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Technical paper:
Self-consolidating concrete columns under concentric compression

Technical paper:
Overview of durability

A look back at 30 years of Fulton Awards

Contents

Front cover photograph: Johann Steyn of MVDxariep Consulting Engineers

CONCRETE SOCIETY
OF SOUTHERN AFRICA

President's Message

The release of this, the second issue of Concrete Beton coincides with the busiest part of the year as everyone gears up for the final few months leading up to the builders' break.

Notwithstanding the maddening race, we hope you will take some time to peruse this edition. It is jam-packed with interesting articles, technical papers, branch activity reports, useful hints and so forth.

In this edition our technical paper is one sourced from the American Concrete Institute and deals with the behavior of self compacting concrete columns under concentric loading. As self compacting concrete has recently become a noteworthy topic and since we are planning a seminar on the subject for early next year, the inclusion of this particular paper should rouse interest.

We have again included one of the papers of the highly esteemed Durability Seminar. This issue includes Brian Perry of the C&CI's seminar paper entitled "Overview of Durability".

Steve Crosswell of PPC's concrete tips 6 & 7 dealing with testing and quality control of concrete complement the high technical quality of our publication. Our feature article deals with the technical aspects of concrete reservoir systems and poses very interesting reading.

Again the branches have been very busy in the last few months and all indications are that this activity will escalate. The branch chatter sections are full of reports depicting the various exciting events that have recently occurred. A quick reference to the branch event diaries at the end of this issue will give an idea of what is still to come. A particularly noteworthy event to watch out for is the Inland Branch's very popular boat races, schedules for Saturday, 13 September 2008 from 07:30 to 14:30 at Victoria Lake, Germiston. Over the last few years this event has grown to become something extraordinary with many industry participants vying for involvement. This year's races promises to be even larger than the previous and we urge all Society members to attend, even if not to compete. Please visit the Society's website for more information.

We are proud to welcome Natasja Pols as the new Senior Administrator. We also report the process of sourcing a new administrative assistant whom we wish to employ in the near future. In the longer term, as many of you are aware, we are intent on appointing a director as well. This all being part of our reconfigured administrative function necessary for the Society to become a resource efficient and highly effective entity.

We also draw your attention to the fact that the "Call for Nominations" for the Fulton Awards 2009 is already open. You may have already observed this by advertisements placed in various media. Please study the announcement in this issue and contact the head office for further details and entry packs.

The Society wishes you well for the extremely busy time ahead and trusts to see many of you at the various events scheduled.

Yours faithfully

Francois Bain Pr. Eng
President

CONCRETE SOCIETY
OF SOUTHERN AFRICA

(Incorporated Association not for gain registered in terms of Section 21 of the Companies Act) Registration number 1996/09468/08

MISSION

To promote excellence and innovation in the use of concrete and to provide a forum for networking and for the sharing of knowledge and information on concrete.

VISION

To be the most relevant forum for all who have an interest in concrete and to promote the concrete related services of the society members.

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A look back at 30 years of Fulton Awards

With the celebration of the 2009 Fulton Awards, 30 years will have passed since the series began in 1979, as a tribute to Dr Sandy Fulton for his outstanding contribution to the basic understanding of concrete, its improvement and development. Sandy Fulton was unquestionable one of the doyens of the international concrete industry. His contributions to the construction industry in general and to concrete technology in particular are, to say the least, impressive.

In essence, through the Fulton Awards, the Concrete Society is recognizing and rewarding "excellence and innovation in the use of concrete", the promotion of which is the core component of the Society's Mission Statement. It is important to keep in mind the fact that the Fulton Award is made for the structure and not individuals. It is presented to the entire team that is responsible for producing the structure, including the owner/developer, all professionals and contractors.

The year stated in the title of the Fulton Award has often led to confusion. Naturally as the years have passed, the rules have become somewhat more complex, but essentially to qualify for consideration, the structure/project must be constructed substantially in concrete, within Southern Africa and should have been substantially completed during the 12 months proceeding the submission date, which is generally at the end of the year. Because of this, the year in which the structure was essentially completed was included in the name, but the award would only be presented in the subsequent year. This system prevailed until 1994, when the 1993 Fulton Awards were presented.

In the following year, 1995, it was decided to remove the potential for confusion and entitle the awards in terms of the year of the award presentation. And so the next award was the 1995 Fulton Award made in 1995, but the rule for essential completion in the previous year still applied. Although there was no break in the series, strictly speaking, there was no 1994 Fulton Award. The awards continued on an annual basis until 1999, where after due to funding constraints, they were held biennially on the odd years, alternating with the Concrete Masonry Awards. A tabulated list of all the Fulton Awards together with some interesting information is provided below.

2007 Building Projects Winner: Athlone Soccer Stadium East Stand.

The inaugural award, the 1979 Fulton Award went to the Public Library in Sasolburg. There were commendations for two projects: Matla Power Station and Maalgat River Bridge. Certificates were presented to representatives of the firms associated with each project at a banquet held after the AGM on Tuesday 4th March 1980 at The Wanderers Club in Johannesburg. A concrete plaque with bronze toned pigmentation was unveiled by the Sasolburg Mayor in a ceremony on 4th June at the library building. The ceremony was attended by Sasolburg Councillors, CSSA Exco members and the judges and it was given television coverage on the program "Portfolio".

Subsequent Fulton Awards were made in two categories, namely Civil Engineering Structures and Building Structures. An added feature, introduced at the third award ceremony, that of the 1981 Fulton Awards held in May 1982, at the suggestion of the then current president, Chris Thompson, was the inclusion of a Fulton Memorial Address to be delivered by an eminent guest speaker. The first Fulton Memorial Speaker was Dr Derek Davis, Executive Director of PCI. Thereafter the

2007 Aesthetic Appeal Winner:
Bosmandam Road Pedestrian Bridge.

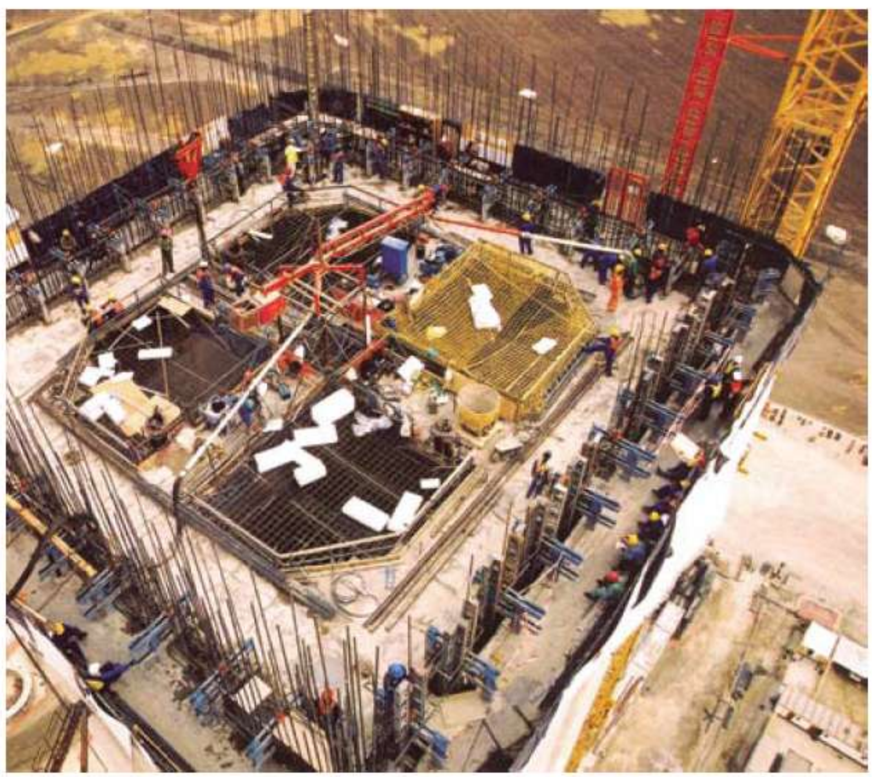
2007 Construction Techniques Winner: Durban Harbour Services Tunnel.

Fulton Memorial Address was entrenched in the Fulton program and from 1983 onwards; a high profile speaker was invited from overseas each year, beginning with Stewart Watson from the USA, who delivered an outstanding address illustrated with over 200 slides of amazing bridge structures around the world and spanning the ages. Unfortunately the opportunity to benefit from international input at these Memorial Addresses was lost between 1998 and 2005, during which time, due to funding constraints, the Society was forced to restrict its invitations to eminent local speakers. It was indeed gratifying to return to the old tradition in 2007, when Ian Booth, CEO of the Concrete Institute of Australia, accepted the invitation to deliver the Fulton Memorial Address at the Awards Ceremony.

In an attempt to bring together the artist and the designer, owner or developer in such a way as to enhance the environment, a third category, Sculptures, was introduced in the 1990 Fulton Awards. There were 10 entries in this category and the award went to "Untitled Relief Panels" owned by Hans Bilgeri and a special Environmental Sculpture Category Award went to the "Harmony Tidal Pool" of the Strand Municipality. Unfortunately this category only lasted four years and due to insufficient interest demonstrated by lack of entries, it fell away in the 1995 Awards.

Another unique feature that was introduced in the same year as the original Fulton Memorial Address was the practice of not divulging the winning projects until the night of the Fulton Awards ceremony. This certainly added an air of anticipation in the build-up to the big night each year. In 1985 it was decided to publish a special Fulton Award Edition of Concrete Beton in which all the entries for the 1984 Fulton Awards were show-cased. Furthermore it was handed out at the Fulton Awards gala function immediately after the announcement of the winners. This concept proved to be highly successful, attracting plenty of sponsorship and has been continued ever since. The bar was raised in 2007, when the CSSA Council decided to elevate the awards ceremony to a prestigious weekend event, held at one of the country's premier resorts, the Champagne Sports Resort in the Drakensberg. This highly successful event, designed not only to celebrate the winners, but also to showcase all the entries in a special exhibition and to treat all attendees to an unforgettable Fulton Awards extravaganza, attracted record attendance, including many "captains" of the construction industry.

In the 1999 Awards, in order to provide opportunity for the recognition of aspects of projects that had achieved excellence, but may well have been overshadowed by large projects with an overall display of excellence such as The "Katze Dam", which incidentally won the Civil Engineering Structure Award in the 1998, it was decided to introduce three new categories to supplement the main Civil Engineering Structures and Building Structures categories.



2007 Civil Engineering Winner: Impala Platinum No 16 Shaft.

And so the categories: Aesthetic Appeal, Design Concepts and Construction Techniques, were established. The first winners in these categories in the 1999 Fulton Awards were "Driekoppies Dam" for Aesthetic Appeal, "Post-tensioned Precast Concrete Reservoirs, Jeppe's Reef Region" for Design Concepts and "Majuba Power Station Cooling Tower Shells" for Construction Techniques. These categories attract considerable interest and continue to be included in the Awards today.

A further notable feature of the Fulton Awards is the judging process. Each year of the Fulton Awards, the Society's president invites the presidents of the institutes of Civil Engineering and Architecture of South Africa to join him in adjudicating the Fulton entries. It is traditional, as far as is practically possible, for all three judges to visit the site of each submission in order to evaluate it. As there is no prescribed method of adjudication, each group of judges determines its own adjudication system, which somehow brings a special sense of uniqueness to each Award. They naturally consider factors such as functional suitability, appearance and harmony with the surroundings, design in relation to the properties of concrete, ease of construction, quality of workmanship and finishes as well as financial constraints and the controls exercised during the project.

Fulton Awards are not only held in high esteem locally, but are also recognized internationally as is borne out by the inclusion of a number of Fulton Award structures in the American Concrete Institutes most recent illustrated publication, "Concrete: A Pictorial Celebration", which show-cases some of the most prestigious structures around the world.

Having been privileged to be involved in the adjudication of two Fulton Awards over the years, I learnt that selecting the "best" from amongst the "excellent" was no easy task. I also realised that in the Fulton Awards, we do not have winners and losers, we only have winners. Because even in the act of entering and justifying the entry, something happens to the status and morale of those concerned with the entry; there is an urge to do even better next time, instilling pride in one's work and finally realizing that teamwork is fundamental to major achievement.

2007 Design Aspects Winner: Mkomaas River Pedestrian Bridge.

Peter Flower
Past President – 1998, 2002 & 2003

** See inside back cover of this edition for a detailed table of Fulton Award winners dating back to 1980.*

CONCRETE CHATTER :

Cape branches visit World Cup Soccer Stadiums

Eastern Cape

The CSSA – Eastern Cape Branch has been steadily increasing its activity within the region. Two further members have joined the branch committee, these being Tseli Mahiele and Forbes Kamba. The current committee has an excellent balance and it represents the industry as a whole. Currently professionals, consultants, suppliers and contractors are represented on the committee.

The committee has spent a great deal of time in organizing relevant and worthwhile site visits and technical discussions. All site visits will be accompanied by technical discussions which will be aimed at addressing the needs of professionals, suppliers and contractors. Recently the branch has embarked on inviting other professionals in the industry to our events so that they also benefit from the discussions and so that everyone can learn together. The result has been that architects and quantity surveyors now also form part of the target group for branch events and discussions.

A major development in the region in August was the distribution of the first newsletter that focuses on local news, events and issues. The aim of the newsletter has been to showcase local projects, local issues and local successes. The branch aims for the newsletter to be a platform for all parties involved in the industry to communicate with each other and learn from each other.

During May the CSSA – Eastern Cape branch arranged a site visit and discussion onto Shukuma Flooring. This visit proved very successful and involved understanding the technical aspects of pre-stressed flooring as well as the benefits of using the system.

Further events confirmed include a visit to the Radisson Hotel (18 storey building). A number of unconfirmed visits are also in the offering and we hope to firm up dates and venues for these shortly. Planning for 2009 has already begun.

The branch committee has also grown in numbers to include the following individuals:

Chairperson - Nick van den Berg; Vice Chairperson - Shaun Hayes; Secretary - Carmen Alting;

Immediate Past Chairperson - Louis Visser; Members - Fanie Smith; Kate Routledge; Tseli Maliehe (new) and Forbes Kamba (new).

SHUKUMA PRESTRESSED FLOORING (10th July 2008) – REPORT

The CSSA (Eastern Cape Branch) held a highly successful site visit and technical discussion on 10th July 2008 at the factory premises of Shukuma Prestress Flooring, attended by over 40 people. Attendees consisted of consulting engineers, architects and suppliers and afforded all an chance to learn more about prestress flooring, what it is, why it can be successfully considered as a flooring option and what the benefits are to using this option.

The CSSA wishes to thank Shukuma Flooring, and Andries Stucki in particular, for sponsoring the event and delivering the presentation (the snacks and drinks were very much appreciated by all). This being the second event this year arranged by the new council we were very encouraged by the support and look forward to producing some more events which are relevant to all in the industry.

The CSSA also wishes to thank all who contributed by filling in their feedback forms since this provides valuable information for us in terms of arranging and benchmarking future events. The results of the feedback will be place on the CSSA Eastern Cape website in due course.

