SEZIONI COMPOSTE ACCIAIO-CALCESTRUZZO INNOVATIVE CON CONNETTORI A TAGLIO COMPOSTI: CRITERI PROGETTUALI PER TRAVI DI SOLAIO IN EDIFICI MULTIPIANO

INNOVATIVE STEEL-CONCRETE COMPOSITE SECTIONS WITH COMPOSITE DOWELS: OPTIMAL DESIGN FOR FLOOR BEAMS IN MULTI-STOREY BUILDINGS

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ABSTRACT

New composite steel-concrete connection systems, known as "composite-dowels", have undergone significant development in recent years, offering new possibilities for design solutions in the field of composite structures. The scope of their use is to optimize the composite cross-section. Their application is possible for infrastructural works, but in recent years their use is extending to the field of multi-storey buildings.
The main objective of this research work is to analyze the potential for multi-storey buildings, identifying the most optimized configurations according with the latest research available results for two innovative types of flooring systems. The performance capability of these solutions is investigated by means of parametric analysis campaigns for two innovative structural solutions in the field of buildings flooring. Results show the high performance of the studied solutions in particular with highly slender structural element and very low steel consumption.

SOMMARIO

Nuovi sistemi di connessione composta acciaio-calcestruzzo, in inglese noti come “composite-dowels”, hanno avuto negli ultimi anni uno sviluppo importante aprendo nuove possibilità per soluzioni nell’ambito delle strutture composte. L’obiettivo del loro utilizzo è ottimizzare la sezione trasversale composta. La loro applicazione è possibile per opere infrastrutturali, ma negli ultimi anni il loro impiego si sta estendendo al campo degli edifici multipiano.

Il presente lavoro di ricerca ha come principale obiettivo l'analisi del potenziale applicativo nel caso di edifici multipiano, identificando le configurazioni più ottimizzate alla luce degli ultimi risultati di ricerca disponibil. La capacità prestazionale di queste soluzioni viene riscontrata attraverso analisi parametriche per due innovative soluzioni strutturali nell'ambito di impalcati di edifici. I risultati dimostrano l'alta prestazione delle due soluzioni studiate, in particolare per ciò che concerne la snellezza dell'elemento strutturale e la ridotta quantità di acciaio strutturale impiegata.

1 INTRODUCTION

Composite-dowels shear connection solutions offer new possibilities for the design of composite beams. This technology is an alternative to the more traditional headed-studs connection. The scope of their use is to optimise the composite cross-section. In common configurations the connection is obtained from hot-rolled double-T profiles. The single-T profiles are obtained by means of a thermal cutting process (Fig. 1). The path of the cutting determines the shape of the composite dowel. The result is a T-shaped steel profile connected by means of the composite dowels shear connection to an upper collaborating reinforced concrete part (Fig. 1). The exchange of contact forces between the steel dowel and the complementary concrete dowel guarantees the shear transfer in the web of the element and the achievement of the composite action. A general review of the topic is given in [1, 2].

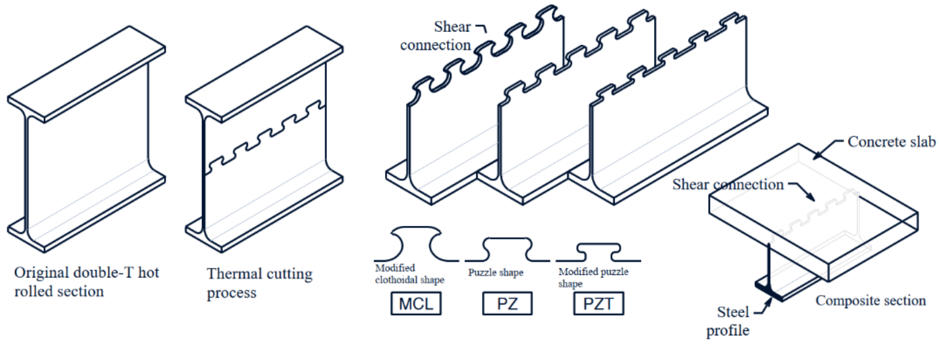

Fig. 1. Composite dowels shear connection concept with hot-rolled sections.

