ULTRA-HIGH-PERFORMANCE CONCRETE : FIRST RECOMMENDATIONS AND EXAMPLES OF APPLICATION

Jacques RESPLENDINO, **Head of Bridges Division,** CETE Lyon, France
Jérôme PETITJEAN, Senior Project Engineer, SETRA, France

ABSTRACT

This paper draws a short review of the use of UHPC, since the first research on Reactive Powder Concrete carried out by Bouygues from 1990 to 1995 ; from the first industrial applications at EDF nuclear power plants in 1997-1998 to the most recent engineering structures completed in 2002.
Then this paper draws a brief sketch of the main features of French recommendations for Ultra-High Performance Concretes (UHPC), drafted by an AFGC-SETRA work group composed of all the private and publics organizations working on these new types of material.
These recommendations were published in June 2002, in bilingual english – french version ; they are intended to constitute a reference document serving as a basis for use of UHPC in civil engineering applications. They deal with UHPC characterization and material properties, design and calculations methods for UHPC, durability aspects in comparison with Reinforced Concrete or HPC.
The paper ends with the presentation of the current civil engineering applications and recent development using UHPCs.

Keywords: UHPC, Fibre, RPC, Recommendations, Durability, Design Methods

1 - INTRODUCTION

UHPC refers to materials with a cement matrix and a characteristic compressive strength in excess of 21,800 psi (150 MPa), possibly attaining 36,250 psi (250 MPa). They are containing steel fibres in order to achieve ductile behaviour and, if possible, to dispense with the need for passive reinforcement.

UHPC differs from HSC and VHSC :
- by its compressive strength which is systematically greater than 21,800 psi (150 MPa),
- by the systematic use of steel fibres and also polymer fibres in some cases,
- by its high binder content and its special selection of aggregates.

The aim of UHPC development is to achieve high tensile strengths through the participation of the fibres which provide tensile strength after the cement matrix has cracked. When the tensile strength is sufficiently high, it may be possible, depending on the way the structure works and the loads to which it is subject, to dispense with conventional reinforcement.

The different UHPC currently marketed are :
- BSI "Béton Spécial Industriel" (special industrial concrete), which technology has evolved to come to Ceracem® concrete, developed by Eiffage in association with Sika.
- Different kind of Ductal® concrete, including BPR (reactive powder concrete), resulting from joint research by Bouygues, Lafarge and Rhodia, and marketed by Lafarge and Bouygues,
- BCV being developed by Vinci group in association with Vicat.

Most cement manufacturers are developing products, and materials are being developed in the laboratories of EDF, LCPC (with CEMTEC® Multiscale technology)…

2 – SHORT REVIEW OF UHPC APPLICATIONS

2.1 – RPC : THE FIRST UHPC DEVELOPED BY BOUYGUES

First research carried out on UHPCs where led by Bouygues from 1990 to 1995 on Reactive Powder Concretes (RPC)[5, 6, 7].

In 1996, the artist Bernar Venet designed the Arc Majeur project for the A6 motorway in France : a monumental sculpture, 185 ft (54 m) high, which finally has not been built (Fig. 1).
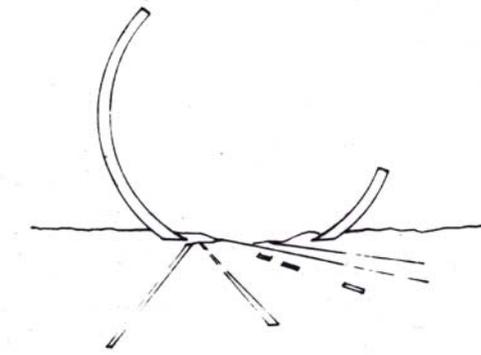
Fig. 1 – Arc Majeur project (1996)

2.2 - SHERBROOKE FOOTBRIDGE

The world's first engineering structure designed with UHPC was the Sherbrooke footbridge in Sherbrooke, Quebec, built in 1997 [9].

Spanning 197 ft (60 m), this precast, prestressed pedestrian bridge is a post-tensioned open-web space RPC truss (Fig. 2), with 4 access spans made of HPC. The main span is an assembly of six 33 ft (10 m) prefabricated match-cast segments.
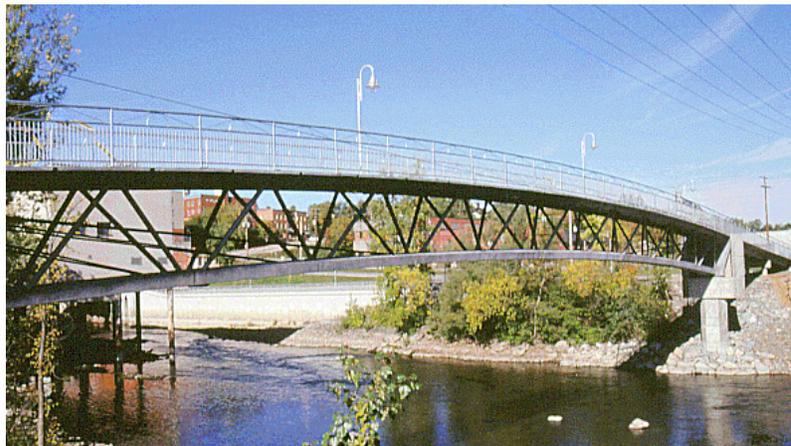