COEGA HARBOUR SITE VISIT (2nd September 2008) – REPORT

The CSSA (Eastern Cape Branch) held a site visit and discussion at the Coega Harbour on 2nd

September 2008, hosted and presented by Transnet. Although attendance at this event was limited to 30 people, over 70 people applied for inclusion on the attendance list. Unfortunately not all could be accommodated and a second visit is being sought. Once again attendees consisted of consulting engineers, architects and suppliers and afforded all a chance to learn more about what is going on at Coega as well as what their future plans are.

The CSSA wishes to thank Transnet, and Gerrit du Plessis and Fazeel Christian in particular, for sponsoring the event and delivering the presentation (the snacks and drinks were very much appreciated by all). Furthermore we wish to thank Renee de Klerk for her contribution on the environmental issues. We want to thank those who attended as well as those who expressed interest but were not able to attend since your support and interest has been very encouraging.

The CSSA also wishes to thank all who contributed by filling in their feedback forms since this provides valuable information for us in terms of arranging and benchmarking future events. The results of the feedback will be place on the CSSA Eastern Cape website once we have it up and running.

UPCOMING EVENTS

On 6th November there will be a Wiehahn presentation and technical discussion sponsored by Wiehahn.
On 25th November there will be Coega bridge site visit and technical discussion sponsored by Newport Construction.
On 4th December and 22nd January there will be a social get together organised by the branch committee.
The Eastern Cape Branch AGM is scheduled for 19th February and this will be sponsored by the CSSA.

KwaZulu-Natal Branch

EVENTS

On 20th November the CSSA KwaZulu-Natal Branch will be organising a visit to the Braamhoek Power Station.
The branch has also has plans to organise site visits to both the new Durban Airport in La Mercy and the King Senzangakhona Soccer Stadium, but dates have yet to be confirmed.
The branch's AGM is scheduled for 9th March 2009.

Western Cape Branch

SITE VISIT TO CAPE TOWN INTERNATIONAL AIRPORT

On 17th July the CSSA Western Cape Branch were invited to visit the Cape Town International Airport site by the Grinaker-LTA / Stocks Joint Venture.

The weather played ball and in between some rather cold and wet days the 17th July was quite pleasant. About 45 members and six guests were present.

After a brief safety induction, Rodney Dicks of KFD Wilkinson gave an overview of the project. It is basically a complete revamp of the domestic arrival and departure terminals and associated infrastructure, including a complete new baggage handling system and an elevated roadway which will separate arrival and departure motor traffic.

Johan Brink of the joint venture briefed members and visitors on the specific project challenges. Completely rebuilding a very busy facility without disrupting any airport operations is quite a task!

The dolosse yard at the Coega project. The CSSA – Eastern Cape Branch visited the project on the 2nd of September.

An overall view of the latest developments at the Coega project in the Eastern Cape.

Brink then escorted members on a tour of the impressive works and he and Mr. George Falk answered various questions along the way. The excellent quality of the concrete structure and the vastness of the open spaces impressed all present.

After the walk about members and guests were joined by some of the JV staff and all enjoyed a wonderful spit braai, kindly sponsored by Formscaff, the major form work subcontractors.

The branch thanks GLTA/Stocks, KFD Wilkinson and KTW for refreshments and especially to Formscaff for a great meal.

SITE VISIT TO GREENPOINT STADIUM

This site visit on 15th May followed a highly successful visit to the Green Point Stadium in April, but this time focused on the detailed aspects involved with constructing the seating beams. The seating units are being precast from reinforced concrete by the joint venture between Cape Concrete and Concrete Units.

Representative of the engineering design team, Henry Fagan and Margaret Collins, presented the geometric challenges posed by the stadium. Details of the complicated curved layout of the stadium, both in plan and vertically, were emphasized – resulting in an extensive range of seating units to accommodate the geometric variances.

The site visit was hosted by Concrete Units and presented a unique opportunity to witness the various construction, storage and handling complexities of the concrete seating elements.

Representative of the engineering design team, Henry Fagan and Margaret Collins, presented the geometric challenges posed by the stadium. Details of the complicated curved layout of the stadium, both in plan and vertically, were emphasized – resulting in an extensive range of seating units to accommodate the geometric variances.

Particularly noteworthy observations of the construction operations were:

- Fully adjustable formwork system
- Reinforcing steel layout, placement and verification procedures
- Concrete casting, finishing and curing methods
- Concrete lifting apparatus
- Three point storage and stacking of the newly completed units until concrete gains sufficient strength
- Rotation of the units for transport and site installation

A site braai with refreshments, sponsored by BASF Construction Chemicals, Concrete Units, Chryso and Megamix, followed the site visit.

Inland Branch

The CSSA Inland Branch held a mini-seminar recently on 'Concrete in Piles'. The event was attended by more than 60 members and guests from all sectors of the construction industry who were formally welcomed by the Chairman of the Inland Branch, Trevor Sawyer. Guest speakers at the seminar were Peter Day of Jones and Wagener, Gavin Byrne of Franki Africa and George Evans from Grinaker-LTA.

First to present was Peter Day and he began by outlining the objectives of specific research that has been carried into concrete piling which were:

To establish - the effect of free fall placement on segregation and strength of concrete; the influence of hole cleaning; what happens to spoil during concrete placement.

He continued by describing current industry practice relating to concrete specifications; cleaning of holes; placement of the concrete; code requirements and frequent gripes. The research work was outlined in some detail, followed by the findings covering the effects of water presence on strength, density, voids and aggregate/cement ratio. The effects of spoil and pouring through rebar were also covered.

Conclusions reached from the research were:

- Free fall placement in dry holes has no effect on concrete quality
- Free fall into 50 mm of water reduced strength at toe by 10%
- Water depths greater than 100mm significantly reduced concrete strength
- No segregation evident except when concrete is discharged slowly (insufficient energy)
- 50mm of spoil can negate end bearing
- Wet spoil is more easily displaced by the concrete
- Effect on concrete strength is more related to water in the hole

The excellent quality of the concrete structure and the vastness of the open spaces impressed all present at the CSSA Western Cape branch Cape Town International Airport site visit.

Substantial progress has been made with the new terminal development at CTIA known as 'Terminal 2010', which is scheduled for completion by the end of 2009. The terminal will cost in the region R1-billion to build.

than spoil

Gavin Byrne was next to present and he provided members with a comprehensive overview of:

Pile types for dry conditions - auger piles, DCIS piles, driven tube piles (bottom), forum bored piles, rotapiles, oscillator piles and CFA and displacement screwpiles with pumped concrete.

Pile types for submerged conditions - auger piles (cased), auger underslurry piles, oscillator piles, tube piles (top driven) and rotapiles.

Methods of concrete placing in both dry and submerged conditions

Structural design of reinforced concrete piles

Working load pile shaft stresses for in-situ concrete

Typical defects in cast in-situ pile shafts - washing out of binder after concrete placement; inclusions of soil / bentonite in pile shaft; discontinuity of pile shaft concrete and contamination of concrete with water.

Method of integrity testing - impact frequency, sonic logging, and rotary coring

George Evans focused very much more on the concrete technology and concreting requirements of concrete piles and stated that the challenge was to transfer the science of concrete technology into concrete structures. If the quality of the concrete is not adequately controlled, the ultimate performance of the pile is at risk.

"Poor placement and inadequate consolidation of concrete are the biggest contributors to poor concrete in structures", he said.

The presentation included details of the requirements of placing the concrete; compaction, or consolidation of the concrete; and meeting the challenge in terms of achieving a concrete with adequate workability, minimum segregation and optimum density. Cements, extenders and additions were covered with reference to cement type, slag, pulverised fuel ash, silica fume, milled limestone and metakaolin.

As part of the preparation for the talk the speaker had consulted an internet forum and he quoted some of the thoughts and ideas on concrete piling that had been submitted.

In conclusion, and prior to refreshments provided by Ash Resources, the organiser of the event, committee member Hanlie Turner formally thanked the speakers for giving of their valuable time to present very interesting and informative papers.

VISIT TO FNB STADIUM (SOCCER CITY)

More than 20 members attended a site visit recently organised by the Inland Branch of the Concrete Society to the construction site of the FNB Stadium (Soccer City) south west of Johannesburg.

The tour began with an overview of the project given my Mike Moody, Project Director from Grinaker-LTA. He explained that the construction was being carried out by a joint venture between Grinaker-LTA (50% Building and 50% Civil) and Interbeton. The client is the City of Johannesburg.

Visitors were shown the original design which was tabled as part of the South African bid for the Soccer World Cup 2010, and the subsequent changes to this after South Africa had been chosen to host the event. The final design mirrors the shape of an African bowl.

Key statistics of the project were outlined which included:

Current project cost - R2,6-billion; 70 000 m3 of concrete; 1 200 piles; 8,5 million bricks and a scheduled completion date of April 2009.

Details of the use of self compacting concrete (SCC) for the project were described by George Evans, also of Grinaker-LTA, although the concrete itself was produced by W G Wearne. Focus centred on the eccentric columns surrounding the stadium which are to support the final shell of the structure. The challenge was to get the concrete to flow and consolidate with 860 kg per m3 of reinforcing steel present (see photos below).

Evans went on to explain the differences between high slump concrete, self levelling concrete and self compacting concrete. He explained why only self compacting concrete could have achieved the results that were obtained, and paid tribute to W G Wearne for the excellent results achieved.

The advantages of using SCC on site were cited:

- Consistent production, supply and performance
- Consistent consolidation and off shutter finish
- Reduced variablilty
- Improved construction joints
- Extended workability of the concrete
- High early strength

The party was then given a guided tour of the site which was very impressive in terms of the logistics, layout, scale and the progress made to date. Thanks to Grinaker-LTA/Interbeton joint venture for being gracious hosts and for allowing our members to visit their site.

Drinks and snacks were served at the end of the tour by courtesy of Sika South Africa.

UPCOMING EVENTS

On 6th November there will be a branch committee meeting held at the C&CI premises in Midrand.

On 7th November there will be a Chairman's Breakfast with a guest

Sika sponsors Soccer Stadium visit

Greenpoint Stadium was the location for a recent site visit co-sponsored by Sika S.A. and Lafarge and hosted by Stadium JV: M&R, WBHO. Around 100 delegates attended and were transported to and around the site by bus, thereby enabling strict safety precautions to be upheld. Delegates included engineers, architects, suppliers and other contractors not involved in the project, all of whom showed great interest in the high profile site.

Everyone alighted in the centre of the (future) pitch where M&R, WBHO gave a presentation on the construction progress. Project director, Andrew Fanton later gave a video presentation detailing the project from conception date through stages of construction to final completion. Many interesting questions were raised and points discussed on the placing of the precast seats and the height of the stadium. Phillip Ronné of BKS kindly managed the event

Up to May 2008, Sika supplied the following materials to the Greenpoint stadium project:

- Anchorfix-2 (1 000 cartridges): High performance anchoring adhesive;
- SikaGrout-212 (100 tons): Expansive, cementitious grout;
- Sikacrete-214 (50 tons): Free flowing structural repair micro-concrete;
- SikaTop Armatec 110 Epocem (2 tons): Bonding agent and anti-corrosion coating;
- Sika MonoTop-612 (30 tons): One component polymer modified repair mortar containing Silica Fume and synthetic reinforcement fibres.

Self-Consolidating Concrete Columns under concentric compression

Chien-Hung Lin, Chao-Lung Hwang, Shih-Ping Lin, and Chih-Hsiuan Liu

ACI member **Chien-Hung Lin** is a Professor in the Department of Civil Engineering, National Chung Hsing University, Taichung, Taiwan. He is a member of Joint ACIASCE Committee 441, Reinforced Concrete Columns. His research interests include reinforced concrete and pre-stressed concrete.

Chao-Lung Hwang is a Professor in the Department of Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan. His research interests include concrete technology and construction materials.

Shih-Ping Lin is employed at a consulting company in Taichung, Taiwan. He received his MS and PhD from the Department of Civil Engineering, National Chung Hsing University.

Chih-Hsiuan Liu is a former graduate student at National Chung Hsing University where he received his MS in civil engineering.

Two series of column specimens were tested to investigate the behaviour of self-consolidating concrete (SCC) columns under concentric compression. The first series contained 16 columns made with normal concrete (NC), and the second 16 columns were made with SCC. The test variables included the concrete strength, amount of longitudinal reinforcement, volumetric ratio of transverse reinforcement, strength of transverse reinforcement, and arrangement of transverse reinforcement. Comparisons were made between the SCC and NC specimens. Behaviour of the SCC used in this study was also compared with that of high-flowability concretes in other studies. The results show that SCC can have better structural performance than NC, as long as the concrete is properly proportioned. The ductility and crack control ability of SCC columns are better than NC columns. Stiffness of SCC is also higher than that of NC. Mechanical behaviour of the SCC in this study was better than other SCC compared due to the larger amount of coarse aggregate used.

INTRODUCTION

Self-consolidating concrete (SCC) has become more popular in the past decade due to its excellent flowability. SCC consolidates under its own weight without the need of external vibration, and its flowability is even better than that of high workability concrete (HWC).[1,2] HWC contains more coarse aggregate and exhibits lower slump than SCC. It is quite suitable for casting heavily reinforced concrete members such as columns and beam-column joints with SCC. In seismic design, it is usually required that a large amount of transverse reinforcement should be provided to confine the core concrete and longitudinal reinforcement in those members.[3] Apart from easier concrete placement, it has been found that SCC can have better bond with reinforcing bars[4] and better ductility.[5] In some cases, however, SCC may also exhibit lower stiffness and strength[5] and less ductility[6] than NC. To achieve high flowability, it is usually necessary to reduce the amount of coarse aggregate to some extent. For SCC, the amount of coarse aggregate used in the concrete usually ranges from 750 to 850 kg/m^3 (46.7 to 53.0 lb/ft^3) of concrete. The amount of coarse aggregate and water in the fresh concrete, however, has a significant effect on the behaviour of the hardened concrete. The coarse aggregate provides restraint when the cement paste deforms. A larger amount of water used in the concrete also tends to relatively reduce the amount of coarse aggregate, and it could result in lower concrete strength. In addition, less coarse aggregate and a larger amount of water in the fresh concrete would result in higher creep and shrinkage of the hardened concrete, as implied in the ACI 209 report.[7] In this study, the amount of coarse aggregate in SCC was kept approximately the same as in normal concrete (NC) greater than 900 kg/m^3 (56.1 lb/ft^3). The amount of water was kept as low as possible.