Composite dowels solutions have undergone significant development in the recent years, and currently a technical specification document is under development [3]. The first major realisation in bridge engineering using an open cut composite dowel dates back to 2003 and there are more than 40 realisations to date. So far, the application field involves mostly bridge constructions [4]. In recent years their use has extended to the field of multi-storey buildings. An example of application in buildings is the realization of the Wiesbaden Carpark in Germany [5]. In the present article the parametric study to determine the optimal design solutions of two flooring technologies (Fig. 2) using composite dowels as shear connection is presented. The design is done with products and design standard according to the European normative framework.

1.1 Research objectives and methods

The objective is the determination of optimised configurations for two analysed innovative floor types. These employ a composite dowels shear connection. The parametric analysis is carried out by automating the input setting, calculation running and output saving of a computational sheet.

This was developed specifically for the design of composite dowels flooring solutions. Input and resulting outputs are saved in databases and postprocessed. For more extended results, the reader can refer to the work of Profico [6] where both solutions are studied in worked examples.

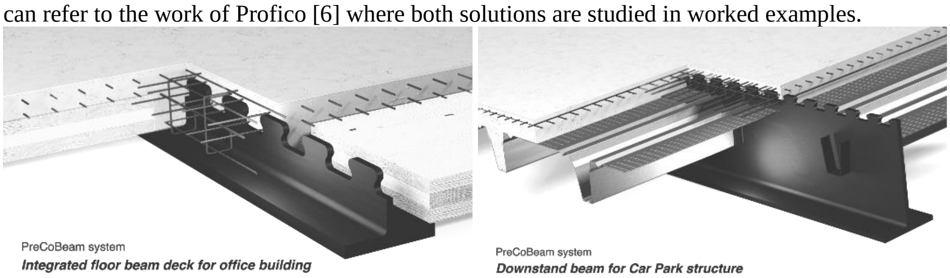

Fig. 2. Two innovative flooring solutions using composite dowels studied.

2 CASE STUDY 1: INTEGRATED FLOOR BEAM DECK FOR OFFICE BUILDING

2.1 Description

A slim-floor technology is considered. The intended use is office/residential. The longitudinal and transversal reference directions are defined as shown in Fig.3. In the transversal direction, the structural technology is timber-concrete composite with the use of a CLT panel and an upper concrete slab. In the longitudinal direction, the main girders are arranged with spacing L_{inter} and with a span length L. The CLT panel is not considered to be statically collaborating in the longitudinal direction. The cross-section of the main beams is mixed steel-concrete. The shear connection is made of composite dowels.

The materials are S460 structural steel, C35/45 class concrete, B500 class reinforcing steel and C24 timber for the CLT panels.

The geometries of the section and shear connection are described by the parameters defined in Fig.3. The static scheme considered is simply supported beam in the longitudinal direction. In addition to the structural permanent loads, defined in accordance with the respective geometries of the structural parts and specific weights of the materials used, the uniformly distributed loads on the deck surface of $G_2=1.50\ kN/m^2$ for the non-structural permanent and $Q=3.80\ kN/m^2$ as variable load are considered.

The parametric analysis is set up considering the following constructive, executive and geometric constraints:

- in order to obtain an overall optimised configuration, a separate analysis was carried out to determine the suitable timber-concrete composite solution in the transversal direction to be coupled with the main girder spacing L_{inter} . The product of the analysis was the triplets spacing length, CLT panel thickness, minimum concrete slab thickness $\{L_{inter}, h_{CLT}, h_{slab}\}$ such that the SLS deformability check was met with a $\delta_{transverse}/L_{inter}$ limit of 1/300. In the direction transversal to the beam (L_{inter}), the slab is considered continuous over at least two equivalent fields partially clamped. The effective flexural stiffness modulus defined by means the “gamma method” [7] is used for the CLT – concrete composite panel. This is also applicable to composite timber-concrete structures as described in [7].
- for the defined thickness of the solution in the transversal direction $h_{slab}+h_{CLT}$, there is a geometric constraint placed on the total section height of the main beam. The composite steel-concrete section has a total height of $h_{slab}+h_{CLT}+h_f$. The reinforcement bars passing through the concrete dowel of the shear connection shall also be arranged appropriately

in the upper concrete slab. For this reason, the hot rolled section's family used is also constrained when selecting the L_{inter} spacing length.

- to ensure adequate anchorage of the transversal bars passing through the concrete dowels, the CLT panel can be locally cut adjacent to the steel web.

For this case the optimum criterion is the slenderness of the structural element.