Fig. 2 – General view of Sherbrooke footbridge

The cross section is made of a ribbed slab 1.19 in (30 mm) thick, with a transverse prestressing made of greased-sheathed monostrands. The truss webs are made of RPC confined in stainless steel tubes (Fig. 3).
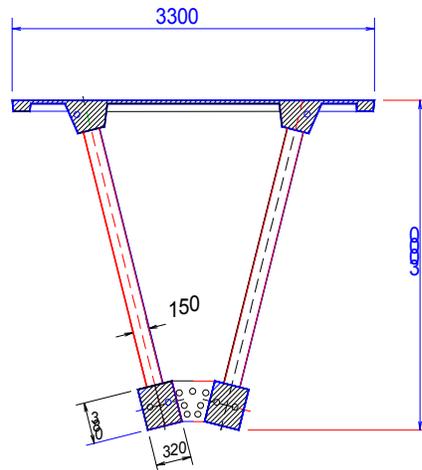
Fig. 3 – Typical cross section of Sherbrooke footbridge

The structure is longitudinally prestressed by an internal prestressing placed in each longitudinal flange and an external prestressing anchored at the upper part of the end diaphragms and deviated in blocks placed at the level of the lower flange.
The connection between the flanges and truss diagonals is ensured by greased-sheathed monostrands and miniaturized anchorage specially designed by VSL for RPC.

2.3 – FIRST INDUSTRIAL APPLICATIONS : BEAMS OF CATTENOM AND CIVAUX POWER PLANTS

During years 1997 and 1998, the utility EDF carried out two important precasting sites using beams of UHPC, made of BSI and Ductal[®] [10, 11, 12]. These building sites consisted in replacing cooling towers steel beams in Cattenom (with BSI and Ductal[®]) and Civaux power plants (with BSI).

The extremely aggressive environment of the cooling towers induces important corrosion of the steel structures. UHPC with its outstanding qualities in terms of durability allows to replace steel beams with light elements with very long lifetimes without maintenance or repair.

At the end of year 2000, the AFGC-SETRA working group on UHPCs visited a cooling tower at the Cattenom power plant. It was the opportunity to compare UHPC condition with steel elements. Under a normal layer of sediment, no damage of UHPC was noticed (Fig. 4).

Fig.4 - Comparison between steel and UHPC elements conditions – Cattenom beams.

2.4 – THE FIRST ROAD BRIDGES MADE OF UHPC : BOURG LES VALENCE BRIDGES

During years 2000-2001, the French Government, represented by its Regional Department of Public Works for the Drôme district with the assistance of the Service d'Etudes Techniques des Routes et Autoroutes (SETRA) and the Centre d'Etudes Techniques de l'Equipement (CETE) of Lyon, realized the world first UHPC bridges, built by contractor Eiffage Construction with BSI on Valence bypass [23, 24, 25,26].
Each bridge has two isostatic spans of about 72 ft (20 m). The road deck was made continuous by placing in situ UHPC between the two spans (Fig. 5).
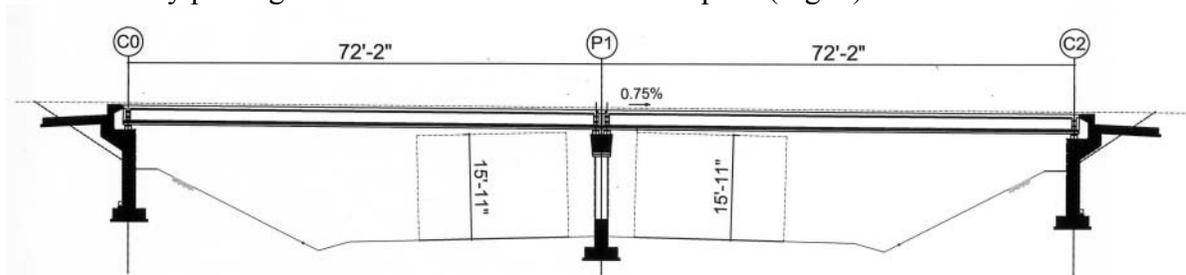

Fig. 5 - Longitudinal cross-section of OA4

Each deck supports a 29.5 ft (9 m) wide road pavement with 3.3 ft (1 m) and 6.6 ft (2 m) sidewalks (Fig. 6). Transversally both decks are identical; they are made from an assembly of five π-shaped precast beams made from BSI, jointed together longitudinally with in situ UHPC.

All the beams are prestressed by pre-tension. There is no transverse prestress, and no transverse passive reinforcement, except where π-shaped beams are transversally jointed together.
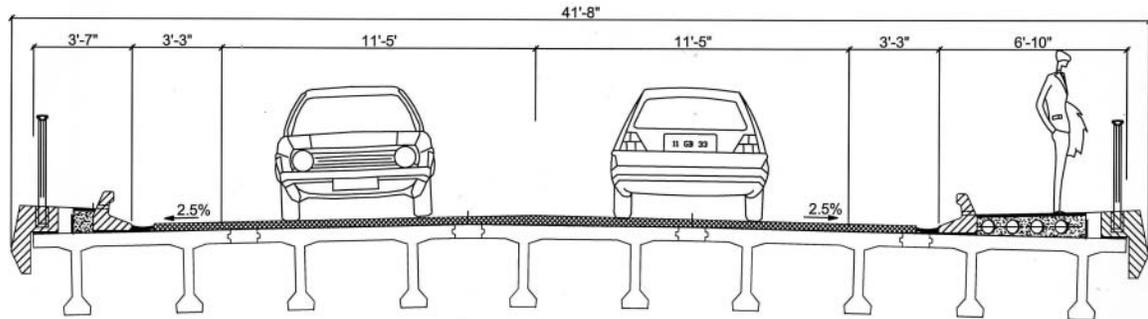
Fig. 6 – Bourg-lès-Valence bridges - Typical cross-section

The bridges were realized under an "Innovation Charter", and were designed and built in close collaboration with recommendations of a AFGC-SETRA working group on UHPCs.

