Concrete Beton

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The Official Journal of
The Concrete Society
of Southern Africa

CONCRETE SOCIETY
OF SOUTHERN AFRICA

Technical paper:
Shear failure of steel fibre-reinforced concrete based on push off tests

Technical paper:
Constructing for durability

New CSSA focus areas for 2009

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Front cover photo: courtesy Gautrain

CONCRETE SOCIETY
OF SOUTHERN AFRICA

President's Message

As this is the first edition of the Concrete Beton published since the Annual General Meeting, I would like to take this opportunity to convey my greatest appreciation to the Society for entrusting me with the task of heading up the leadership thereof for the 2008 / 2009 term, and I am honoured to now take up this position.

The following two years promise to be both busy and exciting with many government capex projects either starting or being well underway, leading up to the 2010 Soccer World Cup and beyond.

Considering this "buoyed" mood in the industry, and further to several preceding years of planning, the leadership of the Society has decided to amend certain structures and processes within the organization in order to streamline our functions, ensure our sustainability and most importantly enhance our relevance and value to our members.

In order to achieve the sustainability that we desire, we have identified a number of areas that we intend augmenting.

Firstly, we have decided to reconfigure the administration function to become a resource efficient and highly functional entity. We will shortly appoint a new Office Administrator, and soon thereafter an Administrative Assistant, to ensure continuity and smooth day to day running of the Society's Head Office. Within a year we aim to have a Director in place who will have a more strategic function.

In order to improve on the frequency and quality of functions and events, upon the said new administrative function being in place, the organization of all events will be centralized from head office in order to standardize quality and corporate identity.

A further crucial resolution reached by Council is to introduce a tiered corporate membership. This scenario will provide member companies with clearly defined benefits, which will obviously be dependant upon the level of membership decided upon. Such companies will still have to nominate a certain amount of individual members and in this way we do not loose the importance we attach "individual membership". Individual membership will still be available for those who prefer this option.

We feel that as the Concrete Beton is the only accredited journal in the concrete industry in Southern Africa, it is common sense that this publication should receive flagship treatment.

To this end, we are intent on improving the quality and quantity of our publications, especially the Concrete Beton as well as to distribute to a wider readership. Many of you will have noted the elevated quality of this particular edition. We have entered into an agreement with Crown Publications who will be publishing these documents henceforth on an outsourced basis. The Concrete Society will still retain all rights on the publication, however and our Editorial Board will still ratify all content.

This move expands our exposure, not only to our membership but also to the broader industry and will greatly assist in promoting The Society and bolstering membership.

The aforementioned decisions were taken after a significant amount of debate and consideration and we are of the opinion that Council's resolutions on these matters represent the best options to minimize the Society's financial dependence on a few sources and the resultant risk and represent a more financially stable entity.

We will soon be embarking upon a "road-show" to present our proposed intended new organizational format and protocols to the industry leaders.

You are obviously aware of the enormous success of The 2007 Fulton Awards gala weekend held at the Champagne Sports Resort in June of last year. We will be utilizing the same venue for the 2009 Fulton Awards and we can report that plans for this affair are well under way and it promises to be even more memorable event. Don't miss it!

This particular function was, in essence, the Council's first major thrust as part of its plans to generate a "new look" Society.

A call for nominations for entries for The 2009 Fulton Awards has already been made and requests for entry packs have already started rolling in. We ask that the membership please consider suitable entries and forward the details to our administrator as soon as possible.

We are introducing some small amendments with regards to entry regulations since the last awards. Firstly, in an attempt to promote concrete to Architects as a finish material in it's own right, we have opted to change the naming of the category "Aesthetic Appeal" to that of "Concrete in Architecture."

In an attempt to further enhance the status of the event, we have decided to not only judge the projects in the various categories, but also judge the entry pack submissions as part of the adjudication score. So please polish up the old grammar when putting together those submissions!

In this issue of Concrete Beton we report back on the Annual General Meeting which was held in March of this year. The event was highlighted by the presentation of the invited Key Speaker, Mr DA Kruger, the Assistant Advisor: Techno-Economics at the Chamber of Mines of South Africa, who enlightened us on the impact of the recent electricity crisis on the mining industry.

Branch reports received indicate some very exciting site visits, mostly to the 2010 Soccer World Cup Stadiums in the various centres. It is heartening to see this kind of activity taking place at branch level and the magnitude of attendance at these events is inspiring.

In addition to our usual Accredited Technical Papers, we have opted to include the papers submitted for the Society's highly acclaimed Durability Seminar held in October 2007 in the next few additions of Concrete Beton. In this addition we include George Evans of Grinaker LTA's paper entitled "Constructing for Durability" which gives a very informative overview of the Contractor's take on this extremely contentious topic.

The Gautrain project is hurtling ahead and we include an article covering the technical aspect of the viaducts which form an integral part of this significant project.

Old favourites such as the popular series of Steve Croswell's "Concrete Tips", as part of the "Conquest" section of the publication, are retained and this edition has no less than three "Concrete Tips" articles included.

