

**CHINA –**

**CONCRETE CONSTRUCTION INDUSTRY – CEMENT BASED MATERIALS AND CIVIL INFRASTRUCTURE (CBM & CI)**

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**ABSTRACT:** This paper presents a summary of major advances in China regarding the concrete construction industry in the last five years (2002-2007). The advances in the materials affect the design and construction of the facilities. These facilities are essential to the well-being of the nation's civil infrastructure.

The issues facing the technology of concrete materials/production/quality assurance practice/design/construction and the maintenance of constructed facilities are summarized.

The paper summarizes the potential advances that may occur in the following decade (2008-2018) in concrete technology in China and their effect on the concrete construction industry in China.

## 1. INTRODUCTION

### 1.1. Demographics

China is the most populous country in the world with 1.314 billion people by the end of 2006, about one-fifth of the world's total. Most of the population lives in the middle and lower reaches of the Yellow River, Yangtze River and Pearl River valleys, and on the Northeast Plain. The population density is about 350 persons per mile [1, 2] (135 persons per km<sup>2</sup>), roughly four times greater than that of the U.S.

### 1.2. Education

Since 1950, China has provided nine-year compulsory education for a fifth of the world's population with only two percent of the world's total education spending. It has the world's largest number of people receiving education, more than 300 million. Net elementary school enrollment has reached 99%, and gross enrollment rates in junior high schools, senior high schools, and higher learning institutions are 95%, 53% and 21%, respectively. Nine-year compulsory education operates in more than 95% of China's populated areas, illiteracy in the young and middle-aged population is under four percent, and education in China has reached the average level for middle-income countries. By the end of 2005, China had 2,273 institutions of higher learning with more than 21 million students.

Population	1314.48 million	(December 2006 estimate)	
Age structure	0-14 years	15-64 years	65 years and over
	19.8%	72.3%	7.9%
Male	51.5%		
Female	48.5%		
Population growth rate	5.28‰	(2006 estimate)	
Birth rate (est. 2006)	12.09 births//1,000		

### 1.3 Unique Materials and Environmental Conditions

The environmental conditions in China are relatively harsh for concrete materials and structures with aggressive exposure to salt and sulphate attack. In summer, the temperature is high in most of China while in winter the temperature varies greatly between the northern and southern parts, from -30 °C to above 20 °C.

## 2. OVERVIEW OF THE LAST FIVE YEARS (2002-2007)

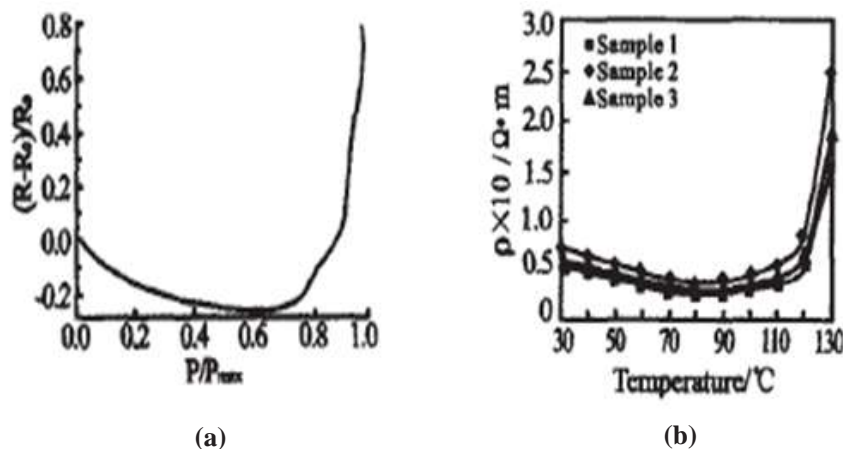
### 2.1 Materials

#### 2.1.1 Carbon Fiber Reinforced Concrete (CFRC)

Carbon fibers reinforced polymer mixed in concrete can not only improve the tension strength of concrete, but also can improve its electro-thermal effect, piezoresistivity, temperature resistance, electromagnetic shielding effect, and electro-mechanical effect. CFRC is now being studied as a kind of smart concrete at the Wuhan University of Technology. **Figure 2.1** (adapted from reference [3]) show some of the effects of CFRC mentioned above. In China, CFRC will play an important role in the maintenance, repair and retrofit of the existing structures and in construction of new structures of the future that are intelligent concrete structures.

