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Potentials and Developments of Materials for Structural Concrete

Potentiels et développements des matériaux pour le béton structural

Möglichkeiten und Entwicklungen der Werkstoffe für den Konstruktionsbeton

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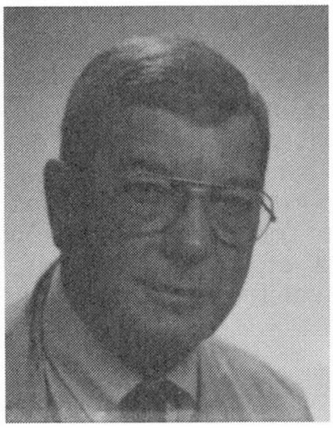

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SUMMARY

The structural materials concrete, reinforcing and prestressing steel as well as the post-tensioning systems in general reflect a high technical standard. Certainly, there exist regional differences in view of economic and other factors and due to different resources. Improvement will continue, new materials will advene. Dominant factor of materials development will be their suitability to satisfy the performance requirements of structures.

RESUME

Les matériaux de construction, c'est à dire béton, aciers d'armature et de précontrainte, systèmes de précontrainte, reflètent un niveau technologique généralement élevé. Certainement, il y a des différences régionales à cause de facteurs économiques et de ressources différentes. Le perfectionnement continuera, des matériaux nouveaux apparaîtront. Le facteur déterminant pour le développement des matériaux sera leur capacité à remplir les conditions de performance des structures.

ZUSAMMENFASSUNG

Die Baustoffe Beton, Bewehrungs- und Spannstahl sowie die Systeme zur Vorspannung weisen im allgemeinen einen hohen Entwicklungsstand auf, wobei bedingt durch wirtschaftliche und andere Faktoren sowie durch die verfügbaren Rohstoffe Unterschiede gegeben sind. Die Weiterentwicklung wird stetig voranschreiten, neue Werkstoffe treten hinzu. Wesentlich ist die Fortentwicklung der Werkstoffeigenschaften im Hinblick auf deren gezieltes «Performance» im Bauwerk.

1. INTRODUCTION

With its 1987 Symposium at Paris-Versailles the International Association for Bridge and Structural Engineering audaciously cast a glance into the future of the development of concrete structures. This glance was not a purely technological one. In fact, it dealt with the entirety of Vitruvian virtues the well - designed and well-built structure must possess: firmitas, the strength and durability; utilitas, the permanent fitness for use; and venustas, the immensurable architectural quality. It is the author's impression that the on-coming Leningrad Symposium adheres to this unified approach to structures, this time being devoted to bridges. In this triad of virtues materials play an important role.

The IABSE Symposium of Paris-Versailles and the 13th Congress of Helsinki belong to the very near past. So does the XIth FIP-Congress in Hamburg 1990. On all these occasions, the evolution of materials was dealt with, partly globally, partly specifically. Enlightening keynote lectures devoted themselves to this evolution from different personal view points [1], [2], [3]. Thus, it cannot be expected that in such short meantime lightnings of innovation have struck by the dozen. Nevertheless, it is important to follow both the steady stream of improvement and the emergence of innovative ideas pertaining to structural materials at close distance to keep the engineers in practice abreast with change.

2. ON CONCRETE TECHNOLOGY

2.1 Today's status

Many studies describe concrete as the dominant construction material also of the on-coming century. In view of concrete's known potentials, economy, and abundant raw materials base this forcast seems realistic. But even then, it will not only be concrete's adjustable compressive strength - which surely is an indispensable asset - but other concrete properties which will promote its use. Such properties are among others: durability, chemical resistance, protective quality for environmental engineering structure etc.

Concrete is the result of a steady evolution. Many efforts were necessary. Important ones pertain to: the clarification of cement hydration; the continuous improvement of the technology and quality control of cement production; the emergence of chemical admixtures and the rediscovery of pozzolana; and the advances of in-plant production technology and on-site processing and quality control of concrete. Science and industry have jointly shared these efforts. The state of compound knowledge on concrete technology is high. This fact is also true for the regulations. The new European concrete code prEN206 reflects the present standard of technique.

In the past decades the knowledge on the composition and behaviour of concrete, on admixtures and additives, on compaction and curing, etc. was primarily developed at universities, at governmental research centers and at laboratories of the cement industry. It appears that concrete suppliers and constructors are becoming increasingly involved in developmental work for specific tasks. Especially in Japan significant job-tailored research and development is performed today by the concrete contractors themselves. The author believes that in the future it will be essential to bridge the gap between research and practice more expediently and effectively as today. Materials research must orient itself more to performance demands and the technologies of execution. Experience of the past enforces to focus more on durability and other performance related concrete properties than on the strength. Encompassing quality control will ensure the realization of envisaged properties of concrete in the structure. In the context with quality assurance, it is expected that the development and use of non-destructive, on-site test methods to ascertain the attainment of performance related concrete properties and others in the structure will gain strong momentum.

