Underspanned Bridge Structures in Reactive Powder Concrete (RPC)

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Summary

Adapted structures must be developed so that modern reactive powder concretes (RPC) can be incorporated into new construction projects in an efficient and logical way. The steps of this development, from the analysis of the material characteristics, to the determination of the structural requirements, to the arrival at an appropriate adapted structure are described. An Outlook on the development of the Structural Elements is given.

Keywords: reactive powder concrete, underspanned (bridge-) beams, constructive details, slender concrete elements

1. Introduction

Over the past decade, much research has been undertaken on the composition of RPC. Thus, in order to ensure the efficient use of RPC in new construction projects, a need has arisen for the development of structural and constructive elements adapted to its characteristic attributes.

With this in mind, the main goal of the research described herein will be to establish a scientific basis for the design of RPC structures. The focus will be placed on constructive elements (bars, nodes, fittings), and in particular, on their application to underspanned bridge structures. The original contribution lies mainly in the use of concrete in the form of slender elements rather than the massive elements more commonly associated with concrete structures.

2. Material

Improvements in the concrete mix design, along with the addition of metallic fibers, have lead to a new high performance cement material known as reactive powder concrete (RPC). Bouygues, Lafarge and Rhodia with their product: *"Ductal"* are the precursors of this new concrete technology. To determine the mechanical characteristics of this material, an experimental investigation was carried out on RPC Type *M2C* produced by Holcim SA. [1].

2.1 Composition and Optimization

Table 1 Composition M2C

CEM III/A 52.5	638 kg
crushed furnace slag	231 kg
silica fume	239 kg
furnace slag sand	1085 kg
superplasticizer	23.7 kg
metallic fibers (l=25 mm, ϕ=160 µm)	116 kg
water	173 l

The RPC Type *M2C* used for these tests has a composition quite similar to that of normal concrete (Table 1). There is a significant quantity of cement, silica fume and superplasticizer. The water / cementitious materials ratio is quite small (W/C < 0.2). The optimization of the RPC performance is achieved by improvements in the homogeneity and the compactness. By reducing the particle size and optimizing the mechanical properties of the fresh concrete, a more homogeneous material results. The compactness is influenced by optimization of the granular mix, the water/cement ratio and the use of ultra-fine pouzzolanics and superplasticizers. Through these methods, the pore sizes in the microstructure are reduced. This reduction of the defect size leads to a higher compression resistance and lower permeability .The addition of metallic fibers to the granular mix increases the tensile strength and improves the cracking behavior. Heat treatment can result in an additional improvement of the quality of the microstructure [2][3].

2.2 Characteristics

The characteristic behavior of the RPC was analyzed in an experimental investigation [1]. As shown in Fig. 1, in compression, the behavior is characterized by an initially steady, linear load-deformation relationship, a short nonlinear phase and then fracture, which is characterized by a decrease in the stress. The stress then stabilizes at a residual value. The heat treatment has a considerable influence on the compressive resistance. With curing at 90°C, the compressive resistance rises from 120 MPa to 180 MPa.

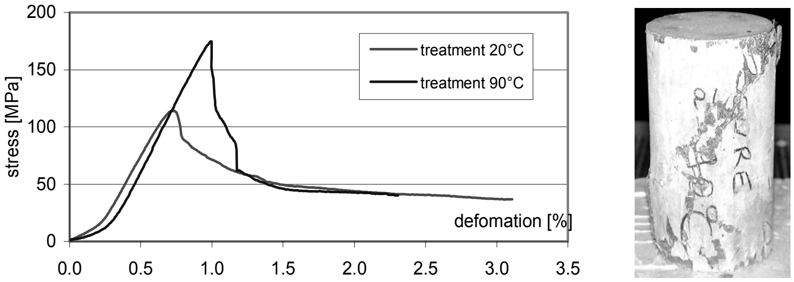


Fig. 1 Compression – deformation diagram; specimen

In tension (Fig. 2), the material initially demonstrates a linear elastic phase corresponding to the homogeneous non-cracked state. This phase is followed by a decrease in stiffness until the peak stress (10 MPa) is reached. This phenomenon corresponds to the creation of multiple micro-cracks, which are well distributed throughout the specimen thanks to the presence of the metallic fibers. Following this phase, the gradual opening of the macro cracks can be observed. After the peak stress, the stress can be seen to decrease gradually. The material is seen to have significant deformation capacity.

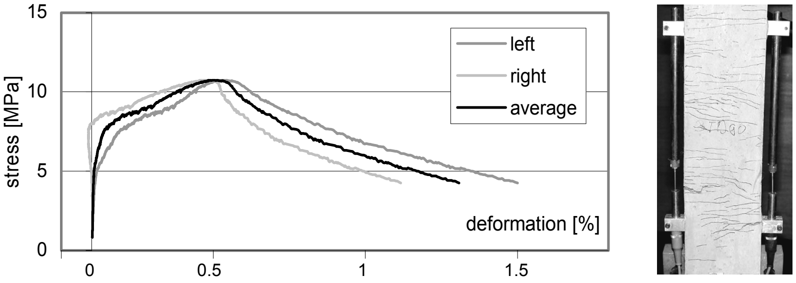
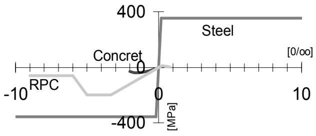


Fig. 2 Traction – deformation diagram; specimen

By comparison with other published experimental results, the determined behavior of *M2C* (see Table 2) can be characterized as representative of RPC. The Young's modulus (≈ 30 GPa *M2C*) shows large variation, which is likely due to the different addition materials, in this case the 'soft' furnace slag sand.

