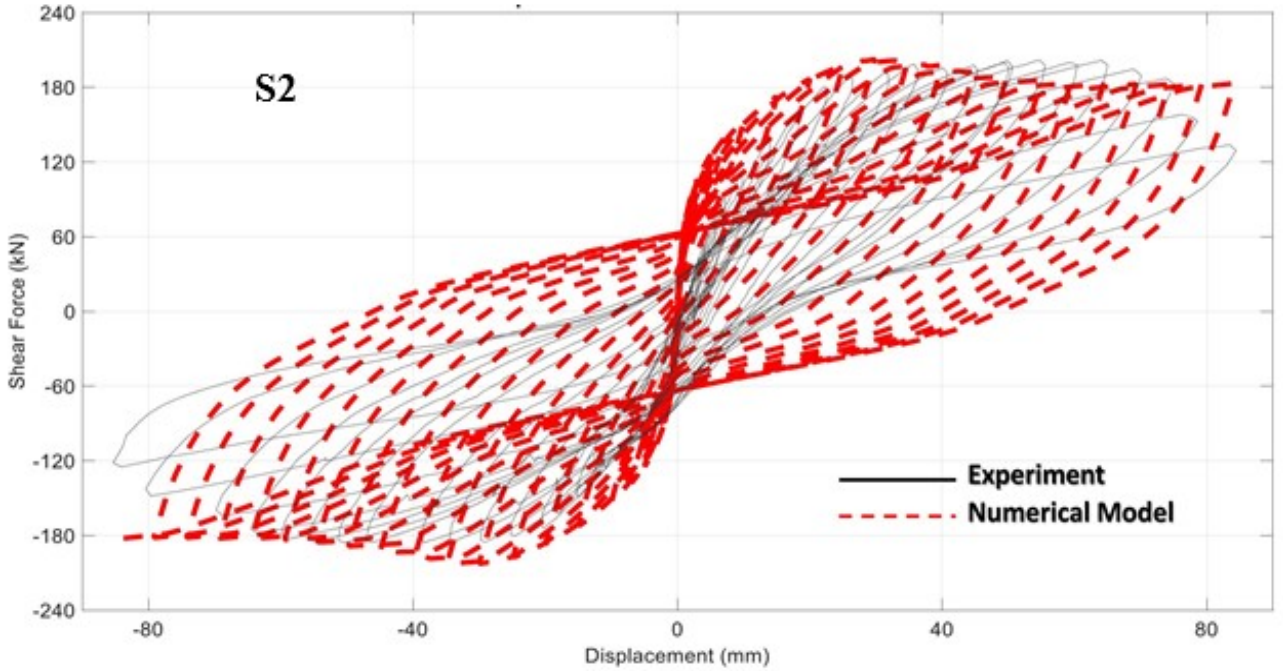
- Figure shows the effectiveness of the prestressed concrete column (S2) in terms of the lateral force vs. lateral displacement hysteresis. The hysteresis of a standard reinforced concrete column (S1) is also presented here for comparison.
- Number and size of concrete cracks were smaller in the prestressed column than the standard reinforced concrete column during the loading and unloading reversals [Liu (2008)].
- Figure shows that the accumulated energy dissipation is smaller in the prestressed column than the standard reinforced concrete column as anticipated inherent to the rest-position oriented hysteretic behaviour.
- Therefore, the reason why the energy dissipation is smaller in the prestressed column than the standard reinforced concrete columns is that fewer concrete cracks dissipate less energy.
- This effect has to be considered in design based on the total response of a bridge/building system.





