MODELLING OF THE BENDING BEHAVIOUR OF DOUBLE FLOOR SYSTEMS FOR DIFFERENT CONTACT SURFACES

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ABSTRACT

In the practice of prefabricated concrete structures considerable surfaces of intermediate floors are constructed using double floor systems with prefabricated bottom layer and upper layer. This second layer is cast on site. The quality of the prefabricated concrete is often of superior class with respect to the monolithic layer. In the service state of the double floor system, important compressive stresses appear in the upper concrete layer. On the other hand, the bond quality between the concrete layers cast in successive stages raises questions especially in the case of hollow core floor units with no connecting reinforcement in-between. The paper presents results of the numerical models prepared for double floor elements having different thicknesses for the top and bottom layers, subjected to bending. Three situations have been studied: stepped top surface of the prefabricated slab with no connecting reinforcement, broom-swept tracks on the prefabricated slab with no connecting reinforcement and broom-swept tracks on the prefabricated slab with stirrups connecting the concrete layers. For each situation two different ratios of the thicknesses of the layers have been considered. The results are emphasizing the critical regions of the elements, the differences in crack development and in the behaviour resulting from surface preparation and use of connecting reinforcements.

Keywords: precast concrete slab; overtopping; concrete bond; numerical model; experiment

REZUMAT

În practica structurilor prefabricate din beton planşee intermediare de suprafață considerabilă sunt realizate din elemente de planşee prefabricate cu suprabetonare. În mod curent calitatea betonului este de clasă inferioară în suprabetonare. În exploatarea planşeelor apare compresiune importantă în suprabetonare în câmp. Pe de altă parte, apar incertitudini în calitatea aderenței dintre straturile turnate în etape diferite, în special în cazul elementelor de planşeu de tip fâşii cu goluri realizate fără conectori pentru conlucrarea straturilor de beton. Articolul prezintă rezultate ale modelării numerice realizate pentru elemente de planşeu compus având grosimi diferite ale staturilor inferioare şi superioare de beton, solicitate la încovoiere. S-au studiat trei variante: suprafață superioară cu trepte a plăcii prefabricate fără armătură de conectare, suprafață superioară măturată a plăcii prefabricate fără armătură de conectare şi suprafață superioară măturată a plăcii prefabricate cu etrieri, care leagă cele două straturi. Pentru fiecare situație au fost luate în considerare două rapoarte diferite între grosimile straturilor. Rezultatele evidențiază zonele critice ale elementelor, diferențele în evoluția apariției fisurilor şi în comportamentul elementelor cauzat de pregătirea suprafeței şi de armăturile de legătură.

Cuvinte cheie: planşee prefabricate din beton armat; suprabetonare; aderența betonului, modelare numerică; experiment.

1. INTRODUCTION

Due to the advantages of precast structures in industrial and civil construction, precast elements are starting to regain importance and volume. In the practice of the precast concrete structures, considerable surfaces of intermediate floors are made using double floor systems with prefabricated bottom layer and cast-on-site upper layer of concrete topping. Depending on the openings and intensity of the applied loads, several different solutions are used, among which hollow core floor units (Fig. 1.a) [1] and TT panels (Fig. 1.b), solid composite flooring type units using thin-slabs with stirrup type connectors (Fig. 2.a) and lattice girder type connectors (Fig. 2.b) [2] are to be mentioned.

