

NONLINEAR ANALYSIS OF HOLLOW-CORE SLABS WITH AND WITHOUT FRP REINFORCEMENT

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Abstract: *In this study, a numerical model about the shear behaviour of precast prestressed hollow-core slabs is presented. The nonlinear analysis is conducted using the Abaqus software and the results are expressed as a comparison between hollow-core units with and without fiber reinforced polymers. Fiber Reinforced Polymer (FRP) composite is commonly used to strengthen and retrofit a large number of structural elements, being a high strength composite material made of a polymer matrix reinforced with fibers. The shear strengthening technique consists in the appliance of FRP on the inner surface of the slab's voids. The comparisons are detailed in terms of load-deflection curves, failure load and crack pattern.*

Key words: *hollow core slabs, fiber reinforced polymers, finite element modelling, shear strengthening.*

1. Introduction

Prestressed hollow core concrete slabs were first developed in the 1950s and since then their purpose grew substantially in floors and roofs of residential, commercial and industrial buildings, as well as detention centers [2]. In addition to their remarkable structural advantage and the capacity to cover large spans, hollow core slabs present other advantages such as relatively low weight, ease in construction, superior thermal and acoustical properties, high fire resistance and short construction time [1,3]. Fiber reinforced polymers are considered a merging of an on-going process in the expansion of new and improved construction materials with novelty in building technology. This type of composite materials suggests an expanding solution in the retrofitting of concrete structures. Their exceptional mechanical properties and low weight make fiber reinforced polymers an effective alternative to traditional strengthening techniques. Apparently, the efficiency of retrofitting the shear capacity of reinforced concrete elements using externally bonded FRP strips was confirmed by experimental studies. Shear capacity of FRP strengthened members presents a 60% increase over the un-strengthened ones. Furthermore, flexural rehabilitation has been demonstrated its performance through a considerable number of researches [5].

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2. Numerical Study of Full-Scale Hollow-Core Slabs

2.1. Modelling considerations: material constitutive behaviour, model geometry, boundary conditions and solution control

Toward an increase of shear capacity, it is analysed a method of applying the FRP composite strips on the internal surface of the precast slab's voids [7]. To assess the usefulness and accuracy of this strengthening procedure, the present research is based upon a comparison between a four-voids hollow core slab without FRP reinforcement and one with FRP strips on the inner perimeter of its voids, as illustrated in Fig. 1. Finite element simulation is conducted with the Abaqus software [8].

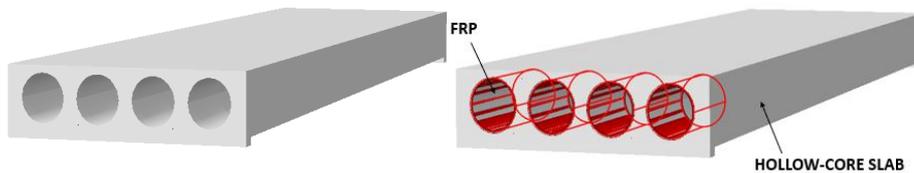


Fig. 1. Four voids hollow-core slab without and with FRP strips

The cross-section of the studied specimens is emphasized in Fig. 2, while the static scheme is presented in Fig. 3. Both the non-retrofitted and the retrofitted HCS have a length of 5000 mm, a depth of 320 mm and a width of 1200 mm. Regarding the prestressing level, each unit has ten prestressing tendons, composed of 7-wire, low-relaxation strands with a 13 mm diameter and a cross-sectional area of 100 mm².

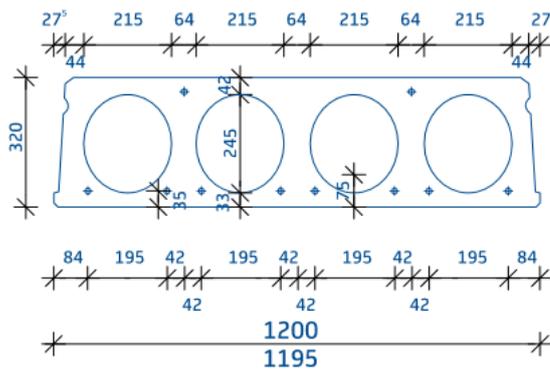


Fig. 2. Cross-section of the HCS units (unit: cm)

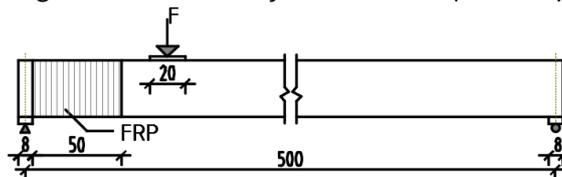


Fig. 3. Static scheme (unit: cm)

