Proceedings of the 1st International Workshop on Service Life Design for Underground Structures

首届地下工程服务寿命国际专题研讨会论文集

Serviceability of Underground Structures

地下结构服役性能

Edited by YUAN Yong, J. Walraven, YE Guang

主 编［中］ 袁 勇

副主编［荷］ J. 瓦尔拉芬 ［中］叶 光

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袁 勇 主编 J. 瓦尔拉芬 叶 光 副主编

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Preface

On behalf of the Organizing Committee, it is our pleasure to welcome you all to the First International Workshop on Service Life Design for Underground Structures co - organized by Tongji University and Delft University of Technology. The workshop is supported by International Concrete Structure Association (fib), China Civil Engineering Society (CCES), International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM), National Natural Science Foundation of China (NSFC), and Science and Technology Commission of Shanghai Municipality (STCSM).

As a result of the booming of world's economy and the urbanization of many developing countries, an increasing demand has risen to a high quality large scale infrastructure. There is a growing consciousness that not only safety and serviceability have to be achieved, but as well durability and sustainability. In the design philosophy of underground structures in Europe, those two criteria have obtained an important position in the development of life cycle design principles. Meanwhile a substantial number of structures have been realized according to this new design philosophy. In order to support this development numerous research programs have been, and are being, carried out. This workshop aims at bringing leading experts all over the world together to present and discuss their new ideas on the philosophy of service life design and serviceability of underground structures, effects of methods and experiences gained up to now. The current event is the first joint initiative of Tongji University and Delft University of Technology, and we hope it will explore a wider cooperation between these two leading universities in future.

The workshop is deeply honored to have Professor Sun Jun and Professor Joost Walraven to be the chairmen of this workshop. We are extremely grateful for their kind support of the workshop.

We would also like to express our sincere gratitude to the keynote speakers and authors whose contributions have made this workshop possible. Our thanks also goes to all those who have devoted their time and effort in the organization of the workshop.

We hope that you all will have a pleasant and memorable stay and a fruitful exchange of knowledge and opinions in Shanghai.

Yuan Yong
Joost Walraven
Ye Guang
On behalf of the Organizing Committee.
October 2006, Shanghai, China

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HIGH PERFORMANCE CONCRETE AS A TOOL FOR DURABILITY OF STRUCTURES

J. C. Walraven

(Delft University of Technology, The Netherlands Delft 2600AA)

Abstract The development of concrete during the last 10 years may, without exaggeration, be qualified as revolutionary. In the paper the significance of conventional high strength concrete (up to about C115,) self compacting concrete and high performance fiber reinforced concrete is highlighted. It is shown that the aspect of durability plays a dominant role with regard to the chances of application of those materials. It is shown as well that "high performance concrete" is an intermediate step to "defined performance concrete"

1 INTRODUCTION

The development of the material concrete during the last 10 years may, without exaggeration, be qualified as revolutionary. A decade ago the maximum concrete class in most design codes was still C55/65. Meanwhile it has raised to C90/105 (Eurocode 2003). Some countries, like Germany, even allow designs in concretes up to C100/115. Further to high strength concrete, self-compacting concrete was developed, in the same strength classes. Considerable discussion arose on the question of SCC is in all respects comparable to conventional concrete, and whether the same rules apply. More recently a considerable development arose in the field of high performance fiber concrete. Now it is possible to compose concretes with cylinder compressive strengths of 200MPa and even more. Further to their high strength, those concretes exhibit an excellent ductility. Those new materials are a challenge to the structural designer. Several first projects have been realized. In line with the classical perception of design, those structures were designed principally for bearing resistance (safety) and serviceability. Since, during recent years, a growing consciousness developed with regard to the significance of the aspect "durability" or, in other words, "service life design", the supposed implicit durability of those new high performance materials was welcomed as a pleasant further advantage. The most recent development with regard to the ideas concerning structural design, is the consideration of a defined service life. This includes the selection of an appropriate material and structural system for any environmental condition. This brings further chances for those high performance materials, especially in the case of unfavorable environmental conditions. In this paper examples are given of the application of new types of high performance concretes, with special consideration of the role of durability.