RESEARCH SIGNIFICANCE

SCC can be used to ease the casting of heavily reinforced construction elements such as columns and beam-column joints. SCC, however, may have lower stiffness and ductility than NC based on the same strength condition.[5,6] Research on HWC columns has been reported,[1,2] and it suggests that a larger amount of coarse aggregates should be used in the concrete for better structural performance. With a larger amount of coarse aggregate, the column has larger stiffness and the concrete spalls more gradually after the column reaches the peak strength. This study used approximately the same amount of coarse aggregates in the SCC as normally used in NC. Test results of the SCC columns under concentric compression were compared with NC, HWC,[1] and other SCC[6] column specimens. The results show that structural performance of the SCC used in this study was better than NC and other SCC specimens.[6]

Proportioning of SCC

It is rather easy to meet the flowability requirements in proportioning SCC, but it becomes difficult when the mechanical behaviour of hardened concrete is to be considered at the same time. The mixture proportions of SCC in this study followed the "densified mixture design algorithm (DMDA)."[8-11] The design procedures are different from the conventional ACI method.[12] In ACI procedures, it begins with determining the amount of water and cement and ends with calculating the amount of fine aggregates. In the DMDA method, it begins with determining the maximum density of solid materials and ends with calculating the amount of water and cement.

It has been found that the maximum packing density of aggregate is advantageous for making concrete regarding workability, strength, stiffness, creep, shrinkage, permeability, and durability. The DMDA method applies the particle packing concept and develops a particle filling model to proportion material mixture by minimizing voids and hence maximizing the weight of larger particles. Class F fly ash is used as fine particles to fill the void between the aggregates rather than as partial replacement for cement or sand in the traditional method, and it is expected to react with free lime generated from the hydration of cement to chemically form low-density gel. Minimum cement paste acts as glue to bind 426 ACI Structural Journal/July-August 2008 all solid particles together and to fill the rest of the void. In this study, Type I Portland cement and blast-furnace slag cement are used and deemed major binders. Slag partially replaces cement not only to maintain a proper amount of binder for early strength but also to reduce the stickiness of SCC due to the large amount of fine material used. The carboxylic acid-based high-range water-reducing admixture added to the mixture develops a steric hindrance effect on the surface of cement particles and can significantly reduce the internal shear force and greatly reduces the water content.

It significantly increases the flowability of concrete under minimum water content to ensure SCC with no obvious bleeding and segregation. Consequently, the cement content of concrete will be significantly reduced. Also, because the size of coarse aggregate affects the flowability of concrete, a smaller-sized coarse aggregate was used in this study, which was limited to 10 mm (0.4 in.). Details of the DMDA approach can be found elsewhere.[10,11]

To prevent bleeding and segregation, silica fume was added to the SCC in this study. Silica fume can be categorized as a type of viscosity-modifying admixture (VMA).[12] With the use of silica fume, a larger amount of coarse aggregate can be used in the SCC, resulting in high flowability and better structural performance. With the use of silica fume, SCC can contain more than 900 kg/m^3 (56.1 lb/ft^3) of coarse aggregate without difficulty.[12]

The SCC in this study satisfied the Japan Society of Civil Engineers (JSCE) flowability requirements.[13] The flow test, V-funnel test, and U-box test were employed to estimate the flowability of the fresh concrete. The flow test is almost the same as the slump test, except that the flow test measures the spread diameters of the concrete specimens after removing the slump cone. The V-funnel test measures the time that fresh concrete flows out from a funnel. The concrete with good flowability would take a shorter time to flow out. The U-box apparatus serves as a measurement for the self consolidation of concrete. The fresh concrete is placed in the upper box and it flows through the gate into the lower box.

When the flow stops, self-compaction performance is estimated by the height reached in the lower box.

Table 1—Specimen properties

Specimen no.	f_c', MPa	ρ_g	f_{yh}, MPa	s, mm	$\rho_s f_{yh}$, MPa	Tie arrangement
N1	31.1	0.0255	*	*	*	A
N2	43.2	0.0255	*	*	*	A
N3	56.1	0.0255	*	*	*	A
N4	31.1	0.0255	447.2	90	5.87	B
N5	44.5	0.0255	447.2	90	5.87	B
N6	55.1	0.0255	447.2	90	5.87	B
N7	44.5	0.0172	447.2	90	5.87	B
N8	40.4	0.0344	447.2	90	5.87	B
N9	41.3	0.0255	560.0	90	6.02	B
N10	44.2	0.0255	339.4	90	4.35	B
N11	43.7	0.0255	447.2	150	3.51	B
N12	43.2	0.0255	447.2	60	8.80	B
N13	43.2	0.0255	447.2	60	13.18	C
N14	41.6	0.0255	339.4	68.4	5.73	B
N15	44.5	0.0255	560.0	112.8	4.80	B
N16	44.4	0.0255	447.2	135	5.87	C
S1	29.0	0.0255	*	*	*	A
S2	40.9	0.0255	*	*	*	A
S3	53.7	0.0255	*	*	*	A
S4	30.2	0.0255	447.2	90	5.87	B
S5	41.9	0.0255	447.2	90	5.87	B
S6	53.2	0.0255	447.2	90	5.87	B
S7	40.6	0.0172	447.2	90	5.87	B
S8	39.2	0.0344	447.2	90	5.87	B
S9	41.2	0.0255	560.0	90	6.02	B
S10	43.1	0.0255	339.4	90	4.35	B
S11	41.8	0.0255	447.2	150	3.51	B
S12	42.5	0.0255	447.2	60	8.80	B
S13	42.2	0.0255	447.2	60	13.18	C
S14	43.7	0.0255	339.4	68.4	5.73	B
S15	42.0	0.0255	560.0	112.8	4.80	B
S16	42.7	0.0255	447.2	135	5.87	C

*Specimens with no ties.
Note: 1 MPa = 0.145 ksi; 1 mm = 0.0394 in.

TEST PROGRAM

This is the second project of a series of study on high flowability concrete columns under concentric compression carried out at the National Chung Hsing University. The first one was on HWC[1] columns. The test program in this second project is similar to that presented in Reference 1 for easier comparison. Thirty-two column specimens were constructed and tested in this project. Sixteen of the specimens were made with NC (slump less than 200 mm [8 in.]), whereas the others were made with SCC. The column ends were tapered to prevent unexpected local failure at the ends, and the test region was in the middle (600 mm [24 in.]) of the specimen.

The cross section of the columns was 300 x 300 mm (12 x 12 in.) in size, as shown in Fig. 1. Three concrete strengths were used: 28, 41, and 55 MPa (4, 6, and 8 ksi). The yield strength of longitudinal reinforcement was 552 MPa (80 ksi). The specimen properties are shown in Table 1. The f_c' and f_{yh} values shown in Table 1 are actual material strengths. Series N represents NC columns and Series S represents SCC columns.

Six specimens (N1, N2, N3, S1, S2, and S3) without ties were prepared as unconfined specimens to establish the in-place strength of concrete in columns to be compared with the standard cylinder test results. The spacing of 10 mm (0.4 in.) transverse reinforcement was 60, 68, 90, 113, 135, and 150 mm (2.4, 2.7, 3.5, 4.4, 5.3, and 5.9 in.) for other specimens, and the amount of transverse reinforcement used met the requirements of ACI 318-05, Section 21.4.4,[3] for seismic design.

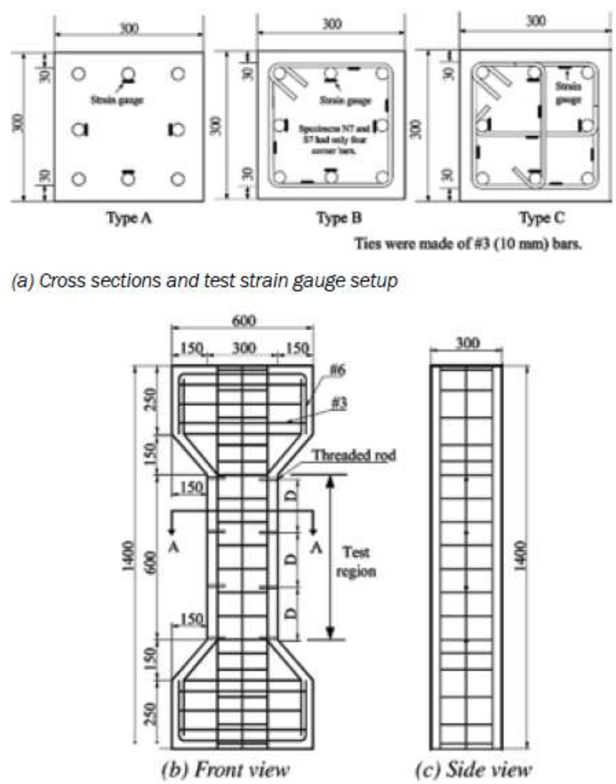


Fig. 1—Specimen details

The mixture proportions for the concrete are shown in Table 2.

Table 2(a)—Mixture proportions for normal concrete

Concrete strength, MPa	Water/ cement	Cement, kg/m³	Water, kg/m³	Coarse aggregates, kg/m³	Fine aggregates, kg/m³
28	0.60	359	216	988	762
41	0.54	398	214	988	735
55	0.48	465	222	945	700

The maximum aggregate size of SCC was 10 mm (0.4 in.), whereas the maximum aggregate size of NC was 19 mm (0.75 in.). Class F fly ash and Type G high-range water-reducing admixture were used in this study. The concrete was mixed and placed in the laboratory. The capacity of the mixer was approximately 0.3 m³ (10.6 ft³), and each specimen was cast with one batch of concrete. The NC was consolidated based on suggestions by ACI 309.[14] Twelve ϕ100 × 200 mm (ϕ4 × 8 in.) concrete cylinders were made at the time each column specimen was cast to monitor the strength development of the concrete. The specimens and the cylinders were covered with wet burlaps for the first three days and then cured under ambient temperature and humidity.

The properties of fresh concretes and the JSCE requirements for SCC are shown in Table 3.

Six electric dial gauges were installed in the test region of the specimen to measure the axial deformations of the column. Strain gauges were attached to four longitudinal steel bars and every tie leg at the mid-height of the column.

Linear variable differential transformers (LVDTs) were also mounted in the test region to monitor the lateral displacements.

The load was applied by a 6 000 kN (1 348 kip) material testing system. The specimens were tested under monotonic loading. During each load step, the crack widths were measured using a portable stand microscope that contained a 25X magnifier and a scale chamber with minimum scale division of 0.05 mm (0.002 in.). The applied load was controlled by displacement. The test setup is shown in Fig. 2.

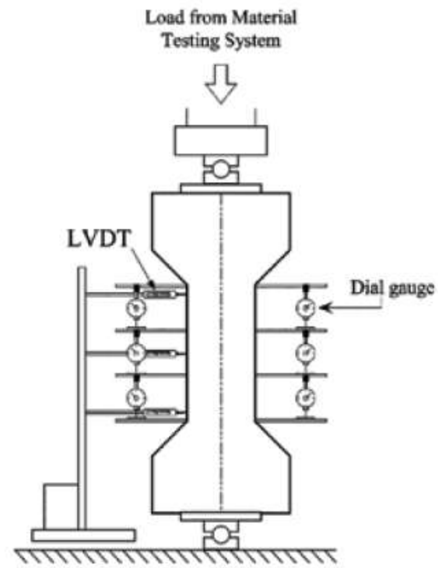


Fig. 2—Test setup

TEST RESULTS

General behavior

Figure 3 shows a typical axial load-axial deformation curve of a column specimen.

SCC columns used approximately the same amount of coarse aggregates as the NC columns and they behaved slightly stiffer in the ascending range than NC columns, as illustrated in Fig. 4. SCC columns exhibited smaller crack widths than the NC columns.

The crack widths of SCC columns in this study were even smaller than those of HWC columns[1] due to better flowability and larger amount of supplementary cementitious materials added in the SCC. The maximum load occurred at an axial strain of approximately 0.00335 for NC columns on average, and 0.00308 for SCC columns on average, as shown in Table 4.

Table 2(b)—Mixture proportions for self-consolidating concrete

Concrete strength, MPa	Water/ binder	Cement, kg/m³	Fly ash, kg/m³	Slag, kg/m³	Silica fume, kg/m³	Water, kg/m³	Coarse aggregates, kg/m³	Fine aggregates, kg/m³	High-range water-reducing admixture, kg/m³
28	0.51	188	120	25	5	168	925	919	3.0
41	0.45	226	110	29	10	167	920	897	3.2
55	0.40	264	110	27	20	165	920	853	4.8

Note: 1 kg = 2.2 lb; 1 m = 39.4 in.

Table 3—Properties of fresh concretes

	Compressive strength, MPa	Slump, mm	Slump flow, mm	Time to reach 500 mm slump flow after 1 hour, seconds	U-box test, mm	V-funnel test, seconds
Normal concrete	29.3	190	300	—	—	—
	41.8	150	275	—	—	—
	55.2	120	245	—	—	—
Self-consolidating concrete	29.2	290	695	4	305	18
	42.1	275	685	4	310	15
	55.8	265	660	4	312	18
JSCE requirements for self-consolidating concrete	—	—	600 to 700	3 to 15	≥300	7 to 20

Note: 1 MPa = 0.145 ksi; 1 mm = 0.0394 in.

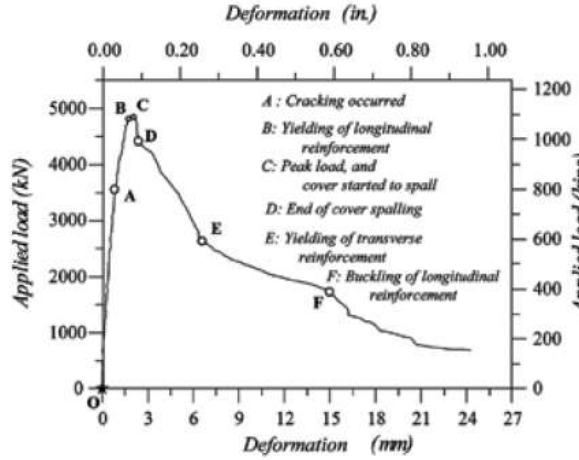


Fig. 3—Typical load-deformation curve

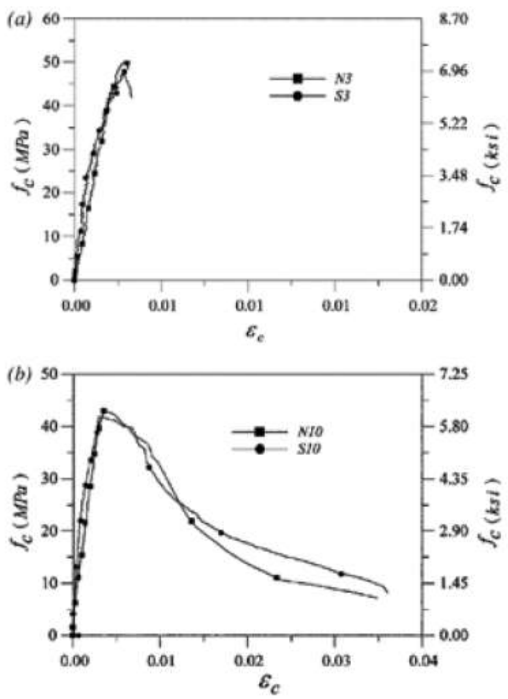


Fig. 4—Comparisons of stress-strain curves of SCC and NC

The slightly smaller strain in SCC could be attributable to higher stiffness (due to a lower water-cementitious material ratio [w/cm] and higher density) and finer microcracking. In general, SCC columns exhibited better ductility than NC columns in the descending range, and the load dropped more gradually than NC columns after peak load. The better behaviour of SCC over NC could be attributed to better particle gradation, fewer voids, and a denser matrix structure.

