Analysis of Prestressing in Notched Concrete Beams

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Abstract. There are great uncertainties when addressing the assessment of prestressed concrete members (PCM), and in particular of the effective prestressing force. One of the most recent and promising methods to assess the actual prestressing force is the Isolated Concrete Block Method, which is based on the local decompression of concrete by introducing surface notches. The motivation of this work is to study the effect of this decompression and its scope is focused on analyzing the concrete decompression by means of numerical modelling, as a preliminary step of a subsequent experimental program. The methodology is based on the response of a tailor-made finite element model that reproduces the effect of the notches depending on key parameters such as notch depth, prestressing force, distance between notches, measurement base length, cross-section dimensions or tendon eccentricity. The results obtained show the level of decompression after sawing the concrete depending on the parameters considered, which will be used to select appropriate instrumentation for further experimental testing and verification.

Keywords: Concrete · Prestressed · Notch · Cut · Modelling

1 Introduction and Objectives

Main codes and standards offer sufficient provisions for prestressing design of prestressed concrete members (PCM). The designer must set the prestressing force and estimate the prestressing losses, so that the PCM meets its requirements over its service life. In addition, PCM can be instrumented during casting (e.g. vibrating wire strain gauges, magnetoelastic devices, …) with the aim of measuring parameters of interest for a real-time monitoring in service in a direct manner [1]. In particular, a key parameter is the residual prestressing force at each time.

In this context, a good number of recent studies [1–4] carried out on existing prestressed concrete elements report about difficulties in the determination of the prestressing losses and the residual prestressing force. Since lots of PCMs have been cast without any kind of instrumentation, the residual prestressing force can only be estimated in an

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indirect manner. In these cases, additional complexity must be considered in relation to the initial prestress, the materials properties and their evolution and the accounted short- and long-term prestress losses.

Regarding the indirect methods, it should be noted that they can be both destructive and non-destructive, the last including cases of reduced local damage susceptible of aesthetic restitution. A recent and promising indirect non-destructive testing method is based on performing surface notches by saw-cutting the concrete [5–7].

To this end, and as a previous step to establish the criteria of a subsequent experimental program, a numerical modelling on notched prestressed concrete beams is carried out with the main objective of measuring the decompression of concrete strains in PCM after inducing saw-cutting. It is intended to study the effect of parameters such as the notch depth, level of prestressing force, distance between notches, measurement base length, cross-section dimensions or tendon eccentricity.

2 Numerical Modelling of Notched PCMs

The numerical modelling of the notched in PCMs is based on the Finite Element Modelling (FEM). As a preliminary step a 2D linear elastic model is implemented (Fig. 1), and therefore, the concrete material model is defined by its elastic concrete modulus (E_c) and its corresponding Poisson coefficient (ν).

The prestressed force is applied by means of an external straight tendon modelled as a truss element with a given prestressing force (P) and a constant eccentricity (e_p) anchored at both ends to steel plates in order to apply the force in a distributed way. The beam modelled has a span-length of 2 m, which results in a sufficiently long distance able to isolate the effect of notching within the beam, and without interacting with the prestressing transmission zone at both ends of the element. The beam is modelled statically determined, and therefore, the boundary conditions have been included as a simple supported beam.

In the center of the beam, a refined modelling is required to perform the notches based on an adaptive meshing towards the position of the notches given a distance between notches. Moreover, between notches specific nodes are introduced in order to serve as virtual instrumentation, measurement base length, to assess the mechanical behavior between the notches.

The effect of the notch formation is achieved thanks to implementation of a phased-analysis carried out thanks to the capabilities of the software Diana [8].

With the numerical model, it is feasible to generate curves representing the isolation of the concrete block in compression between the notches (Fig. 2) as a function of the notch depth, in a similar way to the work carried out by Bagge [5]. It is important to note that in these curves the y-axis represents the average dissipation of the normal strains within the measurement base length considered. So given the specific data such as the cross section dimensions (bxh), the eccentricity of the prestressing reinforcement (e_p), the distance between notches (D) and a measurement base length (BL) is possible to plot the response of the dissipation of the longitudinal strains (ΔStrain) as a function of the notch depth, as shown in Fig. 2.

