

A STUDY ON RFC CONSTRUCTION IN CHINA

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ABSTRACT: Rock-Filled Concrete (RFC) is a new type of concrete which employs Self-Compacting Concrete (SCC) technology. RFC is produced by pouring ready-mixed SCC into the voids of large chunks of rock with the minimum size of 300 mm in a formwork. These large rocks are typically obtained near the dam sites without the need for crushing. The SCC fills the void space between the chunks of rock due to its good fluidity, and thereafter the mix sets to form the RFC mass. Various experiments had been carried out both in the laboratory and on the jobsite since it was first developed in 2003, demonstrating that RFC performed satisfactorily in the early stage and after hardening with regard to strength, permeability and thermal rising. Furthermore, the environmental impact assessments of RFC were also carried out by comparing it with conventional vibro-compacted concrete and Roller Compacted Concrete (RCC) in order to evaluate the social impacts. After two types of RFC construction technologies were developed, RFC has been employed in a number of hydraulic engineering structures in China. In this paper, based on the applications, a typical RFC construction system was described and the costs of RFC in these projects were assessed. All of the experiments and applications show that RFC had significant advantages in mass concrete construction, which indicates that RFC is potentially promising.

KEYWORDS: rock-filled concrete, applications, new construction system

1. INTRODUCTION

A new type of concrete named Rock-Filled Concrete (RFC) was developed in China, based on the Self-Compacting Concrete (SCC) technology. The concept of RFC (Chinese Patent No. ZL03102074.5) was first proposed by Jin and An, in 2003, and has rapidly grown and been put into practical use since

2005.

As shown in Figure 1, RFC is a combination of SCC and rock. During the practical employments in different projects in China, two types of RFC construction technology were developed, typical RFC construction technology (Chinese Patent No. 0710100315.3) and dump-type RFC construction technology (Chinese Patent No. 200710121791.3),



Figure 1 composite of RFC

shown in Figure 2. RFC is produced by filling the working space with large-scale rocks, the size of which should be larger than 300mm, to form a rock-chunk mass first. And then, SCC is either pumped into the working space or poured directly on to the surface of rock-chunk mass; and thereafter, SCC flows down and fills all of the void spaces by its own weight because of its good fluidity and high segregation resistance. Dump-type RFC on the other hand, is produced by first pouring SCC into a working space and then dumping chunks of rock into the SCC. Then the mix sets to form the RFC mass.

2. PROPERTIES OF RFC

A number of experiments and assessments had been carried out to study the properties of RFC after it was proposed. RFC performed satisfactorily in regard to compaction ability in the early stage, compression strength and permeability after hardening, environmental impact during construction, all of which are described in the following sections.

2.1 Experiments

2.1.1 Compaction ability tests

The compaction tests of RFC were first carried out in laboratory to study the filling ability of SCC in rock-chunk mass. The chunks of rock with the minimum size of 150mm were put into a 2.0m by 0.5m by 0.5m acrylic form. Then, SCC with a slump flow value of 65cm was poured on the surface of rock-chunk mass.

As shown in Fig.3, it was found that SCC did fill every void space effectively between chunks of rock and a high quality RFC specimen was obtained. The results show that SCC has enough flow ability to fill all of the voids in rock-chunk mass. Furthermore, the results can be extrapolated to larger dimensions, since the dimensions of void space would be greater

