NUMERICAL VALIDATION OF A DOWEL ACTION TRIPLE-BLOCK TEST SET-UP

Isabella Giorgia Colombo[1], Matteo Colombo[1], Katherina Folres Ferreira[1], Paolo Martinelli[1] and Marco di Prisco[1]

[1] Department of Civil and Environmental Engineering, Politecnico di Milano, Italy

Corresponding author email: isabellagiorgia.colombo@polimi.it

Abstract

Dowel action provided by steel rebars in reinforced concrete is particularly relevant in existing reinforced concrete structures characterized by lack of construction details and designed with obsolete code. In the 80's and 90's, dowel action effect was widely investigated at Politecnico di Milano by means of monotonic tests performed on single-block specimens. In the framework of the Research Project of National Interest "*Failure mechanisms due to lack of construction details and degradation phenomena in existing reinforced concrete structures*", this previous investigation is now extended by performing an experimental campaign that includes cyclic tests. Hence, a triple-block test set-up - particularly suitable for conducting cyclic tests - was designed. This paper aims to numerically validate the triple-block test set-up, by comparing its behaviour to that obtained in the previous experimental campaign for the single block in monotonic tests. A good agreement is achieved in terms of global behaviour, failure mechanisms and shear force at which reinforcement yielding occurs, while a difference in terms of stiffness is highlighted.

Keywords: dowel action, weak mechanism, triple-block test set-up, FEM, numerical validation.

[redacted] Introduction

The study of the dowel action dates back to the 30's when the use of reinforced concrete (RC) slabs started to spread for pavements and airport runways construction (e.g. Friberg 1940). Then, in the 50's and 60's, the investigation on dowel action extended to RC structural elements or composites in which multiple shear resisting mechanisms are acting (e.g. Krefeld and Thurston 1966). Starting from the 70's, analytical and numerical models have been developed in order to predict the dowel strength (e.g. Johnston and Zia 1971, Dulacska 1972, Soroushian et al. 1986, Vintzeleou and Tassios 1987).

The most recent studies on the dowel action concern the behaviour of:

- beam-column joints subjected to monotonic (Magliulo et al. 2014) and cyclic loads (Zoubek et al. 2015), with particular reference to prefabricated buildings;
- adjacent RC pavement slabs; the main investigations in the literature have been conducted using analytical or numerical approach (Maitra et al. 2009), in particular on loss of plugs (Davids 2000), misalignment of connectors (Prabhu et al. 2009) and effect of temperature (Shoukry et al. 2003);
- shear connectors currently used in composite steel-concrete beams with puzzle shape (Lorenc 2014).

Dowel action can be classified on the basis of two main mechanisms: a weak mechanism, with the bar acting against the concrete cover (Figure 1 – aI, bI) and a strong mechanism, with the bar acting against the concrete core (Figure 1- aII, bII, c). (Dei Poli et al. 1993).

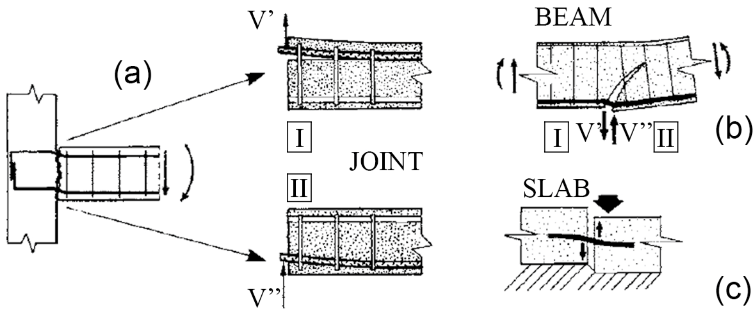

Figure 1. Dowel action in RC concrete elements acting against concrete cover (aI, bI: weak mechanism) and against concrete core (aII, bII, c: strong mechanism); (Dei Poli et al. 1993).

In literature, four main test set-ups for the investigation of the dowel action could be identified: RC beams in bending (e.g. Jelic et al. 1999), push-of specimens (e.g. Dulacska 1972, Soroushian et al. 1986), divided beam specimens (e.g. Krefeld e Thurston 1966) and block specimens. Concerning the latter, specimens could be constituted by 1 block (e.g. Dei Poli et al. 1992, Dei Poli et al. 1993), 2 blocks (e.g. Jimenez et al. 1978, Moradi et al. 2012, Sørensen et al. 2017) or 3 blocks (e.g. Vintzeleou and Tassios 1987).

