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DEVELOPMENT OF AN EXPERIMENTAL SETUP FOR MEASURING THE EFFECTIVENESS OF STRENGTHENED PRESTRESSED CONCRETE CYLINDER PIPES (PCCP)

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Abstract

This paper presents the results of a numerical investigation on the behavior of Prestressed Concrete Cylinder Pipes (PCCP) under the Three Edge Bearing Test (TEBT) (diametrical compression test). The main goal is to develop an experimental setup in the lab in order to evaluate the efficiency of different strengthening schemes with Fiber Reinforced Polymer (FRP) repair methods. The PCCP specimens under evaluation are assumed to be prefabricated parts of an existing water infrastructure network. For practical reasons we chose to define a typical length of 1.0m for all investigated numerical specimens. On the whole, four (4) pipe models are considered: a non-prestressed initial specimen, a prestressed virgin specimen, a strengthened prestressed specimen with internally applied FRP sheet and a last strengthened prestressed specimen with externally applied FRP sheet. The numerical assessment of External Load Crushing Strength by the Three Edge Bearing Test Method is realized using 3D FEM software and in compliance with the terms of ASTM C-497 standard. The developed experimental setup will be fabricated in the Laboratory for Strength of Materials and Structures "LSMS" of Civil Engineering Faculty of Aristotle University of Thessaloniki (AUTh). For all four (4) numerically examined models we employed all the geometrical and mechanical properties of materials from existed PCCP pipes, that LSMS had the chance to measure in the past. The numerically simulated models were evaluated and discussed in terms of load-deformation response and observed limit states of damages.

Keywords: Prestressed Concrete Cylinder Pipes (PCCP), External Load Crushing Strength, Three Edge Bearing Test, Numerical simulation.

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1 INTRODUCTION

Prestressed Concrete Cylinder Pipes (PCCPs) were first manufactured in 1942 as lined cylinder pipe. The prestressing wire in lined cylinder pipe is wrapped directly around the steel cylinder. A second type of PCCP was developed in 1952 that has concrete encasement of the steel cylinder on both sides. Known as embedded cylinder pipe, it differs from lined cylinder pipe by the encapsulation of its steel cylinder in a concrete core. Therefore, the prestressing wire is wrapped around the concrete core rather than the steel cylinder as in lined cylinder pipe. The typical diameter ranges for lined and embedded cylinder pipe are between 0.40 to 1.50 meters and 0.75 to 6.50 meters, respectively. PCCPs are typically manufactured according to the American Water Works Association (AWWA) standard C304. [1,9]. With the onward maturity of the prestressed concrete technology of the latest years, PCCPs have been used in oil, water conservancy, hydropower engineering and other areas. Also, it has been demonstrated that in the sector of large diameter pipes, PCCPs are more competitive than any other type of pipes [2-4]. In recent years, research has been conducted in the field of experimental and numerical study of concrete pipes utilizing the Three Edge Bearing Test (TEBT) and Finite Element Method (FEM) simulation respectively [5-7]. Another interesting and growing segment of scientific study is the investigation of the strengthening repair methods of PCCPs implementing novel FRP and CFRP technology [8-10].

The “Laboratory of Strength of Materials and Structures” of Aristotle University of Thessaloniki has commenced a research project, which scope is to investigate both experimentally and numerically the mechanical behavior of PCCPs. This project aspires to address issues such as the response of PCCPs under the Three Edge Bearing Test (TEBT) and under internally applied fluid pressure, as well as the effectiveness of specific strengthening repair methods. In the current paper part of these results are presented. More specifically, the behavior of two (2) pipes specimens (one with and one without prestress) under TEBT is examined experimentally and numerically and the efficiency of two (2) strengthening methods (internal and external confinement of PCCPs with FRP double mantle) is assessed.

2 EXAMINED SPECIMENS AND EXPERIMENTAL SETUP

The geometry of the examined pipes is depicted in Figure 1 and the denomination of the four (4) specimens alongside with their main dimensions is presented in Table 1. All specimens have the same internal diameter, i.e., 1.80m, while the external diameter is 2.16m for Spec 2, Spec 3, Spec 4 and 1.98m for Spec 1.