There are also a number of new features we intend including in future issues of Concrete Beton. One of these is the introduction of a "Letters to Editor" section for which prizes for the best letter per addition and an overall prize for the best letter for the year will be awarded. So please feel free to get typing and send in those letters.

We are also considering including a "New Products" section which will be a forum for briefly introducing new products in a mini-advertorial type format.

In closing, I am proud to say that the Council is made up of a number of strong and very competent individuals and I am sure that together with the 'new look' administrative function, we will be running efficiently and provide our members with top class service.

Yours faithfully

Francois Bain PrEng
President

New CSSA focus areas for 2009

The Annual General Meeting of the Society was held at the offices of SAICE in Midrand, Gauteng. Outgoing president, Dave Miles welcomed members to the meeting, which included national office bearers as well as members of the local Inland branch.

The President's report had been previously circulated, but the following significant points were highlighted were mentioned:

- A 3,6% decrease in membership (mostly students);
- Irma Dyssel had resigned as national administrator leading to some administrative 'difficulties';
- Fulton Awards had been the highlight of the year with over 450 people attending the weekend in the Drakensburg;
- Many changes were planned to add more value for members and improve services;
- Society will be segmented into four main groups: publications; admin; functions and finance;
- Publications: these will be outsourced to external publisher - Crown Publications, thereby increasing issues to six per year and reaching a circulation of 5 000.
- Admin: plan to employ a full-time director of the society, plus admin staff to assist.
- Functions: an events coordinator will be engaged in due course;
- Finances: this will continue to be externally outsourced.

Commenting on membership of the Society the president reported that a decision had been made to introduce a Corporate Membership category in 2009 with the assurance that clearly defined benefits will accrue to those companies that joined.

In conclusion he thanked council for their support over the last two years, with what turned out to be a daunting amount of work. The president then, in presenting the society's chain of office, wished Francois Bain well as the incoming president, and assured him of his support as the immediate past president. He also extended his good wishes to Philip Ronné who had been elected as vice president of the society.

Francois Bain, the new president for 2008/09 presented his first address to the members, stating that this was a time full of changes in the society and 'getting down to business'. The departure of Irma Dyssel had been a catalyst to effect these changes which the outgoing president had outlined earlier.

The Fulton Awards had reached new heights and a new standard had been set which will be continued in 2009 and beyond.

The council members elected were described as a 'solid bunch' and the president stated that he was privileged to work well with them as a team. In conclusion he said that 2008/2009 promised to be very exciting years to be at the helm of the Society, and he planned make a great success of it.

The 2008/09 officer bearers for the CSSA are:

Exco:
President: Francois Bain
Vice-President: Philip Ronné
Immediate Past President: Dave Miles
Treasurer: Garth Gamble
Members:
Peter Flower (2008/09)
Zoe Schmidt (2008/09)
Nico Pienaar (2007/08)
Branch Chairmen:
Eastern Cape: Nick van den Berg (2008/09)
Western Cape: Lawrence Hendricks (2007/08)
Inland: Trevor Sawyer (2007/08)
KwaZulu-Natal: Dion Kuter (2008/09)
Directors:
President: François Bain
Vice-President: Philip Ronné

Outgoing president of the Concrete Society of Southern Africa Dave Miles and newly elected president Francois Bain at the CSSA's Annual General Meeting.

APOLOGY

We apologise for the omission of the professional and contract team for the L'Ormarins article in the Concrete Beton Issue 117 of December 2007. The team was:

- Specialist Concrete Sub-Contractor: Melt Wahl Concrete Services
- Owner: Johann Rupert
- Architect: Johan Wessels Argitek
- Main Contractor: J Van Der Sluys
- Consulting Engineer: De Villiers & Hulme Consulting Engineers
- Concrete Supplier: Lafarge

Electricity supply in South Africa: The mining industry experience

DA Kruger. • Assistant adviser: Techno-Economics at the Chamber of Mines of South Africa

Synopsis

A policy decision by Government in 1998 that Eskom was not to construct new generation capacity lies at the root of the current shortage of electricity. When that decision was taken it was expected that private sector entities would build and operate power stations. This, however, did not happen.

Economic growth resulted in the demand for electricity increasing until the generation reserve margin decreased to the point where the existing generation capacity can no longer meet the demand. This, together with primary energy supply problems, resulted in increasing load shedding that culminated in the near collapse of the electricity supply system in January 2008. At that time mines and other large industrial electricity users were deprived of electricity to restore the system balance.

As a result the mining industry came to a virtual standstill for five days. It took almost a week to regain sufficient electricity supply to resume limited mining operations.

Significant additional electricity generation capacity is expected to come into service only from 2012. Until that time demand side management measures appear to be the only option to maintain the electricity supply system balance.

Introduction

During mid-January 2007 South Africa experienced a severe electricity shortage when some Eskom generation units failed while a number of other units were out of service for maintenance. This resulted in extensive unplanned load shedding that affected all consumers, including a number of mines.

