ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Application of Self-Compacting Concrete for Dam Construction

A Thesis in Construction Technology and Management

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Date: May, 2017.

Addis Ababa

A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science.

The undersigned have examined the thesis entitled '**Application of Self-Compacting Concrete for Dam Construction'** presented by **Derese Birbirsa**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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DECLARATION

I confirm that research work titled "**Application of Self-Compacting Concrete for Dam Construction'**" is my own work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.

Derese Birbirsa

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List of Abbreviations

ASR	Alkali-Silka Reaction
CA	Coarse Aggregate
CBI	Central Bureau of Investigation.
CRMs	Cement Replacement Materials
DE	Delay Ettringite Formation
DRUW	Dry Rodded Unit Weight
FA	Fine Aggregate
GGBS	Ground Granulated Blast Furnace Slag.
GHG	Green House Gas
HPC	High Performance Concrete
HRWRA	High Range Water Reducing Admixture
JSCE	Japan Society of Civil Engineers
LP	Limestone Powder
LSCC	Limestone Powder Self Compacting Concrete.
RCC	Roller Compacted Concrete
RFC	Rock- Filled Concrete
s/a	Sand To Aggregate Ratio
SCC	Self Compacted Concrete
SP	Super Plasticizer
UCL	University College of London.
VMA	Viscosity Modifying Admixture
W/P	Water to Powder Ratio

Acknowledgment

First of all I would like to thank the almighty GOD for giving me such strength to successfully complete this work. I would also like to extend my gratitude for my Msc sponsor Addis Ababa University.

I would also like to gratefully acknowledge my advisor Dr. Esayas G/youhannes for his help starting from the proposal to completion of this work.

I also wish to thank: Ato Bayelegn Zewde and Getaneh Solomon for their unlimited support in every aspect I need and all the Addis Ababa Institute of Technology, Construction Material Testing Laboratory workers.

Finally, special thanks go to all my friends and colleagues for helping me physically in the laboratory work and ideally supporting me with different ideas related to my work.

Abstract

SCC is mainly characterized by its flow ability to pass through and bond congested reinforcement under its own weight and high resistance to aggregate segregation. Now a day the use of this material in the construction industry is becoming common. However the use of SCC for mass concrete structures like dam construction is not common, because due to its high cement content, it can cause thermal cracking problems and increases the project cost significantly. But studies show that by increasing the maximum aggregate size in self-compacting concrete, and decreasing the unit cement content by partial substitution of cementations material, this problem can be minimized.

The aim of this thesis is to find alternative construction material for dam construction from SCC and preplaced aggregate and compare its performance and material cost with that of conventional concrete. the new material in this research is a combination of SCC and preplaced aggregate. The maximum aggregate size used for the SCC mix is 12.5mm and for the preplaced aggregate is 300mm. To study the required performance of this material, three different mixes were used. The first mix is C-25 conventional concrete which is used as a reference mix and the second mix SCC in which only cement is used as a powder material. In the third mix the SCC was prepared by partially replacing the cement with limestone powder. Finally, a dam model was prepared in the laboratory to test the combined performance of SCC and the preplaced aggregate when it is used for dam construction. All the cubic and the core samples from the dam model was tested for its compressive strength and permeability and compered with each other.

According to the test result, the SCCs are less permeable than the conventional concrete and the core sample from the dam model. The compressive strength of the core sample is much less than the conventional concrete. The cost analysis also shows that the material cost of conventional concrete is higher than the dam model.

Keywords: dam model, limestone powder, self-compacting concrete, super- plasticizer.

CHAPTER ONE

1. INTRODUCTION

Self-compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in sections with congested reinforcement.

Since SCC can have the characteristics of high density and high strength without compaction, the use of this material for buildings has been highly promoted. However, the use of SCC for mass concrete such as dams can cause thermal cracking problems due to its high cement content. For this reason, studies are being made to solve such problems by increasing the maximum aggregate size in SCC and decreasing the unit cement content. Through the development of technologies and further studies, SCC is started to be used for massive structures like: bridges, pavements, etc. in different countries specially, in Japan and china. Stability and flow-ability are the main characteristics of SCC. They are achieved by limiting the coarse aggregate content, the maximum aggregate size and reducing water–powder ratios together with using super-plasticizers (SP) [1]. During the transportation and placement of SCC the increased flow-ability may cause segregation and bleeding which can be overcome by enhancing the viscosity of concrete mix, this is usually supplied by using a high volume fraction of paste, by limiting the maximum aggregate size or by using viscosity modifying admixtures (VMA). On the other hand, achieving high powder content by increasing the cement content is not feasible, and may lead to a significant rise in material cost and some negative impacts on concrete properties associated with the rise in temperature during hydration and higher drying shrinkage.

Concrete gravity dam is a mass concrete structure type which needs proper design and construction different from the conventional concrete. The main difference between mass concrete construction and other typical concrete structure types is its thermal behavior. At a high temperature, the interior concrete tends to expend, while at a low ambient temperature, the exterior concrete tends to shrink and resist interior concrete to expend, thus causing thermal stress. The high thermal gradient between the center and the surface may cause thermal cracks when the thermal stress in concrete exceeds its tensile strength. It is reported that the main causes of temperature rise in mass concrete is the heat librated by cement hydration. The control of heat generated from cement evolution is one of the most effective ways to reduce the temperature rise in mass concrete dams; methods include the use of low heat- generating cement and the control of the amount of cement content by using the large size of aggregate and partial replacement of cement by pozzolanic materials.

Alternatively, incorporating cement replacement materials (CRMs) in concrete can impart many advantages to concrete through enhancement of particle distribution, cohesiveness, and reduction of the risk of thermal cracking as well as the improvement of certain mechanical and other properties [3].

The objective of this research is therefore; to find alternative construction material for dam construction by combining SCC with preplaced aggregates and compare their material cost.

1.1 Background

For several years beginning from 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. Sufficient compaction by skilled workers is required in order to realize durable concrete structures. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One of the solutions to achieve durable concrete structures independent on the quality of construction work was the employment of self compacting concrete. Self compacting concrete is concrete that can be compacted into every corner of a formwork purely by means of its own weight and without the need for vibrating compaction. Okamura first proposed the necessity of that type of concrete in 1986.Investigations to develop self-compacting concrete including fundamental study on the workability of concrete were carried out by Ozawa and Maekawa at the University of Tokyo [1].

The prototype of self-compacting concrete was first completed in 1988 for the first time by using the materials in the market. The prototype proved to have satisfactory performance with regard to drying and hardening shrinkage, heat of hydration, denseness after hardening, and other properties [1].

The concrete was named “High performance concrete” and it was defined as follows at the three stages of concrete:

- Fresh :self-compactable
- Early age: avoidance from initial defects
- Hardened: protection against external factors

At almost the same time,” High Performance Concrete” was defined as a concrete with high durability due to low water cement ratio. Since then, “high performance concrete” has been used for referring to high durability concrete in the world. The introduction of new admixtures and cementations materials has allowed the production of high performance concrete (HPC) which has three major important properties such as : high strength, good flow ability and high durability.[1]

Self-compacting concrete (SCC) is defined in different ways by different researchers and some of them are listed here. Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

Self-consolidating concrete (SCC) is highly flow able, no segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. In general, SCC is concrete made with conventional concrete materials and, in some cases, with a viscosity-modifying admixture (VMA). [11]

SCC is widely used in various types of practical structures worldwide, except in massive concrete constructions in hydraulic engineering, because it has high cement content and releases more heat during hydration. These characteristics result in high cost, significant environmental impact, and difficulty in temperature control for thermal behavior. Thus, researchers are making efforts to apply SCC in massive concrete constructions in hydraulic engineering, accompanying with lower costs and less environmental load. One of the limitations of SCC to be used for mass concrete structure is its sensitive to thermal crack which affects the durability of the structure. To overcome this deficiency of SCC, researchers developed rock filled concrete (RFC) which is the combination of SCC and rock blocks.

Rock-filled concrete (RFC), is a new type of concrete based on the technology of SCC, was developed for use in massive structures in China [3]. It has been used in more than 40 projects in China, most of which are large-scale concrete construction projects in hydraulic engineering. On the basis of the technology of self compacting concrete (SCC), the construction process of RFC involves two major steps: (1) filling in-situ formwork with large-scale rocks that pile on one another under gravity, and (2) pouring fresh SCC into the pre-packed rock skeleton to fill the voids between rocks and produce a consolidated concrete structure . The application of large-scale aggregates presents many advantages, such as less cement usage, less deformation, less hydration heat, no vibration, faster construction speed, and less CO2 emission [45].

1.2. Statement of the Problem

Currently, construction in Ethiopia is highly increasing on every sector of the construction industry such as transport and communication sector, water and energy work, building and other infrastructures. This consumes more than 60% of the national budget of the country and needs special attention to improve researches on the sector. It is also known that different hydro electric power dams are under construction in Ethiopia. Most of the dams are gravity dams and recently RCC materials are commonly used for the construction of such dams. But this type of construction consumes huge amount of construction material and takes long construction period which increases overhead cost and significantly affect the environment. Even if, all the costs and other performances are not significantly differ, having alternative construction material is always advantageous.

The importance of this research is therefore, to find alternative construction material for massive structures which is durable, fast construction, environmentally friendly and economical.

1.3. Research Objective

The objective of this research is to study the performance of self-compacting concrete (SCC) combined with preplaced aggregate to be used as alternative construction material for dam construction and compare its material cost with the conventional concrete.

1.4. Research Significance

The successful completion of this research has a significant contribution in the development of the construction industry of our country by:

- Having alternative construction materials for the construction of hydraulic structures.
- Introducing new work methodology related to the SCC.
- Introducing environmentally friendly materials. This is due to the fact that if the proposed construction material is used, most of the dam body will be filled by the preplaced aggregate and it reduces the cement and normal aggregate production. Therefore, when the production of cement and aggregate is reduced, the air polluting gases released by such factory will also be minimized.

1.5. Research Methodology

The topic this research is selected based on the problem statement that had been stated before. After the problem is stated and the necessary terms are defined, literature review and required tests are conducted. In order to achieve the above stated goal of the research, the following procedures were followed.

- Literature review:

In this section previous works related to the topic were reviewed and summarized. Accordingly, materials related to self-compacting concrete, powder additives for cement replacement especially limestone powder and rock fill dams were thoroughly reviewed.

- Prepare mix design for the conventional concrete and SCC:

Once the required and related materials are reviewed, the next step is to perform the physical quality test of the ingredient materials and prepare mix design for both the reference mix and self compacting concrete. One of the drawbacks of self compacting concrete is that it doesn't have standard mix design method like that of normally vibrated concrete.

- Assess its performance

After the mix design completed by trial method for SCC and as per the ACI method for the conventional concrete, it was cast and tested for its fresh and hardened properties. The compressive strength of the three cubic samples were tested at the age of 7days, 14days and 28days and the permeability test were also done for all the samples and compared.

- Preparation dam model

To show the combined effect of the self-compacting concrete and the rock block a dam model was prepared in the laboratory and core samples from the model were taken and tested for its compressive strength and permeability.

- Analysis and discussion:

Having all the test results, analysis and discussion was made on the results and finally some points were concluded and recommended.

- Cost analysis

Finally, the material cost for each samples were analyzed and compared.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 General overview

The development of construction industry leads to the innovation of the different construction materials. Concrete is a man-made material which has the vastest utilization worldwide. This fact leads to important problems regarding its design and preparation to finally obtain an economic cost of the product on short and long time periods. The material has to be also "friendly with the environment" during its fabrication process and also its aesthetical appearance when it is used in the structures. Its wider application created an opportunity for the researchers to develop different concrete types and admixtures for different applications. Some of the alternatives to conventional concrete (special concretes) are :- self consolidating concrete, shot Crete concrete, lightweight concrete, high strength concrete, high performance concrete, roller compacted concrete etc.

In Japan, booms in construction of infrastructures, office buildings and houses during high economic growth in the 1960's through the early 1970's as well as during bubble economic growth in the late 1980's progressed the mechanization of construction works but caused several problems, e.g the raise in labor's wages and the low quality structures due to the shortage of skilled workers. In concrete structure, construction works were rationalized to solve the problems in such a ways that precast concrete elements were applied, and reinforcements were automatically fabricated and concrete surface were mechanically finished, while site cast concrete was still dependent on the labor skill. In this condition, the low durability in concrete structures became a social problem in the middle of 1980's.

Toward durable concrete structures which are independent of workmanship and labor skill, Okamura proposed self-compacting concrete (SCC), which can fill the inside of forms thoroughly with its own weight causing neither defects nor segregation, and his group developed the prototype in 1989.[1]

Self-consolidating concrete (SCC) is highly flow able, non segregating concrete that can spread into place, fill the formwork, and encapsulate the reinforcement without any mechanical consolidation. In general, SCC is concrete made with conventional concrete materials and, in some cases, with a viscosity-modifying admixture (VMA). SCC has also been described as self-compacting concrete, self-placing concrete, and self-leveling concrete, which all are subsets of SCC.

Self compacting concretes are highly flow able concretes that can spread into place under their own weight and achieve good consolidation without vibration and without exhibiting defects due to segregation and bleeding.[22] Compaction is the key to producing good concrete with optimum strength and durability. However, in Japan in the early 1980's, because of the increasing reinforcement volumes with smaller bar diameters and a reduction in skilled construction workers, full compaction was difficult to obtain or judge, leading to poor quality concrete [3]

Professor Okamura therefore proposed a concept for a design of concrete independent of the need for compaction. Ozawa and Maekawa produced the first prototype of SCC at the University of Tokyo in 1988 [2]. Since that time, it has been the subject to numerous investigations in order to adapt it to modern concrete production. At the same time the producers of additives have developed more and more sophisticated plasticizers and stabilizers tailor-made for the precast and the ready-mix industry. SCC was first developed in Japan in the 1980's and The Technology was transferred to Europe in the 1990's with the development of poly carboxylate generation of super plasticizers and to North America in the Late 1990's via primarily University Research.[2]

The widespread research and development of Self Compacting Concrete (SCC) in the past years has led to a substantial and increasing number of publications of all types and its application. In this chapter those considered most relevant to the current study are reviewed and summarized.

Self-compacting concrete (SCC) is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

2.1. Self compacting concrete categories

Based on the original concept of Okamura and Ozawa SCC is often classified as powder type, VMA type or combined type, depending on the method of providing viscosity[4]. These three types of the SCC are briefly described as follows:-

- Powder-type SCC: is characterized by a low W/P ratio and a high powder content, which are required to limit the free water content and increase the plastic viscosity. This was the first prototype of SCC generated. The key to success is to increase the powder content while decreasing the W/P ratio and use a super plasticizer to provide consistence. Because of the high powder content, powder-type SCC mixes are sensitive to changes in constituent materials. Usually additions are used to replace cement to control strength and heat of hydration. Due to the low W/P ratio, such concretes are anticipated to have a high strength and shrinkage, and low permeability. In this case Attention should be paid to the interactions of superplasticisers and powders.

- VMA-type SCC: is characterized by a high viscosity modifying agent(VMA) dosage, which is added primarily for increasing the plastic viscosity. Compared with powder-type SCC, VMA-type is higher in super plasticizer dosage or W/P ratio to obtain the required filling ability. Powder content is less because viscosity is controlled by the addition of VMA. In this type Attention should be paid to the compatibility between super plasticizers and VMAs.

- Combined-type SCC: is developed to improve the robustness (toughness) of powder type SCC by adding a small amount of VMA. In such mixes, the VMA contents are less than those in the VMA-type SCC; the powder content and W/P ratio are less than those in the powder-type SCC. Viscosity is provided by the VMA along with powder. This type of SCC was reported to have high filling ability, high segregation resistance and improved robustness. [5]. Attention should be paid to the compatibility between super plasticizers, VMAs and powders. However, since there is no distinct division among the above three types, SCC is more conveniently divided into two kinds: with or without VMA. [5].

2.2. Properties of Self-Compacting Concrete

This section introduces the fresh properties of SCC and the principles of how these are achieved. The mechanical properties and durability are then also briefly reviewed. The realization of SCC has changed the usual concept of consistency of concrete. Before the appearance of SCC, the consistency was usually measured by slump test. SCC, however, is flow able but sticky, and requires additional evaluation. The fresh properties of SCC are therefore expressed by such terms as segregation resistance, passing ability between gaps, filling capacity, etc.

2.2.1 Fresh Properties of Self Compacting Concrete

SCC rheology is characterized by a low yield stress to ensure high deformability and moderate plastic viscosity to maintain homogeneous suspension of solids, hence reducing interparticle collision, segregation, and flow blockage. The main requirements of SCC involve securing high levels of deformability while maintaining a highly stable mixture. There are some essential requirements a fresh concrete should satisfy in order to be said SCC.

It is the fresh, plastic properties of SCC that differentiate the material from conventional concrete. These characteristics are: stability, filling ability, and passing ability. Relationships of responses obtained from various practical test methods to assess both the static and dynamic stability of SCC in conjunction with rheological parameters have been reported that the rheological properties of SCC influence the characteristics of stability, filling ability, and passing ability.[5]

SCC is dictated by the application. For example, passing ability is only important for reinforced concrete applications and in sections that will restrict the flow of concrete into place. The level of passing ability is dictated by the amount and spacing of reinforcement in the proposed structure. In addition to the application, the availability of quality raw materials will influence the levels of performance achievable. Placing methods and formwork should also be reviewed.