The External Load Crushing Strength of the examined pipes specimens is calculated by utilizing the Three-Edge Bearing Test Method in accordance with ASTM C-497 standard. The experimental setup scheme is outlined in Figure 2, along with the real experimental configuration developed at the “Laboratory of Strength of Materials and Structures” of Aristotle University of Thessaloniki. In total, an instrument which measures the applied load (load cell) and four (4) Linear Variable Differential Transducers (LVDTs) were installed. Also, deformation strips were selectively placed at some points in order to have better control of the loading process and enhance the accuracy of the experimental device, especially in the area of the failure.

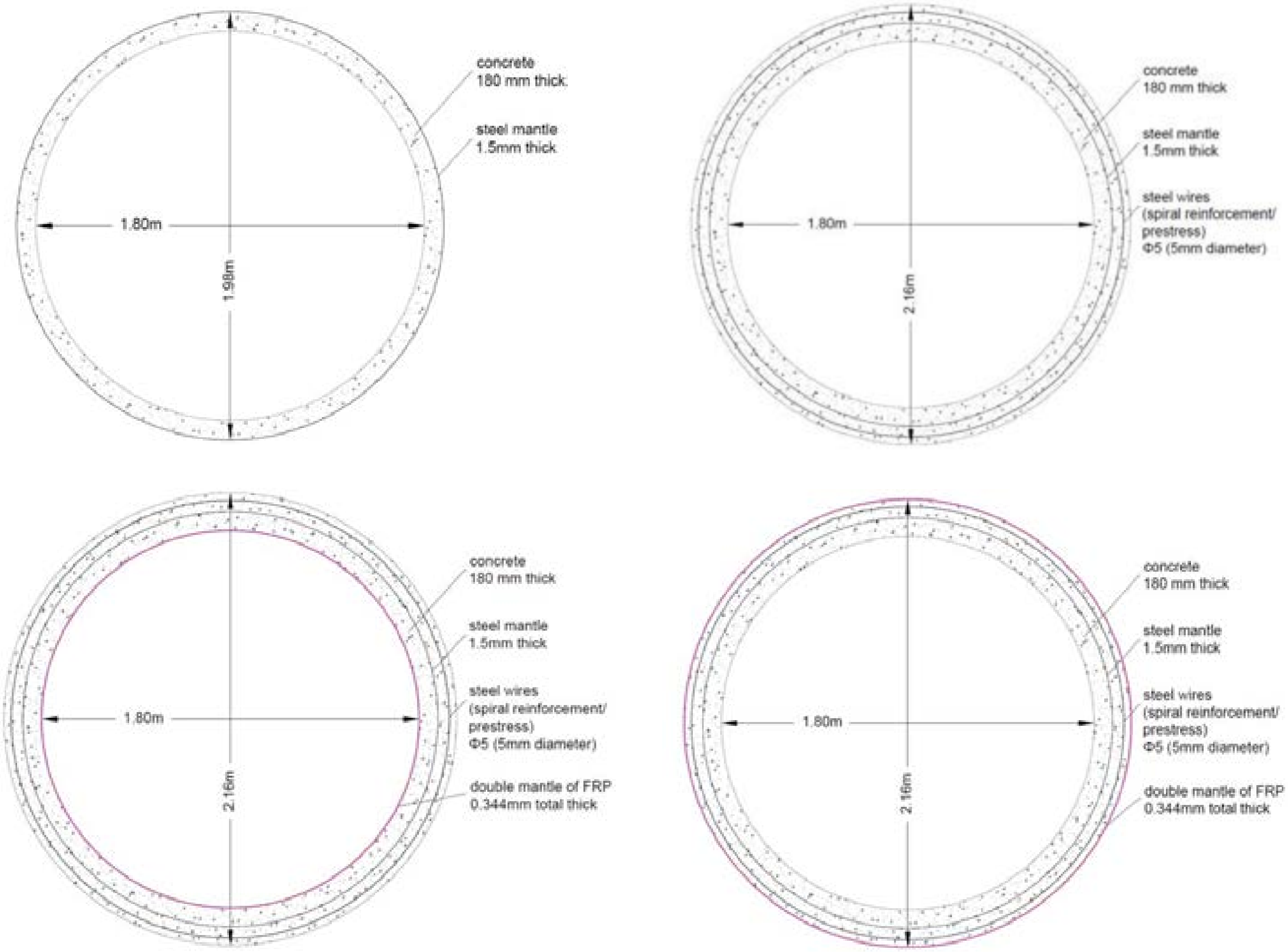

Figure 1: Geometry of the four (4) examined models: unprestressed maternal – Spec 1 (top-left), prestressed maternal – Spec 2 (top-right), FRP internally strengthened prestressed – Spec 3 (bottom-left) and FRP externally strengthened prestressed – Spec 4 (bottom-right)