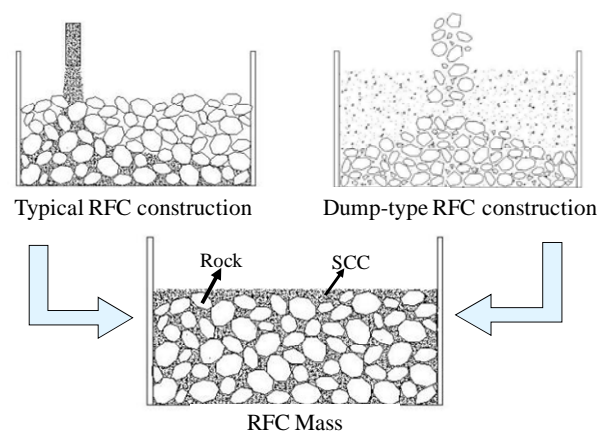


Figure 2 RFC construction technology

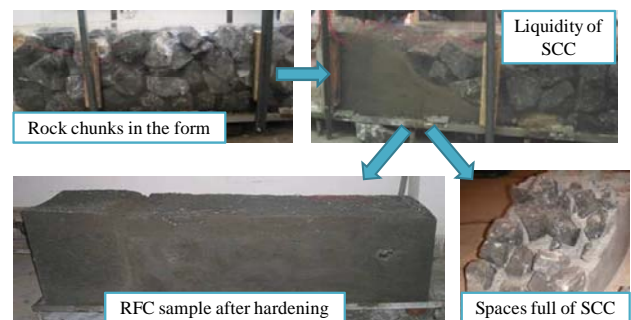


Figure 3 compaction tests of RFC

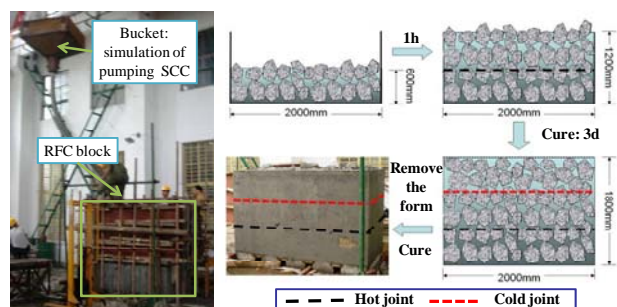


Figure 4 construction of RFC block

in rock-chunk mass of larger dimensions.

2.1.2 Compression strength and permeability tests

In order to study the compression strength and permeability of RFC, a 2.0m by 1.0m by 1.8m RFC block, was constructed using the same processes in a dam construction.

As shown in Figure 4, a bucket was used to simulate the pumping process of SCC. Since there are hot joints and cold joints in the dam structures which are created by the limited thickness of concrete, the RFC block was casted in three lifts

with a thickness of 0.6m to create a hot joint and cold joint between the lifts. Then 18 specimens in three cases were cut from the normal RFC, the hot and cold joint areas, respectively, to study the permeability of RFC, and the other 9 specimens were cut from the normal RFC to study the compression strength of RFC.

The results of permeability and compression strength tests are shown in Table 1 and Figure 5, respectively. According to the “Test Code for Hydraulic Concrete” (DL/T 5150-2001), the permeation resistance index was used to evaluate the permeability of RFC, which was calculated using the following equation:

$$W = 10 \cdot H - 1$$

where,

W : permeation resistance index

H : permeation resistance pressure, MPa

The required permeation resistance index of the dam concrete in hydraulic engineering is from W2 to W10 in China and the minimum index of RFC is

Table 1 permeation resistance index of RFC

Specimen position	Normal RFC	Hot joint	Cold joint
Permeation resistance index	W35	W31	W14

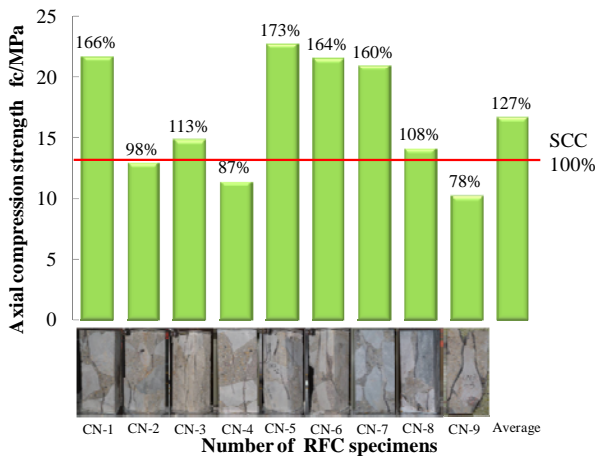


Figure 5 comparison of strength of RFC and SCC

W14. The results indicate that the permeability of RFC is high enough to satisfy the requirements of the dam concrete in hydraulic engineering. In addition, the average axial compression strength of nine RFC specimens was 1.27 times the value of SCC, which shows that the strength of RFC is higher or at least equivalent to that of SCC used in the RFC construction.