This application also required to settle special calculation methods and design rules which are not currently covered by codes for the type of concrete employed. They were used to finalize some material characterization procedures and design calculation methods given by recommendations.

2.5 – THE SEOUL AND SAKATA MIRAI FOOTBRIDGES WITH DUCTAL®

In 2001-2002, contractor Bouygues TP built a footbridge over the Han river running across Seoul in South Korea[27]. Jointly conceived by the City of Seoul and "France's Year 2000 Committee" to commemorate the new Millennium, the footbridge symbolises the co-operation and friendship between South Korea and France. It is made of an arch spanning 394 ft (120 m), with two steel access spans (Fig. 7).

Fig. 7 – General view of Seoul footbridge

The arch has a π-shaped cross-section (Fig. 8), 4.3 ft (1.30 m) deep. The upper flange is a ribbed slab 1.19 in (30 mm) thick, with a transverse prestressing made of greased-sheathed monostrands. The webs are 6.35 in (160 mm) thick and are inclined outward. The arch is an assembly of six 66 ft (20 m) prefabricated segments, connected on site by means of temporary supports. The elements are jointed together by an internal longitudinal prestressing placed in haunches in the lower and the upper parts of the webs.
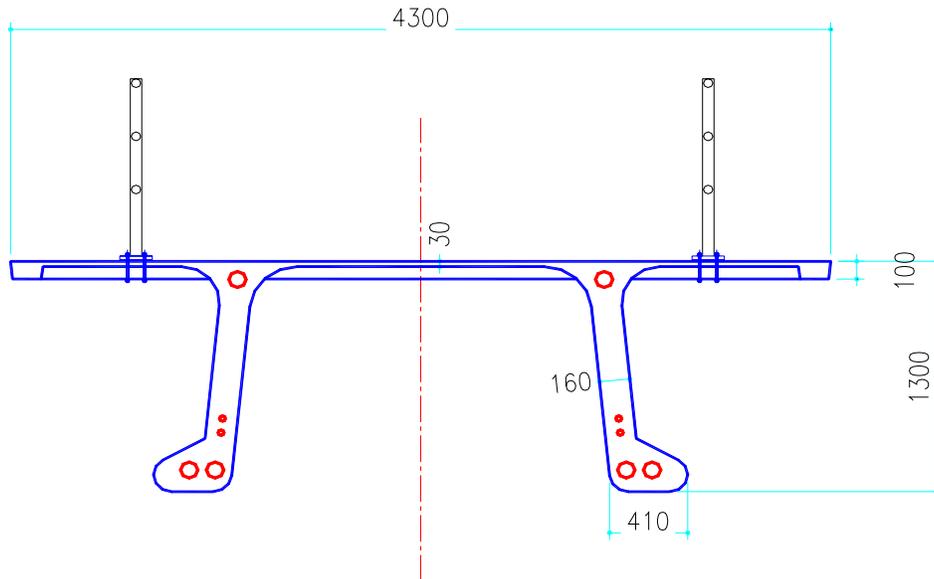
Fig. 8 – Cross-section of Seoul footbridge

This very slim structure has eigen frequencies of vibration sensitive to the pedestrian traffic. Vibration calcutation have been carried out and tuned mass dampers have been installed to reduce the effect of the first three modes of vibration of the footbridge.

Fig. 9 - Ductal® footbridge project in Sakata City, Yamagata Prefecture.

We can also mention the first Ductal® footbridge built in Japan with a span of 164 ft (50 m). The deck is a simple beam 8 ft (2.4 m) wide with circular web holes. The structure is longitudinally prestressed by an external prestressing and has no passive reinforcement. This footbridge was completed at the end of 2002 (Fig. 9).

2.6 – MISCELLANEOUS APPLICATIONS

Apart from these main civil engineering structures described above, some other applications have been realized with UHPC.

Among these applications, we can make mention of these Ductal® ones:

- The construction of punched and thin accoustic sound panels for the underground Mocano railway station (16,150 ft^2 (1500 m^2) of panels – 39 yd^3 (30 m^3) of concrete)
- The construction of architectural wall panels for Rhodia head office in Aubervilliers,
- The construction of 6,300 anchor plates with polymer fibres and 200 plates with steel fibres for reinforced earth. This solution with UHPC was choosen for its durability performances because the structure was located on the sea-front on La Réunion island (Fig. 10).
- a replica of the "Arbre Martel", a tree-shaped structure originally sculpted by brothers Martel
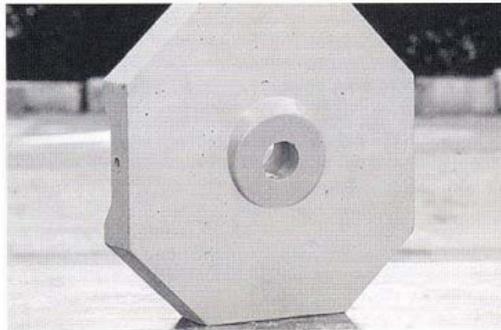

Fig. 10 - Ductal® Anchor plates

BCV concrete is being developed by contractor Vinci and cement manufacturer Vicat, but has been already used in some applications:

- Construction of stays for a treatment reservoir of rainwater in Les Houches, France.
- Injection of curved saddles for stay cables in the pylons of Sungai Muar bridge in Malaisia (Fig. 11).
- Construction of foundations blocks for the roof of the Cluses toll-gate on A40 motorway.

