Vinnytsia National Technical University
(full name of the higher education institution)

Faculty of Construction, Civil and Environmental Engineering
(full name of the institute, name of the faculty)

Department of civil engineering, urban planning and architecture
(full name of the department)

MASTER'S QUALIFICATION THESIS

On topic:

«Self-compacting concretes for the formation of complex monolithic constructions with the use of additives»

Performed by: 2nd year student, group 2B-22m

Specialty 192 Civil Engineering and Construction
(code and name of specialty)

SUN Wenjun
(surname and initials of student)

Supervisor: PhD, docent POPOV Volodymyr O.
(surname and initials)

Opponent: PhD, docent REZYDENT Natalia V.
(surname and initials)

Admitted to defense

Head of Department CEUPA

PhD, docent Shvets Vitaliy V.
(surname and initials)

«____» ________________ 2024

Vinnytsia, VNTU – 2024

Vinnytsia National Technical University
(full name of the higher education institution)
FACULTY OF CONSTRUCTION, CIVIL AND ENVIRONMENTAL ENGINEERING
(full name of the institute, name of the faculty)
DEPARTMENT OF CIVIL ENGINEERING, URBAN PLANING AND ARCHITECTURE

Education level master
Studies direction 19 Architecture and construction
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APPROVED
Head of Department CEUPA
Svets V.V.
«__» ________ 2024

T A S K

OF MASTERS QUALIFICATION THESIS

Sun Wenjun
(FULL NAME)

1. Master's thesis topic Self-compacting concretes for the formation of complex monolithic constructions with the use of additives
Master's thesis supervisor Popov V.O., PhD, docent of CEUPA Department,
(surname, first name, patronymic, academic degree, academic title)
approved by order of the higher educational institution from «__» ____ 20__ No___
2. Deadline for submission of work by a master's student June 10, 2024
3. Initial thesis data: Work by scientific direction. Current regulatory sources on preparation of concrete mixture and their components. Initial information on self compacting concrete (SCC), its physical and mechanical properties in the unhardened state, information on the rational use of SCC during reconstruction under compressed conditions to strengthen defective structures and to create complex forms, information about the advantages and disadvantages of SCC over ordinary concrete
4. Content of the settlement and explanatory note (list of issues to be developed): Introduction, which should reflect the relevance of the topic, purpose, scientific novelty, research methods, tasks, object and subject of research. The research part, consisting of three sections: Chapter 1, in which have to be performed an analysis of the state of designing the receipts of ordinary and SC concrete mixtures, advantages and disadvantages, methods of rational application and engineering experience of application on bases of normative and literary sources on the topic of MQT. Chapter 2, in which have to be performed comparison of recipes of self-compacting concrete according to the preparation methodology of the Sika company and Chinese standards, and a rational method of preparation is proposed. Chapter 3 – should contain information on the rational technology of SCC application for strengthening building structures, including engineering recommendations for quality control of concrete and finished products using SCC. Chapter 4 — Economic part, in which to investigate

the economic effect of the offered solutions of SCC mixture in comparison with classic ones. Conclusion in which to reflect the main scientific and practical results of the work performed

5. List of graphic material (with exact indication of mandatory drawings)

Posters that reflect: 1-5 — topic, purpose and tasks of the work, scientific novelty, research objec subject of study, main goals, publications; 6-7 — the current state of the theory and practice of monolith concrete in China with concrete development, the differences between SCC and ordinary concrete, 8-1 — rational preparation technology and recipe of self-compacting concrete by China and Europea standards on example of B35 (C30/35); 11-14 – rational technology of application of self-compactin concrete; 15-16 – Results of economic calculations; 17-18 – MQT Conclusions

6. Consultants of thesis parts

Part	Surname, initials and position of consultant	Signature and date	
		Task issued	Task accepted
Introduction, Chapter 1	Popov V.O., docent of CEUPA Department		
Chapter 2	Popov V.O., docent of CEUPA Department		
Chapter 3	Popov V.O., docent of CEUPA Department		
Chapter 4. Economic part	Popov V.O., docent of CEUPA Department		

7. Issue date of the task February 04, 2024

CALENDAR SCHEDULE

No	The name of the stages of the master's qualification work	The term of performance of work stages	Note
1	Scientific analysis of the state of the design of concrete mixtures for repairing and strengthening defective structures, description of properties of SCC. Preparation the Chapter 1.	to be completed by March 20, 2024	
2	Preparation the Introduction.	until 01.04.2024	
3	Preparation the Chapter 2. Rational preparation technology and recipe of self compacting concrete	to be completed by April 10, 2024	
4	Preparation the Chapter 3. Rational technology of application of self-compacting concrete	to be completed by April 30, 2024	
5	Preparation the Chapter 4. Economic part Preparation the Conclusions.	to be completed by May 15, 2024	
6	Preparation for publication and publication of MQT results. Approbation	to be completed by May 30, 2024	
7	Checking work for plagiarism	10.06.2024	
8	Preliminary defense of the master's qualification thesis	12.06.2024	

Graduate student ________ SUN Wenjun
(signature) (surname and initials)

Master's thesis supervisor ________ POPOV V.O.
(signature) (surname and initials)

ABSTRACT

UDK 624.012.4-183.2, 624.21.09

Sun Wenjun. Self-compacting concretes for the formation of complex monolithic constructions with the use of additives. Master's qualification thesis in the specialty 192 - "Civil Engineering and Construction", educational program - "Industrial and Civil Engineering". Vinnytsia: VNTU, 2024. 108 p.

Have been studied the application of self-compacting concrete in bridge, chemical building structures strengthening engineering and other types of reinforcement structures engineering and also, during the construction of new structures of complex geometric shape in the master qualification work. Have been optimized the preparation method of self-compacting concrete by scientific comparing the receipt of formation self-compacting concrete mixture in China and Europe.

On the example of strengthening existing defective reinforced concrete structures of bridges and foundations of technological units of chemical production have been carried out the rational technological recommendations for the use of self-compacting concrete were developed and optimization of these solutions Have been summarized the construction process of self-compacting concrete bridge reinforcement and corresponding quality control suggestions. Finally have been the economy of self-compacting concrete and traditional concrete, which has certain guiding significance.

The master's qualification work contains 38 sheets of graphic part.

Key words: monolithic reinforced concrete structures, methods of reinforcement, complex shape, self-compacting concrete, adhesion superplasticizers, polycarboxylates, microsilica, additives, fly ash.

摘要

UDK 624.012.4-183.2, 624.21.09

孙文俊,自密实混凝土与添加剂的使用形成复杂的整体结构。硕士学位论文专业编号 192 -“建筑与土木工程”，研究方向-“施工管理”文尼察:VNTU, 2024。108 页。

研究了自密实混凝土在桥梁、工业建筑结构加固工程和其他类型的钢筋结构工程中的应用，以及在复杂几何形状的新型结构施工中的应用。通过科学比较中国和欧洲的自密实混凝土配合比，优化了自密实混凝土的配制方法。

以实际工程中既有缺陷钢筋混凝土结构的桥梁及基础加固为例，提出了合理的自密实混凝土使用技术建议及优化方案，总结了自密实混凝土桥梁加固的施工过程及相应的质量控制建议。最后对自密实混凝土的经济性与传统混凝土进行了比较，具有一定的指导意义。

硕士论文工作包含 38 张图形部分。

关键词:整体钢筋混凝土结构，加固方法，复杂形状，自密实混凝土，粘结性减水剂，聚羧酸盐，硅粉，添加剂，粉煤灰。

Introduction

Actuality of topic. Today, in the People's Republic of China, in Europe, and throughout the world, there is an urgent problem of reconstruction and strengthening of existing dilapidated buildings and structures. This especially applies to building structures made of reinforced concrete in important sectors of the national economy, such as production and road and transport infrastructure.

World experience in reconstruction design shows that the cost of such works often exceeds the cost of new construction. However, sometimes it is unprofitable to stop technological processes or break transport and logistics connections. Accordingly, in such a case, the only possible and rational option to restore the design characteristics of buildings is to perform strengthening works. This especially applies to building structures of bridges, powerful technological units of continuous chemical production and other responsible building structures.

In such cases, cost-effective reinforcement of defective structures is carried out using one of the well-known classic methods, such as changing the design scheme, installing a metal bracket, and arranging a reinforced concrete jacket etc.

However, classical methods of strengthening do not always allow to achieve the desired result. This is due to the problems of bad adhesion of fresh concrete of reinforcing structures to old concrete of a defective structure, incomplete inclusion of reinforcing structures in the work, technological complexity of performing reinforcement works.

In addition, the use of the classical technology of reinforcing structures with the use of pre-reinforced concrete jacket is often hindered by the compressed conditions of work, under which it is not possible to either supply the mixture to the place of reinforcement, or to effectively vibrate the place of reinforcement and, finally, to control the quality of the work.

One of the newest methods of overcoming these problems is the use of highly mobile, fast-hardening concrete mixtures to restore or increase the design strength of the responsible defective building structure. One of the examples of such mixtures is self-compacting concrete, which is able to penetrate into all cracks and cavities without vibration, that is, without the participation of manual human labor.

However, the cost of such repair mixtures is very high. Thus, there are economic obstacles to the mass implementation of this technology.

Therefore, the study of the issue of rational strengthening of worn building structures, especially complex forms in compressed or hard-to-reach conditions of a real construction site with the use of the latest and effective building repair mixtures is important and relevant.

Connection of work with scientific programs, plans, topics. The scientific work was carried out in accordance with the research topic of the department of Construction, Urban Economy and Architecture, VNTU, Ukraine, No60-K6 "Improvement of calculation methods and technologies of automated design and installation of the building-foundation-base system, taking into account information technologies for supporting construction objects" (01.01.2024-31.12.2026).

The purpose and objectives of the study . The main goal of scientific research is to create a rational methodology for selecting a self-compacting concrete mixture and its formulation for performing repair work in compressed working conditions and (or) for restoring the design bearing capacity of structures of complex shape.

In this work, it is necessary to solve the following tasks of scientific research:

- to study the historical experience of the production and use of concrete as a construction material in China and around the world;

- to study the method of forming self-compacting concrete, its recipe, as well as the advantages and disadvantages of self-compacting concrete over classic concrete mixtures;

- to analyze the state of the issue of strengthening existing reinforced concrete building structures;

- to determine rational methods of strengthening structures that are in hard-to-reach places or have a complex structural shape;

- to determine additives that increase the mobility of the concrete mixture without increasing the water-cement ratio;

- to propose a rational technology for laying self-compacting concrete;

- to propose a rational construction of reinforcement frame and its adhesive additives within self compacting concrete technology of restoration of the structure.

Object of study – worn-out reinforced concrete building structures that need repair and strengthening.

Subject of study – repair self compacting concrete mixtures for arranging reinforcements of complex shapes and for performing work in compressed production conditions.

Research methods. Have been used mathematical methods, methods of scientific analysis and synthesis, methods of construction chemistry, methods of technology and rational organization of construction works.

The novelty of the obtained results consists in the developed methodology for carrying out repair work using self-compacting concrete mixtures in conditions difficult for workers to access without the use of vibration, as well as in the proposed recipe for repair self-compacting concrete mixture with the use of superplasticizing and air-entraining additives, which has the ability to harden quickly.

Personal contribution. All scientific research carried out in this work, including scientific analysis of sources in the direction of creating self-compacting concrete repair mixes, summarization of current European and Chinese regulatory documentation, scientific search and substantiation of a rational formulation of self-compacting concrete, as well as methodologies for strengthening worn structures in hard-to-reach areas places, performed by the author personally.

Approbation of the results of the master's thesis.

The results of the work were tested on:

- International scientific and practical Internet conference "Youth in science: research, problems, prospects (MN-2024)", held on November 15, 2023 to May 20, 2024at VNTU, Vinnytsia, Ukraine.

- "LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024)", held on March 20-23, 2024 at VNTU, Vinnytsia, Ukraine.

Publications.

1. Sun Wenjun. Overhaul of the crossbars systems of bridge supports with the installation of reinforced concrete brackets [Electronic resource] / V. Popov, Wenjun Sun // Electronic scientific publications. Abstracts of the report at the LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024) (Vinnytsia, 20-23.03.2024) – Electronic text data – 2024. P. 1338 – 1340. Link: https://conferences.vntu.edu.ua/index.php/all-fbtegp/all-fbtegp-2024/paper/view/20947/17448

2. Sun Wenjun. Strengthening the foundations of the primary ammonia reforming furnace in conditions without working free space using self-compacting concrete [Electronic resource] / V. Popov, Wenjun Sun, Xiaohong Li // Abstracts of the report at the International scientific and practical Internet conference Youth in science: research, problems, prospects (MN-2024), (VNTU) – Electronic text data – 2024. Link: https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21531

CHAPTER 1

ANALYSIS OF THE CURRENT STATE OF THE THEORY AND PRACTICE OF MONOLITHIC CONCRETE

1.1 Concrete is a modern construction material

Since the invention of Portland cement nearly 200 years ago, cement concrete has made great contributions to the development of human society. Concrete is the most widely used building material today. It is usually made of ordinary Portland cement mixed with sand, gravel, and water. According to statistics, the global concrete consumption reached more than 4 billion tons in 2019, and it is expected that by 2030, this figure will exceed 6 billion tons[1]. Why is it the most widely used engineering material? There are three main reasons. First, the raw materials that make up concrete are readily available and cheap. Secondly, concrete is easy to make a variety of sizes of components; Finally, concrete is made of sufficient water resistance and durability.

1.1.1 Modern classification of concrete for structures

Concrete can be regarded as a composite material similar to artificial stone, mainly composed of sand, stone, cement slurry (cementitious material), if the performance of its composition materials to be changed, or add some new components, you can get many different combinations, you can get a variety of different performance of concrete varieties.

A) Classification by cementing material:

A.1) inorganic cementing material concrete, such as ordinary concrete, gypsum concrete, silicate Concrete and water glass concrete, etc.

A.2) organic cementing material concrete, such as asphalt concrete and polymer concrete.

B) Classification by apparent density:

B.1) Heavy concrete, the apparent density is greater than 2500kg/m3, with special density and special weight The aggregate made of concrete. Such as barite concrete, steel chip concrete and so on.

B.2) Ordinary concrete, which is commonly used in construction, has an apparent density of 1900~2500kg/m3, the aggregate is sand and stone.

B.3) Lightweight concrete is concrete with an apparent density of less than 1900kg/m3. Lightweight concrete can be divided into the following three categories:

1) Light aggregate concrete, its apparent density of 800~1950kg/m3, light aggregate including float Stone, scoria, ceramite, expanded perlite and expanded slag, etc.

2) Porous concrete (foamed concrete, aerated concrete), its apparent density is 300

~1000kg/m3 Foamed concrete is made of cement slurry or cement mortar and stabilized foam; Aerated concrete is made of cement, water and aerating agent.

3) Large hole concrete (ordinary large hole concrete, light aggregate large hole concrete), its composition There is no fine aggregate. The apparent density of ordinary large-hole concrete is 1500~1900kg/m3, which is prepared with crushed stone, soft stone and heavy slag as aggregate. The apparent density of light aggregate large-hole concrete is 500~1500kg/m3, which is prepared with ceramic particles, pumice stone, broken brick and slag as aggregate.

C) Classification by function:

According to the different functions of use, concrete can be divided into structural concrete, thermal insulation concrete, Decorative concrete, waterproof concrete, refractory concrete, hydraulic concrete, Marine concrete, road concrete and radiation proof concrete, etc.

D) Classification by construction process:

According to the different construction technology, concrete can be divided into centrifugal concrete, vacuum concrete,Grouting concrete, shotcrete, roller compacted concrete, extruded concrete and pumped concrete, etc.

1.1.2 Historical tour of emergence of concrete as a construction material

Traditional concrete is an artificial stone composed of cement, stone, sand and water mixed evenly in a certain proportion. Obviously in these four materials, stone, sand and water are existing in nature, and can glue stone sand into a whole cementing material - cement is not in nature, in a sense, the development history of traditional concrete should be a history of the development and application of cementing materials, admixtures and admixtures.

The history of concrete can be traced back to earlier civilizations before ancient Rome. Marcus Bocius Cato, in his work De re Rustica, published in 184 BC, recorded the ancient concrete-stucco ratio: one part dissolved limestone to two parts sand [2]. In the Ten Books of Architecture, Vitruvius wrote about raw concrete: "There is a powder that produces amazing effects in its natural state." Various powders, when mixed with lime and gravel, not only make other buildings strong, but also harden underwater when building embankments in the sea [3]. The ancient Romans also found that adding some volcanic ash materials to the lime can not only improve the strength of the hardened body, but also enhance the ability of the hardened body to withstand water. In the southern Italian city of Pozzuoli, the ancient Romans harvested a pink volcanic ash to make the famous Pozzuoli cement. The Opera House of Pompeii (Fig. 1.1), built in 75 BC, is one of the most important buildings built with this cement, which was mainly used as a foundation and filling material.

Figure 1.1 – The Opera House of Pompei

The Roman architectural wonder of the Pantheon (built in 27 BC, destroyed in 80 AD, rebuilt in 118 AD) is a brilliant creation of ancient concrete. Its cylindrical main body is covered with a huge dome 43.3 meters in diameter and 43.3 meters in height, forming a perfectly proportioned spherical space. Light pours down from a circular hole about 8.9 meters in diameter in the middle of the dome to create a sacred atmosphere (Fig. 1.2) [4].

The Pantheon uses concrete as the aggregate for the walls and the dome, the lower part uses heavy tuff aggregate, the middle uses porous volcanic rock and broken brick, and the dome uses pumice mixed porous volcanic rock, and the proportion of aggregate decreases as the upper part goes [5].

Figure 1.2 –The Pantheon

In ancient Rome, the Colosseum (built in 82 AD) and the public baths (mainly built in the 3rd and 4th centuries AD) used concrete as a compressive component of buildings. The Leaning Tower of Pisa (built in 1173 AD) is considered to be the last miracle built by the Romans, its column wall system is made of solid concrete, the wall is 2.7 meters thick, and the reinforced tower still maintains a 5 degree Angle to the vertical direction. The famous port of Naples was built with concrete made of water-based cement mixed with volcanic ash and lime, and is still intact after more than 2,000 years. Due to the limited amount of natural volcanic ash, people tried to use sintered clay products such as waste porcelain and broken bricks to replace volcanic ash after grinding, and mixed with lime. It turns out that this mixture also has good gelling properties, a discovery that opens up the possibility of artificially preparing volcanic ash materials. Further, people use limestone containing a certain amount of clay (so-called "natural mudstone") after calcining and grinding to make "natural cement". On this basis, the production technology of making hydraulic lime by calcining and grinding a certain amount of limestone and clay mixed with artificial ingredients has been developed. This is the prototype of Portland cement production.

In 1756, in the process of building a lighthouse, Smiton studied the influence of different limestone in the "lime - volcanic ash - sand" three-component mortar on the performance of the mortar, and found that the limestone containing clay, after calcination and fine grinding treatment, the mortar made of water can slowly harden, and the strength in the sea water is much higher than the "Roman mortar", and can withstand the scouring of the sea water. Smiton used the newly discovered mortar to build the world-famous Eddystone lighthouse in Plymouth Harbour [6].

In 1976, the British J. Parker fired Roman cement with clay limestone, which set fast and is suitable for water-related projects, and is widely used in Britain [7]. In 1824, the British Aspdin calcined limestone and clay together and invented Portland cement, which is the Portland cement we widely use today[8]. Because its color is similar to the stone color produced in Portland Island, England, it was named Portland cement, which created the history of modern mixing, and Aspuddin is also considered to be the originator of modern cement. In 1886, the Americans first calcined the clinker in a rotary kiln, making Portland cement enter large-scale industrial production. The first house built entirely of concrete was in 1835 by John Bardsley, a cement manufacturer in Kent, England White House (Fig. 1.3), its walls, door lintels and decoration are made of concrete, and even the garden floor is paved with concrete material products, but the technology at the time has not reached the use of concrete floor slab [4].

Figure 1.3 – England White House

In the mid-19th century, the French florist Monier invented the reinforced cement technology, he embedded steel wire mesh in the production of cement flowerpots, making the sturdiness of the flowerpots greatly strengthened.Thus opening up the first reinforced concrete [9].Since then, reinforced concrete has been widely used in building components in France, Germany and the United Kingdom, greatly improving the carrying capacity of buildings and structural integrity.

The generation and development of modern architectural movement is almost the same time as reinforced concrete. Concrete as a new mixed material inevitably promotes the new development of architectural art. At the beginning of the 20th century, concrete structure has developed into a high-strength, composite frame structure form. August Perret, the pre-eminent concrete architect of the early 20th century. His industrial and technological buildings such as the 25 Rue de Franklin apartment, the Theatre des Champs-Elysees in Paris, and the Esd clothing factory in Paris create a classical facade through exposed concrete frames. He used concrete as a material in the noble building type of people's minds - the church, the design of the church of Our Lady of Lancy. Auguste Perret's architectural works established the reputation of concrete and became known as the "cement poet" [10]. Since the 1930s, engineers have actively used reinforced concrete structures to innovate, and almost every new building is an innovation in structural art, proving the powerful structural expression of concrete. Lix Candela has been committed to the research and practice of reinforced concrete shell structures.

Designed in 1958, the Mantiales big Rice (Fig. 1.4) is an eight-petal wave form of a parabolic shell structure.

Figure 1.4 – Mantiales big Rice

Candela designed many factories and warehouses using the rich and varied Spaces created by structural forms. In the 1950s and 1960s, people recognized and appreciated the concrete surface without secondary treatment and the structural plasticity of concrete, and many famous architects and excellent concrete architectural works emerged during this period. For example, Louis Kahn was hailed as a poet in the architectural field. He designed the Yale University Art Museum (built in 1953, Fig. 1.5) adopts triangular ribbed floor to solve the problem of large span. Since the 1990s, the development of concrete buildings has shown new characteristics.