Specimen Name	Description	External Diameter/ Internal Diameter
Spec 1	Maternal unprestressed specimen	1.98/1.80
Spec 2	Maternal prestressed specimen	2.16/1.80
Spec 3	FRP internally strengthened, prestressed specimen	2.16/1.80
Spec 4	FRP externally strengthened, prestressed specimen	2.16/1.80

Table 1: Geometric properties of the four (4) examined specimens

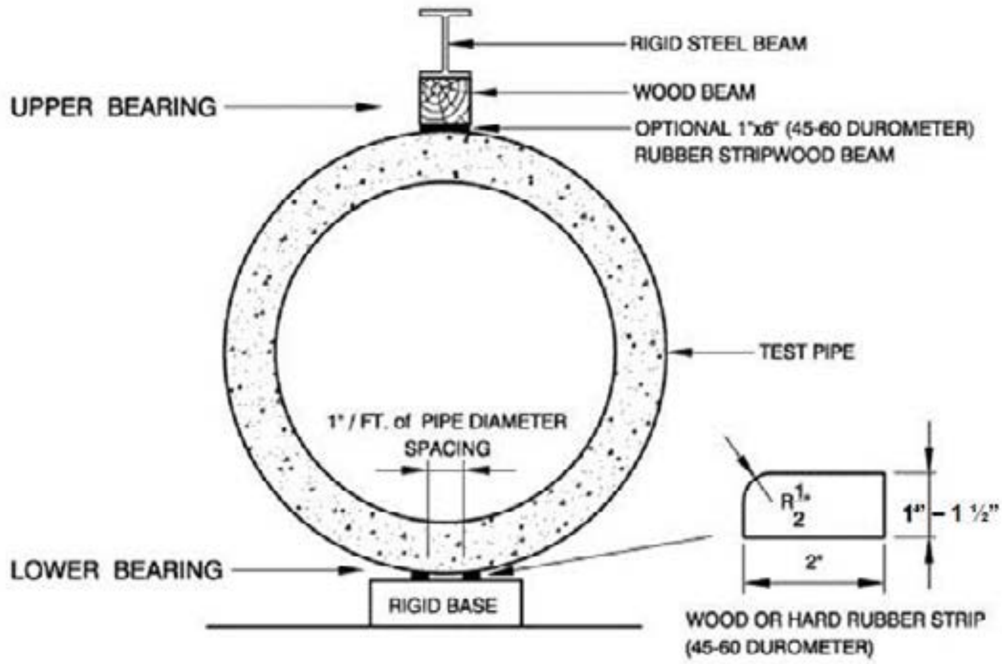

Figure 2: Scheme (top) of the experimental setup of the Three Edge Bearing Test as per ASTM C-497

3 NUMERICAL MODELING

Three-dimensional finite element numerical models have been built adopting a macro modeling approach with homogenized non-linear material laws. It should be underlined that all materials that compose the pipe specimens have been tested at the "Laboratory of Strength of Materials and Structures" of Aristotle University of Thessaloniki and have been adopted in the Finite Element Analysis (FEA) software in order to non-linear realistic numerical models. All the parameters used for the constitutive law are listed at table 2. The models of the four (4) specimens are presented in Figure 3.

