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Self Compacting Concrete: An Overview

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Abstract : ***Designing a concrete mix for some particular aspects of durability is relatively simple if a correct choice of the constitute materials is made. Adopting carefully designed concrete mixtures in the actual construction is no guarantee that the structures will be durable up to its designed life cycle. The first obstacle is non-homogeneity of the concrete in various parts of the structures caused by insufficient or lack of vibration due to carelessness of the workers or improper supervision. This report illustrates how a combination type SCC, made with a Viscosity Modifying Admixtures in an aqueous solution may be utillised efficiently for constructing durable structure with readily available local material and labour and present several international projects where SCC has been used with success.Also this report illustrates the study carried out on determination of suitable methods for assessing SCC at site. This work is based on the method for assessment of key properties of SCC like flow, passing ability, filling ability and segregation resistance. Final aim of this work is to decide and proposed a test method, which gives fast and accurate assessment of fresh SCC properties. A combination of Slump-flow test and L-Box test has been found suitable for workability assessment of SCC at job sites.***

Keywords: scc,concrete,slump, test, viscosity,etc

I. INTRODUCTION

Concrete is being used over 150 years. It is mixed, placed into form and then compacted. It is essential to compact the concrete so that it should completely cover the reinforcement and fill all the space in the form for meeting strength and durability requirement. The air entrained in concrete during mixing has to be completely expelled out for getting uniform dense mass. If compaction is not complete, it will lead to loss in strength and also affect performance of the structure. The compaction becomes difficult when percentage of reinforcement is high which does not allow insertion of vibrator at some places. Also the vibration increases noise level in and around construction site. Self-compacting concrete was therefore developed to overcome the problems mentioned above.

Self compacting concrete is defined as a concrete which is capable of self consolidating without any external efforts like vibration, floating, poking etc. The mix is therefore required to have ability of passing, ability of filling and ability of being stable. Concrete is heterogeneous material and the ingredients have various specific gravity values and hence it is difficult to keep them in cohesive form. This is especially true when the consistency is too high. The material having higher specific gravity would like to settle down which makes the mix no more a concrete and it becomes system of sediment layers of concrete ingredients. To overcome this, one can add more amounts of fines and use super-plasticizers. Superplasticizers reduce water demand and at the same time increase fluidity. However, there is chance of bleeding and mix may become sticky. To overcome this problem viscosity-modifying agent (VMA) is required to be added. VMA is a pseudo plastic agent, which thickens the water and keeps the mixture under suspension, providing segregation resistance. The principle of sedimentation velocity is inversely proportional to the viscosity of the floating medium is applied in the system. The VMA offers high shear resistance to the ingredients at rest and less shear resistance at movement and this property keeps the coarser particles under suspension in self-compacting concrete The concept of self-compacting concrete was first introduced in Japan in the early 1990. The concept of self-compacting concrete with high flowing characteristics proved to be a special form of interest in the range of product of High Performance Concrete. Self Compacting Concrete is newly evolved HPC with excellent deformability and segregation resistance. The specialty of SCC is that it can flow through and fill the gaps of reinforcement and corners of molds under its own weight. SCC is a special form of HPC which distinguish itself with consolidation properties with high flowability, SCC as the name signifies should be able to fill occupy and compact itself by its self weight and under gravity. SCC should be able to assume any complicated formwork shapes without any cavities and entrapment of air.

- PERFORMANCE REQUIREMENT OF SCC

Important property of SCC, differentiating it from conventional concrete, is its user-friendly performance in fresh state. The mix flows without segregation and it is able to completely fill the form in spite of dense reinforcement, inserts etc. It is having high de-formability with moderate viscosity, which ensures homogenous dispersion of concrete ingredients and uniform suspension of solid particles during casting and up to setting. It is able to retain fresh concrete properties for longer duration when compared with conventional concrete mix. It offers resistance to bleeding and segregation.

II. INGRADIENTS

Coarse and fine aggregate used for producing self-compacting concrete are the same as those used for conventional concrete. However, a careful consideration is given to the shape and particle size distribution of coarse and fine aggregate. These parameters are of significance in offering mobility as well as stability to the mix. Also the aggregate used should have maximum packing density. The material chosen by Kaiga Project was well-graded crushed granite aggregate having maximum size as 20 mm? The flakiness and elongation indices were 12% and 13% respectively. Table-1 gives the test results on various properties of coarse aggregate used at Job site.