Figure 1.5 – The Yale University Art Museum

The performance of concrete materials has been greatly improved, concrete can be smooth, can be flexible, can be colorful and even transparent, high-performance concrete in cement, aggregate, additives, tensile reinforcement and other aspects have been improved, bringing a new application world of concrete materials. High performance concrete has strong impermeability and tensile resistance, no cracks, and has good application in bridge engineering, underground engineering, hospital, laboratory and other buildings. Self-compacting concrete increases the proportion of cement and fine aggregate and improves the problem caused by vibration of concrete. Glass fiber, steel fiber, fabric, etc. used in the concrete mixture can reduce cracks, reduce the thickness of the protective layer of concrete to the steel bar, the thickness of the shell, and ultra-thin and ultra-light components. At present, have been used fiber reinforced or fabric reinforced concrete is widely used in thin sheet components such as ceilings, thin shells, vertical panels, and sun shields, and can even replace the use of steel bars, and there is still a broad space for development of its research and application. The wave of diverse and rich concrete applications has produced many active architects and excellent works, such as the Science Museum in Valencia Science City in Santiago Calatrava, Spain (Fig. 1-6), and the Tannerife Concert Hall in the Canary Islands, Spain.

Figure 1.6 – The Science Museum in Valencia Science City

The application of contemporary concrete materials in architectural design can be described as a hundred flowers, but there are also some problems in concrete materials and technology, such as the technical requirements of concrete pouring are very high, the application of concrete is still an expensive practice, and the application of high-performance concrete needs to be developed.

1.1.3 The history of the use of concrete as a construction material in China

China is one of the birthplaces of world civilization, and the ancient adhesive materials such as lime and clay in construction.According to archaeological findings, the ground similar to the concrete structure was found at the architectural site of Dadiwan in Qin 'an 4,000 years ago (Fig. 1.7), which was identified that the grayish blue ground not only contains the same "calcium silicate" component as modern concrete close to that of Portland cement No. 100.

Figure 1.7 – The remains of a building found in Terra Cove

It is the oldest concrete material in the world."[11]. However, modern concrete technology in the real sense was introduced into China with the intervention of modern Western countries. In 1889, China's first cement factory – Qixin Cement Factory (Fig. 1.8) was built in Tangshan, marking the official entry of cement industry into China.

In 1905, the first concrete building in China was the three-storey Martin Hall at Sun Yat-sen University, which is not only the oldest building in the university, but also the earliest reinforced concrete mixed structure building in China.

In the late 19th century to the early 20th century, with the introduction of Western construction technology, concrete began to be applied in the field of construction in China.

Figure. 1.8 – China's first cement factory

After the founding of New China, in order to meet the needs of large-scale economic construction and urbanization development, concrete as an important building material has been widely promoted and used. After the reform and opening up in the 1980s, China began to introduce a large number of foreign advanced technology and management experience, and concrete technology has been rapidly developed. During this period, China's concrete industry began to integrate with international standards, and there were significant improvements in concrete In the 21st century, with the continuous prosperity of the construction industry and the progress of science and technology, China's concrete technology has reached the international advanced level. With the development of technology, many excellent architectural works have emerged, such as Harbin Opera House, Shanghai Tower, Guangzhou Opera House, Three Gorges Hydropower Station, Baihetan Hydropower Station, Hong Kong-Zhuhai-Macao Bridge and so on.

1.2 Recipe of ordinary cement concrete.

Ordinary concrete is made of water, cement and aggregate mixed, hardened artificial stone. Among them, the cementing material is cement and water, that is, cement and water constitute cement slurry. Aggregate is sand and stone, sand is fine aggregate, stone is coarse aggregate. The cement mortar is wrapped around the surface of the aggregate and filled between the aggregate and the particles. The cement slurry lubricates the aggregate before hardening, and binds the aggregate together to form a hard whole after hardening [12]. Cement is the most important component material of concrete, which has an important influence on the quality and technological properties of concrete. Cement is an important factor affecting the performance of concrete. The key to improve the performance of concrete is to select the type, strength grade and dosage of cement reasonably. Aggregate in concrete mainly plays the role of skeleton, support and stable volume (reduce the volume change of cement during setting and hardening). According to the size of particle size and its role in concrete, aggregate can be divided into fine aggregate and coarse aggregate. The fine aggregate in ordinary concrete is usually sand, which can generally be divided into natural sand and machine-made sand. Natural sand is naturally generated, artificially mined and screened rock particles with a particle size less than 4.75 mm, including river sand, lake sand, mountain sand, desalinated sea sand, but excluding soft, weathered rock particles. Machine-made sand is a rock, mine tailings or industrial waste particles with a particle size less than 4.75 mm (excluding soft and weathered particles) made by mechanical crushing and screening after soil removal treatment, commonly known as artificial sand.

Aggregate particle size greater than 4.75 mm rock particles called coarse aggregate, commonly used gravel and pebbles. The gravel is mostly made of natural rock by crushing and screening, and can also be crushed and screened by large pebbles. The surface of the gravel is rough, multi-angular, and relatively clean, and the cement paste is more firm. Gravel is the largest coarse aggregate used in construction projects. Pebble, also known as gravel, is a particle with a particle size greater than 5mm formed by the long-term action of natural rocks under natural conditions. According to its source, it can be divided into river pebble, sea pebble and mountain pebble, among which river pebble is more used. The content of organic impurities in the pebble is more, but compared with gravel, the surface of the pebble is smooth, less cement slurry is needed when mixing concrete, and the workability of the mixture is better. However, the bonding force between pebble and cement stone is poor, and the strength of pebble concrete is lower than that of crushed stone concrete under the same conditions. Therefore, under the same water-binder ratio, the concrete mixed with crushed stone has less fluidity but higher strength; Pebbles, on the other hand, have greater mobility but lower strength.

The preparation process of concrete has to go through two stages, namely fresh concrete and hardened concrete. Freshly mixed concrete refers to the state that has just been mixed well and has not yet set and hardened, and most concrete has a certain fluidity at this time. For newly mixed concrete, its workability, which is closely related to the construction process, is the most concerned performance. The performance of hardened concrete involves mechanical properties, physical properties and durability according to its environmental conditions and technical requirements. The more important indicators of ordinary concrete are compressive strength, flexural strength, elastic modulus, bonding strength, impermeability, frost resistance and so on.

1.3 Additives to concrete

Concrete admixture is a basic component of concrete except cement, stone, sand and water. It is an important method and technology for optimizing concrete performance. Concrete chemical admixtures are such a kind of substances: it is added to concrete with a small amount in the concrete mixing process, which can effectively improve the physical and mechanical properties of concrete, improve the strength and durability of concrete, reduce the amount of cement, reduce the size of structures, so as to save energy consumption and improve the environment [13]. Concrete admixtures are divided into four categories according to their main functions:

1) Admixtures to improve the variable performance of concrete mixing, including various water reducing agents, air entrainment agents and pumping agents.

2) Admixtures that adjust the setting time and hardening properties of concrete, including retarding agents, early strength agents and accelerating agents.

3) Admixtures to improve the durability of concrete, including air entraining agents, water repellent agents and rust inhibitors.

4) Admixtures to improve other properties of concrete, including air entraining agents, expansion agents, antifreeze agents, colorants, waterproofing agents, etc.

1.4 Self-compacting concrete (SCC)

Self Compacting Concrete (Self Consolidating Concrete), short for SCC, refers to the concrete that can flow and be dense under its own gravity, and can completely fill the formwork even in the presence of dense steel bars, while obtaining good homogeneity, and does not require additional vibration [14]. The performance of SCC after hardening is similar to that of ordinary concrete, while the performance of freshly mixed concrete is very different from that of ordinary concrete. SCC belongs to the category of high performance concrete, which greatly improves the construction performance under the premise of ensuring sufficient strength, durability, constructability, applicability, strength and volume stability. It breaks through the limitations of the traditional vibrating concrete in the forming method, completely relying on its own gravity (or just external slight vibration) can flow freely through the steel bar gap to fill each corner of the template, hardening to meet the requirements of strength and good durability. Since the SCC doesn't need vibration molding in the pouring process, the noise pollution in the traditional vibration concrete construction is significantly reduced, and the labor intensity of workers is greatly reduced. In addition, it solves the problems of dense reinforcement, complex structure and other holes caused by aggregate obstruction, and reduces the upper and lower layered honeycomb surface caused by leakage vibration and over-vibration in traditional concrete construction, improving the quality and durability of concrete. At the same time, the preparation of SCC requires a large amount of industrial solid wastes such as fly ash, granulated blast furnace slag and silica fume, which is conducive to the comprehensive utilization of resources and the protection of ecological environment [15].

1.4.1 The difference between self-compacting concrete and ordinary concrete

The performance of self-compacting concrete is improved by adding admixtures and admixtures on the basis of ordinary concrete and adjusting its mix ratio. Table 1.1 lists the performance differences between the two devices.

Table 1.1 – Differences between self-compacting concrete and ordinary concrete

Property/Aspect	Self-Compacting Concrete (SCC)	Normal Concrete (NPC)
Flowability	Very good, self-leveling	Requires compaction
W/C Ratio	Typically below 0.5	Typically 0.5 … 0.6
Fine Aggregate	Closely controlled	Relatively loose
Coarse Aggregate	Closely controlled size and grading	Looser requirements
Admixtures	Significant use, such as fly ash, silica fume	Less use
Additives	High-range water reducers and viscosity modifiers	Standard water reducers
Construction Method	No compaction needed	Requires compaction
Construction Speed	Fast	Slow
Strength Development	Usually rapid	Depends on mix and cure
Durability	High, good resistance to permeation	More variable
Shrinkage	Low	Higher
Cost	Higher	Lower
Application Field	Suitable for complex structures	Widely used
Environmental Impact	Lower	Higher (due to compaction)
Sustainability	High	Relatively lower

1.4.2 The field of application of self-compacting concrete

Due to its excellent fluidity and self-filling ability, self-compacting concrete is particularly suitable for the following applications:

Complex structures: SCC can flow freely and fill structures with dense reinforcement or complex shapes, such as nuclear reactors, box beams of Bridges, columns and joint areas of beams.

Engineering with high durability requirements: The density of SCC helps to improve the durability of concrete structures, which is suitable for Marine engineering, tunnels, DAMS and other projects with high durability requirements.

High-strength concrete structure: SCC can be formulated into high-strength concrete, suitable for high-rise buildings, long-span structures and other projects requiring high-strength support.

Construction difficult areas: SCC does not need to be vibrated, and is suitable for parts that are difficult to reach manually or cannot be used by mechanical vibration, such as narrow Spaces or deep foundations.

Rapid construction projects: SCC's rapid construction characteristics are suitable for projects that require a shorter duration, such as emergency repair projects or rapid construction projects.

Precast components of complex structures: SCC is very useful in the production of precast concrete components, as it ensures that the concrete is evenly distributed within the mold, improving product quality.

Restoration and reinforcement works: SCC can be used for the restoration and reinforcement of existing structures, especially when new concrete steel members are inserted into the existing structure, such as the reinforcement method of increased section.

Environmental requirements: The SCC construction process is low noise, less waste, suitable for areas with high environmental requirements, such as downtown areas, night construction.

Construction in special environments: SCC can be constructed in special environments such as high or low temperatures because it does not require vibration, reducing dependence on environmental conditions.

Underground structure: SCC is suitable for the construction of underground structures such as underground continuous walls and foundation plates, which usually have a large volume and complex geometry.

Decorative concrete: The high fluidity of SCC makes it also useful in the field of decorative concrete, such as surfaces requiring fine texture or color distribution.

3D printing concrete structures: With the development of 3D printing technology, SCC's vibration-free properties make it an ideal material for printing complex concrete structures.

1.4.3 Advantages and disadvantages of self-compacting concrete over ordinary concrete

Self-compacting concrete takes into account the characteristics of ultra-high strength and self-compacting, and has the following advantages over traditional concrete:

1) Effectively reduce the cross-section area of the structure and reduce its own weight

The apparent density of ordinary reinforced concrete is about 2551kg/m3, and the strength is generally 8 to 10 times of the payload. In the process of practical engineering application, in order to ensure the strength of the structure, it is often used in large quantities, which is easy to cause a large cross-section of the structure and a large weight. Ultra-high strength self-dense concrete has an ultra-high strength grade (≥C100), which can reduce the amount of steel and structural cross-section area when used, and thinner or smaller structural members can meet the strength requirements. In addition, the stiffness of ultra-high strength concrete is larger, the elastic modulus is higher, and the creep is smaller under the long-term stress state, which can produce more lightweight prestressed reinforced concrete structural members.

2) Significantly improve the workability of freshly mixed concrete and achieve self-compacting

The high amount of cementing material and sand rate can make the concrete flow compaction molding only by its own weight, omitting the vibration process, effectively pouring irregular complex components, and improving the freedom of design. The use of self-compacting concrete can improve production efficiency, reduce labor, reduce construction noise, improve working environment, improve concrete quality and shorten construction period.

3) The structure is very dense and the durability is improved

Most of the durability problems of concrete are due to its high porosity, many capillary pores connected with the outside world, more internal defects, many cracks in the transition zone between cement stone and aggregate interface, and low strength. The use of ultra-high strength self-compactness concrete slurry has more volume, more colloids and crystals generated by hydration, and can be dense structure. Coupled with low water-adhesive ratio, fewer defects left after moisture drying or hydration, resulting in ultra-high durability of concrete.

4) Save raw materials, reduce carbon emissions, and improve economic efficiency

Ultra-high strength self-dense concrete has a high compressive strength ratio, less concrete consumption can meet the structural needs, save raw materials, reduce the mining of sand aggregate, reduce carbon emissions, and have good technical and economic effects.

At present, there are still many problems in ultra-high strength self-compacting concrete:

1) The design model of the mix ratio of ultra-high strength (≥C100) self-compacting concrete is not established.

2) High viscosity leads to poor workability

In order to achieve the purpose of ultra-high strength, the amount of newly mixed concrete cementing material is high, and the water consumption is very low, generally 150kg/m3 below, the formation of its fluidity mainly depends on the adsorption and dispersion of highly efficient water reducing agent, which will lead to the viscosity of newly mixed concrete, which may exceed the pressure that existing equipment can bear, and the pumping volume will be greatly reduced, which is prone to pumping accidents. Such as pipe blocking, pipe explosion, etc., affect the safety of pumping.

3) Large shrinkage

Due to the large amount of cementing material, low water-binder ratio and high hydration heat of ultra-high strength self-compacts concrete, the shrinkage of concrete is large, which affects the safe use of structure.

1.5 Conclusions on chapter 1

Concrete is a traditional reinforcement material with strong bonding performance and high durability, and the process is simple, and the application is wide, and can be widely used in the reinforcement of general beams, plates, columns, walls and other concrete structures. In the concrete strengthening project, the use of ordinary concrete can not meet the design requirements because of the narrow construction surface and dense reinforcement. Self-compacting concrete perfectly solves the problems existing in the reinforcement process of ordinary concrete. It can fill the space in the formwork by itself without vibrating under its own weight, and maintain its own uniformity and compactness through dense steel bars to form a dense concrete structure. The following article will be the application of dense concrete in structural reinforcement engineering, in view of the problems faced by self-compacting concrete in structural reinforcement engineering, a series of self-compacting concrete research is carried out, including the design method of self-compacting concrete mix for reinforcement, reinforcement engineering construction technology and so on.

CHAPTER 2

RATIONAL PREPARATION TECHNOLOGY AND RECIPE OF SELF-SEALATING CONCRETE

2.1 Description of the recipe of classic self-compacting concrete by Chinas codes

2.1.1 General requirements for preparation of self-compacting concrete

The mix ratio of self-compacting concrete should be designed according to the characteristics of the engineering structure form, construction technology and environmental factors, and on the basis of comprehensive consideration of the performance, strength, durability and other necessary performance requirements of the self-compacting concrete mix, the calculation of the mix ratio is proposed [16]. The test mix ratio meeting the working requirement was obtained by the test mix and adjustment in the laboratory, and the benchmark mix ratio was obtained by further checking of strength and durability. The absolute volume method should be adopted in the design of the mix ratio of self-compacting concrete, and the dosage of cementing material should not be greater than 600 kg/m3, The cohesiveness and fluidity of the slurry can be improved by increasing the volume of the slurry appropriately or by adding admixtures. The design method is suitable for self-compacting concrete with strength grade less than C60, and the mix ratio of other self-compacting concrete with strength grade should be determined by test.

2.1.2 Mix ratio design raw material requirements

Portland cement or ordinary Portland cement should be used to prepare self-compacting concrete, and should comply with the current national standard GB 175-2023[*1];Coarse aggregate should be reasonably graded, and the maximum nominal particle size should not be greater than 20 mm; For structures with dense reinforcement and complex shape or projects with special requirements, the maximum nominal particle size of coarse aggregate should be determined by test verification according to the actual situation. The needle and flake particle content of coarse aggregate shall comply with the provisions of Table 2.1. It should also conform to the mud content ≤1.0% and the mud lump content ≤0.1%. Medium sand in grading zone II should be used for fine aggregate[*2], It should also meet the requirements of sand clay content ≤3.0% and clay lump content ≤1.0%. Water and admixtures should also meet the relevant regulatory requirements.

Table 2.1 – Content of acicular and flaky particles of coarse aggregate

strength grade of concrete	≥C60	C55～C30	≤C25
Acicular and flaky particles content（%）	≤8	≤10	≤15

[*1] GB 175-2023 China standard for general purpose Portland cement.

[*2] The grain gradation of sand was divided into three gradation zones: zone I, Zone II and zone III according to the cumulative screening percentage corresponding to the 0.600mm screen hole. Coarse sand with good gradation should fall in zone I; Well-graded medium sand should fall in zone II; Fine sand is in zone III.

2.1.3 Description of properties of self-compacting concrete

The performance index of the self-compacting concrete mix is the performance index of the concrete mix before pouring to the site. The properties of self-compacting concrete mix include filling property, clearance permeability and anti-segregation property. The performance indexes are divided according to Table 2.2, and the data of each index are obtained by test.

Table 2.2 – Performance index of self-compacting concrete mix

<table>
<tr><th>performance index</th><th>SF1</th><th>SF2</th><th>SF3</th><th>significance</th></tr>
<tr><td>slump flow SF (mm)</td><td>500 ~ 600</td><td>600 ~ 700</td><td>700 ~ 800</td><td rowspan="2">control target</td></tr>
<tr><td>spreading time T_{500} (s)</td><td colspan="3">3 ~ 20</td></tr>
<tr><td>slumps H (mm)</td><td>≥240</td><td>≥250</td><td>≥260</td><td rowspan="4">Selective limit index (At least one out of four)</td></tr>
<tr><td>J-ring height difference B_J (mm)</td><td colspan="3">≤20</td></tr>
<tr><td>V Funnel emptying time VF (s)</td><td>4 ~ 20</td><td>7 ~ 20</td><td>9 ~ 20</td></tr>
<tr><td>U-box filling height UH(mm)</td><td>≥320 (accessible)</td><td>≥320 (Barrier type 2)</td><td>≥320 (Barrier type 1)</td></tr>
</table>

In general, SF1 is suitable for the pouring of reinforced concrete structures and components with minimum net spacing of steel bars above 200mm, large section size and small reinforcement amount, as well as the pouring of unreinforced structures. SF2: Suitable for the pouring of reinforced concrete structures and components with a minimum net spacing of 60 ~ 200mm; SF3: It is suitable for the pouring of reinforced concrete structures and members with the minimum net spacing of steel bars of 35 ~ 60mm, complex structure shape and small section size of members.

2.1.3.1 Test method for performance index of self-compacting concrete

A)Test method for slump, spread and spread time

A.1)The slump, expansion and expansion time of self-compacting concrete should be tested by the following instruments and tools□

Concrete slump cylinder□

The bottom plate shall be a hard non-absorbent smooth square plate, the side length shall be 1000 mm, the maximum deflection shall not exceed 3 mm, and the central position of the slump cylinder and concentric circles of 200 mm, 300 mm, 500 mm, 600 mm, 700 mm, 800 mm and 900 mm in diameter shall be marked on the surface of the plate Fig 2.1.

Figure 2.1 – Slump spread test base plate

Material container, scraper, steel ruler, level, stopwatch and wet cloth, etc

A.2) Test procedure

The bottom plate should be placed on a solid horizontal surface, and the two vertical directions of the bottom plate should be levelled with a level. The surface of the bottom plate and the inner wall of the slump cylinder should be clean with a wrung out wet cloth. There should be no clear water on the inner wall of the slump cylinder and the bottom plate. Place the slump cylinder in the center of the bottom plate and press the foot pedals on both sides;

Under the condition that the concrete mix does not produce segregation, the slump cylinder is filled with the concrete mix at one time by using the material container. The slump cylinder should be kept in a fixed position when loading, and should not be moved, tamped or vibrated;

Use a scraper to scrape off the top of the slump cylinder and the surrounding concrete residue, so that the concrete is flush with the upper edge of the slump cylinder, and then the slump cylinder is quickly lifted up about 300 mm along the vertical direction at a constant speed, and the lifting time should be controlled within 3 s to 7 s. From the beginning of feeding to lifting slump cylinder should be completed within 1.5 minutes.

Slump is the height difference between the barrel height and the highest point of the concrete test. The measurement should be accurate to 1 mm, and the result should be revised to about 5 mm

When measuring the spread time (T500) with a spread of 500 mm, the time shall be measured from the moment the slump cylinder is lifted off the ground until the outer edge of the extended concrete first touches the circumference of the 500 mm diameter drawn on the slab, and the test result shall be accurate to 0.1s.

The state of the concrete mix after the final collapse should be observed. When the coarse aggregate is deposited in the center or the cement slurry is precipitated at the edge of the concrete after the final expansion, the anti-segregation of the concrete mix can be judged to be unqualified and should be recorded.

B) J ring height difference test method

B.1) The following instruments and tools should be used in the J-ring height difference test of self-compacting concrete:

Concrete slump cylinder

The J-ring shall be made of steel or stainless steel, the central diameter and thickness of the ring shall be 300 mm and 25 mm respectively, and 16 round steel Φ16 mm×100 mm shall be locked on the ring with nuts and washers, and the center distance of the round steel shall be 58.9 mm (Fig. 2.2).

Figure 2.2 – J-ring test

The bottom plate shall be a hard non-absorbent smooth square plate, the side length shall be 1000 mm, and the maximum deflection shall not exceed 3 mm.