2.2 Social impacts assessments

Besides the tests mentioned above, the social impacts of RFC were also assessed. In this paper, the cost and environmental aspects of RFC are assessed. In this section, the environmental impact assessment is described and the cost assessment is presented in the next section of this paper.

The energy consumption and CO₂ emissions, from materials manufacturing to concrete casting, were selected as main indicators to assess the environmental impacts of RFC construction technology in dam construction, compared with conventional vibro-compacted concrete (*abbrev.* Conv.C) and Roller Compacted Concrete (RCC). The results are shown in Figure 6. Through the quantitative calculation of environmental impacts, it

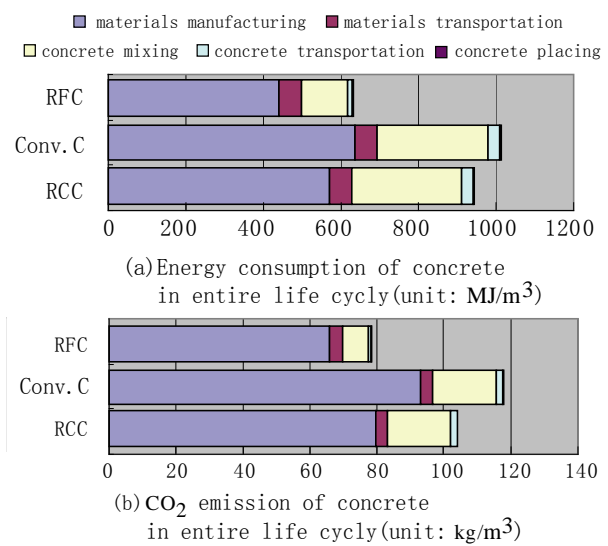


Figure 6 environmental impacts assessments of three types of concrete in dam construction

is suggested that the employment of RFC leads to a reduction of 381.64MJ and 312.52MJ in energy consumption, as well as 39.36kg and 25.68kg in CO₂ emission, respectively, compared with Conv.C and RCC. It is shown that the use of RFC can mitigate the negative effects on the natural environment.

3. APPLICATIONS OF RFC

Since the RFC performed satisfactorily in both properties and social impacts, it was first used in dam construction in 2005. Since then, the practical application of RFC has accelerated, and it has already been used in a number of hydraulic engineering structures in China.

In this section, the reasons for the use of RFC are first introduced. Then, the applications of two types of RFC construction technologies are presented.

3.1 Reasons for use of RFC

As a new type of construction technology, RFC has mainly been used to solve the problems existing in practical structures. The immediate reasons for the use of RFC are summarized as follows:

- (1) Using low unit cement content in the composite of material results in low heat of hydration, which makes it much easier to ensure temperature control;
- (2) Simplifying the construction of RFC by eliminating the surface roughening process and allowing for continuous pouring of SCC, both contribute to a faster construction;
- (3) Eliminating the need to vibrate concrete by using SCC results in compaction being ensured to be independent of the quality of construction work;
- (4) Simplifying the aggregate production and concrete mixing machinery contributes to cost reduction;

- (5) Using the rock-chunk mass as the skeleton of concrete results in relatively little drying and shrinkage; and,
- (6) Reducing noise as well as energy consumption contributes to lower emissions of the greenhouse gas (GHG) carbon dioxide (CO₂), and also sulphur dioxide (SO₂).

3.2 Application of typical RFC construction technology

First, the typical RFC construction technology has been employed in the Baoquan pumped-storage power station project, located in Henan Province. The auxiliary dam of the upper reservoir of the project was designed as a 50,000m³ masonry gravity dam which is 42.6m high. However, there were some problems with the practical masonry construction, such as low construction efficiency and low construction quality. Such problems also existed in the gully backfill construction in the Baoquan project.