2 FROM NORMAL STRENGTH CONCRETE TO HIGH STRENGTH CONCRETE (C90/105)

A first interesting case of a large size application of the "classical" high strength concrete C90/105 was the Stichtse Bridge, which was finished in 1996.

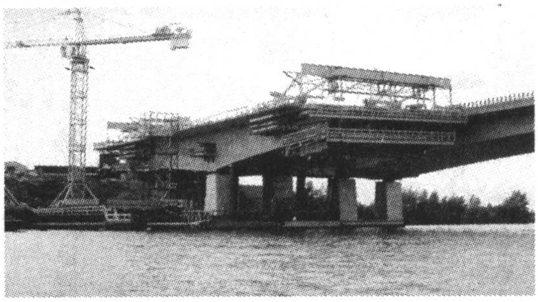


Fig. 1 Stichtse Bridge, the first prestressed bridge in high strength concrete (C90/105) in Europe, 1996

The prestressed bridge had a main span of 160m. The concrete was composed with 475 kg/m^3 cement (50% blast furnace cement and 50% portland cement (in order to reduce the rate of hydration and avoid early age cracking). The average 28-days cube strength was about 100MPa. The reduction of the weight of the upper part of the bridge was 30%. The reduction of the amount of prestresssing steel was as well about 30%. Similar savings concerned the foundation structure. A considerable advantage was, moreover, the speed of construction. In classical free cantilevering bridge structures the length of a section was 3.50m. Now, because of the weight reductions, the cantilevering equipment could carry a section with a length of 5m. This caused a reduction of the construction time with 3 months, with implicit considerable cost savings. On the basis of these cost savings, obtained with regard to the newly erected structure, the bridge in C90/105 was competitive with alternative designs in lightweight concrete C35/45 and normal concrete C55/65. However, the durability of the structure was considered as a further, considerable advantage. This was the more important, since the Ministry of Infrastructure is itself responsible for the maintenance. The definitive choice for HSC was taken on the basis of this argument. Soon after the finalization of the Stichtse Bridge, another bridge in C90/105, the Bridge Dintelhaven, Rotterdam, with a span of 170m, was built.

However, those two bridges appeared not to be trendsetting, as was expected after their successful realization. The most important reason for this was, remarkably, the further consideration of durability as a design criterion. Fig. 2 shows the basic idea behind this change in opinion. It shows the relation between the water/cement ratio, the degree of hydration and the water permeability (Powers, 1968).

It is shown that particularly in cases where the W/C ratio exceeds 0.6, the permeability increases considerably with the W/C ratio, due to the increase in the capillary porosity. The figure shows how the water permeability depends on the W/C ratio and the degree of hydration. In principle, the same influence holds true for gas and ion permeability. For a concrete C90/105 a W/C of about 0.4 is necessary. The figure shows, that for such a concrete with a degree of hydration of 80% and more, the permeability is near to 0. However, the figure shows as well that a well-cured concrete (high degree of hydration) with a W/C ratio of

0.5 gives as well a very low permeability. That means that also a structure built in C55/65, with appropriate curing, can guarantee a durability which is sufficient to keep the maintenance cost at a very low level during many years.

Calculations showed, that the optimum result, both regarding the cost of realizing the structure and its maintenance, is indeed obtained with a concrete C55/65, Nowadays the use of concrete C55/65 for bridges has therefore been accepted as the standard in the Netherlands.

Basically this is an interesting example of "defined performance design", a new approach, taking into account not only design criteria with regard to bearing capacity (structural safety) and serviceability, but as well a performance criterion concerning durability (defined low maintenance service life).

