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Experimental tests of some composite steel-concrete, wood-concrete and concrete-concrete elements

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SUMMARY

The paper presents the results of experimental tests of some composite steel-concrete, wood-concrete and concrete-concrete elements. Deflections at midspan under monotonically increasing static load were measured. The influence of different composite making means on the results was researched. The emphasis was given to efficiency of different composites with Omnia-slabs that are commonly used in practice.

Key words: *experiment, composite element, steel-concrete, wood-concrete, concrete-concrete, static load, deflection.*

1. INTRODUCTION

For testing purposes of a numerical model for simulation of composite structures exposed to short-term static loads, which will be presented in some of the next issues of this magazine, experimental tests of several composite elements made of different materials and with different composite making methods [1] were carried out. Description of carried out experiments and an overview of the results are presented in this paper. Behaviour of composite girders exposed to monotonously increasing static load to fracture was observed. Load was applied by hydraulic press at midspan. Load-bearing system of all tested elements was a simple beam. Deflections at midspan were measured. Relationship between the load (force) P and measured deflection δ is shown on P-δ diagram for all elements. Obtained diagrams show effects of different composite making methods. It is followed by and overview of carried out experimental tests per separate composite types (steel-concrete, wood-concrete and concrete-concrete). Three equal elements were made and tested for each composite type and composite making mean. As decisive, average value of measured data for all three elements was presented.

2. STEEL AND CONCRETE COMPOSITES

Geometry of tested composite girder is shown in Figure 1. Composite girder is made of rolled steel section IPE 100 and reinforced concrete slab. Girder length is *300 cm*, while total height of a composite cross-section is *16 cm*.

Steel girder IPE 100 is *10 cm* high with *5.5 cm* wide flange, made of steel St 240/360.

Reinforced concrete slab is *45 cm* wide and *6 cm* high. It is made of MB 30 concrete [2] with the aggregate grains $\leq$ *16 mm* because of small slab thickness. Concreting was carried out on vibrating table, with usual curing. The following concrete properties were determined experimentally on the day of testing [2]: compressive strength *31.5 MPa*, tensile strength *2.40 MPa* and modulus of elasticity *3.00 GPa*.

Slab was reinforced at mid-height by welded wire-fabric reinforcement Q-196 (*ϕ6.0/10 cm* in both directions). Wire-fabric reinforcement quality was MA 500/560 [2]. Experimentally determined tensile strength was *650 MPa*.

Steel girder and concrete slab were made composite by dowels shown in Figure 1c. Dowels are made of smooth reinforcement *ϕ8 mm* in diameter and steel quality St 500/560. They are *4 cm* wide and *5 cm* high, welded to the top flange of steel girder in the length of *5 cm*. They are placed at *10 cm* axial distance along the composite girder length. Selected dowel type pertains to the so-called slender dowels.

Supports and loads of a composite girder are shown in Figure 2. Girder span is *2.8 m*. It is supported by steel roller bearings of *30 mm* diameter. Force is applied via stiff steel I section for purposes of uniform force distribution along concrete slab width.

Relationship between applied force P and measured deflection δ is shown in Figure 3. Linear behaviour of composite girder to about 75% of ultimate bearing capacity can be observed, after which there is non-linear behaviour due to dowel yielding. The loss of bearing capacity of composite girder is a consequence of concrete slab fracture around midspan.

For an illustration of the effect of beam and slab composite, the same figure shows *P-δ* relationship for (non-composite) steel section IPE 100. Girder behaviour has not been monitored to the moment of fracture, but to the occurrence of large deflections (*40 mm≈L/70*).