Material law assigned to concrete – Concrete Damaged Plasticity					
ELASTIC PROPERTIES		*COMPRESSIVE BEHAVIOR*		*TENSILE BEHAVIOR*	
Mass Density (ton/mm^3)	2.5E-09	Yield Stress (MPa)	Plastic Strain	Yield Stress (MPa)	Plastic Strain
Young's Modulus (MPa)	39000	11.88	0	1	0
Poisson's ratio	0.25	35.3	0.0012	0	0.005
		43	0.0021		
		48	0.0028		
		43.2	0.0043		

		9.6	0.02	
Material law assigned to steel mantle – Plastic				
ELASTIC PROPERTIES		*TENSILE BEHAVIOR*		
Mass Density (ton/mm^3)	7.85E-09	Yield Stress (MPa)	Plastic Strain	
Young's Modulus (MPa)	200000	300	0	
Poisson's ratio	0.30	300	0.0085	
		390	0.0485	
		420	0.0985	
		450	0.4	
		360	0.42	
		40	0.45	
Material law assigned to steel wires – Plastic				
ELASTIC PROPERTIES		*TENSILE BEHAVIOR*		
Mass Density (ton/mm^3)	7.85E-09	Yield Stress (MPa)	Plastic Strain	
Young's Modulus (MPa)	210000	1400	0	
Poisson's ratio	0.30	1500	0.0007	
		1600	0.0012	
		1700	0.0022	
		1800	0.0047	
		30	0.015	
Material law assigned to Fiber Reinforced Polymer (FRP) - Elastic				
ELASTIC PROPERTIES				
Mass Density (ton/mm^3)	1E-09			
Young's Modulus (MPa)	240000			
Poisson's ratio	0.15			

Table 2: Parameters of constitutive laws for concrete, mantle steel, wires steel and FRP materials