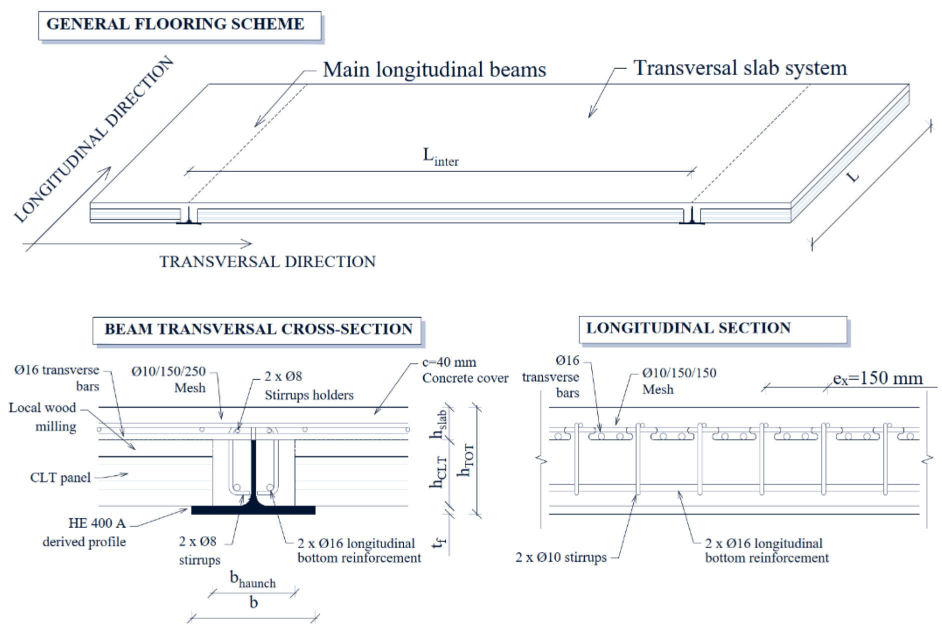

Fig. 3. Configuration of the first case study.

2.1 Parametric analysis setup

The parameters varied are described in the table below.

Table 1. Set of values considered and varied parameters

Set of values	Varied parameter
L={6000, 7000, ..., 14000 mm}	Span lengths
L_{inter}*={5000, 5500, ..., 7500 mm}*	Main girder spacing lengths
*Hot rolled section members=**	Hot rolled section members of related family
Shape={PZ, PZT}	Shape of the composite dowel
h_{slab}*={70, 80, ..., 100 mm}*	Concrete slab thickness

* See hot-rolled sections belonging to the family associated with the spacing

The design checks conducted at the ULS are: bending, vertical shear and longitudinal shear, whereas at the SLS: deflection under variable loads and vibrations check. Moreover the minimum degree of shear connection and geometric detailing were also checked.

2.1 Results

In Fig. 4 and Fig. 5 the studied cases satisfying all the checks are shown for the PZ and the PZT dowel shapes, respectively.

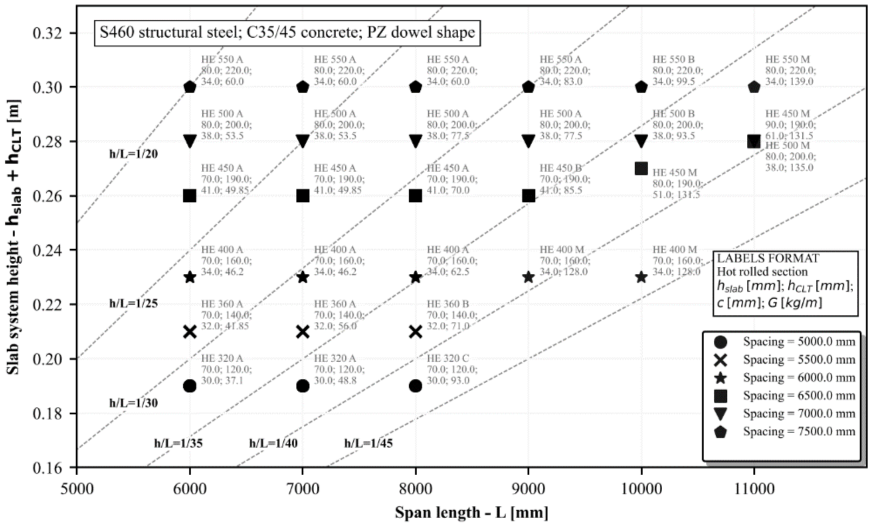

Fig. 4. Results for the PZ dowel shape series.