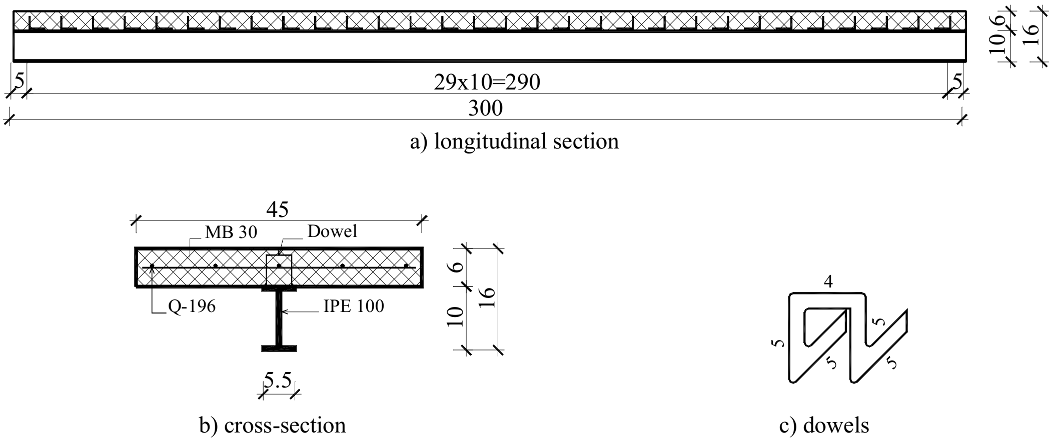


Fig. 1 Geometry of composite steel-concrete girder (dimensions in cm)

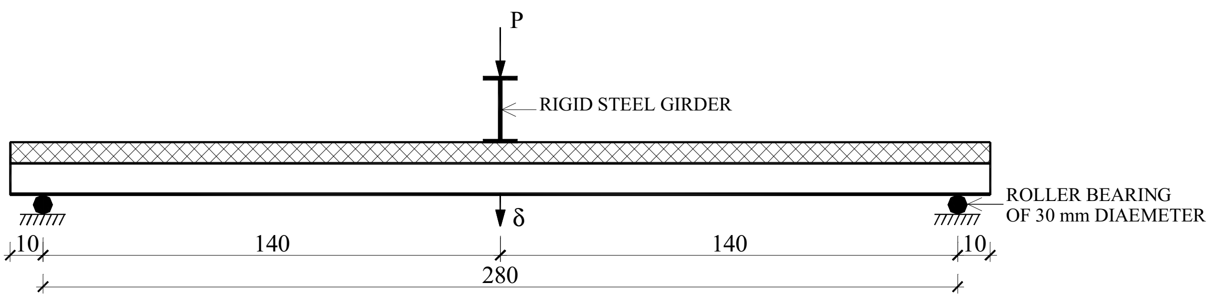


Fig. 2 Scheme of supports and loads of composite girder

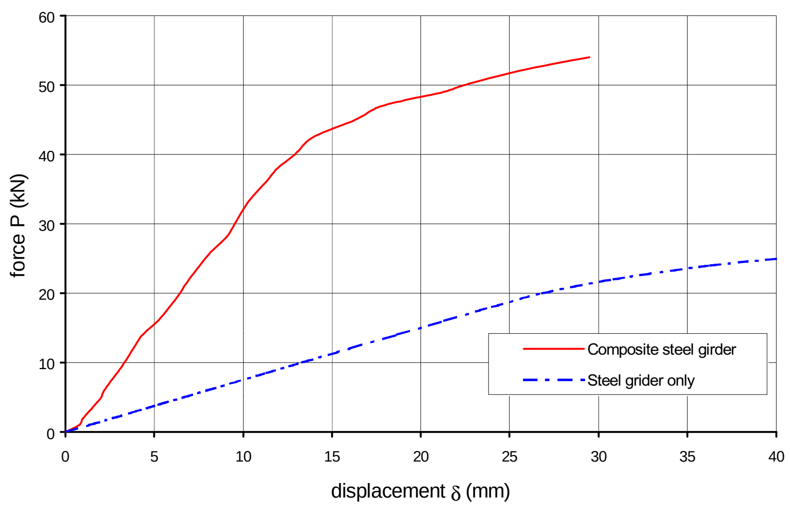


Fig. 3 Girder deflection at midspan

3. WOOD AND CONCRETE COMPOSITE

Geometry of tested wood-concrete composite girders is shown in Figure 4. Composite girders were made of wooden beam and reinforced concrete slab. Girder length is *300 cm*, while total height of a composite cross-section is *16 cm*.