The essential requirements for fresh properties of SCC are definitely self-compact ability and this property is achieved through the following three principal characteristics:

- ✓ The ability to flow into forms;
- ✓ The ability to freely pass through reinforcements;
- ✓ Resistance to segregation

a. Filling ability:- reflects the deformability of SCC, i.e. the ability of fresh concrete to Change its shape under its own weight [3]. Deformability includes two aspects: the deformation capacity is the maximum ability to deform, that is, how far concrete can flow; and deformation velocity refers to the time taken for the concrete to finish flowing, that is, how fast concrete can flow. Filling ability is a balance between deformation capacity and deformation velocity. For example, a concrete with high deformation capacity and very low deformation velocity tended to be very viscous and would take long time to fill the formwork.[2]

SCC must flow into the intended area without segregation. To achieve a high filling ability it is necessary to reduce inter-particle friction among solid particles (coarse aggregate, sand and powder) in concrete by using a superplasticiser and a lower coarse aggregate content.[5,6]

Adding more water could improve filling ability by decreasing inter-particle friction, but it also reduces viscosity, thus leading to segregation. Too much water also leads to undesirable influences on strength and durability. That is, too small and too large W/P ratios both result in poor filling ability. Unlike water addition, which reduces both the yield stress and viscosity, the incorporation of a superplasticiser not only reduces the inter-particle friction by dispersing cement particles but also maintains the deformation capacity and viscosity. It also imparts less effect on hardened properties than water. Particle size distribution also affects filling ability. Inter-particle friction can be reduced by using continuously graded materials, aggregates and powder.[5]

The level of filling capacity required for SCC depends on the conditions, not only of the structural detailing of formwork and reinforcements but also the concreting practice such as speed and volume of concrete deposited. Self-compacting concretes with the same mix proportion and the same rheological properties may show the different filing capacity required according to the condition. Since SCC is usually deposited into formwork at a fixed position, it must achieve self- leveling in order to flow in to the intended area with its own weight and cause no or little segregation during flow in order to obtain the homogenous concrete structures.

b. Passing Ability:- is the characteristic of SCC to flow through and around obstacles Such as reinforcement and narrow spaces without blocking. When SCC is placed in the structure with congested reinforcements, it must pass smoothly between small gaps of reinforcements without blockage due to the interactions between aggregate particles and /or between aggregate particles and reinforcement.[7] When concrete approaches a narrow space, the different flowing velocities of the mortar and coarse aggregate lead to a locally increased content of coarse aggregate. [3,8]

Some aggregates may bridge or arch at small openings which block the rest of the concrete. Therefore blocking mainly depends on the size, shape and content of coarse aggregate.

A reduction in coarse aggregate content and lowering the size are both effective in inhibiting blocking. Paste volume of the concrete is also an important factor on blocking. It was also concluded that blocking depends mainly on the yield stress, whereas plastic viscosity does not influence the passing ability of SCC. However, a paste with sufficient viscosity also prevents local increases in coarse aggregate and hence blocking is avoided.[9] By incorporating powders such as fly ash, and limestone powder, viscosity increases because of better distribution and particle packing. Another way to ensure sufficient viscosity is the use of VMA. Passing ability is therefore achieved by a reduction in coarse aggregate size and content and use of VMA or proper selection of powder.

c. Segregation Resistance:- is the characteristic of SCC to remain homogeneous during and after transporting and placing. It is passing ability that distinguishes SCC from other high consistence concrete.[10] Free water, which cannot attach to the solid particles and moves freely in the concrete, is the main influence on segregation. Segregation which happen during placing is called dynamic segregation. After placing, if coarse aggregate settles and the free water rises causing bleeding, this is called static segregation. Bleeding water reaches the concrete surface or is trapped under obstacles such as coarse aggregate and reinforcement bars which weakens the interfacial zone and results in impaired strength and durability. Enhancement of segregation resistance includes binding extra free water by lower W/P ratio, use of VMA or a high volume of powder, hence providing proper viscosity to ensure homogeneous flow. Limiting the size and content of coarse aggregate are also effective in inhibiting segregation.[11]

The above three key properties are to some extent related and inter-dependent. A change in one property will normally result in a change in one or both of the others. Both poor filling ability and segregation can cause insufficient passing ability, i.e. blocking. Risks of segregation increase as filling ability increases. SCC is actually a trade-off between filling ability and segregation resistance.[11] The fresh properties of SCC are influenced by the variation in the fineness and moisture content of the aggregates, different batches of superplasticiser or cement and changes in the environmental conditions such as temperature and humidity etc. SCC should have some tolerance to such changes.

In general, the performance requirements of SCC are complex and depend on several parameters, including service loading and environmental conditions, intended placement method, labor skill, and quality assurance and quality control measures. The required workability for placing concrete depends on the type of construction, selected placement and consolidation methods, complexity of the formwork, and structural design details that affect the degree of congestion of the reinforcement.[12]

2.2.2 Test Methods for Fresh Properties of SCC

Development of an acceptable SCC for each application starts with trial mixtures. To effectively accomplish this task, test methods that quantify filling ability, passing ability, and stability should be used. Establishing the initial target value for slump flow is the first step in developing a SCC mixture. Based on the application, the mixture designer rates the characteristics of an element as low, medium, or high.

Table 2.1. Slump flow range.

Range	Slump
Low	<550mm
Medium	550 to 650mm
high	>650mm

Once the initial slump flow target is set, trial mixtures should be proportioned with those materials that will be used for the intended project. As these mixtures are evaluated, testing for the other SCC properties, such as passing ability and stability, should be conducted.[12]

- Filling ability (deformability) and stability:-

The slump flow test is a measure of mixture filling ability. This test is performed similarly to the conventional slump test using the standard ASTM C 143/C 143M slump cone. Instead of measuring the slumping distance vertically, however, the mean spread of the resulting concrete patty is measured horizontally. This number is recorded as the slump flow. Requirement on flow and T50 values should be different for different maximum sizes/shapes of aggregates and admixtures. It is difficult to assess the segregation/settlement tendency. The fresh concrete is poured into a mould in the shape of a frustum of a cone. When the cone is withdrawn upwards, the distance the concrete has spread provides a measure of the consistency of the concrete.

Figure 2.1 Slump flow measurement.

- Passing ability:-

There are two methods used to measure this property of SCC: these are:- J-ring and L- box.

The J-ring consists of a ring of reinforcing bars that will fit around the base of a standard ASTM C 143/C 143M slump cone. The slump cone is filled with concrete and then lifted in the same fashion as if one were conducting the slump flow test. The final spread of the concrete is measured, and the difference between the conventional slump flow value and the J-ring slump flow value is calculated. [12]

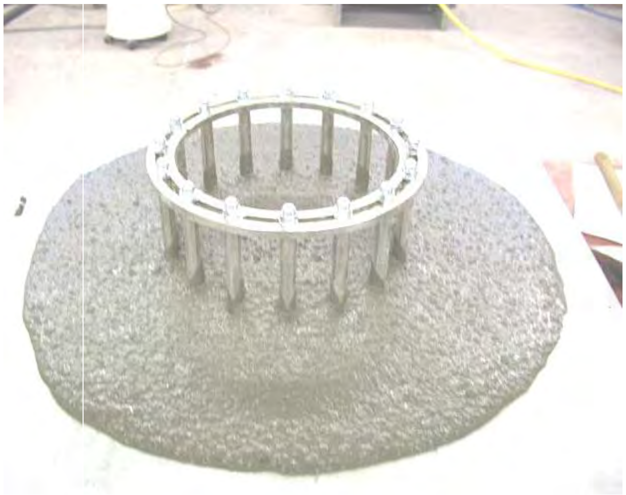

Figure 2.2 Passing ability measurement by J-ring

The L-box test consists of an L-shaped container divided into a vertical and horizontal section. A sliding door separates the vertical and horizontal sections. An obstacle of three reinforcing bars can be positioned in the horizontal section adjacent to the sliding door. The vertical section of the container is filled with concrete and the sliding door is immediately removed, allowing the concrete to flow through the obstacle into the horizontal section. The height of the concrete left in the vertical section (*h*1) and at the end of the horizontal section (*h*2) is measured. The ratio of h2/h1 is calculated as the blocking ratio.[12]

The fresh concrete is poured in the vertical part of the L-box. When the sliding gate is lifted the concrete spread provides a measure of the filling ability and the passing ability of the concrete. After the sliding gate is lifted the following parameters may be measured. When the concrete has stopped flowing, the distances H1 and H2 are measured; Calculate H2/H1 (acceptable value of the passing ability ratio, H2/H1, is normally $\geq$0.80.[12]

Figure 2.3 Blocking ratio measurements by L-box.

- Stability or segregation:

V-funnel test:-
The flow ability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured. Further, T_{5min} is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. According to Khayat and Manai, a funnel test flow time less than 6s is recommended for a concrete to qualify for a SCC.[13]

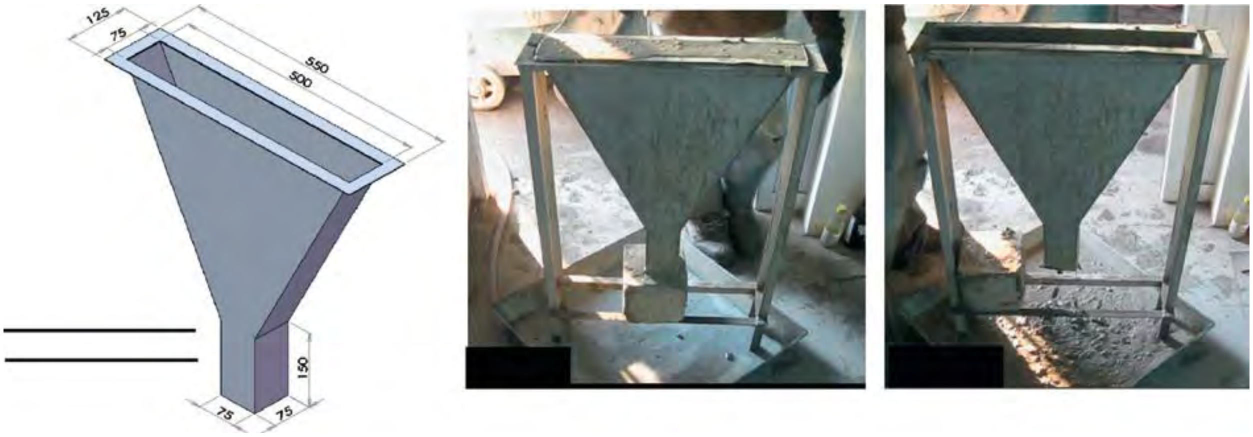

Figure 2.4 Flow ability measurements by V-funnel

2.2.3 Hardened Properties of Self Compacting Concrete

While some of the fresh properties of SCC differ significantly from those of conventional concrete, hardened concrete properties of SCC may be designed through the mixture proportion to be similar, or better than, those of a conventional concrete mixture. If specific key properties are important in a particular application, these should be considered when developing SCC mixtures. Special emphasis will be given to the importance of the stability of SCC and its impact on the homogeneity of mechanical properties. Important engineering properties such as strength, dimensional changes and durability mainly depend on the pore system, such as the total surface area, the total pore volume, the pore size distribution and the pore connectivity.

Hydration

When concrete is subjected to high temperature at early age, many physical and chemical changes of the hardened concrete can take place. The main factor contributing to temperature rise in mass concrete is heat evolution due to an exothermic reaction of cement. Understanding the mechanism of heat generation for cement is the key to controlling the temperature of mass Concrete. Experimental investigations revealed that when the concrete is subjected to high temperature over a short period during early age, there is a possibility of long term strength reduction and increase in permeability. Extensive researches have been carried out to model the heat of hydration of cement, since it is very important to predict the temperature rise especially in mass concrete structures. There are three possible effects of excessive temperature rise in concrete due to heat of hydration of cement.

- Development of tensile stress in concrete due to contraction under internal/external restrain during temperature drop.
- Change in microstructure of hydrated cement paste. It is a well established fact that the durability depends on the permeability of concrete. When the concrete is subjected elevated temperature even due to heat of hydration of cement, there can be many changes in the micro structure of the hydrated cement paste. As a result of micro structural changes in concrete subjected to elevated temperature at early age can affect the mechanical properties of concrete as well.
- Change of composition of hydrated products. [33]

➢ Formation of Ettringite

Out of the four main compounds of cement, 2CaO.SiO2 (C2S), 3CaO.SiO2 (C3S), 3CaO.Al2O3 (C3A), 4CaO.Al2O3.Fe2O3 (C4AF), tricalcium alumunate (C3A) is the one responsible for the formation of ettringite. When C3A reacts with water in the presence of gypsum, the ettringite (C3A.3CaSO4.H32) is formed. C4AF also reacts with gypsum and produce (C3(AF).3CaSO4.H32). These reactions are not only exothermic, like reactions of all other compounds in cement with water, but also create volume expansion. Since these reactions occur at very early stage of cement hydration, i.e. fresh stage of concrete, the volume expansion will not create any destruction. Ettringite is not a stable phase at high temperature and it converts to form monosulphate hydrate releasing sulphate ions if the early age temperature is higher than 70 °C. These sulphate ions will be absorbed into C-S-H gel which is the main product of hydration of C2S and C3S. Once the concrete has hardened, under permanently or intermittently wet condition, monosulpahte reacts with these sulphate ions and converts to ettrintgite. This is known as delayed ettringite formation (DEF). Since ettringite takes up more space than monosulphate from which it forms, the transformation is an expansive reaction causing cracking in concrete.[33]

Mechanical properties

Given the same raw material sources and the same specified compressive strength, the engineering properties of SCC should be similar to those of conventional concrete.[12]

i. **Compressive strength**

Compressive Strength is one of the most important properties specified for concrete because it is a direct reflection of the capacity of the structure to resist forces and it is a reasonable indicator of other properties.[12] SCC requires that the concrete should be highly flow able, yet cohesive enough to resist segregation. This often necessitates the use of a water cementations material ratio (w/cm) that is lower than that typically used for comparable conventional concrete. As a result of a low w/cm, higher compressive strengths are achieved. SCC typically used for precast can be proportioned with a w/cm of 0.32 to 0.40. Mixtures with a greater w/cm (higher than 0.40) are sometimes employed for cast-in-place and repair applications, and have strength characteristics similar to conventional concrete. Mixture proportion adjustments may be needed to ensure adequate stability. Because w/cm is a key component in determining the compressive strength of concrete, other changes in mixture proportions compared with conventional concrete may affect the rate of development and ultimate compressive strength. These can include sand-total aggregate *(s/a)* ratio, the type and amount of supplementary cementitious materials and fillers, and the combination of chemical admixtures. The lower w/cm that is sometimes selected to enhance fresh concrete characteristics will normally yield a higher 28-day compressive strength than typical values required by the design of the concrete structure.

Measured compressive strength, as opposed to specified compressive strength, should be used when estimating other mechanical properties that are calculated using a value of compressive strength. Even at the same w/cm, properly designed SCC can exhibit higher compressive strength. The reduction of the risk of bleeding and segregation along with the lack of mechanical vibration can further promote a more uniform microstructure and less porous interface zone between the cement paste and aggregate and embedded reinforcement.[15]

ii. Flexural strength

Like conventional concrete, the flexural strength of SCC depends on the w/cm, coarse aggregate volume, and the quality of the interface between the aggregate and cement paste. SCC flexural strength may be higher than that of conventional concrete with similar mixture proportions.[13]

iii. Modulus of elasticity

Elastic modulus is used to calculate the elastic deflection, which is a controlling parameter in design of slabs, prestressed and post-tensioned structures. The elastic modulus is the ratio between stress and strain. For concrete the stress-strain curve is non-linear, from which different elastic moduli can be determined. It is known that the elastic modulus of concrete depends on the Young's moduli of the constituents and their volume ratio. It decreases with lower aggregate contents, or with higher cement contents or higher porosity. Since the coarse aggregate content of SCC is less than NVC, the elastic modulus of SCC might be anticipated to be lower. This was confirmed by Dehn et al. (2000).[4] Holschemacher and Klug (2002) analyzed their database and found that the elastic modulus of SCC could be 20% lower than that of NVC made of the same aggregate with the same strength.[14] Another analysis based on a vast amount of literature showed that the elastic modulus of SCC was 40% lower than that of NVC at low cube compressive strength; but the difference reduced to less than 5% at higher strength (90~100 MPa).[15]

Elastic modulus of concrete is related to compressive strength, aggregate type and content, and unit weight of the concrete. Adjustments in mixture proportions, especially the *s*/*a*, will influence the elastic modulus of the SCC. Some observations have shown that for equal compressive strength, the elastic modulus of SCC can be as much as 10 to 15% lower than that of conventional concrete of similar compressive strength due to the required adjustments of mixture proportions to make SCC.[19] Other researchers found that SCC and conventional concrete for housing applications with the same mixture proportioning, developed with a relatively low binder content for SCC develop the same elastic modulus.

iv. Drying, and plastic shrinkage

- Drying shrinkage results from the loss of water from the cement paste into the atmosphere. Water held by capillary tension is one of the important factors influencing the drying shrinkage. It is related to the water and paste contents, as well as aggregate volume, size, and stiffness. High paste volumes and reduction in aggregate content can lead to greater potential for drying shrinkage. Paste volumes can be optimized during the mixture-proportioning process through the selection of aggregate content, composition, and admixtures. Drying shrinkage has been reported to be similar to or lower than that of conventional concrete of similar compressive strength.[6] Mortsell and Rodum (2001) reported that the drying shrinkage of SCC developed for housing applications was essentially the same as that of conventional concrete with the same mixture proportions. For SCC, as for other types of concrete, the higher the w/cm the lower the autogenous shrinkage, and the higher the drying shrinkage.[6]

Shrinkage, is important for concrete because it produces tensile stress within the concrete leading to adverse cracks which makes it possible for gas, water and harmful chemicals to penetrate into the concrete and cause further durability problems. Shrinkage was important for pre stressed concrete because it relaxed the pre-stressing force, thus reducing structural capacity. [12] The use of a higher content of paste, powder and superplasticiser in SCC all may contribute to higher shrinkage and creep than in NVC. The drying shrinkage of SCC was found to be 10~50% higher than that of NVC.[17] However, it was reported that SCC's denser microstructure suppresses drying shrinkage and lower shrinkage of SCC was reported.[6,13]