Fig. 11 - Curved saddles for stay cables –Sungai Muar bridge

3 – THE FIRST RECOMMENDATIONS ON UHPC

The first French recommendations for Ultra-High Performance Fiber-Reinforced Concretes (UHPC) were published in 2002, in bilingual English-french version.
These recommendations integrates feedback from experience with the first industrial applications and experimental structures described below, as well as more than 10 years of laboratory research.
They are intended to constitute a reference document serving as a basis for use of this new material in civil engineering applications.
These recommendations are divided in three parts:
- A first part devoted to characterization of UHPC, giving specifications on the mechanical performance to be obtained and recommendations for characterizing UHPC. This part also deals with checks of finished products and of the concrete as it is produced.
- A second part deals with the design and analysis of UHPC structures, the particularity of which is to integrate the participation of fibres and the existence of non-prestressed and/or non-reinforced elements.
- A third part deals with the durability of UHPC.

3.1 - BEHAVIOUR AND MECHANICAL CHARACTERISTICS OF UHPC

3.1.1 - General

The first part of the recommendations reminds the main UHPC mechanical characteristics, including in annex values given by the principal manufacturers.

3.1.2 - Effect of heat treatment

The recommendations remind the principal effects of heat treatment[5], which substantially reduces delayed shrinkage and creep effects, but must be carried out only after the concrete has set in order to avoid any risk of Delayed Ettringite Formation (DEF). Heat treatment therefore requires good knowledge of the setting time and a means of checking it.

3.1.3 - Principal mechanical characteristics

After reminding the real compressive behaviour[6], the recommendations give a conventional constitutive law with a yield plateau which can be used for regulatory calculations regarding ULS bending.
The recommendations also give values of Poisson's ratio, thermal expansion coefficient, shrinkage strain and creep coefficient without or in case of heat treatment.

3.1.4 - Impact strength

The recommendations also account for the knowledge on UHPC behaviour under dynamic loading, which has been studied through impacts on radioactive-waste containers[1, 2, 3, 4]
The recommendations enlight the principal concepts for UHPC calculations under dynamic loads defined and validated by experience.

3.1.5 - Tensile behaviour

An important part of the recommendations deals with the tensile behaviour characterized by :
- An elastic stage limited by the tensile strength of the cement matrix f_{tj},
- A post-cracking stage characterized by the tensile strength of the composite material reached after matrix cracking.
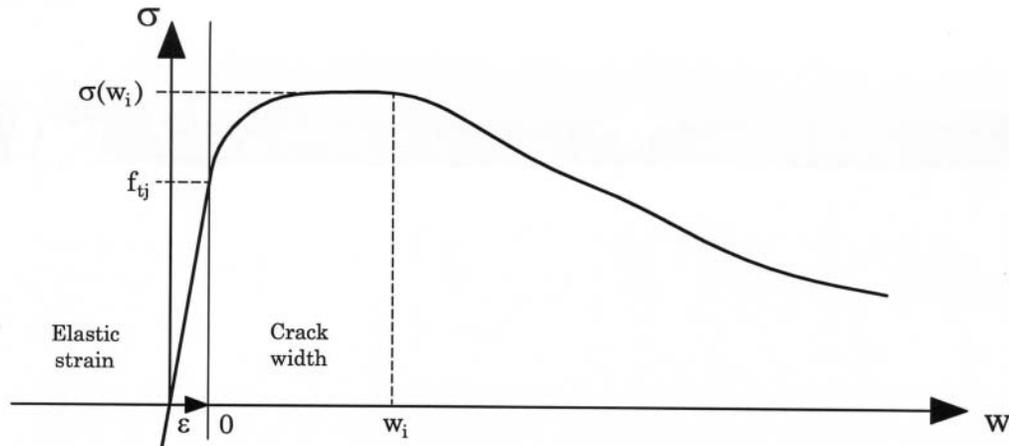

Fig. 12 - Example of a UHPC tensile constitutive law

The post-cracking behaviour is very important because it may dispense with the conventional reinforcement in the design of some structures.
On the other hand, it is quite difficult to characterize this behaviour because it depends very much on the mixing and placement process :
- Any flow during concrete placing tends to align fibres in the direction of flow,
- Fibres close to walls are naturally aligned parallel to the formwork. This phenomenon ceases beyond a distance from the formwork in excess of the fibre length. The closer component thicknesses are to the length of fibres, the greater is the effect on the effective tensile strength of the parts,
- Preferential gravitational orientation of fibres can sometimes occur, due to the natural behaviour of fibres in the viscous-liquid phase of concrete before it sets.