Wooden beam of square cross-section *10/10 cm* is made of coniferous lumber of Class II. The following wood properties were determined experimentally on the day of testing [3]: modulus of elasticity in direction of wood fibers *7.0 GPa*, axial tension strength *31.5 MPa* and axial compression strength *31.5 MPa*. It shall be mentioned that there were many natural anomalies in the wooden beam structure (knots, fiber deviation etc.) along the length as well as per cross-section height.

Reinforced concrete slab is *50 cm* wide and *6 cm* high. It is made of MB 30 concrete [2] with the aggregate grains *≤ 16 mm*. Concreting was carried out on vibrating table. The following concrete properties were determined experimentally on the day of testing: compressive strength, tensile strength and modulus of elasticity (Table 1). Slab was reinforced at mid-height by welded wire-fabric reinforcement Q-196 (ϕ *6.0/10 cm* in both directions) of MA 500/560 quality [2]. Experimentally determined fracture strength was *650 MPa*.

Table 1 Tested concrete properties [2]

Girder type	Compressive strength [MPa]	Tensile strength [MPa]	Modulus of elasticity [GPa]
N1	31.5	2.40	30.0
N2	32.4	2.41	30.5
N3	31.5	2.40	30.0

Three different wood-concrete composite types were analyzed (see Figure 5). Dowels were used for girder *N1* while girders *N2* and *N3* were made composite by gluing. Detail description of composite making method is given hereinafter.

Girder N1 - composite by dowels

For this type of girder, composite was made by steel dowels. Dowels are made of smooth reinforcement of *8 mm* diameter and St 500/560 quality. They are *6 cm* wide and *12 cm* high. At the bottom, dowels are pointed for better penetration into lumber. Before dowel placement, holes of *7 mm* diameter were drilled through wooden beam and filled with epoxy glue for better connection between the dowel and lumber. Dowels are placed at *10 cm* axial distance along the composite girder length.

Girder N2 - composite by epoxy glue and "dry gluing"

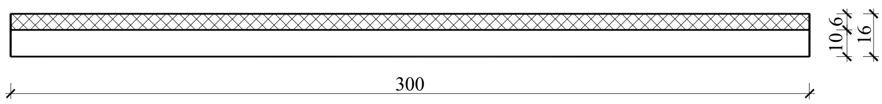
Wooden beam and concrete slab were made composite by two-component epoxy glue NOVOPOX UV, manufactured by Nova-chem, Karlovac. Ratio of component mixing was A:B=9:5 (volume). For this type of girder, reinforced concrete slab has already been concreted. At concrete age of 21 days, beam and slab were glued by "dry gluing". Beam and slab contact surfaces were well cleaned. Glued contact withstood compression for 48 hours.

Girder N3 - composite by epoxy glue and "wet gluing"

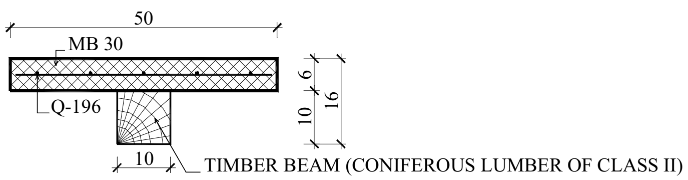
Wooden beam and concrete slab were made composite by the same epoxy glue as for girder *N2*, but by the "wet gluing". Namely, glue film was applied on the top chord of wooden beam immediately before slab concreting. Then, fabric reinforcement was placed and concreting was carried out on vibrating table.