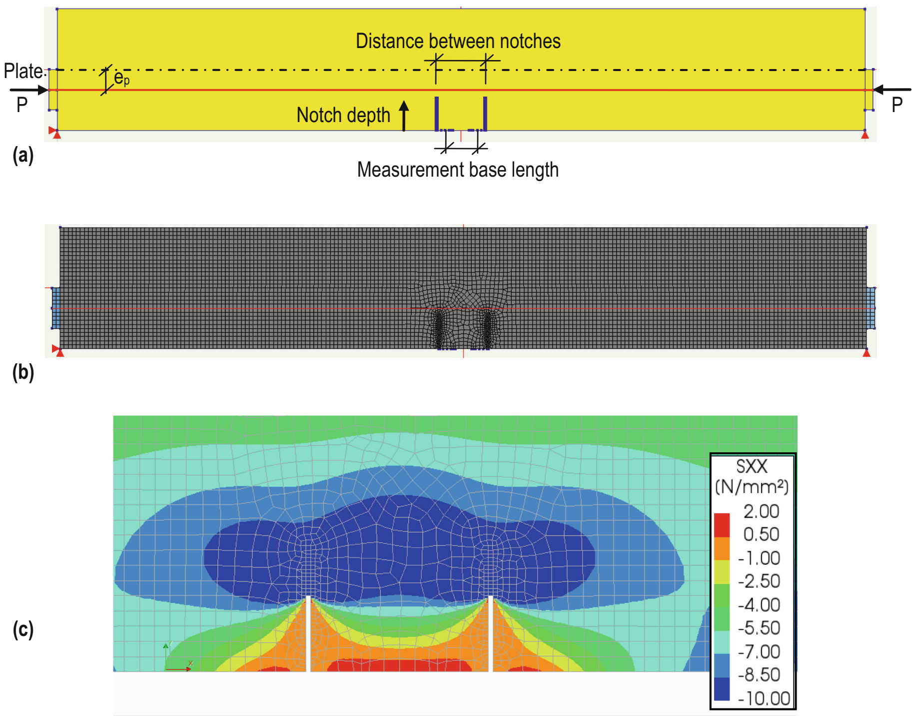

Fig. 1. Numerical model of notched PCM: (a) geometry view, (b) mesh view, (c) results view showing normal stress distribution in x direction (SXX)

The thickness of the notch has been fixed in all the analyses at 3 mm, which approximately corresponds to the average thickness obtained when sawing beams in the lab. In any case, in preliminary numerical analysis, it has been observed that the influence on the response of the curves of notch widths ranging from 1 to 6 mm is negligible.

In these curves, a characteristic S-shape is observed with a high rate of concrete strain release for low notch depth that gradually slows down for increasing ones. Moreover, it is feasible to plot the response for different values of the prestressing force P. In this case, it is important to outline that the curves are proportional to the level of prestressing force P considered.

3 Analysis of the Isolation of the Concrete Block

3.1 Effect of the Distance Between Notches

In this section it is studied how the distance between notches influences the isolation of the concrete compression block. Different values of the distance between notches from 100 to 160 mm have been studied.

As an example, a case with D = 120 mm is shown in Fig. 2 and with D = 160 mm in Fig. 3. The dimensions of the section, the eccentricity of the tendon and the measurement base length are kept constant in both cases.

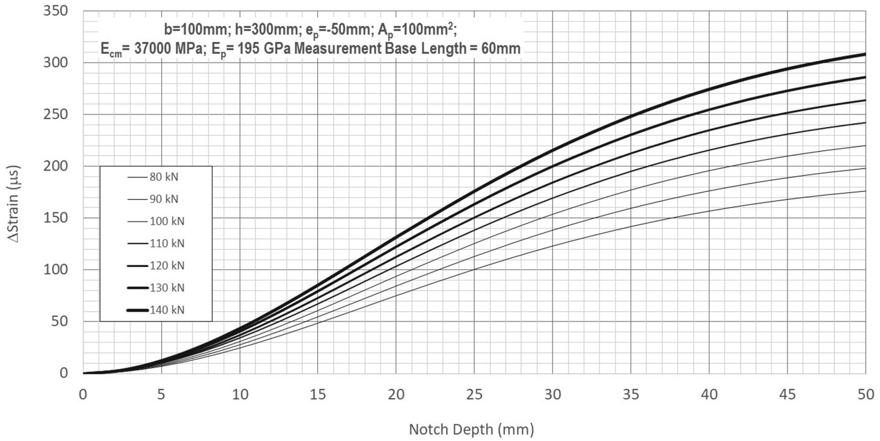

Fig. 2. Notched PCM (b = 100 mm; h = 300 mm; e_p = 50 mm; D = 120 mm; BL = 60 mm)

As it can be observed, the decompression in the first case is faster than in the second one. For example, for a notch depth of 30 mm and a prestressing force P = 110 kN, when the distance D = 120 mm the decompression is 170 μs while for a distance D = 160 mm it is only 105 μs (about 38% lower).

3.2 Effect of the Measurement Base Length

This section focuses on how the length of the measurement base length influences the isolation of the concrete compression block. Different base lengths (BL) between 40 and 100 mm have been studied.