In the late 80’s and 90’s, at Politecnico di Milano, Dei Poli, di Prisco and Gambarova developed a wide experimental campaign on dowel action by testing single-block specimens. The investigation concerned both strong and weak mechanism, and accounted for many variables: diameter of the dowel, position of the first stirrup, concrete cover, use of normal strength, high strength and fibre reinforced concrete (Brenna et al. 1989, Dei Poli et al. 1987, 1988, 1992, 1993). All the tests were performed by applying a monotonic displacement.

This experimental campaign has been extended in the framework of a Research Project of National Interest in Italy (PRIN) titled: “*Failure mechanisms due to lack of construction details and degradation phenomena in existing reinforced concrete structures*”, focusing in particular on cyclic tests. The triple-block specimen results particularly indicated for this kind of tests; hence, it has been selected for this new experimental campaign. In this paper, the triple-block specimen test-set-up has been validated on the basis of the results of the previous monotonic experimental tests performed on single block specimens.

[redacted]Triple-block set-up

In the framework of the PRIN project, the following variables are taken into account: concrete cover (c), presence or absence of stirrups, and type of load (monotonic or cyclic). In this paper, the specimen with concrete cover equal to d_b, being d_b the dowel diameter, including stirrups and subjected to a monotonic load is taken as a reference.

The test set-up and the reinforcement of the triple-block specimen are shown in Figure 2a and 2b, respectively. In particular, the central block is over-reinforced, so that the failure will occur in the lateral blocks due to weak mechanism activation when the central block in moved upward.

Each block is 300 mm long, 300 mm deep and 200 mm high. The dowel ($\phi 18 = d_b$) longitudinally run along the three blocks, with a net concrete cover equal to 18 mm. Between the blocks, Teflon sheets 0.5 mm thick are placed, thus minimizing friction.

The lateral blocks are reinforced with stirrups ($\phi 8$), with the first stirrup placed at the distance $b = d_b$ from the shear plane and the distance between the stirrups equal to $6d_b$. An additional reinforcement (steel net, see characteristics in Figure 4b – type 1) is placed at the mid height of the concrete cover in order to restore the cover that is crossed by ducts for the placement of inductive displacement transducers (not shown here) aimed at measuring the vertical displacement of the dowel.