Since then the situation has not improved significantly and the mining industry continues to operate with a constrained supply of electricity.

Given that electricity is a critical input in mining operations and the total dependence of the mining sector on Eskom, this situation is likely to persist until Eskom commissions new generation capacity.

Background

In 1998 Government adopted a policy position that Eskom was not to build additional generation plant. Instead it was expected that independent private entities would enter the market and build generation plant. Unfortunately low rates of return on capital invested and the lowest price of electricity in the world were not incentives for private investment electricity generation.

By 2004 it became clear that, owing to economic growth, the demand for electricity was approaching the available supply while no private generation had yet materialised. The Chamber of Mines, as well as other bodies, brought this situation to the attention of the Minister of Minerals and Energy and later that year the position was reversed and Eskom was given permission to build new generation capacity.

Since then the situation deteriorated. For a while Eskom managed to avert a shortage of supply by increased utilisation of its plant, but higher utilisation of mid-life plant inevitably lead to increased risk of unplanned breakdowns of plant.

The first manifestation of a crisis was on 18 January 2007 when unplanned outages of generation plant threatened system stability and Eskom was forced to shed load by disconnecting consumers with little or no warning.

The winter of 2007 passed without generation outages due to unprecedented plant utilisation. During the latter half of that year the need to take generation plants out of service for maintenance together with unplanned outages owing to breakdowns resulted in load shedding on a daily basis.

Large mines, as key industrial customers, were increasingly required to reduce their demand in terms of the demand market participation scheme.

By January 2008 Eskom's reserve margin was between 8% and 10% against an aspiration of 15%.

A number of generation units were in mid-life requiring major planned maintenance and refurbishment. Power stations were also utilised above design levels, thus requiring more maintenance. Consequently unplanned outages occurred increasingly. In addition generation output was impacted as the heavy rains during January 2008 constrained the coal supply and affected the coal quality negatively.

The situation became critical on 24 January 2008 when Eskom experienced a shortage of 4 000 MW despite the implementation of load shedding and the reduction in demand by key industrial customers. Fears that the shortage could increase to the extent of affecting system stability resulted in Eskom declaring 'force majeure' and it requested gold, platinum and coal mines, as well as some large industrial customers, to reduce their demand to survival levels on 25 January 2008. The mines were also warned that, should they continue normal operations, their electricity supply could not be guaranteed.

The affected mines immediately ceased operations and all personnel was withdrawn from underground mines. That meant that workings where blasting had taken place on that day remained unsupported and experienced deteriorating conditions.

Following discussions by mining industry representatives with the Ministers of Minerals and Energy and Public Enterprises and Eskom, it was agreed to increase the electricity supply to the affected mines by 640 MW on 27 January to allow personnel to enter the mine workings and carry out making safe and maintenance operations.

On 29 January It was agreed at a meeting of mine representatives, the management of Eskom and the Ministers of Public Enterprises and Minerals and Energy that the electricity supply would be increased to 80% of normal demand with immediate effect and to 90% of normal demand by 30 January. In the event the increase to 90% of normal supply only commenced on 31 January.

From 24 January to 1 April 2008 the supply of electricity to consumers, other than the mines and large industrial consumers, continued at normal levels without interruption. This meant that during this period only the mines and large industrial consumers contributed to decreasing the demand for electricity to stabilise the system.

The Electricity Supply Industry

The electricity supply industry comprises the generation, transmission and distribution sectors.

The generation sector is dominated by Eskom with 28 licensed power stations with a licensed capacity of some 40 800 MW.

Electricity supply in South Africa: The mining industry experience

some of these power stations are not presently operational; some are being re-commissioned. Eskom's actual capacity is therefore in the region of 38 000 MW.

Some 1 200 MW imported electricity is available from Cahora Bassa.

There are 16 licensed municipal power stations with a licensed capacity of 1 841 MW. A number of these are not operational and most are quite old. The net municipal capacity is therefore probably about 700 MW.

In addition there are 11 operational licensed private power stations with a licensed capacity of 1 348 MW. The net capacity available is in the region of 1 280 MW.

Eskom owns and operates the national transmission system that conveys electricity at voltages above 132 000 V.

The distribution sector consists of systems owned and operated by Eskom Distribution and a number of systems owned and operated by various municipalities.

During the 2006/2007 year Eskom sold 218 120 GWh of electricity.

Coal Supply to Eskom

The majority of Eskom's power stations are coal fired. The mining industry is thus the largest supplier to Eskom. During 2006/2007 Eskom burned just more than 119 million tons of coal, i.e. 550 kg coal per MWh electricity produced. This makes Eskom the largest coal consumer in South Africa as it uses 48,5% of local coal sales.

Traditionally each coal fired power station received its coal supply from a dedicated or captive colliery. Controlling the quality of the coal was relatively easy and the price paid for the coal was determined by long-term cost-plus contracts.