As an example, a case with a BL = 60 mm is shown in Fig. 2 and other case in Fig. 4 for a BL = 100 mm. In both cases, the section dimensions, the tendon eccentricity and the distance between notches remain constant.

It is noteworthy that the decompression in the second case is faster than in the first one. For example, for a notch depth of 30 mm and a force P = 110 kN when BL = 60 mm the decompression is 170 μs while for BL = 100 mm it is 190 μs (about 12% higher).

3.3 Effect of the Concrete Cross-Section Dimensions

In this section it is studied how the cross-section dimensions influence the isolation of the concrete compression block. Rectangular cross-sections have been considered in this study by means of two total depths h = 300 mm and h = 200 mm.

As an example, Fig. 2 shows a case with a cross-section depth h = 300 mm and Fig. 5 a case with a depth h = 200 mm. The eccentricity of the tendon, the distance between notches and the measurement base length are kept constant in both cases.

As it can be observed, in the second case the decompression is more marked than in the first one. For example, for a notch depth of 30 mm and a prestressing force P = 110 kN, when h = 300 mm the decompression strain is 170 μs while for h = 200 mm

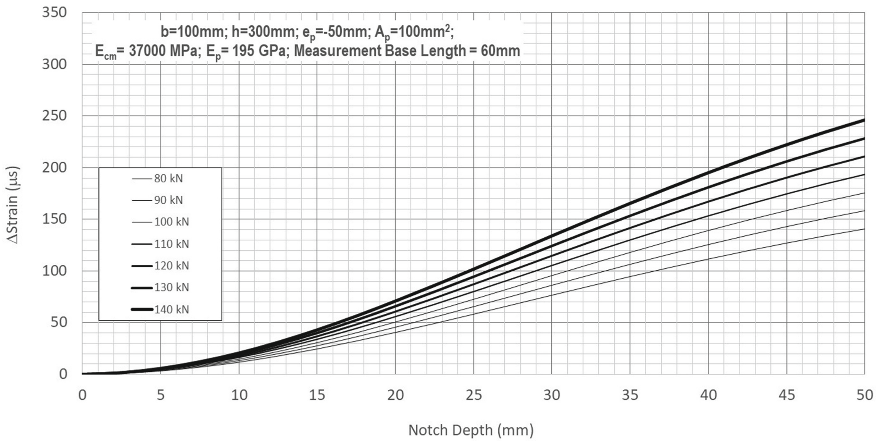

Fig. 3. Notched PCM (b = 100 mm; h = 300 mm; e_p = 50 mm; D = 160 mm; BL = 60 mm)

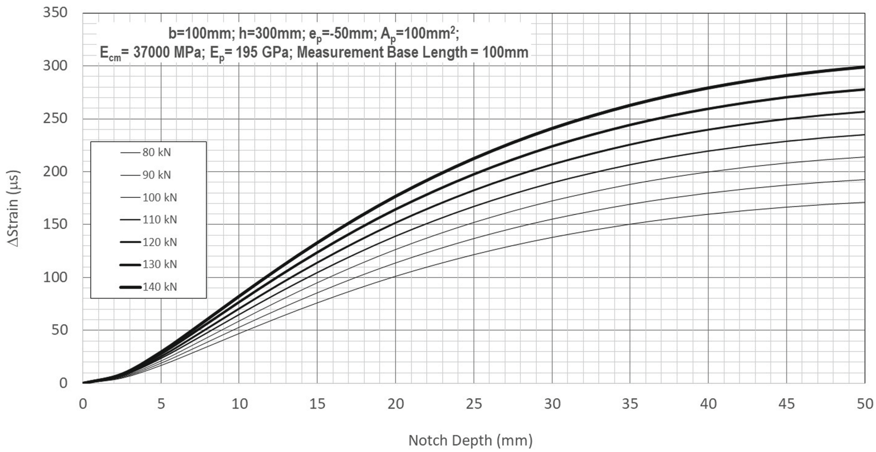

Fig. 4. Notched PCM (b = 100 mm; h = 300 mm; e_p = 50 mm; D = 120 mm; BL = 100 mm)

it is 285 με (approximately 68% higher). This result makes sense given the fact that the same prestressing force is acting on a section of smaller dimensions inducing higher concrete strains before performing the notches in the prestressed concrete beam.

3.4 Effect of the Tendon Eccentricity

This section presents the study on how the eccentricity of the prestressing tendon influences the isolation of the concrete compression block. Two configurations have been addressed in this study: prestressed concrete beam with eccentric tendon and prestressed concrete beam with centered tendon (Fig. 1).