In this paper, the concrete damage plasticity model (CDP) is chosen to simulate the hollow-core slabs' behaviour. CDP is characterized by the assumption that the main failure mechanism of concrete is caused by cracking in tension and crushing in compression [8]. The stress-strain response under uniaxial loading is given by the equation below:

$$\sigma = (1 - d) * E_0 * (\epsilon - \epsilon^{pl}) \tag{1}$$

where σ, ϵ and ϵ^{pl} represent the stress, total strain and plastic strain, E_0 is the modulus of elasticity and d the damage factor [8].

The constitutive relationship for the prestressing strands is summarized by the dual slash-curve model [9]. Also, the behaviour of FRP used for the retrofitting of HCS is assumed to be linear elastic [3].

Regarding the element types, a C3D8R (8-node linear brick, reduced integration with hourglass control) element has been chosen for concrete volumes, a T3D2 (2-node, three-dimensional truss element) for the prestressing tendons modelling and a four-node quadrilateral in-plane stress/displacement shell element with reduced integration and a large-strain formulation (S4R) for the fiber reinforced polymer strips [7, 8].

Material properties used in the present research:

- Concrete class C 50/60 (with an average result of the concrete ultimate compressive strength 59.3 MPa; Young's modulus 36773.33 MPa; Poisson's ratio 0.2) and the parameters used in the concrete damaged plasticity model are given in Tab. 1:

Parameters in Concrete Damaged Plasticity model

Table1

Dilatation angle	Eccentricity	f_{b0}/f_{c0}	k	Viscosity parameter
30°	0.1	1.16	0.667	0.0005

- Prestressing tendons: Young's Modulus 210000 MPa; Poisson's ratio 0,3.
- FRP: Young's modulus 82000 MPa; Poisson's ratio 0,3.

Fig. 3 and Fig.4 illustrate the studied finite element's model geometry for the control hollow-core slab (HCS) and the strengthened one.

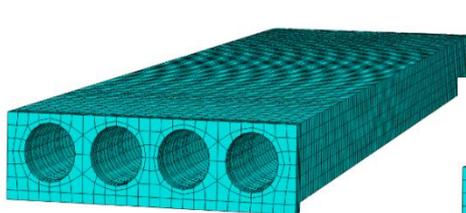


Fig. 3. Control HCS

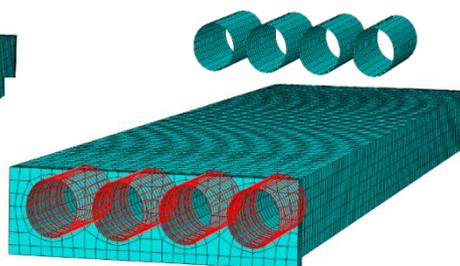
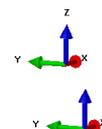


Fig. 4. Strengthened HCS



The boundary conditions for the support plates are pin support on the loading side of the model (the nodes on the bottom face of the support plate are constrained in the x,y and z directions) and roller support on the other side (the nodes on the bottom face of the support plate are constrained only in the y and z directions).

The interface between the FRP and concrete was simulated by a tie constraint, which ties two separate surfaces together (master surface: concrete and slave surface: FRP) so that there is no relative motion between them. This type of constraint allowed the fusion of two regions, though the meshes created on the surfaces of the regions may be dissimilar [8].

Finite element analysis is divided into two steps. The first step consists of the application of prestress in the tendons, while in the second step of the analysis, the HCS is subjected to the self-weight as a uniform load on the element and moreover, to a line load in the vertical direction, gradually applied. The Riks-Wempner method or the arc length method has been chosen in the present modelling to conduct the nonlinear static analysis [4, 10].

2.1. Validation of the Finite Element Modelling

The load-deflection relationship reflects the behaviour of the studied elements during the entire loading history and it represents a significant assessment criterion for a finite element model performance [3]. Fig. 6 emphasizes the comparison of the load-deflection relationship of the predicted finite element model with and without fiber reinforced polymers. It can be noticed that the developed finite element model can reasonably predict the behaviour of the un-strengthened and strengthened precast hollow-core slabs in terms of the initial stiffness, the ultimate failure load and the deflection corresponding to failure [6] [7]. With reference to the load, the differences of control HCS (un-strengthened) and strengthened HCS are under 5%. Both curves exhibit similar behaviour in the elastic range, whereas in the post-elastic domain the nonconformity arises.