Material container, scraper, steel ruler, level, stopwatch and wet cloth, etc

B.2) Test procedure

First wet the bottom plate, J-ring and slump cylinder, slump cylinder inner wall and bottom plate should have no clear water. The bottom plate placed on a solid horizontal surface should be calibrated horizontally first, and the J-ring should be placed in the center of the bottom plate;

The slump cylinder should be inverted in the center of the bottom plate, and should be concentric with the J ring. The concrete mix should be filled with a container at one time, and the slump cylinder should not be moved, tamped or vibrated;

Use a scraper to scrape the residual concrete at the top and surrounding of the slump cylinder, and then lift the slump cylinder upward at a constant speed of 250 mm±50 mm in the vertical direction, and the lifting time should be controlled within 3 s to 7 s. From the beginning of feeding to lifting slump cylinder should be completed within 1.5 minutes. After the concrete extension is terminated, the difference between the height of the concrete in the center of the extension plane and the height of the concrete in the outer edge of the J ring is measured;

As shown in Fig. 2.3, the height difference between the top surface of the concrete mix and the top surface of the J ring at the center of the J ring is measured with A steel ruler□ Δh_0 □, Then, the height difference between the top surface of the concrete mix and the top surface of the J ring at four positions was measured along the two vertical directions of the outer edge of the J ring Δh_{x_1} Δh_{x_2} Δh_{y_1} Δh_{y_2} Unit: mm;

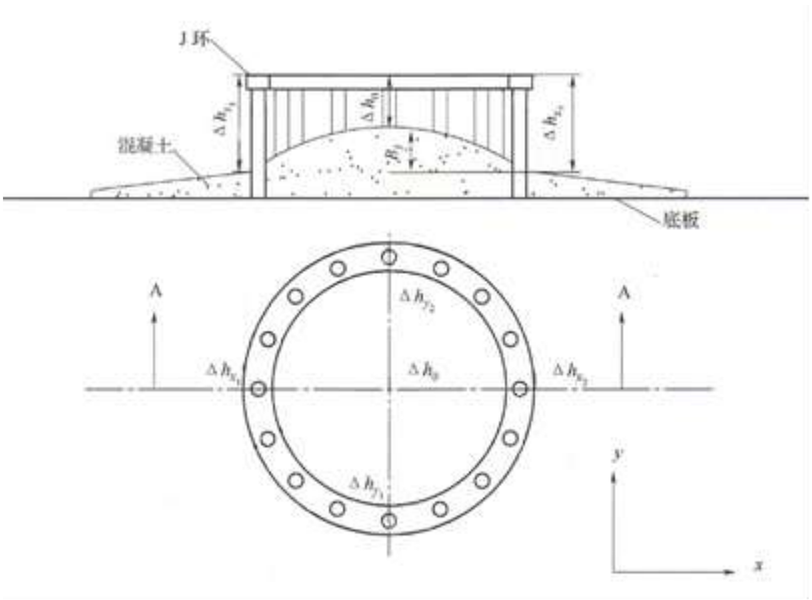

Figure 2.3 – J-ring height difference test point diagram

J-ring height difference BJ is calculated according to formula 2.1, and the result is accurate to 1 mm.

$$B_J = \frac{\Delta h_{x_1} + \Delta h_{x_2} + \Delta h_{y_1} + \Delta h_{y_2}}{4} - \Delta h_0 \qquad (2.1)$$

It should be observed whether there is aggregate blockage near the J-ring round steel. When the coarse aggregate is blocked near the J-ring round steel, the gap passability of the concrete mix can be judged to be unqualified and should be recorded.

C) V funnel emptying time test method

C.1) The following instruments and tools should be used in the self-compacting concrete V funnel emptying time test:

The shape and internal size of the V funnel are shown in Fig 2.4. The capacity of the funnel is 10 L. The inner surface of the funnel should be smooth after processing and trimming. The material of the V funnel can be metal or plastic.

Figure 2.4 – V-funnel.

At the outlet of the funnel, a bottom cover that can be opened quickly and has water tightness should be provided. The top edge of the funnel should be processed smoothly and the structure is smooth; Material container (about 15 L capacity), receiving container, scraper, stopwatch and wet cloth.

C.2) Test procedure

The funnel is washed with clean water and placed on the bench so that the top surface is horizontal and the main side is vertical. Ensure that the funnel is stable and wipe the inner surface of the funnel with a wet wrung out cloth so that the surface is wet and free of bright water.

A receiving container for concrete is placed under the discharge port of the V funnel. Before the concrete mix is filled into the funnel, the bottom cover of the funnel outlet should be confirmed to be closed.

Use the container to fill the concrete mixture smoothly into the funnel from the upper end of the funnel at one time to the full, without moving, ramming or vibration.

Scrape the top surface of concrete along the upper end of the funnel with a scraper.

After standing for 1 min, quickly open the bottom cover of the discharge port of the V funnel and start the timing at the same time, from the top view to the time of light at the discharge port (t), the result should be accurate to 0.1 s.

The determination of funnel emptying time should be carried out two tests on the sample within 5 min. The average value of the two tests was taken as the test result.

It is necessary to observe and record whether the concrete is blocked during the discharge process. When the coarse aggregate is blocked at the discharge port, it can be determined that the anti-segregation of the concrete mix is unqualified and should be recorded.

D) Test method for U-box filling height

D.1) The following instruments and tools should be used in the filling height test of self-compacting concrete U-box.

Fig. 2.5 shows a U-shaped box. The material should be steel or plexiglass, and the inner surface should be smooth to minimize friction between the concrete and the container. The packing device after assembly should be strong and able to observe the flow state of concrete.

Figure 2.5 – U-shaped box

Place A barrier in the center of the U-box. The type 1 barrier consists of 5 Ø10 mm optical round steel bars, and the type 2 barrier consists of 3 Ø 13 mm optical round steel bars.

The barrier type can be selected according to the shape, size and reinforcement status of the engineering structure and the grade of self-dense concrete;

A groove is arranged in the central part of the U-shaped box, in which a partition board and an open interval door can be inserted. By virtue of the insertion device, room A and room B can be separated into two Spaces.

D.2) Test procedure

U-shaped box should be placed vertically, the top surface is horizontal;

In the U-shaped box, insert the spacer door and install the spacer of the barrier barrier;

Wipe the surface of the U-shaped box, spacer door, partition board and barrier barrier, etc., with a wrung out wet cloth and no clear water;

Close the spacer door, use the container to pour the concrete mixture into room A continuously at one time to the full, without moving, ramming or vibration;

Scrape the top surface of the concrete along the upper edge of the filling container with a scraper and let it stand for 1 min;

Pull the spacer door up continuously and rapidly, and the concrete flows through the barrier to room B until the flow stops, during which time the filling device must remain stationary and not move;

In room B of the U-box, starting from the lower end of the filled concrete, the height of the filled concrete to its top surface is measured with a steel ruler, that is, the filled height (UH). If the U-box is made of opaque material, the difference between the height from the bottom of the concrete to the top of the unit minus the depth from the top of the unit to the rising top of the concrete can be measured. When measuring, the filling height of the two ends and the center of the three positions should be taken along the direction of the width of the container, and the average value should be taken, and the result is accurate to 1 mm.

2.1.3 Calculation method of self-compacting concrete mix for reinforcement

(1) Determine the volume (Vg) and mass (mg) of coarse aggregate

Table 2.3 – Absolute volume of coarse aggregate per cubic meter of concrete

Liquidity index	SF1	SF2	SF3
Absolute volume of coarse aggregate per cubic meter of concrete (m^3)	0.32~0.35	0.30~0.33	0.28~0.32

1)The absolute volume Vg of each cubic meter of concrete coarse aggregate can be selected according to Table 2.3.

$$m_g = V_g \times \rho_g \tag{2.2}$$

2) The volume Vm of mortar is calculated according to the following formula

$$V_m = 1 - V_g \tag{2.3}$$

3) The volume fraction of sand in the mortar can be 0.42~0.45

4) The amount of sand per cubic meter of self-compacting concrete Ms can be calculated according to the formula below

$$V_S = V_m \times (0.42 \sim 0.45) \tag{2.4}$$

$$m_S = V_s \times \rho_s \tag{2.5}$$

5) Mortar volume Vp can be calculated according to the following formula

$$V_P = V_m \times V_s \tag{2.6}$$

6) The apparent density of the cementing material can be calculated with the relative content of mineral admixture and cement and their respective apparent density

according to the following formula:

$$\rho_b = \frac{1}{\frac{\beta}{\rho_m} + \frac{(1-\beta)}{\rho_c}} \tag{2.7}$$

ρ_b −parent density of cementing material (kg/m³)

β −Mass percentage of mineral admixtures in self-compacting concrete as cementing material (%)

ρ_m −Mineral admixture apparent density (Kg/m³)

ρ_c −Cement apparent density (Kg/m³)

7) Self-compacting concrete preparation strength (f_{cu0}) calculation

$$f_{cu,0} = f_{cu,k} + 1.645\sigma \tag{2.8}$$

8) Determine the proportion of water and cementing material

$$m_w/m_b = \frac{0.42 f_{ce}(1 - \beta + \beta \cdot \gamma)}{f_{cu,0} + 1.2} \tag{2.9}$$

ρ_m −28-day measured compressive strength of cement (MPa); when the 28-day compressive strength of cement cannot be measured, the value obtained by multiplying the corresponding value of cement strength grade by 1.1 can be used as the cement strength.

β −When two or more kinds of mineral admixtures are used, β1, β2, β3 can be expressed, and the corresponding calculation can be made (according to the requirements of self-compacting concrete workability, durability, temperature rise control, etc., reasonable selection of cement and mineral admixtures in the cementing material type, mineral admixtures accounted for the quality of the amount of cementing material The fraction β should not be less than 0.2.

γ −Is the gelling coefficient of mineral admixture; For limestone powder (β≤0.2), Class I or II fly ash (β≤0.3), S95 or S105 slag powder (β≤0.4), 0.2, 0.4 and 0.9, respectively;

m_b − Mass of cementing material per cubic meter of self-compacting concrete (kg);

m_w − Mass of water per cubic meter of self-compacting concrete (kg)

9) The mass (mb) of the cementing material per cubic meter of self-compacting concrete can be determined by the volume of the slurry in the self-compacting concrete Product (Vp), based on the apparent density (ρ_b) of the cementing material, water binder ratio (mw/mb) and other parameters, and calculated according to the following formula:

$$m_b = \frac{(V_p - V_a)}{(\frac{1}{\rho_b} + \frac{m_w/m_b}{\rho_w})} \tag{2.10}$$

ρ_m − In order to introduce the volume of air, for non-entrained self-compacting concrete,Va is generally desirable 10L;

ρ_w − For the apparent density of the mixed water, take 1000kg/m

10) Water consumption (m_w) per cubic meter of self-compacting concrete can be calculated according to the amount of cementing material (m_b) and water-binder ratio

(m_w/m_b) per cubic meter of self-compacting concrete, and according to the following formula:

$$m_w = m_b \times (m_w / m_b) \quad (2.11)$$

11) The mass of cement (m_c) and the mass of mineral admixtures (m_m) per cubic meter of self-compacting concrete can be determined according to each The mass of the cementing material (m_b) and the mass fraction of the mineral admixture in the cementing material (β) in the cubic meter self-compacting concrete,And calculated according to the following formula:

$$m_m = m_b \times \beta \quad (2.12)$$

$$m_c = m_b - m_m \quad (2.13)$$

12) According to the test, select the variety and dosage of admixtures, and the amount of admixtures is calculated according to the following formula:

$$m_{ca} = m_b \times \alpha \quad (2.14)$$

m_{ca} − Admixture amount per cubic meter of self-compacting concrete (kg);

α − The amount of admixture, expressed as a mass percentage of the total amount of gelling material (%), shall be determined by test.

2.1.4 Laboratory mix test, adjustment, determination

If the workability does not meet the requirements, the amount of water reducing agent can be adjusted. If the adjustment still does not meet the workability requirements, the composition of water reducing agent and gelling material can be selected again. Re-determine the absolute volume of coarse aggregate; After the workability meets the requirements, go to the next step to check whether the strength requirements are met. If the strength requirement is not met, the W/B calculation is re-performed. To meet the strength requirements, the mix ratio can be fine-tuned according to the performance requirements to determine the laboratory ratio.

2.2Additives (superplasticizers) used to create self-compacting concrete (SBC)

High efficiency water reducing agent is a new type of chemical admixture, its chemical properties are different from ordinary water reducing agent, in the normal dosage has a higher water reducing rate than ordinary water reducing agent, no serious retarding and excessive entraining problems, high efficiency water reducing agent is also known as superplasticizer, superfluid agent, high range water reducing agent and so on. There are many kinds of high efficiency water reducing agent, mainly naphthalene series high efficiency water reducing agent, melamine high efficiency water reducing agent, sulfamate high efficiency water reducing agent, fat high efficiency water reducing agent[17].

2.2.1 The classification of superplasticizers

1) sulonated naphthalene formalde-hyde condesate (SNF) [18]

sulonated naphthalene formalde-hyde condesate (SNF) is a product formed from naphthalene and naphthalene homophones by sulfation, hydrolysis, condensation with formaldehyde, and drying with sodium hydroxide or partial sodium hydroxide and lime water. The main component of this type of superplasticizer is naphthalene or naphthalene homolog sulfonate formaldehyde condensation, which is an anionic surfactant. The content of sulonated naphthalene formalde-hyde condesate (SNF) is 0.3% to 0.8% of cement mass, the optimal content is 0.5% to 0.8%, and the water reduction rate is 15% to 25%. When adding naphthalene superplasticizer to concrete, the slump value of concrete increases obviously with the increase of cement content, but the compressive strength of concrete does not decrease under the same water consumption and water-cement ratio. Under the condition that the amount of cement and slump value are the same, the water reducing rate and the compressive strength of concrete will increase with the increase of the amount of water reducing agent, the increase rate is faster at the beginning, but when the amount reaches a certain value, the increase rate decreases rapidly.

2) polycarboxylates high performance water-reducing admixture,PCA

polycarboxylates high performance water-reducing admixture, the solid content of PCA liquid products is generally 18% to 25%. Compared with other high efficiency water reducing agents, it has low dosage and high water reducing rate because of its unique dispersive water reducing mechanism. According to the effective composition, the content of this type of water reducer is generally 0.05%~0.3%, and the water reduction rate of this type of water reducer with the content of 0.1%~0.2% is higher than the water reduction rate of sulonated naphthalene formalde-hyde condesate(SNF) with the content of 0.5%~0.7%. polycarboxylates high performance water-reducing admixture, PCA's water reduction rate is generally 25% to 35%, up to 40%.

Compared with traditional superplasticizers, polycarboxylates high performance water-reducing admixture, PCA has its unique performance advantages: low content, high water reduction rate, the content is usually 0.05%~0.5% of the amount of cement material, and the highest water reduction rate can reach more than 30%; The freedom of molecular structure change and the variety of raw materials make it possible to realize molecular design; It has good compatibility with cement, admixtures and other admixtures, and good slump retention performance. Can be used to prepare ordinary, high strength, high fluidity, high durability, self-compacting concrete, wide adaptability; The appearance color of concrete is uniform, smooth and less defects, suitable for the preparation of fair-faced concrete; It can effectively control the early hydration and temperature rise of cement in concrete, and is suitable for the preparation of mass concrete. It can be applied to special concrete with high strength and ultra-high strength, such as 150MPa ultra-high strength fluidity concrete, etc. It provides a technical guarantee for the large amount of fly ash, slag, steel slag and other industrial wastes to be used in concrete projects, promotes the recycling of waste, can greatly reduce the amount of cement, and has a significant role in energy saving and emission reduction; The production process does not use formaldehyde, strong acid, strong alkali and industrial naphthalene, which causes less harmful substances to environmental pollution and is conducive to the sustainable development of building engineering materials.

3) melamine sulfonate formaldehyde polycondensate

melamine sulfonate formaldehyde polycondensate is an admixture made of melamine, formaldehyde and sodium bisulfite as the main raw material under certain conditions through hydroxymethylation, sulfonation and condensation. melamine sulfonate formaldehyde polycondensate has a strong dispersive effect on cement, which can improve the fluidity of newly mixed concrete, or greatly reduce the water consumption (water reduction rate can reach 18%~25%); It has the advantages of no retarding effect, good early strength effect and small entraining effect. No chloride ions, no corrosion to the steel bar; At the same time, it has good adaptability to steamed concrete products. Because the color of this type of water reducer is light (colorless or white), it is often used in decorative concrete and other fields.

4) amino-aryl-sulphone phene formaldehyde condensate

amino-aryl-sulphone phene formaldehyde condensate is an admixture formed by reaction condensation with sodium p-aminobenzenesulfonate, phenol and formaldehyde as the main raw materials at a certain temperature. amino-aryl-sulphone phene formaldehyde condensate effect on concrete properties, with sulonated naphthalene formalde-hyde condesate(SNF) is similar, with the advantages of sulonated naphthalene formalde-hyde condesate(SNF). In contrast to sulonated naphthalene formalde-hyde condesate(SNF), it has hydration film lubrication, so the amino-aryl-sulphone phene formaldehyde The dispersion effect of condensate on cement particles is stronger, which can significantly improve the adaptability to cement, not only the water reduction rate is high, but also the plasticity is good.

5) aliphatic hydroxy sulphonate condensate

aliphatic hydroxy sulphonate condensate is an aliphatic hydroxy polymer derived from condensation of carbonyl compounds as the main raw material. The finished product is generally a reddish-brown liquid with a certain viscosity and a solid content of 35% to 40%.

2.2.3 C35 self-compacting concrete mix design

1) Raw material

The cement is P·O42.5R cement with specific surface area of 320□/kg, density of 3030kg/m3, initial setting time 142min, final setting time 241min, 28d compressive strength 47.8MPa, 28d flexural strength 7.8MPa.Fly ash I grade fly ash, fine The temperature is 21.6%, the water requirement is 102%, the firing loss is 1.76%, and the apparent density is 2800kg/m3. Mineral powder is limestone powder, calcium carbonate content97.36%, fineness 11.3%, mobility ratio 97%, apparent density 2800kg/m3. polycarboxylates high performance water-reducing admixture, PCA, light red, water reduction rate of 30% to 40%. The diameter of the gravel is 5mm to 20mm, the apparent density is 2784kg/m3, the sand is made of machine-made sand, the apparent density is 2738kg/m3, and other indicators of the coarse aggregate and fine aggregate meet the requirements of the code after test [47, 48].

2) C35 concrete mix calculation

Volume and mass of coarse aggregate(2-15): Vg=0.32m3 when the filling index is SF1.

$$m_g = v_g \times \rho_g = 0.32 \times 2784 = 891kg \tag{2.15}$$

Mortar volume (Vm) is calculated according to Formula (2.16):

$$V_m = 1 - V_g = 1 - 0.32 = 0.68\, m^3 \tag{2.16}$$

Sand volume fraction (Φ_s) according to the specification can determine its value range of 0.42 ~ 0.45, set sand The volume fraction is 0.45. Volume (V_s) and mass (M_s) of sand in 1m³concrete according to formula (2-17) and (2-18)Calculate.

$$V_S = V_m \times \Phi_s = 0.68 \times 0.45 = 0.31\ m^3 \quad (2.17)$$

$$M_S = V_S \times \rho_s = 0.31 \times 2738 = 845\ kg \quad (2.18)$$

Slurry volume (Vp) is calculated according to equation (2.19)

$$V_P = V_m - V_s = 0.68 - 0.31 = 0.37\ m^3 \quad (2.19)$$

In the design of cementing material dosage part, fly ash, mineral powder in the cementing material dosage occupied The mass fraction was 0.2, respectively, and the apparent density of the cementing material composite (ρ_b) was calculated according to formula (2.20)

$$\rho_b = \frac{1}{\frac{0.2}{2300}+\frac{0.2}{2800}+\frac{0.6}{3030}} = 2806\ kg/m^3 \quad (2.20)$$

Preparation strength $f_{cu,0}$ calculated according to equation (2.21):

$$f_{cu,0} \geq f_{cu,k} + 1.645\sigma = 35 + 1.645 \times 5 = 43.27\ m^3 \quad (2.21)$$

The water-binder ratio is calculated according to equation (2.22)

$$m_w/m_b = \frac{0.42\times50.8\times(1-0.2-0.2+0.2\times0.4+0.2\times0.9)}{43.27\times1.2} = 0.35 \quad (2.22)$$

The mass of $1m^3$ cementing material (mb) is calculated according to equation (2.23)

$$m_b = \frac{0.37 - \frac{10}{1000}}{\frac{1}{2806} + \frac{0.35}{1000}} = 509kg/m^3 \quad (2.23)$$

The water mass (mw) in 1m3 concrete is calculated according to equation (2.24):

$$m_w = m_b \times (m_w/m_b) = 509 \times 0.35 = 178kg \quad (2.24)$$

According to the proportion, the quality of cement, fly ash and mineral powder is: Cement 305kg; Fly ash 102kg; Mineral powder 102kg.

Admixture according to recommended dosage 1.5%, which is 7.6kg

3) Base mix ratio

Base mix of concrete to C35 calculated according to this section (Table 2.4)

Table 2.4 – Base mix ratio

cement	Fly ash	Mineral powder	water	sand	cobble	admixture
(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)
305	102	102	178	845	891	7.6

The concrete mix is tested and slump extension test and 7-day compressive strength test are carried out. The slump extension is 421 mm and the 7-day compressive strength is 38.2Mpa. The concrete mix has poor encapsulation, segregation, thick mixture and poor workability. It is necessary to further adjust the mix ratio.

2.3 Self-compacting concrete according to the recipe of the Swiss company Sika

2.3.1 Description of self-compacting concrete formulations based on "EFNARC

1)Requirements for self-compacting concrete

SCC can be designed to fulfil the requirements of EN 206 regarding density, strength development, final strength and durability. Self-compacting concrete must meet the following three indicators: Filling ability, Passing ability, Segregation resistance" [18].

2) Test method for performance of self-compacting concrete

EFNARC believes that For site quality control, two test methods are generally sufficient to monitor production quality. Typical combinations are Slump-flow and V-funnel or Slump-flow and J-ring(Table 2.5). With consistent raw material quality, a single test method operated by a trained and experienced technician may be sufficient.

