

Maintaining simplicity in design, precasting and construction

Grooved Hollowcore: a simplified way to significantly reduce concrete consumption and increase profit margins

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A method to make hollowcore slabs fixed at their ends which allows for a reduction of up to 20% of the depth and consumption of concrete of finished floors has been developed, thoroughly tested and protected by patents by the engineering company Elastic Potential, in Barcelona, Spain. The method consists of producing hollowcore units with deep grooves across their top surface. Once at the job site, right on top of the grooved slabs one places negative-moment resistant reinforcement bars and pours a conventional topping, 50 mm thick at least. The significant cost reductions in the production and transportation of slabs allow the precaster to rapidly amortize the new machinery required to produce the grooved slabs. At the present date, leading machinery suppliers already have machinery available to produce Grooved Hollowcore slabs or are developing it and plan to have it soon available (Prensoland, Echo Precast Engineering, UltraSpan, Elematic, Nordimpianti, Spancrete).

In a number of situations in everyday practice, the structural performance of a floor is superior when it has its ends fixed rather than having them pinned. For structural floors made with hollowcore units, a solution to obtain fixity was developed 20 years ago: opening the ends of some cores, placing steel rebars for negative moments in the cores and filling them with concrete. However, the vast majority of hollowcore floors currently built are pinned-pinned. This is because the solution of opening cores is more complicated and not always cheaper than the conventional pinned-pinned solution.

The main concept: improved structural performance made simple

Now, a simplified solution, called Grooved Hollowcore, has been developed to make fixed hollowcore floors almost as simple as the conventional pinned-pinned floors, but significantly cheaper than pinned-pinned floors.

Finished floors can be much cheaper because the depth of slabs (and the consumption of concrete) is reduced up to

20%. As a consequence, slabs are up to 20% lighter, easier to transport and to handle. Fixity is achieved by two modifications to common practice. On the one hand, slabs are produced with deep grooves across all the top surface. This requires an appropriate machine (see below the section “Availability of machinery”). On the other hand, when slabs are placed on site, reinforcement bars to consider negative bending moments are placed right on top of the slabs (without the need of spacers), and a structural topping (of 50 mm at least) is poured just as in common practice (see Fig. 1). Some relevant details in the figure: reinforcing bars are placed right on the slab; the slabs are conveniently separated from the beam to let concrete fill the gap and negative moment function appropriately; plugs may be needed to prevent the holes of the slabs to be filled with concrete.

Even considering the need for a topping, floors using Grooved Hollowcore slabs can be much cheaper than a conventional pinned-pinned floor without topping.

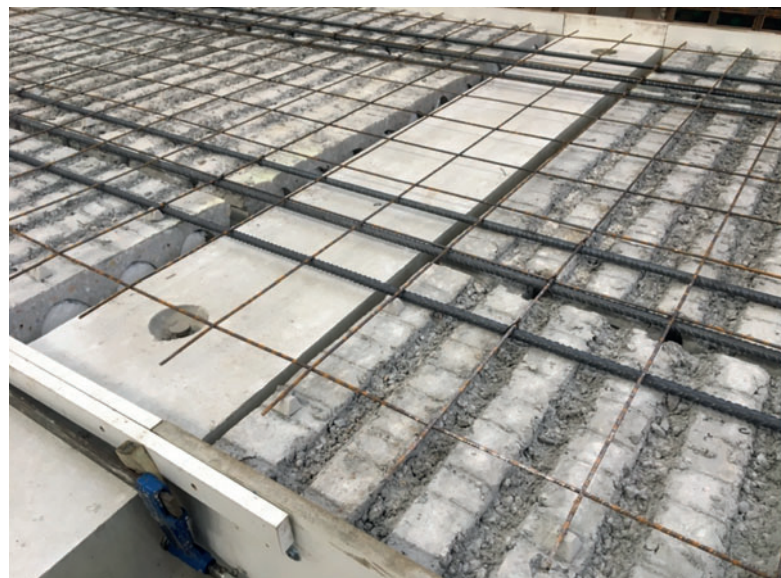


Fig. 1: Grooved Hollowcore floor before the concrete of the topping is poured.