- Plastic shrinkage: SCC can be prone to plastic shrinkage cracking given the fact that these mixtures may exhibit little or no surface bleeding. SCC should be protected from rapid moisture loss just like conventional concrete that exhibits little or no surface bleeding. Protection is then required to prevent surface drying during the first 24 hours (Gram and Piiparinen 1999; Turcry et al. 2002). In applications where the shrinkage characteristics are an important design parameter, this aspect of the SCC mixture should be considered in design and verified by testing.

v. Creep in compression

Creep is defined as the gradual increase in strain for a constant applied stress. It is also a time-dependent deformation. Creep takes place in the cement paste and is influenced by porosity which relates to the W/C ratio. As cement hydrates and porosity decreases, creep decreases. In addition, aggregates restrain the creep of paste. For this reason, a higher amount of aggregates and a higher elastic modulus of aggregates will lead to a reduced creep.[19]

Creep is mostly affected by the rigidity of the cement paste and concrete as well as coarse aggregate volume and stiffness, curing time, curing method, temperature, relative humidity, and concrete age at the time of load application. As in the case of drying shrinkage, creep of SCC is highly dependent on the mixture composition, paste volume, and aggregate content. For the same mixture proportions as those for conventional concrete, creep of SCC is expected to be similar to that of conventional concrete.[12] When the SCC is proportioned with greater paste volume, however, it can exhibit higher creep than conventional concrete with a similar compressive strength. Certain test results have shown that the creep coefficient of mature SCC coincided well with the same property of conventional concrete when the strength at load application was similar and was held constant.[19]

vi. Durability

Since vibration makes water accumulate on the surfaces of coarse aggregate particles, NVC tends to contain a porous matrix and weak interfacial zones which result in inferiorities in hardened properties. Elimination of the compacting process and incorporation of powders led to a denser cement matrix and improved interface between aggregates and paste.[7]

Durability is a general analysis of the service life and the performance of concrete in an aggressive environment. Physical damage to concrete includes wetting/drying, freeze/thaw or heating/cooling cycles. Chemical damage consists of sulphate attack, acid attack, chloride attack and alkali-silica reaction (ASR) in which water acts as a carrier.

vii. Resistance to freezing and thawing and deicer salt scaling

Saturated concrete exposed to severe environments requires a satisfactory air-void system, sufficient maturity, and proper aggregates. When a proper air-void system is provided, SCC can exhibit excellent resistance to freezing and thawing and to deicing salt scaling.[20,21]

viii. Permeability

Concrete used in water- retaining structures, exposed to severe weather, or exposed to an aggressive environment must be virtually impermeable or watertight. Water tightness refers to the ability of concrete to hold back or retain water without visible leakage. Permeability refers to the amount of water migration through concrete when the water is under pressure, and also the ability of concrete to resist penetration of any substance, be it a liquid, gas, or chloride ion. The need for information on the permeability of concrete dates from the early 1930s. Designers of dams and other large hydraulic structures needed to know the rate at which water passed through concrete that was subjected to relatively high hydraulic pressures. Today there is renewed interest in the permeability of concrete. But this interest does not center on the flow of water through concrete in water works structures. It deals mainly with permeability to deleterious substances such as chloride ions from seawater and deicing salts, sulfate ions, and other aggressive chemicals. The growing awareness of the role permeability plays in the long-term durability of concrete has led to the need for ways to quickly assess the permeability of concretes. The use of admixtures such as silica fume, latex emulsions, and high- range water reducers allows placement of highly impermeable concrete.[22]

Permeability is a process in which water is transported under a hydrostatic pressure differential. The main influences on permeation include the paste volume, the pore structure and the interfacial zone between the mortar and aggregates. The overall porosity of SCC was lower than that of NVC of equivalent strength because of the higher powder content, lower W/P ratio and improved microstructure.[15,22]. Zhu and Bartos reported that the oxygen permeability for SCC was only 30~40% of that of NVC with the same strength grade C40.

Difference between Conventional Concrete & SCC

SCC flows under its own weight without segregation, and passes through restricted areas without blocking. This is clearly and significantly different to conventional concrete. The key properties of SCC are filling ability, passing ability and segregation resistance. Robustness and consistence retention are also important to the use of SCC. SCC is not a new concrete, but rather a sophisticated and evolving technology. It requires a fundamental understanding of both the fresh and hardened properties, which vary in a wide range. In comparison with conventional concrete, SCC can only be achieved with the use of chemical admixtures and mineral additions. Fresh properties of SCC are obtained by properly adjusting the constituent materials. SCC is characterized by low yield stress and proper viscosity. These are obtained by using superplasticisers, reducing the volume of coarse aggregate, limiting free water content by either incorporating a high amount of powder and/or the addition of VMAs. Nevertheless, because of elimination of compaction and lower W/P ratio, its performance is comparable or better than that of conventional concrete. Any differences in the hardened properties and durability are largely within the normal range that might be anticipated for conventional concrete.

These differences are summarized as follows:

Hydration, compressive strength and strength development of SCC and conventional concrete do not differ significantly under comparable conditions. Splitting strength, fire spalling and elastic modulus of SCC and conventional concrete are different and no consistent results are given for shrinkage and creep. The reason for the difference in hardened properties and durability between NVC and SCC may lie in better microstructures and homogeneity of SCC and Higher contents of superplasticisers, VMA or powder Water movement; especially sorption near surface concrete is one of the most important properties for evaluating the durability of concrete. Although there are some differences in hardened properties between SCC and conventional concrete, those differences can be attributed to their different mix proportions. Most comparisons are made between SCC and conventional concrete and based on the same strength. Since SCC can be designed from fresh-property requirements, it is necessary to infer its hardened properties and durability from fresh properties. Further research on the influence of fresh properties, on hardened properties and durability might be useful.

2.3 Mixing Procedure and Test Methods

Since the first developments of self-compacting concrete (SCC), several methods have been proposed for its mix design, especially in the 90s, coinciding to the period of a quick increasing use of SCC. In general, all methods reflect, with greater or lesser extent, some concern with the optimization of the granular skeleton and the reduction of the paste volume. In large scale applications, the economy and robustness of the mixtures are always a present concern. It is a common ground that there is no single universal solution, but rather a very wide range of possible solutions that, taking into account locally available materials, are able to give a satisfactory outcome in each particular situation.[23] The overall quality of SCC depends not only on the properties of the raw material, but also on their qualities. The proposed mix design concept is aimed at a mixture with economic, sufficient mechanical properties and good durability. [24]

Since, self-compatibility is largely affected by the characteristics of materials and the mix proportions, it becomes necessary to evolve a procedure for mix design of SCC. Mix design methods of both SCC and conventional concrete are based on volume composition with subsequent conversion to batch weights for production.

The main differences in the mix design methods between SCC and conventional concrete.

- ➢ The design of conventional concrete start from determining the W/C ratio to meet the strength requirement and finishes by calculating the amount of aggregates according to a British method. SCC on the other hand is usually designed starting with the required fresh properties; the principles are adding superplasticisers with/without VMA, limiting the aggregate content and an appropriate W/P ratio to meet the fresh-property requirement. Designs of SCC usually do not consider strength because the W/P ratio of SCC is low which ensures high strength, often greater than is required for structural purposes [25]. Because of different conceptions and a wide range of possible constituent materials, many methods have been proposed and developed. Among these, some are discussed below.

2.3.1 General Mix Design Method

The first well known mix design method was proposed in 1993by Okamura, Ozawa and Maekawa, which was later improved in 1998 by the contribution of Ouchi et al. [26]. This method, developed in the University of Tokyo, was then known as the general method. The general method assumes as the starting point the design of the mortar phase, which must meet certain flow requirements, necessary to achieve a SCC. In this system, the coarse aggregate and fine aggregate contents are fixed and self-compatibility is to be achieved by adjusting the water /powder ratio and super plasticizer dosage. The coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume.The required water /powder ratio is determined by conducting a number of trial.[19] The general method considers some of the mix design parameters as almost constant, which allows little flexibility in optimizing the granular skeleton, usually leading to higher portions of paste when compared to an optimized granular structure. The general tendency was to focus on optimizing mixture proportions, aiming to reduce paste volume, mainly by increasing the volume of aggregate.

Different approaches were used for the development of SCC. Looking at the application of the SCC from 1993 to 2003, Domone concluded that successfully performed SCC were obtained for a great variety of constituents and mix proportions, but considerable scope for optimisation of mixes for greater efficiency and economy was still possible. As the most critical parameters for successful SCC mix design, Domone [10] has identified: the coarse aggregate volume, the paste content of concrete and the fine aggregate percentage of the mortar. The powder content and water/powder ratio have shown greater flexibility. Nepomuceno et al. [27] have also proposed a methodology for the mix design of the mortar phase of SCC that allows to reconcile fresh properties and compressive strength when binary blends of powders are used. Later, a new methodology for the mix design of SCC was proposed by the same research team [27].

The new methodology here described is based on simple procedures and assumes the SCC as a two phase material, the mortar phase and the coarse aggregates. The study was focused on SCC in which adequate viscosity is achieved by controlling the amount of powders.

A study done in Yogi Vemana University on mix procedure of self-compacting concrete also presents simple steps of achieving successful SCC. Accordingly, the relative proportions of key components are considered by volume rather than by mass. A simple tool has been designed for self compacting concrete (SCC) mix design with 29% of coarse aggregate, replacement of cement with Metakaolin and class F flash, combinations of both and controlled SCC mix with 0.36 water/cementations ratio(by weight) and 388 litre/m3 of cement paste volume. Crushed granite stones of size 16mm and 12.5mm are used with a blending 60:40 by percentage weight of total coarse aggregate.[28]

From the above study the following detailed steps for mix design are concluded:

1. Assume air content by percentage of concrete volume.
2. Input the coarse aggregate blending by percentage weight of total coarse aggregate.
3. Input the percentage of coarse aggregate in DRUW to calculate the coarse aggregate volume in the concrete volume.
4. Adjust the percentage of fine aggregate volume in mortar volume.
5. Obtain the required paste volume.
6. Adopt suitable water/ binder ratio by weight.
7. Input the percentage replacement of fly ash by weight of cementations material.
8. Input the dosage of SP by percentage weight of binder.
9. Adjust the binder (cementations material) content by weight to obtain the required paste.[28]

According to this method, the mortar is the first step in producing SCC: it has properties that ensure the filling ability, passing ability and segregation resistance of the concrete itself; and possess sufficient viscosity to support the coarse aggregate. This method gives a better analysis and understanding of the behavior of SCC than others.

2.3.2 Developments at University College of London (UCL)

The mortar experiments in general-purpose method are useful for a quick evaluation of design SCC, and it seems that when the mortar is right, the mixes will achieve the required properties. Based on this principle, research on SCC started at UCL in 1994 with a substantial laboratory investigation by Chai and Jin, and continued in the current research. The relationships between the properties of the mortar and the derived SCC with coarse aggregate of 50~55% of its dry rodded bulk density were established. Mortar testing was shown to be an efficient and effective method of assessing SCC. Based on Jin's work, the relationships between the properties of the mortar and the derived SCC with a higher coarse aggregate content were established in the research and adopted. The UCL method described as follows includes the modifications from the above research.

1. Coarse aggregate is estimated from the code. The method is applicable to a coarse aggregate of 16 or 20 mm maximum size, crushed or uncrushed; the dividing line between coarse and fine aggregate is 4 or 5 mm.
2. Sand to mortar volume ratio is set at 45% which is a typical value for SCC
3. Air content is estimated as 1%.
4. Cement content is estimated based on previous experience and the 28-day compressive strength required.
5. Water/powder ratio, admixture dosage and powder composition are determined from mortar tests.

2.3.3 Central Bureau of investigation (CBI) method

The CBI mix design method was proposed by the Swedish Cement and Concrete Research Institute. It considers SCC as being composed of aggregates and paste that is made up of water, admixture and powders. It aims to produce a mix with an optimum aggregate skeleton and hence the minimum but sufficient paste content and is based on the blocking criterion. This design method consists of three stages, namely, to calculate the minimum paste volume, paste composition and SCC evaluation.

2.3.4 Japan Society of Civil Engineers (JSCE) method

This is the only method proposed for the design of a SCC with VMAs. Different constituent material ranges are specified for mixes with or without VMA and with various different VMAs. Consequently, the fine aggregate content can be calculated from the volumes of coarse aggregate, water, powder and air.

Table 2.2 JSCE recommendation (Japan Society of Civil Engineers, 1998)

Materials	**SCC without VMA**	**SCC with VMA**
Coarse aggregate content	0.30~0.32 m3/m3; maximum size 20 or 25 mm.	0.30~0.32 m3/m3; maximum size 20 or 25 mm.
Water content	155~175 kg/m3	≤ 180 kg/m3
Water/powder ratio	28~37% by weight	Depends on the type and content of VMA
Powder content	0.16~0.19 m3/m3	Depends on the type and content of VMA
Air content	4.5%	4.5%

This is a way to design SCC for strength, which is consistent with practice codes. The method leads to less paste, thus saving costs and improving strength, permeability, creep and drying shrinkage [41]. It should be noted that this method ignores the contribution of GGBS and fly ash to the strength by using the W/C ratio in order to simplify the design. This may lead to a higher long-term strength than required.

2.3.5 Laboratory Central des Ponts et Caussées (LCPC) method

This French approach was developed at the Laboratory Central des Ponts et Caussées (LCPC). The concept of 'reference relative viscosity' is used to evaluate the packing state of the constituent materials and an optimized overall particle size distribution is obtained. This method has reduced concrete trials, however, it required a number of preliminary tests and it does not apply to mixes with VMA.

The successful development of SCC must ensure a good balance between deformability and stability. Researchers have set some guidelines for mixture proportioning of SCC, which include

i) Reducing the volume ratio of aggregate to cementations material
(ii) Increasing the paste volume and water-cement ratio (w/c);
(iii) Carefully controlling the maximum coarse aggregate particle size and total volume; and
(iv) Using various viscosity enhancing admixtures.[29,30]

For SCC, it is generally necessary to use superplasticizers in order to obtain high mobility. Adding a large volume of powder material or viscosity modifying admixture can eliminate segregation. According to the American concrete institute (ACI) for determining performance requirements and proportioning of SCC, it involves the following steps.

Step 1: Determine slump flow performance requirements.
Step2:Select coarse aggregate and proportion
Step3:Estimate the required cementations content and water;
Step 4: Calculate paste and mortar volume;
Step 5: Select admixture;
Step 6: Trial Batch mixture;
Step 7: Test. When assessing the workability attributes of SCC (stability, filling ability, and passing ability), the slump flow test as well as a test to evaluate stability and passing ability (such as column segregation, J-ring, or L-box) should be run; and

Step 8: Adjust mixture proportions based on the test results and then re batch with further testing until the required properties are achieved.[12]

Generally, one of the drawback of SCC is there is no common standard for its mix design. Thus, it needs some trails to obtain the desired properties. But the above methods and others guidelines can be used as base for initial trail.

2.4 Applications of Self-compacting Concrete

SCC is concrete made with conventional concrete materials and, in some cases, with a viscosity-modifying admixture (VMA). Properly proportioned and placed SCC can result in both economic and technological benefits for the end user. The in place cost savings, performance enhancements, or both, are the driving forces behind the use of SCC.

The use of self-compacting concrete (SCC) is spreading worldwide because of its very attractive properties in the fresh state as well as after hardening. The use of SCC will lead to a more industrialized production, reduce the technical costs of in situ concrete constructions, improve the quality, durability and reliability of concrete structures and eliminate some of the potential for human error. It will replace manual compaction of fresh concrete with a modern semi-automatic placing technology and in that way improve health and safety on and around the construction site. .[12]

Specifically, SCC can provide the following benefits:

- Reduce labor and equipment.

No need for vibration to ensure proper consolidation. This also results in savings in equipment purchasing and equipment maintenance and operation; and Less need for screeding operations to ensure flat surfaces (self-leveling characteristic).

- Enable the casting of concrete that develops the desired mechanical properties independent of the skill of the vibrating crew.
- Accelerate construction through higher rate of casting or placing and shorter construction duration.
- Facilitate and expedite the filling of highly reinforced sections and complex formwork while ensuring good construction quality. This can ensure better productivity; reduce the labor requirement and cost, or both.
- Enable more flexibility in spreading placing points during casting. This can reduce the need for frequent movement of transit trucks and the need to move the pump lines to place concrete (possible reduction in the number of pumps, pump operators, and so on). This greater flexibility in scheduling construction activities and procuring the required resources results in both time and resource savings.
- Reduce noise on the job site (especially critical in urban areas and for sections requiring heavy vibration consolidation):

- Reduce the need of vibration for construction typically requiring the use of heavy consolidation (such as fiber-reinforced concrete and precast operations). In some cases, the use of noise-free or silent concrete can potentially extend construction hours in urban areas, enabling the scheduling of some construction activities during otherwise curfew periods to alleviate difficulties related to traffic conditions in urban areas; and
- Reduce insurance premiums. Pre casting facilities generating considerable noise pollution are sometimes required to pay premiums to national insurance agencies responsible for eventual treatment of hearing-impaired workers. Insurance premium reductions can partially offset the additional material cost of SCC, making it attractive for precast operations.
- Permit more flexibility for detailing reinforcing bars. Avoid the need to bundle reinforcement to facilitate placement and consolidation, and in some cases, enable the use of small and closely spaced reinforcing steel to control cracking;
- Create smooth surfaces free of honeycombing and signs of bleeding and discoloration, obtained when using a well-proportioned SCC mixture, high-quality formwork with an adequate release agent, and sound placement practices.[12]

2.5. Cost and Performance Optimization of SCC

The design of mass concrete structures is generally based on durability, economy, and thermal action, with strength often being a secondary, rather than a primary, concern. The one characteristic that distinguishes mass concrete from other concrete work is thermal behavior. Because the cement-water reaction is exothermic by nature, the temperature rise within a large concrete mass, where the heat is not quickly dissipated, can be quite high. Significant tensile stresses and strains may result from the restrained volume change associated with a decline in temperature as heat of hydration is dissipated. Massive structures, such as gravity dams, resist loads primarily by their shape and mass, and only secondarily by their strength. Of more importance are durability and properties connected with temperature behavior and the tendency for cracking. [44] Therefore, in order to reduce the heat of hydration of cement, the cement should be replaced with some other mineral additives: like fly ash, slag, limestone powder etc.