TABLE-1 TEST RESULT OF COARSE AGRREGATE

SR .No.	Description of Test	Results Obtained	Permissible limits (NPCIL specification)
1	Specific Gravity	2.67	2.6 min.
2	Absorption %	0.8	3.0 max
3	Flaky particles%	13.2	15.0 max.
4	Elongated particles%	12.2	15.0 max.
5	Crushing value%	15.3	30.0 max
6	Abrasion value%	15	30.0 max
7	Impact value %	21	30.0 max

Fine aggregate was blend of manufactured sand and river sand in proportion 70% and 30% respectively.

Self-compacting concrete needs high volume of paste to be mobilized and hence, high volume of powder contents passing through 100-micron sieve is required. Generally 170 to 250 liters / cu. m. powder content is required. In order to maintain the cement content to a reasonable level, 35 to 50% of total powder content was replaced by fly-ash. Table-2 gives test results on various properties of fly ash used at Kaiga site.

TABLE-2: TEST RESULT ON PROPERTIES OF FLYASH

SR. No.	Tests	Units	Obtained values	Permissible limits as per IS-3812 Grade-I
1	Physical characteristics	m2		
	i. Fineness – specific surface.	N/mm2	406	320 min
	ii. Lime reactivity Avg. Comp. Str.	N/mm2	6	4.0 min
	iii. Comp. Str. At 28 days.		38.2	< 80% of the plain cement mortar.
2	Chemical characteristics			
	i. Sio2 + Fe2O3 + Al2O3	% by mass	94.2	70.0 min
	ii. Sio2	% by mass	62.1	35.0 min
	iii. Mgo	% by mass	1.08	50 max
	iv. SO3	% by mass	0.5	2.75 max
	v. Alkalis (K2O + Na2O)	% by mass	0.2	1.5 max
	vi. Loss on ignition	% by mass	0.58	12.0 max

The SCC with fly ash exhibited better properties like segregation resistance, almost nil bleeding, lesser dosage of admixture. High range water reducing admixture is essential to get desired flow characteristics and its retention for longer time. Sulphonated Naphthalene based admixture conforming to type-G and Type-F as per ASTM C 494 having approximately 28% water reduction was used. The dosage was ranging from 0.8% to 2% of powder content by weight. Type-F exhibited lesser retention properties whereas Type-G exhibited good retention property. However, with Type-G, setting time got prolonged when used along with viscosity-modified admixture (VMA). In view of this, a tailor made admixture to suit the requirements has been used. If VMA is not used, the mix is very sensitive to a slight variation in moisture content in fine aggregate. Hence, it is necessary to use VMA. Poly-acrylic based VMA was used to reduce the sensitivity of concrete mix to minor variations.

- OPTIMIZATION OF PROPORTION OF INGRADIENTS

To arrive at suitable mix proportion, extensive Otrials were conducted at concrete testing laboratory (CTL) at Kaiga project. Preliminary trials were conducted to establish optimum quantity of coarse aggregate, fine aggregate and water content for different unit powder content in the mix and to arrive at the requirement of high range water reducing admixture and VMA.Just because of very high slump, the concrete doesn't become SCC. The flow of SCC should be with moderate viscosity while remaining as a homogenous mix. Hence, SCC should have optimum unit water content along with optimum dosage of admixture as well as VMA. Increase in unit water content will reduces the viscosity considerably resulting in decrease in de-formability of mixture. Whereas though it gives desired flow but may have an unacceptable mix stability. Most of the coarser particles will remain as a heap at the center of flow table. At the same time decrease in unit water content increases the dosage of admixture, which in turn results in very high viscosity of the mix that fails to pass V-funnel test. It is therefore essential to find out optimum unit water content by trials.Trials were conducted using powder content of 450 Kg/ cu. m. and above in increments of 50 Kg/ cu. m. with varied unit water content along with fixed dosage of admixture and VMA. The results are summarized in the graph given as figure – 1.

