The “High-Performance Concrete Carpet”, A New Type Of Concrete Course Layer

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SYNOPSIS

The paper gives an overview on an on-going R&D project carried out by LCPC (France). The aim is to develop a purely hydraulic road structure in accordance with modern infrastructure requirements, which may also be used to rehabilitate old rigid pavement. The High-Performance Concrete (HPC) carpet consists in building a thin, reinforced and unbonded HPC course layer over an hydraulic subbase. The concept is presented in details, and various questions are addressed, among which feasibility, texture, cracking, risk of buckling, resistance to traffic-induced degradation and economy. At this stage of development, where most laboratory research has been carried out successfully, the concept looks attractive and fits well with the present trend of sustainable development. A further validation is now necessary, through experimental test sections of sufficient size.

1. INTRODUCTION

Since the beginning of concrete technology era, this material has been used in road infrastructures. In some countries, like Germany, it became the dominant material for high-traffic, main national network roads. However, in France, bituminous materials won the battle for this type of infrastructure, while concrete found significant, although less prestigious markets, like urban pavement, airports, tramway infrastructure or agricultural tracks. Meanwhile, it has been a permanent policy for French road authorities to support innovation in concrete pavement technology, in order to maintain excellence and competition between both technologies, for the benefit of all users. This is why LCPC, a government-supported research institution, launched a research programme in 1999 called ‘MHyR’ (Hydraulic Materials for Roads). One of the aims of this programme was to develop innovative hydraulic materials, trying to carry out a technology transfer from the most advanced concrete sectors (like the bridge one) to pavement construction techniques.

In this framework, the concept of High-Performance Concrete (HPC) Carpet was proposed [1]. The paper presents the development of HPC carpet, the research undertaken, and the remaining questions. The potential benefits are stressed in the conclusion.

2. DESIGN OF THE HPC CARPET

The basic idea lies in the separation of the two functions of pavement: the bearing, structural function and the contact function with the vehicle wheels. As for the first one, and if we restrict ourself to hydraulically bound materials, it can be demonstrated that compacted materials like cement-treated base materials or roller-compact concrete (RCC) provide the most economical solutions, in terms of cement amount per unit surface. However, these materials, as compared to vibrated concrete, may display a limited evenness, and they are prone to crack, due to restrained thermal (and hydraulic) shrinkage. This is a reason why they need a protecting course layer.

To date, it has been impossible to develop continuous bonded course layers which are not subject to reflective cracking. As a matter of fact, the movements between two adjacent blocks of rigid materials, either horizontal (from thermal changes) or vertical (from traffic loads) tend to damage the course layer in the vicinity of the joint. Thus, in the HPC Carpet, an innovative solution is proposed, as an unbonded, thin, continuously reinforced high-performance concrete layer:

- the absence of bond allows limited slip motions between base and course layer, so that the crack opening of the structure may increase or decrease without creating any significant stress in the course layer;
the top layer is thin (6 cm) in order to create a soft slab able to deform continuously when the structure is subject to vertical deflection. The ‘carpet’ term originates in this peculiarity;
- the course layer is reinforced to provide ductility and strain capacity;
- the concrete is of the high-performance type, because of the required abrasion resistance [2], and to prevent reinforcement corrosion. Hence, as a consequence of limited thickness, the concrete cover needs to be much lower than in conventional continuously reinforced concrete (CRC).

In a recent European project [3], attempts were made to develop a similar structure, with two important differences:
- the concrete layer was supposed to be stuck to a bituminous base course, as in the white-topping technique;
- reinforcement was made up with longitudinal rebars in combination with a fibre concrete.

In the HPC carpet, a welded wire mesh is preferred (with steel percentages of 1.1 and 0.55 % in the longitudinal and transverse directions, respectively), since it seems more efficient to place steel along the principal stress directions instead of disseminating steel fibres, which are randomly dispersed (in the best case) and not perfectly anchored in the matrix. However, longitudinal reinforcement with fibre concrete could be equally envisaged, if this last solution displays a lower total cost (including placement cost). Fig. 1 shows the principle of HPC carpet.