The methods outlined in these Recommendations take account of all these phenomena which are dissociated in two approaches.
Using characterization tests depending on the type of structure studied (thin slabs, thick slabs, beams, shells), and which can be of two types (direct tensile test or flexural tensile test), the Recommendations give for each proposed test procedure, the transfer factors to go from test results to an "intrinsic" curve for tensile behaviour which does not depend on test specimen size or on the type of test used.

Once the intrinsic curve for tension is determined, the recommendations give instructions for taking into account of the effect placement methods have on the real strength values to be considered in calculations. This correction of the intrinsic strength curves consists in applying a reduction coefficient 1/K representing the difference between the intrinsic curve and what would have been obtained on specimens taken from an actual structural element.

To determine this K factor, the recommendations impose suitability tests conducted on a representative models of the actual structure. The tensile strength measured on samples of the testing model allow to determine the K value. The principal results of this characterization process applied to the innovative Bourg-lès-Valence bridges[26] are enclosed with the recommendations.

3.2 - STRUCTURAL DESIGN METHODS

3.2.1 – Generalities

The design methods proposed in the recommendations are based on the French codes for prestressed or reinforced concrete (BAEL[16], BPEL[17]) based on semi-probabilistic limit states verifications. The recommendations complete these design codes with specificity concerning UHPC which is essentially the strength provided from fibres which allows to design a structure without any conventional reinforcement[19, 20, 21].
For calculation, one may use an intrinsic law for characteristic tension drawn up assuming isotropic distribution of fibres throughout the structure.
In order to integrate the actual disparity in the fibre orientation due to placement, the various verifications are allocated an "orientation coefficient" 1/K determined by suitability tests as explained hereabove.
The value of this coefficient depends of the studied phenomena.
As for beams, the recommendations propose two values for this coefficient :
- A local value concerning designs which propose to use fibre tensile strength in zones of material of reduced size in comparison with the piece size,
- A global value when justifications concern a sufficiently large zone so as to limit the effect of the local disparity in fibres orientation.

3.2.2 - Normal stress verifications

For normal stress verification, the recommendations use the AFREM method[18] which concerns fibre concrete, and use a stress – crack width constitutive law $\sigma = f(w)$.
Moreover, in order to simplify calculation by using a traditional stress - strain law, the recommendations introduce the notion of characteristic length l_C , to go from crack width w to strain ε :

$$\varepsilon = \frac{f_{tj}}{E_{ij}} + \frac{w}{l_C} \qquad (1)$$

The value of l_C depending on the sectional area.

Minimum fibre content and non-brittleness check

In order to guarantee sufficient ductility (in tension and compression), the recommendations consider a minimum fibre content and a non-brittleness check, which ensures that fibres can take tensile stress in case of matrix cracks.

Serviceability limit states

The analysis for standard sections is carried out considering that plane sections remain plane, and the concrete behaviour law detailed as below :
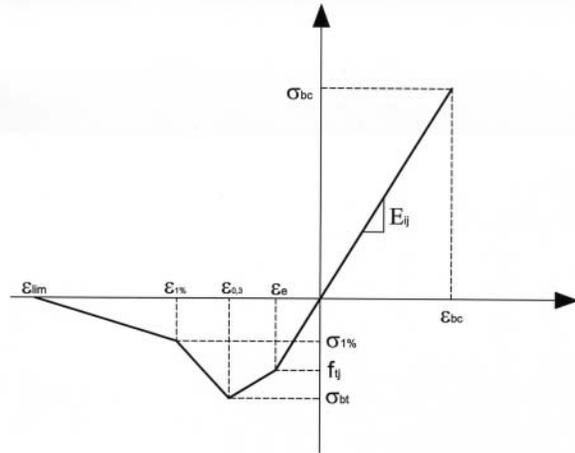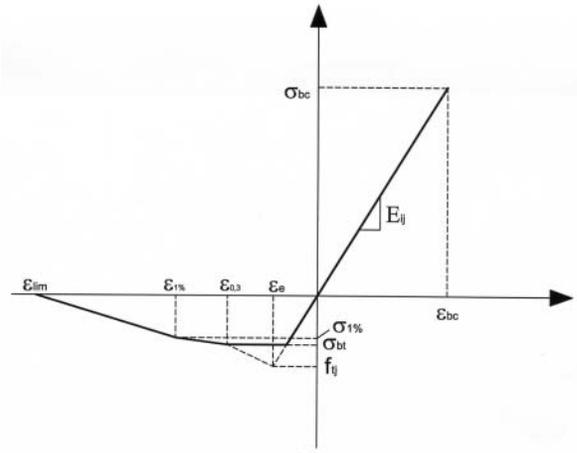
Fig. 13 - SLS strain hardening law   Fig. 14 - SLS strain softening law

The limit stresses at the SLS are the same as a traditional concrete in case of a reinforced or prestressed structure (limitation of concrete compression, and steel under tension).
These checks are completed when there is no passive or active reinforcement by prescriptions concerning crack width :
- 12 mils (0.3 mm) for normal cracking, 8 mils (0.2 mm) for detrimental cracking and 4 mils (0.1 mm) for highly detrimental cracking.

Fatigue checks

Results about UHPC fatigue strength are limited[13]. In expectation of progress in this field of knowledge, the recommendations propose limits for tensile stress in case of parts subject to fatigue.