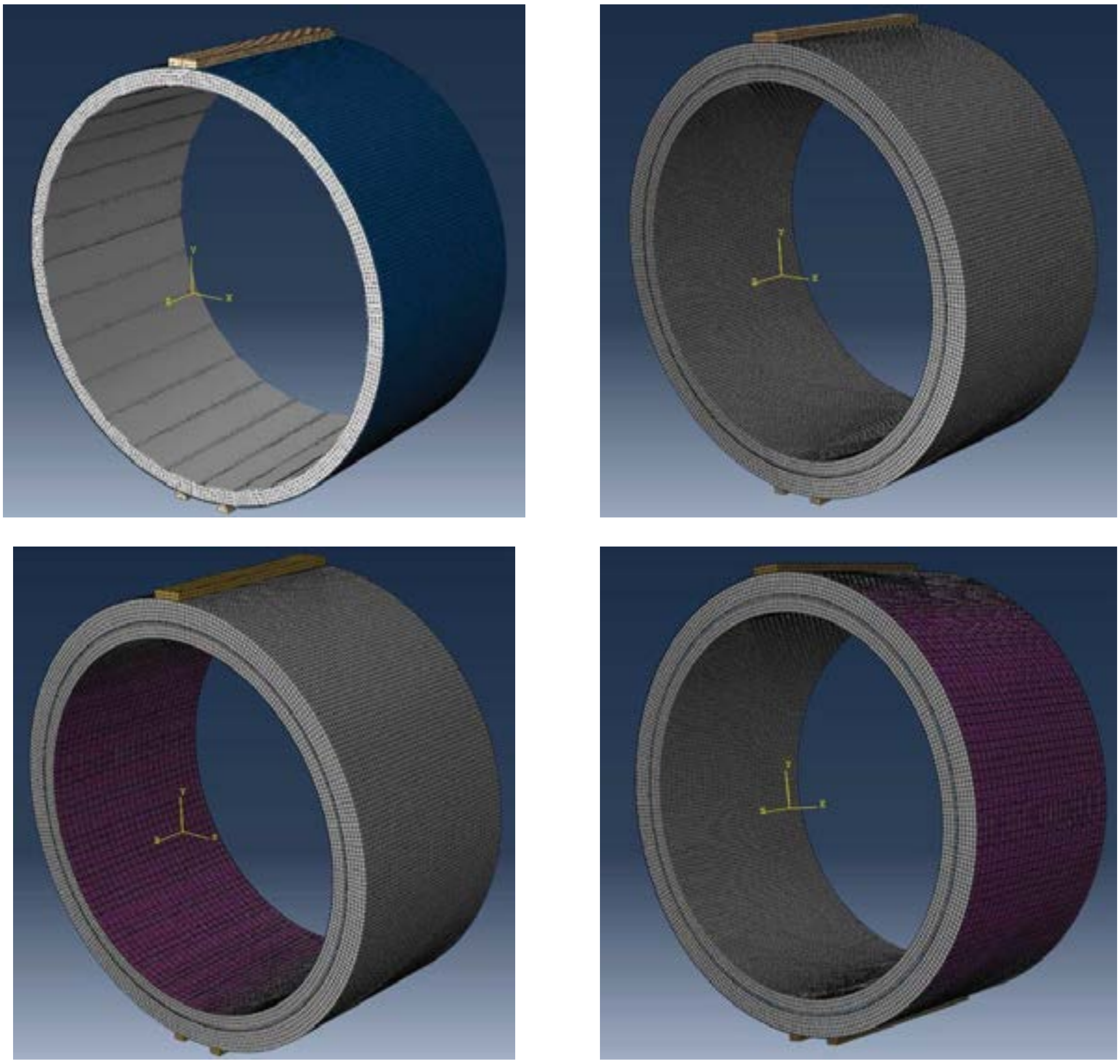

Figure 3: FEM Models of the four (4) examined specimens: maternal unprestressed – Spec 1 (top-left), maternal prestressed – Spec 2 (top-right), FRP internally strengthened & prestressed – Spec 3 (bottom-left) and FRP externally strengthened & prestressed – Spec 4 (bottom-right)

The numerically obtained results were initially evaluated in terms of applied load – developed deformations graphs, as presented in figures 4. It is depicted that for all 4 models we manage to get a non-linear behavior. In addition, the adopted numerical methodology, of applying loads and imposing restrains (experimental setup in the lab) resulted to very rational data since we were able to yield the utilized materials, obtain the bearing capacity of all models and get the post maximum decrease behavior.

Moreover, we see that the bearing capacity is increasing by adding, initially the prestress (Spec2) then by applying internally FRP sheets (Spec3) and finally by applying extremally FRP sheets. It has to be mentioned that the depicted results are estimations of the real performance of the PCCP pipes and they aim to predict in a realistic way the performance of a PCCP pipe and evaluate the efficiency of strengthening schemes.