The hardened SCC is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

SCC mixes usually contains a powerful superplasticizer and often use a large quantity of powder materials and/or viscosity modifying admixtures. The superplasticizer is necessary for producing a highly fluid concrete mix, while the powder materials or viscosity modifying agents are required to maintain sufficient stability/cohesion of the mix, hence reducing bleeding, segregation and settlement. As an increase in cement content leads to a significant rise in material cost and often has other negative effects on concrete properties (e.g., increased thermal stress and shrinkage etc.), the requirement for increased powder content in SCC is usually met by the use of pozzolanic or less reactive filler materials. Lime stones are sedimentary rocks primarily of calcium carbonate and it is generally obtained from the calcareous remains of marine or fresh water organisms embedded in calcareous mud.[31]

Limestone powder has been used to produce cement in some countries, it is mentioned that up to 35% of limestone powder can be added to produce Portland limestone cement and Portland composite cement. The use of limestone powder in concrete, particularly in SCC, has been widespread in Sweden and France, where limestone powder is stored in silos alongside the cement in ready-mix concrete plants. The addition of fine limestone powder can significantly improve the workability of self-compacting concrete and it has shown to enhance the rate of cement hydration and strength development, as well as to improve the deformability and stability of fresh SCC. Preliminary studies carried out as part of a major European research project on SCC suggested that fine limestone powder could be used effectively in SCC. The SCC mixes containing fine limestone powder showed improved fresh properties, higher than expected compressive strength and excellent surface finish. This was attributed to improved particle packing and water retention of the fresh mixes, as well as to possible chemical reactions involving cement hydrates and CaCO3. [31]

From the experimental investigation done limestone powder replacing cement, it was observed that the replacement of cement with limestone powder as mineral admixture in SCC with 30 percent fly ash show improved workability and mechanical properties up to 20 percent.

Chloride content of SCC decreased with increase of cement replacement with limestone powder up to 20%. Further it was also observed that the chloride content reduced with increase in depth from the top surface of specimen. Compressive strength of SCC subjected to acidic attack decreased compared with reference mix. [33]

Mixtures containing moderate amounts of cementations materials and fine fillers decrease the coarse aggregate volume and reduce the risk of blockage while simultaneously increasing the segregation resistance and reducing the costs associated with high volumes of Portland cement and superplasticizer. Mineral admixtures such as fly ash, limestone powder, blast furnace slag, silica fume, brick powder, etc, have been used in attempts to improve the properties of SCC.[33]

Limestone powder(LP) is the most common additive for improving the flow ability of SCC. The addition of limestone reduces the initial and final concrete setting times while increasing the total shrinkage only slightly compared to conventional concrete The limestone filler also acts as a viscosity enhancer, increasing the workability.[32]

The viscosity of cement-based material can be improved by decreasing the water/ cementations material ratio (w/cm) or using a viscosity-enhancing agent. It can also be improved by increasing the cohesiveness of the paste through the addition of filler, such as limestone .[19] However, excessive addition of fine particles can result in a considerable increase in the specific surface area of the powder, which results in an increase of water demand to achieve a given consistency. On the other hand, for fixed water content, high powder volume increases inter particle friction due to solid–solid contact. This may affect the ability of the mixture to deform under its own weight and pass through obstacles.

Partial replacement of cement by an equal volume of limestone powder with a specific surface area ranging between 500 and 1000 m^2/kg resulted in an enhancement in fluidity and a reduction of the yield stress of highly flow able mortar. Other investigations have shown that partial replacement of cement by an equal volume of limestone powder varying from 5% to 20% resulted in an enhancement of the fluidity of high-performance concrete having a W/C ratio ranging between 0·5 and 0·7.[34]

This improvement may be due to the increase in W/C or in paste volume. Indeed, for given water content, partial replacement of cement by an equal volume of a filler results in an increase in W/C. On the other hand, partial replacement of cement by an equal mass of limestone powder results in an increase of powder content, i.e. an increase in paste volume. For example, the partial substitution of cement by 40% (by mass of limestone filler) having a specific gravity of 2·7 yields to a 17% increase in powder volume. [35]

The durability of a concrete repair can depend on many factors. Those most often considered are cement reactivity with environment, low permeability, diffusion coefficient of species such as sulfate ions and compressive strength. The water absorption is also very important factor effecting durability such as freezing and thawing. The use of mineral additives may provide a way of improving the durability of SCC depending on the type and amount of mineral additive used. In addition, in the absence of self-compact ability the success of mortars depends on the compaction degree supplied at application site. For improving strength and durability properties; limestone powders produce a more com-pact structure by pore-filling effect. [36]

2.6 Rock Fill Concrete [RFC]

Concentrated efforts to develop technology for increasing the durability of construction work and to affect labor savings have been conducted in dam construction in Japan. The development of RCC construction method is an example of these efforts. In addition, the application of SCC for dams has been the subject of research with the aim of further rationalization of construction works. Since SCC can have the characteristics of high density and high strength without compaction, the use of this material for buildings has been highly promoted. However, the use of SCC for mass concrete such as for dams can cause thermal cracking problems. For this reason, studies are being made to solve such problems by increasing the maximum aggregate size in SCC and decreasing the unit cement content.

As the use of SCC for such massive civil works can be quite effective from the view of saving labor and improving speed of construction, SCC has been used at several dam. Performance requirements of SCC for dams include specified fluidity, self-filling capacity, material segregation resistance, and properties that will minimize thermal cracking in mass concrete. Lowering the cement content to reduce the heating effect of cement can be effectively accomplished by increasing the maximum aggregate size.[38]

Rock-filled concrete (RFC) was developed by Tsinghau University in China in 2003 as an application of self-compacting concrete (SCC) that can then be used as ‘‘normal’’ concrete for massive concrete constructions. RFC is produced by filling the voids of rock blocks with SCC, which has good fluidity and segregation resistance. The integrated performance of RFC was studied by conducting tests on its compaction, compression strength, tensile strength, and permeability. Results indicated that RFC meets the requirements of hydraulic concrete. RFC exhibits remarkable advantages, such as high construction efficiency, low cost, low heat of hydration, and low environmental impacts. These advantages contribute to a simpler construction management and an easier quality control, signifying that RFC is a promising technology in hydraulic engineering.

SCC is widely used in various types of practical structures worldwide, except in massive concrete constructions in hydraulic engineering, because it has high cement content and releases more heat during hydration. These characteristics result in high cost, significant environmental impact, and difficulty in temperature control. Thus, different researchers are making efforts to apply SCC in massive concrete constructions in hydraulic engineering, accompanying with lower costs and less environmental load. [35,36]

RFC is a combination of SCC and rock and it is produced by filling SCC into the voids of rock blocks having a minimum size of 300 mm because of SCC's good fluidity and segregation resistance. In the RFC mass, only 40–45% of the volume needs to be filled with SCC, which significantly reduces the total proportion of cement in a unit of RFC and highly improves the construction efficiency. RFC performs satisfactorily in reducing cost and heat of hydration.

Since its development, SCC has been used in many practical structures in the world. However, compared with conventional vibro-compacted concrete, SCC displays a lower E-modulus, higher shrinkage, a greater rate of creep and is also more costly in seeking to achieve the same compressive strength. Thus, SCC has seldom been used as a standard concrete in dam construction. Yet, scope exists to employ SCC in some degree, especially in light of the further challenge faced by dam engineering of the need to pay more attention to reducing costs and environmental impacts in future projects. To overcome such challenges of the limitations of the use of SCC, and to improve the economics and environmental performance of dam projects, engineers in China began to develop RFC technology as a new type of concrete for structures, especially large-scale structures such as dams.

According to previous studies on the energy consumption and emissions during a dam's lifetime, i.e., material production, transportation, construction, and operation and maintenance stages, the total energy consumption is reduced by 55%, and approximately 64% of CO2 emissions are saved when RFC is used instead of conventional concrete (Conv. C). Thus, RFC is more environmentally friendly than Conv. C.

RFC is based on the self-compatibility of SCC, which should flow into every void of the block mass purely by means of its own weight and without the need for vibrating compaction. This characteristic requires the high fluidity of SCC without aggregates segregation during placement. The production of SCC with excellent workability requires appropriate mix proportions. RFC is a two-phase material composed of rock and SCC, and thus, the integrated properties of RFC, such as compactness, mechanical properties, and permeability need to be studied.

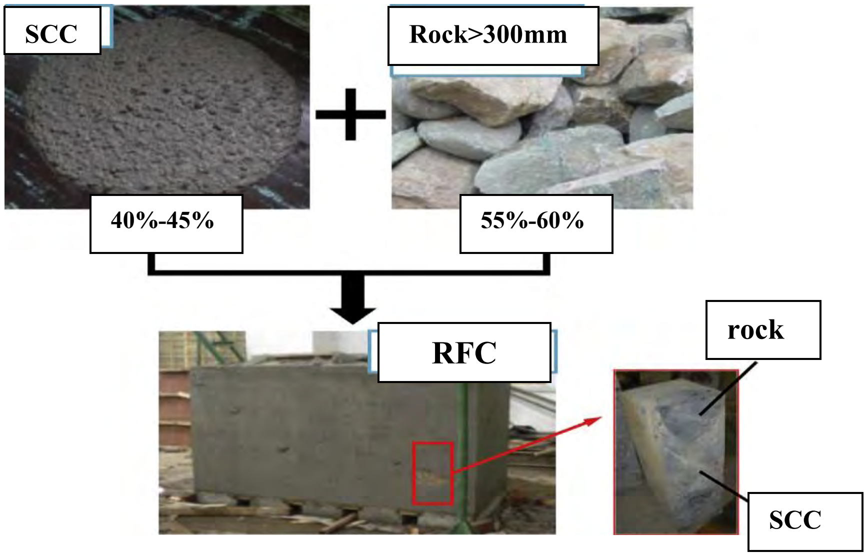

Figure 2.5 Composite of RFC

The properties of RFC are affected by the gradation of the rock blocks, unit rock block content, unit SCC content, and so on. Different research result showed that the thickness of rock-block mass should be less than 1.5m to ensure effective compactness after the RFC sets. Massive concrete structures, in particular concrete dams, require a reduction of the unit cement content to lower the financial cost as well as the heat of hydration. Generally, using larger aggregate in concrete production is an effective way to reduce the unit cement content, and fully-graded aggregate is usually used in concrete for dam construction.

Compared with conventional vibro-compacted concrete, RFC needs a more stable, stiffer and closer formwork due to the high deformability of SCC.

2.6.1 Benefits of RFC

Since the development of RFC in 2003, the concrete has already been used in two hydraulic engineering projects and is planned to be used in a few more projects. The main reasons for the employment of RFC can be summarized as: Using low unit cement content in the composite material results in low heat of hydration, which makes it much easier to ensure temperature control.

Simplifying the placement of RFC by allowing for the use of general purpose machinery, eliminating the surface roughening process and also allowing for continuous pouring of SCC, all contribute to faster construction activities and shortening of the overall construction period. Eliminating the need to vibrate concrete by using SCC results in compaction being ensured independent of the quality of construction work. Simplifying the aggregate production and concrete mixing machinery contributes to cost reduction. Using the rock-block mass as the skeleton of concrete results in relatively little drying and shrinkage; and Reducing noise as well as energy consumption contributes to lower emissions of the greenhouse gas (GHG) carbon dioxide (CO2), and also sulphur dioxide (SO2).

2.6.2 Practical Application of RFC

To put RFC into practical application, two types of RFC construction method were proposed based on the construction processes of SCC and rock, namely: **general-type** and **riprap-type** RFCs.

General type RFC construction method

In general-type RFC construction method, the working space is initially filled with rock blocks to form a rock-block mass. SCC is pumped or poured directly on the surface of the rock-block mass. Thereafter, SCC flows downward and fills the void spaces by its own weight because of its high fluidity and segregation resistance.

Generally, general-type RFC construction method is proposed for projects with large working spaces, such as dam construction which are used to transport the rock blocks, to construct the rock block mass and to pour SCC on the surface of the rock-block mass. All these processes should be performed simultaneously in a large working space. After the first lift of RFC is finished, the next cycle of construction is then performed. As a result, fast construction activity can be achieved by the continuous pouring of SCC and the cyclic construction of RFC. The thickness of a lift of rock-block mass should be less than 2.0 m to ensure construction quality. The pump, bucket, and excavator can also be used in SCC casting, but pumping is generally proposed.[37]

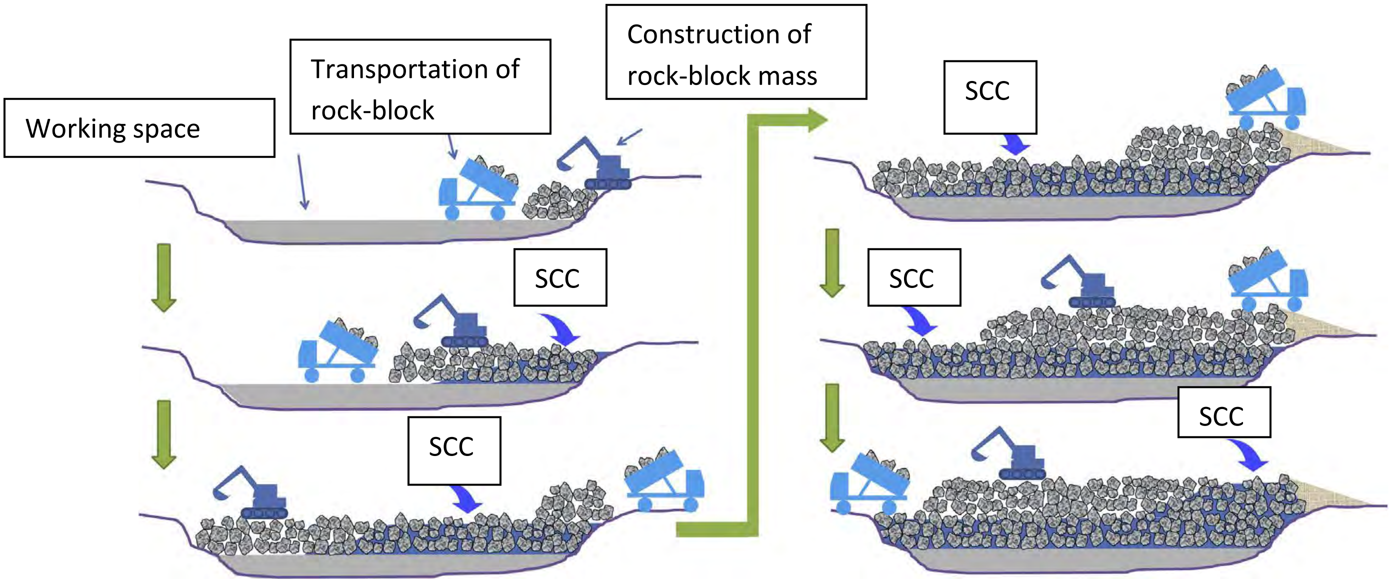

Figure 2.6 Cyclic constructions with general-type RFC construction technology.

Riprap-type RFC construction technology

In riprap-type RFC construction, SCC is initially poured into a working space, and then rock blocks are dumped into the pre-poured SCC. The advantages of riprap-type RFC construction technology can be fully exploited in projects with small working spaces and a significant drop in elevation, such as caissons and cave backfills in foundation treatment projects, in which rock blocks cannot be easily transported and packed by general-purpose machinery. Continuous construction can also be realized through the riprap-type RFC construction technology.

SCC is directly poured into the working space from the mixer truck After which, the rock blocks are directly dumped into the working space by a dump truck or bulldozer. The thickness of the poured SCC layer is initially determined by the drop distance of the rock block.

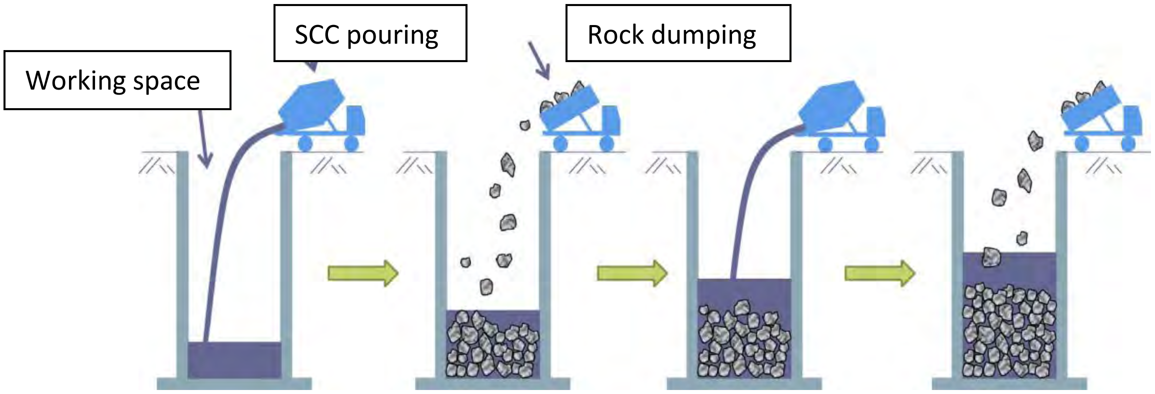

Figure 2.7 Cyclic constructions with riprap-type RFC construction technology.