#### 2.1.2 Self-Consolidating Rock-Fill Concrete (RFC)

Self-consolidating (also termed as self-compacting) rock-fill concrete (RFC) is a new kind of concrete proposed by Tsinghua University. This type of concrete is constructed by pouring the self-compacting concrete into the rock-fill body. Laboratory test results show that by using this technology a dense and high strength concrete structure can be easily constructed. Higher speed of construction, lower price and lower temperature rise due to hydration make this technology available in the construction of mass concrete such as RFC arch dam/gravity dam and RFC core rock-fill dam [4].



**Figure 2.1** (a) Sense, balance and increase zones of CRRC under stress, (b) character change of CFRC resistance under different temperatures. Adapted from reference [3].

### 2.1.3 Reactive Powder Concrete (RPC)

Reactive powder concrete (RPC) is an ultra-high-strength, high-ductility, low-porosity cementitious composite material with advanced mechanical and physical properties. By introducing fine steel fibers, RPC can achieve remarkable flexural strengths up to 7,000 psi (50 MPa). **Table 1** presents typical concrete mixture proportions and mechanical properties of RPC200.

Beijing Jiaotong University has been studying mineral admixtures, fiber types and curing methods for RPC since 1999. RPC materials with the compressive strength of 10,350 psi (140 MPa), flexural strength of 2,400 psi (16 MPa), and lost weight ratio of 0.0 after 800 cycles of freezing and thawing were produced and applied in a sidewalk flat system in the Qinghai-Tibet railway project. These materials satisfied the special needs of the tough environment on the Qinghai-Tibet plateau [5,6].

## 2.2 Production

Lots of key projects, such as the Three Gorges Project (TGP), Qinghai-Tibet Railway Project, South-to-North water diversion project and Beijing Olympic facilities, are under construction in China, thus increasing the demand for and production of cement and concrete. There are more than 60 large cement production companies and about 2000 concrete producing companies. Large cement production companies are defined as companies with greater than 1 million tons of production. The amount of concrete produced/year in China is approximately 2.6 billion cubic yards (2 billion cu meters), and the average growth rate is larger than 10%, which is expected to last 5-10 years (**Table 2**) [2, 7, 8].

**Table 1** Typical concrete mixture proportions and mechanical properties of RPC 200

Mixture Proportions Plain or with fibers	mixture proportion		mixture proportion
	Without fibers	With fibers	With fibers
Cement	1	1	1
Silica fume	0.325	0.325	0.325
Sand	1.432	1.432	1.43
Reactive sand	0.3	0.3	0.3
Super plasticizer	0.027	0.027	0.027
Water	0.28	0.28	0.26
Steel fiber	—	0.2	0.2
Compressive strength psi (MPa)	24,000 (163)	31,000 (217)	28,000 (/197)
Variance coefficient (%)	4.00	11.0	9.0
Elastic modulus psi x10 <sup>6</sup> (GPa)	6.5 (46)	6.9 (49)	6.9 (49)

**Table 2** Production of cement and concrete in China, 2002-2006

Year	Cement Production (billion tons)	Growth rate	Concrete Production (billion cu m)	Ready-mixed Concrete Production (billion cu m)	Percent of Ready-mixed Concrete
2006	1.24	16.9%	2.16	0.43	19.9%
2005	1.06	10.0%	1.85	0.36	19.5%
2004	0.97	12.5%	1.7	0.29	17.1%
2003	0.86	18.9%	1.5	0.21	14.0%
2002	0.72	9.1%	1.3	0.14	10.8%

### 2.3 Quality Assurance Practices

In the last five years, significant advances have taken place in the quality assurance of concrete materials and structures. For example, to strictly control the project in TGP, a good quality assurance system was established and played an important role in the quality control of TGP. This included the China Yangtze Three Gorges Project Standards (TGPS), a quality management organization and responsibility system, a quality accident response procedures reward and penalty system, a unit work appraisal system, and a stratified quality inspection system.