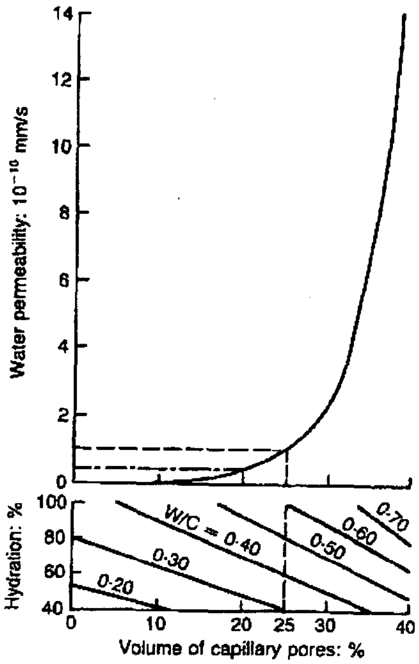


Fig. 2 Influence of W/C ratio on permeability of concrete (Powers, 1968)

An interesting example of the application of a modern high performance concrete including the aspect of durability is shown in Fig. 3. It shows the assemblage of a prestressed precast beam for the metro station of the Ajax Amsterdam Soccer Stadium. The structure consists of four box girder beams with at two sides a cantilevering platform. Altogether this means a length of 6 times 350m, or 2.1km of precast members. The individual beams have a length of 25m and are made of self-compacting concrete C55/65. The choice for self-compacting concrete was made for reasons of production. Not only the labour conditions in the precast concrete factory are considerably improved, because of the reduction of noise, dust and vibration, but also considerable advantages are obtained with regard to the cost of the formwork. For beams made in conventional concrete, normally heavy vibration devices are necessary, because of the mass of the beams. The formwork has to be designed to resist those vibrations. By using self-compacting concrete no mechanical vibration is necessary, which means a considerable reduction of the wear of the formwork. So, the formwork can be lighter and has a much stronger service life, which reduces the production cost. It should be noted that the choice of the concrete mixture is an optimum in al respects, including durability. Selfcompacting concrete has conquered the precast concrete industry because of its advantages in production. The optimum self compacting concrete is a cement-rich mixture, so that automatically higher strength classes are involved. The choice for a concrete C55/65 is therefore an optimum for the cost of materials, the production and durability.

Another interesting project, in which design for durability played a role, was the foundation of the high speed rail track from Amsterdam to Brussels. In the western part of The

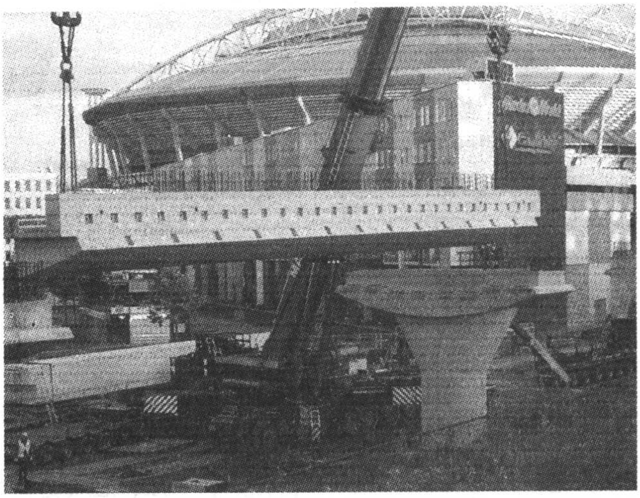


Fig. 3 Assembly of a precast SCC bridge beam in concrete strength class C55/65 in Amsterdam

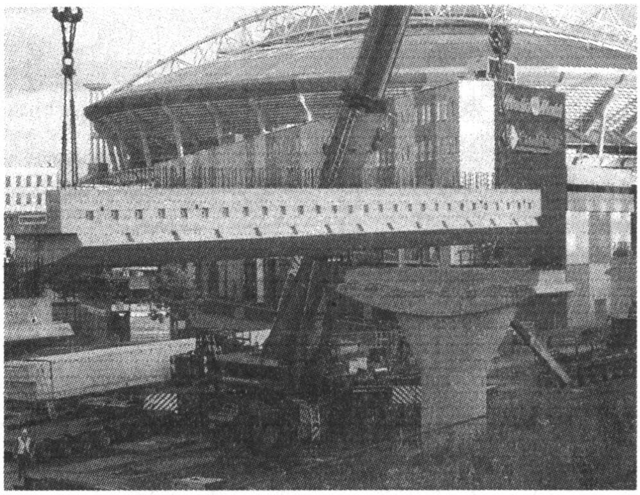


Fig. 4 Foundation piles for a settlementfree slab for the high speed railway track Amsterdam-Brussels