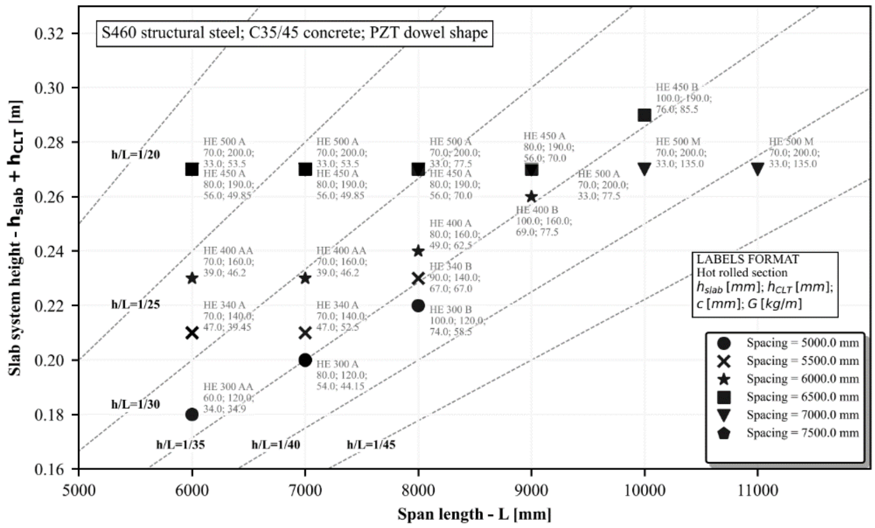

Fig. 5. Results for the PZT dowel shape series.

For each couple span length-spacing length the configuration minimizing the total height of the section is identified. Information are provided regarding the amount of steel used *G* and the related steel section, the defined geometric parameters and the concrete cover of the top reinforcement *c*.

The line representing a slenderness equal to $L/h_{TOT}=35$ can be interpreted as an optimal line representing a high performance index. Cases close to this line are optimized both in the transversal direction and in the longitudinal direction.
Notice that with increasing span lengths, the solution that minimizes the total height varies from "AA" members of the hot rolled sections families to the "M" member.
For span lengths larger than 8000 mm one of the most critical check is the ULS bending resistance check. The concrete strut crushing check of the longitudinal shear ULS check appear also to determinant. For all the cases satisfying the other checks, the vibration frequency of the structure is larger than 3.3 Hz. Degrees of shear connection are in some cases smaller than 1.0. The SLS deflection checks do not appear to be the decisive.

5 CASE STUDY 2: DOWNSTAND BEAM FOR CARPARK STRUCTURE

2.1 Description

The case of a steel-concrete composite beam adopting a composite shear connection is analysed. The single steel T-profile is connected to a concrete slab. The longitudinal and transversal directions are defined in accordance with Fig. 6. In the transversal direction, a Cofraplus®220 technology is used for the slab system. The cold-formed profiles are fixed to the steel profile web by means of welded wings supports. In the longitudinal direction, the main beams are arranged according to a spacing length $L_{inter}=5000\ mm$ with a span length $L=16000\ mm$.
The same materials as case study 1 are considered.