Table 2.5 – Workability properties of SCC and alternative test methods

Property	Test methods Lab (mix design)	Field (QC)	Modification of test according to max. aggregate size
Filling ability	Slumpflow	Slumpflow	none
	T50cmslumpflow	T50cmslumpflow	
	V-funnel	V-funnel	max 20mm
	Orimet	Orimet	
Passing ability	L-box	J-ring	Different openings in L-box,
	U-box		U-box and J-ring
	Fill-box		
Segregation resistance	GTM test	GTM test	none
	V-funnel at T5minutes	V-funnel at T5minutes	

3) Workability criteria for the fresh SCC

EFNARC considers that the performance indicators of self-compacting concrete should meet the requirements of Table 2.6.

Table 2.6 – Acceptance criteria for Self-compacting Concrete

№	Method	Unit	Typical range values	
			Minimum	Maximum
1	Slump flow by Abrams cone	mm	650	800
2	T50cmslumpflow	sec	2	5
3	J-ring	mm	0	10
4	V-funnel	sec	6	12
5	Time increase, V-funnel at T5minutes	sec	0	3
6	L-box	(h2/h1)	0,8	1,0
7	U-box	(h2-h1) mm	0	30
8	Fill-box	%	90	100
9	GTM Screen stability test	%	0	15
10	Orimet	sec	0	5

Special care should always be taken to ensure no segregation of the mix is likely as, at present, there is not a simple and reliable test that gives information about segregation resistance of SCC in all practical situations.

4) Mix composition

In designing the mix it is most useful to consider the relative proportions of the key components by volume rather than by mass.Indicative typical ranges of proportions and quantities in order to obtain self-compactability are given below. Further modifications will be necessary to meet strength and other performance requirements. The mix ratio parameters are described as follows:

Water/powder ratio by volume of 0.80 to 1.10;

total powder content - 160 to 240 litres (400-600 kg) per cubic meter;Coarse aggregate content normally 28 to 35 per cent by volume of the mix; water/cement ratio is selected based on requirements in EN 206.

Typically water content does not exceed 200 litre/m3;The sand content balances the volume of the other constituents.

Laboratory trials should be used to verify properties of the initial mix composition. If necessary,adjustments to the mix composition should then be made. Once all requirements are fulfilled, the mix should be tested at full scale at the concrete plant or at site. In the event that satisfactory performance cannot be obtained, then consideration should be given to fundamental redesign of the mix. Depending on the apparent problem, the following courses of action might be appropriate: using additional or different types of filler, (if available); modifying the proportions of the sand or the coarse aggregate; using a viscosity modifying agent, if not already included in the mix; adjusting the dosage of the superplasticizer and/or the viscosity modifying agent; using alternative types of superplasticizer (and/or VMA), more compatible with local materials; adjusting the dosage of admixture to modify the water content, and hence the water/powder ratio.

2.3.2 Swiss Sika B35 (C30/35) self-compacting concrete formula design

Sika is a leader in self-compacting concrete (SCC) and in a sense represents the level of self-compacting concrete development in Europe. The company has developed a range of high performance admixtures and additives specifically for SCC, including Sika ViscoCrete high performance water reducing agent, Sikafume micro-silicon powder, Sika Stabilizer stability regulator, etc. Sika has extensive experience in the design and production of SCC mixes, and its products give concrete excellent fluidity, resistance to segregation and filling. Sika ViscoCrete water-reducing agent can effectively reduce the water consumption of SCC and improve the strength and durability. Sikafume micro-silica powder can improve the compactness and impermeability of concrete, and improve the long-term performance. Sika Stabilizer stability stabilizer ensures a good uniform distribution of SCC within the template. The following table (Table 2-7) shows the B35 concrete formula designed and adjusted by Sika based on the EFNARC self-compacting concrete specification.

Table 2.7 – B35 self-compacting concrete formula

cement M400	water	sand	cobble(5mm-10mm)	cobble(2mm-5mm)	admixture(sika viscocrete-1020sk)	sikafume	sika mix plus
(kg)	(L)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
460	195	800	891	250	4.4	12.5	0.08

The concrete mix is tested, and slump extension test and 7-day compressive strength test are carried out. The slump extension is 580mm, the 7-day compressive strength is 36.8Mpa, and the working performance is good.

2.4 Comparison of mixtures according to composition according to Chinese and European technologies for the creation of SCC B35, F200, W8.

2.4.1 Comparison of European self-compacting concrete code and Chinese self-compacting concrete code

The Chinese code divides self-compacting concrete into three grades according to the net distance of reinforcement used, while the European code has no clear concept of classification. The maximum particle size of aggregate is 25mm in China and 20mm in Europe. The amount of coarse aggregate per unit volume varies according to different grades in China's regulations. The value of grade 1 is 0.28-0.3m^3, grade 2 is 0.3-0.33m^3, and grade 3 is 0.32-0.35m^3, and the value of European ungraded aggregates is 0.28-0.35m^3. Unit water consumption is 155-180kg in China and less than 200kg in Europe. The ratio of water to powder material is 0.8-1.15 in China and 0.8-1.10 in Europe. The pulp volume per unit volume is specified as 0.32-0.4m^3 in the Chinese regulations, while the European regulations do not. The powder limit of aggregate is less than 0.075mm in China and less than 0.125mm in Europe. For the design method of self-compacting concrete, the Chinese code provides a clear design method and procedure, while the European code only gives the parameters but not the design method and procedure. For the detection methods of self-compacting concrete, the Chinese code and the European code mainly use U-box test, V-funnel test, T50 anti-segregation test and slump expansion test, but China subdivides the performance indicators according to different grades of self-compacting concrete, while the European code does not subdivide.

2.4.2 Comparison and optimization of two formulations of C35 self-compacting concrete

From the design basis of the mix ratio, according to the comparison in 2.4.1, the European specifications do not grade the self-compactness concrete, but only provide some guiding parameters and test methods, and rely more on market research and development, which is conducive to innovation. The Chinese code subdivides the performance of self-compacting concrete and gives clear design methods and steps, which has practical guidance significance and is convenient for the popularization and application of this technology.

From the perspective of the composition of the formula, on the whole, China's formula uses more admixtures such as fly ash and mineral powder to improve the working performance of concrete. The dependence on admixtures is not strong, and the amount of cement is relatively low. However, the reliability of its working performance is not high, and subsequent optimization is needed. European formulations (taking Sika as an example) rely more on the use of admixtures, the amount of cement is larger, the reliability is higher, but the marketing has certain limitations. In addition, from the selection of coarse aggregate, the particle size of Chinese formula aggregate is 5mm to 20mm, and that of European formula (taking Sika Company as an example) is 2mm to 10mm, and the specific surface area of coarse aggregate is larger, which increases the amount of cement, and in a sense also has a certain impact on the strength.

A large number of tests have proved that there are many factors affecting the performance of concrete, among which water-binder ratio, sand rate, admixture (fly ash, mineral powder, etc.) have a greater impact on concrete. The water-binder ratio of the Chinese formula is 0.35, the sand rate is 0.48, and the proportion of admixture is 0.2 fly ash and 0.2 mineral powder. Casi Company formula water binder ratio 0.42, sand rate 0.45, no admixture. It can be seen that the sand rate is basically the same, and the water-binder ratio and the admixture are different greatly. It can be seen that the key factors affecting the performance of the two groups of concrete are water-binder ratio, fly ash content and mineral powder content. Taking the above three factors as key factors (table 2.8), test method (table 2.9) was used to adjust the China mix ratio [47, 48].

Table 2.8 – Test level factor

level	factor		
	Water-binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio
1	0.35	0.1	0.1
2	0.38	0.2	0.2
3	0.41	0.3	0.3

Table 2.9 – Orthogonal test level factor

ID	Water-binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio	Slump spread (mm)	7-day compressive strength (Mpa)
1	0.35	0.1	0.1	388	37.8
2	0.35	0.2	0.2	425	38.5
3	0.35	0.3	0.3	421	37.4
4	0.38	0.1	0.2	452	37.2
5	0.38	0.2	0.3	385	38.6
6	0.38	0.3	0.1	607	37.4
7	0.41	0.1	0.3	510	36.7
8	0.41	0.2	0.1	534	35.8
9	0.41	0.3	0.2	580	35.1

The water-binder ratio is increased by 3% step by step from the calculated mix ratio of 0.35, which is close to the 0.48 of Sika Company. The fly ash and mineral powder are fluctuated by 0.1 respectively on the basis of the original 0.2. The Slump spread and 7-day compressive strength were measured and used as assessment indexes.

When the Slump spread is used as the assessment index, the larger the value, the better, and the maximum level K test number corresponding to the same column number is the best. The evaluation index, K value and average value of factor Water-binder ratio $\bar{k}$ are calculated as follows:

$$K_1 = 388 + 425 + 421 = 1234 \tag{2.25}$$

$$K_2 = 452 + 385 + 607 = 1444 \tag{2.26}$$

$$K_3 = 510 + 534 + 580 = 1624 \tag{2.27}$$

$$\overline{K_1} = \frac{388+425+421}{3} = 411.33 \tag{2.28}$$

$$\overline{K_2} = \frac{452+385+607}{3} = 481.33 \tag{2.29}$$

$$\overline{K_3} = \frac{510+534+580}{3} = 541.33 \tag{2.30}$$

The calculation method of K value and average $\bar{k}$ of fly ash and mineral powder is the same as above, and the calculation results are listed in Table 2.10. The sum of K values of each factor at each level is equal, indicating that the K value of each factor is calculated correctly.

Table 2.10 – Calculation table of K value and $\bar{k}$ value of each factor

ID	Water-binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio
K_1	1234.00	1350.00	1529.00
K_2	1444.00	1344.00	1457.00
K_3	1624.00	1608.00	1316.00
$\bar{k}_1$	411.33	450.00	509.67
$\bar{k}_2$	481.33	448.00	485.67
$\bar{k}_3$	541.33	536.00	438.67
Σk	1434.00	1434.00	1434.00

Calculate the range R of the three factors of water-binder ratio, fly ash and mineral powder respectively:

$$R_1 = 1624 - 1234 = 390 \quad (2.28)$$

$$R_2 = 1608 - 1344 = 264 \quad (2.29)$$

$$R_3 = 1529 - 1316 = 313 \quad (2.30)$$

The larger the range value, the greater the influence of this factor. From the results of range calculation, the water-binder ratio has the greatest influence on slump expansion, followed by fly ash and mineral powder. Fig 2.5 shows the impact trend.

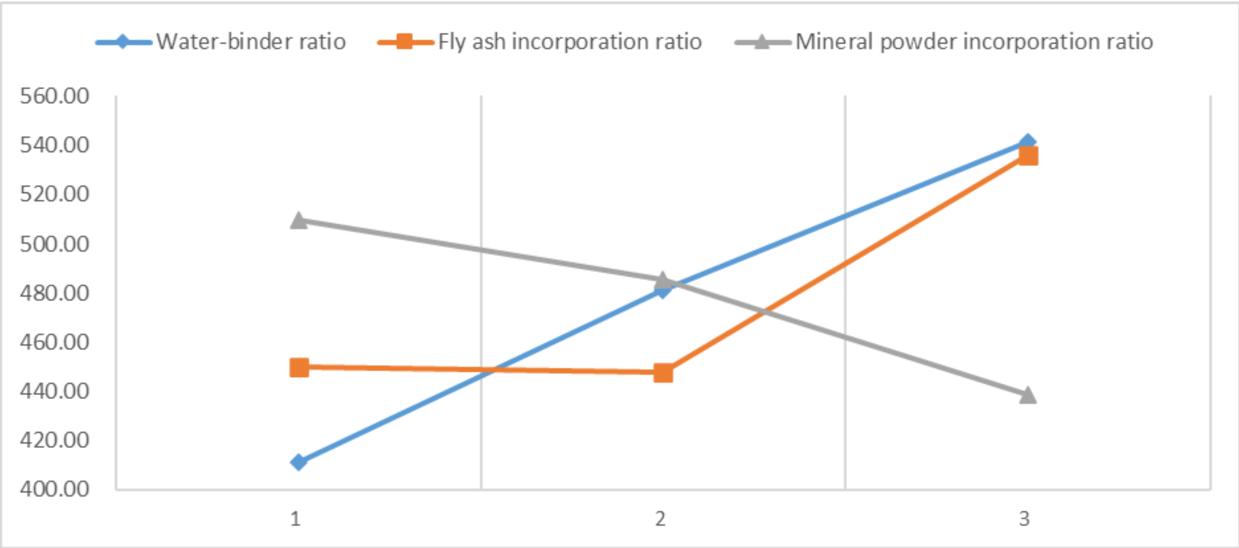

Figure 2.5 – Trend chart of each influencing factor

With the increase of water-binder ratio, slump extension increases. When the fly ash incorporation ratio increased from 10% to 20%, slump expansion did not change significantly, and when it increased to 30%, slump expansion increased significantly. The slump expansion of the ore powder increases significantly at 10% incorporation, and decreases significantly with the increase of incorporation. As a result, the optimal amount of fly ash and mineral powder is 30% and 10% respectively. From the results of 7-day compressive strength, the strength of concrete decreases when the water-binder ratio reaches 0.41, so it is appropriate to choose 0.38 as the water-binder ratio.

In summary, it can be determined that the combination numbered 6 in Table 2.9 is the optimal combination, and its slump expansion degree and 7-day compressive strength index can meet the requirements. The C35 self-compacting concrete fit optimized according to the sixth set of data is shown in Table 2.11.

Table 2.11 Optimized mix ratio of C35 self-compacting concrete

Cement60% (kg/m3)	Fly ash30% (kg/m3)	Mineral powder10% (kg/m3)	water (kg/m3)	sand (kg/m3)	cobble (kg/m3)	admixture (kg/m3)
305	153	51	193	845	891	7.6

2.5 Conclusions on chapter 2

In this chapter, the application technical specifications and EFNARC specifications of self-compacting concrete are compared with JGJ/T283-2012 Self-compacting Concrete Guidelines. The biggest difference is that JGJ/T283-2012 classifies the performance of self-compacting concrete, and gives a clear calculation method and step of the mix ratio, which is more conducive to market promotion; However, EFNARC does not classify, but only gives some parameters of concrete mix ratio, which is more flexible in use and conducive to innovation.

Secondly, taking the B35 self-compacting concrete mix ratio of Sika Company as an example, the B35 concrete mix ratio calculated according to JGJ/T283-2012 is compared. The B35 concrete mix ratio of Sika Company is more dependent on the admixture, and the reliability is better. The B35 concrete mix ratio calculated by JGJ/T283-2012 is less dependent on admixtures, and more is to add fly ash, mineral powder and other admixtures to adjust the working performance of self-compacting concrete, but the reliability is relatively low.

Finally, by comparing the formula of B35 self-compacting concrete of Sika Company, the key factors affecting B35 self-compacting concrete are analyzed by orthogonal test method, and the mix ratio of B35 self-compacting concrete calculated by JGJ/T283-2012 is optimized.

CHAPTER 3

RATIONAL TECHNOLOGY OF APPLICATION OF SELF-COMPACTING CONCRETE

3.1 Analysis of typical defects of reinforced concrete building structure

Concrete was found in ancient Rome, has a long history of use, with the continuous development of human society, concrete is also constantly updated and developed. Historically, the development of the construction industry is mainly divided into three stages: from the construction of a large number of buildings to the parallel construction and reinforcement transformation, and then the reinforcement transformation is an important part [19, 20]. With the development of the construction industry to a certain extent, the reinforcement and transformation of old buildings will occupy a dominant position [21]. Under normal circumstances, the process structure has a fixed life, and people generally interpret it as a designed life limit. For ordinary houses, the design life limit is generally 50 years [22], and the design life of bridge structures is generally 100 years [23]. Although the structure is at or near the design life, it does not mean that the building cannot be used, but it is more or less there are some diseases. Some building structures limited to the current technical design will also produce some defects. During the use of engineering structures, due to the influence of environmental factors, such as load changes, use function changes, temperature, humidity, freeze-thaw, chlorine salts, etc., material degradation will lead to diseases. Fire, flood, earthquake and other disasters will also cause different degrees of impact on the building structure. The disease of concrete structure is mainly manifested in the following aspects [24].

A) Injure of concrete structure

During the use of concrete, the structural properties change due to the action of load, resulting in the deterioration of its durability or service function (Fig 3.1).

Figure 3.1 – Injure of concrete structure

B) Crack of concrete structure

A discontinuous phenomenon of concrete structure due to changes in external load, temperature, humidity and other environment, manifested as "cracking" (Fig 3.2).

A) Corrosion of concrete structure

The main external manifestations of the corrosive medium to the physical and chemical destruction of concrete structure are peeling, falling off, corrosion of steel bars and so on (Fig 3.3).


Figure 3.2 – Crack of concrete structure


Figure 3.3 – Corrosion of concrete structure

B) Frost heave failure of concrete structure

In the wet state, due to the change of temperature, the water in the internal void of the concrete structure will freeze and expand, which will cause damage to the building. (Fig 3.4)

Figure 3.4 – Frost heave failure of concrete structure

C) Leakage of concrete structure

Water leakage, seepage, moisture and other phenomena occur due to damage or aging of concrete structures (Fig 3.5).

Figure 3.5 – Leakage of concrete structure

D) Aging of concrete structure

The durability of concrete structure decreases for a long time, and cracks, carbonization, brittleness, falling off, and so on appear (Fig 3.6).

Figure 3.6-Aging of concrete structure

Obviously, reinforced concrete structure in the use of inevitable diseases, which is also the embodiment of the law of nature, these diseases affect the use of the building function and even harm the safety of the building structure, which can not be ignored. Compared with the demolition and reconstruction of the building structure, it has more advantages for the reinforcement of the original structure. Firstly, the reinforcement can save the land area; Secondly, the reinforcement and renovation make full use of the existing structure, which not only reduces the investment and shortens the construction period, but also satisfies the function and safety of the structure, and has good economic value. Thirdly, the combination of reinforcement and earthquake resistance can also improve the earthquake resistance of the original structure and extend the service life.

3.2 Application of self-compacting concrete in increasing section reinforcement engineering

At present, the common concrete structure reinforcement methods [25,26] in the field of concrete structure reinforcement can be divided into: increasing section reinforcement method, cladding steel reinforcement method, prestress reinforcement method, changing the structural force transmission path reinforcement method, external adhesion reinforcement method of flexural members and other reinforcement methods, etc. Each reinforcement method has its own characteristics and adaptation range, and should be selected according to specific conditions. The increasing section reinforcement method is applicable to the concrete section bearing capacity, which needs to be greatly improved. This method improves the bearing capacity and stiffness of reinforced concrete beams by increasing the section area of the original structure and adding reinforcement [27]. It is also suitable for serious concrete corrosion, by chiselling the damaged concrete of the original structure, appropriately increasing the section or not increasing the section to replace the damaged concrete. Compared with other reinforcement methods, increasing section reinforcement method has simple construction process, low reinforcement cost and reliable force, but the gap between the template and the original structure is small, the template model is irregular, and there are steel bars distributed among it, which is not convenient for the vibration of concrete, ordinary concrete is difficult to achieve dense filling, and the quality is difficult to guarantee. Self-compacting concrete just makes up for this defect, self-compacting concrete is vibration-free, the aggregate particle size is small, the fluidity is large, in the concrete pouring project can only rely on its own weight to fill the complex and narrow model corner.

comparing the reinforcement method of self-compacting concrete with the reinforcement method of ordinary concrete, self-compacting concrete can avoid the disadvantages of the difficulty to guarantee the compactness of ordinary concrete with the reinforcement method of self-compacting concrete with the reinforcement method of ordinary concrete with expanded section and ensure the quality of reinforced concrete under the condition that the engineering cost has little influence. At the same time, because there is no vibration in the construction process, it can save machinery and power consumption, save labor and shorten the construction period. After reinforcement, the new and old structures are compatible as a whole, with good reinforcement effect, high durability, low maintenance cost, in line with the requirements of green construction, with far-reaching economic and social benefits, and a wide range of application prospects.

3.2.1 The basic method of increasing section reinforcement of self-compacting concrete

The method of increasing section reinforcement of self-compacting concrete is to increase the cross-sectional area and reinforcement of the member by pouring new reinforced concrete outside the original concrete member, so as to improve the bearing capacity and stiffness of the member and reduce the slenderness ratio of the column.

According to the force characteristics of the component, weak links, geometric size and convenient construction, the reinforcement can be designed to increase the section of one side, two sides, three sides, four sides, etc. [28].

The four-sided reinforcement method is often used for axial compression column members (Fig 3.7).

Figure 3.7 – Column reinforcement on four sides

For eccentric compression column members, unilateral reinforcement is generally adopted. When the compression side is weak, the compression side is strengthened, and the tension side is strengthened. The beam members can be either one-sided reinforcement or three-sided reinforcement (Fig 3.8) according to the different forces in the reinforcement area. Generally, a slab is strengthened on one side, and a concrete wall is strengthened on both sides or one side (Fig 3.9).

Figure 3.8 – The beam is strengthened on one side

Figure 3.9 – Reinforcement of shear wall

The minimum thickness of self-compacting concrete should not be less than 40mm when reinforcing plates and 60mm when reinforcing beams. The strength grade of concrete should not be lower than C20, and it should be one level higher than the strength grade of the original component concrete. Gravel or pebble should be used, and its maximum particle size should not be greater than 20mm. The diameter of the reinforcement bar of the reinforcement plate should be 6-8mm; Ribbed steel bars should be used for longitudinal reinforcement of beams. The minimum diameter of steel bars should not be less than 12mm for beams and 14mm for columns. The maximum diameter should not be greater than 25mm; The diameter of the closed stirrup should not be less than 8mm, and the diameter of the U-shaped stirrup should be the same as that of the original stirrup. The net distance between the reinforced reinforcement bar and the reinforced bar of the original member should not be less than 20mm, and should be welded with short bars. The diameter of the short reinforcement should not be less than 20mm, the length should not be less than 5d(d is the smaller value of the diameter of the new longitudinal reinforcement andthe original longitudinal reinforcement), and the middle distance between the short reinforcement should not be more than 500 mm (Fig. 3.10).