In the in-situ tests, the RFC performed satisfactorily in apparent density, core compression strength and water pressure resistance, the results of which are shown in Table 2. Then it was used in the practical constructions to solve the problems mentioned above. As shown in Figure 7, approximate the top 3m of the dam, with a volume of about 4,500m³, was constructed with RFC, and was finished in 2006. The picture of RFC construction on the jobsite is shown in Figure 8. Chunks of rock were transported to the working space by dump truck, and then constructed to

Table 2 results of in-situ tests in Baoquan

	Apparent density	Core compression	Water pressure
Results	2415 kg/m ³	23.7MPa	1.33Lu

rock-chunk mass by excavators and bulldozers in the working space. SCC was transported to the working space by tower crane and bucket after it was mixed in the plant, and then directly casted on the surface of rock-chunk mass. Since only several laborers were needed in the working space, the use of RFC was straightforward and the construction was simpler and faster. After finishing the construction, a cost assessment was carried out. The data showed that the volume ratio of SCC was 42.8% and chunks of rock were 53.2%. The other 4% of volume is composed of air. In addition of a cost of Rmb160-Rmb180/m³ for SCC, and of Rmb40/m³ for chunks of rock, the cost of materials was calculated to be approximately Rmb90-Rmb98/m³. The cost of

materials is about 70% of total cost, and then the total cost of RFC may be approximately Rmb128-140/m³.

Through the successful application of RFC on part of the auxiliary dam, most of the engineers knew more about the benefits of RFC and came to an agreement on using RFC instead of conventional vibro-compacted concrete in the gully backfill project. The total volume of the concrete in the backfill project was 130,000m³, and approximately 50,000m³ of the concrete used in the backfill project was constructed with RFC and finished in 2007. The statistics data showed that the highest construction intensity of RFC was 1,000m³ per day, which was as twice that of conventional concrete.

3.3 Application of dump-type RFC construction technology

The dump-type RFC construction technology has also been used in the construction of Xiangjiaba hydropower station, which is located at Jinshajiang River in Sichuan Province, and it will be the third largest hydropower station in China. As shown in Figure 9, the open caisson group, composed by 10 caissons with a total volume of 80,000m³, is the

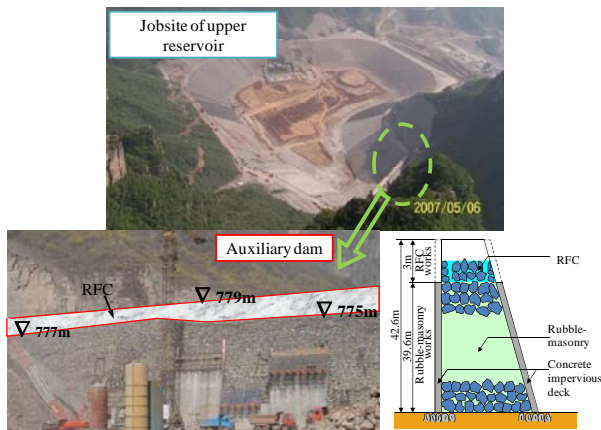


Figure 7 auxiliary dam of upper reservoir in Baoquan

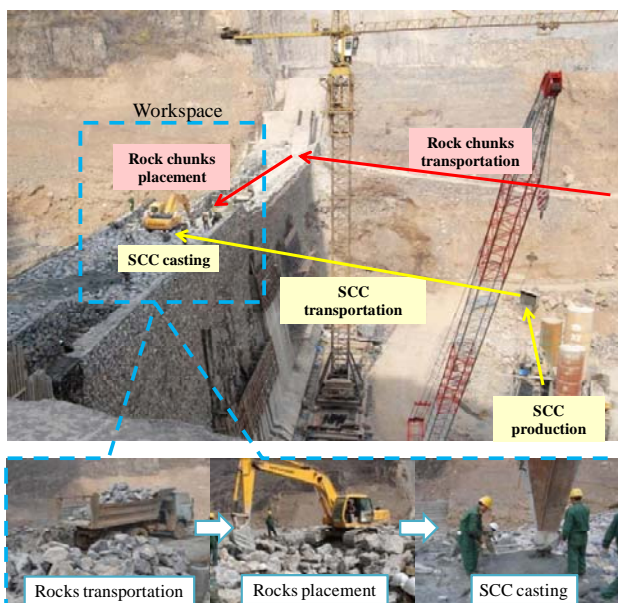


Figure 8 RFC construction at the jobsite of the dam



Figure 9 the Chinese biggest caisson group in the Xiangjiaba project

largest caisson group in China, and the maximum depth of the caisson is 54.7m.