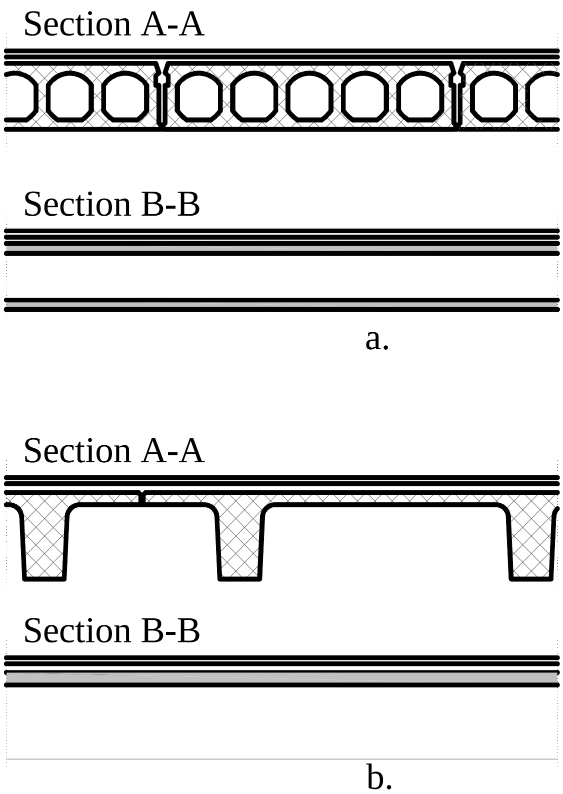

Fig. 1. Intermediate floors using hollow core floor units and TT panels [1]

The listed solutions are not exhaustive, but are still covering an increased percentage of the intermediate floors used for precast structures.

Besides their role to resist and transmit vertical loads, intermediate floors should also provide the role of horizontal diaphragm [3]. The top concrete layer cast on site is providing the continuity and spatial rigidity of the structures. Bond between layers is provided by the contact surface that separates these layers [4]…[8], as well as the connecting reinforcements, if any [9]. Since in case of hollow core floor units, reinforcing steel connectors cannot be used between the layers, all the stresses at the interface have to be transmitted only by the concrete bond.

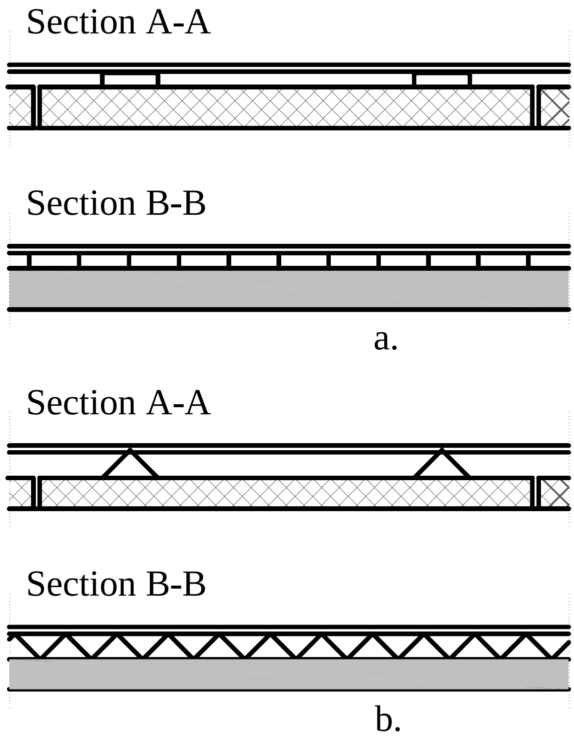

Fig. 2. Intermediate floors using stirrup and trigon type connectors [2]

The quality of the concrete used for the prefabricated slab elements is at least equivalent with the concrete used for the concrete topping. In some cases, due to the concrete quality used in prefabrication, but also due to technological conveniences (e.g. hollow core floor units), the concrete quality of the prefabricated slab elements is much higher than the ready-mixed concrete used for over-concreting (with concrete classes of up to C30/37). Usually, in service state, the vertical loads produce mainly tension stresses in the prefabricated part of the intermediate floor, while in the concrete topping important compression stresses occur around the openings. For this reason, it has been proposed to reduce the volume of on-site concrete works to the lowest possible level and to take advantage of the compression strength of the topping concrete.

The proposed research program is based on casting and testing of elements, conforming to the principle of the use of high performance concrete class for the concrete topping, followed by the development of the numerical model, calibrated using the results of the experiments.

In the numerical modelling, the types of considered elements will be extended by also considering other reinforcement layouts.