Now a day, RFC has been successfully applied in more than 60 hydraulic engineering projects in China with the two types of construction technology proposed above. [38]

Application of General-Type RFC in China

- ✓ **Gravity dam construction**: Changkeng third reservoir. General- type RFC construction technology was employed in the Changkeng third reservoir reconstruction project**.** It has a capacity of 1,310,000 m3. In 40 years increasing seepage passages have placed the dam at risk, and reinforcements had no significant effects. The reservoir required urgent reconstruction. RFC was used in the reconstruction project to utilize old dam materials and hasten the construction during the dry season. Old dam materials were utilized to replace some of the rock blocks. Dump trucks were used to transport the rock block to the working space, while excavators and bulldozers were used to construct the rock-block mass in the working space. The batching and mixing plant was built slightly farther from the dam body, so the mixed SCC was transported from the plant to the placement area by concrete tankers. The tower crane or pump was used to pour SCC into the working space. The reconstruction of the Changkeng third reservoir was completed within nine months, and the total RFC used was approximately 18,000 m3. The new reservoir has a maximum height of 26.5 m and a capacity of 1,613,200 m3.[37]
- ✓ **Arch dam construction**: General-type RFC construction technology was also employed in the arch dam construction. The reservoir had a capacity of 1,080,000 m3, and the designed dam height and dam crest length of the single-curvature arch dam were 24 and 129.8 m respectively. High altitude brought difficulties in the transportation of materials and the construction speed. Therefore, RFC was used because of its low heat of hydration, simple temperature control measures and high construction efficiency. Rock blocks were transported onto the working space by a tower crane while the SCC was poured through the long pump line.

Owing to the fast RFC construction speed, this arch dam construction completed from July 2012 to April 2013. The total RFC usage was 11,400 m3. Tested results showed that the strength grade, anti-permeability grade, and frost resistance grade of the constructed RFC, were all meet the requirements of hydraulic concrete.[37]

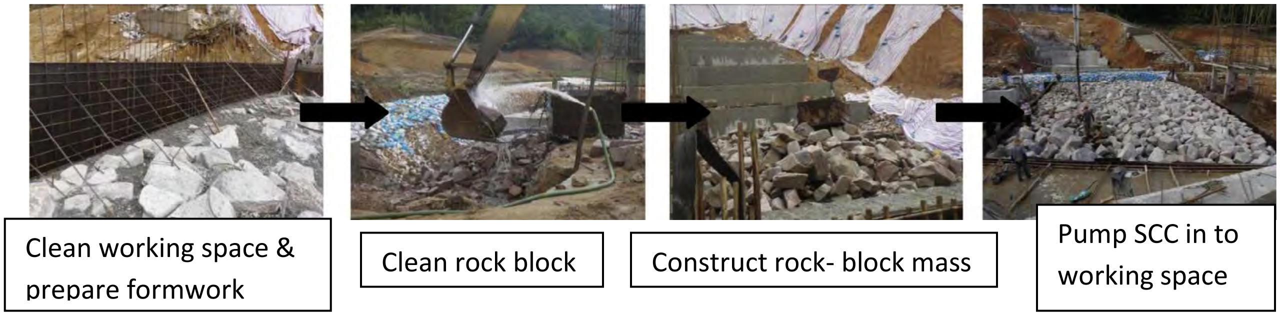

Figure 2.8 Construction procedure of RFC.

✓ **Dam reinforcement**: Hengshan reservoir. Since 2010, the continuous study and application of RFC have been further extended in reinforcing dams. The 69 m-high dam of the Hengshan reservoir in Shanxi Province, the first double-curvature thin-arch dam in China, required strengthening and reinforcement. Placing concrete behind the dam was proposed, which resulted in an arch gravity dam after reinforcement. RFC was proposed in the reinforcement project to solve the problems of temperature stress and the binding of fresh and old concrete. The project was completed in 2010, and approximately 37,000 m3 of RFC was constructed. one of the main purposes for using RFC is to reduce the total proportion of cement and decrease the heat during hydration. To validate this assumption, a tests was conducted on the temperature during the construction process. As a result, The temperature rise was about 10^{o}C on average, much lower than the averages for SCC and Conv. C. Thus, RFC with a large amount of rock blocks releases low heat of hydration and is eco-friendly. [37]

✓ **SCC used in concrete dam (China)**.

RFC was used for dam constructions by the initiating of Tsinghua University, and technically consulted by Tsinghua-Maeda-Okamura Advanced Construction Technology Research Center (TMOACTRC). The Standard codes for RFC was prepared by this center prior to the placing of the concrete, seminars and meetings were carried out by the initiating of the Tsinghua University, with the participation of the Client, the Contractor and the Subcontractors. The Technical specification for RFC was prepared by TMOACTRC. Quality management for SCC was done by the technical staff team of Tsinghua University, which included students under consulting of TMOACTRC. Some problems were faced such as the deforming of the formwork during the placing of the concrete owing to the inexperience of workers in the early stage of construction, however, it has improved gradually. The University and the Client cooperated closely together on this case, and consequently the introduction of this new technology has started smoothly, and has spread in China.

Figure 2.9 RFC constructions in china.

- **Gravity dam in a reservoir project in Beijing**

RFC was first used in a gravity dam in a reservoir project in Beijing, The 13.5m high, 2,000m3 gravity dam was finished in 2005. SCC was transported from batching and mixing plant by mixer truck. It was then pumped into the working space containing rock-blocks by pump truck, and the compacted RFC was obtained without any recourse to vibro compaction. At the dam, lifts of 1.2m were executed, and good quality RFC was revealed by later tests.

- ✓ **Auxiliary dam, Baoquan pumped storage project**

Another application of RFC was in part of the auxiliary dam of the upper reservoir of the Baoquan pumped storage project, in Henan province, in 2006. The dam was designed as a 50,000m3 masonry gravity structure of 42.6m height and 196m in crest length. However, the top 3m of the dam, with a volume of 3,000m3, was constructed of RFC to solve the problems in the practical construction, such as low construction efficiency and low construction quality.

Dump trucks were used to transport rock blocks to the working space, and excavators and bulldozers were used to construct the rock-block mass in the working space. The batching and mixing plant was built at the lowest level of the auxiliary dam, thus the mixed SCC was transported from plant to placement area directly by tower crane and bucket. There were up to six workers in the working space to assist by cleaning the working space, building stone walls, and so on. In general, since there is no need for vibro-compaction in the RFC execution, the employment of the material should offer great simplification of execution and speed up the construction of more massive concrete projects.

- ✓ **Gully backfill project**

After finishing the RFC construction on part of the auxiliary dam at Baoquan, most of the engineers involved, including those with the owners, designers and constructors, 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. In this project, SCC with the index of C10 was used to construct RFC to reduce the cost, since the designed index of conventional concrete is lower than that in the auxiliary dam. The transportation of rocks and construction of rock-block mass was similar to that in the auxiliary dam. Due to the large working space and significant drop in elevation at the particular location on the site, a chute was used to transport SCC from mixer truck to placement area and an excavator was used to pour SCC in the working space.

Application of Riprap-Type RFC in China

Aside from dam construction and reinforcement, RFC was also used in the caisson backfill of the Xiangjiaba hydropower project, the third largest hydropower station in China. The open caisson group, composed of 10 caissons with a total volume of 80,000 m3, was the largest caisson group in China. The maximum depth of the caisson was 54.7 m. Given the difficulty of transporting concrete to a caisson depth of more than 54 m and the vibro-compaction executed by labors at the bottom, constructing the caisson backfill using Conv. C was challenging. Thus, riprap-type RFC was introduced to solve these problems. Finished in 2008, the total RFC constructed in the caisson backfill project was approximately 70,000 m3. SCC and rock blocks were cast simultaneously into the caisson, which greatly hastened the construction. The backfill construction of one caisson was completed within one week when RFC was employed, whereas the designed construction period using Conv. C for backfilling required 45 d. RFC offers great simplification in execution and speeds up the construction of massive concrete projects.[37]

- ✓ **Cost and environmental assessment**

Generally speaking, the cost of materials is one of the most important considerations on projects. After completing the RFC work at Baoquan, a cost assessment was done with the contractor's data. With an assumed void ratio of 45% for the RFC on the project, a cost of Rmb160-Rmb180/m3 for SCC, and of Rmb40/m3 for the rock blocks, the cost of materials was calculated to be approximately Rmb112-Rmb121/m3. If we assume that the cost of materials is 70% of total cost, then the total cost of RFC may be approximately Rmb160-173/m3.

As mentioned above, dams should be constructed with more attention paid to reducing environmental impacts in future. With regards to the environmental aspects of RFC, studies on the environmental impact assessment of RFC, conventional vibro-compacted concrete and RCC (Roller Compacted Concrete) were also carried out.

Compared with conventional concrete and RCC, the innovative construction method of RFC leads to a great reduction in workload of aggregate crushing in materials manufacturing phase, as well as that of concrete mixing, transportation and placing. In addition, it needs no vibro-compaction and surface roughening in the concrete placing phase. The study shows that RFC has better environmentally-friendly grading compared to conventional concrete and RCC, through the quantitative calculation in environmental impact of concrete in the entire life cycle. In the gravity dam construction, the employment of RFC can mitigate the negative effects that will inflict on the natural environment, such as CO2 emission and energy consumption.

CHAPTER THREE

3. EXPERIMENTAL PROGRAM

In this section, a physical property test for the concrete components was done. A concrete samples were produced for conventional concrete, normal SCC and self-compacting concrete with powdered limestone after their respective mix design were prepared.

3.1 Material Physical Quality Tests

Concrete is a mixture of different materials up on which its quality and performance depend. The major constituents of concrete are:-aggregate (coarse and fine), cement (binder), water and admixtures if necessary. Since the quality of the constituent material directly affects the quality of the concrete it is necessary to test and know the physical property of those materials.

3.1.1 Cement

Dangote Ordinary Portland cement of grade 42.5 was used and its setting time was tested. The physical properties of the cement are given in table 3.2.

Physical tests done for the cement are:

- Normal consistency of hydraulic cement and Setting time of hydraulic cement

Normal consistency of hydraulic cement refers to the amount of water required to make a paste of satisfactory workability.

Test method: C 187 – 98 Standard Test Method for Normal Consistency of Hydraulic Cement was used. [44]

Table 3.1 Normal consistency test result.

No	Cement weight(gm)	Water added (gm)	% of water	Penetration depth(mm)	Water cement ratio at 10±1mm penetration
1	500	140	28%	7mm	0.29
2	500	145	29%	10mm	

Note: the usual range of water – cement ratio for normal consistency is between 26% and 33%.

The **initial and final setting time** of the hydraulic cement was performed and the results are summarized in table 3.2.

Test method: C 191 – 01 Standard Test Method for Setting Time of Hydraulic Cement was used. [44]

Table 3.2 Cement physical properties.

Physical properties	Obtained Result	Standard requirement
Vicat initial setting time (minutes)	175	Not less than 45 minutes
Vicat final setting time (minutes)	260	Not exceeding 600 minutes
Specific gravity	3.15	----

3.1.2 Aggregates

Locally available natural sand with 4.75mm maximum size was used as fine aggregate, and Crushed stone with maximum size of 20mm and 12.5mm as coarse aggregate. Both the fine and coarse aggregates used for this research was taken from the AAiT's laboratory. The physical quality tests for the aggregates were tested and their results are given in table 3.2

Table3.3 Physical properties of aggregates

No	Properties	Aggregates	
		Fine aggregates	Coarse aggregate
1	Specific gravity	2.45	2.74
2	Fineness modules	3	2.87
3	Silt content	3%	---
4	Absorption capacity	1.01%	1.33%
5	Moisture content	2.04	1.78
6	Bulk density (kg/m3)	------	1657.24

3.1.3 Water:

As the rule of the thumb for water quality is, “If you can drink it, you can make concrete with it”, therefore potable water found in the AAiT compound was used for all concrete mixes.

3.1.4 Admixture:

MegaFlow SP1-High range water reducing super plasticizer was used for the SCC mix design to enhance the flow ability of the fresh concrete without additional water. According to ASTM C494 standard, this admixture is categorized as type F high range water reducing admixtures.

3.1.5 Lime Stone Powder:

The natural limestone powder from around Sebeta was used as partial cement replacement for this research.

3.1.6 Preplaced Aggregate

The preplaced aggregate with a maximum size of 300mm from around Sebeta River in Mogele Mountain was used for preparing the dam model for this research.

3.2 Concrete Mix Design

3.2.1 Conventional Concrete

Mix design consists of two interrelated steps, to produce as economically as possible and concrete of good performance. These are:

1. selection of the suitable ingredients (cement, aggregate, water and admixtures) &
2. determining their relative quantities (“proportioning”)

A properly proportioned concrete mix should possess the following qualities:-

a. Acceptable workability of the freshly mixed concrete
b. Durability, strength, and uniform appearance of the hardened concrete and
c. Economy

In this section different trail mix designs are formulated for both the conventional concrete and SCC as shown below until the required proportioning is achieved.

- 1st Trail Mix- Design for Conventional Concrete

Concrete of compressive strength 25 Mpa (C-25) was used as a reference mix.

ACI concrete mix design method was used for the normally vibrated concrete and the procedures are shown as follows.

1. choice of slump

   Maximum slump= 100mm and minimum slump= 25mm.
2. maximum size of aggregates
   - sand or fine aggregates =4.75mm
   - coarse aggregates =19mm
3. Estimation of mixing water and air content

   Assume non air entrained concrete

   From table 2 of ACI standards, for non-air entrained and slump of 75-100, the water in $1m^3$ of concrete is 205Kg.
4. Water to cement ratio selection

   From table 3a of ACI, for C-25 and non-air entrained concrete water to cement ratio is 0.610.
5. Cement content calculation

   For slump of 75-100

   Water content=$205Kg/m^3$

   Water/cement=0.61

   $$cement\ content = water\ content/(\frac{w}{c})$$

   $$= \frac{205}{0.61}$$

   = <u>336 kg/m</u>^{3}
6. Estimation of coarse aggregates content.

   From table 4 of ACI, for maximum size of aggregate= 20mm and fines modules for sand = 3.00, the volume of coarse aggregate per unit volume of concrete is

   $$= 0.60$$

$$requered\ dry\ mass\ of\ C.A = 0.60 * 1657.24$$

= **995 kg/m3**

7. Estimation of fine aggregates content

At the end of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity is determined by difference. Either of the two procedures may be employed:

- The weight method or
- The absolute volume method

If the weight of the concrete per unit volume is assumed or can be estimated from experience, the required weight of fine aggregate is simply the difference between the weight of fresh concrete and the total weight of the other ingredients. Therefore, I preferred the weight method.

- Content of fine aggregate (F.A) = unit weight of concrete – (C.A + cement + water)

First estimate the unit weight of fresh concretes from tables.

From the table the unit weight of fresh concrete corresponding to max. Aggregate size of 20mm and non- air entrained is **2345kg/m^3.**

Fine aggregate content = [2345 – (995+336+205)] **= 810 kg/m^3**

8. Moisture adjustment

Absorbed water does not become part of the mixing water and it must be removed from the mixing water, if moisture content is greater than absorption capacity. But, if absorption capacity is greater than moisture content of aggregate, we need to add water up to its moisture capacity. Therefore, in this case since the moisture content of the aggregates is greater than their absorption capacity, water should be deducted from the mixing water.

Removed water from C.A = 1.78 - 1.33 = **0.45%**

Removed water from F.A = 2.04 – 1.01 = **1.03%**

Total water required = 205-[994.40*(0.45/100)+809.60*(1.03/100)] = **193 kg/m3**

9. Trial batch

Nine cubes were required for compressive strength test three cubes for durability test and three cube for permeability, a total of fifteen cubes were required for the reference mix.

Concrete volume = $15(0.15^3)$ = 0.050625m3

Considering 20% waste = 0.010125m3

V_{total} =0.050625+ 0.010125= **0.061m3**

Table 3.4 Ingredient proportions for the 1st trail of conventional concrete.

Ingredients	**Weight (kg/m3)**	**Weight per trail volume(Kg)**
Coarse aggregate	995	61.4
Fine aggregate	810	49.2
Cement	336	20.4
Water	193	11.7
Conc. Unit weight	**2334.00**	

- 2nd Trail Mix- Design for Conventional Concrete

Since the first trail mix design of conventional concrete doesn't satisfy the fresh properties requirements of SCC, second trail is done by changing only the maximum aggregate size from 20mm to 12.5mm and similar procedure was followed as that of first trail and got the following proportions. The estimated ingredients for a meter cube of concrete is therefore, summarized as follows.

Table3.5. Ingredient proportions for the 2nd trail of conventional concrete.

Ingredients	**Weight (kg/m3)**	**Weight per trail batch (kg)**
Coarse aggregate	878	53.30
Fine aggregate	862	52.40
Cement	354	21.50

Water	204	12.40
concrete Unit weight	**2298**	

3.2.2 Self- compacting Concrete (SCC)

- 1st Trail Mix Design for Self-Compacting Concrete (SCC)

One of the limitation of self compacting concrete is there is no standard for its mix design. According to ACI 237R-07, the following steps are used for determining performance requirements and proportioning of SCC.

- Step 1: determine slump flow performance requirements.
  Accordingly, the slump for this case is in the range of 550mm – to 700mm
- Step2: select coarse aggregate and proportion.
  Max. Aggregate size =20mm.
  For the first trial use 37% C.A and 40% of F.A with w/c =0.4

  - C.A = 2334*(37/100) = 863.00kg

  -F.A = 2334*(40/100) = 933.00kg
- Step3: estimate the required cementations content and water.

Using the conventional concrete mix water which is 193 kg/m^3, and since the super plasticizer admixture is fluid assuming about its 80% is water, it should be deducted from the mixing water. The dosage of super plasticizer for the first trial was 1.3% of cementations materials.