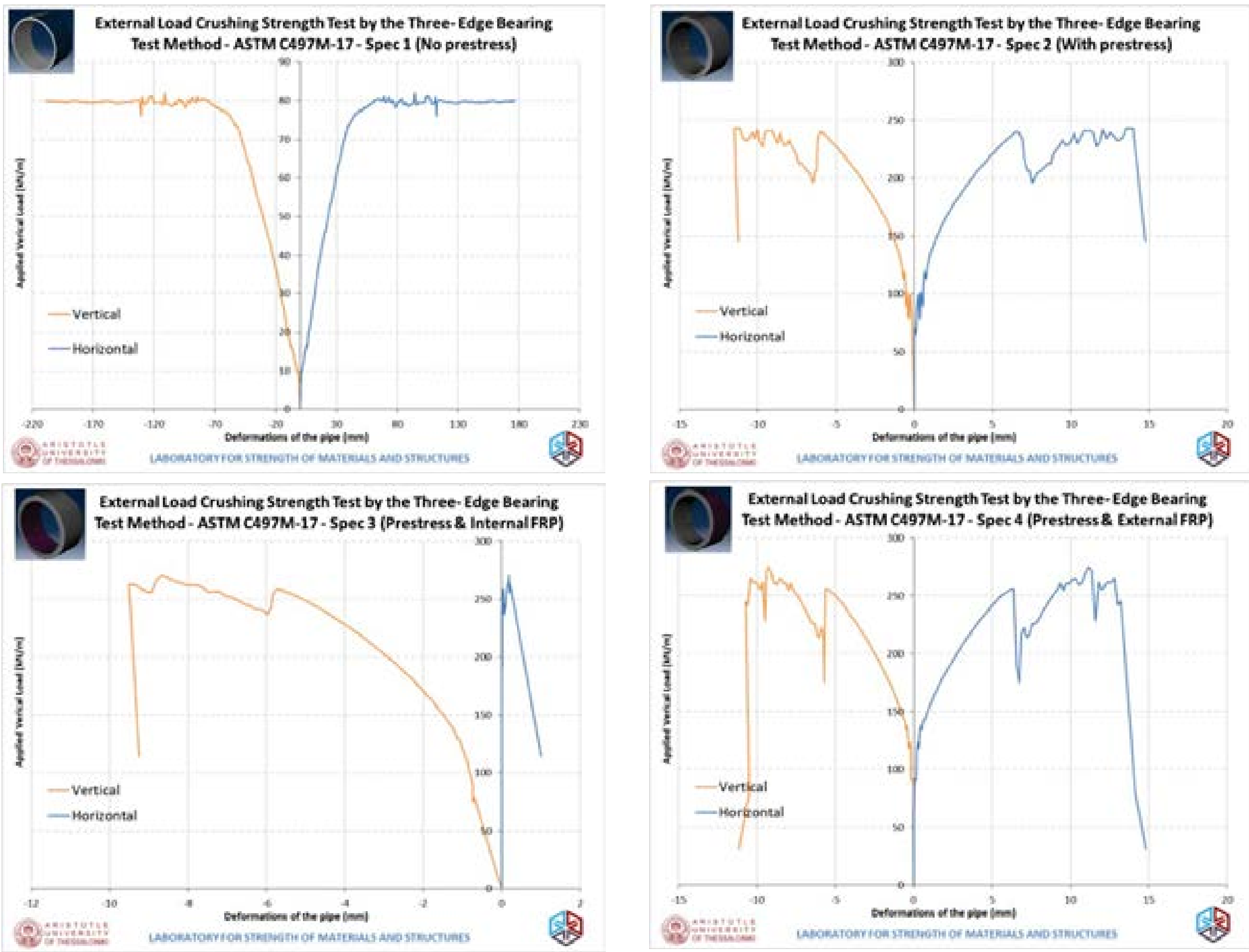

Figure 4: Numerical results - diagrams of applied force, vertical deflection and horizontal swelling of Spec 1 (top-left), Spec 2 (top-right), Spec 3 (bottom-left) and Spec 4 (bottom-right)

Figure 5 presents (plastic strain components) the damage pattern that is attained in the numerical simulations. It is depicted that plastic strains are developed on the faces of PCCP model that suffers from tension. These are the regions that we expect to get the developed cracks, under the present loading conditions. The developed damage pattern indicates the qualitatively realistic FE model.