Currently a number of coal fired power stations do not have captive collieries and in some cases the captive collieries are unable to supply all the coal required by their respective power stations. This compels Eskom to source coal from a number of other, mostly smaller, collieries on short-term contracts at the prevailing market price. This complicates quality control and increases coal costs.

In excess of 50% of the coal supplied to Eskom is produced by opencast collieries. During the heavy rains of January 2008 the production at these collieries was constrained and the coal produced had very high moisture content. This caused problems with coal handling and combustion at power stations.

Another constraint was limited transport capacity. Inland coal transport takes place mainly by road which is costly and inefficient and has undesirable side effects. The road transport is necessary because Transnet does not provide a suitable transport service.

The result was that some power stations experienced insufficient coal supply while some received sub-standard quality coal. This problem has not yet been fully resolved.

The Governance of the Electricity Supply Industry

The Department of Minerals and Energy is responsible for the management of South Africa's energy resources. As such it formulates policies on the generation, transmission, distribution and utilisation of electricity and drafts legislation to give effect to these policies.

The National Energy Regulator, established in terms of the Electricity Regulation Act, No. 4 of 2006, is the custodian and enforcer of the national electricity regulatory framework. It regulates the electricity supply industry through the setting of license conditions for generation, transmission, distribution, trading and export of electricity.

Electricity Planning in South Africa

The responsibilities of the Department of Minerals and Energy include the formulation of an Integrated Energy Plan (IEP) for South Africa that will facilitate policy formulation and decision making. IEP 1 was completed in March 2003. It was, to a large extent, a qualitative overview. Work on IEP 2 commenced late in 2005. The process was, however, suspended in mid-2006. Instead the Department issued the Energy Security Master Plan – Electricity 2007-2025 during December 2007.

The National Energy Regulator formulates the National Integrated Resource Plan. This plan is essentially a demand forecast matched with generation possibilities. It appears that the main purpose of the plan is to inform licensing decisions for generation capacity.

The Department of Environment Affairs and Tourism is developing a long-term strategy for the mitigation of greenhouse gas emissions. A large part of the work concerns electricity generation.

Eskom develops its Integrated Strategic Electricity Plan internally. It is essentially Eskom's long-term generation plan.

The electricity planning process, and indeed the energy planning process, in South Africa is fragmented and inadequate. There is insufficient co-ordination between the various planners and plans are formulated for different purposes.

The current plans address mainly the long-term demand, while little or no attention is directed to meeting the short-term demand, i.e. the next 5 years. The plans also do not adequately consider the potential of demand side management and energy efficiency to alleviate the electricity shortfall.

Electricity in the Mining Industry

In 2007 the approximately 1 150 mining electricity customers in South Africa consumed 15% of the electricity sold in the country. Of these 1 127 purchased electricity directly from Eskom, while the rest were supplied by municipalities. Eskom's mining customers consumed 32 421 GWh of electricity during the 2006/2007 year.

Electricity is an important input for all forms of mining; it is a major energy source for the transport of personnel, material and ore, production machines and mineral processing. In addition it is the exclusive power source for vital health and safety related applications such as the pumping of water, ventilation and refrigeration. Most underground mines experience an inflow of groundwater. This water has to be pumped out to maintain safety in the workings. Some gold mines in South Africa are situated in an area where the ore body is overlain by water bearing dolomitic strata. One such mine pumps some 70 Ml of groundwater per day to surface. The workings of mines are ventilated to remove dust and fumes and provide healthy atmospheres for workers. A survey of South African gold mines indicated that the average quantity of ventilating air circulated was some 6 cubic m per second per 1000 ton of rock mined per month. A mine producing 200 000 ton per month would therefore circulate 1 200 cubic m of air per second. That is 1,2 tons of air per second. The virgin rock temperature increases with depth. The rate of temperature increase, or the geothermic gradient, varies according to the type of rock and differs from place to place. In mine workings heat flows from the exposed rock surfaces and heats up the air. In order to provide a safe environment for workers in deeper mines it is necessary to cool the ventilating air. This is achieved by refrigeration plants which supplies chilled water that is in turn used to cool the air. The installed refrigeration capacity in South African gold mines exceed 1 400 MW of cooling power. In underground gold operations these health and safety applications may consume in excess of 55% of the total electricity used. On the average gold mine the cost of electricity amounts to some 11,4% of the total working cost. On collieries the average cost of electricity amounts to some 8% of the total cost for underground mines and 6% for opencast mines. During 2006 / 2007 the mining sector paid on average 16,9 c/kWh for electricity purchased from Eskom. Eskom does not provide special tariffs for mines; its mining customers are subject to the same tariffs as its other industrial customers.

During 2005 the Department of Minerals and Energy and a number of industrial undertakings, including most large mining companies, signed the Energy Efficiency Accord. In terms of the Accord the signatories agree to co-operate to pursue national energy efficiency targets on a voluntary basis. The target, set in terms of the Energy Efficiency Strategy of the Republic of South Africa, is a national final energy demand reduction of 12% by 2015, expressed as a percentage reduction against the projected national energy use in 2015, with a final energy demand reduction target for the industry and mining sector as a whole of 15% by 2015.