Netherlands the upper soil is weak and the bearing layer of sand is found at a depth of about 15m. This means that a pile foundation is inevitable. Altogether 500.000 piles had to be produced, transported and placed in order to enable this project, Fig.4. The piles support a concrete slab with a thickness of 500mm. No settlement of the slab is allowed, because of the difficulty of making adjustments in a later stage. Because of the importance of the project, and the practical impossibility of carrying out retrofitting during the use of the structure, high demands were imposed on the durability of those piles. According to the specifications, along the whole track at the surface of the concrete a chloride content had to be assumed, equal to that of sea water. Furthermore it had to be assumed that there is sufficient accessibility of oxygen to support the corrosion process. The quality of the concrete, which had to assure a maintenance free service life of 100 years, was essential, both in the sense of reliability and cost. Therefore comparison tests were carried out on mixtures with various W/C ratios and slag content of the binder. In the tests the gas-permeability and chloride penetration were investigated. The gas-permeability was measured with the so-called Cembureau test; the chloride penetration was measured by the Rapid Chloride Migration test. Fig. 5 shows the relation between the permeability and the W/C ratio for different slag contents. The figure shows that for a W/C = 0.4 the best results are obtained and that the slag content does not matter. However, for a slag content of 30% the results are still very reasonable, for all tested W/C values.

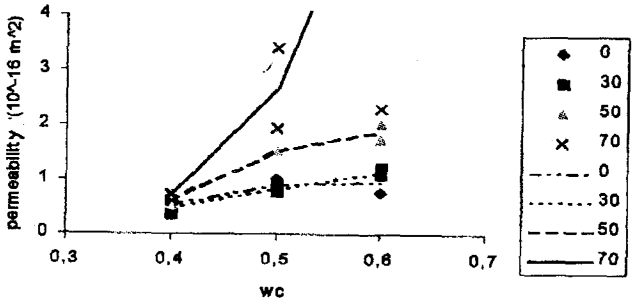


Fig. 5 Gas permeability as a function of water/cement ratio for various slag- % in the binder

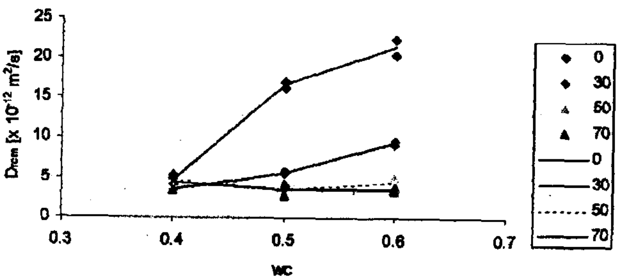


Fig. 6 Coefficient of diffusion as a function of the W/C-ratio and the percentage of slag in the binder

Fig. 6 shows the results of the chloride penetration tests. This figure shows that also here the best results are obtained for W/C = 0.4, which could truly be expected. However, a higher percentage of slag in the binder appears to be very favorable for all W/C ratio's tested. The figures show that for a W/C ratio of 0.5 with 30% slag content of the cement (giving a 28-day cube strength of 50 about MPa) the results are nearly as good as for a W/C ratio of 0, 4 without slag (giving a cube strength of about 70MPA). This shows that the highest strength is not always the best solution, especially if economic considerations play a significant role as well, like in the case considered.

This shows that "defined performance concrete" may be a more suitable target than "high performance concrete"

3 FROM HIGH STRENGTH TO ULTRA HIGH STRENGTH CONCRETE

About 10 years ago it became clear that the development of high strength concrete would not stop at a strength of about 100MPa. At the 4th International Symposium on "Utilization of High Strength/High Performance Concrete" in Paris 1996, for the first time attention was given to the properties and possibilities of concrete with ultra high strength. Ultra High Strength Concrete is made regarding the following considerations:

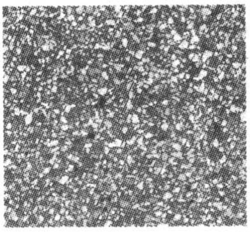
(1) Large aggregate particles lead to stress concentrations which limit the strength: the concrete should therefore be as homogeneous as possible by reducing the maximum particle size.