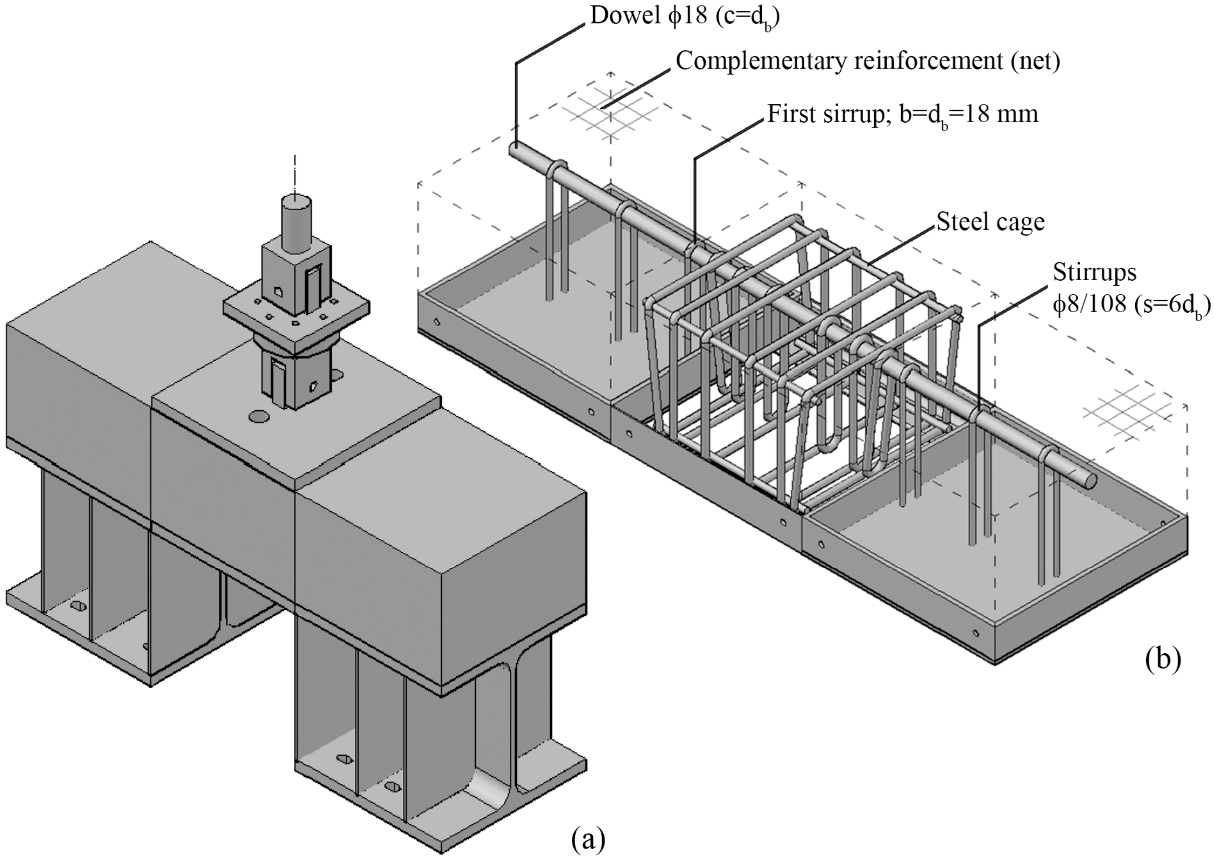

Figure 2. a) triple-block test set-up, b) reinforcement of the specimen; (specimen size: 900 × 300 × 200 mm).

[redacted] FE modelling

The FE model of the triple-block specimen was built and processed in Abaqus 6.14-5 environment and it is shown in Figure 3 in terms of geometry, constrains and mesh. In order to reduce the numerical effort, half of the specimen has been reproduced exploiting *yz*-symmetry. It is worth noting that, for validation purposes, the materials (steel and concrete) constituting the triple-block specimen are assumed exactly the same of specimens by Dei Poli et al. (1993).

3.1. Geometry modelling

As visible in Figure 3a, the concrete blocks are modelled as solid and homogeneous, while the dowel, the stirrups, the net and the cage are modelled as beams. Beam elements are embedded in the concrete blocks and the interaction between these blocks is characterized by a hard contact in normal direction and by absence of friction in tangential direction. Concerning constraints, displacements orthogonal to the symmetry plane are prevented, the bottom surface of the lateral block is cantilevered (U1=U2=U3=0), and a vertical displacement is imposed to the bottom surface of the central block (U2=1).

The mesh is shown in Figure 3b. Eight-node reduced integration and hourglass control brick elements (C3D8R) with three degrees of freedom per node are employed to discretise the concrete blocks. Two-node beam elements (B31) with six degrees of freedom per node are used to discretise the steel reinforcements. The mesh characteristics are collected in Table 1.

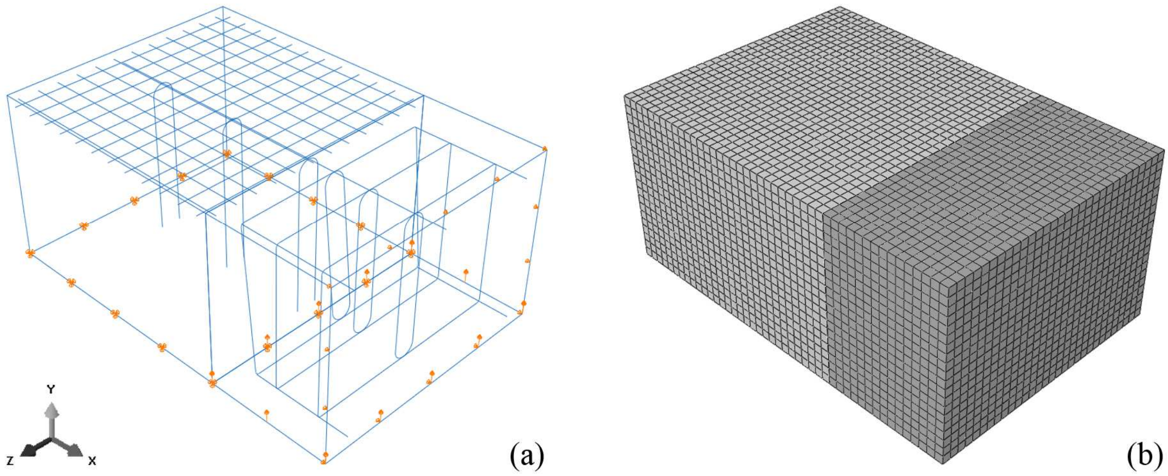

Figure 3. Triple-block FE model: a) geometry with constrains, b) mesh.