2. NUMERICAL MODELLING

2.1. Model calibration using experimental results

In order to calibrate the numerical model, two type of surface treatments were applied for two different thicknesses of the prefabricated concrete slab:

- 50 mm and 60 mm-thick precast slabs, respectively, with only broom-swept tracks on the top (modelled as smooth surfaces) (Fig. 3);
- 50 mm and 60 mm-thick precast slabs, respectively, with stepped top surfaces (Fig. 4).

Fig. 3. Precast slabs with broom-swept tracks

Fig. 4. Precast slabs with stepped top surfaces

The dimensions of the steps at the top of the precast slabs were taken according to Eurocode 2 [10] provisions. The concrete class used for the precast part was C20/25, this being produced in a concrete mixing plant.

The slab dimensions were all the same: 300 mm wide and 1500 mm long.

The longitudinal reinforcement consisted of 3Ø12 bars of S500 quality. In the transversal direction, only constructive reinforcements were used. For both 50 and 60 mm thick elements, the same reinforcing was used.

For the concrete topping, C55/65 class concrete was used. The thickness of the concrete topping has been set to 30 mm for the 50 mm-thick precast slabs and to 40 mm for the 60 mm-thick precast slabs. The resulting double floor elements have a total thickness of 80 and 100 mm, respectively, satisfying the minimum requirement of 80 mm of the seismic code [3].

The load scheme used during the testing of the double floor elements is displayed in Fig. 5.

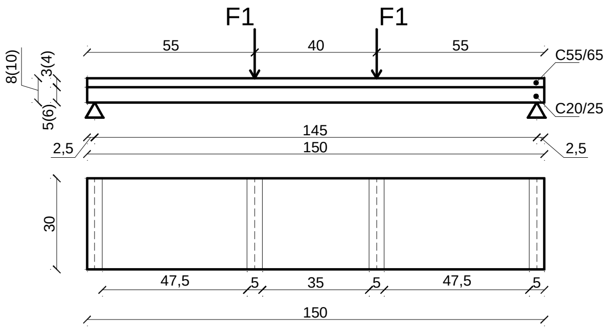

Fig. 5. Load scheme of the double floor elements during testing

The behaviour of the double floor elements subjected to the total loading P (=2×F_1) is shown in Fig. 6 (80 mm-thick double floor elements) and Fig. 7 (100 mm-thick elements).

2.2. Numerical Modelling

For the numerical modelling of the double floor elements the Atena 3D Software for analysis of concrete and reinforced concrete structures was used [11][14][15].