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The beneficiaries of Grooved Hollowcore

All the actors in the value chain may get significant advantages and profits from using Grooved Hollowcore.

The precaster can produce much thinner slabs, which often also require less reinforcement. As an average, slabs can be up to 20% thinner than conventional slabs, when compared to a current solution with topping, and up to 25% thinner than conventional slabs, when compared to a current solution without topping. And consumption of prestressing steel also drops up to 15% as an average. In addition, as slabs can be 20% to a 25% lighter, their transport is also less costly.

If thinner slabs are sold at the same price (or at a slightly lower price) than current pinned-pinned slabs (considering that both offer the same performance), the precaster may get important additional margins, improving profitability significantly. These increased margins account already for the fact that Grooved Hollowcore slabs (much thinner) can be sold at a price slightly under the price of pinned-pinned equivalents (thicker), to balance the additional cost that the contractor may have in the job due to placing steel for negative moments reinforcement.

The contractor, in turn, will not only benefit from a lower price of the slab; but will also benefit from the fact that slabs are lighter: beams, columns and foundations can be reduced. Also, as slabs are thinner (and beams may also be shallower), the structural floor as a whole may be 5 cm (2") to 15 cm (6") thinner. Thus, the height of each level of the building may be reduced by that amount. This allows for a reduction of the area of the façade, leading to extra cost reductions. It has been studied that in Europe, summing all these cost cuts and considering a construction cost of the building of 500 €/m² to 1000 €/m², the contractor may get cost cuts from 2 €/m² to 6 €/m² (around 0,5% of the cost of the whole job). The actual cost cuts for the contractor depend on the floor depth reduction, on the type of foundations (piles or footings) and on the price of the façade per m².

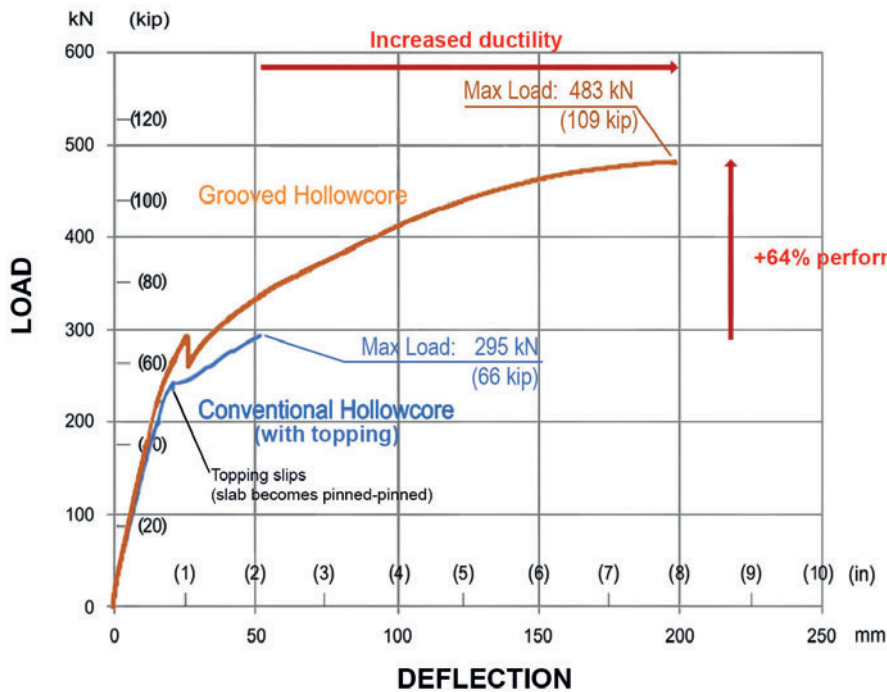


Fig. 2: Load-deflection diagrams obtained, when loading two identical floors - one using Grooved Hollowcore units and the other one using conventional hollowcore units

The developer and the designers of the building (architect, engineer) can also get a number of advantages. Grooved Hollowcore slabs with the same depth as conventional pinned-pinned hollowcore slabs are able to carry up to 25% more load (see Fig. 2), or increase the span by up to 25%. Also, the liberty of design can be increased: cantilevers are made possible, and big openings in slabs are also easy to achieve because the slabs cut at midspan may work cantilevering from their end bearing. In the experimental work shown in Figure 2, the conventional hollowcore test ended shortly after the topping had debonded, as the slabs became pinned-pinned.