### 2.4 Design Practices

The *code for design of concrete structures/GB50010-2002* is used by the designers in China. This code is a revision of *GB50010-1989* and was enacted by ministry of construction of China in 2002.

### 2.5 Construction Practices

The world-famous Three Gorges Project and the Qinghai-Tibet Railway Project are examples of successful construction practices with proper planning, scheduling, and implementation. These have resulted in modern wonders of the world. These two projects are briefly described below.

#### 2.5.1 Three Gorges Project (1993-2009)

The total volume of the main projects, including the dam and power station buildings, is about 36.7 million cu yards (28 million cubic meters), which is world's largest hydropower project as far as the total quantity of concrete placed [9]. In 1999, 2000 and 2001, the volume of concrete placed reached 6.0, 7.1 and 5.3 million cu yds (4.58, 5.4 and 4.02 million

cu m), respectively. The maximum volume of concrete placement per day/month/year is 28 thousand cu yds (22 thousand cu m), 0.72 million cu yds (0.55 million cu m) and 7.1 million cu yds (5.4 million cu m) respectively, all of which have exceeded the world records set by the former USSR Kuibyshev hydropower station.

Joint construction technology based on hi-tower flatliners was used in TGP to assure the speed of concrete placement, which used six hi-tower flatliners as the main equipment and gantry cranes, belt cranes, and cable cranes as auxiliary equipment.

### **2.5.2 Qinghai-Tibet Railway Project**

The Qinghai –Tibet Railway project is another miracle in the world in construction practices because the 1216-mile (1956-kilometer) railway, including a number of concrete bridges and concrete piles, has been built in five years (2001-06-29 to 2006-07-01) under such a severe environment. The constructors successfully overcame the challenges of permafrost, low temperature, and lack of oxygen on the roof of the world. Concrete with high durability and high performance concrete was used and *Technical standards for the durability of concrete in perennial frozen ground on the Qinghai-Tibet Railway* were enacted to ensure the quality of the concrete construction [6]

## **2.6 Maintenance of Existing Facilities**

There has been some effort in the past to strengthen and repair existing concrete structures. The total area of the buildings in China is at least 10.9 billion square yds (10 billion square m), most of which are concrete structures built over 20 years ago. Thus far the total square meters of strengthening and repairing work has been more than 1 million square meters. Traditional methods such as the exterior-steeling method, pre-stressing methods and section-enlargement methods are being used in China for the strengthening/retrofitting of existing facilities [10].

## **3. ISSUES - CONCRETE INDUSTRY**

### **3.1 Materials**

Raw materials for concrete are plentiful in China. The cement production there is almost half of the production of the world. The biggest issue is that the energy consumption is too high, and about 0.15 tons of coal are consumed when one ton of cement is produced, which is 15% higher than the advanced level of the world. Since 2001, new dry process kilns to produce cement have been developed at a faster pace to reduce the energy consumption of cement production.

### **3.2 Production**

The degree of mechanization of concrete production plants is still low in China. Currently, ready-mix concrete constitutes about 20% of the total concrete market. This is likely to increase to about 40% in the coming decade.

### **3.3 Quality Assurance Practices**

In the past five years, the typical 28-day cube strength of concrete has been between 4,350 psi (30 MPa) and 7,000 psi (50 MPa). More and more companies compete to produce concretes with strengths in excess of 12,000 psi (80 MPa) to reduce the designed sizes of building sections and to increase the speed of construction due to the early strength gain of high strength concretes. However, the wide use of concretes with early high strength and higher cement fineness has led to unexpected cracks in some structures. This has become a common problem in China for recently constructed concrete structures.