Mixing water = 193-(6.25*0.8) = 187.20kg

Cement content = 187.20/0.4 = 468.00kg

- Step 4:calculate paste and mortar volume
- Step 5: select admixture
- For the first trial HRWRA 1.3% of cementations materials was used.
- Step 6: batch trail mixture.

The estimated ingredients for a meter cube of concrete are tabulated below.

Table3.6. Ingredient proportions per meter cube and per trail batch for the 1st trail of SCC.

Ingredients	**Weight (kg/m3)**	**Weight per trail batch(kg)**
Coarse aggregate	863	52.40
Fine aggregate	933	56.70
Cement	468	28.50
Water	193	11.70
Admixture	6.25	0.40

The main differences between the conventional concrete and self compacting concrete is observed in their fresh properties. In this trail the result for SCC doesn't fully satisfy the requirements of standard, specially the V-funnel test and L-box blocking ratio test result is out of the range. Therefore, the second trail is done as follows with some ingredient quantity modification.

- 2nd Trail Mix Design for Self-Compacting Concrete (SCC)

In the second trail similar steps were followed as that of the first trail with only some quantity change for the components. Accordingly, the maximum aggregate size was set to be 12.5mm, aggregate content is also became 37% C.A and 45% F.A., HRWRA -1.8% of cementations material and others remain the same. The quantities of the components are given in table12 below.

Table 3.7. Ingredient proportions per meter cube and per trail batch for the second trail of SCC.

Ingredients	**Weight (kg/m3)**	**Weight per trail batch(kg)**
Coarse aggregate	850	51.60
Fine aggregate	1034	62.80
Cement	490	29.75
Water	203	12.34
Admixture	9.20	0.56

The result of second trail also shows that the V-funnel (5min.) and L- box blocking ratio are not satisfied, thus a third trail is needed with some modification in the quantity of the components.

- 3rd Trail Mix Design for Self-Compacting Concrete (SCC)

Here also similar steps were followed as above with only some quantity change for the components. Accordingly, the maximum aggregate size remains 12.5mm, aggregate content became 35% C.A and 47% F.A., HRWRA -2.1% of cementations material and others remain the same. The quantities of the components are given in table13 below after adjusting the mixing water as per the admixture.

Table 3.8. Ingredient proportions per meter cube and per trail batch for the third trail of SCC.

Ingredients	**Weight (kg/m3)**	**Weight per trail batch (kg)**
Coarse aggregate	804	48.85
Fine aggregate	1080	65.60
Cement	487	29.60
Water	195	11.85
Admixture	10.70	0.65

Summary of experimental procedure for cement based SCC

The procedure adopted in the study is as follows

1) Using ACI mix design method, initial mix design was carried out at coarse aggregate content of 37% percent by volume of concrete and fine aggregate content of 40% percent by volume of concrete. These Trial mixes were designed with super plasticizer content of 1.3% for mix TR1.
2) To proceed towards achieving SCC, the coarse aggregate content was kept constant at 37% and the fine aggregate content was increased to 45% by volume of concrete and super plasticizer content at 1.14 percent of powder content. This is done for mix TR2.
3) Coarse aggregate content was reduced to 35% and fine aggregate content was further increased to 47%, and super plasticizer content is also increased to 2.1%. In this case the required fresh properties of the SCC were achieved.

For each trial, tests are carried out in order to check that the mix satisfies slump flow test, V-funnel test and L-box passing ability test.

3.3 SCC with powdered limestone (LP).

To ensure its high filling ability, flow without blockage and to maintain homogeneity, SCC requires a reduction in coarse aggregate content and hence a high cement content which can increase cost and also cause temperature rise during hydration as well as possibly affect other properties such as creep and shrinkage. Therefore significant quantities of additions are often incorporated to replace some of the cement, to enhance the fresh properties and reduce heat Generation. In this case lime stone powder is used as partial replacement of cement. Different trails were done as follows until a satisfactory self-compacting concrete is obtained.

1st Trail mix design for SCC with powdered limestone (20%LP &2.1% SP).

The first trail was done by replacing 20% of the cement by limestone powder keeping all the other ingredients constant.

Table3. 9. Ingredient proportions for the 1st trail of SCC with 20% LP.

Ingredients	Weight (kg/m3)	Weight per trail batch(kg)
Coarse aggregate	804	48.85
Fine aggregate	1080	65.60
Cement	390	23.70
Limestone	98	5.95
Water	195	11.85
Admixture	10.70	0.65

The fresh property results of this trail mix don’t satisfy the requirements. It shows that pass ability and segregation resistance ability is low which also affects the overall performance of the concrete. Therefore, additional trail mix should be conducted with the re-proportioning the concrete components.

2nd Trail mix design for SCC with powdered limestone (20%LP & 2.3% SP).

In the above first trail a high range water reducing admixture of 2.1% was used which satisfied the third trail of normal SCC. Here additional trail mix is done by making the HRWRA 2.3% ,limestone powder 20% and keeping all the other ingredients constant as per trail one.

- Super plasticizer admixture 2.3% of cement and cementations material.
- Mix water = 203.18-(11.19*0.8) = 195kg
- Cement content = 194.23/0.4 = 486 kg

Table3.10 Ingredient proportions per meter cube and trail batch for the 2nd trail of SCC with LP.

Ingredients	**Weight per m3(kg/m3)**	**Weight per trail batch (kg)**
Coarse aggregate	804	48.85
Fine aggregate	1080	65.60
Cement	390	23.70
Limestone	98	5.95
Water	195	11.85
Admixture	11.20	0.68

In this trail the fresh property of self compacting concrete is also not fully satisfied. The V-funnel and blocking ratio are out of the requirement range thus it needs another trail.

3rd Trail mix design for SCC with powdered limestone (15% LP & 2.3% SP).

In the second trail above the pass ability and segregation resistance is not satisfied yet. The reason may be dosage of limestone powder and therefore a third trail is done by replacing 15% cement by limestone powder keeping all the other ingredients constant as that of second trail.

- Super plasticizer admixture 2.3% of cement and cementations material.
- Mix water = 203.18-(11.19*0.8) = 195 kg

Cement content = 194.23/0.4 = 486 kg

Table3.11. Ingredient proportions per meter cube and trail batch for the 3rd trail of SCC with LP.

Ingredients	**Weight per m3(kg/m3)**	**Weight per trail batch(kg)**
Coarse aggregate	804	48.85
Fine aggregate	1080	65.60
Cement	413	25.10
Limestone	73	4.44
Water	195	11.85
Admixture	11.20	0.68

Now all the required fresh properties of SCC are fully satisfied and the hardened properties of this trail can be comparable with the normal SCC.

Table 3.12 Summary of mix proportion for all trails of SCC.

No	**mix**	**Cement (kg/m^3)**	**LP (kg/m^3)**	**F.A (kg/m^3)**	**C.A (kg/m^3)**	**Water (kg/m^3)**	**S.P (%)**
1	Tail-1	468	-	933	863	193	1.3
2	Tail-2	490	-	1034	850	204	1.8
3	SCC	488	-	1080	804	195	2.1
4	Tail-1withLP	390	98	1080	804	195	2.1
5	Tail-2withLP	390	98	1080	804	195	2.3
6	SCC with LP	413	73	1080	804	195	2.3

By reducing contents of coarse aggregate from 37% to 35% and increasing fine aggregate contents from 40% to 47%, the required results in all the tests i.e., slump flow, V-funnel and L-Box were obtained. Mixes Tail-1, Tail-2, Tail-1with LP and Tail-2 with LP were considered as trial mixes, as these mixes do not fulfill all the fresh properties requirements of the SCC. SCC and SCC with LP are the mixes that satisfy all the fresh properties of SCC and Mix proportions for all trail mixes are given in Table 3.12.

CHAPTER FOUR

4. RESULT AND DISCUSSION

In this chapter, the whole set of test results are combined and analyzed. Some correlations found throughout the project are presented and discussed.

4.1 Fresh concrete test result

4.1.**1 Conventional Concrete**

The fresh property to be measured for the conventional concrete is its workability which is determined by the slump result. Thus, the slump for the first trail of conventional concrete is **85mm** and for the second trial which is the reference mix is **95mm**.

4.1.2 Pure Self Compacting Concrete (SCC)

The main difference between SCC and conventional concrete is on their fresh properties. Using the same material used for conventional concrete, the first trail mix design was performed for SCC and its fresh properties results are shown in table 4.2.

Self- compacting concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC and no single method has been found until date which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Table 4.1, gives the recommended values for different tests given by different researchers for mix to be characterized as SCC mix.

Table 4.1 Recommended values of fresh properties for SCC.

No.	Property	Range
1	Slump flow diameter	500-700mm
2	T_{50cm}	2-5 sec.
3	V-funnel	6-12 sec.
	V-funnel T5min	9-15sec.
4	L-Box(H_2/H_1)	≥ 0.8

- Slump flow test.

The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T_{50cm} is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm.

Figure 4.1 Slump Flow test

- V-funnel test

The flow ability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured. The funnel is filled with concrete and the time taken for it to flow through the apparatus is measured. Further, T_{5min} is also measured with V-funnel, which indicates the tendency for segregation, wherein the funnel can be refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation, the flow time will increase significantly. According to Khayat and Manai, a funnel test flow time less than 6s is recommended for a concrete to be qualified as SCC.

Figure 4.2 V- funnel tests

From the values in table 4.2, the fresh properties of SCC are not satisfied or out of the recommended range except the slump and T_{50cm} value. Therefore, it needs further trial. Since the ingredients of the conventional concrete and SCC should be the same for comparison, the first trial of both the conventional concrete and SCC should be repeated with some modification on the constituent dosage. For the second trial, the maximum coarse aggregate size is changed to 12.5mm, the fine aggregate and high range water reducing admixture content is also increased.

Table 4.2 Fresh properties test result for pure self compacted concrete (SCC)

Mix	**Slump(mm)**	**T_{50cm}**	**V-funnel T^b_f sec.**	**V-funnel (5min)**	**L-box blocking(H2/H1)**
Tail-1	610	4.9	12	35	0
Tail-2	640	3.8	7	21	0.267
SCC	670	2.8	3.93	9.05	0.9

Table 4.2 presents the results of workability tests, conducted to achieve self-compacting concrete. The trials were started at 37 percent volume of total concrete as content of coarse aggregates and 40 percent by volume of concrete as contents of fine aggregates and variation in super plasticizer was carried out to achieve SCC mixes. In case of further trials, the coarse aggregate content and fine aggregate content were varied with further variation in water/cement

ratio. Similarly, different trails were carried out until mix characterizing all the properties of SCC was obtained.

- L-Box test

The passing ability is determined using the L- box test as shown in Fig 4.3. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section is expressed as a proportion of that remaining in the vertical section (H2/H1). This is an indication of passing ability. The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be ≥ 0.8.

Figure 4.3 L-Box test

As shown in table 2.18 the values of test results for the first and second trails do not satisfy the requirements. Because the flow ability of the concrete with V-funnel $_{(5min)}$ is 35sec, and 21sec for Tail-1 and Tail-2 respectively and pass ability L-box blocking ratio 0, 0.267 for Tail-1 and Tail-2 respectively are out of the recommended values. Thus, a third trail was done and all the values obtained are reasonable and satisfy the requirements.

Some of the workability characteristics were obtained in Tail-2, but not all values were within recommended limits. The consistency and workability of Tail-2 satisfied slump flow property but the V-funnel and L-box are not within the range. Thus it needs further trails.

In the 3rd trail, SCC mix has satisfied all the recommended values for its fresh properties and therefore, all the hardened properties of SCC were done based on these results.

4.1.3 Self-Compacting Concrete with limestone powder.

The ability of SCC to flow under its own weight is achieved by trail mix design mainly increasing the paste content and reduces the coarse aggregate contents and sometimes also reduces its size. The increment in the paste will definitely increases its cement content which significantly affects the concrete cost. On the other hand the higher cement content in the concrete the higher the heat released by hydration reaction. This heat of hydration will create a temperature difference between the outer and the inner part of the concrete specially if it is mass concrete and this eventually causes crack.

Therefore, in order to reduce the cost and improve the durability of the concrete, the cement content should be reduced as much as possible by partial replacement with other pozzolanic materials without affecting the concrete quality. In this thesis limestone powder from around Sebeta specific place Geja was used as partial replacement of the cement. Three trails were done with different limestone powder contents and its property were tasted and compared with the pure SCC. In the first and second trail, 20% of the cement content was replaced by LP, with different dosage of super plasticizer and was failed to meet the fresh properties requirements. Finally, 15% replacement of cement by LP satisfied the recommended values with some modification of SP contents and its hardened properties were tasted and compared with pure SCC. The fresh property results for each trial are given in table 4.3

Table 4.3 fresh properties test result for self compacted concrete with limestone powder (SCC)

Mix	**Slump (mm)**	**T_{50cm}**	**V-funnel T^b_f sec.**	**V-funnel (5min)**	**L-box blocking ratio (H2/H1)**
Tail-1 with LP (20%)	590	5.5	14.8	42	0
Tail-2 with LP (20%)	650	4.8	10	17	0.73
SCC with LP (15%)	690	3.2	4.93	8.05	0.93

As it is listed in table 4.3, the first trail was done by 20% replacement of the cement with LP and keeping all the other ingredients constant, and the result shows none of the requirements were satisfied except the slump flow. In the second trail only V-funnel (5min) and L-box blocking ratio (H2/H1) were failed to satisfy the requirements and Finally, a third trail was done by reducing the LP content to 15% and keeping all other components constant. This gives all the fresh property results within the recommended value.

4.2 Hardened Concrete Test Result

4.2.1 Compressive strength

- **Conventional concrete**

The compressive strength of SCC and normally vibrated concrete of similar composition does not differ significantly. But SCC may has a tendency of a higher splitting tensile strength: the reason for this fact is given by the better microstructure, especially the smaller total porosity and the more even pore size distribution within the interfacial transition zone of SCC; further due to the higher content of ultra fines particles a dense cement matrix is present. The compressive strength of both SCC and conventional concrete is done and their average results are tabulated below.

Table 4.4 Compressive strength of conventional concrete for trail-1

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.3	8.3	8.4
Avg. Failure load (KN)	435.9	585.5	632.9
Avg. Compressive strength(Mpa)	**19.7**	**26.0**	**28.1**

Table 4.5Compressive strength of conventional concrete for trail-2

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.3	8.1	8.3
Avg. Failure load (KN)	510.4	609.5	650.2
Avg.Compressive strength(Mpa)	**22.7**	**27.1**	**28.9**

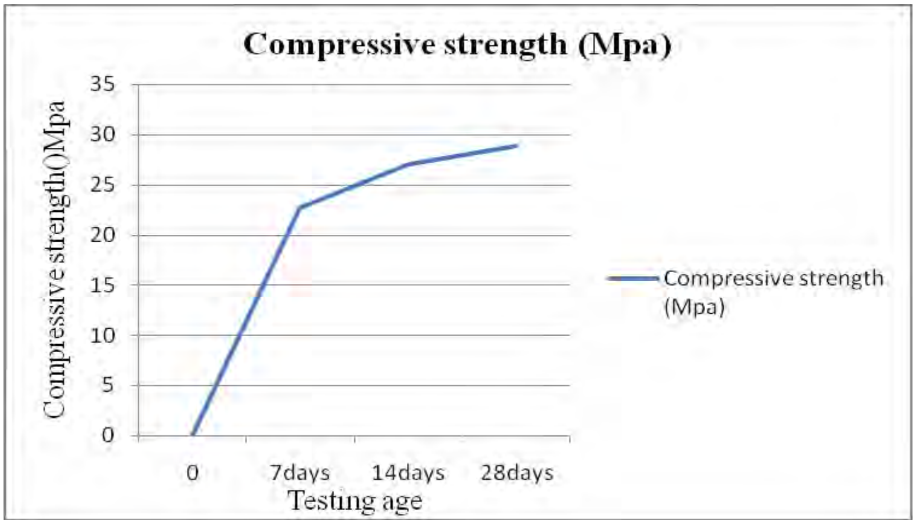

Figure 4.4 Compressive strength of the reference mix (conventional concrete)

- **Pure Self-compacting concrete**

The hardened properties for the SCC was done only for the second and the third trials and the first trail was neglected for its hardened property since it doesn't totally satisfy its fresh property and to reduce research cost by saving the materials.

Table 4.6 Compressive strength of self-compacted concrete for trail-2

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.1	8.2	8.4
Avg. Failure load (KN)	409.2	500.1	560.4
Avg. Compressive strength(Mpa)	**18.2**	**22.2**	**25.9**

Table 4.7 Compressive strength of self-compacted concrete for trail-3(SCC)

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.0	8.0	7.8
Avg. Failure load (KN)	583.9	712.6	719.4
Avg. Compressive strength(Mpa)	**26.0**	**31.7**	**32.0**

Figure 4.5 shows the comparison of compressive strength for the second trial of pure SCC and its third trail. It was observed that the compressive strength of the third trail which fully satisfies the fresh property requirements of the SCC was better at all the testing ages. This indicates that the fresh property of SCC directly influences its hardened property.