Because of complicated geological conditions, there was a serious construction lag period during the sinking process of the caissons. A faster construction of concrete backfill was required. However, the significant drop in elevation of up to 57.4m made the caisson backfill construction tough to be constructed by conventional concrete, due to the difficulty of concrete transportation to the bottom of caisson and vibro-compaction executed by laborers at the bottom. RFC, constructed with the

dump-type RFC construction technology, was introduced to solve the problems.

First of all, the in-situ tests were carried out with the dump-type RFC construction technology. As shown in Figure 10, SCC was poured into the workspace from a mixer truck directly and then chunks of rock were dumped into SCC with bulldozers and excavator. After hardening, the apparent density, core compression strength and adiabatic thermal rising were tested. The results are shown in Table 3, and showing that the designed requirements are satisfied.

Table 3 results of in-situ tests in Xiangjiaba

	Apparent density	Core compression	Thermal rising
Results	2508 kg/m ³	33.4MPa	9.3℃



Figure 10 in-situ tests in the Xiangjiaba projects

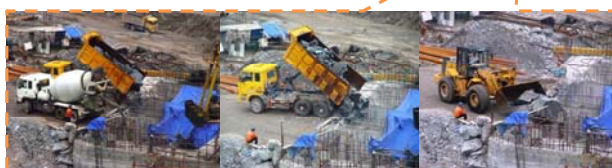
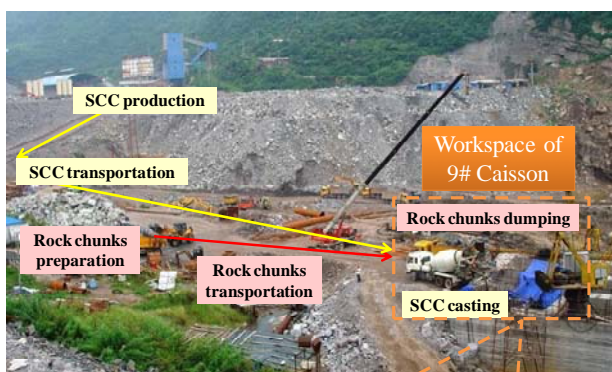


Figure 11 RFC construction at the jobsite of caisson backfill project

The picture of RFC construction on the jobsite of caisson backfill project is shown in Figure 11. SCC was transported from batching and mixing plant by mixer trucks and then casted into caisson directly. The construction of chunks of rock was similar to that of SCC, transported to the working space by dump trucks and bulldozers and then dumped into the caisson containing SCC. As Figure 11 shows, SCC and chunks of rock could be cast into the caisson at the same time, which leads to a significant increase in the construction ability.

By backfilling with dump-type RFC construction technology, the backfill construction of one caisson could be finished in one week, while the designed construction period backfilled with conventional concrete was about 20~30 days. The cost assessment of RFC was also carried out. The cost of RFC was 10Rmb/m³ lower than conventional vibro-compacted concrete.

4. CONSTRUCTION SYSTEM OF RFC

All of these experiments and applications show that RFC performs satisfactorily in early stage and after hardening. It especially has great advantages in mass concrete construction.