Axial strength

Table 4 shows the maximum axial strengths of the specimens. The nominal strengths calculated by the ACI Code method are also listed in the table. All the experimental strengths were slightly greater than the nominal strengths. The average ratio of experimental strength P_{max} to nominal strength P_o was 1.07 for NC columns (with a standard deviation of 0.0131) and 1.08 for SCC columns (with standard deviation of 0.0141). This proved that the consolidation method used for NC was adequate. Both the SCC and NC columns reached their anticipated strengths in this study. Smaller waterbinder (or water-cement for NC) ratios were used in SCC and the strengths of SCC were quite close to those of NC, as shown in Table 1.

The average ratio of unconfined in-place strengths f'_{co} to cylinder strengths f'_c for Specimens N1 to N3 and S1 to S3 was found to be 89% for both NC and SCC columns. This is approximately the same as that in HWC columns. The ACI Code uses 0.85 and is slightly more conservative.

Table 4—Axial strains and strengths of specimens

Specimen no.	Axial strain at maximum load	Maximum load P_{max}, kN	Nominal axial strength P_o, kN	Age at test, days
N1	0.00372	3758	3507	30
N2	0.00325	4724	4408	26
N3	0.00290	5768	5372	29
N4	0.00358	3741	3502	29
N5	0.00351	4938	4506	30
N6	0.00328	5572	5296	28
N7	0.00336	4536	4137	26
N8	0.00314	4795	4571	28
N9	0.00358	4551	4266	30
N10	0.00334	4814	4487	26
N11	0.00294	4798	4448	28
N12	0.00348	4809	4409	28
N13	0.00408	4713	4405	29
N14	0.00312	4569	4285	29
N15	0.00301	4853	4502	26
N16	0.00332	4841	4498	26
Average (SD): 0.00335 (0.0003074)				
S1	0.00317	3548	3349	28
S2	0.00247	4582	4237	30
S3	0.00240	5673	5191	28
S4	0.00342	3782	3437	26
S5	0.00304	4640	4315	30
S6	0.00278	5637	5160	28
S7	0.00311	4216	3842	30
S8	0.00301	4707	4477	26
S9	0.00302	4619	4260	29
S10	0.00290	4824	4398	30
S11	0.00269	4621	4303	28
S12	0.00367	4711	4355	29
S13	0.00387	4707	4336	28
S14	0.00298	4837	4445	30
S15	0.00305	4633	4317	29
S16	0.00366	4785	4368	30
Average (SD): 0.00308 (0.0004134)				

Note: SD = standard deviation; 1 MPa = 0.145 ksi; 1 kN = 0.225 kips.

Crack width

Crack widths were observed before yielding of the longitudinal reinforcement. The columns did not exhibit apparent cracks until approximately 80% of the peak loads during the tests. The cracks usually formed in the longitudinal direction, and they coincided with the cover spalling from core. Table 5 lists the maximum crack width at 80% of the maximum load for each column. The values W_{NC} and W_{SCC} are the maximum crack width for NC columns and SCC columns, respectively. Each SCC column, except Specimen S6, had a smaller maximum crack width than its companion NC column. The average ratio of W_{SCC}/W_{NC} was 0.822. It indicates that SCC columns have better crack control ability than NC columns. The ratio was even smaller than that of HWC[1] (0.96).

Table 5—Crack widths of specimens

Specimen no.	W_{NC}, mm	Specimen no.	W_{SCC}, mm	W_{SCC}/W_{NC}
N1	0.358	S1	0.269	0.751
N2	0.266	S2	0.218	0.820
N3	0.227	S3	0.200	0.881
N4	0.170	S4	0.160	0.941
N5	0.139	S5	0.110	0.791
N6	0.089	S6	0.092	1.034
N7	0.191	S7	0.117	0.613
N8	0.095	S8	0.074	0.779
N9	0.144	S9	0.102	0.708
N10	0.141	S10	0.111	0.787
N11	0.204	S11	0.179	0.877
N12	0.106	S12	0.086	0.811
N13	0.099	S13	0.090	0.909
N14	0.103	S14	0.099	0.961
N15	0.144	S15	0.106	0.736
N16	0.146	S16	0.111	0.760
Average (SD)				0.822 (0.10634)

Note: SD = standard deviation; 1 mm = 0.0394 in.

It is believed that adding supplementary cementitious materials such as fly ash, slag, and silica fume can improve the development of high-flowability concretes to improve the density of the concrete matrix and enhance the bond between the mortar matrix and coarse aggregates. The smaller crack widths of SCC could be because SCC had more supplementary cementious materials than HWC. The transition zone between aggregate and paste became stronger due to pore confinement that occurred after using supplementary cementitious materials.

Stress-strain curves for concrete

The stress-strain curves for different concretes were plotted in this study. The stress in the longitudinal steel was obtained by the measured strain and the stress-strain curve of the longitudinal steel. The force carried by concrete in the specimen was derived by subtracting the longitudinal steel force from the total applied load. The concrete stress was then obtained by dividing the concrete force by the concrete area. Before the peak load (Point C in Fig. 3) of the specimen, the concrete cover was included in the concrete area; and it was totally removed after Point D (Fig. 3). Between Points C and D, the concrete cover spalled gradually, and a linear transition was used. Figure 4 shows some examples of the comparison of the NC and SCC stress-strain curves. Generally, SCC exhibited higher stiffness before peak stress and slower descending rates (better ductility) after peak stress. The stiffness E_{test} is defined as the secant modulus of elasticity of concrete corresponding to $0.45f_c'$, as shown in Fig. 5.

The $E_{test}/\sqrt{f_c'}$ values for NC and SCC are listed in Table 6. The average stiffness of SCC in this study was 1.20 times that of NC.

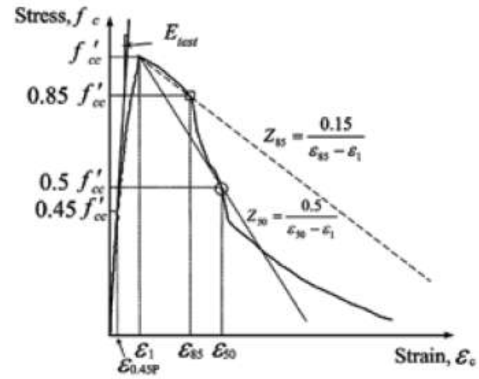


Fig. 5—Comparisons of Z_{85} and Z_{50}

One way of comparing the ductility of concrete is using an index Z_{50} to reflect the slope of the descending branch of the stress-strain curve, and it is defined as:

$$Z_{50} = \frac{0.50}{\varepsilon_{50} - \varepsilon_1}$$

Definitions of the notation in Eq. (1) are illustrated in Fig. 5. The Z_{50} values are tabulated in Table 6. Each SCC specimen, except Specimen S11, had a smaller Z_{50} value than its companion NC specimen, and it indicates that the ductility of SCC is better than that of NC. The average ratio of $Z_{50'SCC}$ to $Z_{50'NC}$ was 0.782. A smaller Z_{50} value indicates better ductility of the concrete. The unconfined specimens (N1 through N3 and S1 through S3) exhibited much less ductility (as shown in Fig. 4(a)) due to much earlier buckling of longitudinal reinforcement; Z_{50} values were not available, and they were not included in the ductility comparison.

Table 6—Modulus of elasticity and ductility of normal concrete and self-consolidating concrete

NC specimen no.	$E_{test}/\sqrt{f_c'}$	$Z_{50,NC}$	SCC specimen no.	$E_{test}/\sqrt{f_c'}$	$Z_{50,SCC}$
N1	3127.96	—	S1	3807.16	—
N2	3248.43	—	S2	3842.75	—
N3	3490.96	—	S3	4165.59	—
N4	4105.21	37.913	S4	4357.64	31.965
N5	2528.99	50.186	S5	4430.57	33.661
N6	3115.55	36.930	S6	3747.53	23.111
N7	3722.13	49.761	S7	4237.15	35.293
N8	3240.05	48.648	S8	4340.94	41.799
N9	3483.77	33.447	S9	3740.52	24.341
N10	2217.99	48.814	S10	4024.46	38.992
N11	3599.74	47.165	S11	3941.92	55.748
N12	4378.17	20.813	S12	3317.94	17.655
N13	3275.40	11.145	S13	2102.71	10.239
N14	3054.06	22.080	S14	4695.49	19.923
N15	3476.01	50.505	S15	4199.72	35.135
N16	3673.63	49.130	S16	3419.89	33.775

Note: 1 MPa = 0.145 ksi; — = not available.

Table 7—Comparison of maximum stress and ductility index μ of confined concrete

Specimen no.	f'_{cc}, MPa	f'_{cc}/f'_{co}	μ_{NC}	Specimen no.	f'_{cc}, MPa	f'_{cc}/f'_{co}	μ_{SCC}
N4	31.21	1.140	5.085	S4	30.36	1.175	6.149
N5	43.81	1.134	4.977	S5	41.74	1.167	6.966
N6	52.59	1.051	7.174	S6	51.90	1.076	9.728
N7	43.72	1.132	4.707	S7	39.85	1.114	5.846
N8	40.28	1.043	5.176	S8	38.77	1.084	5.590
N9	41.69	1.079	6.138	S9	41.71	1.166	8.443
N10	43.13	1.117	5.372	S10	41.86	1.170	6.225
N11	40.80	1.056	4.772	S11	39.36	1.100	5.479
N12	44.78	1.160	8.265	S12	44.12	1.233	9.342
N13	45.94	1.190	7.596	S13	46.73	1.306	15.538
N14	40.72	1.054	8.387	S14	43.38	1.212	10.114
N15	43.52	1.127	4.619	S15	41.80	1.168	6.065
N16	42.94	1.112	4.760	S16	42.01	1.174	7.372

Note: 1 MPa = 0.145 ksi.

Another way of comparing the ductility of the confined concrete is using a ductility index μ. The ductility index μ is defined as A_u/A_p, where A_u is the area under the stress-strain curve before the stress drops to 50% of the maximum stress and A_p is the area under the stress-strain curve up to peak stress. The values of μ are shown in Table 7. Each SCC column had a larger μ value than its companion NC column.

The average of $^{\mu}SCC/^{\mu}NC$ was 1.324. If A_u were defined as the area under the stress-strain curve before the stress drops to 25% of the maximum stress, the average of $^{\mu}SCC/^{\mu}NC$ would be 1.208.

The effect of each variable on ductility index μ can be seen in Table 7. An increase of longitudinal reinforcement, increase of transverse reinforcement yield strength, and decrease of transverse spacing would improve the concrete ductility. NC specimens with Type C tie arrangement (Specimen N16) showed less ductility than that with Type B, although Type C had more transverse reinforcement than Type B. This could be attributed to the congestion problem

in the NC specimen. On the contrary, the SCC specimen with Type C tie arrangement (Specimen S16) exhibited better ductility than the specimen with Type B (Specimen S5), and this was due to higher flowability of SCC and better concrete quality obtained in the specimen.

Specimens N5, N14, N15, S5, S14, and S15 had the same $\rho_s f_{yh}$ value (5.9 MPa [0.86 ksi]), but different fyh values (447, 339, and 560 MPa [64.8, 49.2, and 81.2 ksi]). It shows that specimens with smaller tie spacing (larger ρ_s)would have better ductility, although the values were the same. It also shows that the SCC specimens had better ductility than NC specimens. As for the effect of concrete strength, the values of μ and Z_{50} did not show a reasonable trend in this study as seen in Tables 6 and 7. Usually concrete with higher strengths exhibit less ductility, but specimens with higher strength had larger μ values (Specimens N6 and S6) and a smaller Z_{50} value (Specimen S6) in this study. The f'_{cc}/f'_{co} value, however, did decrease as the concrete strength increased, as shown in Table 7. The values for the confined specimens in Table 8 were taken from the unconfined column (Specimens N1, N2, N3, S1, S2, and S3) tests. The other test variables had similar effects on the ratio as on the ductility index μ as depicted in Table 7. An increase of longitudinal reinforcement, increase of transverse reinforcement yield strength, and decrease of transverse spacing would increase the f'_{cc}/f'_{co} ratio. The average f'_{cc}/f'_{co} ratio for NC was 1.107 and 1.165 for SCC.

The SCC had approximately the same amount of coarse aggregate as NC, but it contained more supplementary cementitious materials and less water content than NC, and it had a denser matrix structure and exhibited better performance than NC.

Comparisons with other high-flowability concretes

Comparisons between SCC used in this study and HWC,[1] and other SCC[6] were made. The results show that the overall behaviour of HWC was better than the SCC made in this study, whereas the SCC in this study was better than the other SCC.[6]

Comparisons with HWC

The HWC specimens had the same cross-section size and were tested in the same way as in this study. The maximum size of aggregate used in the HWC was 10 mm (0.4 in.), which is the same as that used in SCC in this study. The concrete strength and transverse reinforcement yield strength in HWC were approximately the same as those in SCC. The slump of HWC was 230 ± 20 mm (9.06 ± 0.79 in.), which was less than that of SCC (greater than 270 mm [10.6 in.]). But HWC contained more coarse aggregates (>1000 kg/m³ [62.3 lb/ft³]) than SCC, and it exhibited a better mechanical performance than SCC.

The stiffness E_{test} depends on the unit weight and strength of the concrete, as indicated in the ACI 318-05 Code.3 The unit weights of the high-flowability concretes and NC were approximately the same, as shown in Tables 8 and 9, and the $E_{test}/\sqrt{f'_c}$ values listed in Table 8 and 9 were used for comparisons.

Table 8—Modulus of elasticity and ductility of high-workability concrete[1] and self-consolidating concrete[6]

Specimen no.	$\rho_s f_{yh}$, MPa	w_c, kg/m³	$E_{test}/\sqrt{f'_c}$	Z_{50}
HWC[1]				
H4	5.93	2355	6271.42	18.137
H5	5.93	2351	5318.30	15.875
H6	5.93	2408	5680.45	15.185
H7	5.93	2351	5355.57	15.695
H8	5.93	2351	4836.83	15.652
H9	6.66	2351	6649.82	15.383
H10	4.91	2351	4462.21	15.311
H11	3.57	2351	5059.48	28.818
H12	8.91	2351	5365.65	9.206
H13	5.93	2351	5454.48	19.109
H14	6.06	2351	6467.23	11.712
H15	5.45	2351	4918.16	19.844
SCC[6]				
SCC-28-Q-1	11.06	2334	3528.90	31.118
SCC-28-Q-2	11.06	2334	3145.42	35.413
SCC-28-Q-3	11.06	2334	2800.93	26.507
SCC-28-S-1	8.78	2334	3353.87	71.306
SCC-28-S-2	8.78	2334	3537.40	65.531
SCC-28-S-3	8.78	2334	3564.23	70.842
SCC-42-Q-1	11.06	2345	2672.70	34.693
SCC-42-Q-2	11.06	2345	2802.48	40.796
SCC-42-S-1	8.78	2345	2983.03	78.040
SCC-42-S-2	8.78	2345	3664.44	77.736

Note: 1 MPa = 0.145 ksi.