To date the mining industry has achieved electricity savings of more than 200 MW.

The Impact of the Electricity Supply Constraint on the Mining Industry

The mining sector, together with Eskom's other major industrial customers, which comprise the vast majority of South Africa's export industries, have borne the brunt of the electricity emergency. While the impact is not the same for all mines, it is mostly the large-scale deep level gold and platinum mines that were hit the hardest.

Given the critical importance of sustaining a safe working environment, a 10% reduction in electricity supply to such mines has to come out of production electricity as illustrated below.

A survey of the impact of a 10% reduction undertaken by the Chamber of Mines indicates that for the deep level mines production at 90% electricity sustained for one year would result in a 10% to 20% decrease in production.

For the period from 2008 to 2012, an investment decline of R23 billion would occur compared to a base case of 100% electricity supply. The impact of the emergency was

already felt in January when large year-on-year declines in production were recorded for gold (down 16,5%) and platinum (down 15,9%) with total mining production down 10,7%. The large-scale surface operations in the coal, iron ore, chrome and manganese were less affected by the electricity cuts.

Currently underground gold and platinum mines are experiencing great difficulty in operating at 90% of their normal electricity supply. It became clear that the 10% could only be achieved by closing parts of mines.

Consequently the Chamber of Mines requested Eskom to allow those mines where such closures were imminent to increase their electricity demand. Eskom agreed and the process to increase the supply commenced on 14 March 2008.

The Future

During 2007 Eskom installed open cycle gas turbine generators with a capacity of 1 036 MW at Mossel Bay and Atlantis in the Western Cape. During 2008 this capacity is to be expanded by a further 1 000 MW. These open cycle gas turbine generators use diesel fuel and are very expensive to operate. They are, however, useful during short periods of peak demand.

During the early 1990s Eskom mothballed three older power stations: Camden near Ermelo, Grootvlei near Balfour and Komati between Middelburg and Bethal. Work is currently underway to re-commission these power stations.Camden Power Station will be the first to be fully returned to service and it will add 1 600 MW to the Eskom system. The final unit is scheduled for commissioning by the second quarter of 2008. Grootvlei Power is scheduled to be in full commercial operation by March 2009 providing 1 200 MW. Komati power station, with a capacity of 1 000 MW, is scheduled to be in commercial operation by 2011.

Arnot, one of South Africa's oldest power stations, is undergoing extensive refurbishment to increase its capacity by 300 MW

Work commenced in 2007 on the construction of Medupi coal fired power station at Lephalale in Limpopo Province. This power station will have an installed capacity of 4 788MW installed capacity. The first unit is scheduled to be commissioned by the first quarter of 2012 and the final unit in 2015.

Construction of the Ingula pumped storage scheme in the Drakensberg, with a planned output of 1 332 MW, is underway. The station is planned to be fully operational by the middle of 2013.

Construction of Project Bravo, a new coal fired power station, near the existing Kendal Power Station, is to commence during 2008. This power station, with an installed capacity of 4800 MW, is planned for full commercial operation by 2015/2016. Eskom is also investigating the construction of a large pumped storage scheme, Project Lima, along the escarpment between the Nebo Plateau and the Steelpoort River valley, in Mpumalanga Province. A capacity of 1 500 MW is envisaged. Eskom is investigating the construction a 3 500 MW nuclear power station as the first step in installing up to 20 000 MW of nuclear power generation capacity. An environmental impact assessment is being conducted at 5 possible sites.

Conclusion

While it appears that Eskom's long-term plans will provide sufficient generation capacity to meet the demand by 2014 with a comfortable reserve margin, generation capacity will remain constrained until at least that time as illustrated below.

Since the current utilisation of the generation plant is not sustainable, the situation is likely to deteriorate further.

While open cycle gas turbines can be installed relatively quickly, this may not be a solution to the generation shortage; South Africa has almost no natural gas. Consequently open cycle gas turbines will have to be operated with liquid fuel, which is already in short supply as well as expensive.

Co-generation by industrial electricity consumers appears to be a partial solution to the problem. A number of entities have generation capacity that could be utilised for co-generation. Others have unutilised energy resources, such as combustible waste products or waste heat that could be used for co-generation. So far the process to implement co-generation has been slow and onerous.

As no other significant practical options are available, the only other means of ensuring a stable electricity supply is to curb the demand. This should ideally be done through the implementation of energy efficiency measures. There is currently, however, no legislation in place that empowers Government to impose energy efficiency measures. A draft Bill has been formulated, but is still to be introduced in Parliament.

To mitigate the economic impact of the electricity shortage it is necessary for Government to:

- accelerate and simplify the process to introduce co-generation
- enact the Energy Bill without delay to provide a legal basis for compulsory energy efficiency measures
- introduce incentives for energy efficiency measures.