Ultimate limit states

Ultimate plastic strain of structure reinforced only with fibres are not very significant, so that recommendations do not allow non-linear calculation with plastic hinges if there is no passive or prestressing reinforcement capable of withstanding forces and moments when the participation of fibres is overlooked.
However, it may be possible to use a non-linear model using the constitutive law of the material.
For ultimate resistance calculation, recommendations propose a concrete behaviour law defined as below:
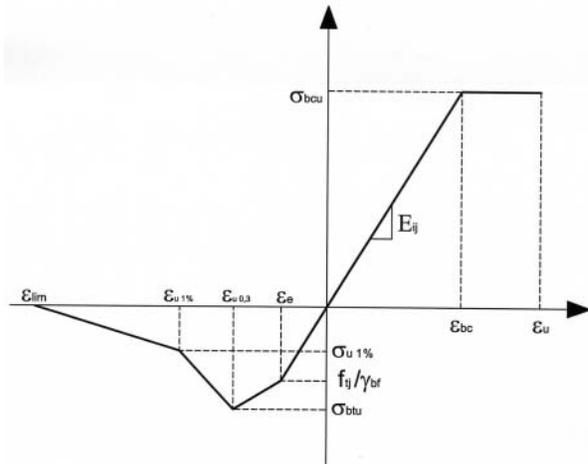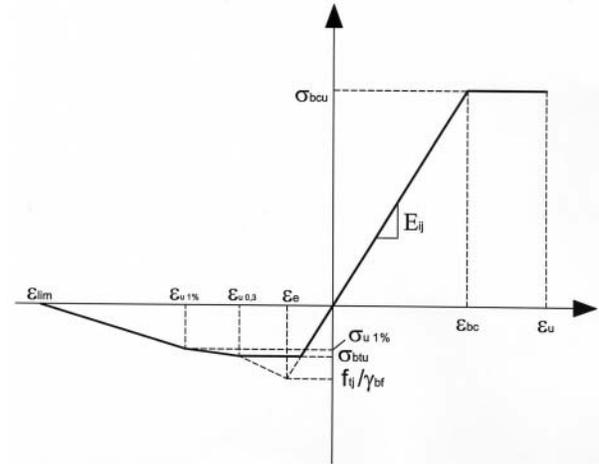
Fig. 15 - ULS strain hardening law   Fig. 16 - ULS strain softening law

Moreover, the recommendations draw back that the methods which use ultimate strains to calculate ultimate resistance effects are valid only when there is passive or active reinforcement. In this case, this type of method gives pessimist results because it does not take all the fibres potential into account.

3.2.3 - Shear stress verifications

At serviceability limit state, the recommendations propose to keep the shear stress limits of the French code for prestressed concrete.
These limits which tend to avoid cracks in prestressed structure should not be changed for UHPCs.
At the ultimate limit state, the recommendations introduce fibre shear strength which complete resistance of the concrete and the potential active or passive reinforcements.
Moreover concrete shear strength of a UHPC must be taken different of a traditional concrete, because of aggregate interlock which increases quite less than the compression strength. Test results about this phenomenon are lacking for classical FRC[19]. Hence the recommendations limit concrete shear strength approximately at the value obtained with a 17,400 psi (C120) concrete.

3.2.4 - Checks of zones submitted to concentrated forces

The recommendations complete actual regular prescriptions dealing with verifications of beam end blocks (equilibrium of bottom wedge, equilibrium of the compression strut), and verifications of the distribution of the prestressed concentrated forces. They account for complementary resistance brought by fibres.

4 – DURABILITY OF UHPC

4.1 - INTRODUCTION

The recommendations provide the main UHPC durability indicators. These indicators have been proposed by the AFGC working group "durability indicators".
Moreover, the recommendations deal with specific indicators specific to UHPC, and expose actual knowledge on fire performance.

4.2 - "CONVENTIONAL" AGGRESSIONS AND ASSOCIATED DURABILITY INDICATORS

The following table gives the principal results obtained for UHPCs compared to the values corresponding to ordinary concrete, and to HPC[22] :

	OC	HPC	UHPC	UHPC
Water porosity (%)	14 - 20	10 - 13	6 – 9	1.5 – 5
Oxygen permeability (m^2)	10^{-16}	10^{-17}	10^{-18}	$<10^{-19}$
Chloride-ion diffusion factor (m²/s)	2.10^{-11}	2.10^{-12}	10^{-13}	2.10^{-14}
Portlandite content (kg/m^3)	76	86	66	0

Table 1 – Durability indicators for UHPC, traditional concrete and HPC

The results presented above confirm the position of UHPC with respect to other types of concrete: for all the "conventional" durability indicators, the values obtained for UHPC indicate a clear improvement in durability.

4.3 - INDICATORS ASSOCIATED WITH SPECIFIC FEATURES OF UHPC

Are there any kinds of damage specifically related to the features of UHPC, i.e. other than the conventional damage mechanisms that could affect it? The following questions are often asked, for example:
- How good is the long-term stability of the admixtures used in large quantities (compared to previous practice)?
- Possible rehydration: because of the limitation of hydration reactions due to the low water content, there are some residual anhydrites and gypsum. In the long term, could these grains of calcium sulphate cause swelling and microcracking?
- Corrosion of steel fibres
- Chemical aggression of polymer fibres

So far all the available research and published results show that there is no real problem with any of these phenomena, for the reasons explained below.

