Practical application of the "Saw-Cut" technique on prestressed concrete beams under laboratory conditions

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Summary

Existing prestressed concrete structures (EPCS) face uncertainties when assessing prestressing force, which diminishes over time due to various factors that give rise to the so-called prestress losses. Incorrect estimation of these losses can lead to design inefficiencies or structural issues. While force monitoring is feasible during concreting, existing EPCS lack suitable devices, necessitating indirect methods to determine the residual prestressing force. In this research, the saw-cut testing technique is applied in a post-tensioned concrete beam under laboratory conditions. By performing notches, isolated concrete blocks are formed, and the subsequent released stresses are obtained from back calculations based on the concrete deformation measurements within the block and considering material properties. As the prestressing force is controlled continuously, the findings enhance understanding of saw-cutting, enabling future applications to determine prestressing in unmonitored EPCS.

1 INTRODUCTION

A significant portion of the existing bridges in Europe and the United States constructed using prestressed concrete structural elements (EPCS) date back to the 1950s and 1960s and are approaching the end of their service life, regardless of the prestressing technique employed (post-tensioned or pre-tensioned) [1].

This raises questions about the condition of such elements and their impact on the overall structural behaviour. Most EPCS nearing the end of their service life were constructed according to outdated codes and standards that did not adequately consider time-dependent effects of concrete and steel, as is now recognized. The oversight of deferred effects' magnitude and consequently the structural stress state, coupled with unforeseen loading conditions and premature degradation of EPCS, results in a state of tensile uncertainty that must be addressed promptly.

In the case of prestressed concrete, the prestressing force decreases over time due to various factors such as friction between steel and concrete, elastic shrinkage of concrete, and steel relaxation. This progressive loss of prestress is a complex and critical phenomenon, which implies uncertainties in the stress state of EPCSs [2,3].

Understanding this phenomenon is crucial to assess the current state of prestressed concrete structures, as prestressing is essential for preventing premature aging and issues like excessive deformations and unexpected cracks.

Traditional maintenance through visual inspection [4] proves insufficient for detecting issues in prestressed concrete structures, where damage can be concealed due to induced compression from prestressing [5,6]. This limitation is concerning given the increasing incidence of premature aging in these structures.

Recent research [7,8] has highlighted challenges in determining prestress losses and residual force in existing structures, especially those lacking appropriate instrumentation. These difficulties can contribute to uncertainties regarding structural safety, potentially leading to collapses.

Addressing these challenges necessitates adopting advanced scientific methods to accurately assess existing structures, as indicated in the World Road Association's 2020-2023 Strategic Plan [9].

Previous studies have noted discrepancies among different structural design codes [10], thus emphasizing the need to implement experimental residual prestress analysis techniques, considering the structure's characteristics and future functionalities.

In this context, a study is proposed utilizing the saw-cut technique on a prestressed concrete beam within a controlled laboratory setting, complemented by finite element modelling. This study will encompass a detailed methodology covering measurement techniques, material properties, instrumentation, and result analysis.

The saw-cut method, involving controlled cuts in the beam to release internal stresses and measure deformations, is presented as an innovative strategy for evaluating residual prestress [11]. By combining this with numerical simulations, a more comprehensive understanding of structural behaviour and prestress losses over time is sought.

This integrated approach aims to surpass the limitations of conventional inspection methods and provide a solid foundation for evaluating and maintaining prestressed concrete bridges and structures. Additionally, it is expected that the results will contribute to developing more effective maintenance practices and extending the lifespan of these critical infrastructures.

2 TECHNIQUES FOR OBTAINING RESIDUAL PRESTRESS.

The techniques used to obtain residual prestress in EPCSs are divided into two main groups: direct methods and indirect methods [12]. Direct methods involve continuous monitoring techniques using sensors during execution in the EPCSs, classified into actions on the prestressing tendon and measurements on the concrete.

Regarding direct methods involving action on the prestressing tendon, various types of sensors are used to measure tensions and prestressing forces, such as strain gauges, fibre optic sensors, force transducers, elastomagnetic sensors, and ultrasonics, among others.