Table 9—Modulus of elasticity and ductility of companion normal concrete for high-workability concrete[1] and self-consolidating concrete[6]

Specimen no.	$\rho_s f_{yh}$, MPa	w_c, kg/m^3	$E_{test}/\sqrt{f_c'}$	Z_{50}
		HWC[1]		
N4	5.93	2268	5784.45	43.771
N5	5.93	2300	4142.64	40.548
N6	5.93	2347	7019.37	20.299
N7	5.93	2300	5181.61	40.644
N8	5.93	2300	2648.98	65.669
N9	6.66	2300	3245.08	32.060
N10	4.91	2300	2576.88	41.353
N11	3.57	2300	7154.99	62.893
N12	8.91	2300	3867.87	28.840
N13	5.93	2300	3161.90	59.673
N14	6.06	2300	3079.58	33.548
N15	5.45	2300	5369.11	73.569
		SCC[6]		
OPC-28-Q-1	11.06	2339	2577.02	28.920
OPC-28-Q-2	11.06	2339	2733.76	32.671
OPC-28-Q-3	11.06	2339	2864.62	30.912
OPC-28-S-1	8.78	2339	1866.32	51.937
OPC-28-S-2	8.78	2339	2134.85	61.516
OPC-28-S-3	8.78	2339	2965.13	69.252
OPC-42-Q-2	11.06	2347	2948.22	41.890
OPC-42-Q-3	11.06	2347	2343.01	31.399
OPC-42-S-1	8.78	2347	2650.14	74.538
OPC-42-S-2	8.78	2347	2619.21	76.593
OPC-42-S-3	8.78	2347	2849.55	67.889

Note: 1 MPa = 0.145 ksi.

The average stiffness of HWC was approximately 1.39 times that of its companion NC (with a standard deviation of 0.4878), whereas the average stiffness of SCC in this study was 1.19 times that of NC (standard deviation of 0.3470). The HWC exhibited higher stiffness than the SCC in this study.

Many studies have shown that transverse reinforcement is quite essential in confining the core concrete. Spacing, configuration, and strength of the transverse reinforcement all affect the confining effect. For simplicity, the product $\rho_s f_{yh}$ was used to evaluate the effect of transverse reinforcement on confinement, where ρ_s is the volumetric ratio of the transverse reinforcement and reflects spacing and configuration of the transverse reinforcement, and f_{yh} represents the yield strength of the transverse reinforcement. The $\rho_s f_{yh}$ values of HWC were close to those of SCC in this study, as shown in Table 8, but HWC had better ductility than SCC. The average ductility indicator Z_{50} of HWC was 0.40 times that of NC (standard deviation of 0.1316), whereas the average Z_{50} of SCC in this study was 0.81 times that of NC (standard deviation of 0.1477). It is apparent that the better ductility of HWC is not due to the transverse reinforcement. It has been pointed out that the column concrete tends to spall more gradually after the peak load (Point C in Fig. 3) if a larger amount of coarse aggregate is added to the concrete.1

The stress-strain curves of HWC and SCC in this study were normalized and plotted in the same figure (Fig. 6). In general, the HWC curves cover the curves of SCC in this study as shown in Fig. 6. The HWC contained less supplementary cementitious materials than the SCC in this study and it had better mechanical performance than SCC. It seems that the effect of adding supplementary cementitious materials in the concrete is not as prominent as that of coarse aggregate on the stress-strain behavior. The reason why HWC exhibited higher stiffness and better ductility could be attributed to its larger amount of coarse aggregate. The amount of coarse aggregate affects both the slope of the ascending branch of the stress-strain curve (stiffness) and the slope of the descending branch (ductility index Z_{50}).

Comparisons with other SCC

Studies on the behavior of confined SCC have also been carried out.[5,6] The SCC in Reference 5 had less stiffness and strength than NC, whereas the SCC in Reference 6 had less ductility than NC. The amount of coarse aggregate contained in the SCC in Reference 5 was approximately 830 kg/m^3 (51.7 lb/ft^3) of concrete for normal-strength concrete ($f_c' \leq 50$ MPa [7.25 ksi]). The amount of coarse aggregate contained in the SCC in Reference 6 was 790 kg/m^3 (49.2 lb/ft^3) of concrete. These were all less than the amount used in this study (920 kg/m^3 [57.3 lb/ft^3] of concrete).

The mixture proportions of SCC in Reference 6 are shown in Table 10.

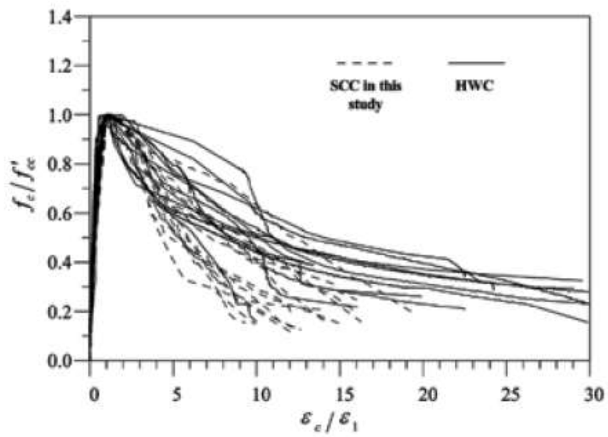


Fig. 6—Comparisons of stress-strain curves of HWC and SCC in this study

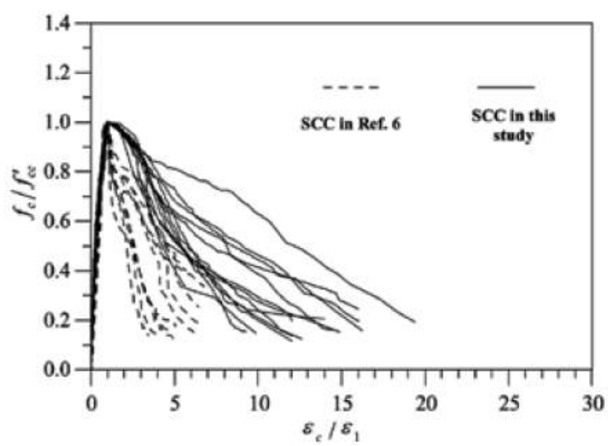


Fig. 7—Comparisons of stress-strain curves of SCCs

The SCC in Reference 6 did not have any VMA added in the concrete, and a lower amount of coarse aggregate was used to meet the JSCE flowability requirements. The amount of cementitious materials added in the SCC in Reference 6 was larger than that of

Table 10—Mixture proportions of SCC[6]

Design strength, MPa	Cement, kg/m³	Limestone, kg/m³	Water, kg/m³	Coarse aggregate, kg/m³	Fine aggregate, kg/m³	HRWRA, kg/m³
28.0	310	230	170	790	830	4.4
42.0	350	190	170	790	840	4.6

Note: HRWRA = high-range water-reducing admixture; 1 kg = 2.2 lb; 1 m = 39.4 in.

SCC in this study. The $\rho_s f_{yh}$ values of the SCC specimens in Reference 6 were larger than those of the SCC specimens in this study, as shown in Table 8. The average Z_{50} value of SCC in Reference 6 was approximately 1.07 times that of its companion NC (standard deviation of 0.1680). The ductility of SCC used in Reference 6 was significantly less than that of SCC in this study even though it had a higher amount of transverse reinforcement. The normalized stress-strain curves of SCC in Reference 6 were compared with the SCC in this study, as illustrated in Fig. 7. The figure shows that the curves of the SCC in this study cover those of the SCC in Reference 6, and it indicates that the SCC in this study had higher stiffness and better ductility. Again, this could be attributed to the larger amount of coarse aggregate used in the SCC in this study.

CONCLUSIONS

Based on the experimental and analytical results presented herein, the following conclusions can be made:

1. The SCC in this study has higher stiffness than NC (with approximately 15% increase), but less than that of HWC[1] (39% increase). The ductility of confined SCC was found to be better than that of NC (with an increase of 32%) but is less than that of HWC (77% increase). The higher stiffness and better ductility of HWC could be attributed to the higher amount of coarse aggregate contained in the HWC (>1000 kg/m³ [62.3 lb/ft³] of concrete);
2. SCC columns showed smaller crack widths than NC columns in this study. The crack widths of SCC columns are approximately 82% of those of NC columns. The crack widths of SCC specimens are even smaller than those of HWC due to better flowability and larger amounts of supplementary cementitious materials added in the SCC;
3. A larger amount of coarse aggregates improves the mechanical behaviour of the hardened concrete. It is suggested that the amount of coarse aggregates in SCC should be kept approximately the same as that in NC (900 kg/m³ [56.1 lb/ft³] of concrete, could be a minimum). The SCC used in this study exhibited satisfactory structural performance.

NOTATION

A_g = gross area of column section
A_{st} = total area of longitudinal reinforcement
b_c = core dimension measured center-to-center of perimeter tie
E_{test} = modulus of elasticity of concrete corresponding to $0.45f'_{co}$, as defined in Fig. 5
f'_c = concrete strength obtained from cylinder test
f'_{cc} = compressive strength of confined concrete in member
f'_{co} = compressive strength of unconfined concrete in member
f_l = average confinement pressure
f_s = stress in transverse reinforcement
f_y = yield strength of longitudinal reinforcement
f_{yh} = yield strength of transverse reinforcement
P_{max} = maximum column axial load
P_o = nominal column axial strength, = 0.85fc'(Ag – Ast) + fy Ast
s = spacing of transverse reinforcement
w = crack width
Z_{50} = slope of descending branch of concrete stress-strain curve calculated based on 0.5fcc'
Z_{85} = slope of descending branch of concrete stress-strain curve calculated based on 0.85fcc'
ε_1 = strain corresponding to peak stress of confined concrete
ε_{50} = strain corresponding to 50% peak stress of confined concrete
ε_c = strain in concrete
ρ_g = ratio of longitudinal reinforcement, Ast /Ag
ρ_s = ratio of volume of transverse reinforcement to volume of con crete core

REFERENCES

1. Lin, C. H.; Lin, S. P.; and Tseng, C. H., "High-Workability Concrete Columns under Concentric Compression," ACI Structural Journal, V. 101, No. 1, Jan.-Feb. 2004, pp. 85-93.

2. Lin, C. H., and Lin, S. P., "Flexural Behavior of High-Workability Concrete Columns under Cyclic Loading," ACI Structural Journal, V. 102, No. 3, May-June 2005, pp. 412-421.

3. ACI Committee 318, "Building Code Requirements for Structural Concrete (ACI 318-05) and Commentary (318R-05)," American Concrete Institute, Farmington Hills, MI, 2005, 430 pp.

4. Chan, Y. W.; Chen, Y. S.; and Liu, Y. S., "Development of Bond Strength of Reinforcement Steel in Self-Consolidating Concrete," ACI Structural Journal, V. 100, No. 4, July-Aug. 2003, pp. 490-498.

5. Paultre, P.; Khayat, K. H.; Cusson, D.; and Tremblay, S., "Structural Performance of Self-Consolidating Concrete Used in Confined Concrete Columns," ACI Structural Journal, V. 102, No. 4, July-Aug. 2005, pp. 560-568.

6. Chen, Y. F., "An Investigation on Confinement Behavior of Square Self-Compacting Concrete Columns," MS thesis, Department of Civil Engineering, National Taiwan University, Taiwan, 2003, 245 pp. (in Chinese)

7. ACI Committee 209, "Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures," Designing for Creep and Shrinkage in Concrete Structures, SP-76, American Concrete Institute, Farmington Hills, MI, 1982, pp. 93-300.

8. Hwang, C. L., and Chen, Y. Y., "The Property of Self-Consolidating Concrete Designed by Densified Mixture Design Algorithm," First North American Conference on the Design and Use of Self-Consolidating Concrete, 2002, pp. 121-126.

9. Hwang, C. L., and Hung, M. F., "Durability Consideration of Self-Consolidating Concrete," First North American Conference on the Design and Use of Self-Consolidating Concrete, 2002, pp. 385-390.

10. Tsai, C. T.; Li, L. S.; and Hwang, C. L., "The Effect of Aggregate Gradation on Engineering Properties of High Performance Concrete," Journal of ASTM International, V. 3, No. 3, Mar. 2006, 12 pp.

11. Hwang, C. L., and Hung, M. F., "Durability Design and Performance of Self-Consolidating Lightweight Concrete," Construction and Building Materials, 1995, pp. 619-626.

12. Mehta, P. K., and Monteiro, P. J. M., Concrete, McGraw-Hill, 2006, 659 pp.

13. Uomoto, T., and Ozawa, K., "Recommendation for Self-Compacting Concrete," Japan Society of Civil Engineering, Aug. 1999, 77 pp.

14. ACI Committee 309, "Guide for Consolidation of Concrete (ACI 309R-96)," American Concrete Institute, Farmington Hills, MI, 1996, 39 pp.

Overview of durability

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INTRODUCTION

Concrete is the most widely used man-made product in the world and is second only to water as the world's most utilised substance.

In the context of concrete, durability can be defined as "the capability to maintain the serviceability of a product or construction over a specified period of time".

The durability of concrete must be seen as the interaction between concrete, as a system and its environment. Any assessment of the potential durability of a concrete structure must take into account both of these. Factors associated with the concrete system influence its ability to resist deterioration while environmental factors influence the degree of aggressiveness to which the concrete will be exposed. The factors that affect durability are shown in Figure 1 and are discussed below.

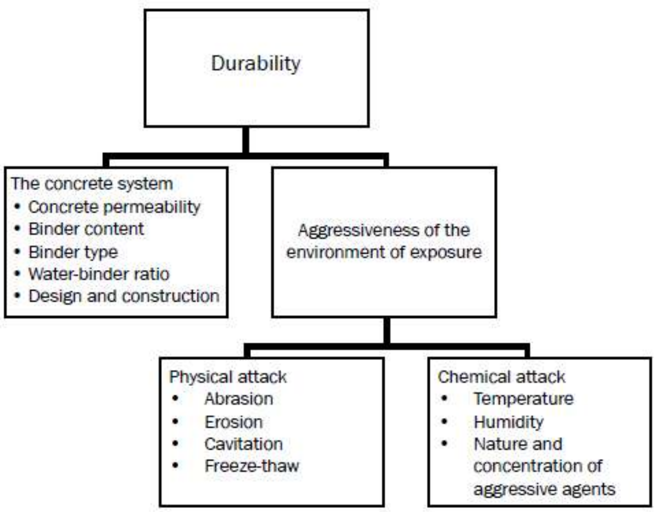


Fig. 1—Concrete and environment: factors influencing the durability of concrete

As can be seen, a wide variety of agents are aggressive to concrete and the reinforcement contained within it. This paper will identify most of those agents that have the potential to attack concrete and discuss them briefly. Their effect on the concrete is covered as well as their possible modes of ingress into the concrete.