Table 1. Triple-block FE model: mesh characteristics.

Characteristics	Concrete	Steel	Entire Model
Nodes	30597	1297	31894
Elements	27000	1421	28421
Elements type	C3D8R	B31	-
Elements over the thickness	20	-	20
Max. aspect ratio	1.0	-	1.0

3.2. Material modelling

In the following, the constitutive laws adopted for concrete and steel are described. As anticipated, for the validation procedure, the material properties of concrete and steel have been assumed equal to those constituting the specimens of Dei Poli et al. (1993) here used as reference.

In particular, concrete had an average cylindrical compressive strength of 23.5 MPa (Dei Poli et al. 1988). According to Model Code 2010 (2013), concrete was classified as C16 grade, characterized by a modulus of elasticity of 28.8 GPa, a Poisson's ratio of 0.2, a mean tensile strength of 1.9 MPa and a fracture energy of 129.35 N/m. The elastic parameters are used to define the elastic behaviour, and the plastic behaviour is introduced using Abaqus Concrete Damage Plasticity (CDP) model. No damage curves are defined; hence, the model simply behaves as a plasticity model. The adopted plasticity parameters are listed in Table 2. In compression, the well-know Sargin's curve is used (Model Code 2010 2013); inelastic behaviour of concrete is assumed to start at 40% of the mean compressive strength. In tension, the plastic behaviour is defined specifying a post failure stress-fracture energy relation. As CDP model assumes a linear post-failure behaviour, only the area under the first branch of the stress-crack opening displacement curve proposed by Model Code is considered (0.081 N/mm).

Concerning steel constituting rebars, the elastic behaviour is defined through an elastic modulus of 210 GPa and a Poisson's ratio of 0.3. Plasticity is introduced defining a stress-inelastic strain relationship deduced from the experimental results of bars tested in tension by Dei Poli et al. (1987), characterized by a yield strength equal to 490 MPa and an ultimate strength of about 700 MPa, at a strain of 10%.

Concerning steel constituting the net, the same elastic parameters are used, while the yield strength is assumed equal to 280 MPa to be consistent with Dei Poli et al. (1993).

Table 2. Plasticity parameters of the CDP model (f_{b0}/f_{c0}: ratio between the biaxial and the uniaxial compression strengths; K: Drucker-Prager surface modifier).

Dilatation angle	Eccentricity	f_{b0}/f_{c0}	K	Viscosity parameter
38	0.1	1.16	0.67	0

[redacted]Validation of the FE model

4.1.1. Reference experimental tests

The experimental campaign on dowel action held by Dei Poli et al. (1993), Series D, was taken as reference for the validation of the numerical model proposed in this paper. The scope of the program was to investigate the effects of concrete cover and stirrups on the weak mechanism of dowel bars embedded in concrete using single block-type specimens.

Each specimen (Figure 4) consisted of a 300 x 400 x 200 mm^3 block reinforced with a longitudinal bar (dowel, d_b = 18, 24 mm) and stirrups (ϕ = 6, 8 mm) with spacing, *s*, equal to $6d_b$ and distance *b* of the first stirrup from the shear plane equal to d_b. The vertical displacement of the dowels was measured by introducing displacement transducers directly in contact with the bar with a spacing equal to 13 mm. Specimens were also provided with light steel nets lying in the mean plane of the cover in order to prevent or control longitudinal cracks due to the presence of ducts left in concrete for the placement of displacement transducers.

For the validation of the numerical model, the results of three experimental tests are considered (Table 3), being V_{max} the maximum dowel strength of the specimen when subjected to monotonic loads, and Δ_1 the corresponding dowel displacement measured on the shear plane.