(2) The packing density of the particles should be as large as possible. This includes the appropriate use of fillers.

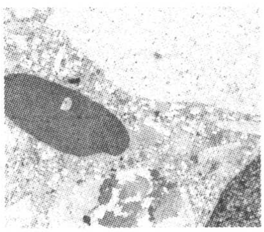
(3) Free water in the concrete should be avoided, since it leads to damage (internal stresses and microcracking due to drying out). So, the mixture composition should be such, that all the water is used for hydration. The remaining cement acts as a filler.

(4) Short fibers should be added for ductility.

It was shown that concretes up to strength classes B200 can be made on an industrial scale. It was claimed as well that even higher strengths then C200 are possible. In that case heating and pressure during hardening should be applied. Fig. 7 shows, for the sake of comparison, the material structure of a normal strength and a high strength concrete.



C200



C30

Fig. 7 Material structure of a concrete C200 in comparison with a concrete C30

An example of the composition of Ultra High Perfpormance Fiber Reinforced Concrete (UHPFRC) is given in the following. It is a so-called BSI (Béton Spécial Industriel) that was developed in France. The composition of 1 m^3 concrete is as follows:

Cement	1100kg
Silica Fume	165kg
Aggregate (0~6mm)	1050kg
Steel fibers 3 Vol. %	235kg
Superplasticizer	40kg
Water	200kg

The steel fibers had a length of 20mm en a diameter of 0. 3mm. The concrete is self-compacting and showed the following mechanical properties:

28-days cube comp. strength	175～210MPa
Axial tensile strength	8MPa
E-modulus	64 000MPa
Specific mass	2 800kg/m^3

Fig. 8 shows some beams made of BSI by the Dutch Firm Hurks beton. The beams were produced for the cooling tower of a nuclear reactor in Cattenom, France. The beams had to be resistant to the very aggressive environment in the cooling tower, due to spraying with chloride containing water and the warm inner climate. Before, precast concrete beams had been applied, which had to be replaced already after 25 years. Before applying the BSI beams a considerable testing program was conducted. The steel fibers are homogeneously mixed through the concrete. The outer end of the fibers at the concrete surface corrods, but this has no influence on the durability.

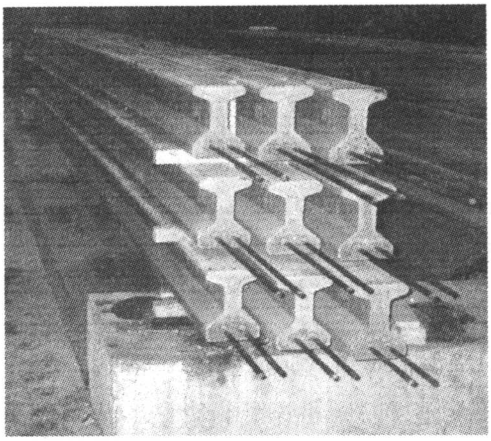


Fig. 8 Prestressed beams made of UHSFRC

Some beams were subjected to a three point bending test. They showed a large flexibility: a beam of 6m long and 0. 24m high showed at reaching the maximum load a deflection of 200mm, in combination with cracks up to 0. 3mm. After unloading, the beams fully recovered to their original shape and no cracks could be observed anymore. Under the maximum service load the cracks were very fine.

Fig. 9 shows another application: the viaducts in Bourg-les-Valences in France. Also here BSI was used. The beams were TT beams, which contained no other reinforcement than prestressing strands. The TT-element used have a width of 2 200mm and a cross-sectional depth of 900mm. The deck is 150mm thick.

The bridge has a weight which is only 1/3 of a bridge in conventional concrete. This compensates partially for the higher price of UHSFRC. Furthermore the beams can be more easily transported and mounted. Because of the high cost of the material, the design should be directed to get an optimum between dimensions, material cost and durability. In order to be able to achieve the optimum design with regard to safety, serviceability and maintenance cost