Fortunately, with many concrete structures, particularly inland in South Africa, durability concerns are often unwarranted as many of the aggressive agents covered in this paper are unlikely to be a threat. Precautions need only be taken to counter these agents if they are likely to be present during the life of the concrete.

AGGRESSIVENESS OF THE ENVIRONMENT

The environmental attack on concrete can be divided into physical attack and chemical attack. These will be dealt with separately.

Physical attack of concrete

Reinforced concrete can be damaged physically by several mechanisms including abrasion, erosion, cavitation, salt crystallisation and freezing.

Abrasion

Abrasion refers to the wearing of the concrete surface by repeated rubbing or friction. Abrasion can be caused on horizontal surfaces used for industrial processes or hard standings and roads traversed by vehicles. Generally abrasion resistance is addressed by appropriate choice of aggregates and a reduction in the water/cement ratio.

Erosion

Erosion is defined as the wearing away of a concrete surface by the abrasive action of fluids and suspended solids as well as by wind-borne sand. It is therefore a special case of abrasion and similar measures would be adopted to provide resistance.

Cavitation

Cavitation occurs when a high velocity flow of fluid is subject to a sudden change in direction or velocity causing a low-pressure zone and the formation of vapour pockets. These vapour pockets collapse by implosion resulting in highly localised impact pressures on the surface. The design of hydraulic structures must include measures to prevent the occurrence of cavitation.

Salt crystallisation

When water droplets containing salts are deposited on the surface of concrete they may penetrate into the concrete if the surface is permeable. If the water evaporates, the salts will re-crystallise with an expansive action, the surface of the concrete paste will be broken up and become powdery. The action is repetitive and progressive, and can remove a substantial thickness of surface material.

Freezing

In cold-rooms or areas that experience sub-zero temperatures, damage of the concrete can occur due to freezing of water in the pore structure. The increase in volume of water as it freezes will break up the concrete surface. Concrete needs to be protected from freezing until it achieves certain strength.

In freeze-thaw deterioration, cracks are propagated by the cyclic freezing and thawing actions. Air entrainment of the concrete is one solution to minimising the damage to concrete exposed to freeze-thaw conditions.

Chemical attack of concrete

The aggressiveness of chemical attack is influenced by a number of factors that include:

- Temperature: The temperature of liquids strongly influences the rate of reactions between the liquid and concrete.
- pH: the lower the pH of the liquid, the greater is its aggressiveness.
- Dissolved ions: the presence of sulfates, magnesium and ammonium ions are of importance.
- Softness: The softness of the water is important in leaching attack.
- Turbulence: The more turbulent the flow, the greater the rate of attack.
- Wet/dry cycling: The deposition of salts in the concrete pores can result in physical damage to the concrete.

Chemical attack of concrete can be either water-borne or air-borne.

Water-borne chemical attack

Water-borne chemical attack includes attack by water, acids, alkalis, sulfates and other chemicals.

Attack by water

The most important mechanisms of deterioration are:

- Purity of the water: Very pure waters are calcium hungry and leach out components of the cement paste.
- Acidity or alkalinity: Acid waters are highly aggressive, whereas alkaline waters can be protective at high pH values.
- Dissolved salts: Calcium salts are generally protective whereas magnesium and ammonium are corrosive. Sulfate ions can cause spalling corrosion and chloride ions can corrode reinforcement.

The assessment of the aggressiveness of water to concrete can be assessed using the corrosion index approach covered in Fulton's Concrete Technology. The aggressiveness of groundwater to concrete can be assessed using the approach suggested in BRE Special Digest 1:2005 Concrete in aggressive ground.

Attack by acids

Acids react with the alkaline components of the cementitious binder lowering the degree of alkalinity or completely neutralising it. Disintegration of the matrix is inevitable and no concretes made with portland cements are truly resistant to common inorganic acids.

Attack by alkalis

Alkalis are generally benign and alkaline attack of the matrix is not a common durability related problem unless the concrete is exposed to very high concentrations of alkali metal hydroxides such as caustic soda.

Attack by sulfates

Sulfate ions will react with the tri-calcium aluminate (C_3A) which is a component of cement. The reaction is expansive and will cause the concrete on the surface to break up and the concrete will be seen to "dust". The mechanism is progressive and will eventually remove a significant depth of concrete from the surface.

Attack by other chemicals

Many chemicals used in industry and agriculture react with concrete to reduce its durability. The mechanisms of attack and the preventative measures necessary for chemicals used in industrial processes are specialised and will therefore not be addressed in this paper.

Attack by atmospheric and other gases

The major atmospheric gas, nitrogen, has little effect on concrete in its elemental form. However, when combined with hydrogen to form ammonia it can be very aggressive to concrete. Similarly nitrous compounds can dissolve in atmospheric moisture and result in acid attack as noted above.

Oxygen is also not aggressive to concrete unless combined with nitrogen, carbon or sulphur to form acids which can then attack concrete as indicated previously.

However, carbon dioxide is one of the major factors contributing to the deterioration of concrete. Its action is slow due to the low concentration of CO_2 in the atmosphere and results in the conversion of the calcium oxides and hydroxides in concrete to calcium carbonate.

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$$

This conversion to carbonates results in a lowered pH and in a destabilisation of the complex silicates formed during the hydration and hardening of concrete. The pH is reduced from about 12,5 to about 8,5 with complete carbonation. When the carbonation depth reaches the reinforcing steel, the low pH causes the gamma-ferric oxide layer on the reinforcement to become unstable and the steel is depassivated. When this occurs and providing sufficient oxygen and moisture are available, the steel will start corroding. The rate of carbonation of concrete is strongly affected by the relative humidity of the pore structure and also increases with increasing temperature.

DISRUPTION OF CONCRETE

The durability of concrete can also be negatively affected by disruption of the concrete due to expansive reactions within the concrete. These expansive reactions can be due to the corrosion of reinforcing steel within the concrete or to alkali silica reactivity of the aggregate.

Corrosion of reinforcing steel

Concrete and steel reinforcement work extremely well together for two important reasons:

- The coefficient of thermal expansion of the two materials is almost identical, and
- When steel is placed in an environment that is alkaline or has a high pH, it forms a coating layer of gamma ferric oxide Fe2O3 which protects it from further corrosion or from the formation of more destructive oxides or rust. While the environment remains alkaline, this layer will protect the steel.

When cement hydrates, one of the by-products of the hydration reaction is the formation of calcium hydroxide $Ca(OH)_2$ - a very alkaline material that will raise the pH of concrete to about 12. While this calcium hydroxide is present in sufficient quantities, the concrete will protect the steel from further corrosion or rusting.

As discussed previously, carbonation of concrete causes the gamma-ferric oxide layer to become unstable and the steel to become depassivated. When this occurs and providing sufficient oxygen and moisture are available, the steel will begin corroding.

Chloride ions are not aggressive to concrete but are able to break down the passivating layer of gamma ferric oxide on the steel reinforcement and initiate corrosion.

The corrosion or rusting of steel is an expansive reaction and the oxides left when the reaction is complete will have a volume that is about eight times as great as that of the original steel. The expansion will cause cracking and push the cover concrete off the steel, causing spalling. This will open cracks, eventually expose the steel and corrosion will accelerate.

Alkali Silica Reaction

In some parts of the world, including some parts of South Africa, concrete aggregates have been found to be reactive in the highly alkaline pore structure of concrete. This causes the aggregate to expand, breaking up the concrete matrix. For ASR to occur, the aggregate must be reactive, there must be sufficient alkalis and moisture must be present.

INGRESS OF AGGRESSIVE AGENTS

Obvious avenues for the ingress of aggressive agents such as carbon dioxide or chlorides are defects in the concrete. In addition, increased permeability of the concrete can make it susceptible to the ingress of such agents. The following figures show the typical causes and patterns of most forms of cracking.

Typical defects in plastic concrete

Voids

Voids in concrete are caused by poor material selection, poor mix proportioning and sub-standard workmanship while the concrete is plastic.

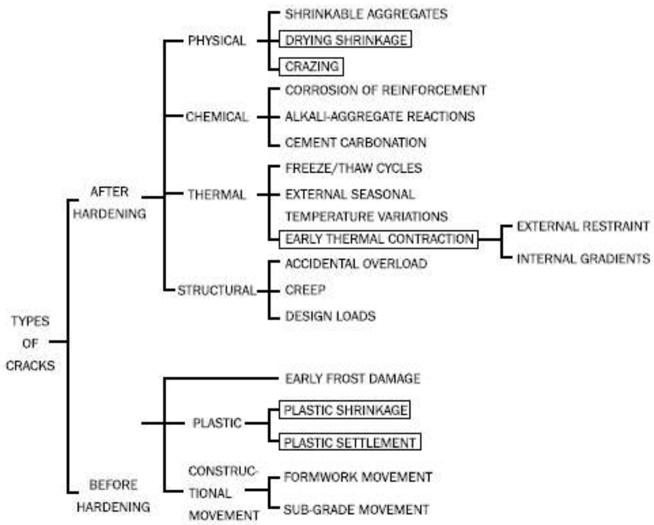


Fig. 2—Causes of cracks in concrete

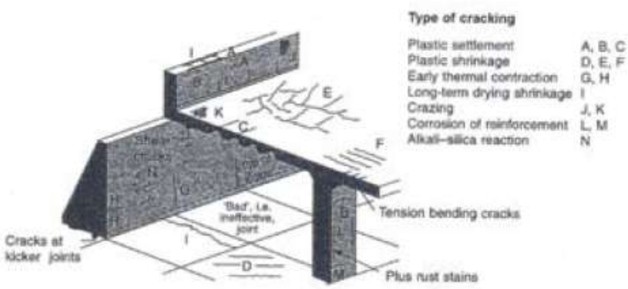


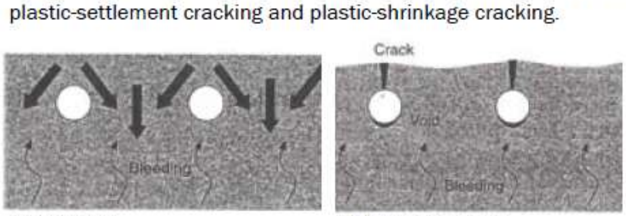
Fig. 3—Typical crack patterns

<u>Bleeding</u>

Concrete is a suspension of sand, stone and cement in water. The solid materials are all heavier than water and will sink to the bottom, forcing water to the surface where it is known as bleed water. As the solid particles migrate downwards, their passage is obstructed by coarse stone aggregate and steel reinforcement and the formation of voids under these obstructions is common-place.

The greater the depth of the concrete element, such as a column or deep beam, the further the water has to migrate when forced upwards. The effect is cumulative, and a greater proportion of water will pass through the top metre of a column than the bottom. Conversely there will be a considerably larger movement of solid particles at the top of a column than at the bottom with a consequently greater risk of cracking, increased permeability and reduced durability. Channels are often left in the concrete as a result of bleeding and these can provide pathways for the ingress of aggressive agents.

The degree of bleeding can influence the formation of both plastic-settlement cracking and plastic-shrinkage cracking.

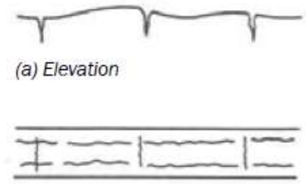


(a) Initiation *(b) After a few hours*

Fig. 4—Bleeding

<u>Plastic-settlement cracking</u>

Plastic-settlement cracking occurs simultaneously with bleeding and is the cracking that is propagated vertically or horizontally when the settlement of solid particles in concrete is inhibited by reinforcement or other sources of restraint such as those caused by changes in the section dimensions. (see Figures 5, 6 and 7).



(a) Elevation

(b) Plan

Fig. 5—Plastic-settlement cracking over reinforcement

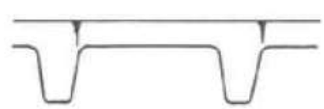


Fig. 6—Plastic-settlement cracking at change in section in coffered slabs

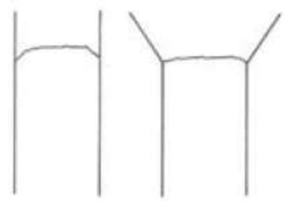
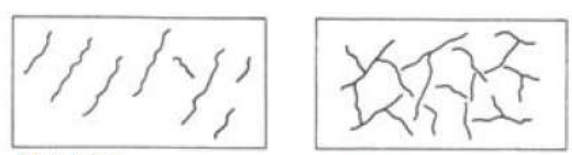


Fig. 7—Plastic-settlement cracking at change in section in columns or at stirrups

<u>Plastic-shrinkage cracking</u>

Plastic-shrinkage cracking is caused a by rapid loss of moisture during the period before curing begins; this causes differential shrinkage which results in cracks. Plastic-shrinkage cracks appear when the rate of drying is more rapid than the upward movement of bleed water to the surface. Plastic-shrinkage cracking is influenced by factors such as wind velocity, the relative humidity of the atmosphere and the temperatures of both air and concrete.



(a) Diagonal *(b) Random*

Fig. 8—Typical plastic-shrinkage crack patterns

<u>Movement of formwork</u>

The movement of formwork and/or falsework during or after concrete placement can cause cracking.

Grout loss

Grout loss occurs when forms are not grout tight and this can result in honeycombing and/or permeable concrete.

Quantity and type of binder in the mix

If insufficient binder is used in concrete, the growth of crystal gel will not achieve a dense matrix and the voids that cannot be filled with gel will provide access to aggressive agents at a microscopic level. It is generally considered that a minimum of 375 kg/m^3 of cement is necessary to achieve a reasonably impermeable matrix. Note that reasonably high strength concrete can be produced with considerably less cement if superplasticisers are used in the mix to achieve low water/cement ratios. The resultant concrete may not, however, have the requisite degree of impermeability. Certain binders such as fly ash can improve impermeability of concrete if curing is thorough.

Typical defects in hardened concrete

Cracks are caused by tensile forces that are set up in the concrete by loss of moisture or other causes.

Drying shrinkage cracking

Drying shrinkage cracks will usually traverse the least dimension of the element, will reach the edges and are often relatively straight.

Drying shrinkage cracking usually occurs at an early age after stiffening and hardening have commenced and will depend on the rate at which water can evaporate.

Drying shrinkage cracking occurs because moisture loss from the surface of concrete can continue over a long period of time, and the reduced volume of the concrete will result in internal tensile forces that may cause cracking if their magnitude exceeds the concrete's capacity to resist them.

The magnitude of the shrinkage will depend on the amount of moisture lost, i.e. high workability that has been achieved by the addition of water will result in high concrete shrinkage. Concrete with a high water requirement, perhaps because it contains a high proportion of fines or cement, will also have a high shrinkage.

Thermal cracking

The temperature of concrete that is batched and mixed at a high temperature may increase still further due to additional heat generated by the hydrating cement. This heat will result in a thermal expansion which can crack the concrete surface as the core expands. If the concrete sets in an expanded state, cooling of the concrete on removal of the formwork, can cause a contraction which may cause cracking. This type of cracking is normally only associated with large elements and high cement contents. Control of this type of cracking is usually by reducing the temperature of concrete at placement and control of thermal gradients within the concrete, often by means of insulation.