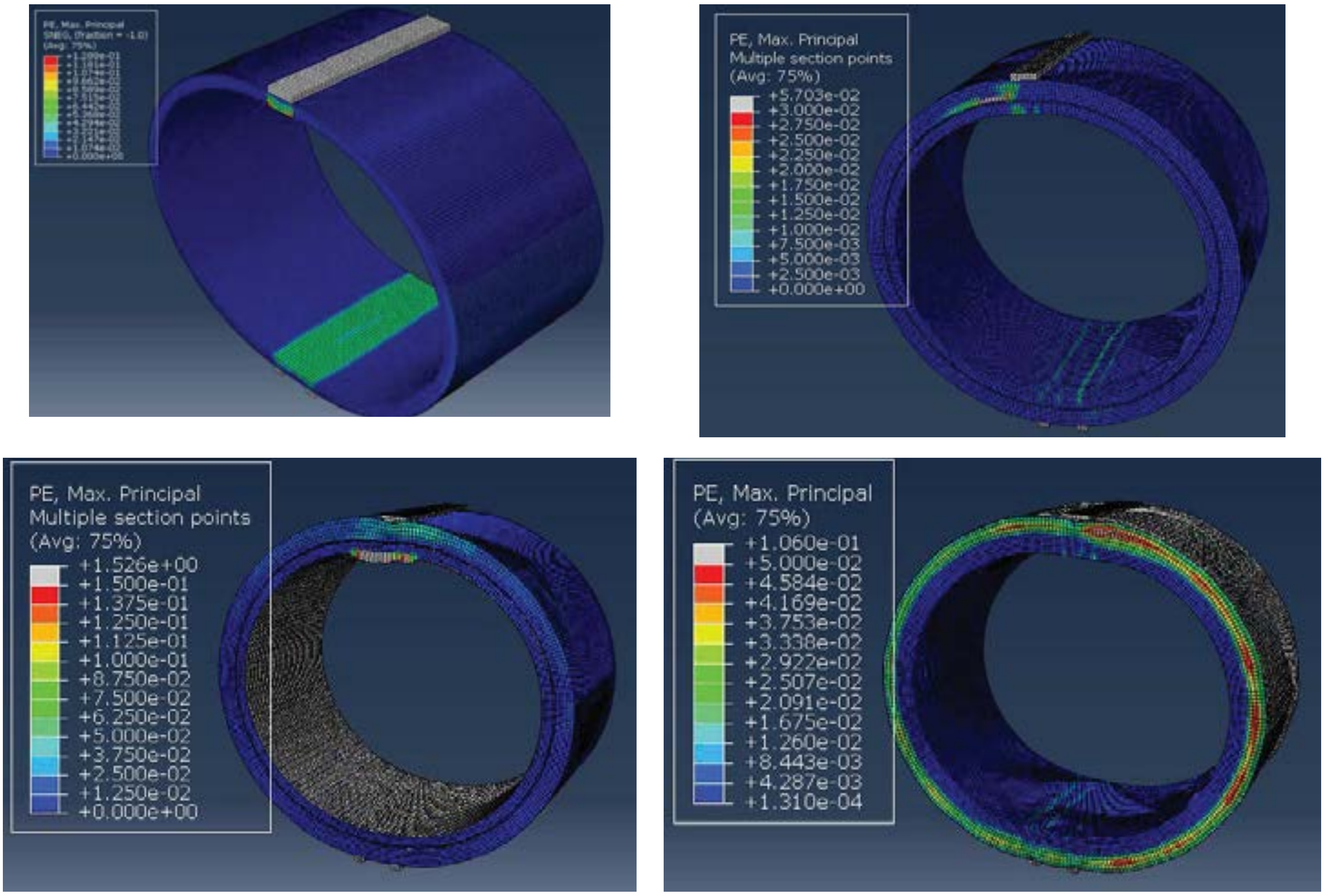

Figure 5: Numerical results - plastic strain components (PE) of Spec 1 (top-left), Spec 2 (top-right), Spec 3 (bottom-left) and Spec 4 (bottom-right)

Taking under consideration the aforementioned results, it is clear that the maternal prestressed specimen (Spec 2) develops 3 times larger strength than the maternal unprestressed specimen (Spec 1). This is indicative of the highly significant contribution of the perimetric prestress and how important it is that it remains active and is not disabled by any damages or corrosion. Also, as expected, the strengthened specimens (Spec 3 and Spec 4) demonstrate greater bearing capacity than the maternal prestressed specimen (Spec 2). More specifically, the FRP internally strengthened specimen (Spec 3) indicated an increase of 12.4% in maximum bearing capacity compared to the maternal prestressed specimen (Spec 2), while the FRP externally strengthened specimen (Spec 4) demonstrated a similar behavior.

4 CONCLUSIONS

The behavior of Prestressed Concrete Cylinder Pipes (PCCPs) under the Three Edge Bearing Test (TEBT) is discussed here, mainly focusing on the contribution of the FRP strengthening method in the PCCPs response. Numerical models were developed using all the available information about the mechanical properties of the materials used in an effort to numerically reproduce the realistic behavior of the pipe. The goal is to estimate the bearing capacity of the models, their damage patterns and finally quantify the experimental setup that has to be constructed in the Lab. The main conclusions are enlisted below:

- The perimetric spiral prestress in very significant as it increases the bearing capacity of the concrete pipe by 3 times.
- The strengthening of the PCCP with FRP is efficient and results in a 12,5% growth of the bearing capacity
- The developed 3-D FEM models, are considered realistic and can be utilized to built the experimental setup in the Lab

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