Load-bearing system and load transfer from the press to the girder are the same as for steel-concrete composite girder (see Figure 6). Steel washer of *100/100/8 mm* size was added between roller bearing and wooden beam to prevent local pressing of roller bearing into the wood.

Relationship between force and displacement at midspan for all three composite girder types is shown in Figure 7. As can be observed, behaviour of girders *N2* and *N3* is very similar, although deflections are somewhat smaller and fracture force is somewhat greater for girder *N2*. Sliding of joint plane has not been observed while fracture occurred through tensile zone of wooden beam. Deflections were greater and fracture force smaller for girder *N1*, which points to smaller efficiency of dowels in comparison with composite by gluing.



a) longitudinal section



b) cross-section

Fig. 4 Basic geometry of wood-concrete composite girder (dimensions in cm)

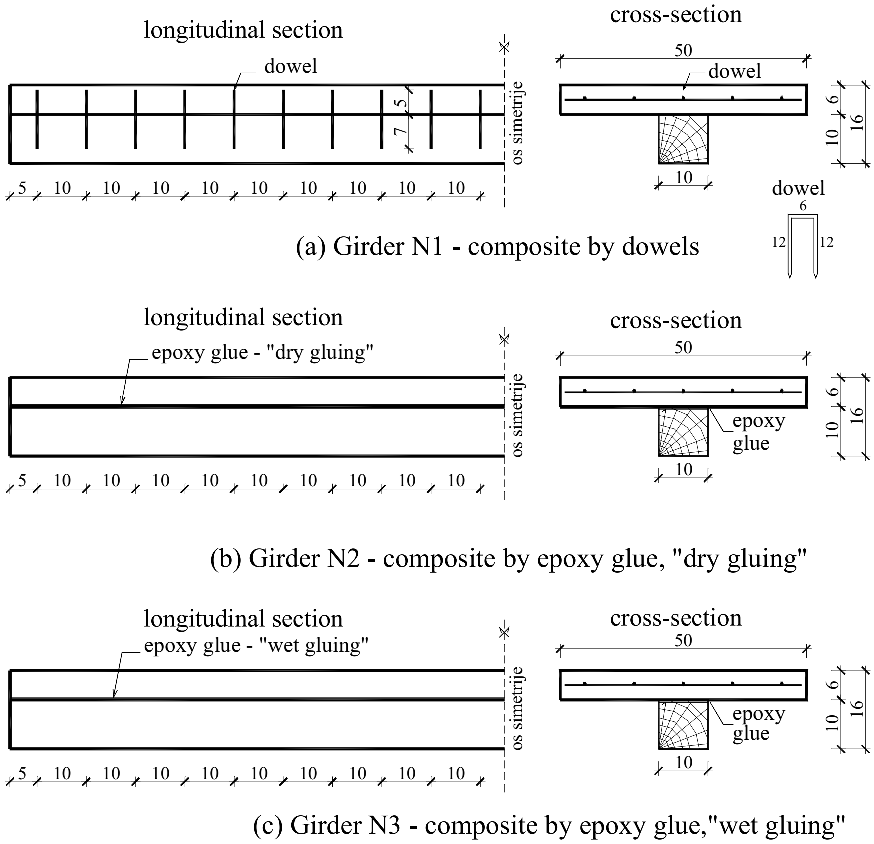


Fig. 5 Wooden beam and reinforcement slab composites (dimensions in cm)