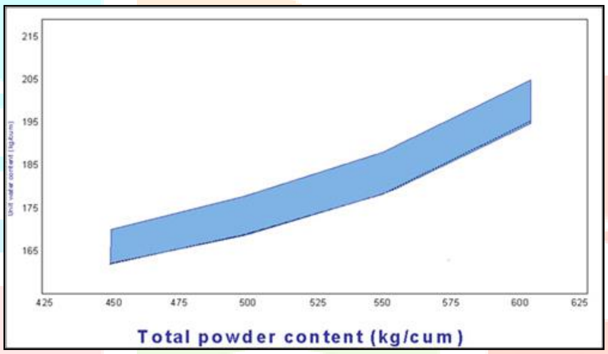

FIGURE 1 - POWDER CONTENT Vs UNIT WATER CONTENT

- **DETERMINATION OF COARSE AND FINE AGRREGATE CONTENT**

De-formability of SCC depends on coarse aggregate content and if coarse aggregate content exceeds certain limit, collision of aggregate particles takes place near obstacle and the passage is blocked, even if the mix is moderately viscous. Hence, coarse aggregate volume is kept within 23% to 32% of solid volume of concrete, depending upon the powder content. Studies were conducted by varying coarse aggregate volume with different powder content and passing ability tests were conducted. Volume of fine aggregate in SCC is comparatively higher than that in conventional concrete. The stability of fresh concrete, which refers to ability of concrete to resist bleeding, sedimentation and segregation, depends on cohesiveness and viscosity of the mix. Hence, special attention is required in selecting fine aggregate volume. Any increase in fine aggregate volume will also lead to blockage mainly because of increase in inter particle friction. Decrease will lead to low mobility. Studies were conducted to get optimum fine aggregate volume with different powder content.The results of studies are summarized in graph given as figure-2.

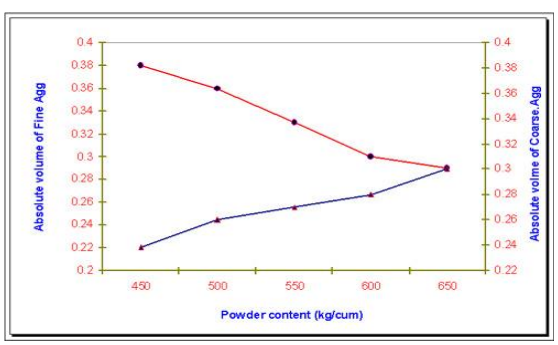

FIGURE 2 - FINE/COARSE AGGREGATE VOLUME Vs. POWDER CONTENT

III. MIX COMPOSITION

Two mixes were arrived at, based on studies conducted to optimize quantities of ingredients of concrete – one with 450 Kg/cu. m. powder content and second with 475 Kg/ cu. m. powder content with replacement of cement by 50% and 36 % of fly ash and 50% of fly ash respectively. Both the mixes have shown acceptable results. However, mix 2 has shown better fluid concrete properties when compared with mix 1. Mix properties are given in table – 3.

TABLE-3: MIX PROPORTION

SR. No.	Material	Mix No. 1	Mix No. 2
1	Cement Kg/m3	300	225
2	Fly ash Kg/m3	175	225
3	Water Kg/m3	165	165
4	Coarse aggregate Kg/m3	730	713
5	Fine aggregate Kg/m3	960	978
6	Naphthalene based HRWR Kg/m3	6.34	5.17
7	Viscosity modifying agent Kg/m3	1.41	1.35

- DESIRED PARAMETERS

SCC is still not covered by any code of practice. However, EFNARC (European Federation Dedicated to Specialist Construction Chemicals of Concrete System) have developed specifications and guidelines for SCC on the basis of work done over 10 years. As per these guidelines, desired parameters are as given in table –4.

TABLE –4: DESIRED PARAMETERS FOR SCC

SR. No.	Test Methods	Units	Minimum	Maximum
1	**Slump flow**	**mm**	**650**	**800**
2	**T50 cm slump flow**	**Sec**	**2**	**5**
3	**“V” funnel**	**Sec**	**6**	**12**
4	**Time increase “V” funnel T5 minute**	**Sec**	**0**	**3**
5	**‘L’ box**	**H2 / h1**	**0.8**	**1**
6	**‘U’ box**	**(h2 - h1) mm**	**0**	**30**
7	**Fill box**	**%**	**90**	**100**