Grooved Hollowcore slabs, typically lighter, are also beneficial under seismic conditions thanks to their reduced mass and to the increased ductility of the beam-slab joint that reduces the risk of progressive collapse. Additionally, as in all continuous floors, the fact of having a significant part of the steel reinforcement (15% to 50%) placed at the top face of the floor allows for an improved fireproof performance. This is because top reinforcement is much less exposed to the heat coming from the bottom typically caused by fire [1].

Finally, using Grooved Hollowcore slabs allows to build floors by emitting 10% to 15% less CO₂. This is the result of reducing the consumption of concrete by up to 20%, and slightly increasing the total amount of steel required. This increase is due to the fact that some prestressing steel of the precast unit is replaced by steel bars placed on site, which typically have a lower strength compared to prestressing steel.

Compatibility with current design codes

Most design codes, including the Eurocode (EC-2) [2] and the American PCI Manual for the Design of Hollow Core [1], accept that hollowcore floors can be designed and built as fixed. This is because the abovementioned solution to get fix-

ity by opening cores has existed for a long time. Consequently, the new solution of Grooved Hollowcore will often be compatible with current codes.

The principle on which Grooved Hollowcore design relies on, is the horizontal shear strength of the concrete-to-concrete junction (slab-to-topping). Again, a number of codes (EC-2 [2]; American ACI-318 [3]) have provisions that may be regarded as compatible with these principles: provisions for horizontal shear strength of the interface of concrete-to-concrete junctions.

Grooved Hollowcore becoming a reality

A technology developed after an extensive tests program

The solution here presented was developed after a complete tests program performed during 18 months at the Universidad Politécnica de Valencia (UPV) in 2016 and 2017, in Spain (see Fig. 3). These tests were conducted by Dr. Pedro Miguel Sosa, Full Professor of Civil Engineering, and Dr. Luíís Pallarés Rubio, Associate Professor of Civil Engineering, under the supervision of Elastic Potential (the firm that holds the patents).

The main aim of the tests program was to find a reliable solution to guarantee a good connection between the hollowcore slab and the topping. The program included small-scale tests, mid-size tests and full-scale tests. The main variables studied were: geometry of the interface; the ages of the two concretes (precast and topping); and the size of specimens. One of the main conclusions of the research was that the different speed and magnitude of shrinkage of the concrete of the hollowcore unit and of the concrete of the topping, known as differential shrinkage, reduces significantly the horizontal shear strength of the junction. This effect may lead to an early detachment of the topping at very low loads. This happens es-