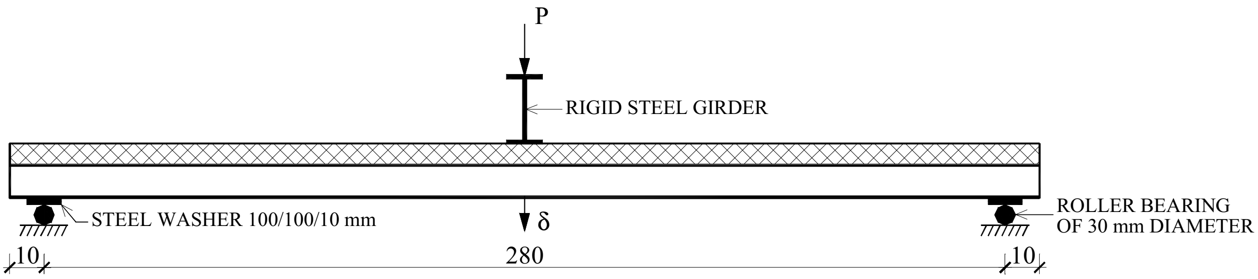


Fig. 6 Scheme of supports and loads of composite girder

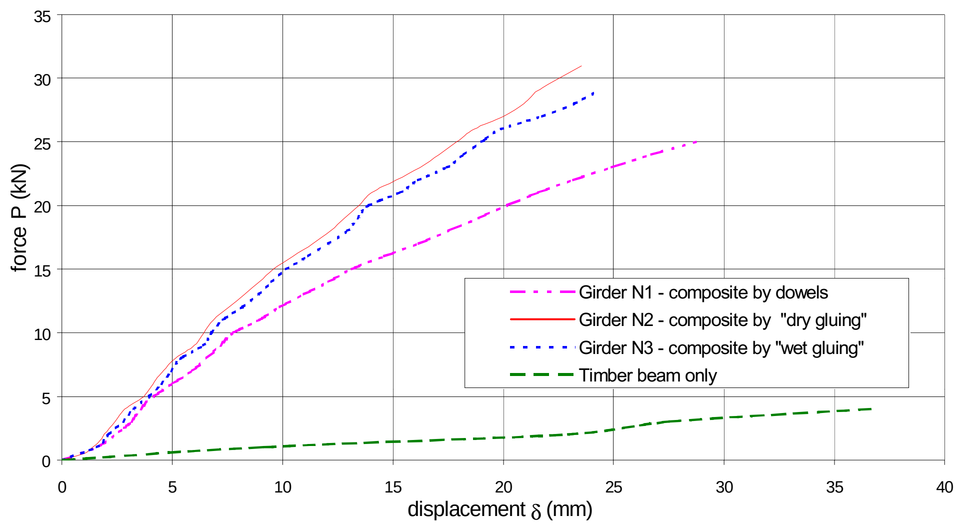


Fig. 7 Deflection at girder midspan

Relationship *P*-*δ* was also shown for (non-composite) wooden beam. There is a drastically greater deformability and far smaller bearing capacity of wooden beam than for composite girder.

4. CONCRETE-CONCRETE COMPOSITES

Concrete-concrete composites were tested on reinforced concrete Omnia-slabs of *150 cm* length, *100 cm* width and *10 cm* total height. Slabs were concreted on vibrating table. Because of small thickness of composite elements, concrete aggregate with grains ≤ 16 *mm* was used. Slabs were reinforced in top and bottom zone by welded wire-fabric reinforcement MA 500/560 of Q-196 type (ϕ *6.0/10 cm* in both directions). Reinforcement protective concrete cover in both zones was *1 cm*.

Several different composite slab types were tested (see Figure 8) in order to observe their efficiency. Slab *P1* is monolithic of *10 cm* height. Other slabs are composite ones i.e. concreted in two phases. Bottom slab of *4 cm* height was concreted in phase I while *6 cm* high top slab was concreted after 21 days (phase II). Detail description of different composite slab types is given hereinafter.