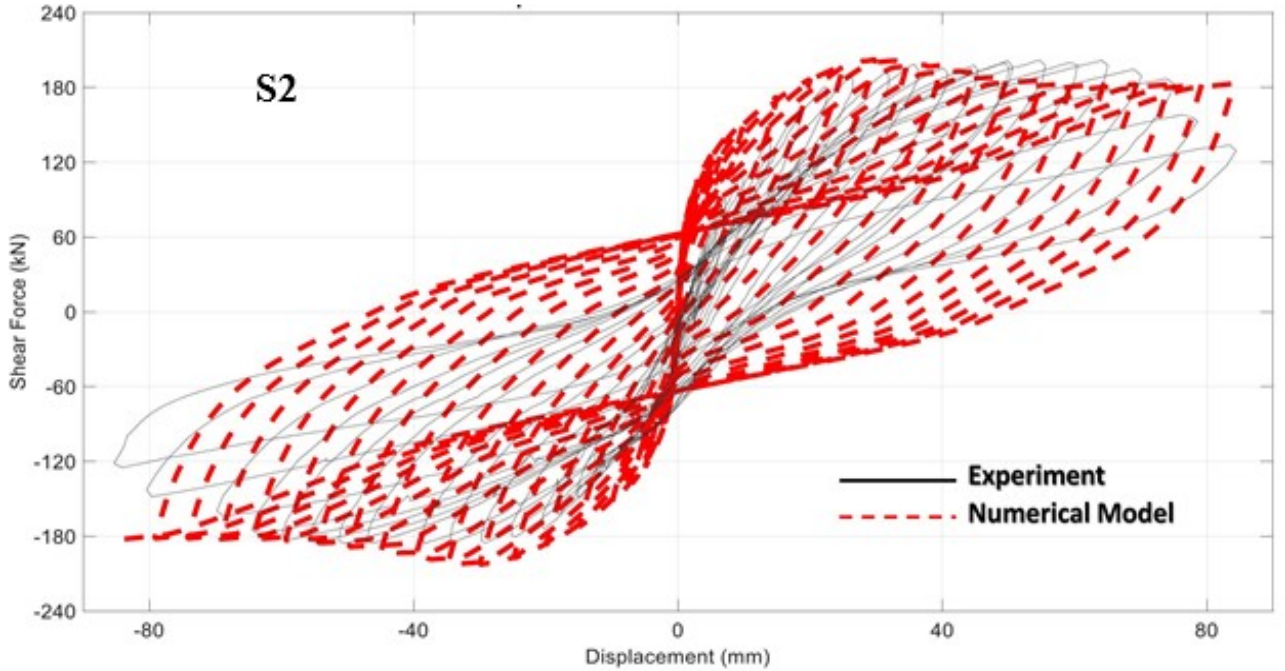
Correlation with Experimental Results

- A remarkable feature of the prestressed concrete column is the rest-position oriented unloading hystereses.
- If one defines the unloaded residual displacement as a residual lateral displacement of a column when the lateral force is equal to zero after unloading from a maximum lateral displacement, then the unloaded residual displacement is significantly smaller in the prestressed concrete column than the standard reinforced concrete column.
- Comparison between the numerical and experimental hysteresis of such columns is indicative of the effectiveness of the implemented modelling.



Correlation with Experimental Results

- Finally, it should be noted that the numerical model doesn't capture to its fully extent the self-centering capacity of the experimental prestressed column with unbonded tendons.
- This limitation could be improved by segmental modelling of the column with more nonlinear fibre and truss elements interconnected to laterally constrained intermediate nodes.
- However, the result is compensated by the simplicity of the model to be applied in a complete finite element model of a whole structure (bridge or building) and not just a component modelling.



HELLENIC OPEN UNIVERSITY

Conclusions

- This analytical study shows that an improved seismic response by limiting residual displacements can be realized through the employment of unbonded post-tensioning prestressing cast-in-place column systems.
- Unbonded prestressing tendons are modelled here with bilinear cyclic nonlinear truss elements exhibiting only tensile behaviour in collaboration with nonlinear force-based fibre frame element with proper nonlinear cyclic constitutive laws for concrete and common steel reinforcement.
- The comparison results between the numerical and experimental hysteresis of such column indicate the effectiveness of the implemented modelling.
- Finally, it is evident that the energy dissipation is smaller in the prestressed columns than the standard reinforced concrete columns because fewer concrete cracks dissipate less energy.
- However, prestressed concrete columns have been seldom constructed throughout the world in spite of their merits. Lack of practice and possible cost increases may be the main reason for limiting the implementation of prestressed concrete columns.

HELLENIC OPEN UNIVERSITY

Thank you for your attention!