Cracking due to overloading

If loads are imposed on concrete that cannot be resisted by either the concrete or the reinforcement, then the result will be cracking of the concrete. This cracking often occurs when props and formwork are removed too early and the concrete has not achieved adequate strength.

Concrete permeability

The permeability of concrete is affected by a number of factors. These include aggregate grading, mix proportions, curing, detailing and construction practice. Each is detailed below.

Grading of fine aggregate

It is impossible to create an impervious, impermeable matrix with a single-sized sand. It is essential that a well graded sand, containing all sand-particle sizes, is used so that fine particles can fill or "clog" the voids between larger particles. The achievable packing pattern with well-graded sand is considerably denser than that of single-sized sand. Too high a proportion of very fine particles (smaller than 150 μm) will create a concrete that has a very high water demand and could be very sticky. Too little fine material will result in excessive bleeding.

Grading of coarse aggregate

The larger the size of the coarse aggregate used in concrete, the lower the water requirement will be. Less water will result in less cement being used, lower shrinkage and lower bleeding.

Mix proportions

Proportioning of concrete which has durability requirements should be carried out by a competent concrete technologist in an accredited laboratory. The type of materials used and their proportioning can have a significant effect on both plastic defects and the permeability of concrete.

Curing of concrete

When water is allowed to evaporate from the surface of concrete before the hydration process is substantially complete, the hydration reaction will cease. The growth of crystal gel will be halted and the density of the paste will be reduced - with a consequent rise in permeability that may facilitate the ingress of aggressive agents.

Curing concrete is essential to ensure the greatest possible strength and the highest degree of impermeability. Not curing concrete is very wasteful as much of the cement close to the surface would not be fully hydrated and play little or no part in the strength of the concrete or in providing adequate protection for the reinforcement.

Detailing

Poor detailing of concrete structures can have an adverse effect no only on cracking, but also on the ease of entry of aggressive agents into the concrete. Correct detailing includes the provision of adequate reinforcing to control cracking, ensuring that there is adequate cover to the reinforcing steel and also that cracking, as a result of changes in section, restraint, etc, are kept to a minimum.

Construction practice

Good construction practice is essential to ensure that concrete has adequate cover, is well compacted, without honeycombing, without plastic shrinkage or plastic settlement cracks, and is effectively cured to ensure low permeability.

CONCLUSIONS

As can be seen from the above, a large variety of agents are aggressive to concrete and the reinforcement contained in it. However precautions only need to be taken to counter these agents if they are likely to be present during the life of the concrete. The most common agents which are readily available in the environment, other than in industrial environments, and which are likely to result in durability problems are chlorides and carbon dioxide. Chlorides are generally only prevalent at the coast and only very close to the coast whereas CO_2 is only like to result in carbonation in the interior of the country. For most structures in the interior of the country, good detailing, good construction and adequate cover will control the rate of carbonation.

It is the intention of this workshop to cover all aspects of dealing with primarily these two primary causes of poor durability of concrete structures, in terms of designing of structures, specifying durability, constructing for durability and testing for durability.

ACI establishes portal for research papers

Dear Mr. Bain,

I would like to congratulate you on becoming the President of the Concrete Society of Southern Africa. As you know, the CSSA has an International Partner Agreement with the American Concrete Institute (ACI).

In response to requests from our International Partners, ACI is establishing a portal for research papers.

The objective is to allow researchers and others to review abstracts of papers published in ACI and its partners' journals and symposia proceedings, while allowing each partner to maintain control of the distribution of the individual papers.

The program would work as follows:

A) ACI will establish a database on our website that will contain abstracts of papers published in Journals and symposia proceedings of ACI and those partners wishing to participate.

B) Each partner will have the option to:

1) Place a PDF of the papers on ACI's website and allow free download of the papers to interested parties, or

2) Establish a link from the abstract on ACI's website to the partner's website. The partner can provide copies of the papers (PDF or hard copy), free or for a fee. If a fee is to be charged, the partner would handle the transaction.

ACI plans to allow ACI members to download a limited number of ACI papers as part of our member benefits and will charge members for additional copies. Non-members may download copies of the papers for a fee.

C) All abstracts and papers included in the database must be in English and in a format utilized by all partners.

D) Papers available on ACI's website for free distribution must be in English and in a PDF format. Papers available on the partners' website may be in English or the local language.

E) ACI will provide and maintain the database at no charge to the partners.

If the Concrete Society of Southern Africa is interested in participating in this program, please let us know so we might forward detailed instructions on how abstracts and/or papers are to be formatted.

Once we have agreed on all of the details, we can then modify our International Partner Agreement to include your participation in a joint research portal.

We believe the establishment of a research portal will be well received by both of our members and the concrete industry. We sincerely hope that you will join us in this exciting venture.

William R. Tolley
Executive Vice President
American Concrete Institute

ACI announces four seminars offered to concrete professionals

The American Concrete Institute (ACI) is pleased to announce four educational seminars to be offered this fall to help the concrete professional remain up-to-date on concrete construction and technology.

ACI has provided the industry with educational seminars since 1969, and each year continues to conduct more than 100 seminars throughout the U.S. to thousands of attendees on a variety of concrete technology-related topics such as structural design, durability, repair, troubleshooting, slabs on ground, and site paving.

In addition to having the most up-to-date information at each seminar, attendees receive 0.75 Continuing Education Units (CEUs), or 7.5 Professional Development Hours (PDHs), free ACI publications usually worth over $100, a continental breakfast, lunch, and refreshment breaks.

As always, ACI members receive special discounts on ACI seminars. For more information on seminars and to register, please call 248-848-3815 or visit www.concreteseminars.com

Changes in 318-08 Building Code

This intensive one-day seminar for engineers, architects, specifiers, building officials, and others involved with structural concrete will guide attendees step-by-step through the significant changes in the 2008 edition of the ACI 318 Building Code Requirements for Structural Concrete. Instructors will explain each change, why it was made, and what it means for the designer and specifier of structural concrete. Locations include: Chicago, Ill.; Washington, DC; Portland, Ore.; Dallas, Texas; Albany, N.Y.; Minneapolis, Minn.; Kansas City, Kan.; Orlando, Fla.; Denver, Colo.; St. Louis, Mo.; Phoenix, Ariz.; New York, N.Y.; Charlotte, N.C.; Des Moines, Iowa; Cleveland, Ohio; New Brunswick, N.J.; Miami, Fla.; and San Francisco, Calif. Additional dates for the 318-08 seminar will be added for the spring 2009 schedule. Visit www.concreteseminars.com for more details.

Seismic Design of Liquid-Containing Concrete Structures

This one-day seminar for designers, engineers, and academia will provide attendees with practical applications of the recently adopted provisions for seismic design of liquid-containing structures by working through extensive design examples. Locations include: St. Louis, Mo.; Cincinnati, Ohio; Denver, Colo.; Phoenix, Ariz.; and Pittsburgh, Pa.

Troubleshooting Concrete Construction

This is a one-day seminar for contractors, design engineers, specifiers, government agencies, and material suppliers. It will provide attendees with solutions to problems with concrete.

Locations include: Milwaukee, Wis.; Altanta, Ga.; Portland, Ore.; Austin, Texas; Boston, Mass.; San Francisco, Calif.; and Minneapolis, Minn.

Construction of Concrete Slabs on Ground

This one-day seminar will provide contractors and engineers with practical, useful information for construction of concrete slabs on ground. Locations include: San Diego, Calif.; New York, N.Y.; Omaha, Neb.; Houston, Texas; Little Rock, Ark.; Tampa, Fla.; Washington, DC; and Indianapolis, Ind.

For more information email Sara.steptoe@concrete.org

ACI Foundation launches new Concrete Legacy Society

The ACI Foundation, a wholly-owned subsidiary of the American Concrete Institute (ACI), is pleased to announce the launch of the Concrete Legacy Society, providing ACI members and concrete industry supporters the opportunity to name ACI and its Foundation in a number of planned giving programs.

Through the Concrete Legacy Society, donors will be able to make planned gifts to ACI, the ACI Foundation, or specific programs of their choosing. Gifts to either ACI or the ACI Foundation will be applied to areas in the greatest need and where the greatest impact will be realized. Alternatively, donors can request that gifts be made specifically to Student Fellowships and Scholarships, the Innovative Concrete Education program, the Concrete Research Council, the Strategic Development Council, or other programs of the donors' choosing. Each of these unique opportunities provides donors with options customized to their interests and charitable preferences.

"We are pleased to be providing the concrete industry with a host of planned giving options to satisfy peoples' desires for charitable giving," says William R. Tolley, president of the ACI Foundation.

"Donors to the Concrete Legacy Society are helping to ensure that future generations will have access to continued advancements in concrete knowledge – advancements that ACI has been providing since its inception in 1904."

Richard D. Stehly, vice president of ACI and a trustee of the ACI Foundation, has become the first to inform the ACI Foundation of his intent to bequest a portion of his estate through the new Concrete Legacy Society.

"ACI has enabled me to remain technically competent, and ACI continues to expose me to all the happenings and new developments in our industry," says Stehly.

"More importantly, though, I am motivated to give back to this industry that has shown such support for me throughout my career."

On its new Web site, the ACI Foundation offers a number of donation tools that provide prospective donors with resources to make informed charitable donations. Those donors wishing to make immediate contributions to ACI or the ACI Foundation may still do so by contacting ACI. **For more information on the ACI Foundation, and to learn how to make a planned gift through the Concrete Legacy Society, visit www.ACIFoundation.org**

Water reservoir built with hollow-core precast slabs

While concrete tank construction systems such as the Brun Tank System, of which Group Five is the sole local licence holder, have been around for a while, a small town in the Free State has made the news in concrete circles for boasting the first complete reservoir (wall & roof) erected using precast hollow-core concrete slabs.

Lindley, the town in the eastern Free State, is where South Africa's first complete reservoir has been erected using precast hollow-core concrete slabs. A skills shortage, especially of concrete aspecialists and shuttering expertise, led to a decision to extend precast slab technology, which has already been successfully used on reservoir roofs, to the walls. Besides negating the skills shortage, opting for the precast route meant substantial cost and time savings, while simultaneously guaranteeing consistency in the quality and requisite properties of the walls.

The Lindley reservoir forms part of the Government's programme of bringing water and water-borne sanitation to all South African communities. At a capacity of 1.2 mega litres, it will supply 950 housing units due to be erected on the outskirts of Lindley during the course of 2008/9.

Johann Steyn of MVDxariep Consulting Engineers, the company responsible for the project's design and project management, said the walls took a mere three days to erect.

"Had we opted for traditional shuttering it would have required four 1.2m lift sections, each of which would have taken about seven days to complete. On this basis the whole project would have stretched over six weeks had we been well equipped and had access to the necessary skills. As things stood at Lindley it would have taken much longer as neither condition applied.

"Being the first of its kind, this project involved a learning curve for all participants. Even so, the entire project took only seven weeks to complete. And, provided all the precast material is to hand, future reservoir projects using precast slab technology on the walls, columns, beams and roofs should take no more than 10 days to complete once the in situ floor has been constructed" said Steyn.

The in situ concrete floor at the Lindley reservoir took three weeks to construct. It comprised a reinforced concrete outer ring beam 400 mm wide x 500 mm deep and projected 300 mm above the concrete floor to provide adequate shear resistance to the reservoir walls. The 150 mm thick reinforced concrete floor was cast in four strips and the joints were sealed with horizontally positioned rubber water stops.

Wall slabs were supplied by Bloemfontein-based Stabilan. Based on hollow-core prestressed technology, each wall slab measures 1.2 m x 4.5 m x 250 mm thick and is rated at a compressive speaker (venue yet to be confirmed).

strength of 50 MPa. However, unlike traditional slabs which are fully hollow-core, the lower 1.2 metre section of each slab was cast in solid concrete to provide additional shear strength. Once installed, the joints between the slabs were grouted and a horizontally positioned steel strap measuring 90 x 8 mm was fastened 1 200 mm from the top of the wall to provide ring tension to the upper section of the wall panels. The inside of the wall was then lined with 30 mm thick gunite and painted with a waterproof sealant from Multi Chemical Construction.

An additional vertically positioned rubber water stop was installed along the bottom of the inner slab wall. It was covered with gunite, half of which was imbedded into the floor to prevent leaking through the bottom of the wall panels.

Precast roof slabs, in various lengths measuring 1.2 m wide and 160 mm thick, were also supplied by Stabilan to cover the 17 m diameter reservoir. They are supported by the precast walls on the circumference as well as two beams which divide the reservoir into three sections. Each beam is in turn supported by three columns. Measuring 330 mm x 330 mm and 330 mm wide x 1 200mm deep respectively, the columns and beams were constructed from masonry with in-fill concrete to utilise local bricklayers. The beams and columns could have been replaced by precast components manufactured by Stabilan.

After being placed in position, the roof slabs were grouted and covered with a cement screed 100 mm thick at the centre of the reservoir and 50mm thick at its perimeter thereby creating a 50 mm drainage slope. Steyn commented further that the quality control of concrete in water retaining structures is all important.

"On-site concrete mixing requires a full-rime supervisor to ensure the correct consistency and this certainly applied at Lindley."

Steyn foresees many more such reservoirs being constructed as the Government's water and sanitation programme gains momentum.

"I believe precast slab technology will come into its own, especially in small towns and rural centres where the expertise for shutter work is simply not available. A different situation applies in the cities where each project should be evaluated on the basis of available skills and equipment at any given time."

In addition to the new Lindley reservoir, a 150 kl sectional steel pressure tower was erected in close proximity to the reservoir. The tower, which comprises a galvanised steel tank on a steel frame, rises to nine meters at its apex. It was installed to feed the surrounding high-lying areas, which due to a lack of water pressure, cannot be adequately supplied by the reservoir. Both the reservoir and the water tower are supplied by electronically controlled pumps which in turn feeds all the other reservoirs in Lindley.

Following a path of least resistance the pump fills the concrete reservoir first. However, an over-riding system of electronically controlled valves has been installed to ensure that when necessary, water can be pumped into the water tower before the reservoir.

CMA director, John Cairns comments that the Lindley reservoir project is further evidence of the versatility of precast hollow-core slab technology.

"Precast concrete is still under-utilised in the country, but engineers are becoming increasingly attuned to its advantages as this project clearly demonstrates," maintains Cairns.

South Africa's first reservoir under construction using precast hollow-core concrete slabs.

Testing and quality control of concrete

By Steve Crosswell Pr Eng MICT (PPC Technical Support Manager)

Introduction

Concrete is unique among construction materials in that it requires various degrees of processing between arriving on site and being placed, compacted, finished and cured. This is true whether the concrete is site batched or arrives ready mixed. It is therefore necessary to sample and test the concrete to ensure that it complies with the requirements of the project specification.