On the other hand, techniques for measuring displacements on the concrete include internal measurements (using techniques like VWDG and VBSG) or surface measurements (using strain gauges, mechanical measurement techniques, or non-contact methods like photogrammetry and laser interferometry).

However, these continuous monitoring methods are not applicable to EPCSs nearing the end of their service life, which require information about their stress state.

For older structures lacking information on prestress evolution, indirect measurement techniques are used, classified by their impact on the structure as destructive (more commonly used in dismantled structures) and non-destructive (more specific, like the Block of Isolated Concrete method - ICBM).

Among the direct action methods on EPCSs, the loading test and crack-reopening are highlighted. These methods have been widely used over time, resulting in a wide variability of results [7,13–21]. The main drawback of these methods is the need for laboratory testing and significant damage to the beam, leading to decompression and consequent crack formation, which would facilitate corrosion and steel degradation if the EPCS were put back into service [15,16,22,23].

Regarding methods applied directly to the prestressing cable, there are two: strand cutting and exposed tendon. The main drawback of the former is the need to remove the area around the strand to install the strain gauge, rendering the EPCS completely useless as the prestressing effect is eliminated. This technique has not been widely used due to its numerous drawbacks [15]. On the other hand, the exposed tendon technique is similar but involves cutting the tendon and applying a force perpendicular to the cable to determine its tension state. It is unclear whether this technique is non-destructive because accessing the prestressing tendon requires removing a large volume of concrete, potentially affecting the beam's functional capacity.

Lastly, different techniques for determining residual prestress in EPCSs are based on actions on the concrete, which have been most employed in recent years, although significant uncertainty and uncontrolled parameters persist.

The first technique worth highlighting is Hole/Core-Drilling, which involves drilling into the concrete using a drill or core bit depending on the diameter. It is a straightforward technique for measuring, but various studies have shown high uncertainties due to unclear stress paths [24,25].

A recent technique is the saw cutting method, which isolates a block of concrete by making cuts. This allows measurements of deformations without interference from prestressing. Studies have shown that placing a strain gauge in the middle of the isolated block allows measurement of deformation as the cut depth increases [26–29].

In conclusion, the apparent conceptual simplicity of the Isolated Concrete Block Method or saw cutting method (ICBM), along with its low impact on the structure (cuts only affect the concrete layer and can be resealed) [30], inspires confidence in overcoming the limitations associated with hole drilling techniques (low stress release, instrumentation difficulty, etc.). Therefore, the ICBM has clear potential to become a practical, economical, and reliable non-destructive method for assessing EPCSs.

3 METHODOLOGY

3.1 Geometry

The experimental specimen is an unbounded prestressed concrete element with a total length of 3.20 meters. The free length between supports is 3 meters, meaning there is a 20-centimeter space at each end that is not subject to support restraints. This configuration allows for analysis of the element's behaviour under specific loading and deformation conditions. Regarding the placement height of the prestressing cable, it follows a straight path and has an eccentricity relative to the centroid of the concrete cross-section of 0.035 meters.

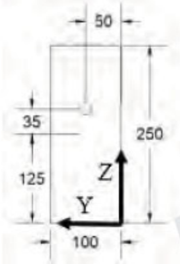

Fig. 1 Cross-section geometry (Units in mm).

The specimen's cross-section has a depth of 0.25 m and a width of 0.10 m. This rectangular cross-section provides adequate contact area for prestressing and ensures the strength and stability of the element. Additionally, the cross-sectional size is designed to meet specific design requirements and ensure a sufficient stress concentration capacity due to prestressing to eliminate the Splitting effect. To achieve this, steel bearing plates with a depth of 0.25 m and a width of 0.10 m are used. These plates are placed at the ends to efficiently distribute and transmit the prestressing force. The use of steel bearing plates allows for a more uniform and controlled application of prestressing force to the element. Figures 1 and 2 illustrates the cross-section details, as well as the front and top view of the specimen