4.3.1 - Stability of admixtures

Should a pH reduction occur, molecules of admixture can be salted out in the capillary pores of the concrete, then can undergo alkaline hydrolysis. This does not compromise the mechanical integrity of the concrete as it is ensured by the hydrated calcium silicates (CSH), independently of the content of the capillary pores.
Bacterial corrosion can also affect porous concrete through surface reactions.
The absence of connections between capillary pores (UHPC) is a favourable factor to limit all these phenomena.
It is deemed that the long-term stability of admixtures does not represent an important potential risk and a few research works have been done on it. The few authors who have studied the leaching behaviour of concretes with admixtures all conclude that the molecules are effectively fixed in the form of insoluble compounds. Only slight surface dissolution causing salting out of a few mg/l has been observed. This conclusion has been confirmed for admixture contents of up to 5% dry extract by mass of cement, which is three times the typical admixture contents in.

4.3.2 - Resumption of hydration

The question of possible structural swelling of HPC and UHPC as a result of possible long-term penetration of water (delayed hydration) is often raised.
Some research started in 1994 have shown the absence of osmotic processes by which water could be "pumped" through the CSH "gel".
 This phenomenon is a consequence of the fact that the UHPC CSH is not really a gel but has a nanocrystalline structure.
Consequently, far from constituting a danger for the durability of HPC and UHPC, residual clinker is an indisputable advantage for UHPC, and it enables:
- to increase the mean modulus of elasticity of the cement paste,
- to close microcracks, by capillary condensation and formation of hydrates,
- to fight chemical aggressions by sustaining the alkaline pH level and ion concentrations necessary for the stability of the hydrates over a distance close to the interface with the external medium.

4.3.3 - Corrosion of steel fibres

All the recent test results now available show that UHPC are particularly effective at maintaining the pH level necessary for passivation of steel reinforcement, and resist to chemical conditions in which ordinary reinforced concretes are rapidly destroyed.
Only the environments which are extremely corrosive for concrete, such as concentrated ammonium nitrate, manage to damage UHPC, and to provoke a corrosion of steel fibres (compounding by the ammonium ion) which is faster than chemical attack of the matrix.

4.3.4 - Durability of polymer fibres

Polymer fibres might deteriorate as a result of oxidation. In addition, they are sensitive to ultraviolet light. Because of its low porosity, UHPC provides a good degree of protection against these kinds of damage.

4.4 - FIRE PERFORMANCE OF UHPC

At the moment, there is insufficient data about the loss of strength depending on the temperature rise versus time so as to establish general design rules.
In addition, some UHPC mixes can scale at the surface, thus need special dispositions (polymer fibres incorporation).
All the manufacturers nowadays are eager to search about these phenomena so as to be able to bring out a formula which can respond to detailed specifications.
Considering the present knowledge, a formula validation needs tests carried out using standardized specimens in the case of a UHPC not subject to scaling, using representative specimens of structural elements in other cases.

CONCLUSION - PROSPECTS

The "Interim recommendations on Ultra High Performance Fibre-Reinforced Concretes (UHPC)" constitute the first reference document serving as a sure basis for use of this new material in civil engineering applications.

The different applications built with this kind of material have demonstrated UHPC's great qualities, making particularly durable parts with outstanding mechanical performance.

Several projects in progress should make the technique going forward and contribute to the development of the material.

We can mention the roof of the Millau Viaduct's toll-gate to be built on A75 motorway, which will have an elegant roof based on a thin Ceracem[®] shell (Cf. "*Construction of the first road bridges made of UHPC*", this symposium)

The publication of the AFGC-SETRA recommendations reinforced interest of foreign countries, and some UHPC bridge projects are currently studied in United States on behalf of FHWA.

Within the framework of National Project MIKTI led by IREX, a feasibility study of UHPC slabs for composite bridges should demonstrate the interest of this material which presents little delayed shrinkage and creep effects and weight saving.

A European project suggested within the framework of the 6th PCRD should allow to investigate the possibilities of using UHPCs in the fields of bridge repair or bridge widening.