IV. WORKABILITY AND COMPACTION

To illustrate the importance of workability and the degree of compaction, two potentially high quality concrete mixes having a water cement ratio of 0.32 were made. The first mix was without an admixture and it had a very low workability (no slump concrete). The second mix had a superplasticisers and it had a high workability (slump > 200 mm). Two series of concrete specimen were cast from each mix. One set was cast without ssscompaction while, the other was fully compacted. After curing for 28 days, these specimens were tested for their compressive strength. For the stiff consistence mix the difference between the un-compacted and the compacted specimen was considerable (10 MPa against 50 MPa) while for the fluid consistence concrete the difference was relatively small (45 MPa against 50 MPa). This clearly shows the importance of the workability of the fresh concrete and the degree of its compaction. Fig. 1 illustrates this point. Concrete with a high workability reach a good degree of compaction with less effort than a stiff concrete. Therefore, to ensure good compaction and homogeneity of the concrete in the structure, it is advisable to have an adequate workability of the fresh concrete related to the type of compaction equipment available on the site. Inadequate curing also affects its durability in a negative way. High cement contents in the mixture and thick sections can cause thermal cracks and increased shrinkage.

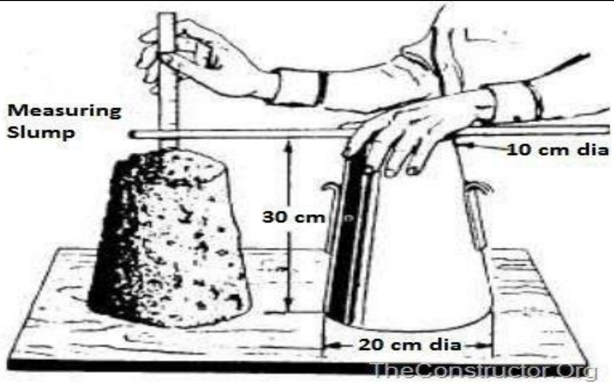

Fig.1: Importance of Compaction on the Quality of Hardened Concrete

Contact with, or the presence of certain chemical in the concrete such as sulphates, chlorides, sulphates, acids, carbon dioxide etc. will also lead to deterioration. Higher ambient temperatures will accelerate the rate of the reaction. Mechanical abrasion or erosion by water or wind will also affect the service life of the structure. These factors may act singly or in combination and the degradation mechanism may be either a physical effect such as shrinkage, creep, expansion, erosion, etc. or a chemical reaction like sulphates attack, carbonation, reinforcement corrosion, alkali silica reaction, etc. The constituent materials of concrete determine its ability to resist certain aggression. Therefore, the choice of good quality materials is of prime importance.

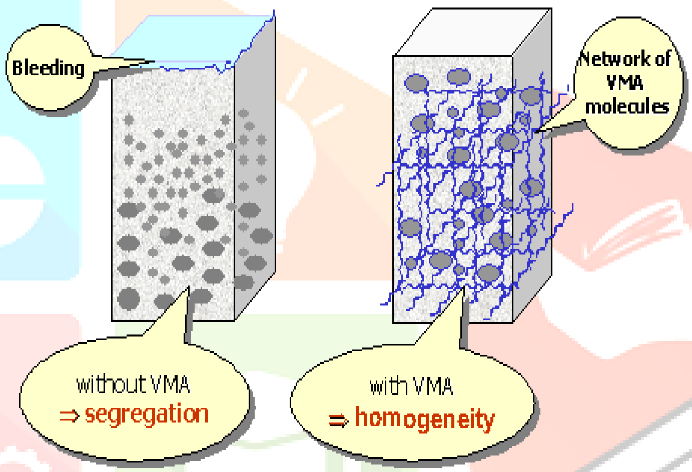

Fig. 2 : Effect of the Viscosity Modifying Admixture on the Stability and Homogeneity of the Concrete

The ionic interactions of the viscosity modifying admixture molecules are flexible and can be partially or completely broken down when a relative low force (shear) is applied. The yield stress is only slightly increased. At normal mixing or placing conditions (moderate shear), the interactions of the viscosity modifier mentioned above, guarantee the homogeneity of the mix and prevent segregation. The balance between the yield stress and the plastic viscosity is the key to the appropriate self-compacting concrete rheology.