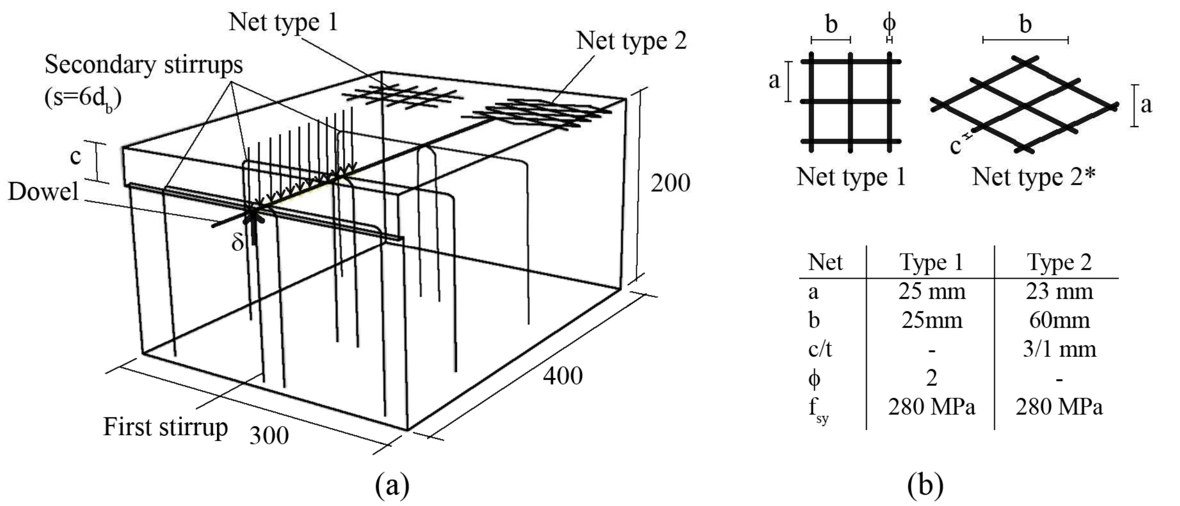

Figure 4. Reference experimental tests: a) geometry and reinforcement details, b) net details (* net type 2 used for specimen with d_b=24mm).

Table 3. Reference experimental tests: results of three D specimens (Dei Poli et al. 1988).

Specimen	$d_b / \frac{c}{d_b} / \frac{b}{d_b}$	f_{cm} [MPa]	V_{max} [kN]	Δ_1 [mm] at V_{max}
D5	18/2/1	23.5	33.49	4.21
D7*	18/1/1	23.4	27.22	5.02
D9**	24/2/1	23.7	57.68	4.82

* mid-section of the loop of the 1st stirrup reduced by 29% in order to avoid mechanical interference between the stirrup and the ducts of the transducers;

** mid-section of the loop of the 1st stirrup reduced by 24% in order to avoid mechanical interference between the stirrup and the ducts of the transducers.

Experimentally, an elasto-plastic behaviour was observed for specimens with d_b = 18mm with failure due to the yielding of both the longitudinal bar and the first stirrup, while for the case of specimens with d_b = 24mm the failure was dominated by the yielding of the first stirrup, leading an elasto-hardening behaviour.

4.1.2. Numerical results for reference tests

The geometry with constrains and the mesh are shown in Figure 5, taking specimen D5 as reference. The model features are the same described in Section 3.

In accordance with experimental tests, the mid-section of the loop of the first stirrups was reduced by 29% and 24% respectively for specimen D7 and D9.