### **3.4 Design Practices**

Several problems exist in some of the codes for the design of massive concrete structures. For example, *Design specification for concrete arch dam / SL 282-2003*, which provides requirements for stress control on concrete arch dams, is not comprehensive and has some drawbacks. In the design standard, there is no relation between the required standard stress and the importance of the structure, and the main tensile stress is not related to the strength of the concrete.

### **3.5 Construction Practices**

Although in the past five to ten years useful experience has been gained in quality control, speed of construction, temperature control of concrete material during production and placement, a number of aspects still need to be improved. For example, requirements or guidance on preventing cracking of massive concrete structures such as concrete dams remains to be improved.

### **3.6 Maintenance of Existing Facilities**

Since the infrastructure is relatively new, currently the need for maintenance of existing facilities is not a prime concern. As the infrastructure ages, there need for maintenance will become more important. The growth of construction is expected to rise in the coming decade and thus the total volume of civil infrastructure will be much larger in a decade's time.

Currently, there is no established code for the maintenance and repair of existing facilities. In the near future it is anticipated that effort will be directed towards development of guidelines, specifications and a code for maintenance and repair of concrete structures.

Use of newer materials such as fiber reinforced polymers (FRP), specifically carbon fiber plastic reinforced polymers for repairs/retrofitting of concrete structures, are not widely used in China. Currently there are no required process and quality standards for materials to be used in the repair and maintenance of existing facilities in China. This is partly because most of the civil infrastructure is relatively young and new construction seems to be in great demand.

## **4. THE NEXT DECADE (2008-2018) – POTENTIAL ADVANCES**

### **4.1 Potential Advances - Materials**

For concrete material, it is anticipated that more use will be made of mineral admixtures (blast furnace slag, fly ashes, silica fume, etc.). This will be necessitated by various needs, such as to reduce the heat of hydration for mass concrete, to improve the durability and strength properties of concrete, and to replace part of the cement in concrete to reduce the cost and/or to address the issue of environmental effects (from the production of cement).

### **4.2 Potential Advances - Production**

The construction of cement production plants and the concrete production facilities are on the rise. It is anticipated that cement produced by new dry process kilns will take up nearly 70% of the cement market, and more additives will be added to the cement to decrease the high amount of energy consumed in its production. The production of concrete is likely to increase by 10% over the next 10 years. Ready-mixed concrete is likely to be about 40% of the total concrete used in the future. There will also be an increase in the mechanization of the production of concrete, and this will improve the quality of concrete and reduce its variability.

One of the most important aspects of concrete production in China will be that the concrete industry is likely to turn into a green industry (meaning more attention to sustainability issues) in the next several decades.

### **4.3 Potential Advances - Quality Assurance Practices**

In the next decade, it is anticipated that quality assurance systems like that used in the Three Gorges Project (TGP) will be employed in more construction projects to control project quality.

#### **4.4 Potential Advances - Design Practices**

With the development of technology for concrete construction, more challenging designs such as higher buildings/dams with fabulous shapes and structures will be undertaken in China.

#### **4.5 Potential Advances - Construction Practices**

In the next decade, Chinese construction workers are likely to take up larger civil projects, such as the South-to-North Water Diversion Project, the Western China Development Program, hydropower station construction in Southwest China, and the high-speed railway project.

#### **4.6 Potential Advances - Maintenance of Existing Facilities**

New materials, such as FRP and intelligent materials, will be researched, studied, and developed for the maintenance and repair of constructed facilities. In addition, quality standards for the maintenance of concrete facilities will be established.

### **5. SUMMARY**

This paper presented the advances achieved in the concrete construction industry in China in the last five years and potential advances anticipated in the next 10 years. The advances anticipated in the materials affect the trends, especially for new construction and maintenance of existing facilities in the civil infrastructure. It is anticipated that for the maintenance of existing facilities, there will be substantial reliance on and use of newer types of concretes and alternate materials like FRP materials.

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