References:

Chamber of Mines website – www.bullion.org.za

Eskom website – www.eskom.co.za

Eskom Annual Report 2007

Facts & Figures 2006 – issued by the Chamber of Mines

NERSA: Electricity supply statistics for South Africa 2005

Cape branches visit World Cup Soccer Stadiums

Eastern Cape

The Concrete Society of Southern African Eastern Cape Branch has experienced significant changes in the past three months. This has seen the election of the new chairperson (Nick van den Berg – Goba), new vice-chairperson (Shaun Hayes – Structural Solutions), new treasurer and secretary (Carmen Alting) and committee members (Kate Routledge – Structural Solutions and Fanie Smith – Concrete 4 U). Louis Visser (Sika) is still on committee as the immediate-past president and Monty Mare (PPC) will be stepping down, but remaining involved, with his pending retirement.

With all these changes has come a great new enthusiasm to make the Concrete Society more relevant to those involved in some way in the concrete industry in the Eastern Cape.

"We are therefore in the process of finalising our diary of events. We have some exciting technical talks planned as well as visits to some prominent sites. All site visits will be accompanied with technical discussions so as to ensure that practical as well as technical lessons can be learnt from the visit. Furthermore we are looking at putting together a golf day towards the end of the year," explains van den Berg.

A special note to those in the East London region:

"We are extremely keen to ensure that you are part of our planning and would appreciate your input and ideas. We need to gauge what the level of interest is and hence any feedback from interested parties from this region is welcome," he continues.

"We will be sending out the diary of events in the next few weeks to all those who we have on our contacts list. If you are not sure if you are on the list and would like to receive this diary then please send me and email and I will ensure you are on of our mailing list. We thank you for your support and hope that the Concrete Society will give you the kind of service you wish for and deserve here in the Eastern Cape," maintains van den Berg.

Nick van den Berg can be contacted at nickv@goba.co.za or Tel: 041-373 6552

Port Elizabeth Stadium Site Visit

The Concrete Society Eastern Cape Branch hosted a site visit to the new Port Elizabeth Stadium on 27 and 28 May 2008. Access to the site was limited to 15 people per visit hence the need to arrange for two visits.

The visit involved a presentation on the progress of the stadium (and it is on time!) and some of the design issues that require resolving. This was followed by a walk around the stadium where various aspects of the construction was explained from the pre-cast yard to the sequencing of the programme.

NMMU Student Prize

The Concrete Society Eastern Cape Branch presented Andre Hefer (NMMU student 2007) with an award for achieving the highest mark in the subject Structures & Concrete III at their annual prize-giving function on 23 April 2008. This award is an annual award that seeks to encourage an interest in structures and in particular concrete. The prize was R500 and a year's membership to the concrete society.

Western Cape

The Western Cape branch recently hosted a site visit to the new Green Point Stadium, Cape Town, on 24 April 2008. More than 90 members and their guests arrived at the stadium for a much awaited visit of the 68 000 capacity soccer stadium.

The site visit kicked off with a tour of the centre pitch of the stadium where the members and guests viewed the Cape Town sun setting on a masterwork in progress. Many of the seats are already in place and one immediately get the feeling of anticipation that a big event is about to occur.

After the tour members were entertained by Andrew Phantom, Project Manager of the Murray & Roberts / WBHO Joint Venture, in the visitor's centre where he explained the significant progress and many obstacles that have and still have to be overcome before the kick-off of the FIFA World Cup in 2010.

Snacks and drinks were served afterwards by courtesy of the sponsors. Thank you to Lafarge and SIKA for sponsoring the drinks and snacks and to the Murray & Roberts / WBHO Joint Venture for receiving the delegation so openhandedly.

The 68 000-seater Green Point Soccer Stadium in Cape Town is beginning to take shape. Delegates from the Western Cape branch of the Concrete Society visited the site recently.

American Concrete Institute announces Spring Seminars

Attendees can earn Continuing Education Units (CEUs) by participating in any of six seminars to be offered this spring.

The American Concrete Institute (ACI) is pleased to announce six educational seminars to be offered this spring 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 visit www.concreteseminars.com

Design of Concrete Slabs on Ground

This one-day seminar will provide engineers and designers with practical tools and information that can be used right away for slab design. Locations include: Atlanta, Ga.; San Francisco, Calif.; Dallas, Texas; Las Vegas, Nev.; Minneapolis, Minn.; Boston, Mass.; and Portland, Ore.

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: Atlanta, Ga.; Dallas, Texas; Las Vegas, Nev.; San Francisco, Calif.; Minneapolis, Minn.; Boston, Mass.; and Portland, Ore.

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: Houston, Texas; New York, N.Y.; Miami, Fla.; Los Angeles, Calif.; Denver, Colo.; and Pittsburgh, Pa.

Simplified Design of Concrete Buildings of Moderate Size and Height

This one-day seminar will focus on the design of concrete buildings of moderate size and height. The purpose of this seminar is to provide civil, architectural, and structural engineers with ways to simplify design procedures. Locations include: Williamsburg, Va.; Jacksonville, Fla.; Denver, Colo.; New Brunswick, N.J.; Des Moines, Iowa; Cincinnati, Ohio; and Albany, N.Y.