SANS publishes the relevant standard methods, among which are:

- SANS 5861-2:2006: Concrete tests – Sampling of freshly mixed concrete
- SANS 5861-3:2006: Concrete tests – making and curing of test specimens
- SANS 5861-1:2006:Concrete tests – Consistence of freshly mixed concrete – Slump test
- SANS 5863:2006: Concrete tests – Compressive strength of hardened concrete
- SANS 865:1982: Concrete tests – The drilling, preparation, and testing for compressive strength of cores taken from hardened concrete

In practice the most commonly specified tests are the "slump test" and the "cube test".

Sampling of concrete

No test can be valid unless the sample is representative of the concrete to be tested. If there is any deviation from the sampling method described in SANS 5861-1:2006 doubt is cast upon the subsequent test results. In other words if the sampling is suspect, don't even waste time making and testing the specimens.

Specified sampling frequency varies but is commonly one sample per 50 m^3 of concrete, or part thereof, per day for each grade of concrete being produced.

The "slump test"

This test measures the consistence (wetness) of the concrete in the medium "workability" range. (Workability is a qualitative term describing the amount of work required to place and compact fresh concrete). The test is used to check that the water content of the concrete does not deviate significantly from the design value.

In the case of ready-mixed concrete the allowable deviation from the specified slump is as follows (SANS 878:2004):

Specified slump (mm)	Tolerance (mm)
50 and less	-15 to +25
More than 50, up to 100	± 25
More than 100	± 40

Large variability in slump test results indicates one or more of:

- Poor control of amount of water added
- Unacceptable variations in aggregate batching
- Change in aggregate water requirement
- Poor testing procedure

Making and curing of test specimens

The three crucial factors in making and curing the specimens (normally cubes) are:

- The condition of the cube moulds. Steel moulds are supplied in matched sets of pieces and the sides and bases from different moulds must not be mixed up.
- The compaction of the concrete. A concrete cube of 150 mm side should weigh approximately 8, 10 kg, while a 100 mm cube should weigh approximately 2, 40 kg.
- The curing temperature which should be between 22 and 25°C

It is important that the cubes are correctly labelled. Experience has shown the best method is to stick a paper label onto the top surface of the cube while the concrete is still plastic. The cube details are then written on the side of the cube with black lumber crayon when the cube is demoulded.

Scratching the cube number on the top surface of the fresh concrete does not work.

The "cube test"

This test measures the uniaxial compressive strength of concrete cubes which are made, cured and tested to very specific requirements. It does not measure or predict in any unique way the strength of the concrete in the structure. The test is simply a quality control test which measures the consistency of the concrete in terms of one particular property ("compressive strength") using an arbitrary test method (SANS 5863:2006). Testing the same concrete under different conditions, for example specimen size, specimen shape, curing temperature, loading rate, etc. will give different results.

From a quality control point of view the importance of the cube test result is not just the value of any individual result, but the variability in a series of valid test results.

What is a valid compressive strength test result?

A valid test result is the mean of the results of tests carried out on three specimens which are sampled from the same batch of concrete, and which are made and cured under standard conditions at any particular age, for example 3 or 7 or 28 days, with the proviso that the range of strengths between the highest and lowest individual result does not exceed 15% of the mean.

An invalid result, or a series of them, indicates one or more problems with the testing procedure. An invalid result is rejected from a quality control viewpoint and the cause of the invalidity must be investigated.

Typical causes include poor sampling and cube making, mislabelling of cubes, out of tolerance cube moulds, operator error, and malfunctioning compression machine.

Compression machine reference testing

It is essential that compression test machines undergo regular reference testing at about three monthly intervals. The fact that a machine is calibrated does not imply that it is producing reliable results. The way to carry out reference testing is to make and cure a large batch of cubes and to circulate sets to participating laboratories for testing. The results are then compared. The testing is normally done at three different strength levels, but not necessarily all at the same time.

Two acceptance criteria are given for general concrete work, both of which must be complied with:

- The result of any valid test must not be more than 3 MPa below the specified strength, e.g. 27 MPa in the case of a grade 30 mix, and
- The average of any three consecutive valid results must exceed the specified strength by at least 2 MPa, e.g. 32 MPa in the case of a grade 30 mix.

In the event of failure, the cause of the failure must be investigated and remedial action taken. Investigation would include checking the sampling and testing procedures, non-destructive testing of the concrete member(s), core testing, and load testing, sometimes all four.

The code also states that if the magnitude of the concrete work, or the sampling frequency, is such that at least 30 valid results for a specific grade of concrete become available in a three month period, the contractor may choose to have results assessed statistically.

In this case the average strength of any 30 consecutive valid results (for each grade) must exceed the specified strength by 1,7 times the standard deviation (SD) of those 30 results. In addition no single valid result may be less than 3 MPa below the specified strength.

Again, in the event of failure the cause must be investigated and remedial action taken.

Statistical analysis of results

Concrete cube strength is a random variable and the test results are influenced by many different factors related to variations in the materials, batching, sampling, testing, equipment and personnel.

Being a random variable, the results of cube tests taken from a particular grade of concrete will, for practical purposes, take the form of a normal distribution when plotted graphically. This type of distribution is sometimes called a "bell" curve because of its shape. (Like many aspects of concrete technology this is not strictly true – low strength and very high strength concrete test results give skewed distribution curves to the left and right respectively, but for practical purposes a symmetrical distribution is assumed.)

The normal distribution curve is characterised by two values, the mean or average value, and the standard deviation which quantifies the spread of the curve either side of the mean value.

The requirement that the average strength exceeds the specified (characteristic) strength by 1, 7 times the standard deviation implies that slightly fewer than 5% of results will fall below the specified strength.

The only factor under the concrete suppliers control is the standard deviation, the specified strength and the "1, 7" being fixed.

The value 1, 7 x SD is called the margin. The higher the SD, the higher the margin and the higher the average binder content of the concrete. In other words the higher the SD, the more expensive the concrete in terms of binder cost.

For example improving control from poor (SD = 7 MPa) to good (SD = 5 MPa) reduces the margin by 1, 7 *(7-5) MPa = 3, 4 MPa. A reduction in average strength by 3, 4 MPa is equivalent to saving 20 kg of binder per cubic metre of concrete. At current prices this is a saving of roughly R10 / m^3. Of course one has to balance this against the cost of the additional quality control necessary to reduce the SD and there is an optimum point where it becomes uneconomical to reduce the SD any further. For sophisticated concrete suppliers this point would be an SD somewhere in the region of 2, 5 to MPa.

The cusum technique

The cusum technique is a more sophisticated statistical tool which is used by large concrete suppliers, e.g. readymix concrete suppliers, to monitor concrete quality for a range of different mixes. "Cusum" is an acronym for cumulative sum and the technique involves calculating the cumulative sum of the differences between actual results and targeted or forecast results. Normally three cusum tables and charts are maintained:

- The mean strength cusum,
- The correlation cusum (correlation between predicted and actual 28 day results)
- The standard deviation cusum.

The slopes of the cusum charts indicate whether the results are over target, on target or under target. Abrupt changes in slope on one or more of the charts indicate that a change has occurred somewhere in the system. The source of the change could be materials related, sampling related or testing related.

Core testing

Core testing is commonly resorted to in the case of the failure of cubes to meet their specified strength. Core drilling, preparation and testing are covered in SANS 865:1982. Acceptance criteria for core test results are given in SANS 10100-2:1980, clause 14.4.3. The average strength of the cores must exceed 80% of the specified strength and no single core strength may be below 70% of the specified strength.

It is important that the test method is followed exactly as experience has shown that test procedures can affect results significantly. Of particular importance are squareness and flatness of the ends of the core. It is interesting that the section of core chosen for testing can significantly affect results. Recent tests carried out on cores from a floor slab consistently gave results 3, 5 MPa higher when the test specimen was cut from the bottom of the core rather than the top.

Apart from strength, core samples can also yield useful information such as degree of compaction, voids content, and distribution of coarse aggregate. The cores can also be analysed for binder content and slices from the cores can be tested for oxygen permeability, water sorptivity and chloride conductivity. They can also be tested for abrasion resistance and depth of carbonation. (The depth of carbonation test must be carried out on a freshly fractured surface, not on the outside surface of the core which will be contaminated with finely ground material from the drilling process).

Further reading

Fulton's Concrete Technology, eighth edition, Cement and Concrete Institute, Midrand, 2001. Chapter 14;

Monitoring concrete strength by the cusum system, Goodman H J, Cement and Concrete Institute, Midrand, 1996

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Fulton Awards Awarded in	CSSA President	Fulton Memorial Speaker	Total № of Entries	Fulton Award Winners in Categories:					
				Civil Engineering Structures	Building Structures	Sculptures	Aesthetic Appeal	Design Concepts	Construction Techniques
1980	MA Vasarhelyi	-	13	Public Library, Sasolburg	-	-	-	-	-
1981	GD Bendall	-	15	Preheater Tower, De Hoek	CSSA & School of Concrete Technology, Halfway House	-	-	-	-
1982	CJ Thompson	Dr D Davis (RSA)	9	Glenwood Tunnel, Durban	SATS Container Workshops, Cape Town	-	-	-	-
1983	KC Tucker	SC Watson (USA)	12	Bloukrantz Bridge, Cape	Port Control Building, Port Elizabet				
1984	EPJ van Vuuren	Prof D Billington (USA)	26	Tutuka Power Station № 2 Chimney, near Standerton	Cape Provincial Administration Head Office, Cape Town	-	-	-	-
1985	A Dutton	F La Due (USA)	18	Main Dam, Otjivero-Gobabis Regional State Water Scheme	No winner-				
1986	DP Samson	Prof W Hestor (USA)	23	Stellenberg Interchange Bridges, Cape Town	Precast Acoustic Drapes - Natal Provincial Theatre Complex	-	-	-	-
1987	JE Hodgkiss	Mrs A Smithson (UK)	21	Lethabo Boiler House Structure, near Vereeniging	Human Sciences Research Council Building, Pretoria	-	-	-	-
1988	JE Hodgkiss	R Lacroix (France)	16	FW de Klerk Bridge, Vereeniging	No winner	-	-	-	-
1989	RJ Snowden	Dr J Davidovitz	22	John Ross Bridge over the Tugela River	NG Kerkkompleks, Somerstrand	-	-	-	-
1990	PC Graham	D Lee (UK)	21	Swartklip Interchange Bridges, Cape Town	South African Trade Mission, Maputo	-	-	-	-
1991	CJ Lloyd	TW Kirkbridge (UK)	29	Malibamatso River Bridge, Lesotho Highlands Scheme	Klein Constantia New Maturation Cellars, Cape Town	Untitled Relief Panels	-	-	-
1992	VE Blackbeard	EC Chaplin (UK)	41	KSM Mill Complex, Pietermaritzburg	Bophuthatswana Parliament Building, Mmabatho	Untitled Concrete Sculptures, Medfem Clinic, Sandton	-	-	-
1993	D Peters	R Choy (Australia)	30	No winner	The Oaks Pavilion,& North Stand, Newlands, Cape Town	Cape of G H Nature Res Gateway Mould for Panoptic Gaze			
1994 *	MG Latimer	P Matt (Switzerland)	21	Tugela River bridge, № B351, N2, Durban – Richards Bay	Shanti Nikatan – House of Peace, Westville, Natal	Woman Dancing, Princess Daisy Boat, Soma Tree			
1995	Prof M Alexander	Dr AK Mullick (India)	18	Main Concrete Structures, Alusaf Hillside Smelter	BMW Pavilion, V & A Waterfront, Cape Town	-	-	-	-
1996	CH Waterson	J Pierce (USA)	17	Johannesburg Stadium, Johannesburg	Standard Bank Centre, Johannesburg				
1997	BA Raath	Sir Michael Fowler (UK)	13	Harper Road Bridge, Johannesburg	Eastgate Centre, Harare	Conch Structure, Lalucia Ridge Office Estate, Umhlanga	-	-	-
1998	PRA Flower	Dr G Rosenthal (RSA)	12	Katze Dam, Lesotho Highlands Scheme	Administration & Academic Building, University of PE	-	-	-	-
1999	DP Samson	L Mills (RSA)	16	New Black River Bridge, Cape Town	No winner	Driekoppies Dam, Mpumalanga	Post-tensioned Precast Concrete Reservoirs, Mpumalanga	Cooling Tower Shells, Majuba Power Station	
2001	G Maritz	-	34	Mozal Aluminium Smelter, Mozambique	Tokara Winery, Stellenbosch,	-	SA Jewish Museum, Cape Town	Sandton Convention Centre, Sandton	Finger Jetty, port of Richards Bay
2003	PRA Flower	-	23	Maguga Dam, Komati River, Swaziland	Apartheid Museum, Johannesburg	-	No award	Westcliff Estate, Johannesburg	Morland Millenium Bridge, Umhlanga Ridge
2005	VA da Silva	-	29	Mohale Dam, Lesotho Highlands	Constitutional Court, Hillbrow, Johannesburg	-	Nelson Mandela Bridge, Johannesburg	Chapman's Peak, Cape Town	Mohale Dam, Lesotho Highlands
2007	DC Miles	-	29	Impala Platinum Mine, No 16 Shaft, Rustenberg	Athlone Soccer Stadium, East Stand, Cape Town	-	Bosmansdam Road Pedestrian Bridge, CT	Mkomaas River Pedestrian Bridge, KZN	Durban Harbour Services Tunnel

CELEBRATING 30 YEARS OF EXCELLENCE

FULTON *Awards*

1979 - 2009

Nominations called for Fulton Awards

The Concrete Society of Southern Africa (CSSA) is calling for nominations of projects for the prestigious Fulton Awards, presented by the Society every two years to honour *excellence* and *innovation* in construction utilizing concrete.

Awards will be made in the following 5 categories:

Overall Civil Engineering Project
Overall Building Project
Concrete in Architecture
Unique Design Aspects
Construction Techniques

Any project completed during 2007 or substantially completed during 2008 is eligible for entry, and projects may be entered in more than one category. *Closing date for nominations is 28 November 2008.*

The Cement & Concrete Institute (C&CI) is confirmed as the anchor sponsor for the 2009 Fulton Awards.

Francois Bain, President of the Concrete Society of SA, says: "The 2009 Fulton Awards marks a very special occasion for the Society being the 30th year celebration of Fulton Awards!" The occasion will be celebrated over the weekend, from 19th to 21st June 2009, at the Champagne Sports Resort in the Drakensberg.

"Through the weekend format, the Society aims to provide increased exposure for all entrants and project submissions. Greater emphasis will be placed on *all entries for the 2009 Fulton Awards* with a special exhibition created for the nominated projects," Bain stated.

"The weekend format also enables the local construction industry to network in a more relaxed environment that stimulates discussion. The main awards evening – a black tie gala occasion – will take place on Saturday, 20 June 2009," he added.

For nomination forms and entry packs, contact The CSSA Administrator on Tel: 011-326 2485 or e-mail admin@concretesociety.co.za

The 2009 Fulton Awards marks a very special occasion for the Society, being the 30th year celebration of the Fulton Awards and will be held over the weekend of the 19th to 21st June 2009.