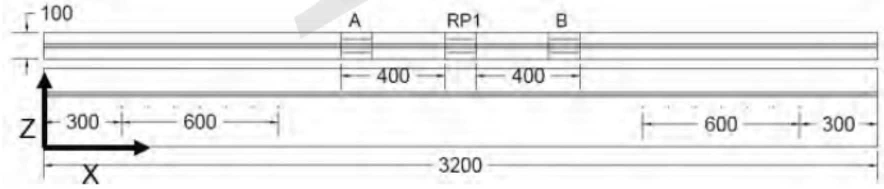

Fig. 2 Top and front view of the specimen (Units in mm)

3.2 Materials.

On the day of the test, specifically at 28 days after casting, the average concrete compressive strength value was 57 MPa, while the modulus of elasticity of the concrete at 28 days was found to be on average 34570 MPa.

Regarding the steel used for the active reinforcement, it is a steel type Y1860 S7 with a diameter of 13 mm, 100 mm^2 of steel area, and the manufacturer specifies an elastic modulus of 195000 MPa.

3.3 Instrumentation

The instrumentation was carried out based on parameters obtained in previous studies [31]. For this specific case, two cutting zones (A and B) and one reference point zone (RP) were selected, as shown in Figure 2. In each of these zones located on the top face (Z=250 mm), two rows of DEMECs were positioned in each measurement zone as shown in Figure 3, totalling 11 DEMECs per row and zone, spaced 10 mm apart. These two rows of DEMECs were placed at 50 mm from each other, with their positioning elevation on the top face at Y=25 mm and Y=75 mm, respectively

Regarding the lateral faces of the beam, there are 2 measurement zones located at the centroid of the cross-sectional area of the beam (Z=125 mm), with 7 DEMECs spaced 100 mm apart, resulting in a total displacement control length in that area of 600 mm, as shown in Figure 4.

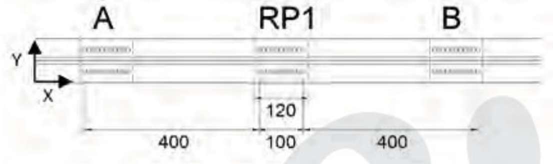

Fig. 3 Top view of the instrumentation layout in the cutting zone (Units in mm)

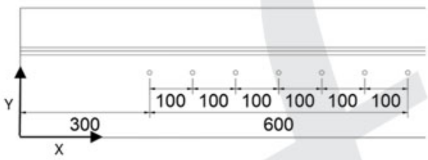

Fig. 4 Lateral view of the instrumentation layout (Z=125mm). (Units in mm)

3.4 Test

The test was conducted following this methodology:

- Placement of the beam at the work site.
- Initial measurements taken.
- Installation of the tendon and distribution plates at the ends of the beams.
- Placement of the force transducer and anchorage wedges for prestressing.
- Tensioning of the prestressing tendon up to 140 kN and subsequent wedging of the jack (126.8 kN).
- Once the tendon force stabilized, measurements were taken to obtain deformations after beam prestressing due to losses from wedge penetration.
- Execution of the cutting sequence in section A involved complete cuts across the width of the section (100 mm), made at two notches spaced 120 mm apart, executed in opposite directions. This methodology was repeated for each of the following depths: 20, 30, 40, and 50 mm. After completing the two notches for a full cut, measurements were taken at all points using two mechanical strain gauge devices (DEMECs). One device had a 400mm gauge length, used to measure from the reference point (RP) to the cutting zone (A or B), capturing deformations within the isolated block relative to external reference points. The other measurement device had a 100 mm gauge length, capturing deformations within the cutting zone itself. Following completion of these measurements, the same sequence was repeated in cutting zone B, with depths of 15, 25, 35, and 45 mm, following the same data collection procedure used in section A, in Fig. 5, the state of the beam after all cuts have been made can be observed.
- Finally, the beam was detensioned to facilitate future tests and assess the recovery capacity of the tested beam after the experiment.

Fig. 5 Specimen in its final state before detensioning.