When the four-sided concrete envelope is used for reinforcement, the enclosing stirrup should be set. When reinforcing with one or both sides, the U-shaped stirrup should be set. The U-shaped stirrup should be welded to the original stirrup. The length of the single-side weld is 10d, the length of the double-side weld is 5d, and d is the diameter of the stirrup (Fig. 3.11) [29, 30].

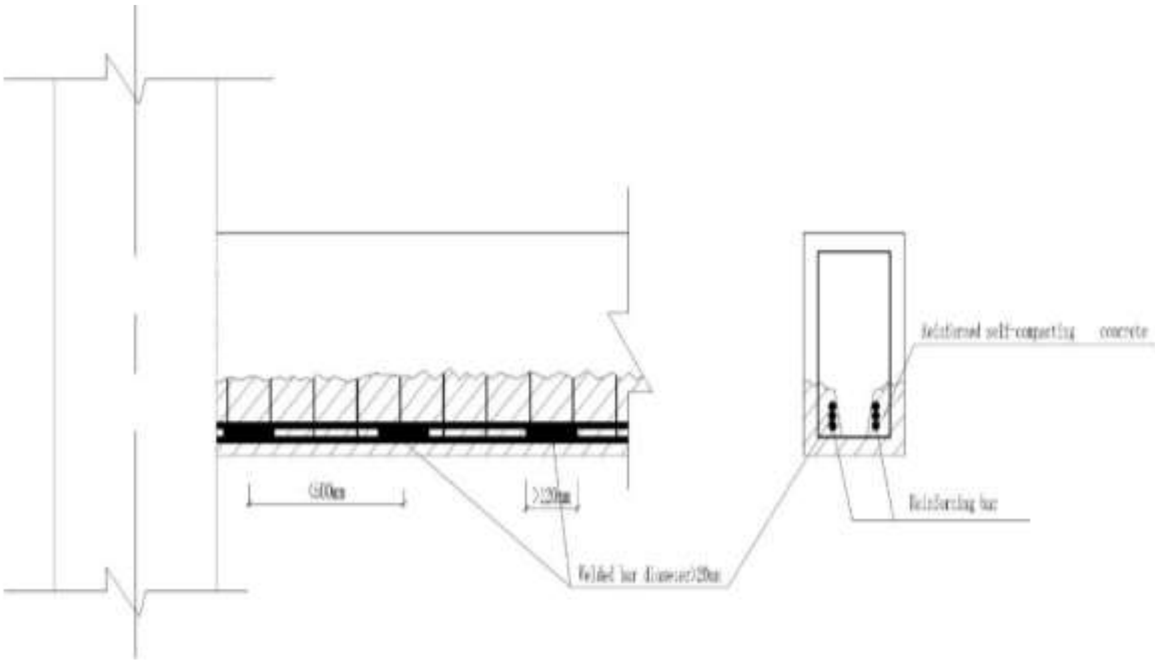

Figure 3.10 Reinforcement structure drawing

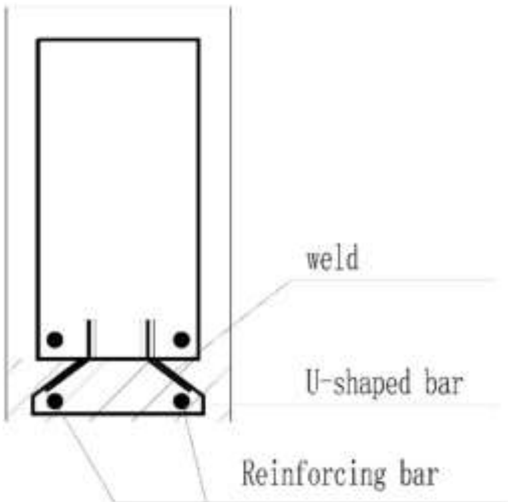

Figure 3.11 U-shaped steel structure

In addition to the reasonable design of the scheme, the most critical problem of the self-compacting concrete reinforcement method is the combination of old and new concrete. Complex stresses such as shear, tension, pressure and bending occur on the bonding surface of new and old concrete, among which the bonding surface shear stress is the most likely to cause damage. Moreover, the shear bearing capacity of concrete material is weak, and the new and old concrete joint is the thinnest ring joint in the concrete structure. So the treatment of new and old concrete sections is particularly important.

3.2.2 Adhesive coating of fittings

For the interface treatment of new and old concrete reinforced by increasing section of self-compacting concrete, the general practice is to clean the bonding surface first, and then brush the interface agent on the bonding surface, and then pour new self-compacting concrete. The bonding strength between new and old concrete structures is largely determined by the treatment of the interface and the interface agent.

A) Concrete bonding interface treatment method

Concrete bonding section treatment refers to the removal of all damaged, loose and attached aggregates, mortar and impurities on the old concrete bonding surface, so that the solid part of the aggregate is exposed to the surface, forming a rough surface, in order to improve the cohesiveness of the new concrete, to a certain extent, the bond strength increases with the increase in surface roughness, and its core is the increase in the contact area.

Common concrete bonding interface treatment methods include manual chiseling, high pressure water injection, sand blasting, acid etching and so on. Each method has its advantages and disadvantages [31, 32]. Manual chisel method (Fig 3.12), which is a common interface roughness treatment method in practical engineering, is to use a hammer, chisel or special small hand-held machinery to knock the old concrete bond surface, so that its surface forms random uneven shape, and increase the roughness of the bond surface.

Figure 3.12 – Manual chisel method

The advantages of this method are simple construction technology, no need for large and expensive mechanical equipment, low engineering cost, and high reliability of interface processing. Its disadvantage is that it is not convenient for large-area mechanized construction, and it will cause disturbance in the old concrete bonding surface and form additional micro-cracks.

High pressure water jet method (Fig 3.13).

This method is to use high pressure water gun to rough the new and old concrete bonding surface. By using the pressure of high-pressure water gun (100-250MPA), the spraying speed, spraying distance and spraying speed are controlled, and the cement stone of the old concrete bonding surface is removed by means of huge impact force, so that the coarse aggregate on the surface of the concrete is exposed and the uneven bonding surface is formed.

Figure 3.13 – High pressure water jet method

The advantages of this method are high mechanized construction level, fast construction speed, small disturbance to the old concrete and good concatenation uniformity.

However, the high pressure water spraying equipment used in this methodis expensive and the engineering cost is large.

In the shot blasting (sand) method (Fig 3.14), steel balls of different diameters are sprayed to the treated surface of the old concrete by a jet, and the roughness of the old and new concrete bonding surfaces can be quantitatively described by the average depth by controlling the jet speed and density.

Acid etching method ,uses a certain concentration of hydrochloric acid to react with cement in the old concrete to improve the micro-roughness of the interface of the old concrete that has been macro-roughened.

Figure 3.14 – High pressure water jet method

This method can increase the contact area of the new and old concrete, improve the microstructure of the interface layer, so as to significantly improve the mechanical bite force and van der Waals force of the bond interface, and greatly improve the bond strength and durability.

3.2.3 Bonding agent

The bond strength of new and old concrete mainly depends on the mechanical bite force, van der Waals force and surface tension [33]. Among them, the mechanical bite force at the macro level is provided by the surface roughness of the old concrete. The mechanical bite force at the microscopic level consists of the following three parts [34] :The burr on the surface of the hydrated calcium silicate of the new concrete and the acicular ettringite radiate outward into the pores of the old concrete, connecting the new and old concrete into a whole; The burr and acicular ettringite on the surface of the hydrated calcium silicate of the new concrete radiate outward into the pores of the old concrete, connecting the new and old concrete into a whole; Materials that are not hydrated or fully hydrated in the existing concrete are hydrated in the new concrete. Based on the microstructurally dominant theory [35], combined with the above theoretical model of new and old concrete and the analysis of bonding mechanism, it can be seen that there are two main reasons for the weakness between the new and old concrete layers: the orientation distribution of $Ca(OH)_2$, AFM and C-S-H gel between the new and old concrete layers will increase the proportion of harmful pores between the layers; At the same time, the secondary crystallization of $Ca(OH)_2$, AFM crystals and poorly crystallized C-S-H crystals in this layer are relatively large, resulting in a low strength of this layer. Due to the large crystal pores between the layers, bubbles are easily generated between the new and old concrete layers under the action of vibration, which increases the defects between the new and old concrete layers and leads to the weakness of the layers.

To reduce the negative effect of weak interlayer between new and old concrete on the structural performance after restoration, it is generally possible to strengthen the bonding property between new and old concrete layers by using interface agents.The main characteristics of the coating agent should be the following three points: it can improve the adhesion between the new and old concrete layers, that is, it has excellent bonding performance with the concrete; It has better strength when the deformation properties of new and old concrete are similar. High durability and compactness to avoid damage to new and old concrete structures caused by external erosion between layers.

Polymer-modified cement-based interface agent is prepared by modifying cement paste and cement mortar with high molecular polymer like emulsion or glue powder. At present, the types of polymers commonly used for bonding polymer-modified cement-based materials in engineering [36, 37] are shown in Table 3.1.

Table 3.1 – Polymer modified cement-based material polymer(begin)

Polymer morphology	Polymer type	Polymer name
Emulsion	Rubber latex	Styrene butadiene latex (SBR), butadiene rubber (MBR) and so on
	Resin emulsion	Thermosetting emulsion: epoxy resin emulsion; Asphaltene emulsion: asphalt rubber; Thermoplastic emulsion: polyvinyl propionate (PVP), polyacrylate (PAE), etc
Liquid state		Epoxy resin
Polymer morphology	Polymer type	Polymer name
Water-soluble polymers and monomers		Polyvinyl alcohol (PVA), cellulose ether, magnesium polyacrylate, etc
Redispersible rubber powder	Thermoplastic rubber powder	Vinyl acetate - tertiary vinyl carbonate (VVA), ethylene-vinyl acetate (EVA), ethylene-acrylic ester (SAE), etc
	Elastic rubber powder	Elastic rubber powderStyrene-butadiene (SBR), etc

The polymer modified cement slurry interface agent can improve the tangential and axial drawing properties between the new and old concrete layers. The interface agent mixed with butadiene emulsion has the best effect on improving the bond properties between the new and old concrete layers, and the interface drawing strength of the new and old concrete on 7d and 28d has increased by 114% and 96% compared with that of the new and old concrete coated with the clean cement slurry interface agent. The splitting tensile strength was significantly higher than that of other experimental groups [38]. By comparing the influence of polymer-modified cement net paste interface agent on the drawing bond performance between the new and old concrete layers with different dosage of butadiene emulsion, it is found that when the polymerization ratio is 1:3, butadiene modified interface agent can improve the bond performance between the new and old concrete layers best, with an increase of 18.7% [39]. The bonding properties of three polymer emulsion mortars, acrylic acid, styrene propylene and chloroprene, under different curing methods were compared. Compared with ordinary mortars, polymer modified mortars can all improve the bonding properties between new and old concrete layers, but acrylic mortar has the highest improvement in the bonding properties of old concrete, and polymer mortar has its own more suitable bonding methods [40, 41]. Compared with ordinary cement-based interfacial agents, polymer-modified cement-based interfacial agents have excellent performance in improving the bond performance between new and old concrete layers. However, due to the complicated cement system and various polymer types, the selection and dosage of polymer in cement-based interfacial agents of bonded polymer modified cement-based are more based on experience in solid projects.

3.3 Technology of laying self-compacting concrete without vibration

The laying of self-compacting concrete includes mixing, transportation, formwork installation, perfusion, maintenance and mold removal of self-compacting concrete. Before mixing the self-compacting concrete, the self-compacting concrete mix is designed and calculated according to the method of 2.2.3, and the self-compacting concrete formula is optimized in the laboratory (the raw materials used to optimize the concrete mix in the laboratory should be the same as the construction raw materials.) according to the method of 2.4.2, so that the strength and engineering performance of the self-compacting concrete mix can meet the construction requirements.

A) Mixing and transportation of self-compacting concrete

The raw materials used for the preparation of self-compacting concrete shall meet the requirements of 2.1.2 (sampling inspection), the self-compacting concrete shall be stirred by horizontal shaft, planetary or countercurrent forced agitator, and the raw materials shall be measured by electronic metering system. The maximum allowable deviation of raw material weighing shall comply with the following provisions (Kg by mass) : gelling material (cement, mineral admixture, etc.)±1%; Admixture ±1%; Aggregate (coarse aggregate and fine aggregate) ±2% : mixing water ±1%. In the production process, due to the detection of the moisture content of aggregate and the adjustment of water consumption according to the moisture content of aggregate, the temperature of raw materials should be controlled in high temperature weather, cement ≤60°C, aggregate ≤30°C, water ≤25°C, fly ash and other admixtures ≤60°C. The mixing time of self-compacting concrete should not be less than 60seconds [42].

In the process of self-compacted concrete transportation, the roller of the mixing truck should keep a constant speed, the speed should be controlled at 3r/min~5r/min, and it is forbidden to add water to the car; The time from the start of the transport vehicle to the unloading of materials should not be more than 120min; Before unloading, the tank body of the stirring transport truck should be rotated at a high speed for more than 20s.

B) Formwork installation of self-compacting concrete

Self-compacting concrete has high fluidity and high side pressure. Self-compacting concrete has almost no ability to support its own weight, and the lateral pressure of the formwork will increase linearly with the increase of the pouring height during the pouring process. The lateral pressure of the formwork should be calculated according to the following formula to ensure that the formwork has sufficient lateral stiffness.

$$F = \gamma_C H \tag{3.1}$$

$F -$ Maximum side pressure of newly poured concrete against formwork (kN/m2)

$\gamma_c -$ Gravity density of concrete (kN/m^3)

$H -$The total concrete side pressure from the calculated position to the top of the newly poured concrete Height (m).

The flow of self-compacting concrete is large, and the small gap between the formwork will cause the slurry leakage phenomenon, which will affect the strength of self-compacting concrete. The formed template should ensure that the size, shape and joint of the component are tight, and no slurry leakage is allowed. When pouring concrete with complex structure shape or closed formwork space, pouring openings and vents should be set at appropriate positions of formwork, The pore size of the vent is 20mm.

C) Placing of self-compacting concrete

The size, shape, strength and stiffness of the formwork should be checked before the casting of self-compacting concrete. When the self-compacting concrete is transported to the construction site, its working performance should be tested (collapse extension test), and the specimens should be preserved under the same conditions. The temperature of self-compacting concrete into the formwork should not exceed 35℃ and should not be lower than 5℃[42]. The horizontal flow distance should not exceed 7 meters, and the tipping height should not be greater than 5 meters. If the structure shape is more complex, you can knock the side of the form to assist concrete compaction.

D) Self-compacting concrete formwork removal and maintenance

When the non-load-bearing form (side form) is removed, the strength of the structural concrete should not be less than 1.2Mpa to ensure that the surface and corners are not damaged; The mold removal time of the bearing formwork (bottom mold) should meet the concrete strength requirements. When the span of the plate and arch is 2m or less than 2m, the design strength level of 50% needs to be reached. When the span is greater than 2m to 8m, a design strength level of 75% is required. For beams (span of 8m and less than 8m), a design strength grade of 75% is required; For load-bearing structures (spans greater than 8m), a 100% design strength rating is required. Cantilever beam And cantilever plates are also required to achieve 100% design strength rating. The strength of concrete can be determined by curing specimens under the same conditions[43]. The complex shape of the structure can extend the removal time of the template according to the actual situation.

After the formwork is removed, the concrete should be maintained in time. Measures such as covering, water storage, film, moisture and spraying curing agent can be adopted for maintenance. The maintenance time shall not be less than 14 days.

3.4 Engineering recommendations for quality control of concrete and finished products using self-compacting concrete

The quality control of self-compacting concrete runs through the selection of raw materials, mix design, construction technology and maintenance and other links, and its quality control must run through the whole process of the formation of high-performance concrete. Only by controlling the quality of each link of the production and construction of self-compacting concrete, can the final formation of products that meet the engineering construction standards. The quality control of self-compacting concrete is to set quality control points and key links through systematic and scientific management and advanced technical means, and carry out strict quality control in the process of its quality formation to ensure the realization of quality objectives such as workability, strength and durability of concrete. In the formulation of the quality control system of self-compacting concrete, according to its quality formation process, the quality control content and raw material selection, mix ratio design, pouring, construction, maintenance and other processes are clearly divided, and a high performance concrete quality control system is established (Fig. 3.15).

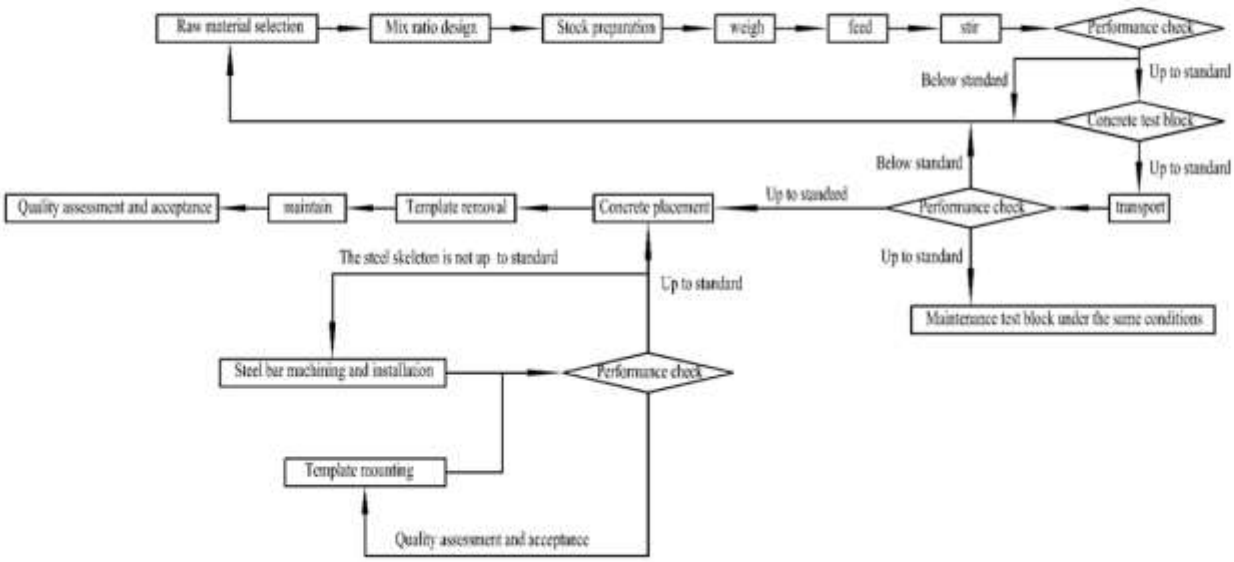

Figure 3.15 – Self-compacting concrete quality control flow chart

According to the theory of whole-process quality control, it can be divided into three stages: pre-control, in-process control and post-process control. In flow chart 3-16, the selection of raw materials and the determination of the mix ratio of self-compacting concrete are taken as the contents of the prior control, the contents of material preparation, weighing, feeding, mixing, transportation, pouring, mold removal and maintenance are taken as the contents of the control, and the quality acceptance and quality assessment of the finished product are taken as the contents of the post-control.

The previous stage is the basis of the quality assurance of the first stage. Only when the quality of the early work is guaranteed can the quality of the subsequent work be realized. Dynamic control is implemented in the quality control, and pre-control, in-process control and post-correction control are carried out through the PDCA cycle.

A) Self-compacting concrete prior quality control

Compared with ordinary concrete, the composition of self-compacting concrete is more complex, and the quality of raw materials is more sensitive to the quality of self-compacting concrete. For the quality assessment of raw materials, chemical tests and physical tests are generally used for assessment (such as mortar strength test, cement stability test, gravel hardness test, sand grading test, etc.). However, due to the large quantity of raw materials, it is impossible to achieve comprehensive quality assessment, so in addition to clear the sampling frequency and sampling capacity, it is also necessary to conduct market research, considering the technical level, goodwill and project performance of raw material suppliers.

The determination of the mix ratio is the key control item of the quality of self-compacting concrete. In the process of the determination of the mix ratio, the characteristics of the project, the use environment and the construction environment must be fully considered. Then, through calculation, trial allocation, adjustment and optimization, the optimal scheme is determined to ensure that each index of self-compacting concrete meets the needs of engineering construction, and the principle of testing before engineering is implemented. If the use of new materials in the mix design must have sufficient test basis, it is necessary to carry out construction site sample test.

B) Quality control of self-compacting concrete

The control process mainly focuses on the preparation of the self-compacting concrete mixture and the self-compacting concrete construction at the self-compacting concrete construction site. Each stage includes different work, and each work connects and influences each other, so the quality control of different work in each stage is more critical. The preparation stage of self-compacting concrete mix (which is generally completed by commercial concrete companies) is to carry out the weighing, feeding, mixing, discharging, quality evaluation and transportation of the components of self-compacting concrete on the basis of the selection of qualified materials and mix ratio design. Different working methods and standards should be developed for different work and performance requirements of self-compacting concrete (such as the order of feeding, mixing time, factory quality inspection standards, etc.), automatic control procedures should be implemented to reduce the error caused by personnel operation, and the quality control system and special person responsible system should be established.

Self-compacting concrete construction stage (generally completed by the construction unit) This work is mainly completed by the construction unit, the main work link includes the preparation of the construction unit personnel, machinery, concrete pouring, vibration, workability evaluation, concrete maintenance and other work. There are many factors affecting the quality of self-compacting concrete in the field construction process, which are often affected by the technical level and method of concrete construction personnel, construction equipment and environment, etc., resulting in the quality problems of concrete in one way or another. First of all, before the self-compacting concrete is poured, the formwork and steel bar inspection batch must be inspected and accepted, and the overall stability of the formwork, dimensional deviation, joint, release agent and steel bar binding, protective layer thickness and other quality must be strictly controlled to prevent the overall quality of self-compacting concrete from being affected by the quality of the formwork and steel bar, and random detection of slump and expansion of high-performance concrete must be carried out. Pouring is allowed only when the workability meets the requirements. Self-compacting concrete in the pouring process to control the mold temperature, tipping height and other indicators, after the mold removal should be timely maintenance, maintenance time should not be less than 14 days.