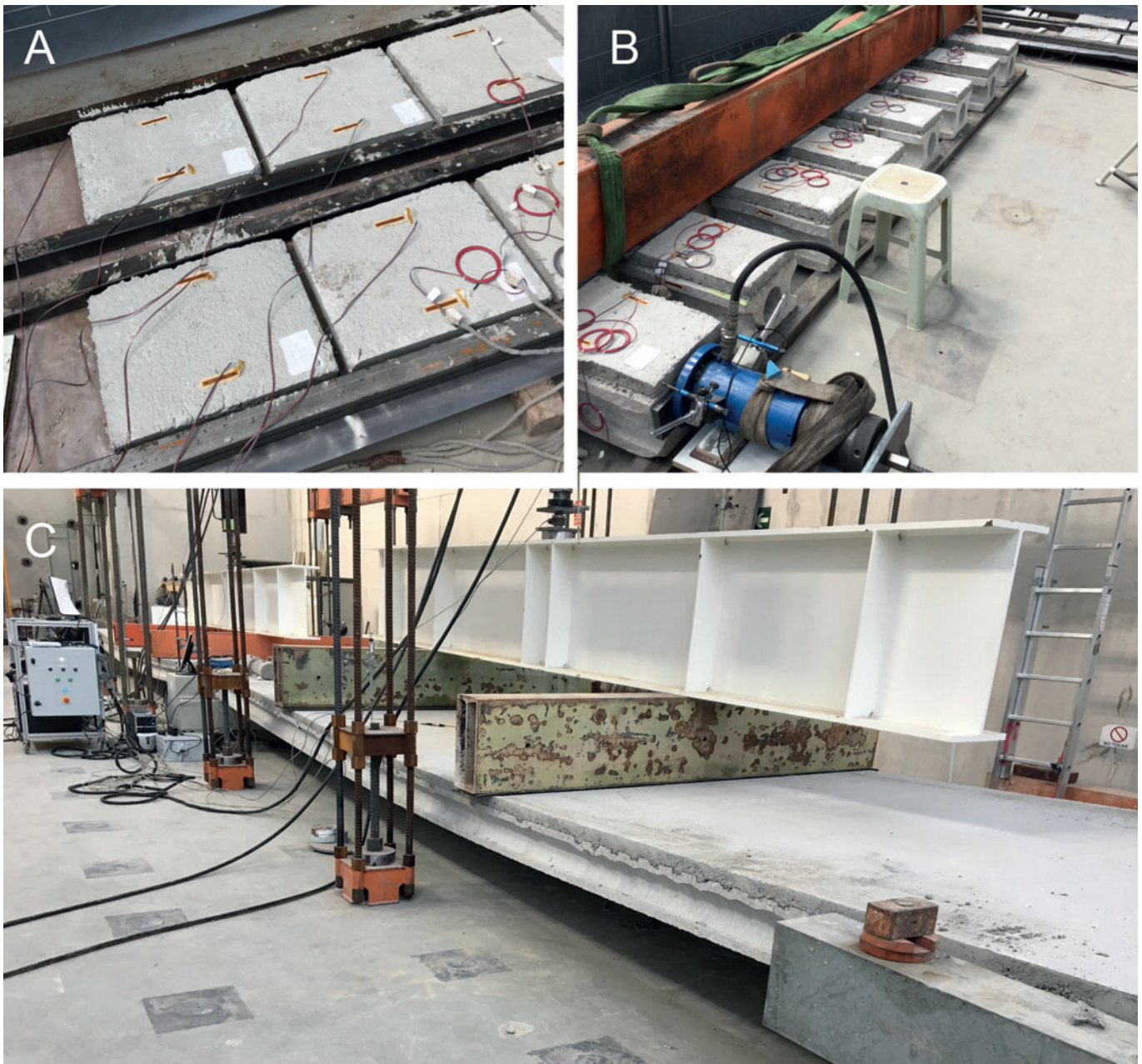


Fig. 3: A. Free shrinkage tests in samples of toppings with different mix compositions; B. Horizontal shear strength tests on small specimens; C. Full-scale test (intensely loaded) on a two-span floor using Grooved Hollowcore.

pecially when shrinkage rates are high in the slab (for example when slabs are some months old when the topping is poured) or when the concrete of the topping has high shrinkage (for example, a high w/c ratio in the topping, an intense heat on site, etc.). These results are consistent with the results obtained and conclusions reached by other authors [4, 5, 6].

The Model Code [7] written by the Fédération International du Béton (fib) also mentions that, in certain structures, differential shrinkage may have to be considered to guarantee the strength of concrete-to-concrete joints. Given the results, tests were performed with a variety of finishes of the upper surface of the slab: moderately smooth (as produced by the precasting machine), brushed, providing isolated deep holes on the

slabs surface and, finally, providing grooves of different depths on the slab surface. Only one solution was able to completely overcome the effects of differential shrinkage and give a reliable and predictable strength. A solution with deep grooves (20 mm) placed across the upper surface of the slab. This solution gave a reliable interlock between the concrete of the topping and that of the precast unit. This reliability was demonstrated by the fact that the failure of the junction happened when either the concrete of the topping or the concrete of the precast slab broke under shear (which is a predictable kind of failure, depending on a reduced number of variables: geometry and strength of concrete). Whereas, in any other studied joint, the concrete of the topping just detached from the concrete of the slab.