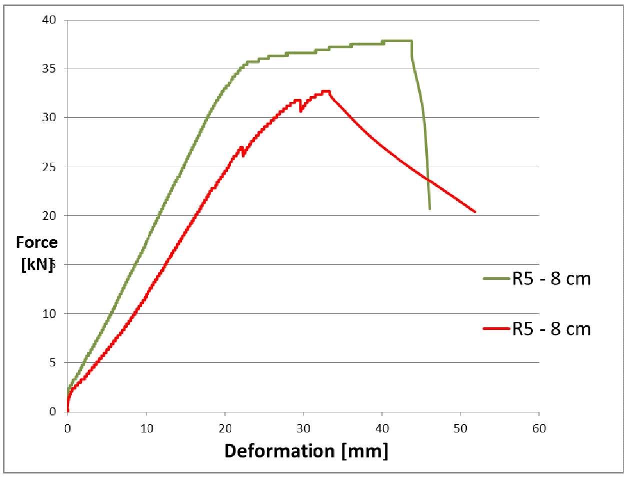

Fig. 6. P-Δ relationship for 80 mm thick double floor elements

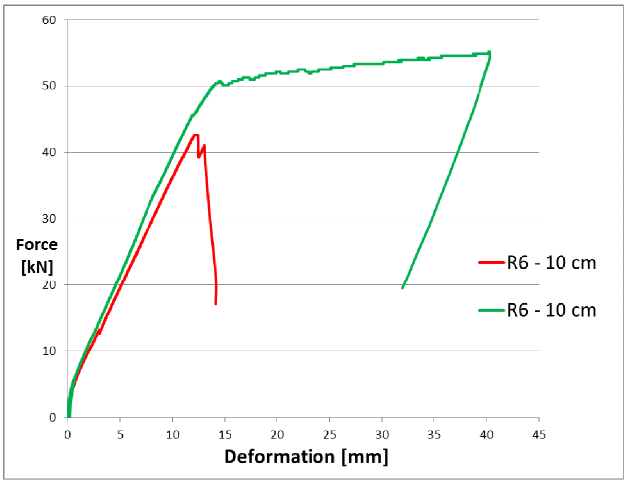

Fig. 7. P-Δ relationship for 100 mm thick double floor elements

The concrete layers of the slab elements were modelled using the SBETA material model, recommended by the Atena 3D Software documentation [11] for cementitious materials. The SBETA constitutive model used for concrete comprises 20 material parameters, calculated based on compressive tests made on cubes prelevated from the concrete that was used. The formula considered in establishing the material parameters has been derived using the CEB-FIP Model Code 90 [12] and other research sources [13]. Longitudinal and transversal reinforcements were introduced as discrete bars, modelled by truss elements. For the load behaviour of reinforcement, a bilinear law was considered. Perfect bond between concrete and reinforcement was assumed. The numerical model used for the double floor elements is presented in Fig. 8.

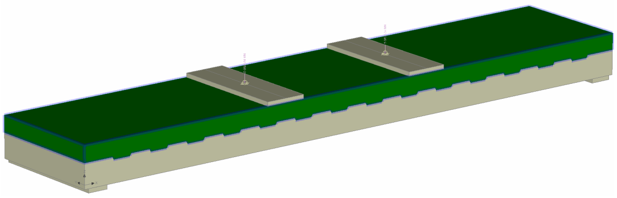

Fig. 8. Numerical model used for double floor elements

The failure surface for interface elements was modelled according to [11] (Fig. 9). The tensile strength was taken f_t = 0.65 MPa, the friction coefficient – equal to 0.3 and the cohesion was taken C = 1.3 MPa [8][9].

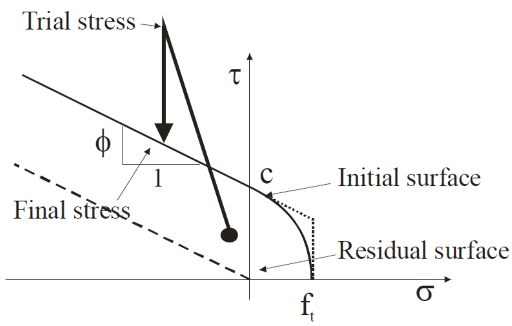

Fig. 9. Modelling of failure surface for interface elements [6]

The modelling was performed for four different situations, for both thicknesses of the double floor elements (80 and 100 mm). The material qualities, dimensions, reinforcement layout and load schemes were considered as used in/during the experiment.

2.2.1. Elements with no connecting reinforcement, with stepped surfaces

For both total thicknesses of the double floor elements, 80 and 100 mm, the P-Δ relationship is shown in Fig. 10. The displacement at the maximum crack opening occurrence (0.2 mm) is 14.68 mm in case of 80 mm-thick elements and 10.18 mm in case of 100 mm-thick elements, while at the maximum crack opening of 0.35 mm the maximum displacements are 17.81 mm and 13.11 mm, respectively (Table 1).