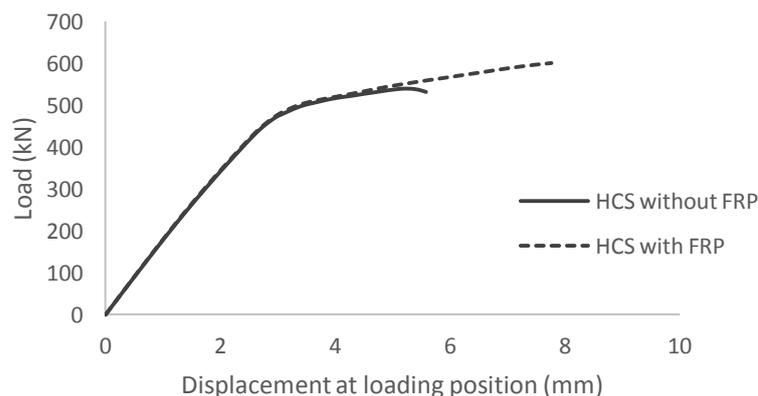


Fig. 6. *Load-deflection curve*

In addition, Fig. 7 and Fig. 8 reflect a comparison between the equivalent plastic strain (PEEQ) results extracted from the two finite element models studied and it

demonstrates a typical crack growth trend within the shear-tension range for the control HCS.

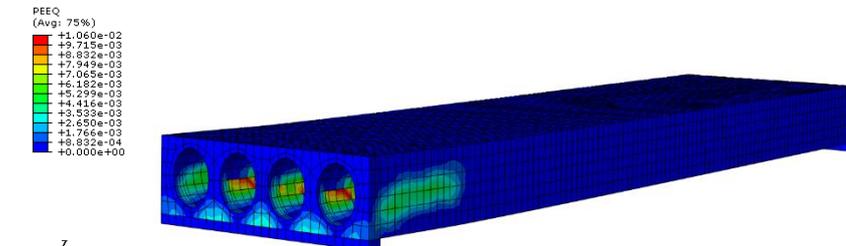


Fig. 7. Plastic strain (PEEQ) for the control HCS at failure load

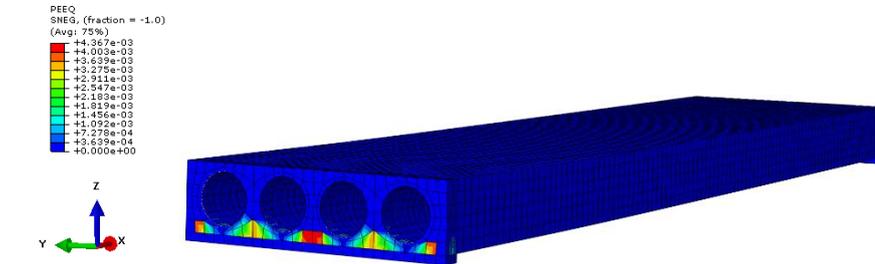


Fig. 8. Plastic strain (PEEQ) for the strengthened HCS at failure load

Moreover, the distribution of the Von Mises stresses in the FRP sheets are shown below, in Fig.9.

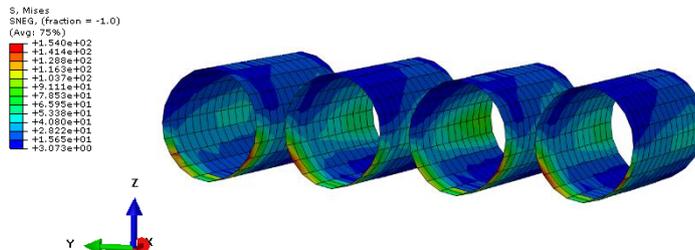


Fig. 9. Distribution of Von Mises stresses in the FRP sheets (in the strengthened HCS)

3. Conclusions

This preliminary study is part of an on-going, ample research and consists the subject of my PhD thesis. Finite element simulation undertaken predicts the flexural and shear behaviour of the un-strengthened and the strengthened hollow core slabs regarding load-deflection relationships, plastic strain and Von Mises stresses in FRP strips. However, it is noticeable that the application of the FRP influence the bearing capacity of the hollow-core slabs. In order to obtain an increase of the shear resistance, a study upon a reduced width of the applied FRP sheets (150° and 90° arc range), a specific length and thickness of the strengthening region is mandatory.

References

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