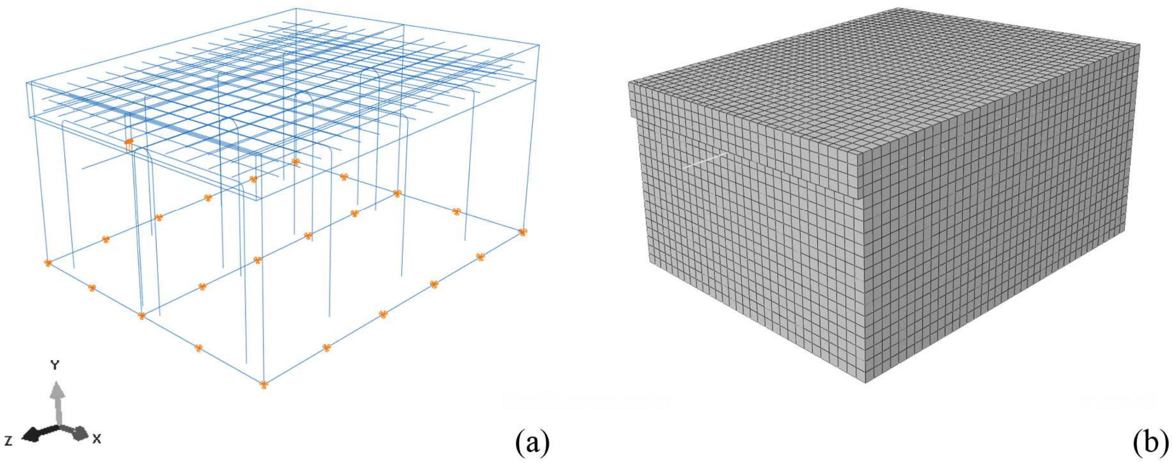

Figure 5. FE model of reference experimental tests: a) geometry with constrains, b) mesh.

In Figure 6a, the comparison between numerical and experimental curves is proposed in terms of global response (shear force vs. displacement of the loading point). A very good correlation is obtained. Looking in detail what is happening in the specimens, points representing steel yielding respectively for the first stirrup, the dowel and the second stirrup are highlighted in Figure 6b with reference to specimen D5.

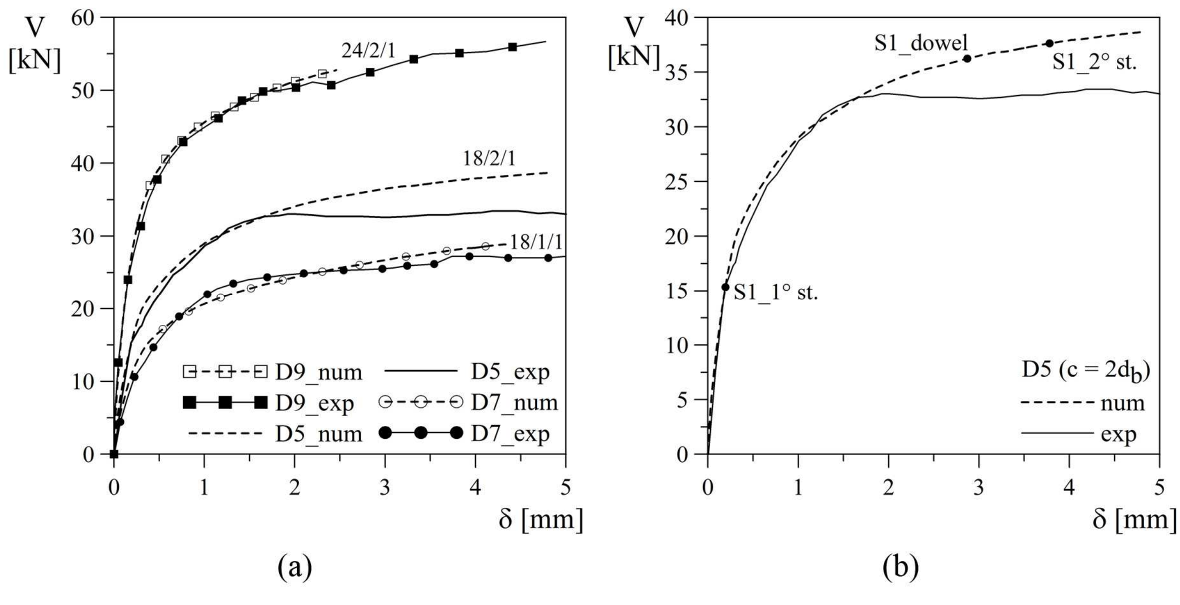

Figure 6. FE model of reference experimental tests – comparison with experimental responses: a) load vs. displacement curves for D5, D7 and D9, b) relevant points for specimen D5.

[redacted]Numerical results for triple-block test set-up

In order to validate the triple-block test set-up with respect to that of the reference tests, the numerical response of both is compared in this section. With this purpose, specimen D7 was remodel in order to take it as a reference for the validation considering its similarity to the features of the triple-block specimen (d_b = 18mm; c = d_b). In particular, the secondary stirrups were removed, and the diameter of the structural stirrups was increased from 6 to 8mm (model named "D7_modified" in Fig. 7).