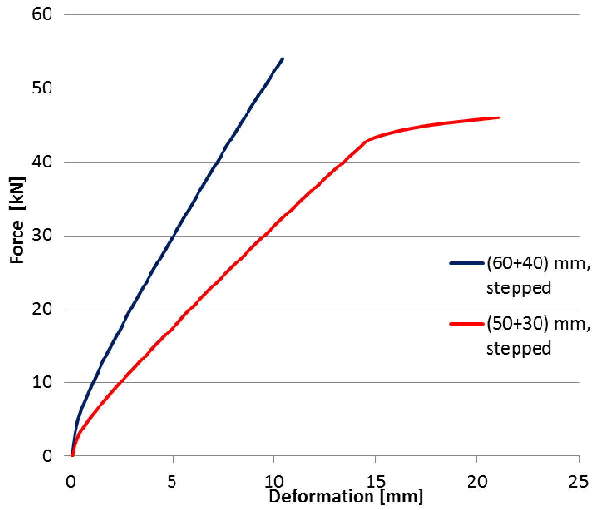

Fig. 10. P-Δ relationship for elements with stepped contact surfaces

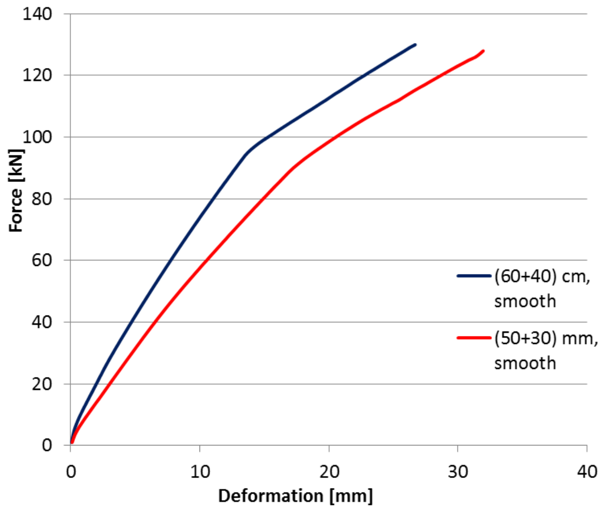

Fig. 12. P-Δ relationship for elements with smooth contact surfaces

The crack pattern at the moment when the maximum crack of 0.2 mm occurs is shown in Fig. 11.

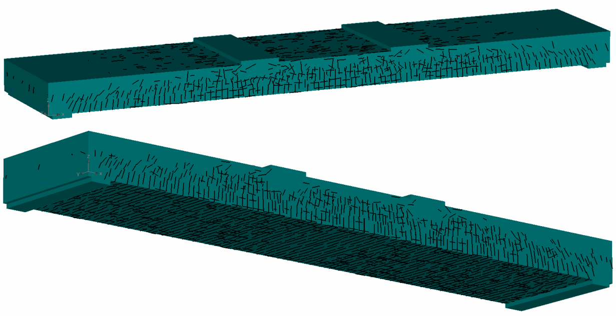

Fig. 11. Crack pattern corresponding to w_{max}=0.2 mm (80 and 100 mm-thick double floor elements)

2.2.2. Elements with no connecting reinforcement, with smooth contact surfaces

Using the same contact conditions and for a smooth upper surface of the precast slab, the P-Δ relationship presented in Fig. 12 were obtained for the 80 and 100 mm-thick elements. The displacements corresponding to the maximum crack openings of 0.2 mm and 0.35 mm are 15.82 mm and 17.53 mm (80 mm), 12.60 mm and 17.50 mm (100 mm), respectively (Table 1).

The crack development for the elements with no connecting reinforcement and smooth contact surfaces at the occurrence of the maximum crack of 0.2mm is shown in Fig. 13.

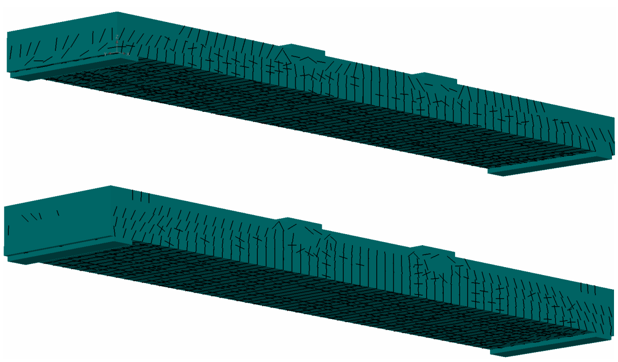

Fig. 13. Crack pattern corresponding to w_{max}=0.2 mm (80 and 100 mm-thick double floor elements)

2.2.3. Elements with Ø6 stirrups and smooth contact surfaces

To the previously studied elements 6 mm diameter stirrups were added, for connecting the layers. The resulting P-Δ relationship is shown in Fig. 14.