C) Self-compacting concrete post quality control

The quality of self-densifying concrete includes two aspects of appearance quality and strength. The general requirements of appearance quality are that the surface of concrete should be flat, the geometric size should meet the design requirements, and there should be no cracks, no pores, no sand holes, no peeling, no peeling, no color difference, no water stains and other defects. The evaluation of appearance quality is mostly subjective, and a clear evaluation method should be established according to the characteristics of the project. For example, the color of concrete can be compared according to the color card made by the sample project. The strength of self-compacting concrete is determined by mechanical test of the same strength concrete specimen. For self-compacting concrete used for structural reinforcement or complex structures, ultrasonic non-destructive testing should also be carried out to detect whether there are internal defects in the concrete structure.

3.5 Engineering case

3.5.1 Project overview

The bridge is located in an area of Yunnan Province and crosses a small river. The current pavement on both sides of the bridge is asphalt concrete pavement. The total length of the bridge is 25m, the upper structure adopts 1×20m simply supported prestressed concrete T beam, and the lower structure adopts U-shaped gravity abutment to expand the foundation. The intersection Angle between the bridge and the river is 90°, the full width of the bridge is 10m, and the net width of the carriage-way is 9m. Each side is equipped with 0.5m reinforced concrete wall guardrail. The upper part of a hole is composed of 5 pieces of prestressed concrete T beams, the height of T beams is 1.5m, and the load of the roadway adopts highway -II class [*4]. Fig 3.16 shows the cross-section of the bridge:

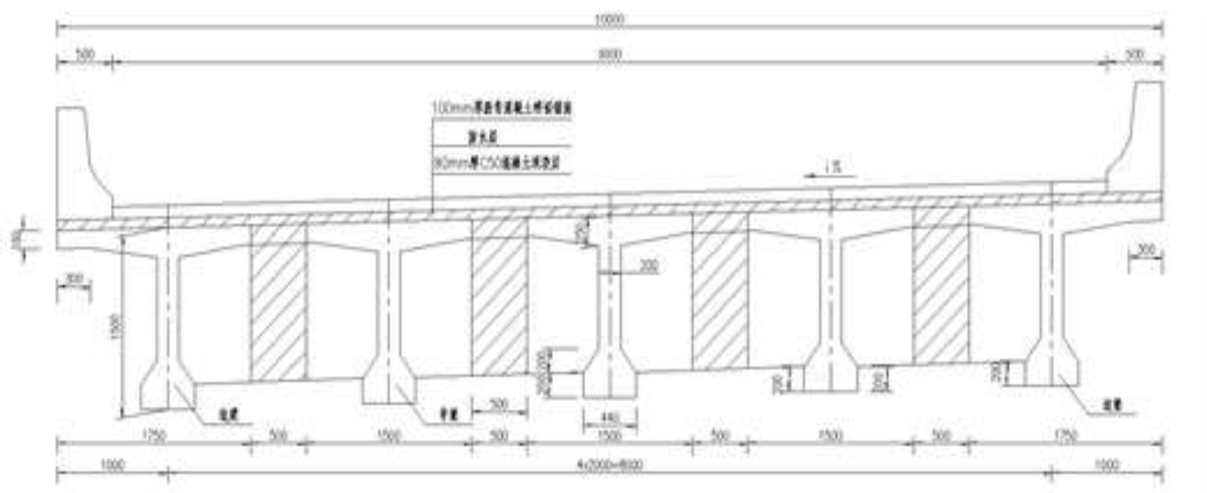

Figure 3.16 – Standard profile of bridge structure

Due to the doubling of traffic volume in recent years, the bridge is in a state of overload operation. At present, the beam structure is cracking (Fig. 3.17), the cracks are distributed in the beam web, and the stirrup is exposed and rusted locally, which leads to certain safety risks of the bridge. In order to eliminate the hidden danger, the bridge must be reinforced.

Figure 3.17 – Cracks in beam web

3.5.2 Reinforcement scheme

Through the investigation of the traffic flow, the current traffic flow meets the requirements of Class I lane load [*6]. Through checking and calculating the load capacity of the beam structure Class I lane, the load capacity is shown in Fig 3.18, 3.19. The calculation results show that the load capacity obviously cannot meet the requirements under the load of Class I lane.

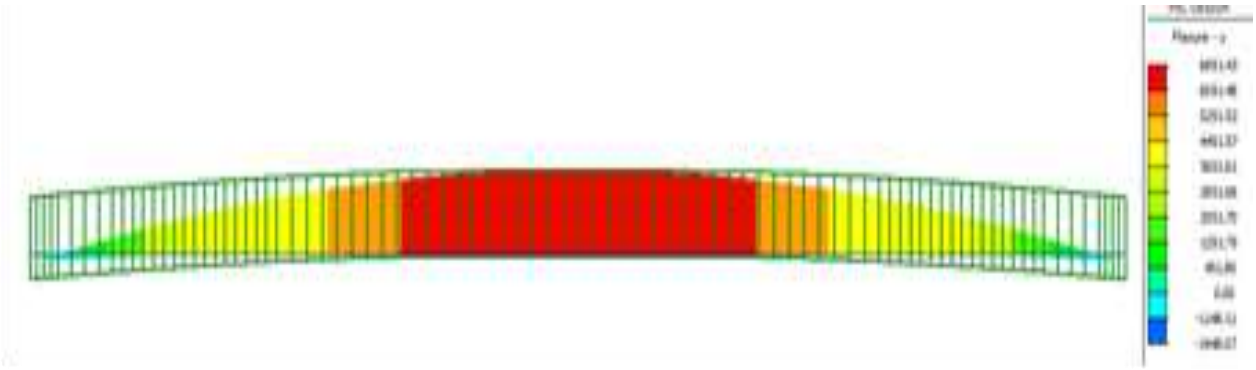

Figure 3.18 -Flexural capacity envelope diagram, [kNm]

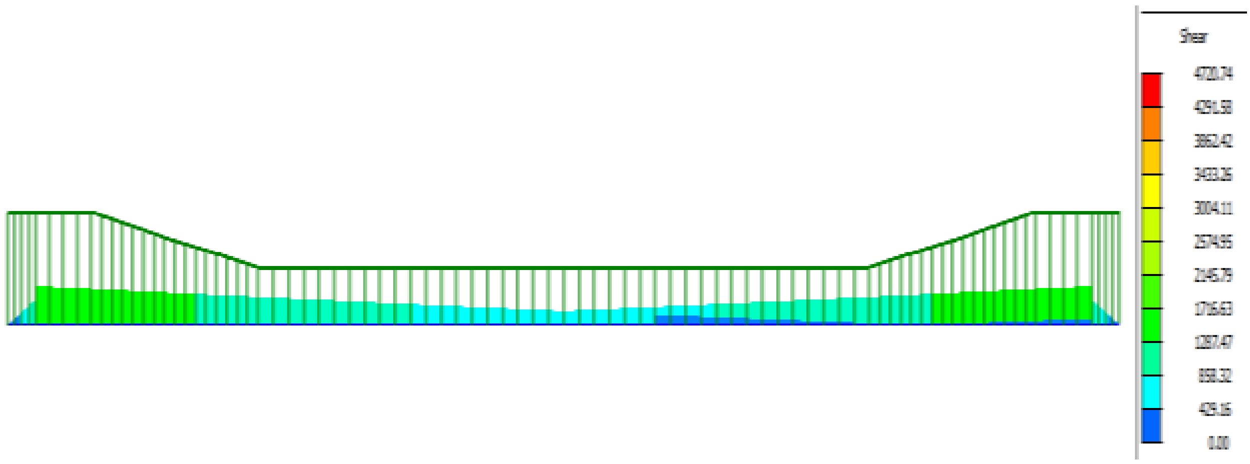

Figure 3.19 – Envelope diagram of shear capacity [kN]

In order to enhance its bearing capacity and consider the demand for durability, the reinforcement method of increasing cross-section is adopted, as shown in Fig. 3.20 … Fig. 3.22.

Since the gap between the original concrete and the formwork is only 160mm, and the reinforcement is densely configured, the construction work is carried out under the bridge floor, and it is difficult to use ordinary concrete for construction.

Therefore, considering the road traffic condition of the bridge, the surrounding human settlement environment and the feasibility of construction, it is decided to use C35 self-densifying concrete for reinforcement and maintenance of the bridge.

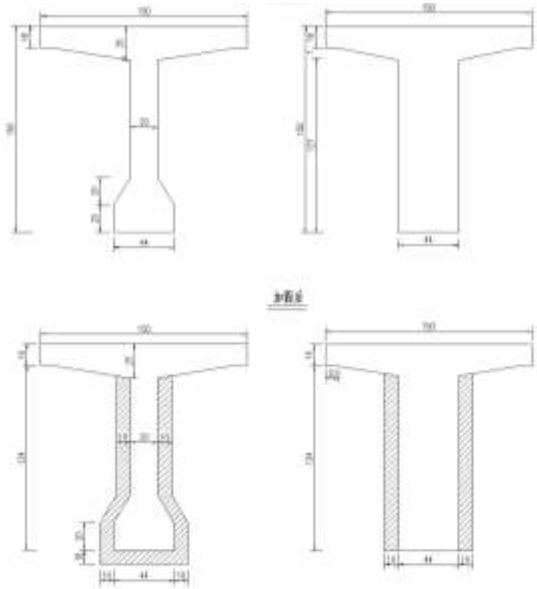

Figure 3.20 – Reinforced structure diagram

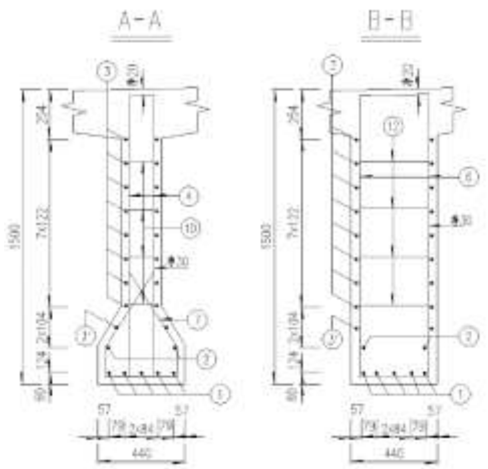

Figure 3.21 – Section of reinforced front beam structure

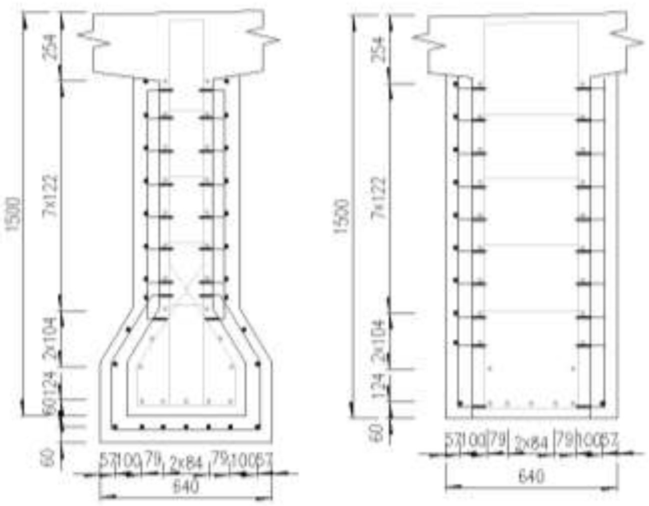

Figure 3.22-Reinforced structure reinforcement section

3.5.3 C35 self-compacting concrete mix

The self-compacting concrete is determined according to the orthogonal test in Chapter 2, and the self-compacting concrete is mixed according to the mix ratio shown in Table 2.11. Before each opening, the test personnel must carry out the moisture content test of fine and coarse aggregates, and then convert the construction mix.

3.5.4 Reinforcement construction

1) Surface treatment

According to the design requirements, the concrete on the surface of the web at the end of the hair should be manually chiseled with the welding parts of the original structure reinforcement to expose the structural hoop and structural reinforcement, and the depth of the hair at the remaining positions should not be greater than 1cm, and the distance between the hair points should not be greater than 3cm. The concrete of the additional horseshoe part is manually chiseled to expose the original stirrup and main reinforcement. The damage to the structural reinforcement should be avoided during the chiseling process. After chiseling, water is used to clean the floating ballast and dust on the surface of concrete.

2)Implant rebar, rebar installation

When welding short steel bars (vertical moment 10cm, vertical moment 15cm) on the original structure, the welding length between the short steel bars and the original structure should be not less than 2cm, and the concrete should be avoided during welding. Weld the new stirrup and the original stirrup together and tie the longitudinal reinforcement. Tie the short steel bar with the new longitudinal main bar and stirrup. In order to ensure the combination of old and new concrete and increase the strength of alkali resistance, anchorage reinforcement is implanted on the side of the beam web. Mark the location and type of the drill hole for planting reinforcement according to the design requirements. The location of the original steel bar should be accurately detected before drilling. If the original steel bar is encountered, the drilling position should be adjusted appropriately to prevent damage to the original steel bar of the structure. After drilling is completed, the dust in the hole is blown out with compressed air after checking the hole depth and aperture, which should be repeated 3 to 5 times until there is no dust in the hole. After the hole is clean, the prepared planting glue is sent into the hole until the planting glue fills the entire hole, and then implant the Φ10 threaded steel bar (HLT planting steel bar) in the form of plum, and do not disturb the steel bar within

Figure 3.23 Reinforcement bar processing and installation drawing

12 hours after planting, if there is a large disturbance, it is appropriate to re-plant the

reinforcement. The length of each embedded-steel bar is determined according to the thickness of the newly added section at the location of the embedded-steel bar, and the embedded-steel bar work should be carried out by a professional team. Fig 3-23 shows the rebar installation.

3.5.5 Interface agent brushing and template installation

Before installing the template, apply the interface agent evenly on the surface of the concrete. Because the fluidity of self-compacting concrete is very large, the pressure generated is greater than the pressure of ordinary concrete, so the template should have enough stiffness. When installing the template, the fixing and support of the template should be strengthened to avoid running the mold.Attention should be paid to the sealing between the formwork, the sealing between the formwork and the beam should also be paid to the sealing, the solid section size is small, the concrete pouring amount is small, the contact surface between the concrete and the formwork is large, and the reinforcement is dense, in order to ensure the pouring quality, the spacing between the pouring mouth should not be too large. A pouring opening is arranged at every 1.2m interval on the mid-span formwork of the beam body, and a vent hole with a diameter of 20mm is arranged at the top of the formwork between the two pouring openings.

3.5.6 Concrete placement

Due to the narrow operation surface and small pouring section of the project, manual pouring can only be adopted (Fig 3.24).

Figure 3.24 – Self-compacting concrete placement

When the concrete is actually poured, the wooden hammer can be slightly knocked on the template according to thesituation, and if necessary, the long drill can be properly inserted and rammed to exclude the air that may be trapped and ensure the density of the poured concrete. When pouring, each piece of beam should be poured at the same time as far as possible to ensure that several consecutive pouring openings are poured at the same time, and a piece of beam should be completed at one time without delay. During the pouring process, the formwork should be inspected at any time. If subsidence, deformation, displacement, torsion or serious leakage is found, the pouring should be stopped immediately. After inspection and strengthening, the pouring can continue.

3.5.7 Concrete removal and maintenance

Due to the relatively large plastic shrinkage of self-compacting concrete, coupled with the non-bleeding of self-compacting concrete, the early water loss of the concrete surface can not be supplemented by the internal, and a large number of surface shrinkage cracks are easy to form, which affects the strength and durability of concrete. In order to obtain early and long-term high strength, high dimensional stability and high durability, wet curing should be started earlier and the curing time should be longer for self-compacting high performance concrete with a large amount of admixture instead of cement. After the completion of the concrete pouring, the mold can not be removed less than 12 hours. After the dismantling of the mold, timely water maintenance, to ensure 7 to 14 days of maintenance period: the first 7 days should be water maintenance at least 4 times a day: morning to work, before lunch, before dinner in the evening, 11 to 12 p.m Between. After 7 days, water maintenance three times a day in the morning, middle and evening.

3.6 Conclusions from technological proposals for the use of self-compacting concrete

Based on the analysis of common diseases of concrete and the characteristics of self-compacting concrete, this chapter puts forward the application of self-compacting concrete in reinforcement engineering with increased section, and establishes the quality control system. And it has been applied in practical engineering.

CHAPTER 4 ECONOMIC PART

4.1 Calculation of the estimated cost (cost) of 1 m3 of monolithic concrete product using self-compacting concrete.

The production of self-compacting concrete products requires the consumption of raw materials, the use of machinery and equipment, the consumption of labor, and the transportation of on-site construction. Therefore, the composition of the cost of self-compacting concrete mainly includes the cost of raw materials, the cost of mechanical equipment (including energy), labor costs and transportation costs. Next, we estimate the cost of 1 cubic meter self-compacting concrete according to the matching ratio in Table 2.11.

A) Determine the cost of raw materials

Under normal circumstances, the raw materials of commodity concrete manufacturers generally adopt the mode of outsourcing. For outsourced raw materials, the cost of raw materials includes the purchase price, transportation expenses, reasonable transportation losses, and taxes and fees of purchased materials. Because in most cases, the quantity of raw materials purchased by commodity concrete companies is relatively large, most of them use a package offer, that is, raw material suppliers bear the transportation of raw materials, and the comprehensive price of taxes and fees. The comprehensive unit price of raw materials in a certain region can be determined through market research and business negotiation.

B) Determine the operating cost of mechanical equipment

The use fee of machinery and equipment generally includes depreciation, major repair costs, general repair costs, installation and demolition and off-site transportation costs, labor costs (machinery operators) fuel and power costs, taxes and other aspects. Generally speaking, the use of machinery and equipment is measured by the unit price of the machine, and the unit price of the machine refers to the total cost of a construction machine in a workbench (8 hours) under normal operating conditions. Mechanical equipment can be used in the construction activities of free equipment, can also be rented. For free equipment, it is necessary to calculate the unit price of the platform shift. For leased equipment, the unit price of the platform shift of the leased equipment is the user fee of the mechanical equipment. The cost estimate in this section adopts the price of the leased machinery shift, which can be obtained through market research.

C) Determination of labor cost

Labor costs refer to the expenses of production workers directly engaged in construction and installation projects, including basic wages, auxiliary wages, wage surcharges, social insurance, etc. [45]. Generally, labor costs are determined according to the guidance of the labor market and the government.

D) Transportation cost

Concrete transportation generally uses a special concrete transport tank truck, its cost is mainly composed of fuel costs, labor costs, depreciation costs of transportation equipment, transportation equipment maintenance costs, etc. The biggest factor affecting it is the transportation distance. This section is estimated by transporting 1 km per cubic meter of concrete. Transportation equipment is often leased in the actual project, and the transportation cost can be obtained by market research.

According to the above factors that constitute the cost of concrete, the cost of C35 self-compacting concrete is estimated, as shown in Table 4.1:

Table 4.1 Cost estimate of making 1m³C35 self-compacting very solid soil for 1Km transportation

Item		Quantity (kg)	Unit price (rmb)	Combined price (rmb)
Cost of materials	cement	305	0.32	97.6
	Fly ash	153	0.21	32.13
	Mineral powder	51	0.82	41.82
	water	193	0.005	0.965
	sand	845	0.003	2.535
	gravel	891	0.002	1.782
	admixture	7.6	4	30.4
Labor cost				46.23
Machine usage fee				6.15
Transportation charge				3.2
Make 1m³C35 self-compacting concrete and transport 1km				207.232

Description: Material unit price and transportation cost are obtained through market research; Labor costs, According to the Construction Project Cost pricing Rules and Mechanical instrument shift fee of Yunnan Province Construction Project Cost pricing Rules and Mechanical instrument shift fee Quota [45,46]

4.2 Determination of generalized cost indicators of classic concrete product

Concrete cost in narrow sense refers to the production cost of concrete mix. In a broad sense, the cost of concrete refers to the completion of the construction of components of a frame structure through some series of organization and work, so that the components play their due roles in the structure. In a broad sense, the cost of concrete includes not only the production cost of the concrete mix, but also the costs incurred in the process of reinforcement installation of concrete components, formwork installation, concrete placement, concrete maintenance, concrete inspection and acceptance, management and organization, etc. The cost of each work includes direct costs, indirect costs, profits and taxes, as shown in Fig 4.1

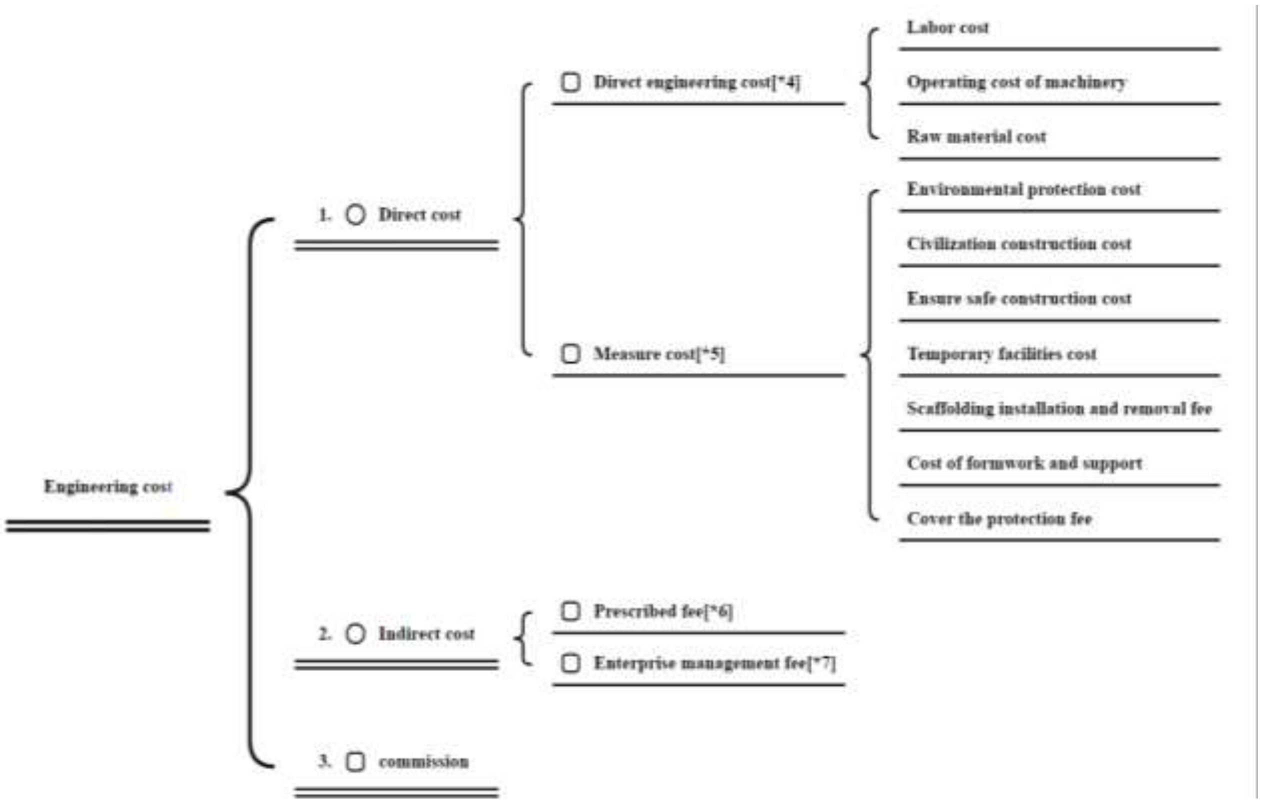

Figure 4.1 – Cost structure

[*4] It refers to the various costs that constitute the engineering entity spent in the process of engineering construction.