Environmental Engineering Concrete Structures: Design and Details

This one-day seminar is for consulting engineers, private industrial firms, government agencies, material suppliers, testing agencies, academia, and contractors. This seminar will provide attendees with information regarding the requirements for design of liquid-containing structures (LCS) and design examples to illustrate practical applications. Locations include: Orlando, Fla.; Kansas City, Kan.; San Diego, Calif.; Milwaukee, Wis.; Seattle, Wash.; Baltimore, Md.; Oklahoma City, Okla.; and Indianapolis, Ind.

Concrete Repair Basics

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25-27 August	Singapore	33rd Conference on Our World in Concrete & Structures
28-29 August	Singapore	5th International Specialty Conference on Fibre Reinforced Materials
24-26 November	Cape Town South Africa	International Conference on Concrete Repair, Rehabilitation & Retrofitting

Shear failure of steel fibre-reinforced concrete based on push off tests

by Bryan Barragán, Ravindra Gettu, Luis Agulló, and Raúl Zerbino

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The paper presents results of an experimental study that analyzes the shear behaviour of steel fibre-reinforced concrete. Direct shear push-off tests are carried out on normal- and high-strength steel fibre-reinforced concrete specimens. The test can be performed in a stable manner for steel fibre-reinforced concrete, permitting the determination of the pre- and post-peak responses and, consequently, characterizing the shear stress that can be transferred across an open crack. The shear stress-slip response is analyzed and toughness-based parameters, for possible use in design, are calculated.

Introduction

One of the most promising structural applications of steel fibre-reinforced concrete (SFRC) is the use of fibres as shear reinforcement, due to the brittle nature of shear failure. This is of further importance when dealing with high-strength concrete (HSC), which is inherently more brittle than conventional concrete. Along these lines, some applications of SFRC have been studied[1] for example, to replace stirrups in thin-webbed beams and enhance the web-flange shear transfer in girders. Also, it has been shown that the shear strength and deformability of shear keys in segmental construction, for example, of pre-stressed bridge girders and tunnel linings, can be significantly increased through the use of fibre reinforcement.

The objective of the present study is to characterize the failure and toughness of SFRC subjected to direct shear loading at the material level. With this aim, the push-off test on a double-notched prism is used to quantify the shear stress-displacement behaviour of SFRC. The experimentally obtained shear stress-slip response is used to calculate toughness-based parameters, which can be employed in structural design. Reference tests were also carried out on plain concrete specimens.

Research significance

The fundamental knowledge of the shear failure and toughness of steel fibre-reinforced concrete is essential for the introduction of ductility or toughness parameters in relevant structural design. If such parameters can be obtained from simple tests, they could be probably used in designs including shear keys, web-flange stress transfer, and punching resistance. Additionally, the validation of a simple test method will facilitate the comparison of the behaviour of different types of SFRC within materials engineering processes aimed at enhancing shear transfer in applications such as slabs and tunnel linings.

Specimen geometry and test setup

There has been significant interest in determining the response of SFRC under direct shear failure, and several types of specimens have been used for this purpose[2,3].

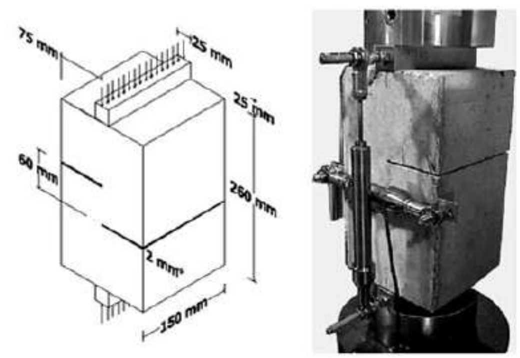

Fig. 1—Push-off specimen in study.

The general objective of performing these tests has been to produce shear failure along a prescribed plane (normally defined by cutting notches in the specimen), employing compression and bending loads. One exception is the Japanese JSCE-SF Standard[4], where a double-shear test is performed on un-notched prisms. However, it appears that even in this case, specimens with notches and a single shear plane lead to more representative results[5]. Among the different approaches used, the most popular seems to be the push-off specimen (Fig. 1), made up of two L-shaped blocks that are connected through a ligament along which the shear loading is applied. Previous researchers[2,6-12] have used different types of push-off tests with variations in the specimen dimensions. In some cases, the notches are cast (that is, not cut), which could cause a non-uniform fibre distribution near the notches due to wall effects. To avoid cracking outside the shear plane, some researchers have resorted to using side grooves (which may result in a two-dimensional crack front) and placing reinforcing bars in the blocks (which may interfere with the fibre distribution). The control of the test could also be a problem[13] if an appropriate testing machine is not used.