The displacements at the occurrence of the maximum crack of 0.2 mm are 16.73 mm and 10.67 mm for the 80 and 100 mm-thick elements, increasing to 22.73 mm and 16.82 mm, respectively, when the maximum crack opening of 0.35 mm occurs.

The crack pattern for the elements with Ø6 stirrups of and smooth contact surfaces for the maximum crack of 0.2 mm occurrence is shown in Fig. 15.

Table 1. *Maximum displacements for w_{max}=of 0.2 mm and w_{max}=of 0.35 mm*

Element / Displacement	w_{max}=of 0.2 mm		w_{max}=of 0.35 mm	
	δ [mm]	δ/L	δ [mm]	δ/L
80 mm smooth	15.82	1/91.66	17.53	1/82.72
80 mm smooth Ø6	16.73	1/86.67	22.73	1/63.79
80 mm smooth Ø8	16.72	1/86.72	22.72	1/63.82
80 mm stepped	14.68	1/98.77	17.81	1/81.41
100 mm smooth	12.60	1/115.08	17.50	1/82.86
100 mm smooth Ø6	10.67	1/135.90	16.82	1/86.21
100 mm smooth Ø8	10.64	1/136.28	16.79	1/86.36
100 mm stepped	10.18	1/142.44	13.11	1/110.60

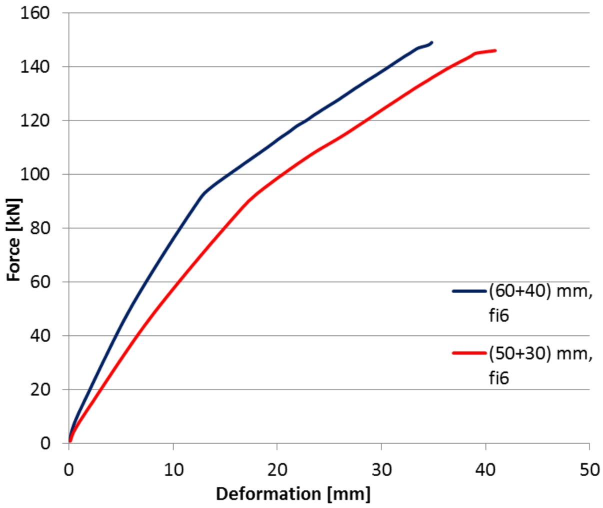

Fig. 14. P-Δ relationship for elements with smooth contact surfaces and Ø6 stirrups

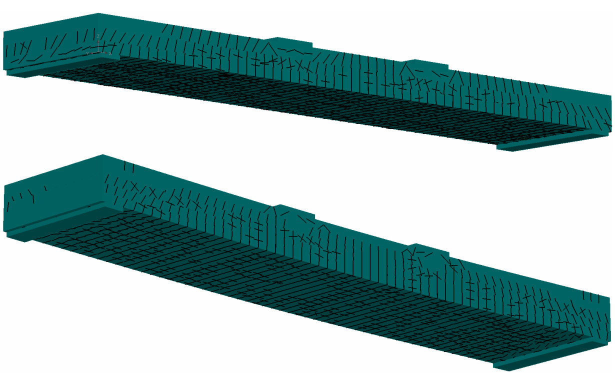

Fig. 15. Crack pattern corresponding to w_{max}=0.2 mm (80 and 100 mm-thick double floor elements)

2.2.4. Elements with stirrups of Ø8 and smooth contact surfaces

The stirrup diameter has been increased to 8 mm in the previously modelled elements.