[*5] It refers to the necessary expenses incurred before and during the construction of a non-

engineering entity in order to complete the construction of the project.

[*6] It refers to the fees that must be paid as prescribed by the government and relevant authorities.

[*7] Refers to the construction and installation enterprise organization construction production and operation management costs.

4.3 Calculation of the economic effect of introduction of self-compacting concrete (comparison with typical analogues)

According to the cost formation process (described in 4.2 in this chapter), the biggest difference between the pouring of traditional concrete members and the pouring of self-compacting concrete members is that the mix ratio of concrete is different, and the second is that ordinary concrete needs vibration while self-compacting concrete does not need vibration during the pouring process. Template installation work, steel bar processing and installation work are the same, measure costs, prescribed costs, enterprise management fees and taxes are the same. Therefore, the cost analysis of ordinary concrete components and self-compacting concrete components only needs to compare the cost of concrete mixing, transportation, pouring and maintenance.

Table 4.2 shows the common concrete mix proportion of C35. The cost of concrete mixing and transportation is calculated according to the mix ratio (Table 4.3). The cost of mixing, transportation, pouring and maintenance of C35 concrete components is calculated according to the cost composition analysis in Figure 4.1 (Table 4.4). The mixing, transportation, placement and maintenance costs of C35 self-compacting concrete members are calculated according to the cost composition analysis in Figure 4.1 and Table 4.5.

Table 4.2 – Common concrete mix proportion of C35

cement	water	sand	cobble
(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)
480	180	580	1230

Table 4.3 – The cost of making 1m³C35 ordinary concrete and transporting it 1Km

item		Quantity (kg)	Unit price (rmb)	Combined price (rmb)
Cost of materials	cement	480	0.32	153.6
	water	180	0.005	0.9
	sand	580	0.003	1.74
	gravel	1230	0.002	2.46
Labor cost				46.23
Machine usage fee				6.15
Transportation charge				3.2
Make 1m³C35 concrete and transport 1km				214.28

Table 4.4 – C35 Ordinary concrete member concrete pouring cost(begin)

Job content	Construction site transportation, pouring, maintenance				
item	name	unit	Labor, machinery, materials, consumption [*8]	Unit price(rmb)	Combined price(rmb)
Labour	Combined workdays	Work day	0.956	80	76.48

Table 4.4 – C35 Ordinary concrete member concrete pouring cost(finish)

Job content	Construction site transportation, pouring, maintenance				
Item	name	unit	Labor, machinery, materials, consumption [*8]	Unit price (rmb)	Combined price (rmb)
Materials	C35 Ordinary concrete	m^3	1.015	214	217.21
	Grass bag (for maintenance)	m^2	0.252	20	5.04
	Water (for maintenance)	m^3	0.789	5	3.945
machine	Concrete insert vibrator	Stage crew	0.077	21	1.617
	Motorized dump truck(Concrete construction site transportation)	Stage crew	0.078	24	1.872
Total price					306.16

[*8] Labor, machinery and other consumption data from the People's Republic of China construction project unified quota

Table 4.5 – C35 Self-compacting concrete member concrete placement costs

Job content	Construction site transportation, pouring, maintenance				
Item	name	unit	Labor, machinery, materials, consumption [*9]	Unit price (rmb)	Combined price (rmb)
Labour	Combined workdays	Work day	0.956	80	76.48
Materials	C35 Ordinary concrete	m^3	1.015	207.23	210.11
	Grass bag (for maintenance)	m^2	0.252	20	5.04
	Water (for maintenance)	m^3	0.789	5	3.945
	Motorized dump truck(Concrete construction site transportation)	Stage crew	0.078	24	1.872
Total price					297.44

[*9] Labor, machinery and other consumption data from the People's Republic of China construction project unified quota

For the same component, the cost of C35 ordinary concrete placement is 306 (rmb), and that of C35 self-compacting concrete placement is 297.44 (rmb), which shows a significant decrease in cost from the results. The main factor affecting the cost is the design of the mix ratio. Compared with the traditional concrete C35 self-compacting concrete mix, the addition of fly ash, mineral powder and other admixtures greatly reduces the amount of cement, and the use of admixtures improves the performance of concrete.

CONCLUSIONS

In this research, through the study of the preparation methods of European and Chinese self-compacting concrete, the mix ratio of C30/35 self-compacting concrete is optimized by orthogonal test. Based on the engineering practice, the application of self-compacting concrete in reinforcement engineering is analyzed, the quality control system of self-compacting concrete in engineering application is proposed, and the mix ratio of optimized C30/35 self-compacting concrete is applied to the engineering example. Finally, the cost formation process of concrete is analyzed, and the cost difference between self-compacting concrete and ordinary concrete is compared.

1) Have been studied the historical experience of the production and use of concrete as a construction material in China and around the world. Have been proven the possibility of concrete as the main structural material of the construction industry on the basis of the performed analysis

2) By comparing the relevant specifications of self-compacting concrete preparation methods in China and Europe, it is found that in addition to certain differences in unit water consumption and water-binder ratio, the biggest difference is that self-compacting concrete in China is classified according to performance requirements, and there are clear and unified design methods and steps. However, the European self-dense concrete preparation only gives the reference value of key data such as unit water consumption and water-binder ratio, and there is no clear unified design method and step.

3) Fly ash can obviously improve the performance of self-compacting concrete.

When the fly ash incorporation ratio increases from 10% to 20%, the slump expansion does not change significantly, and when the fly ash incorporation ratio increases to 30%, the slump expansion increases significantly.

4) The effect of mineral powder on the performance of self-compacting concrete is limited. Slump expansion increases significantly at 10% and decreases significantly with the increase of the addition.

5) This paper analyzes 6 common diseases of concrete structure, puts forward the strengthening method and technology of increasing section by self-compacting concrete, and applies it in practical engineering.

6) According to the whole process quality control theory, the quality control system of dense concrete is established, and the key points of quality control at each stage are expounded.

7) By analyzing the cost formation process of concrete and comparing the cost difference between self-compacting concrete and ordinary concrete, it is found that the main factor affecting the cost is the design of concrete mix ratio. In the design of self-compacting concrete, the addition of admixtures such as fly ash and mineral powder greatly reduces the amount of cement and thus reduces the cost.

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Self-compacting concretes for the formation of complex monolithic constructions with the use of additives

Master's student: Sun Wenjun (China), 690063143@qq.com

Supervisor: Assoc. prof. Volodymyr Popov (VNTU, Ukraine)

02 Research object, subject and the main goal of research

Research object	**worn-out reinforced concrete building structures** that need repair and strengthening
Subject of study	repair **self compacting concrete mixtures** for arranging reinforcements of complex shapes and for performing work in compressed production conditions
The main goal of research	To **create a rational methodology for selecting a self-compacting concrete mixture** and its formulation for performing repair work in compressed working conditions and (or) for restoring the design bearing capacity of structures of complex shape

03

Research novelty

The novelty of the obtained results

consists in the **developed methodology for carrying out repair work using self-compacting concrete mixtures** in conditions difficult for workers to access without the use of vibration, as well as in the proposed recipe for repair self-compacting concrete mixture with the use of superplasticizing and air-entraining additives, which has the ability to harden quickly

04 Research tasks

- to study the historical experience of the production and use of concrete as a construction material in China and around the world;
- to study the method of forming self-compacting concrete, its recipe, as well as the advantages and disadvantages of self-compacting concrete over classic concrete mixtures;
- to analyze the state of the issue of strengthening existing reinforced concrete building structures;
- to determine rational methods of strengthening structures that are in hard-to-reach places or have a complex structural shape;
- to determine additives that increase the mobility of the concrete mixture without increasing the water-cement ratio;
- to propose a rational technology for laying self-compacting concrete;
- to propose a rational construction of reinforcement frame and its adhesive additives within self compacting concrete technology of restoration of the structure

05 Publications based on research results

1) Sun Wenjun. Overhaul of the crossbars systems of bridge supports with the installation of reinforced concrete brackets [Electronic resource] / V. Popov, Wenjun Sun // Electronic scientific publications. Abstracts of the report at the LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024) (Vinnytsia, 20-23.03.2024) – Electronic text data – 2024. P. 1338 – 1340. Link: https://conferences.vntu.edu.ua/index.php/all-fbtegp/all-fbtegp-2024/paper/view/20947/17448

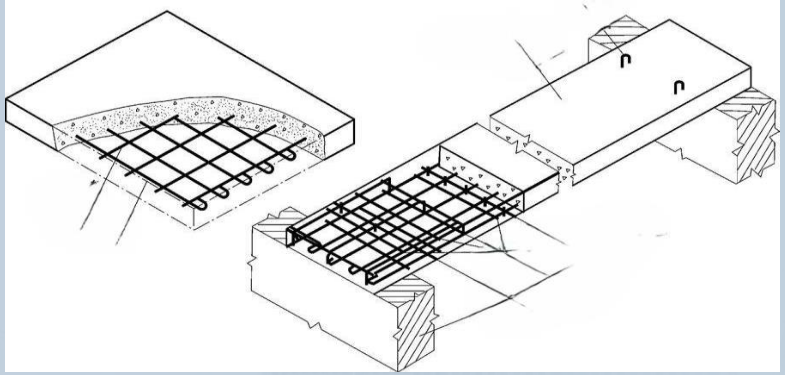
2) Sun Wenjun. Strengthening the foundations of the primary ammonia reforming furnace in conditions without working free space using self-compacting concrete [Electronic resource] / V. Popov, Wenjun Sun, Xiaohong Li // Abstracts of the report at the International scientific and practical Internet conference Youth in science: research, problems, prospects (MN-2024), (VNTU) – Electronic text data – 2024. Link: https://conferences.vntu.edu.ua/index.php/mn/mn2024/paper/view/21531

06 Chapter 1 The current state of the theory and practice of monolithic concrete

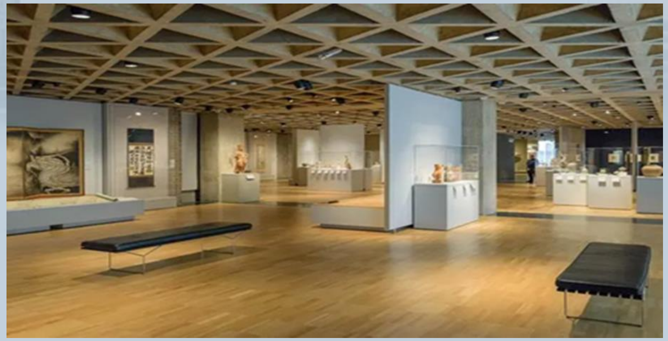
History of concrete

The Pantheon was built in 27 BC

1824, Portland Cement



In the mid-19th century, reinforced concrete was born



At the end of the 19th century, concrete made great progress

Chapter1 The current state of the theory and practice of monolithic concrete

Concrete development

Ordinary concrete

- water
- Cement
- Sand
- gravel

+

admixture1

- Water reducing agent
- Retarder
- And so on

admixture2

- Fly ash
- Mineral powder
- And so on

→

Concrete with different properties

- **<u>Self-compacting concrete</u>**
- High strength concrete
- And so on

Chapter1 The current state of the theory and practice of monolithic concrete

◻ The difference between self-compacting concrete and ordinary concrete

Property/Aspect	Self-Compacting Concrete (SCC)	Normal Concrete (NPC)
Flowability	Very good, self-leveling	Requires compaction
Water/Cement Ratio	Typically below 0.5	Typically between 0.5 and 0.6
Fine Aggregate	Closely controlled	Relatively loose
Coarse Aggregate	Closely controlled size and grading	Looser requirements
Admixtures	Significant use, such as fly ash, silica fume	Less use
Additives	High-range water reducers and viscosity modifiers	Standard water reducers
Construction Method	No compaction needed	Requires compaction
Construction Speed	Fast	Slow
Strength Development	Usually rapid	Depends on mix and cure
Durability	High, good resistance to permeation	More variable
Shrinkage	Low	Higher
Cost	Higher	Lower
Application Field	Suitable for complex structures	Widely used
Environmental Impact	Lower	Higher (due to compaction)

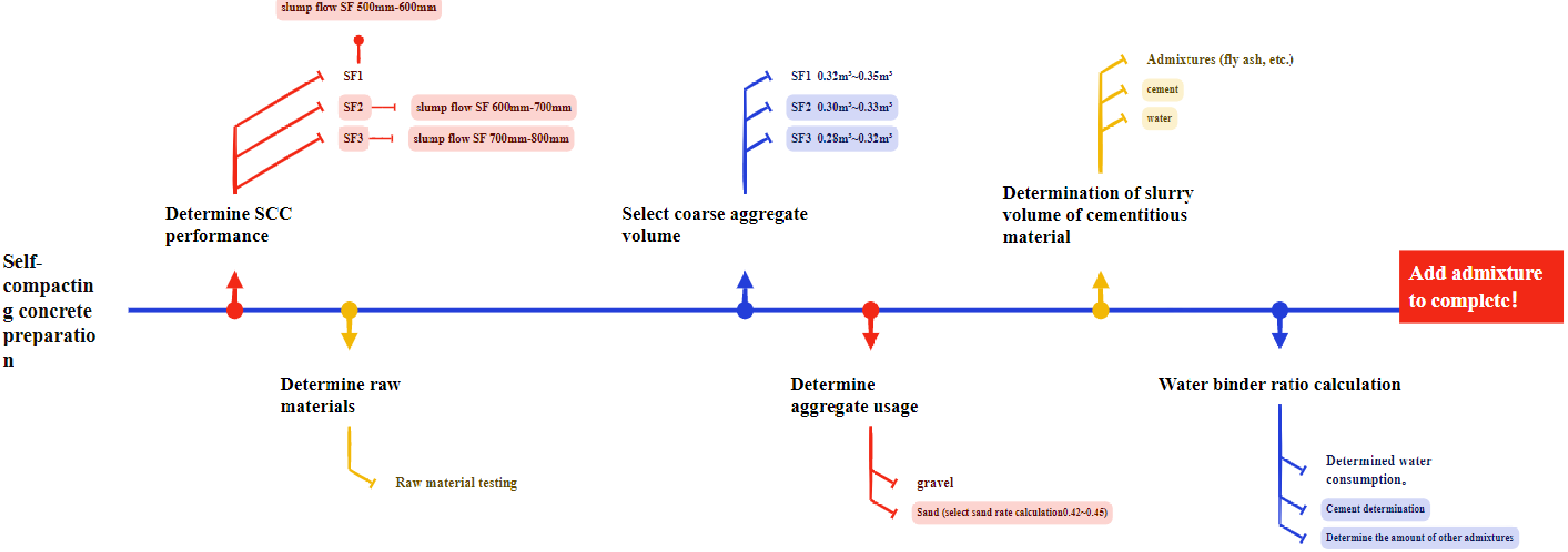
09 Conclusions on chapter 1

- Self-compacting concrete fills the space in the formwork without vibration under the action of its own weight, and maintains its own uniformity and compactness through dense steel bars to form a dense concrete structure, so it can be used for strengthening concrete structures

Chapter 2 Reasonable preparation technology and formula of self-compacting concrete

cement	Fly ash	Mineral powder	water	sand	cobble	admixture
(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)
305	102	102	178	845	891	7.6

☐ Preparation method of self-compacting c



Chapter 2 Rational preparation technology and receipe of self-compacting concrete

Preparation method of self-con

cement M400	water	sand	cobble(5mm-10mm)	cobble(2mm-5mm)	admixture(sika viscocrete-1020sk)	sikafume	sika mix plus
(kg)	(L)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
460	195	800	891	250	4.4	12.5	0.08

Reference index of concrete preparation

Water/powder ratio	volume of 0.80 to 1.10
Total powder content	160 to 240 litres (400-600 kg) per cubic meter
Coarse aggregate content	normally 28 to 35 per cent by volume of the mix
cement	cement ratio is selected based on requirements in EN 206
water content	does not exceed 200 litre/m3

Chapter 2 Rational preparation technology and recipe of self compacting concrete

□ B35 (C30/35) self-compacting concrete mix optimization

Comparison of key factors between C35 and B35 (C30/35)

	China C35	Europe B35 (C30/35)
Water-binder ratio	0.35	0.42
Sand ratio	0.48	0.45
admixture	Fly ash, mineral powder	There is no

Test level factor

level	factor		
	Water-binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio
1	0.35	0.1	0.1
2	0.38	0.2	0.2
3	0.41	0.3	0.3

Factors affecting the performance of the two groups of concrete are water-binder ratio, fly ash content and mineral powder content.

Chapter 2 Rational preparation technology and recipe of self compacting concrete

B35 self-compacting concrete mix optimization

Test level factor

ID	Water - binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio	Slump spread (mm)	7-day compressive strength (Mpa)
1	0.35	0.1	0.1	388	37.8
2	0.35	0.2	0.2	425	38.5
3	0.35	0.3	0.3	421	37.4
4	0.38	0.1	0.2	452	37.2
5	0.38	0.2	0.3	385	38.6
6	0.38	0.3	0.1	607	37.4
7	0.41	0.1	0.3	510	36.7
8	0.41	0.2	0.1	534	35.8
9	0.41	0.3	0.2	580	35.1

Calculation table of K value and k¯value of each factor

ID	Water-binder ratio	Fly ash incorporation ratio	Mineral powder incorporation ratio
K_1	1234.00	1350.00	1529.00
K_2	1444.00	1344.00	1457.00
K_3	1624.00	1608.00	1316.00
$\bar{k}_1$	411.33	450.00	509.67
$\bar{k}_2$	481.33	448.00	485.67
$\bar{k}_3$	541.33	536.00	438.67
Σk	1434.00	1434.00	1434.00

Chapter 2 Rational preparation technology and recipe of self compacting concrete

□ B35 self-compacting concrete r

Cement60%	Fly ash30%	Mineral powder10%	water	sand	cobble	admixture
(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)	(kg/m3)
305	153	51	193	845	891	7.6

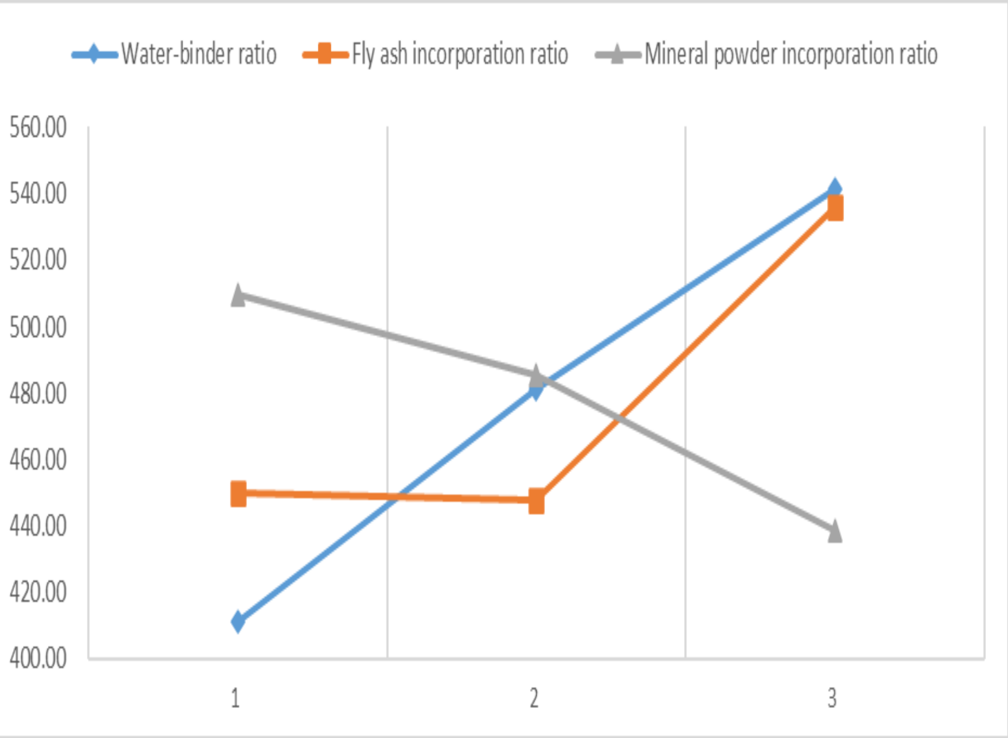


Figure 2.5-Trend chart of each influencing factor

When the fly ash incorporation ratio increased from 10% to 20%, slump expansion did not change significantly, and when it increased to 30%, slump expansion increased significantly. The slump expansion of the ore powder increases significantly at 10% incorporation, and decreases significantly with the increase of incorporation. As a result, the optimal amount of fly ash and mineral powder is 30% and 10% respectively. From the results of 7-day compressive strength, the strength of concrete decreases when the water-binder ratio reaches 0.41, so it is appropriate to choose 0.38 as the water-binder ratio.