The advancement of concrete technology is a steady stream, with many steps of improvement. This process will continue. The development of new materials will persuade designers and constructors to new applications. New designs, novel construction methods, and new applications will inspire materials development, e.g.: polymer modification, shrinkage compensating concrete, fiber reinforcement, etc. Competition with structural steel for high-rise buildings leads to high-strength concrete. There are many examples and questions. Only high strength concrete can be dealt with here, because of its great potential.

2.2 High Strength Concrete

High strength concrete HSC is strongly discussed nowadays and increasingly applied. It is not an invention, but the result of evolution. This evolutionary process lasts already for several decades, it is still going strongly. It is interesting to note that HSC initially emerged at centers of application and not at those of basic research. Such centers are Chicago and Seattle in the U.S., where concrete suppliers, designers, materials technologists, and scientists successfully used HSC for high-rise buildings. Certainly, today HSC is applied in many other places and for a variety of structures. Certain European countries definitely lag behind in this development.

Codes for conventional concrete structures specify upper limits for the compressive strength in the range of C50 to C60 (cylinder strength at 28 days in MPa). The CEB-FIP model code MC90, forerunner of future European concrete rules, points to a C80 strength class which then represents HSC. One of the latest applications in Chicago used HSC with a 56 days strength of 96 MPa for the columns of a high-rise structure. Pilot applications with a strength of around 130 MPA are reported. Such applications reveal the initial goals of HSC: reduction of column size, increase of net floor space, increased stiffness, less creep and shrinkage of concrete. The state of art and the widening scope of application is presented in [4].

High strength of concrete is realized along two ways. Firstly, by lowering the water-cement-ratio in conjunction with advanced methods of materials selection, concrete processing technology and quality control. Secondly, by densification of cementstone and by strengthening the paste-aggregate interface, a goal which can be attained by the addition of ultra-fine silica fume. As the water-cement-ratios for HSC are in the range of 0.3, workability of fresh concrete requires super-plastizisers. In order to improve the workability of fresh concrete, to reduce the heat of hydration, etc. also other pozzolana (ggbs, pfa, etc.) are used. High-density natural aggregate is a prerequisite for very high compressive strength. It is interesting to note that also strong lightweight aggregates can be used.

As the low water-cement-ratio eliminates capillary porosity, HSC has a very low permeability, an essential asset to durability. Though current research is still non-conclusive with respect to the freeze-thaw-resistance in conjunction with deicing salts and air entrainment, HSC is increasingly used for structures subjected to severe environments, such as bridges and car parking garages.

3. ON REINFORCING STEELS

Considered on a world-wide range the development of the non-prestressed normal reinforcement in the shape of straight deformed bars and welded wire mesh is presently in a rather stable state. For usual structural applications the strength grades range between 400 and 500 MPa (yield strength). The bar diameters are usually less than 40 mm. For flexural members the requirement of adequate serviceability sets a limit to the longitudinal steel stress and bar diameter under service load action. For members remaining under service load in the uncracked state these limits may be reconsidered as the use of large diameter bars not only renders enhanced economy but also improved casting and compaction of concrete [2]. This fact is especially true for compression members using high-strength concrete. In consequence of the benefits of the use of large-diameter and normal grade to high-strength bars for massive concrete elements such reinforcing elements are being produced and partly also standardized in Europe, in the United States, in Japan [2], and in the USSR [5]. As the lap splicing of large diameter bars causes severe structural detailing problems and detrimental congestion of reinforcement, the threading of bar's surface facilitates mechanical coupling and end anchoring.

The increase of yield strength and of the bar diameter represents only one aspect of technological development. Economic execution of work requires weldability for all standard welding techniques, also under unfavourable site conditions, without embrittlement of the steel. This aspect and others require additional development.

Especially for marine structures and for some structural components of bridges the durability of the reinforcement may be endangered by the ingress of chloride ions through the concrete cover. Zinc coating of bars does not enhance durability for this type of chemical attack. An effective alternative proved to be the epoxy-coating of bar, a protection now being mandatory for bridge decks in parts of the U.S.

4. PRESTRESSING STEEL AND SYSTEMS

4.1 On Steel Development

The development of the steels for prestressing followed in the past decades different lines. It seems that these lines were not solely determined by technical reasons. For the steel industry the production of prestressing steel never had great economic importance. Thus, materials development depended also on the available production techniques and not only on the demands of concrete industry. In state-controlled economies the development of materials also appears to be politically decreed.