The resulting P-Δ relationships are shown in Fig. 16.

The displacements obtained for this situation are showing a slightly decreased value, as compared to the previous situation: when the maximum crack of 0.2 mm occurs, the values are 16.72 mm and 10.64 mm for the 80 and 100 mm-thick elements, increasing then to 22.72 mm and 16.79 mm, respectively, when the maximum crack opening of 0.35 mm occurs.

The crack pattern on the elements with Ø8 stirrups and with smooth contact surfaces for the occurrence of the maximum crack of 0.2 mm is shown in Fig. 17.

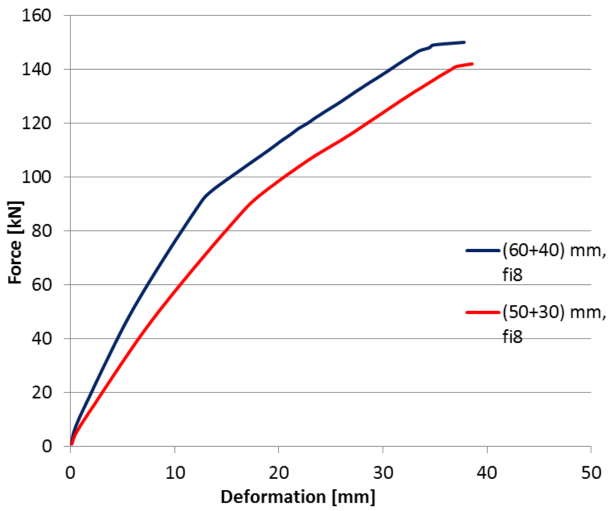

Fig. 16. P-Δ relationship for elements with smooth contact surfaces and Ø8 stirrups

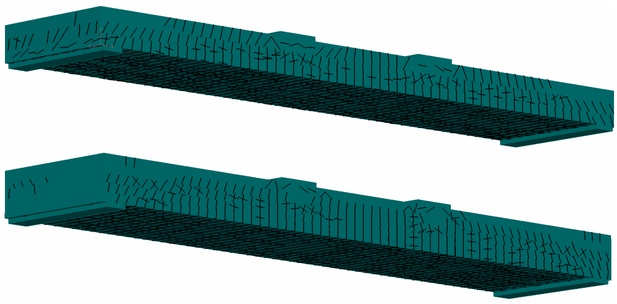

Fig. 17. Crack appearance corresponding to w_{max}=0.2 mm (80 and 100 mm double floor elements)

3. RESULTS. CONCLUSIONS.

A comparison of the P-Δ relationships obtained for similar element thicknesses is shown in Figures 18 and 19.