Chapter 3 Rational technology of application of self-compacting concrete

Common diseases of concrete structure

Crack of concrete structure

Injure of concrete structure

Crack of concrete structure

Corrosion of concrete structure

Frost heave failure of concrete structure

Leakage of concrete structure

Aging of concrete structure

Chapter 3 Rational technology of application of self-compacting concrete

Self-compacting concrete reinforcement engineering technology

Column reinforcement on four sides

The beam is strengthened on one side

Reinforcement of shear wall

Chapter 3 Rational technology of application of self-compacting concrete

Interface processing technology

Manual chisel method

High pressure water jet method

High pressure water jet method

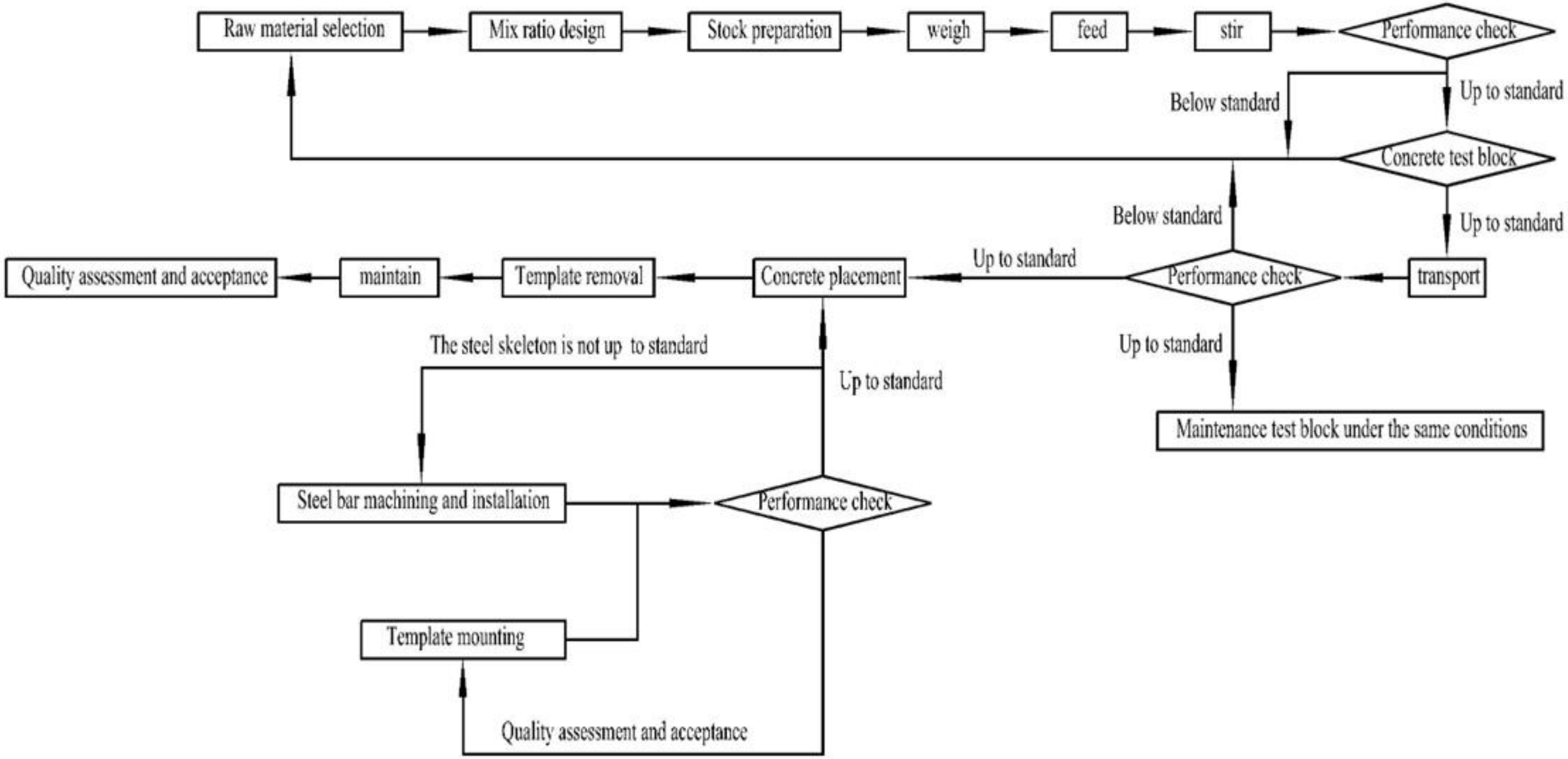
Chapter 3 Rational technology of application of self-compacting concrete

□ Self-compacting concrete laying

1. Mixing and transportation of self-compacting concrete
2. Formwork installation of self-compacting concrete
3. placing of self-compacting concrete
4. Self-compacting concrete formwork removal and maintenance

Chapter 3 Rational technology of application of self-compacting concrete

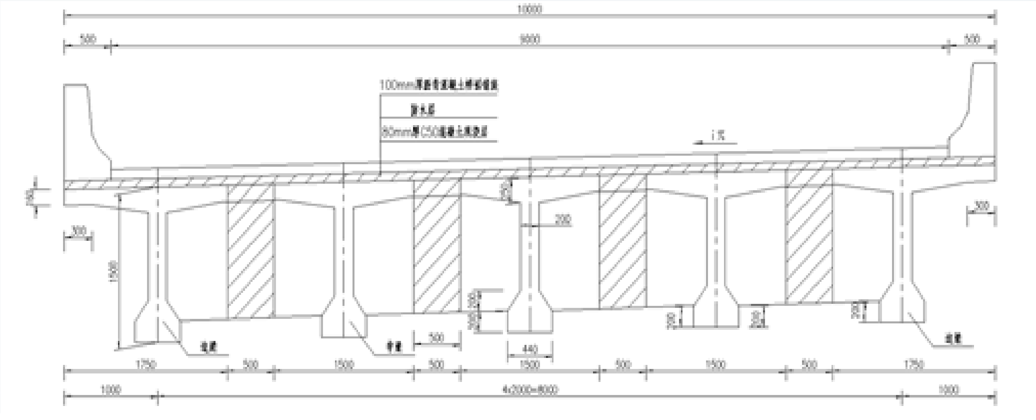
Quality control system

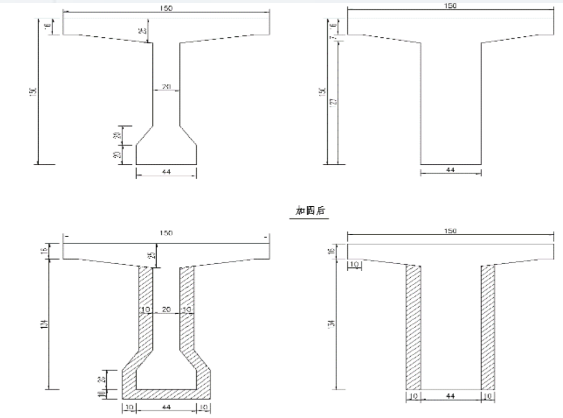


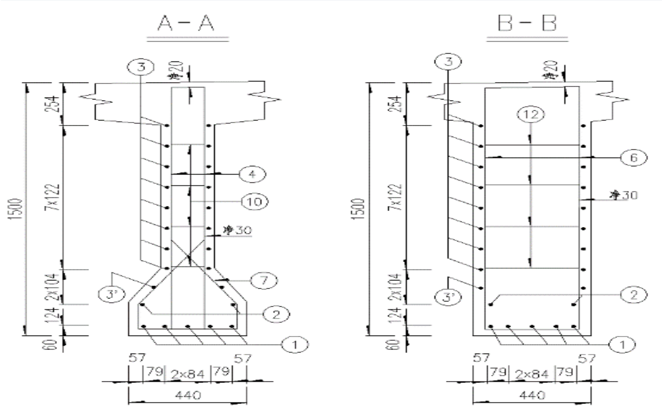
Self-compacting concrete quality control flow chart

Chapter 3 Rational technology of application of self-compacting concrete

◻ Engineering case





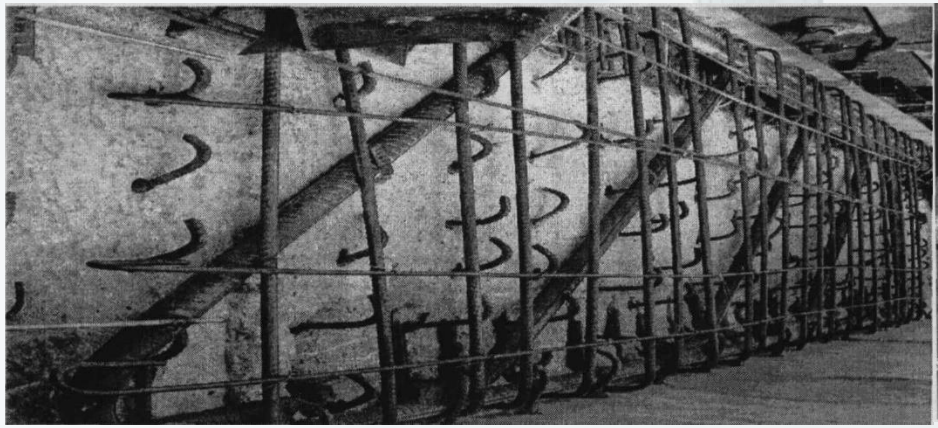


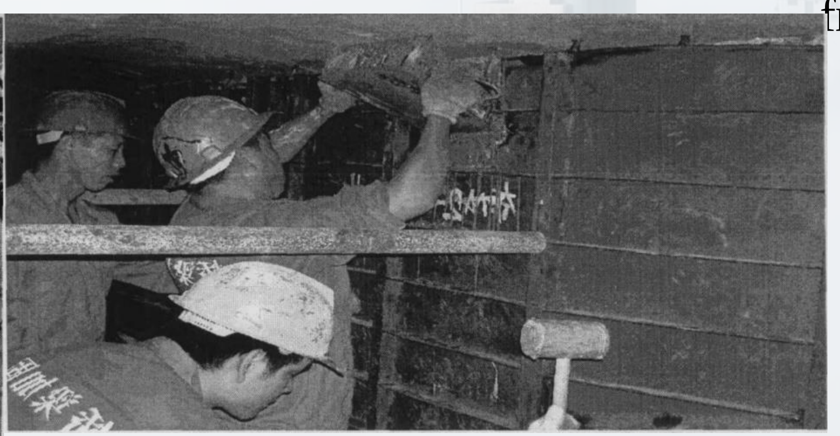
Crack of concrete structure

Standard profile of bridge structure

Reinforced structure diagram

Section of reinforced front beam structure





Chapter 4 Economic part

Cost structure analysis

Crack of concrete structure

- Engineering cost
  1. Direct cost
     - Direct engineering cost[*4]
       - Labor cost
       - Operating cost of machinery
       - Raw material cost
     - Measure cost[*5]
       - Environmental protection cost
       - Civilization construction cost
       - Ensure safe construction cost
       - Temporary facilities cost
       - Scaffolding installation and removal fee
       - Cost of formwork and support
       - Cover the protection fee
  2. Indirect cost
     - Prescribed fee[*6]
     - Enterprise management fee[*7]
  3. commission

Chapter 4 Economic part

□ Cost comparison between C35 ordinary concrete and C35 SCC concrete

Job content	Construction site transportation, pouring, maintenance				
item	name	unit	Labor, machinery, materials, consumption [*8]	Unit price(rmb)	Combined price(rmb)
Labour	Combined workdays	Work day	0.956	80	76.48
Materials	C35 Ordinary concrete	m³	1.015	214	217.21
	Grass bag (for maintenance)	㎡	0.252	20	5.04
	Water (for maintenance)	m³	0.789	5	3.945

Job content	Construction site transportation, pouring, maintenance				
item	name	unit	Labor, machinery, materials, consumption [*8]	Unit price(rmb)	Combined price(rmb)
machine	Concrete insert vibrator	Stage crew	0.077	21	1.617
	Motorized dump truck(Concrete construction site transportation)	Stage crew	0.078	24	1.872
Total price					306.16

Chapter 4 Economic part

Cost comparison between C35 ordinary concrete and C35 SCC concrete

Job content	Construction site transportation, pouring, maintenance				
item	name	unit	Labor, machinery, materials, consumption [*9]	Unit price(rmb)	Combined price(rmb)
Labour	Combined workdays	Work day	0.956	80	76.48
Materials	C35 Ordinary concrete	m³	1.015	207.23	210.11
	Grass bag (for maintenance)	㎡	0.252	20	5.04
	Water (for maintenance)	m³	0.789	5	3.945
	Motorized dump truck(Concrete construction site transportation)	Stage crew	0.078	24	1.872
Total price					297.44

For the same component, the cost of C35 ordinary concrete placement is 306 (rmb), and that of C35 self-compacting concrete placement is 297.44 (rmb), which shows a significant decrease in cost from the results. The main factor affecting the cost is the design of the mix ratio. Compared with the traditional concrete C35 self-compacting concrete mix, the addition of fly ash, mineral powder and other admixtures greatly reduces the amount of cement, and the use of admixtures improves the performance of concrete.

Conclusions

In this research, have been developed a **rational methodology for selecting the composition of self-compacting concrete** using the example of C30/35 concrete. Through the research of the preparation methods of European and Chinese self-compacting concrete, the mix ratio of C30/35 self-compacting concrete **is optimized** by tests. Based on the engineering practice, the application of self-compacting concrete in reinforcement engineering is analyzed, the quality control system of self-compacting concrete in engineering application is proposed, and the mix ratio of optimized C30/35 (B35) self-compacting concrete is applied to the engineering example.

1) Have been studied the historical experience of the production and use of concrete as a construction material in China and around the world. Have been proven the possibility of concrete as the main structural material of the construction industry on the basis of the performed analysis

Conclusions

2) By comparing the relevant specifications of self-compacting concrete preparation methods in China and Europe, it is found that in addition to certain differences in unit water consumption and water-binder ratio, the biggest difference is that self-compacting concrete in China is classified according to performance requirements, and there are clear and unified design methods and steps. However, the European self-dense concrete preparation only gives the reference value of key data such as unit water consumption and water-binder ratio, and there is no clear unified design method and step.

3) Fly ash can obviously improve the performance of self-compacting concrete. When the fly ash incorporation ratio increases from 10% to 20%, the slump expansion does not change significantly, and when the fly ash incorporation ratio increases to 30%, the slump expansion increases significantly.

4) The effect of mineral powder on the performance of self-compacting concrete is limited. Slump expansion increases significantly at 10% and decreases significantly with the increase of the addition.

Conclusions

5) This research analyzes 6 common diseases of concrete structure, puts forward the strengthening method and technology of increasing section by self-compacting concrete, and applies it in practical engineering.

6) According to the whole process quality control theory, the quality control system of dense concrete is established, and the key points of quality control at each stage are expounded.

7) By analyzing the cost formation process of concrete and comparing the cost difference between self-compacting concrete and ordinary concrete, it is found that the main factor affecting the cost is the design of concrete mix ratio. In the design of self-compacting concrete, the addition of admixtures such as fly ash and mineral powder greatly reduces the amount of cement and thus reduces the cost.

Construction and civil engineering

Thank you for listening

ПРОТОКОЛ
ПЕРЕВІРКИ КВАЛІФІКАЦІЙНОЇ РОБОТИ НА
НАЯВНІСТЬ ТЕКСТОВИХ ЗАПОЗИЧЕНЬ

Назва роботи: Самоущільнюючі бетони із застосуванням суперпластифікуючих добавок для формування складних монолітних конструкцій

Тип роботи: Магістерська кваліфікаційна робота
(БДР, МКР)

Підрозділ кафедра БМГА, ФБЦЕІ
(кафедра, факультет)

Показники звіту подібності Unicheck

Оригінальність 94,99 % Схожість 5,01 %

Аналіз звіту подібності (відмітити потрібне):

[V] 1. Запозичення, виявлені у роботі, оформлені коректно і не містять ознак плагіату.

[ ] 2. Виявлені у роботі запозичення не мають ознак плагіату, але їх надмірна кількість викликає сумніви щодо цінності роботи і відсутності самостійності її виконання автором. Роботу направити на розгляд експертної комісії кафедри.

[ ] 3. Виявлені у роботі запозичення є недобросовісними і мають ознаки плагіату та/або в ній містяться навмисні спотворення тексту, що вказують на спроби приховування недобросовісних запозичень.

Особа, відповідальна за перевірку ____ (підпис) Блащук Н.В. (прізвище, ініціали)

Ознайомлені з повним звітом подібності, який був згенерований системою Unicheck щодо роботи.

Автор роботи ____ (підпис) Сунь Веньцзюнь (прізвище, ініціали)

Керівник роботи ____ (підпис) Попов В.О. (прізвище, ініціали)

RESPONSE
of master's qualification thesis supervisor

student SUN Wenjun
(full name)

on the topic Self-compacting concretes for the formation of complex monolithic constructions with the use of additives

The master's qualification thesis researches the recipes of self-compacting concretes, which are recommended by the author of the scientific work, as an effective repair mixture for use in compressed conditions with the use of various additives that increase the mobility of the concrete mixture. The author considered the methodology adopted as basic according to Chinese standards, as well as an alternative method of preparation according to the recipe of the Swiss company Sika.

The master's qualification thesis corresponds to the issued task.

The main result of scientific research is the creation of a rational methodology for selecting a self-compacting concrete mixture and its formulation for performing repair work in compressed working conditions and for restoring the design bearing capacity of structures of complex shape.

The author investigated methods of increasing the mobility of the concrete mixture based on the experience of the Sika company using superplasticizers of the type Sika ViscoCrete and Sikafume micro-silicon powder. As a cheap alternative to polycarboxylates, which are recommended in Europe to increase the mobility of the concrete mixture, the author recommends the use of industrial waste in the form of fly ash.

In addition, the author investigated typical defects and damage of reinforced concrete structures acquired during long-term operation and proposed a rational method of strengthening such structures using self-compacting concrete.

The scientific work contains an economic section that allows you to estimate the cost indicators of the proposed improvements.

The results of scientific research conducted by the author can be applied in the conditions of real construction objects made of reinforced concrete that require reinforcement.

Research in the direction of optimization of the composition of self-compacting concrete mixtures was carried out by the author independently at a high scientific level. During the preparation of the work, the author followed the schedule, presented intermediate results on time. The master's student is erudite, knows how all materials on the rational design of formation and use of self-compacting concrete, knows how to analyze and summarize scientific material. As a result, have been published two scientific publications based on the material of the master's thesis. The main results of the work have been reported on LIII All-Ukrainian Scientific and Technical Conference of the Faculty of Construction, Civil and Environmental Engineering (2024) and on International scientific and practical Internet conference "Youth in science: research, problems, prospects (MN-2024) held on 2024 at Vinnytsia National Technical University, Ukraine.

The research carried out by the author was finished in time, in accordance with the approved calendar schedule. The master's student's level of training meets the requirements of the educational program in the specialty 192 Construction and civil engineering and deserves an "A" grade and the award of a "Master's" degree in civil engineering.

Master's thesis supervisor

PhD, Docent of CEUPA Department — POPOV Volodymyr O.
(position, academic degree, academic rank) (signature) (surname and initials)

RESPONSE OF OPPONENT
on master's qualification thesis

student LI Xiaohong
(full name)

on the topic The method of strengthening the crossbars of bridge bearings by arranging polygonal reinforced concrete brackets

In the master's qualification thesis (MQT) have been investigated rational methods of calculation and design the polygonal reinforcement brackets for defective crossbars of bridge piers. The content of the MQT corresponds to the task. The relevance of the master's thesis is confirmed by the need to create effective and architecturally expressive constructions of reinforcement of existing bridges to increase their strength, reliability and durability, in conditions of increased traffic load.

MQT of scientific direction consists of four main chapters, introduction and conclusions. The first chapter of masters thesis is devoted in general to the analysis of the state of the design bridges, in general, and bridge piers, in particular. The author of the work provided information on bridge construction in China and reviewed the structural components of typical bridge support systems. Have been described problematic issues in the design of constructions of reinforcement of bridge piers.

In the second chapter of the MQT, the author describes the methodology of detailed finite-element model of the structure of polygonal brackets, which are arranged around crossbar systems that have suffered damage due to long-term use. Issues related to determining the location of the most stressed sections of the brackets were studied. Localized areas with tensile stresses in which reinforcement must be installed. Also, in this part of the work, the author proposed a rational construction of reinforcement of polygonal clips, which should be connected to the struts of bridge piers and metal crossbars by gluing anchors.

The third section of the master's qualification work is devoted to technological proposals for the arrangement of polygonal brackets systems with difficult construction using modern formwork systems with an external rack-and-beam frame. The author of the scientific work proposed effective concrete compositions for concreting polygonal brackets and effective adhesive mixtures to joining to existing reinforced structures.

The fourth chapter (economic part) allowed the author to evaluate the feasibility of the provided proposals according to the integral value criterion. The main components of the cost for the installation of the reinforcement brackets were determined, which include the cost of materials and labor costs. The calculations determined that the cost of the proposed method of amplification is higher than the standard method. But regarding to reason that the strength resource, reliability and durability of the structures of bridge piers strengthened by the proposed method is much higher, which, in the final case, will lead to a quick payback of over expenditures.

The main results of the MQT were published in two scientific papers and tested at two scientific conferences.

The following shortcomings can be noted in the work. From the MQT, it is not entirely clear what the crossbar of the bridge support looked like before the reinforcement. Before modeling, two schemes should have been shown – before amplification and after amplification. The author should have described in detail the process of collecting loads on the bridge crossbar. The specified shortcomings don't reduce the overall positive impression of the work and do not have a fundamental meaning.

Scientific studies in the direction of optimization of methods of rational design and modeling stress-strain state of polygonal brackets of reinforcement of bridge pier systems, outlined in the MQT, allow us to conclude that the master's student meets the requirements of the educational program in the specialty 192 "Construction and civil engineering" and, with appropriate protection, deserves an "A" grade and awarding her a "Master's" degree.

Master's thesis opponent
PhD, Docent of thermal power engineering Department
(position, academic degree, academic rank)) (signature) Nataliia REZYDENT
(surname and initials)