Based on the practical applications, the construction systems previously based on

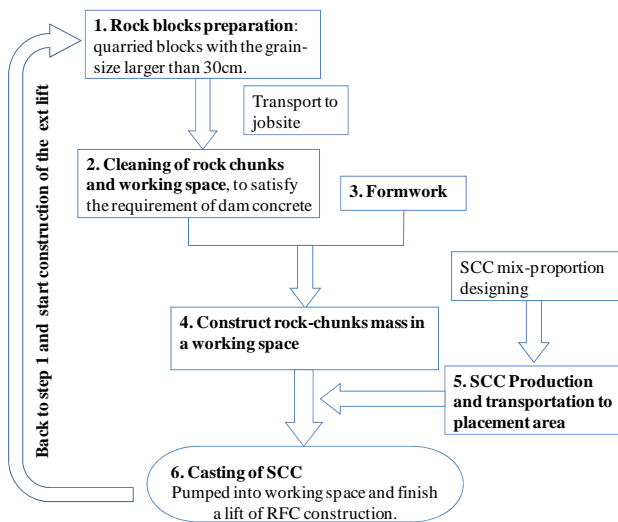


Figure 12 construction system for RFC

conventional vibro-compacted concrete could be greatly improved. As shown in Figure 12, a construction system using typical RFC construction technology is proposed and described in the following paper.

(1) Preparation of chunks of rock

Rubble and cobble stone with a size of not less than 30cm are all permitted to use as chunks of rock during the RFC construction.

(2) Cleaning of working space and chunks of rock

Before RFC construction, the working space and chunks of rock should be cleaned first, and the requirements of conventional concrete dam construction need to be satisfied.

(3) Formwork

Comparing with conventional vibro-compacted concrete, the construction of RFC needs a more stable, stiffer and closer formwork, due to the high deformability of SCC. However, if there are no special requirements in term of visual appearance, a 1.5m high and 30cm thick stone-wall also could be used as a form. The use of stone wall as a form is very effective to ensure the stability, stiffness and closure without the need to remove the form.

(4) Construction of rock-chunk mass

The working space needs to be filled with the prepared chunks of rock by natural placement or

packing. The thickness of rock-chunk mass should be less than 1.5m due to the fluidity limitation of SCC. It should be noted, though, that if laborers are employed to assist the packing process then the available void space of rock-chunk mass could be reduced with consequent further benefits in cost reduction as even less SCC is needed.

(5) Production and placement of SCC

It is recommended that SCC should be mixed at a batching and mixing plant to ensure that the necessary characteristics of the concrete are maintained, such as self-compactability at early stage and the required compressive strength after hardening. The transportation and pouring of SCC should be finished within 90 minutes after it is mixed. General purpose machinery such as a pump, excavator and bucket could be used to cast SCC, though pumping is recommended.

(6) Continuous pouring and cyclic construction

Cyclic activity is possible given the high speed of construction: after finishing the first lift of RFC, the next cycle of construction could be carried out and should be finish in the initial setting time of the first lift. Generally speaking, the initial setting time of SCC is four hours. As a result, the continuous pouring and cyclic activities using RFC could greatly speed up construction work.

On the other hand, it is only to exchange the order of (4) and (5) in the dump-type RFC construction technology. It should be noted that the minimum thickness of SCC casted at the beginning is determined by the drop distance of chunks of rock, which was 2.0m in the RFC construction in the Xiangjiaba project.

5. CONCLUSION

With the adoption of SCC and large scale chunks of rock in RFC construction, there is no need for any kinds of vibro-compaction during execution. Besides,

the low heat of hydration, fast construction activities, high construction quality, low cost, low energy consumption and low emissions of greenhouse gases, all contributed to simpler construction management and easier quality control.

The successful applications and advantages of different types of RFC construction technology show that RFC is potentially promising. Generally speaking, the typical RFC construction technology is proposed to be used in the project with a large working space, such as dam construction. While, the advantages of dump-type RFC construction technology could be fully exploited in the project with a small working space and a significant drop in elevation, such as caisson backfill construction. Several gravity and arch dams, with heights in the 30~50m range, are planning to be constructed with RFC within the next few years in China.

To make full use of RFC, an integrated construction system, including design, construction, evaluation and maintenance, should be developed. As well, a rational training and qualification systems for engineers should also be established. RFC will most likely be used in more projects to offer great simplification of execution and accelerate the construction. It is anticipated that RFC would be used in some higher dams, of approximately 100m in height in the near future.

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