3.5 Numerical model

To assess the different outcomes, a model was created using the DIANA finite element software based on a previous study [30], where parameters were adjusted to replicate the beam's behaviour observed in the test.

All the analysis model data has been tailored to the tested specimen to verify and refine the model for future studies.

As depicted in Fig. 6, the modelling process involved inputting dimensions, supports, and distribution plates to closely emulate the experimental test. Control points were also included to yield results at the same positions as the DEMEC points. The sequence during the numerical analysis corresponds to the phases conducted in the experimental test. The Figure 7 shows the mesh used in the area where the cuts were made, along with the results of the normal stresses for a cutting depth of 32.5 mm.

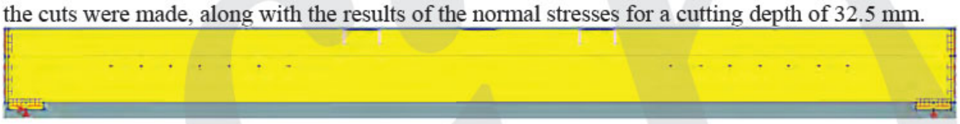

Fig. 6 Lateral view of the model used in the numerical analysis of the specimen.

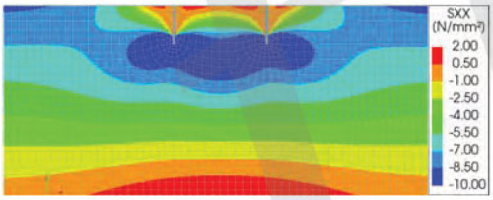

Fig. 7 Results of the longitudinal normal stresses (SXX) in the numerical model at a depth of cut of 32.5 mm.

4 RESULTS

The results obtained from the experimental analysis are shown below. In Fig. 8, the results obtained from the experimental analysis are presented below. It shows the relative displacements with respect to the centre point of the decompression block at each of the shear depths performed of the previously mentioned sequences. On the left, results for cutting zone A (20, 30, 40, and 50 mm) are displayed, while on the right, results for cutting zone B (15, 25, 35, and 45 mm) are shown.

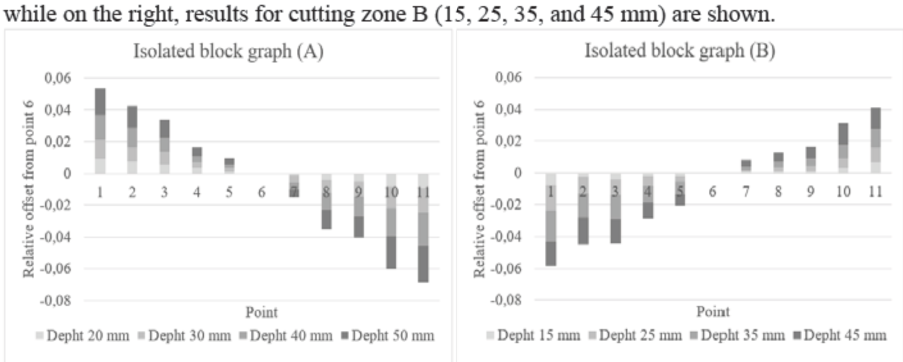

Fig. 8 Relative offset from point 6 variation in Z=250 mm.

In Figure 9, the released deformation results are presented in relation to the cutting depth. This graph spans from the initial prestressing phase (0 mm) to the completion of the final cut during the test, including the unloading of the beam (50 mm). The main objective is to obtain the average deformation profile based on the achieved cutting depth. The graph collectively shows the entire sequence of cuts ordered by depth A (20, 30, 40, and 50 mm) and B (15, 25, 35, and 45 mm).

Both experimental data (using DEMEC 400 and DEMEC 100) and data from numerical analysis are included in Fig. 9. The use of two types of mechanical strain gauge devices (DEMEC 400 and DEMEC 100) allows capturing different ranges of deformation: DEMEC 400 measures deformations from the reference point to the cutting zone, while DEMEC 100 focuses on deformations within the cutting zone itself.