V. TEST METHODS AND TESTING TOOLS

Testing methods and testing tools are also different for SCC when compared with conventional concrete. In case of SCC, flow, filling ability, passing ability, segregation resistance etc. are required to be established. Final aim of this work is to decide and propose a test method that gives fast and accurate assessment of fresh SCC properties at site. Hence, new tools are required to be used. The tests conducted are slump flow test and $T_{50\,cm}$ test, V-funnel test, L-box test, U-box test and fill box test. All the required tools were developed at site as per EFNARC (European Federation Delicate to Specialist Construction Chemicals of Concrete System) guidelines.

1. The filling ability test is characterized by Slump flow and V-funnel test.
2. Passing ability is characterized by L-box test, U-box test, Fill-box Test.
3. Segregation resistance is characterized by V- funnel test.

- **Test on hardened concrete**
- Compressive Strength Test
- Split Tensile Strength Test
- Spit cylinder test
- Standard beam test
- Flexural strength test
- Preparation of SCC specimens:
- All the materials are placed in the mixer well
- The sample is then out and poured in the moulds
- The moulds are socked in water & allowed for curing.

1. SLUMP FLOW TEST

Slump flow test and $T_{50\,cm}$ test is used to measure free horizontal flow of SCC on plain surface without obstruction. It gives good assessment of filling ability and some indications on resistance to segregation. Slump cone is kept on flow table and is filled with SCC without tamping. The cone is then lifted vertically without any jerks and concrete is allowed to flow on the flow table. $T_{50\,cm}$. time is the time required for concrete to cover 50 cm diameter spread from the time of lifting of the slump cone. Also the average flow of concrete, after it stops flowing, is measured. Visual observations are also made to note the distribution of aggregate in the total spread. Absence of uniform distribution indicates poor viscosity. Intentional depression created by finger, if not melded after removal of finger indicates either stickiness or segregation

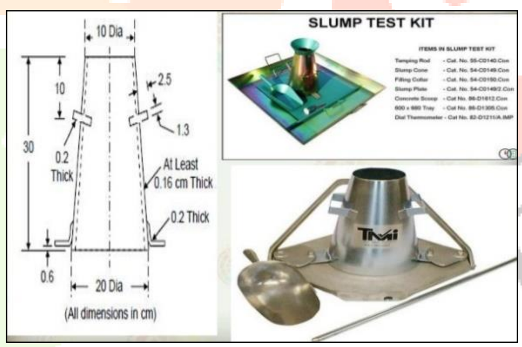

FIGURE.3 - DETAILS OF SLUMP FLOW APPARATUS

- **Expression of results**

Slump for the given sample= _____mm

When the slump test is carried out, following are the shape of the concrete slump that can be observed:

- **True Slump** – True slump is the only slump that can be measured in the test. The measurement is taken between the top of the cone and the top of the concrete after the cone has been removed as shown in figure-1.
- **Zero Slump** – Zero slump is the indication of very low water-cement ratio, which results in dry mixes. These type of concrete is generally used for road construction.
- **Collapsed Slump** – This is an indication that the water-cement ratio is too high, i.e. concrete mix is too wet or it is a high workability mix, for which a slump test is not appropriate.
- **Shear Slump** – The shear slump indicates that the result is incomplete, and concrete to be reteste

2. V-FUNNEL TEST

V-funnel test is designed to assess the flow ability and segregation resistance of SCC. Figure-4 gives details of V-funnel test equipment. It is an inverted cone with 75-mm square opening at the bottom. V-funnel is kept firmly on supporting stand and surface is moisted thoroughly. Sliding gate at the bottom is kept closed. V-funnels are filled up to top by pouring SCC without any external efforts of compacting.

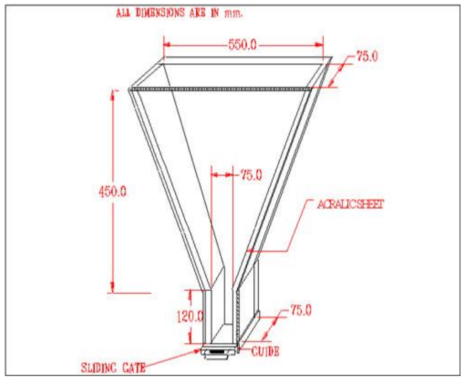

FIGURE 4 - V- FUNNEL TEST EQUIPMENT

Slide gate is opened as quickly as possible without giving any jerk. Time taken to empty the funnel is noted. The test is once again repeated, however, the slide gate is opened five minutes after filling the funnel. Time taken to empty the funnel is once again noted.