The comparison is shown in Figure 7 in terms of shear force vs. displacement curves (a) and maximum principal plastic strains (b). In subfigure (a), the points at which the first stirrup and the dowel yield are highlighted. It is worth noting that the stirrup yielding occurs at the same load level in both the specimens, while the dowel yielding occurs at a load that is 8.5% higher in the case of triple-block specimen with respect to reference test.

As can be notice, there is a difference in the stiffness between the two specimens. The reason of this discrepancy could be the result of the plasticization of the concrete in the central block of the triple-block specimen, exhibiting the activation of the strong mechanism under the longitudinal bar, and the cracking in the concrete cover (for both see Figure 7b). For a fixed displacement, the triple-block specimen shows lower plastic strain in comparison with the specimen with a single concrete block.

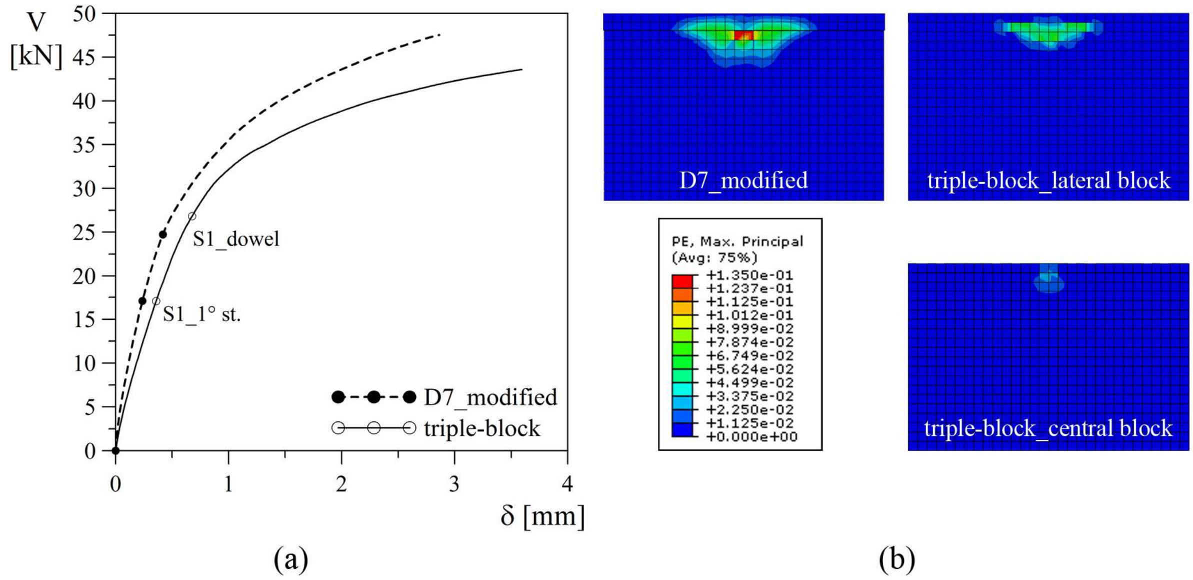

Figure 7. FE model results – comparison between triple-block specimen and reference test D7 (modified): a) shear force vs. displacement curves, b) maximum principal plastic strains in concrete at δ=2.86 mm.

Conclusions

In this paper, the numerical validation of a triple-block test set-up designed for the investigation of the dowel action in the case of cyclic load is presented. This test set-up is used in the on-going experimental campaign of the Research Project of National Interest "*Failure mechanisms due to lack of construction details and degradation phenomena in existing reinforced concrete structures*" in the part concerning the dowel action. This campaign represents the continuation of a previous wide investigation performed by Dei Poli, di Prisco and Gambarova (reference campaign). For this reason, the numerical model has been firstly validated on the basis of the experimental results of this reference tests, finding a very good correlation both in terms of global response and failure mechanisms. Then, the behaviour of the new triple-block test set-up was compared with that of the single block specimen of the reference campaign in the case of monotonic imposed displacement, in order to find eventual differences. The main difference highlighted is related to the stiffness of the global response, lower in the triple-block, mainly due to the additional plasticization of concrete in the central block.

Acknowledgements

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