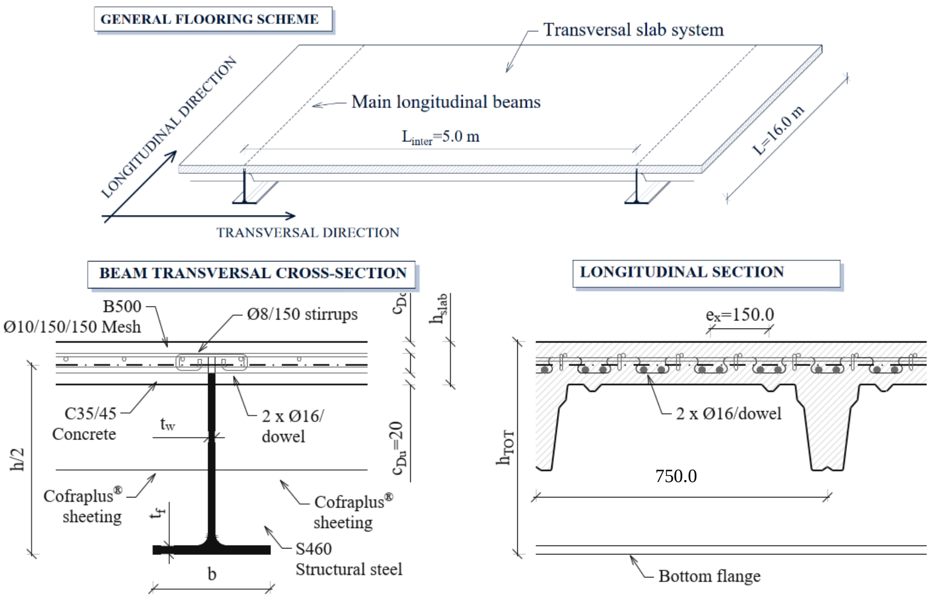

Fig. 6. Configuration of the second case study

The geometries of the section and shear connection are described by the parameters defined in Fig. 6. The considered static scheme is a simply supported beam in the longitudinal direction. In addition to the permanent structural loads, defined in accordance with the corresponding geometries of the

structural parts and specific weights of the materials used, uniformly distributed loads are considered on the deck surface of G_2*=1.00 kN/m²* for the permanent non-structural and *Q=2.50 kN/m²* as the variable load. In relation to the loads and in accordance with the assumed static scheme, the design actions are determined by means of linear elastic analysis.
The analysis is set up considering the following constructive, executive and geometric constraint considerations:

- the adopted spacing of the Cofraplus®220 profile is 0.75m. The spacing of the shear connectors, equal to the scale e_x of the composite dowel constitutes an entire fraction of the adopted Cofraplus® profile spacing. The scale e_x*=150 mm* is chosen. This is set for reasons of ease of execution and design.
- the lower concrete cover c_{Du} of the shear connection is set at 20 mm. This is allowed by the fact that the lower pry-out of the concrete is prevented by the presence of the Cofraplus® profile.

The optimization criterion is the amount of steel used.

2.1 Parametric analysis setup

The parameters varied are described in the table below.

Table 2. Set of values considered and varied parameters

Set of values	Varied parameter
Hot rolled section families={HE1000, HE900, HE800}	Hot rolled section families
Shape={PZ, PZT}	Shape of the composite dowel
h_{slab}*={70, 80, …, 100 mm}*	Concrete slab thickness

The same output parameters are observed as in case study 1. The same checks are conducted as in case study 1.

2.1 Results

Results are illustrated in Fig. 7. The considered cases respecting the checks are highlighted. The interest is here minimizing the amount of steel. The preferred solution consists in using the HE900AA profile with an amount of steel used of 99 kg/m. The check playing a key role is the one of ULS of bending resistance with a degree of utilization of 0.91. The degree of shear connection is less than one, thus involving a Partial Shear Connection situation. The precambering design amount is 130 mm and the deflection under live loads in the long term is 36 mm.

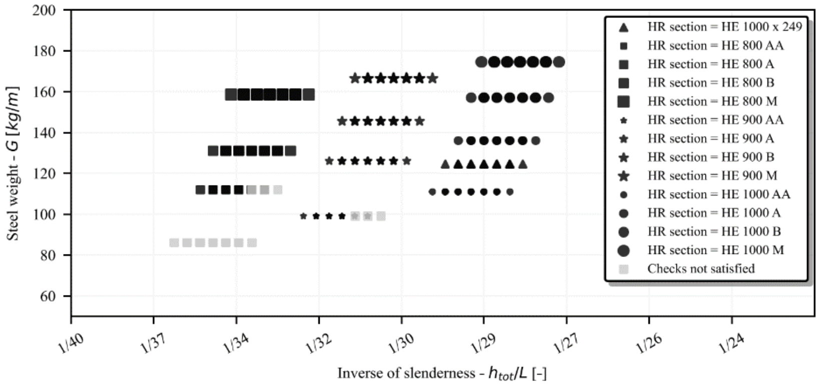

Fig. 7. Results for the second case study.

8 CONCLUSIONS

In the present work two innovative composite solutions for flooring were studied. These directly use the composite dowels technology as shear connection. Both solutions appear to be really competitive under the slenderness and the amount of steel point of view.
Further investigations will include LCA and fire design aspects of the solutions that were not considered so far.

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KEYWORDS

Composite dowels, Innovative shear connection, Precobeam, Car Parks, Buildings, Flooring system