In the Western Countries and in Japan the concrete industry's demand for an increased strength of the prestressing steel seemed to be the dominant factor for development. Consequently, the quenched and tempered prestressing steel was gradually crowded out by the colddrawn, stress-relieved or stabilized wire and strand of high strength. In parallelity with the increase of strength also the increase of total cross-section of strands occurs. We have to expect in the future that 0,7" strands with a strength of 2050 MPa will be used for post-tensioning or maybe even for pretensioning.

The author accepts to be chided for his conservative attitude. However, he is not able to discover the benefits of such a solely economy-oriented development which does not consider the entirety of consequences. Just a few remarks: as strength increases, ductility and fracture toughness will decrease; because permanent prestress is linked to strength, susceptibility of steel to various types of stress corrosion will increase; etc. Hence, new developments must be judiciously introduced with all problems involved being well deliberated.

It is interesting to note that the quenched and tempered steel is in Asia still strongly used. Though having a limited scope of application, the large diameter prestressing bar (yield strength of 800 to 1100 MPa) with either a smooth or threaded surface is owing to its versatility widely used for rock and ground anchors, for tendons and stays, etc.

4.2 Systems and Corrosion Protection

After decades of intensive development, the various anchorage types of post-tensioning systems have attained a high degree of efficiency, reliability and economy. The number of systems reduces, concentration occurs. Systems producers constantly improve with respect to practicability, to the use of tendons as stays, etc.

In contrast to the high standard of anchorage development, the cement injection of ducts of bonded tendons is entailed with the risk of steel corrosion if improperly executed and if deleterious media will enter the duct. Although the protective quality of cement grout is undisputed, adverse conditions on the site may lead to defective grouting. Active improvement of the rheology of fresh cement grout by silica fume modification can remove some of the uncertainties. Still, this method remains tarnished by the uncontrollability of the grouting quality attained. Further improvement is needed.

The development of mono-strand which is encapsulated in PE sheating and protected by grease is one of counter-measures against steel corrosion. The post-tensioning with external unbonded tendons is - together with suitable protection techniques - also one of the methods to counteract corrosion. It is believed that many innovative improvements will arise in the future.

5. EMERGENCE OF FIBER REINFORCED PLASTICS

Fiber reinforced plastics FRP have become an indispensable group of materials for aircrafts and many other applications. Endless, ultra-thin fibers, made from glass, aramid and graphite, are embedded in a thermo-setting matrix resin, in either unidirectional or multidirectional fashion. Thereby, an anisotropic composite arises. The tensile strength of the purely elastic fibers is in the range of 3 to 6 GPa, that of the resin being rather low. Hence, in the composite element, e.g. a prestressing rod, the strength of fibers will be transformed into composite strength dependent on the volume ratio of fibers. With usual fiber volumes of 50 to 70 %, the tensile strength of high grade prestressing steel may easily be matched by FRP. An overview on the potential and properties of FRP is given in [6].

FRP have a high and adjustable axial tensile strength, they are extremely corrosion resistant in many environments and they are very light. These assets caught the interest of the concrete industry, which is looking for alternative materials especially for applications with a high risk of steel corrosion. All over the world cooperations between concrete firms, chemical industry and research institutes were founded for the development and pioneering application of FRP reinforcements, tensile rods for the pre- and post-tensioning of concrete structures. Pilot applications and promising innovations were reported at the IABSE Symposia of Paris-Versailles, Helsinki and Brussels.

There is no sufficient space to deal with these new advanced and still expensive materials in detail here. It is believed that they will in the near future be frequently applied especially in such cases where a high corrosion risk of the prestressing steel and of the conventional reinforcement cannot be eliminated either reliably or economically. The great interest of concrete industry and research is underlined by a very active pre-standard comitee activity all over the world and a series of special conferences in the near future.

6. OUTLOOK

The definition structural concrete must be understood in encompassing breadth. It comprises not only the composite of concrete and steel with or without prestress but the entirety of structure from the design to the realization and maintenance of the structure. Hence the development of materials is strongly interlinked with design and execution, each mutually exerting influence, demand and inspiration upon the other.

The state of knowledge and experience regarding the conventional materials concrete, reinforcing and prestressing steel and post-tensioning systems is rather high, although regional differences of quality cannot be denied. It is believed that in the future the transfer of research findings into practical application will gain momentum. This certainly requires: continuous education of practitioners.

The improvement of conventional materials will continue, revolutionary discoveries are hardly to be expected. Strength is not anymore the dominant virtue of a structural material, it falls in line with other properties equally important for the structure's performance in service. Performance orientation will result in encompassing quality assurance and control of materials, methods, and systems. Stronger focus on durability related performance becomes essential to drastically reduce embarrassing concrete defaults. New non-corroding fiber plastics will supplement conventional materials in special applications.

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