Table 2a/b Material characteristics

Characteristics	Cure 20°C	Cure 90°C
Compression resistance[MPa]	120	180
Young's modulus [10^3MPa]	25-35	25-35
Tensile resistance [MPa]	5-10	5-10
Flexions resistance [MPa]	25	30-35



3. Appropriated Structures

Due to the various boundary conditions (material characteristics, processing methods, price, etc.) for each different construction material, different typical structures tend to emerge. Massive structures are typical in concrete construction as are bare assembled structures in steel-girder construction. For RPC, these '*material adapted structures'* have yet to be found.

3.1 Demands on the Structures due to the Material Characteristics

Based on the tests of the *M2C* produced by Holcim SA, considerations on the demands of the material concerning the structure can be derived. Due to the high resistance of the material, correspondingly small cross sections arise for the structure. Since the Young's modulus compared to normal concrete is hardly raised, very large deformation of the structure results. It is thus necessary to choose stiff static systems (small length-to-depth ratios, hyper static systems) and avoid the use of RPC elements as flexural member [4][5].

The added steel fibers have a significant effect on the reinforcement system. These fibers improve the tensile behavior, increase the ductility of the material and lead to an even distribution of the micro-cracks. This eliminates the need for passive reinforcement implying that structures can be created solely with concrete and pre-stressing cables (see Table 3).

Table 3 Criterion for the demands on the structure

Material Characteristic	**Consequences for the Structure**
High strength at low stiffness	Stiff hybrid systems
Improved tensile behavior due to fiber additive (short steel fibers)	Adapted reinforcement: no passive reinforcement, prestressing
High quality control during casting	Precast in the factory
Precast in the factory	Repetitive elements, stock sections
Heat treatment	Smaller shrinkage and creep,higher strength
Self compacting concrete	Any frame configuration and shape
Expensive material	Economical utilization, slender, efficient

3.2 System

The systems that warrant consideration are therefore hybrid systems, which achieve separation of the tension and compression members through small length-to-depth ratios [6]. Underspanned beams have this quality and will thus be the focus of the remainder of the discussion herein. In underspanned bridge beams (Fig. 3), the shape of the tendon (tension chord) can be optimized with for the anticipated permanent loads. By adding V-shaped struts, the stiffness can also be raised for traffic and asymmetric loads.

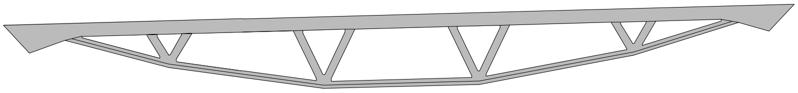


Fig. 3 Underspanned beam

4. Development of the Structural Elements (Outlook)

In bar structures such as underspanned bridges, structural elements are needed that are not used in normal concrete construction. The design, modeling and testing of these elements will be one of the main future targets of the thesis.

4.1 Elements

Bars: There are different demands for the various bar elements of the structure. The tendon must be studied as a tensile element with a continuous pre-stressing cable running along the interior of the cross section. The diagonal elements are loaded primarily in compression; however, under certain load cases low tensile forces can also appear.

Nodes: In underspanned beams, the nodes are loaded in 3 ways (see Fig 4). The first is the deviation force resulting from the tendon (1). In addition, constraint stresses appear from displacement (2) and rotation (3) of the node caused by the pre-stressing process and the various load cases. In an extreme case this can lead to tension in the connected bars. These tensile forces must be anchored within the node and the special material qualities of the RPC (high tensile strength) can be used.

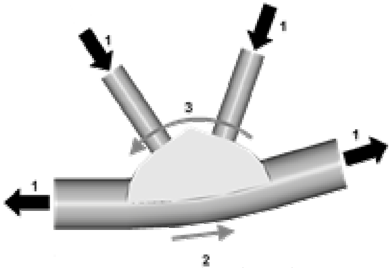


Fig. 4 Load on the node

Connections: The different rod elements are produced as prefabricated parts. To connect them in the factory or on the construction site, adapted fitting systems must be developed. For the different bars (tendon and diagonals) various demands exists for the different connection points (node, slab):

- Tendon: The fitting system must have a passage for the pre-stress cable. The concrete must only transfer compression.
- Diagonals: Mainly compression must be transferred, however it must be capable of resisting some tension.

4.2 Modeling and Analysis

To design and determine the dimensions of structures, it must be possible to describe their behavior with simple models. As RPC has a different material characteristics compared to normal concrete, different models must be used. Especially interesting in the modeling of RPC structures will be the three-dimensional stresses in the node and the deformation behavior of the pre-stressed or fiber reinforced bar elements.

4.3 Experimental Investigation

To control and calibrate the calculation models an experimental investigation is planned. In co-operation with the industrial partners (cement industry, precasting industry) different structural elements will be produced. With the load tests the structural behavior will be examined in the serviceability limit state as well as the ultimate limit state.

5. Conclusion

Based on its material characteristics, various design considerations for RPC structures were discussed. The decision to examine the underspanned bridge beams was explained and justified. Regarding the next phase of the project, especially the nodes and the connections between the different constructive elements provide an interesting field of research.

6. References

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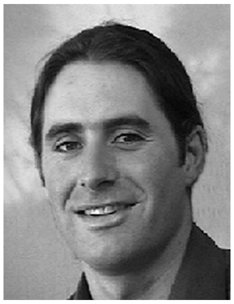

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