- **Self-compacting concrete with limestone powder.**

Table 4.8 Compressive strength of self-compacted concrete with 20% limestone powder

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.1	8.0	8.2
Avg. Failure load (KN)	346.4	409.5	460.6
Avg. Compressive strength(Mpa)	**15.4**	**18.2**	**20.5**

Table 4.9 Compressive strength of self-compacted concrete with15% limestone powder

Types	Age		
	7days	14days	28days
Avg. mass (Kg)	8.2	8.3	8.0
Avg. Failure load (KN)	441.7	500.1	643.4
Avg. Compressive strength(Mpa)	**19.6**	**23.8**	**28.6**

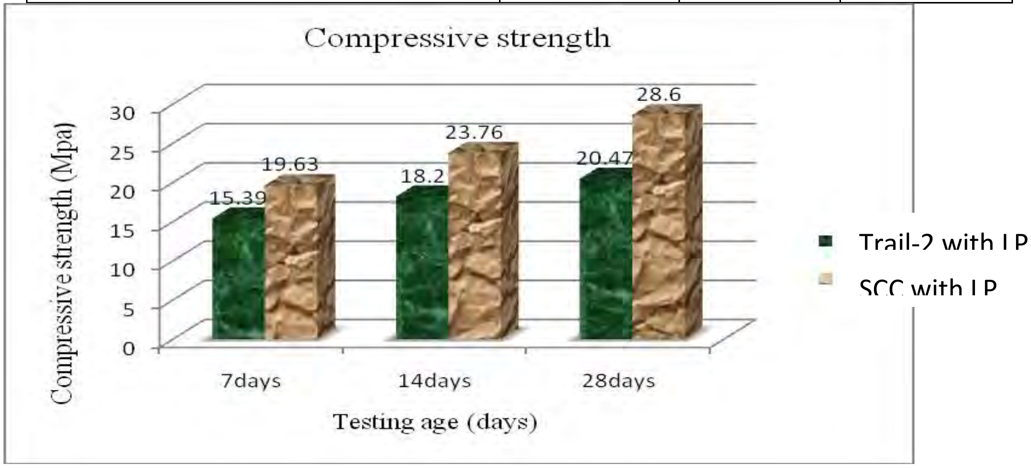

Figure 4.5 Compressive strength of Tail-2 with LP and SCC with LP.

On the above figure, Tail-2 is used to indicate the second trail of SCC with limestone powder and LSCC indicates the self-compacting concrete made with limestone powder replacement which satisfies all the fresh properties requirements of SCC. As it can be seen from figure 4.5, the compressive strength of powder type SCC is influenced by the content of the powder. When the powder content is high the fresh concrete becomes highly viscous and reduces its flow ability which is one of the requirements of the fresh property of SCC. Therefore, this fresh property also affects its hardened property; as a result the compressive strength of powder type SCC with LP content of 15% is greater than that of 20% at all the testing ages.

Summary of compressive strength

As it is shown in all the above tables the mass of conventional concrete and self compacting concrete has no significant difference and similarly the compressive strength of self compacting concrete and the conventional concrete have no significant difference. Table 4.10 shows the average compressive strength of all the samples.

Table 4.10 Summary of compressive strength for all samples.

No	Mix	7days	14days	28days
1	**Conventional concrete**	**22.68**	**27.09**	**28.90**
2	Tail-1	NA	NA	NA
3	Tail-2	18.19	22.23	25.9
4	**SCC**	**25.95**	**31.67**	**31.96**
5	Tail-1 with LP (20%)	NA	NA	NA
6	Tail-2 with LP (20%)	15.39	18.2	20.47
7	**SCC with LP (15%)**	**19.63**	**23.76**	**28.6**

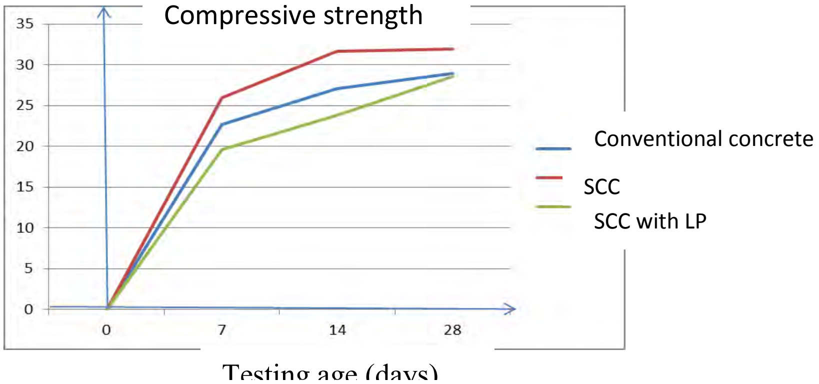

Figure: 4.6 Compressive strength of conventional concrete, SCC and SCC with LP.

From the hardened concrete test result, the compressive strength of conventional concrete at the age of 7, 14 and 28days respectively are 22.9Mpa, 27.1 Map and 28.9Mpa for the second trail which is the reference mix. The compressive strength for the self-compacting concrete is also summarized in table 4.10 above. According to the result the compressive strength of SCC and conventional concrete. has no significant difference and the compressive strength of the powder type SCC was good only if the content of LP is not greater than 15% of the cement content. But figure 4.6 indicates that the long term compressive strength of the powder type SCC may be better than the conventional concrete and cement based SCC.

4.2.2 Durability

Durability is the ability to last a long time without significant deterioration. It is also ability to resist weathering action, chemical attack, abrasion, or any process of deterioration. A durable concrete is one that performs satisfactorily under anticipated exposure conditions during its life span. The material and mix proportions used should be such as to maintain its integrity and, if applicable, to protect embedded metal from corrosion. Even though concrete is a durable material requiring a little or no maintenance in normal environment but when subjected to highly aggressive or hostile environments it has been found to deteriorate resulting in premature failure of structures or reach a state requiring costly repairs. In this research two important properties of hardened concrete were tested and their results are discussed.

I. Compressive strength

To show the effect of sever exposure condition on concrete compressive strength, A cubic sample was cured in salt dissolved water for about 56days and tested for its compressive strength. The salt content used in this case was about 5% of the total water by weight. This is based on the mean salt content of sea water. Accordingly, the following tabulated results were obtained.

Table 4.11 Compressive strength of the samples exposed to dissolved salt.

No	Mix	Average Mass (kg)	Average compressive strength (Mpa)
1	Conventional concrete	8.16	24.86
2	SCC	8.32	30.55
3	Tail-2 with LP (20%)	8.26	21.94
4	SCC with LP (15%)	8.16	30.43

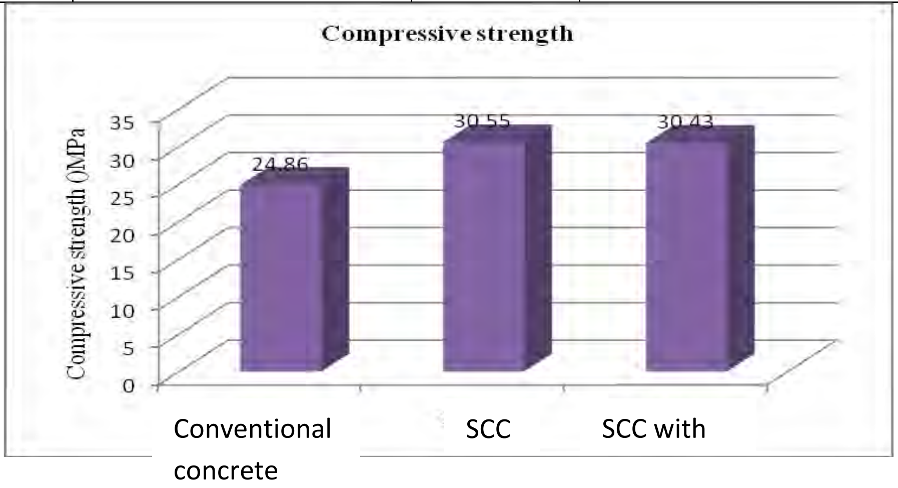

Figure 4.7 Compressive stength of samples exposed to dessolved salt

It is known that the compressive strength of a concrete increases as its age increases. But the above result shows that the compressive strength of Conventional concrete and SCC decreases from its 28day compressive strength result where as the LSCC shows a little bit increases from its 28day results. Therefore, this shows that the self compacting concrete made with limestone powder as partial cement replacement has higher resistance to sever exposure has better durability than the Conventional concrete and pure SCC.

II. Permeability

One of the main characteristics influencing durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide, chloride, sulphate and other potential deleterious substances. A water permeability test were done using all samples and compared with the conventional concrete permeability results. Table 30 below shows the permeability test results of all samples.

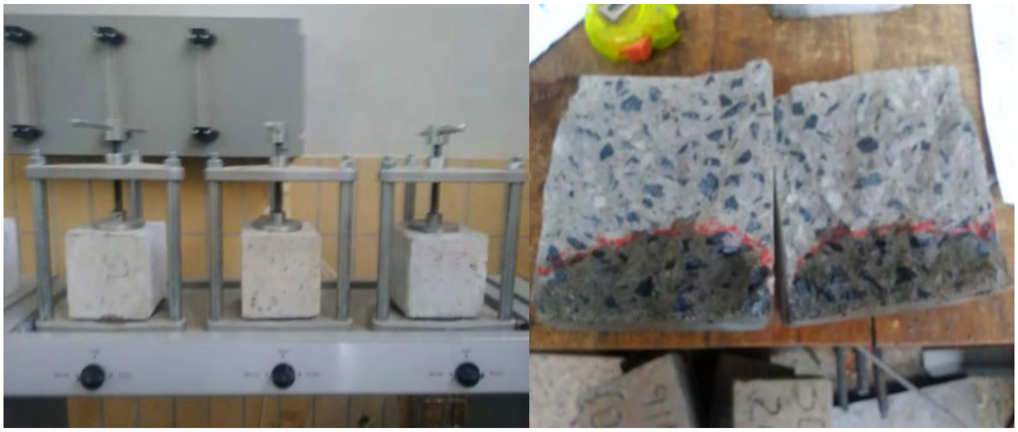

Figure: 4.8 permeability test for the cubes

Table 4.12 Permeability test results for all the samples.

No	Mix	Average penetration depth of water (mm)
1	Conventional concrete.	42.0
2	SCC	32.0
3	Tail-2 with LP (20%)	40.0
4	SCC with LP (15%)	33.0

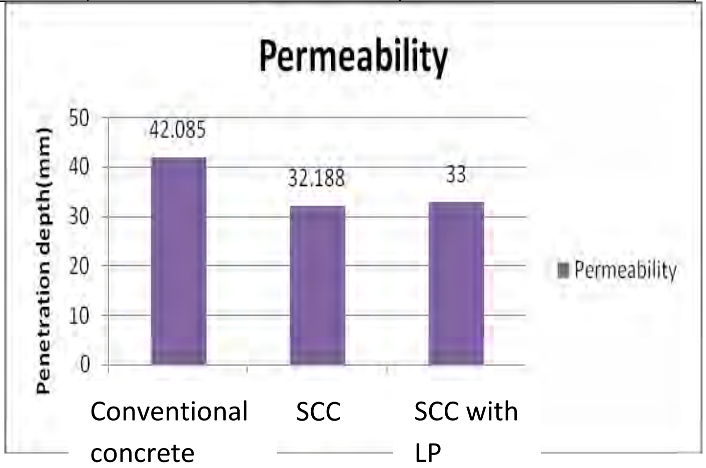

Figure: 4.9 Comparison of permeability for conventional concrete, SCC & SCC with LP

Table 4.12 shows the test result for water permeability of concrete at the age of 56days for all the samples. The result shows the average water penetration depth for SCC and SCC with LP is about 32.0mm and 33.0mm respectively which is almost the same. But the average water penetration depth for the conventional concrete is about 42.0 mm which indicates that it is more permeable than the SCC and LSCC. This means that the hydraulic structure made from self compacting concrete has high durability than conventional concrete. It can also be stated as for determined life span of a hydraulic structure specially dam, it can be achieved with small thickness of the dam by using self compacting concrete as compared to conventional concrete. This significantly reduces the amount of concrete required for the dam and eventually reduces the project cost.

4.3 Dam model

As it was stated in the objective part, the aim of this research is to use self-compacting concrete for dam application in conjunction with preplaced aggregate. Therefore, to show the combined effect of the flowing concrete and the preplaced aggregate, a dam model was prepared and a core samples were taken from the model and some of the hardened concrete properties were tested in the laboratory. The general construction method was used to cast the concrete. That means first the preplaced aggregate with maximum size of 30cm was accumulated at the bottom and the self compacting concrete was poured at different layers. The 15% cement replaced self compacting concrete was used for the model work. The dimension of the model is obtained based on the size of Gibe III dam. Accordingly, the dimension of the dam is shown in figure 4.10 below.

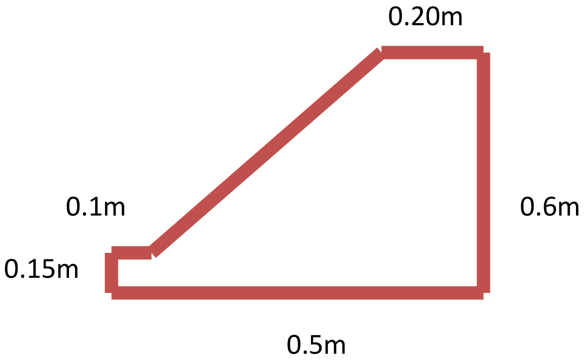

Figure: 4.10 Dam model

After the dam model is well cured for more than 28days about six cylindrical samples were taken after the age of more than 56days and tested for its compressive strength and permeability, since this are the most important hardened concrete properties especially for hydraulic structures like a dam.

Figure: 4.11 the dam prototype and the core point on the dam surface.

Core Sample Test Result and Discussion

To analyze the hardened properties of the dam model, a core samples were taken from the model then its compressive strength and permeability were tested. The aim of this model was to test the core samples for splitting, compressive strength and permeability but unfortunately the larger core drilling machine was broken and the small diameter about 70mm diameter core drilling machine was used. But this sample cannot give the reasonable value for the splitting test, due to its small diameter and only its compressive strength and permeability were tested.

- Compressive strength

From the model about six cylindrical core samples were taken and tested for its compressive strength and permeability. Since sample was broken while smoothing the top and bottom surfaces of the cylindrical samples, the standard dimension were not obtained and this may have its own impact on the result. The result of the compressive strength is given in table 4.13 below.

Figure: 4.12 Core sample and its compressive strength test.

Table 4.13 Compressive strength result for the core samples.

Sample	Dimension(D,H mm)	Failure load (kN)	Cylindrical comp. strength(Mpa)	Cubic comp. strength.(Mpa)
a	70mm, 140mm	47.7	12.4	15.5
b	70mm, 140mm	66.6	17.3	21.6
c	70mm, 140mm	63.5	16.5	20.6
Average				**19.2**

Table 4.13 shows the compressive strength test result for the core samples taken from the model. Its average compressive strength became 19.2Mpa, which is less than that of cement, optimized self compacting concrete. The sample dimensions are less than the standard dimension, but to be conservative, the standard conversion factor was used without considering the effect of its dimension. The reason for this result is may be due to poor quality of the preplaced aggregate, as it can be observed on figure 4.13 the preplaced aggregate part is cracked first, or may be a weak zone created on the joint surface between the self compacting concrete and the preplaced aggregate. But even though, the result of the core sample is less than the self-compacting concrete and the conventional concrete, different literature gives that the value of compressive strength not less than 15Mpa can be used for dam construction since it is not subjected to other

compressive force rather than its own load. Therefore, the value obtained in this result can be implemented for the construction of dam if it satisfies all other requirements.

Figure: 4.13 Compressive strength failure mode of the core sample.

- Permeability

Permeability is one of the most important potential weaknesses in dam construction. Structural weaknesses, such as the surface between the boulders and the self compacting concrete can affect permeability of the dam in this type of construction. In order to study the permeability of this weak zone, a large dam model of dimensions 1.0m by 0.6m by 0.5m was constructed in the laboratory and is shown in Fig.4.10. Since it was difficult to cut the standard specimens from the dam model, as shown in Fig.4.14, cylindrical specimens of dimensions 70mm diameter by 140mm height were taken from the model and its permeability was tested.

Figure: 4.14 permeability test for the core samples.

Table 4.14 Permeability test result for the core sample.

No	Sample	Average Penetration depth (mm)
1	a	40.0
a	b	55.0
3	**Average**	**48.0**

Table 4.14 shows the permeability test result for the core samples taken from the dam model. Three samples were taken for this test and one of the samples was broken while smoothening its surface and the remaining samples were used. The average result of water penetration depth after the samples were set in the permeability machine for three days with about 3bar, 5bar and 7bar pressure respectively is 48.0mm. This shows that the dam model is more permeable than the conventional concrete, SCC and SCC with LP having a value of 42.0mm, 32.0mm and 33.0mm respectively. This is may be due to the weak zone between the self compacting concrete and the preplaced aggregate or the preplaced aggregate may have porous in the surface. As it was visually observed during the test, the moisture penetrates deep on the preplaced aggregate surface than on the concrete parts. But this doesn't mean that this material cannot satisfy the permeability requirements for dam construction, rather it is simply a comparison between the reference materials and that of the model. To decide whether the material satisfies the requirements or not, the code standard of the area should be known to compare it with the result. The 48.0mm penetration depth of the core sample has no big a difference from the conventional concrete which is 42.0mm. If the permeability result doesn't satisfy the requirements it can be used in combination with pure self compacting concrete. That means the upstream and downstream, the part which is exposed to water is constructed by self compacting concrete with small layer of concrete and the remaining part of the dam will be filled by boulders and the concrete. This method significantly reduces the amount of concrete if it is constructed by conventional concrete and has less water permeability than conventional concrete hence, the durability of the dam will also be improved.