### 3. VARIOUS QUESTIONS

Since the proposal of the HPC carpet concept, the research carried out mainly consisted in design calculations, material development and construction of a 10 x 1.50-m test section, which was instrumented and tested with a linear fatigue machine up to $10^6$ cycles [4]. A list of questions is given hereafter, with the answers that can be brought at the present stage of experience.

#### 3.1. Is such a thin concrete reinforced course industrially feasible?

The development of white-topping technique in USA and Europe has shown that it is possible nowadays to cast a concrete course layer with a controlled thickness of 5 to 10 cm. The only difference with HPC carpet lies in the presence of reinforcement. The welded wire mesh panels have to be placed before the slipform machine, which must be fed laterally, or with a concrete pump. The main difficulty lies in the control of concrete cover. At this stage, the use of spacers is envisaged, the function of which will be to impose the location of reinforcement in the mid-plane of the slab.

#### 3.2 What type of surface texture?

Exposed aggregate concrete is a good solution to provide bond with tyres, together with limited noise emissions. Tests on the LCPC test section have demonstrated that this technique is applicable to HPC (see Fig. 2). Moreover, the use of concrete with a soft fresh consistency should help to get a convenient evenness.

Fig. 1. Principle of the HPC carpet. (a): conventional continuously reinforced concrete; (b): high-performance concrete carpet.
3.3. Expected cracking pattern vs. corrosion risk

With commercially available welded wire mesh, a diameter of 7-8 mm can be adopted for the longitudinal reinforcement. A classical cracking calculation carried out following Brice’s model [5] lead to the results given in Table 1. Here, the worse conditions for French climate are accounted for: concrete cast at 30 °C, ambient temperature –10 °C, ultimate hydraulic shrinkage. With these hypotheses, it is realized that the crack opening obtained in HPC should be lower than in conventional CRC. Given the tightness of HPC to aggressive agents (including chlorides), the corrosion of steel reinforcement is not expected to start in the first 20 years. As a comparison, most bituminous course layers in French high-traffic roads last between 8 and 15 years.

3.4. Is the HPC carpet likely to buckle with temperature?

The question of CRC buckling is poorly documented in the technical literature. However, this phenomenon appears from time to time, especially in weak joint zones, several years after construction. With the HPC carpet, this risk must be evaluated, owing to the low thickness and the lack of bond of course layer with the base one.

Here, the strategy is to design a high-shrinkage HPC, in order to create a permanent tensile stress in concrete at mean temperature. The mix-design selected for the construction of LCPC test section, given in the Appendix, is supposed to develop a total shrinkage at 50 % relative humidity of more than 700 $10^{-6}$. Free shrinkage measurements performed on LCPC test
section have confirmed this order of magnitude. From cracking calculations and examination of literature, it is anticipated that, when placed in total restrain conditions, HPC carpet will crack in the first 8 days after construction. Six months after, a temperature increase of 24 °C should be necessary to close the shrinkage-induced cracks. For a total temperature increase of 30 °C – quite a pessimistic estimate for the French climate – a compressive stress of about 3.4 MPa is anticipated. A condition to obtain an upward movement of the slab is the following:

\[ R \leq R_{\text{crit}} = \frac{\sigma}{\rho g} \]

where \( R \) is the longitudinal curvature radius of the course layer, \( R_{\text{crit}} \) the critical value of this radius, \( \sigma \) the compressive stress, \( \rho \) the concrete mass per unit volume and \( g \) the gravity acceleration. Given the current evenness specifications, this condition should be fulfilled with a safety coefficient of about 4 [4].

### 3.5. Will HPC carpet be capable of supporting traffic loads in the long run?

Surface degradations of course layer are difficult to simulate in a laboratory. As a preliminary test, the LCPC test section was submitted to a fatigue loading program with the help of the FABAC machine, a portable, linear fatigue equipment developed under the framework of the past French national project FABAC [6], see Fig. 3. One million of 65-kN single axle twinned wheel loads were applied to the test section. The 2 m-long loaded section of the test section bridged an existing crack in the subbase (which was a 30 year-old secondary road made up with a 20-cm cement-treated structural layer topped by a 5-cm course layer). The only effect of the fatigue loading was to create three thin cracks with a distance of about 50 cm, with no visual evolution after the first cycles (see Fig. 4). No punch-out, nor wear of the course layer was experienced. Therefore, the result of this experiment is considered to be encouraging, even if not totally representative of the conditions of a real, trafficked course layer.