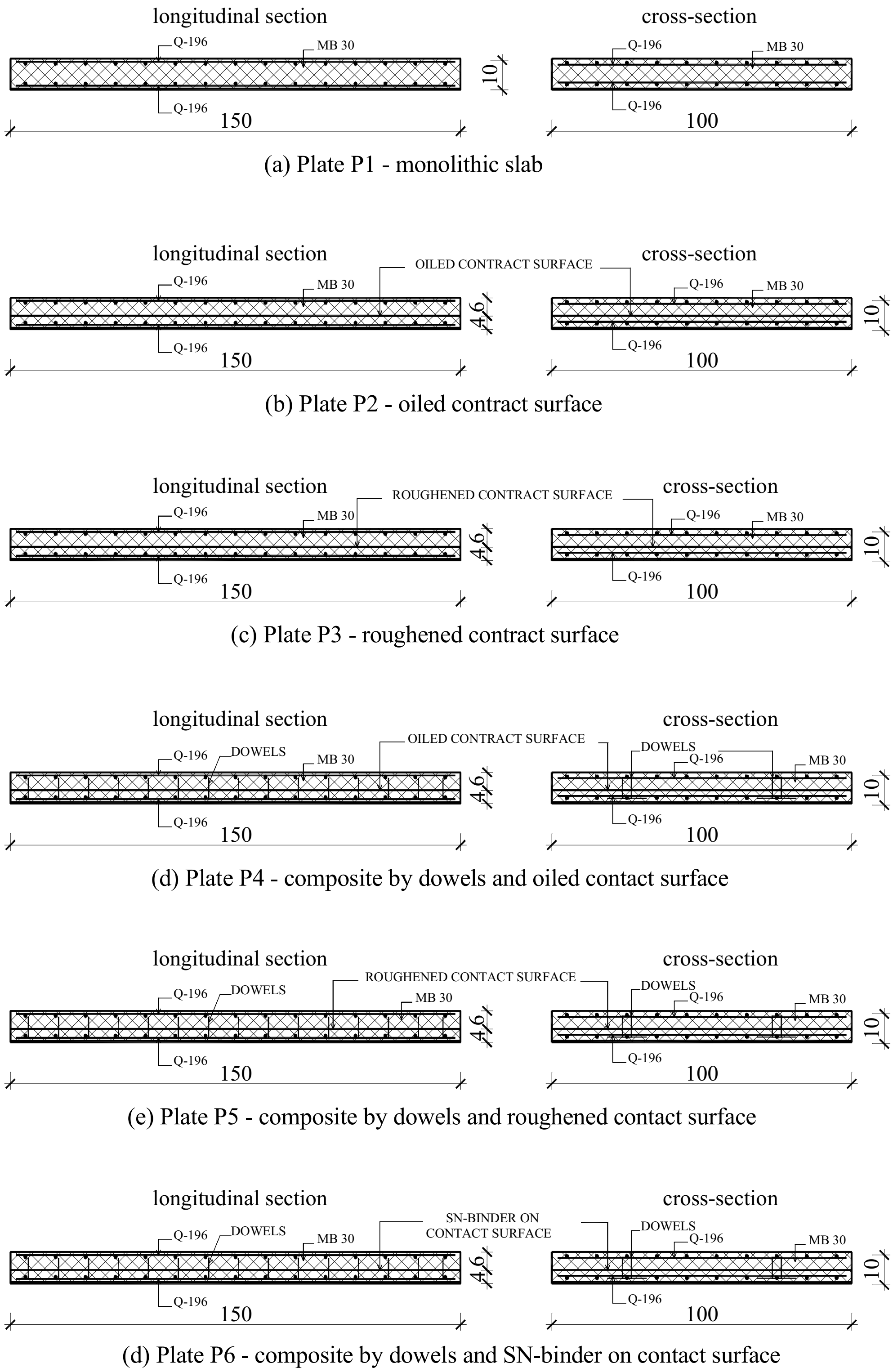


Fig. 8 Types of tested composite slabs (dimensions in cm)

Slab P1 - monolithic slab

Slab P1 is a conventional monolithic reinforced concrete slab, concreted in full height of *10 cm*.