REFERENCES

1. Toutlemonde F., Sercombe J., Torrenti J.-M., Adeline R. , "Développement d'un conteneur pour l'entreposage de déchets nucléaires : résistance au choc", *Revue Française de Génie Civil*, vol. 3, n° 7-8, décembre 1999, pp. 729-756.
2. J. Sercombe, "Modélisation du comportement du béton en dynamique rapide. Application au calcul des conteneurs à haute intégrité", *Thèse de l'Ecole Nationale des Ponts et Chaussées*, Paris, 18 décembre 1997. Publiée dans la collection études et recherches des LPC, série Ouvrages d'Art, OA 30, décembre 1998. 284 pages, 200 réf., résumé anglais.
3. Toutlemonde F., Boulay C., Sercombe J., Le Maou F., Renwez S., Adeline R. , "Characterization of Reactive Powder Concrete (RPC) in direct tension at medium to high loading rates", *2nd International Conference on Concrete under severe conditions : environment and loading, CONSEC'98*, Tromsø, Norvège, 21-24 june 1998, Proceedings edited by Gjørv, Sakai & Banthia, E&FN SPON, vol. II, pp.887-896.
4. Toutlemonde F. , "Résistance au choc des structures en béton. Du comportement du matériau au calcul des ouvrages", *thèse de l'Ecole Nationale des Ponts et Chaussées*, Paris, 16 décembre 1994. Publiée en rapport de recherche du LCPC, hors collection, juillet 1995. 348 pages, 197 réf., résumé anglais.
5. Richard P., Cheyrezy M., "Les Bétons de Poudres Réactives" , *Annales de l'ITBTP*, n°532, Mars-Avril 1995, série Béton 320 pp. 85-102
6. Behloul M., "Analyse et Modélisation du comportement d'un matériau à matrice cimentaire fibrée à ultra-hautes performances (B.P.R.). Du matériau à la structure", Ph. D. Thesis, ENS Cachan, 13 décembre 1996.
7. Behloul M., Bernier G., Cheyrezy M., "Tensile behavior of reactive powder concrete (RPC)", *Proc. of the 4th Int. Symp. on utilization of HSC/HPC, BHP'96*, Paris, Presses de l'ENPC, vol. 3, pp. 1375-1381.
8. Boulay C., Le Maou F., Renwez S., Sercombe J., Toutlemonde F. , "Caractérisation du comportement au choc d'un mortier à ultra-hautes performances grâce à des essais de traction directe", *Rapport d'étude interne LCPC*, juillet 1997.
9. Adeline R., Cheyrezy M., "La passerelle de Sherbrooke : premier ouvrage d'art en BPR / The Sherbrooke footbridge : the first RPC structure", *La technique française du Béton*, AFPC-AFREM, XIII° congrès de la FIP, Amsterdam 1998, pp. 343-348.
10. Birelli G., Chauvel D., Dugat J., Adeline R., Bekaert A., "Industrialisation du BPR. Utilisation dans les réfrigérants à courants croisés et premières règles de calcul / RPC Industrialization. Using in cross flow air cooling towers and first design rules", in *La technique française du Béton*, AFPC-AFREM, XIII° congrès de la FIP, Amsterdam 1998, pp. 203-213.
11. Dutalloir F., Thibaux T., Cadoret G., Birelli G., "Un nouveau béton très hautes performances : le BSI − Première application industrielle / B.S.I. : A new, very high performance concrete. Initial industrial application", in *La technique française du Béton*, AFPC-AFREM, XIII° congrès de la FIP, Amsterdam 1998, pp. 25-32.
12. Le Roy R., Serrano J.J. ,"Centrale nucléaire de Cattenom. Poutres en béton à ultra-hautes performances précontraintes. Mise au point rhéologique du béton B.S.I"., rapport d'étude confidentiel, contrat d'étude LCPC n° 327209, donneur d'ordres EGI.

13. Granju J.-L. et coll. , "Delayed behaviour of cracked SFRC beams, Fibre-Reinforced Concretes BEFIB'2000*", Proc. of the 5th Int. RILEM Symp., Lyon* (France), PRO 15, Rossi & Chanvillard eds, RILEM publications, pp. 511-520.
14. Toutlemonde F. et coll. , "Maintien dans le temps de la résistance en traction des bétons à hautes et très hautes performances", *Rapport pour le Projet National BHP 2000*, Thème BTHP, 101 pages, novembre 2000.
15. Toutlemonde F. , "Caractérisation mécanique de bétons à hautes performances. Bétons d'étude du projet national BHP 2000", groupe BTHP : synthèse, Rapport pour le Projet National BHP 2000, Thème BTHP, janvier 2001.
16. BAEL 91 révisé 99, "Règles techniques de conception et de calcul des ouvrages et constructions en béton armé suivante la méthode des états limites", Fasc. 62 (Titre premier, section 1 du CCTG), avril 1999
17. BPEL 91 révisé 99, "Règles techniques de conception et de calcul des ouvrages et constructions en béton précontraint suivante la méthode des états limites", Fasc. 62 (Titre premier, section 2 du CCTG), avril 1999
18. AFREM – BFM (1995) Recommandations sur les méthodes de dimensionnement, les essais de caractérisation, de convenance et de contrôle. Eléments de structures fonctionnant comme des poutres, décembre 1995
19. Casanova P. , "Bétons renforcés de fibres métalliques : du matériau à la structure", Ph. D. Thesis, ENPC, 1995
20. Rossi P. , "Les bétons de fibres métalliques", Presses de l'ENPC, 1998
21. RILEM TC 162-TDF : "Test and design methods for steel reinforced concrete - Recommendations : σ-ε-Design method", *Materials and Structures*, vol. 33, mars 2000, pp. 75-81.
22. Recommandation AFGC décembre 1997 Durabilité des bétons : Méthodes recommandées pour la mesure des grandeurs associées à la durabilité (L.M.D.C. INSA-UPS, Toulouse).
23. Resplendino J., "Utilisation de béton fibré ultra-performant pour la réalisation de deux ouvrages routiers", Séminaire RILEM, PARIS, 14 septembre 2000.
24. Resplendino J., Roy J.M., Petitjean J., Blondeau P., Hajar Z., Simon A., Thibaux T., "Ouvrages innovants de Bourg-lès-Valence", *Revue Travaux*, No.783, pp. 42-47
25. Thibaux T., Tanner J.A., "Construction des premiers ponts français en béton fibré à ultra hautes performances/construction of the first french road bridges in ultra high performance concrete", in *La technique française du Béton*, AFGC, The first fib congress 2002, Osaka 2002.
26. Hajar Z., Simon A., Lecointre D., Petitjean J., "Construction of the first road bridges made of UHPC", *This symposium*.
27. Behloul M, Causse G, Etienne D, "Passerelle en Ductal® de Séoul/Ductal® footbridge in Seoul", in *La technique française du Béton*, AFGC, The first fib congress 2002, Osaka 2002.