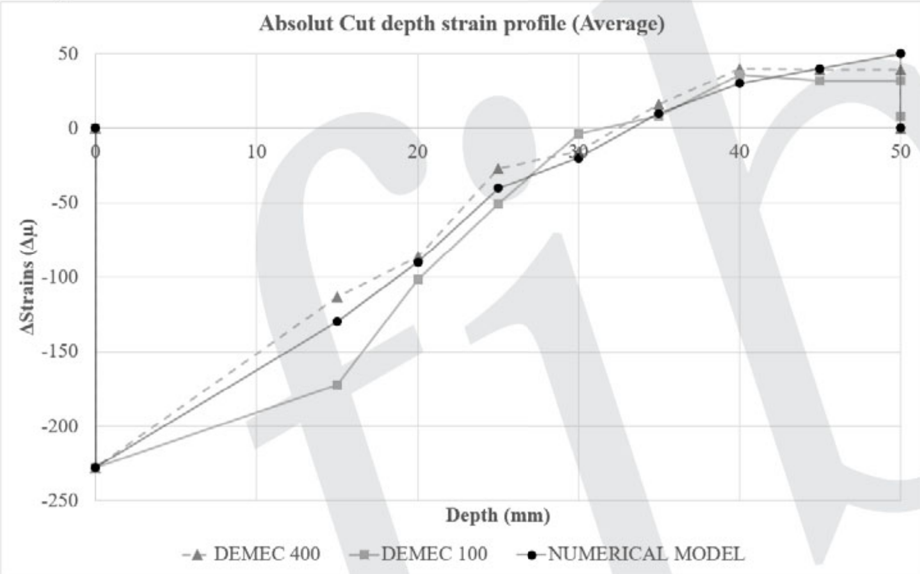

Fig. 9 Representation of the displacement variation as a function of the depth of notch.

5 DISCUSSION

Regarding the analysis of the results at the isolated block level, as the notch depth increases, so do the relative displacements with respect to the centre point of the block, leading to decompression of the block and the generation of a decompression stress field.

Regarding the values obtained for the cutting zones (A and B) and the external reference point (RP), it is notable that the displacements measured with a 400 mm gauge length from an external reference point, as well as the variability among values obtained from internal points using a 100 mm gauge length, show consistency. This suggests that the reference points remain constant at 400 mm out of the cutting zones

Concerning the comparison of cumulative deformation results, both experimental and numerical values show similar outcomes, indicating the correct functionality of the numerical model. It is ob-served that complete release of prestressing-induced tension occurs at depths between 30 and 35 mm.

In addition, it is important to mention that at a depth of 15 mm, there is a slight scatter in the data obtained by the 100 mm gauge length device compared to those obtained with the 400 mm device and the numerical model. This may be attributed to the lower accuracy of the 100 mm gauge length device.

6 CONCLUSIONS

Based on this study of the application of the "saw-cut" method, the following conclusions have been drawn:

- As the depth of the cut increases, a greater variation in displacement between the notches is ob-served, which suggests stress relief within the isolated block.
- The data obtained from different base lengths, between internal points (100 mm base length) and between external reference points (400 mm base length), are consistent.
- The external reference points located 400 mm from the cutting zone remain unchanged.
- The numerical model and the experimental model yield very similar results, indicating accurate element modeling.

- The depth at which total decompression is achieved within the isolated block falls within the notch depth range of 30-35 mm, both in the numerical model and the experimentally tested specimen.

The execution of an experimental test and the implementation of a numerical model have enabled the study of the effect of induced notches in prestressed concrete elements. This study is essential to support the evaluation of residual prestressing force using the non-destructive and indirect methodology known as saw cutting.

Finally, it is important to note that this measurement methodology reduces the influence of thermal variation caused by temperature increases generated during saw cutting. Additionally, it would be interesting to validate the behaviour for different prestressing ages and test ages to evaluate the influence of material time-dependent effects.

7 ACKNOWLEDGMENTS

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