- **Expression of results**

The V-funnel flow time *T*V is the period from releasing the gate until first light enters theOpening, expressed to the nearest 0.1 second.

3. L-BOX TEST

L-box test is conducted to assess the filling and passing ability of SCC. Uniformity of the mix is also examined by inspecting section of the concrete in the horizontal portion of the L-box. Figure-5 gives details of L-box. It consists of rectangular box section in the shape of L. Concrete is made to pass through the obstruction of known clearance. L-box is placed on firm ground and internal surface is moisted. Sliding gate is closed. The vertical section of the apparatus is filled with SCC completely without any external efforts to compact.

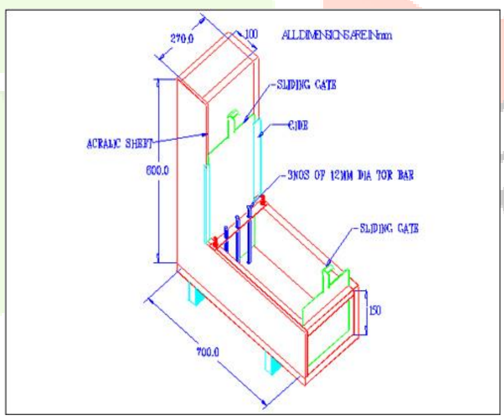

FIGURE 5 - DETAILS OF L-BOX

After waiting for a minute, sliding gate is lifted without any jerks. The horizontal portion of L-box will get filled with concrete from vertical section. Height of concrete at obstruction point as well as at the end point of flow is measured. The ratio of the height at the end point to the height at obstruction gives the blocking ratio.

- **Expression of results**

The passing ratio *P*L or blocking ratio *B*L is calculated using equation (2) or (2’), and Expressed in dimensionless to the nearest 0.01

4.U-BOX TEST

U-box test is conducted to assess filling ability of SCC. Figure – 6 gives details of U-box test apparatus. A middle wall into two compartments divides u-shaped box. An opening with sliding gate is fitted between the two compartments with vertical reinforcement as obstruction through which concrete is made to flow. U-box is placed on firm ground. The internal surface is made moist and central gate is closed

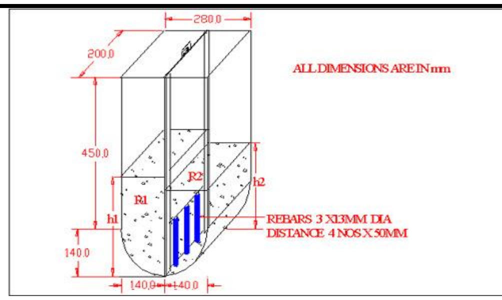

FIGURE 6 - DETAILS OF U-BOX APPARATUS

. Concrete is filled in one limb of U without any external efforts for compaction. The gate is lifted without any jerks after waiting for a minute and concrete is allowed to flow. The height of concrete in each limb of U-box is measured and difference of heights is noted. This indicates self-leveling ability of concrete.

- **Expression of results**

If the concrete flows as freely as water, at rest it will be horizontal, so H1-H2=0. Therefore the nearest this test value, the 'filling height', is to zero, the better the flow and passing ability of the concrete**.**

5. FIIL-BOX TEST

A fill box test is conducted to measure filling ability of SCC in presence of obstacles. Figure-7 gives details of fill box test apparatus. It consists of transparent rectangular box with number of obstacles through which concrete has to flow. The apparatus is placed on firm ground. The SCC is filled in the box through the funnel provided at the topside of the box continuously till the concrete reaches other end of the box through obstacles. The height of concrete at both ends of the box is measured so that volume of concrete filled can be calculated.

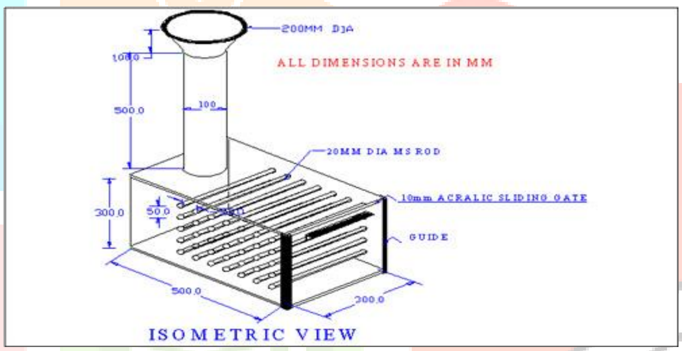

FIGURE 7 - DETAILS OF U-BOX APPARATUS

Net volume of concrete filled is compared with the volume of the box.
Average filling capacity is calculated by
$F=[(h_1+h_2) / 2h_1]\ 100$
Whereas h_1 = Average Height of concrete at pouring end.
h_2 = Average Height of concrete at other end.
This test will also indicate air displacement capacity of SCC