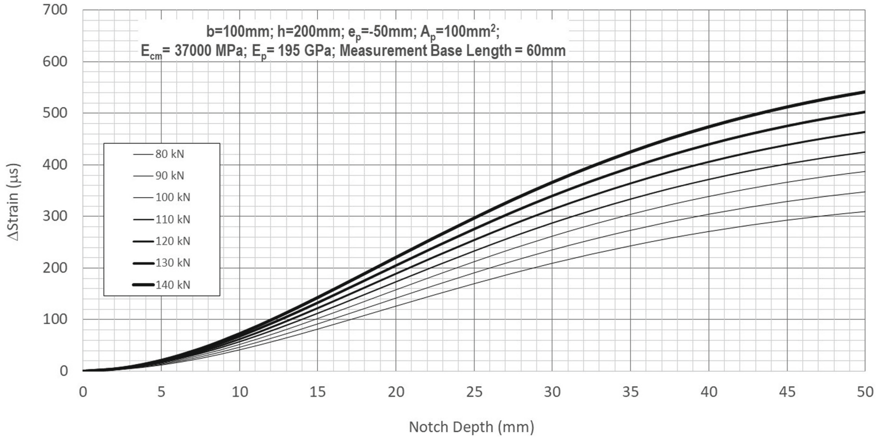

Fig. 5. Notched PCM (b = 100 mm; h = 200 mm; e_p = 50 mm; D = 120 mm; BL = 60 mm).

As an example, a case with eccentric prestressed beam e_p = 50 mm is shown in Fig. 2 and in Fig. 6 for a prestressed beam with centered cable. In both cases, the section dimensions, the distance between notches and the measurement base length are kept constant.

It is observed that the decompression in the first case is greater than in the second case. For example, for a notch depth of 30 mm and a prestressing force P = 110 kN, when the eccentricity e_p = 50 mm the decompression is 170 µs, while for an eccentricity e_p = 0 mm it is only 90 µs (approximately 47% lower). This result is logical since the same prestressing force acting on the centroid of the section generates a uniform compression. Therefore, lower initial compression stresses than in the case of the beam with eccentric tendon are reached in the zone influenced by the notches.

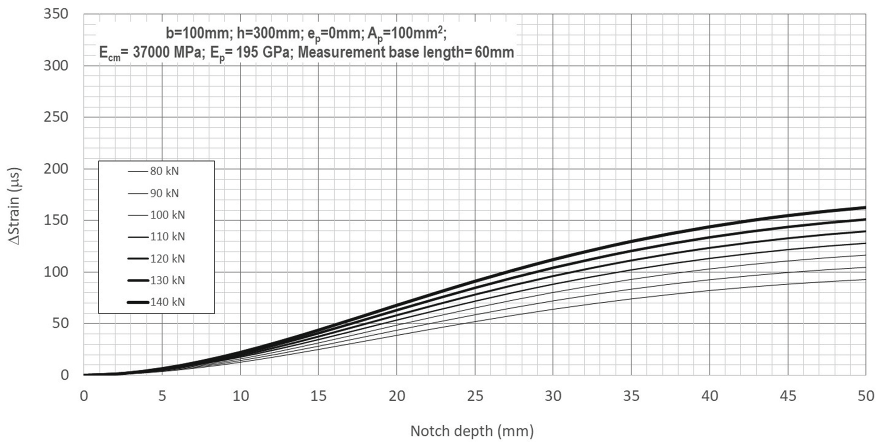

Fig. 6. Notched PCM (b = 100 mm; h = 300 mm; e_p = 0 mm; D = 120 mm; BL = 60 mm).

4 Conclusions

The local decompression of concrete stresses in the so-called Isolated Concrete Block Method has been studied by means of numerical analysis. The effect of the following parameters has been addressed: notch depth, prestressing force, distance between notches, measurement base length, cross-section dimensions, and tendon eccentricity. The following conclusions have been drawn:

- The numerical model developed is capable of simulating the effect of concrete decompression produced by notches in prestressed concrete beams.
- A characteristic S-shape with a high rate of concrete decompression for low notch depths that gradually slows down for increasing ones is observed.
- A proportional release in the concrete strains with the prestressing force applied is achieved.
- The release of concrete strains is lower with increasing distance between notches. Thus, a suitable compromise solution must be established for this distance to measure the decompression satisfactorily.
- The greater the measurement base length, the greater the decompression.
- The lower the section dimensions, the higher the level of decompression. Therefore, the level of decompression is highly dependent on the compression stress in the concrete before saw-cutting.
- The greater the eccentricity of the tendon, the greater the level of decompression. This is due to the higher level of concrete compressive stresses achieved in a prestressed concrete member with a higher eccentricity.

Therefore, based on the conclusions obtained in this study it will be possible to determine the most appropriate values for the parameters involved in the Isolated Concrete Block Method to establish the best experimental methodology for its application in PCMs.

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