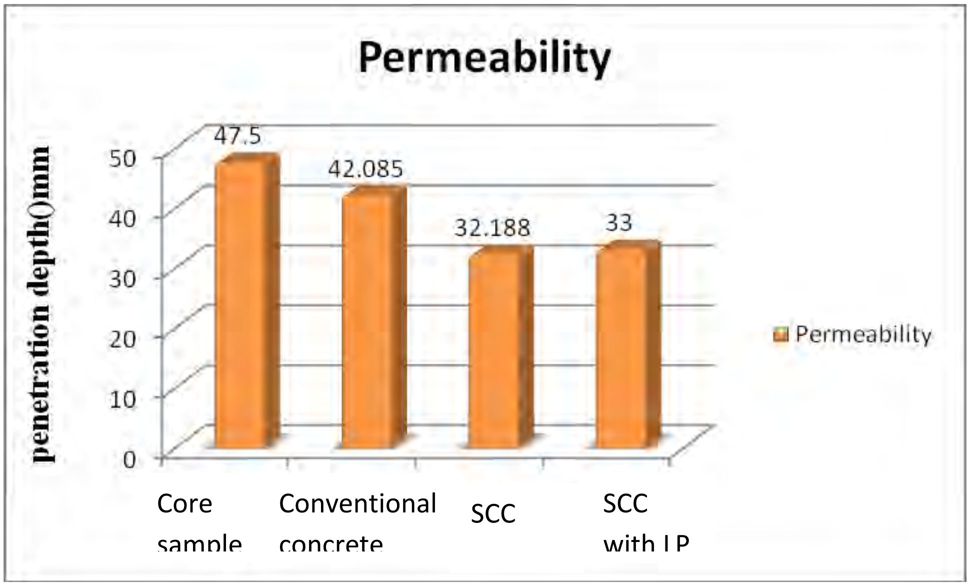

Figure 4.15 Comparison of permeability test result for Conventional concrete, SCC, SCC with LP and core sample.

4.4 Cost Analysis

In any construction project management, the three pillars a manager should consider are the cost, time and quality. But cost is the major factor that influences the implementation of projects. Hence, in order to apply the new alternative construction material in actual work, it needs a cost analysis and comparison with the existing material. The cost of a concrete work mainly consists of the material cost, labor cost and equipment cost. Among this, the material cost covers most of the total concrete costs. Therefore, in this section, only the material cost comparison among the conventional concrete, pure self compacted concrete and cement optimized self compacting concrete was done since the labor and equipment cost needs some assumptions and may deviate from the actual. To Estimate the cost of materials required to produce 1 m3 of C-25 concrete it needs to know actual quantities of the components: cement, water, course aggregate, sand, powder and admixture if any. The dam model prepared in the laboratory is a composite of about 40% powder type SCC and 60% boulders by volume. This significantly reduces the amount of concrete and eventually reduces total project cost

- Materials required and their cost for normally vibrated concrete:-

Table 4.15 Material cost for conventional concrete.

No	type of material	unit	quantity	unit price(ETB)	Amount (ETB)
1	cement	qnt	3.54	235	832.20
2	coarse aggregate	m3	0.53	480	254.40
3	fine aggregate	m3	0.36	380	136.80
4	Water	m3	0.21	1.75	0.40
5	admixture	l	0		0
6	limestone powder	qnt	0		0
	Total				**1223.80**

- Material required and their cost for powder type SCC.

Table 4.16 Material cost for SCC with LP

No	Type of material	Unit	Quantity	Unit price (ETB)	Amount(ETB)
1	cement	qnt	4.13	235	970.55
2	coarse aggregate	m3	0.49	480	235.20
3	fine aggregate	m3	0.45	380	171
4	Water	m3	0.195	1.75	0.35
5	admixture	l	8.95	69	617.55
6	limestone powder	qnt	0.728	115	83.70
	Total				**2078.40**

In this study one of the mixes is produced by replacing cement with limestone powder and the assumption was that this powder may reduce the cost of SCC and enhance the viscosity of the mix and also reduce thermal effects caused by cement hydration.

As is shown in the above two tables, the material cost of the conventional concrete is about 1223.80birr/m3 and the powder type SCC is 2078.40birr/m3 which shows that the material cost of cement replaced SCC is higher than the conventional concrete. This could be due to admixture cost and large powder content required to achieve the fresh properties of SCC.

- Material cost for the dam model.

The dam model is prepared from 40% of cement replaced SCC and 60% of rock blocks and its cost will also consists of the two materials.

- ✓ 40% of LSCC = 0.4(2078.36) = **831.35**birr

The price of the rock block is estimated from the stone masonry: From the quarry site around Addis Ababa a single stone masonry is =6.00birr

The stone masonry dimension is estimated to be 40cmx25cmx15m.

Its volume =0.4x0.25x0.15 =0.015m3 which costs =6.00birr

Cost of 1m3=6.00birr/0.015= 400birr/m3.

- ✓ Since the dam model contains 60% of boulders, its cost =0.6(400) =240birr

Therefore, the material cost of the prototype=240+831.35=**1071.35** birr/m3

The result shows that the cost of the conventional concrete is higher than the composite material, since the cost of the conventional concrete is **1223.80birr/m^3**

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusions

The use of SCC along with preplaced aggregate as alternative construction material for dam construction was studied. Both the fresh and hardened properties of self compacting concrete and the conventional concrete was performed and compared. In addition a limestone powder was used as partial replacement of cement to improve the viscosity of self-compacting concrete and reduce heat of hydration and its cost. Finally a dam prototype was prepared in the laboratory and a core sample was tasted for its hardened properties.

Based on the research result the following conclusions were drawn.

1. The self-compacting concretes were found to be less permeable than the conventional concrete. Here both SCC with powdered limestone and without powdered limestone samples are better than the conventional concrete in resisting water penetration into the concrete. This indicates that if the dam is constructed either by SCC with powdered limestone or without limestone powder, the dam will be more durable than that of the conventional concrete. On the other hand, if we construct the upstream and downstream parts of the dam by a thin layer of only SCC to enhance its water penetration resistance and the main body by the composite material i.e. (the SCC and preplaced aggregate), the durability of the dam will be better than the conventional concrete. The cost could also be reduced, since most of the dam body is filled by the preplaced aggregate which reduces the total volume of SCC.

2. The compressive strength of the core sample of the dam model is less than the conventional concrete and SCC with powdered limestone. But even if, it is less than all samples, its compressive strength is enough for dam structure since dam resists the load coming to it primarily by its weight and shape.

3. As indicated in the objective part one aim of this research is to compare the material cost of the conventional concrete with the new construction material. In this case the new material is the composite of SCC and preplaced aggregate. As it is shown in the cost analysis part, the material cost of conventional concrete is higher than the new material. Therefore, using SCC along with preplaced aggregate will reduce the material cost of a dam by about 40% and enhance its durability.

5.2 Recommendations

Currently the construction industry in Ethiopia is growing fast and consumes huge amount of its annual budget. The reason is that most of the construction materials imported from foreign and less emphasis are given to locally available materials. Therefore, to overcome this problem the use of different alternative construction materials on all of the construction sectors should be investigated based on locally available materials. Based on the investigation made in this research the following recommendations are forwarded.

1. The tensile strength for SCC with powdered limestone and without limestone powder and the model core samples should be conducted to know its resistance against such action.
2. SCC is sensitive to the physical properties and proportions of the ingredients. Therefore, I recommend developing its own sieve gradation standard for SCC.
3. Standard mix design method should be prepared based on locally available materials.
4. The labor and equipment cost of all the samples should be done for a better economic comparison of the materials.

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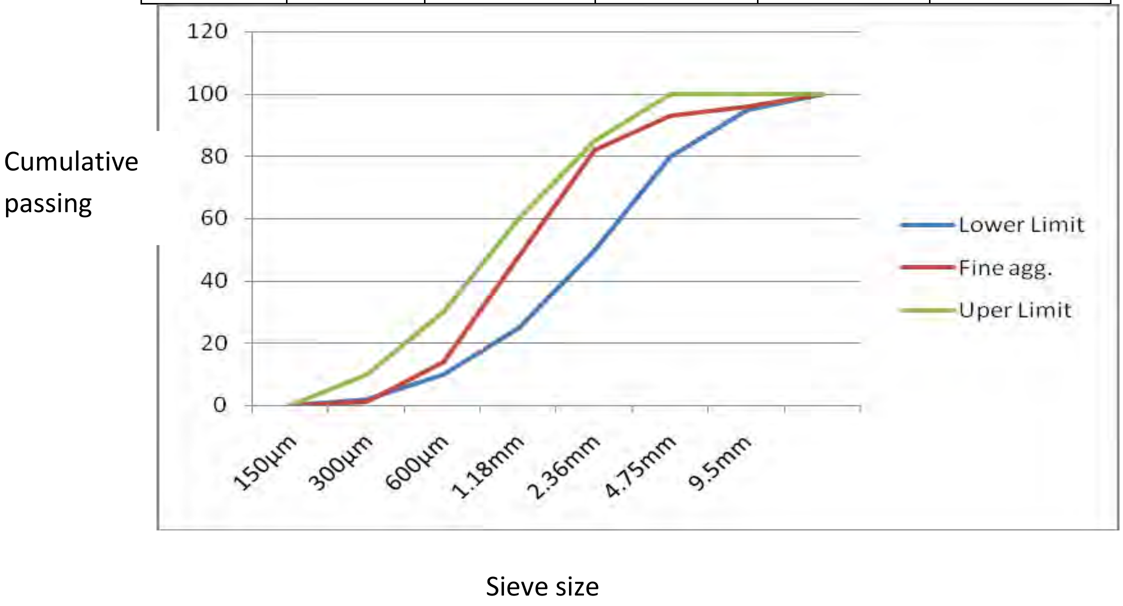
Annex A

Gradation of fine and coarse aggregate

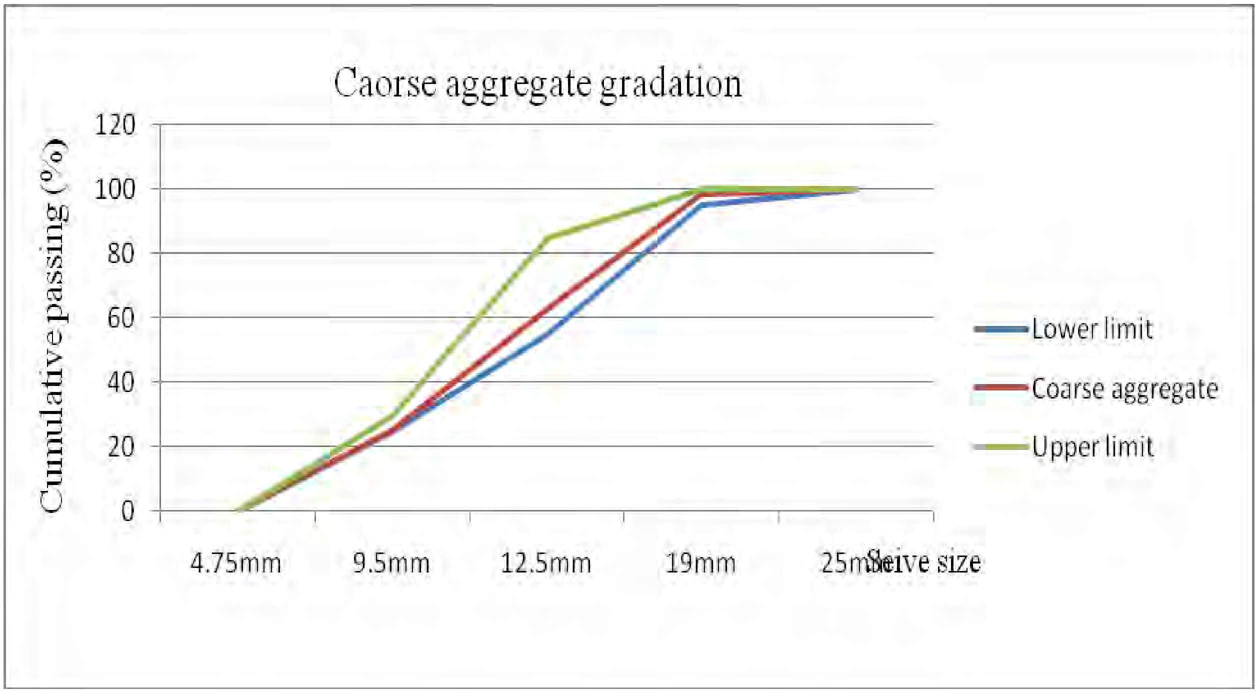
- Gradation of Fine aggregate

Sieve size	Weight of sieve (kg)	Weight of sieve and mass retained (kg)	Weight of mass retained(kg)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	Standard [44]
9.50mm	0.585	-	-	-	-	100	100
4.75mm	0.565	0.585	0.020	4.00	4	96.00	95-100
2.36mm	0.385	0.400	0.015	3.00	7.00	93.00	80-100
1.18mm	0.375	0.430	0.055	11	18.00	82.00	50-85
600µm	0.325	0.495	0.170	34	52.00	48.00	25-60
300 µm	0.300	0.470	0.170	34	86.00	14.00	10-30
150 µm	0.265	0.330	0.065	13	99.00	1.00	2-10
Pan	0.255	0.260	0.005	1.00	99.99	0.01	-
Total	-	-	0.500	FM	3.00		



- Gradation of coarse aggregate

Sieve size	Weight of sieve(gm)	Weight of sieve and mass retained (gm)	Weight of mass retained (gm)	Percentage retained (%)	Cumulative coarser (%)	Cumulative passing (%)	Standard [44]
25mm	1165	0.000	0.000	0.000	0.000	100.000	100.00
19mm	1390	1405	30	1.5	1.5	98.5	95-100
12.5mm	1160	1870	710	35.55	37.05	62.95	-
9.5mm	1165	1935	755	37.80	74.85	25.15	25-55
4.75mm	1175	1649	499	24.99	99.84	0.16	0-10
Pan	735	738	3	0.15	-	-	-
		Total	1997				



Annex B

Compressive Strength of concrete

- Compressive strength of conventional concrete for trail-1

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8126	446.4	19.84
2		150	150	150	8417	432.1	19.20
3		150	150	150	8208	429.11	19.90
Average							**19.65**
1	14	150	150	150	8125	597.20	26.54
2		150	150	150	8231	614.4	27.3
3		150	150	150	8523	544.8	24.21
Average							**26.02**
1	28	150	150	150	8138	654.6	29.09
2		150	150	150	8665	556.8	24.74
3		150	150	150	8330	687.3	30.55
Average							**28.13**

- Compressive strength of conventional concrete for trail-2

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8295	526	23.38
2		150	150	150	8298	499.4	22.20
3		150	150	150	8373	505.7	22.47
Average							**22.68**
1	14	150	150	150	8106	582.2	25.87
2		150	150	150	8135	575.5	25.58
3		150	150	150	8109	670.7	29.51
Average							**27.09**
1	28	150	150	150	8345	636	28.27
2		150	150	150	8371	660.7	29.37
3		150	150	150	8398	654	29.07
Average							**28.90**

- Compressive strength self compacting concrete for trail-2.

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8042	411.70	18.30
2		150	150	150	8140	414.50	18.42
3		150	150	150	7996	401.40	17.84
Average							**18.19**
1	14	150	150	150	8059	501.1	22.29
2		150	150	150	8354	486	21.60
3		150	150	150	8252	513.3	22.81
Average							**22.23**
1	28	150	150	150	8656	593	27.35
2		150	150	150	8434	532.6	23.66
3		150	150	150	8010	555.7	26.70
Average							**25.90**

- Compressive strength of self compacting concrete for trail-3(SCC)

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8062	576.80	25.64
2		150	150	150	7778	553.10	24.58
3		150	150	150	8199	621.80	27.64
Average							**25.95**
1	14	150	150	150	8051	734.20	32.63
2		150	150	150	7859	707.90	31.46
3		150	150	150	7924	695.80	30.92
Average							**31.67**
1	28	150	150	150	7851	840.90	37.37
2		150	150	150	7751	702.80	31.23
3		150	150	150	7834	614.40	27.29
Average							**31.96**

- Compressive strength of powder type self compacting concrete for trail-2

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8123	388.40	17.26
2		150	150	150	8171	313.90	13.95
3		150	150	150	7852	336.96	14.96
Average							**15.39**
1	14	150	150	150	7896	401.20	17.83
2		150	150	150	8137	432.50	19.22
3		150	150	150	7879	394.90	17.55
Average							**18.20**
1	28	150	150	150	8316	459.30	20.41
2		150	150	150	8031	420	18.66
3		150	150	150	8203	502.40	22.33
Average							**20.47**

- Compressive strength of powder type self compacting concrete for trail-3

Specimen No	Test age (days)	Dimension(mm)			Mass (gm)	Failure load (KN)	Compressive strength (Mpa)
		L	W	H			
1	7	150	150	150	8321	445.50	19.80
2		150	150	150	8041	436.60	19.40
3		150	150	150	8045	443.10	19.69
Average							**19.63**
1	14	150	150	150	8198	567.30	25.21
2		150	150	150	8434	476.30	24.73
3		150	150	150	8296	456.80	21.33
Average							**23.76**
1	28	150	150	150	7954	607	26.98
2		150	150	150	7893	665.3	29.57
3		150	150	150	8221	658	29.24
Average							**28.60**

Annex C

Permeability of concrete

- Permeability test result for the conventional concrete.

Spacemen No	Penetration depth (mm)		Average penetration depth(mm)
	Split -A	Split -B	
1	65	35	
	40	60	
	43	30	
Average	**49.0**	**42.0**	**46.0**
2	55	50	
	30	29	
	35	32	
Average	**40**	**37**	**39.0**
Total average			**42mm**

- Permeability test result for the pure self compacting concrete

Spacemen No	Penetration depth (mm)		Average penetration depth(mm)
	Split -A	Split -B	
1	72	74	
	18	26	
	39	38	
	12	16	
Average	**35.0**	**39.0**	**37.0**
2	35	36	
	25	24	

	30	36	
	16	18	
Average	**27.0**	**29.0**	**28.0**
Total average			**32.0mm**

- Permeability test result for the powder type self compacting concrete

Spacemen No	Penetration depth (mm)		Average penetration depth(mm)
1	Split -A	Split -B	
	35	38	
	45	45	
	40	36	
Average	**40.0**	**40.0**	**40.0**
2	40	31	
	12	42	
	30	30	
Average	**27.0**	**34.0**	**31.0**
3	20	18	
	45	45	
	12	30	
Average	**26.0**	**31.0**	**28.0**
Total average			**33.00mm**