### 3.6. How does it compare economically with conventional pavement structures

At this stage of development, two markets are envisaged for the HPC carpet. The first one deals with new, high-traffic roads. Taking into account the mean costs observed on the national network on one hand, and the amount of materials on the other hand, it turns out that:

- the consumption of ‘noble’ materials (Portland cement, steel reinforcement, course-layer type aggregate) per pavement unit surface is lower for the HPC carpet than for conventional CRC solution;
- the initial cost is also lower, as compared to either conventional CRC or current French catalogue bituminous solution (depending on the current cost of bitumen), provided that the HPC carpet is placed over a single layer of roller-compact concrete (RCC).

This assumption is especially interesting if one considers the fact that, when a hydraulic and a bituminous solutions are compared, the latter is almost systematically cheaper in terms of initial costs [7]. Maintenance, and sometimes user costs must be accounted for to demonstrate the interest of classical concrete solutions, an approach not easy to take by owners when the policy is based upon short-term considerations.

The other market where the HPC carpet could fit in is that of old, end-of-life rigid or semi-rigid pavement rehabilitation. These structures consisted in slabs of various lengths (most generally about 5-m long), which are poorly jointed but in good shape in terms of constitutive material. Since horizontal motions between the slabs make difficult to seal the joints with conventional materials, the only present solution is to break the slabs, and to add a complete bituminous pavement structure, using the old road as a foundation. One could imagine to seal these roads with a polyethylene sheet, and to cast a HPC carpet, the strength and the flexibility of which providing a new youth to the road. This solution looks attractive for economical considerations, and also in terms of material transport.
Fig. 3. The FABAC machine.

Fig. 4. Aspect of LCPC test section after fatigue loading.
4. CONCLUSION

The innovative concept of HPC carpet could bring a number of advantages:
- it could help in developing purely hydraulic solutions competitive with other techniques (in terms of initial cost);
- the thinness of the concrete course layer naturally leads to a small maximum size of aggregate, which in turn provides reduced noise emissions [8];
- the intrinsic qualities of HPC (abrasion resistance, compactness, bond to steel reinforcement) should lead to an improved durability for the course layer (up to 20 years and more ?);
- the rapid strength development of HPC makes a ‘fast-track’ technique of the HPC carpet (with the possibility to open traffic at 24 hours); and
- this concept, by reducing the thickness of the course layer, allows an optimization in the use of aggregate resource: hard, high roughness aggregate for a 6-cm layer, and local, medium or low quality materials for the structure. Therefore, the HPC carpet seems to fit in many respects with the modern trend of sustainable development.

LCPC is looking for experimental sites to further validate and to develop this innovative technology.

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5. REFERENCES

APPENDIX

Mix-design of the high-performance concrete used in the LCPC test section. *compressive strength measured on 11x22 cm cylinders.

<table>
<thead>
<tr>
<th>Component</th>
<th>Lab study (kg/m³)</th>
<th>Test section</th>
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<tbody>
<tr>
<td>Pontreux 2.5/6.3 coarse aggregate</td>
<td>912</td>
<td></td>
</tr>
<tr>
<td>Estuaire 0/4 sand</td>
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<td>CEM I PM ES Cement from Le Havre</td>
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<td>Piketty limestone filler</td>
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<td>Anglefort densified silica fume</td>
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<td>Glenium 27 Superplasticizer</td>
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<td>Added water (on dry aggregate)</td>
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<td>? (210)</td>
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<td>Slump (cm)</td>
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<td>22</td>
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<tr>
<td>Yield stress measured with BTRHEOM rheometer</td>
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<td>Plastic viscosity (same apparatus)</td>
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<td>Vicat setting time (on concrete mortar)</td>
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<td>Compressive strength* at 7 days (MPa)</td>
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<tr>
<td>Compressive strength* at 28 days (MPa)</td>
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