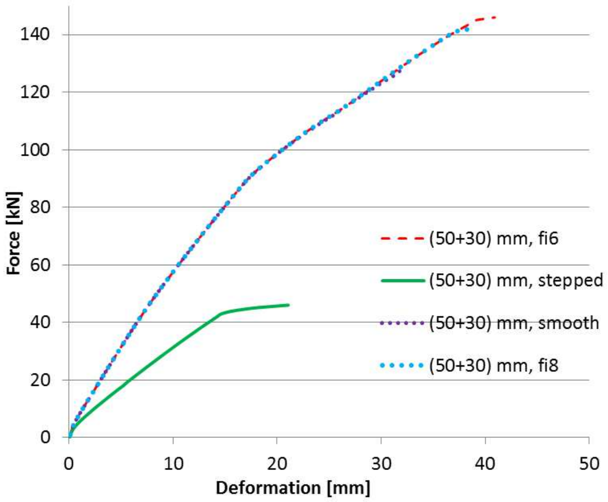

Fig. 18. P-Δ relationships for 80 mm-thick elements

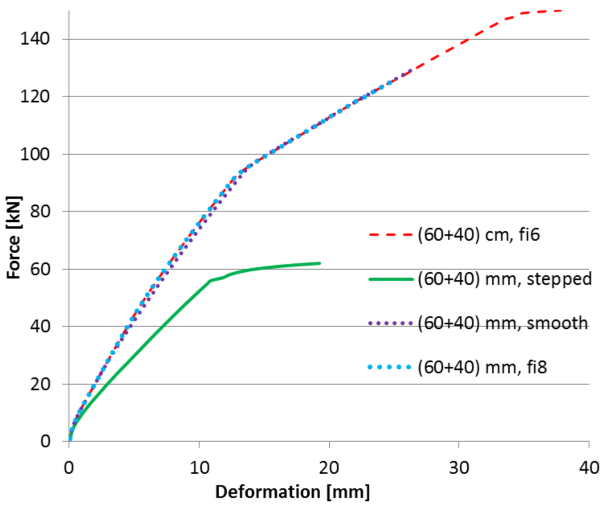

Fig. 19. P-Δ relationships for 100 mm-thick elements

By comparing results, the most important difference to be remarked is the relatively low capacity of the elements with stepped contact surfaces with respect those with smooth surfaces. In the case of the 80 mm-thick double floor elements, the difference is more than 40%, while in case of the 100 mm-thick double floor elements the difference is more than 30%. Even though the same contact conditions were applied and the concrete bond quality was considered according to the calibrated model (Fig. 20), the obtained results were considered unsatisfactory. The necessity of performing appropriate experiments for smooth contact surfaces, in order to calibrate the model, became obvious.

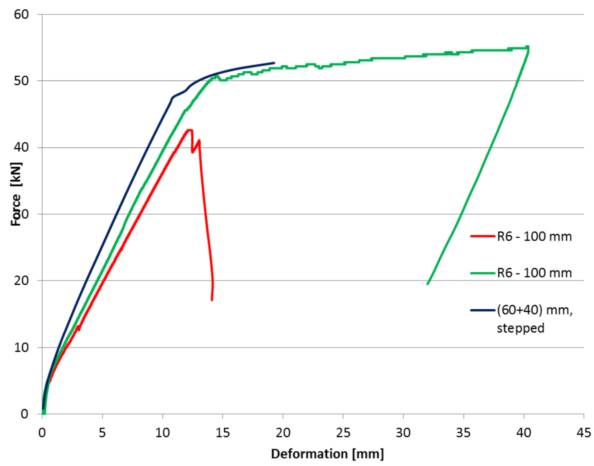

Fig. 20. P-Δ relationships overlapped for model calibration

In practice, when casting the top concrete layer on the 50 and 60 mm-thick precast slabs with broom-swept tracks, the loss of concrete bond between the layers was remarked. This phenomenon highlights the necessity of the treatment of the high performance concrete top layer or of a significant quantity of connecting reinforcements, in order to avoid the loss of the bond between the layers. In the case of stepped surfaces prepared with the presented geometry, the quality of the concrete bond can be considered as appropriate even without connecting reinforcements; however, it implies a high amount of labour or high cost formworks for preparing the stepped prefabricated surfaces.

Based on the experience in the preparation of test specimens, the authors recommend the use of connectors between the layers even in low seismicity areas.

The comparison of the situations when smooth connecting surfaces and when stirrups with different diameters were used showed only a slight difference between the elements with stirrups of different diameters, but both the 0.2 mm and the 0.35 mm maximum crack appear for elements with no stirrups. In the case of the 80 mm-thick elements, the 0.2 mm maximum crack appears at a 4.5% lower load value than in the case of elements with stirrups, while the 0.35 mm maximum crack appears at a 14.2% lower load value. In the case of the 100 mm-thick elements, the load decrease is 1.9% for the 0.2 mm crack and 11.3% for the 0.35 mm crack.

The behaviour of the elements with stirrups corresponds to the expectations. Due to the fact that compression stresses persist in the thickness of the top concrete layer as long as the bond between layers exists, the load capacity of the elements depends on the tensioned reinforcement and on the characteristics of the top concrete layer.

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