Slab P2 - oiled contact surface

Before concreting of the top slab, top surface of a bottom slab was oiled with OPLATAN, formwork oil. The purpose was to diminish slab composite effect.

Slab P3 - roughened contact surface

Top surface of bottom slab of phase I was well roughened to provide for better connection with the top slab of phase II.

Dowels were used for slabs *P4*, *P5* and *P6* (Figure 9). Dowels are made of smooth reinforcement of *5 mm* diameter and St 500/560 quality. They are placed in bottom slabs in phase I, at *10 cm* axial distance along the slab length. There are two rows of dowels within the cross-section, at *50 cm* axial distance.

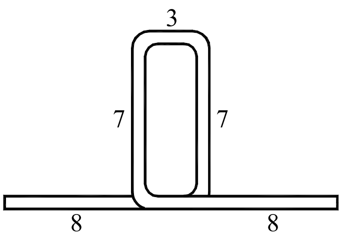


Fig. 9 Dowels for composite Omnia-slabs

Slab P4 - composite by dowels, oiled contact surface

Composite was made with dowels. Top surface of bottom slab (phase I) was oiled with OPLATAN.

Slab P5 - composite by dowels, roughened contact surface

Composite was made with dowels. Top surface of bottom slab was roughened as for slab *P3*.

Slab P6 - composite by dowels, contact surface coated with SN binder

Composite was made with dowels in combination with SN binder film on top surface of bottom slab. One-component acrylic binder NOVACRYL UV, manufactured by NOVA-chem Karlovac, was used.

The following concrete properties were determined experimentally on the day of testing [2]: compressive strength, tensile strength and modulus of elasticity (Table 2).

Quality of used fabric reinforcement was also experimentally determined. Obtained reinforcement failure limit was above the rated one, being 650 MPa.

Table 2 Tested concrete properties

Concreting phase	*Compressive strength (MPa)*	*Tensile strength (MPa)*	*Modulus of elasticity (GPa)*
Phase I	*32.4*	*2.41*	*30.5*
Phase II	*31.5*	*2.40*	*30.0*

Slab supports and loads are shown in Figure 10. Slabs are in the form of simple girder with the span *1.30 m*. They are supported by steel roller bearings of *30 mm* diameter. Force is transferred from the press to the slab via rigid steel I section (for a uniform load distribution per slab width). Relationship between force and displacement for all slab types is shown in Figure 11.