This is a failure in the interface, which is much less reliable, because it is much harder to predict due to the fact that it depends on a much higher number of factors (presence of humidity, water or dirt on the joint, differential shrinkage, hardening speed, etc.). The results of the tests are currently being prepared to be published in scientific papers.

The reaction of precasters

In recent months, Elastic Potential has been presenting the technology individually to some 20 precasters in Europe (Spain, Italy, France, Belgium) and in the US. The vast majority of precasters that listened to the presentation showed genuine interest in the technology, as they understood that it looks very easy to use and that it may lead to significant increases in their margins. Of these, approximately 2/3 decided to check in detail if the cost reductions mentioned above are realistic in their particular case. To do it, they have picked a number of projects that they have designed and built in the recent past, and have asked Elastic Potential to redesign them with Grooved Hollowcore to see the difference. All of the projects redesigned so far have shown to lead to cost reductions as mentioned above. For example, for actual projects studied in Europe, considering an average sales price of the slab of 25 to 40 €/m²; the cost cuts achieved in actual studies ranged from 3 €/m² (for short spans and low loads) to 10 €/m² (for long spans and intense loads). Load and span have a significant influence on the result: the larger the span and the load, the larger the cost reductions that can be achieved. Finally, 90% of those who studied projects in detail, have asked for quotations of machinery to assess if they will do the investment. Based on actual machinery prices, all amortization studies conducted so far have yielded amortization periods of less than 1 year.

Availability of machinery

Elastic Potential considers is very important, and has given priority, to have machinery available to produce the slabs in series. That is why to date, Elastic Potential has been working with globally leading machinery suppliers, and they all see Grooved Hollowcore may be an interesting option for their customers. Currently, the machinery supplier Prensoland can provide with either new machines that produce Grooved Hollowcore slabs or with modifications to their existing machines to enable them to produce Grooved Hollowcore slabs as specified by Elastic Potential.

Echo Precast Engineering and UltraSpan (of Progress Group) are currently prototyping/conceiving machinery that is expected to be ready and available in the first months of 2020. Elematic already has a grooving machine to carve grooves on hollowcore slabs, and is currently working to adjust it for Grooved Hollowcore requirements (expecting to have it ready in early 2020). Besides, Elematic will consider developing a machine that extrudes slabs with grooves (all at once) if it has a commission to do so.

Nordimpianti has a grooving machine able to carve grooves on hollowcore slabs that have previously been produced by

an extruder, a slipformer or a flowformer. Nordimpianti plans to do the required adjustments to their grooving machine, once they will have a commission to produce one.

Spancrete is currently assessing the interest that Grooved Hollowcore may have among their customers, and currently offers machinery alterations to meet those needs.

To each machinery supplier that claims to have a machine ready to produce Grooved Hollowcore, Elastic Potential asks to pass a validation process of their machinery. This is a series of laboratory tests performed on slabs produced with their machinery. These tests check that slabs have certain minimum requirements to be accepted as Grooved Hollowcore slabs.

What is needed to start using Grooved Hollowcore

In the first place, a precaster will want to check if the savings claimed above in this article apply to his case. The way to check it is by contacting Elastic Potential in order to select and send 2 or 3 sample projects to be studied. Elastic Potential will redesign the sample projects (free of charge) and send them back to the precaster for him to assess the cost reductions that can be achieved in production and transportation, and thus the potential extra margins for the precaster. Besides, in order to do an amortization study, the precaster should request a quotation from the machinery supplier.

Once a precaster has decided to start using Grooved Hollowcore, only 3 things are needed:

- a) Learning how to design (calculate) and build with the new slabs (following a manual given by Elastic Potential);
- b) Reaching an agreement with Elastic Potential to use the technology (including the patent [8]);
- c) Purchasing a validated machine from the preferred supplier. ■

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