- **Expression of result**

If the concrete flows as freely as water, at rest it will be horizontal, so average filling percentage = 100%. Therefore the nearest this test value, the filling height', is to be 100%, the better self-compacting characteristics of the concrete.

VI. ADVANTAGES AND DISADVANTAGES

- ADVANTAGES OF SCC ARE:

1. **Better progress** – It allows more amount of free fall and also more horizontal distance upto which concrete can flow without segregation.
2**. Better quality** – Manual variable like mechanical compaction is eliminated. It occupies all the spaces in the form without additional efforts. Gives better surface finish, as percentage of fines is more. Durability increases as dense packing leads to relatively impermeable concrete. Heat of hydration is reduced because of addition of pozollonic material. Reduction in number of construction joints is possible.
3. **Safe-working environment** – Skilled personal like vibrator operator and mason for finishing not required. This leads to reduced labour component and thereby reduction in safety hazards.
4**. Environmental friendly** – Noise level at construction site is reduced considerably. Industrial waste like fly ash and GGBS is used which other wise has to be disposed off safely.
5. **Better mouldability** – More innovative structures can be designed because SCC can flow through any shape of formwork.
6. **Economical -** where source of supplementary material is nearby and also economical on account of reduced labour component for vibration and finishing work.

- **Disadvantages of SCC**

1. More precise measurement and monitoring of the constituent materials.
2. Requires more trial batches at laboratory as well as the ready-mixed concrete plants.
3. Costlier than conventional concrete based on concrete material cost (exception to placement cost)
4. Lack of globally accepted test standards and mix designs.
5. More stringent requirements on the selection of materials

- **APPLICATIONS OF SELF COMPACTING CONCRETE**

The use of self-compacting concrete is increasing rapidly all over the world. The earlier well-known examples are from Japan for the construction of the anchor blocks of the 1,991 meters span Akashi-Kaiyo Bridge opened in 1998 and the prestressed concrete outer tanks for LNG storage in Osaka in Japan. Some significant European structures made with self-compacting concrete are presented here.The art and culture centre of Meudon in France is an architectural master piece designed by Jacques Ripault. It consists of a 450 seats auditorium, a stage at a height of 15 m, the main entrance hall and administrative offices. The auditorium has two circular reinforced concrete walls of 15 m height. The internal wall has a radius of 10,7 m and a thickness of 30 cm. The space between the two walls is utilised as a passageway for the audience. The walls were poured in sections u to 20 m length and 8,10 m height. The choice of self-compacting concrete was a winning solution for this 4,26 million Euro project as it eased the placing of concrete and speeded up the project.

Fig. 8 : Construction phase of Centre d'art de Meudon

For the construction of the Commercial centre in Ferrara 29.0000 cubic meters of self-compacting concrete were placed. The works started in January 2002 and ended in October 2002.

VII. CONCLUSION

Self Compacting Concrete has been successfully used in many parts of the world on major job sites. Substantial amount of information on research, development and exploitation has been published. From our experience we can affirm that with the use of the state of the art superplasticisers based on polycarboxylic ethers and a viscosity modifying admixture of a high molecular weight polyelectrolytes with high affinity to water, it is possible to produce reliable self compacting concrete mixes from readily available local materials. Therefore, there is no reason why the benefits of self-compacting concrete cannot be exploited to enhance the durability of the concrete structures.

- Self Compacting Concrete (SCC) technology can save time, cost, enhance quality, durability and moreover it is a green concept.
- Since the concrete is capable of self-consolidating and reaching the difficult areas in moulds, manual variables in terms of placing and compacting concrete is nil. This factor ultimately yields defect less, better-quality concrete structures.
- Cast-in-place concrete construction in tight space and congested reinforcement, such as, drilled shaft, columns and earth retaining systems, can be accelerated by using SCC.

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