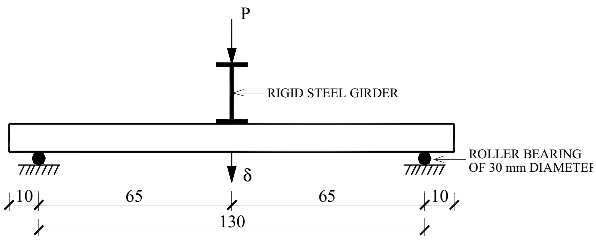


Fig. 10 Scheme of supports and loads of Omnia-slab

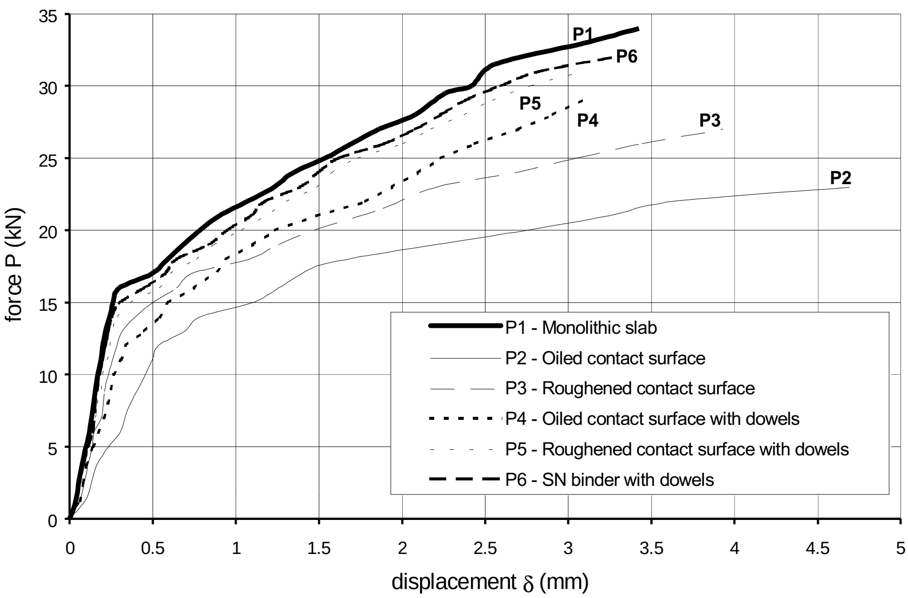


Fig. 11 Deflection at slab midspan

As can be observed, the best results were obtained for monolithic slab *P1*, while the worst ones were for slab *P2*. With an exception of oiled slab *P2*, all slabs have similar deformability at small loads. Linearity limit is the lowest for slab *P4*, and the highest for monolithic slab *P1*. Linearity limit for slabs *P3*, *P5* and P6 is between those two values. After occurrence of the first cracks, monolithic slabs showed the best behaviour. Composite slabs *P5* and *P6*, showed close results. For smaller loads, slab *P3* shows better results than slab P4. However, that relation changes with the load increase. Obviously, behaviour of composite slabs strongly depends on composite making method, which is particularly pronounced in post-elastic zone (after occurrence of the first cracks and begging of composite joint sliding). Slab *P2* showed unexpectedly good results, which proves that roughness of contact surface greatly affects the composite degree.

5. CONCLUSIONS

Based on carried out experimental tests of composite elements of steel-concrete, wood-concrete and concrete-concrete systems, the following can be concluded:

- Soft (elastic) dowels for composites made of steel beam and compressive concrete slab are efficient and provide high degree of composite cross-section of steel-concrete system.
- Wooden beam and compressive concrete slab composite made by gluing are more efficient than composites with conventional dowels.
- Wooden beam and compressive concrete slab composites made by "dry" gluing and "wet" gluing show similar results. "Dry" gluing was somewhat more efficient (see Ref. [4]).
- Composite level between prefabricated concrete Omnia-slabs and monolithic concrete above them, i.e. deflections of composite slabs, strongly depend on composite type.
- For composites made of prefabricated concrete Omnia-slabs and monolithic concrete above them by adequately shaped dowels, and normally rough top surface of Omnia-slab coated with SN binder, very high composite level is obtained. Namely, behaviour of such composite element is very close to that of a monolithic slab of the same thickness. Extremely favorable results are also obtained for similar composite making without SN-binder, which is commonly used in practice.
- Even when dowels have not been used at contact surface, there is relatively high composite level between Omnia-slab and monolithic concrete by adhesion and friction only.

6. REFERENCES

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EKSPERIMENTALNA ISPITIVANJA NEKIH SPREGNUTIH ELEMENATA SUSTAVA ČELIK-BETON, DRVO-BETON I BETON-BETON

SAŽETAK

U radu su prikazani rezultati eksperimentalnih ispitivanja nekih spregnutih elemenata sustava čelik-beton, drvo-beton i beton-beton. Mjereni su progibi u sredini raspona nosača pod monotono rastućim statičkim opterećenjem. Istražen je utjecaj pojedinih tipova sredstava za sprezanje na dobivene rezultate. Naglasak je stavljen na utvrđivanje učinaka različitih načina sprezanja omnia ploča koje se često koriste u praksi.

Ključne riječi: *eksperiment, spregnuti element, čelik-beton, drvo-beton, beton-beton, statičko opterećenje, progib.*