Taking advantage of the previous experience with this type of test and extending it further, a test geometry and configuration that would permit failure dominated by shear along the vertical plane, at least in the SFRC specimens, were adopted. It was also intended to have a specimen that is based on standard dimensions and easy to handle and test. After several preliminary tests considering different variations of the width of the loading bar, boundary conditions, mode of control, and loading rate, the specimen and test setup given in Fig. 1 were chosen.

The push-off specimen is obtained from one of the halves of a notched or un-notched beam previously tested in flexure after cutting away the part that could be affected by the fracture process.

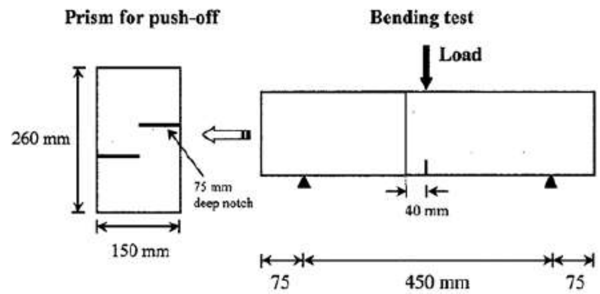

Fig. 2—Preparation of push-off test specimen.

This facilitates the use of standard moulds and the same specimen for both flexural and shear tests. In the present study, all the specimens were cut from 150 x 150 x 600 mm notched beams that had been tested under centre point loading, as in Fig. 2. The specimen length was chosen to be 260 mm and two notches of 75 mm length were cut 60 mm apart, perpendicular to the axis of the specimen, as in Fig. 1. The load is applied through steel bars of 25 mm width, and 2 mm thick Teflon sheets are placed between the fixed loading platens of the machine and the bars to compensate for nonparallel loading surfaces.

In discussing such shear tests, one conceptual aspect that has to be addressed is the failure mechanism, which appears to be governed by splitting-tension rather than by shear.

Nevertheless, the tensile stresses are approximately an order of magnitude smaller than the shear stresses and, consequently, shear cracking is expected to dominate the failure when tensile cracking is restrained by the fibres. Moreover, in the present specimen, the use of a ligament length of 60 mm, which is small compared with the total specimen length, helps the development of shear cracking.

To ensure the presence of dominant shear stresses in the ligament, the specimen geometry was studied using elastic finite element analysis (by means of the DRAC code).

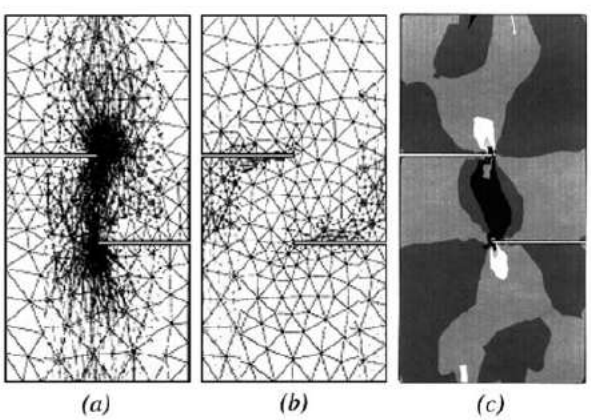

Fig. 3—Finite element mesh used and distributions of: (a) compressive; (b) tensile; and (c) shear stresses (darker areas indicate higher magnitudes of stress).

The stress distributions obtained are given in Fig. 3, where it can be seen that high compressive stresses occur along the central plane (Fig. 3(a)) with some tensile stresses near the notch faces (Fig. 3(b)), indicating the possibility of cracking.

The shear stress distribution is shown in Fig. 3(c), with darker zones indicating higher stresses; it can be seen that there is a zone of high shear stresses between the tips of the notches, confirming that shear failure would occur if tensile cracking was to be restrained by the fibres. This was also seen in independent analyses of the same specimens performed at the Politecnico di Milano[14].

The tests were performed in a servo-hydraulic testing system under closed-loop control with a constant piston displacement rate of 0.001 mm/s, which resulted in the peak load occurring at about 5 minutes and a test duration of approximately 30 minutes. Three specimens were tested for each concrete. In addition to the load, displacements were measured by means of linear variable differential transformers (LVDTs) of 2 mm span, mounted horizontally and vertically on one of the faces of the specimen, as in Fig. 1. The vertical LVDT gives the load-line displacement, which is taken as the slip, once the crack has formed. The horizontal LVDT gives the dilatation of the crack or the crack width during the shear failure. All measurements were recorded continuously using the controller and software.

Materials and specimen preparation

Two concrete mixtures were studied: a normal-strength, 30 MPa concrete, C30, and a high-strength, 70 MPa concrete, C70. Table 1 gives the proportions of the two mixtures. In each mixture, two dosages of steel fibres, 20 and 40 kg/m^3, have been incorporated. In both cases, the fibres were non-coated, collated, and hooked-ended, with circular cross sections. The characteristics of the fibres can be seen in Table 2; the fibres denoted as RC-80/60 BN were incorporated in the C30 concrete and the higher-strength fibres, denoted as RC-80/30 BP, were used in C70 concrete. The shorter fibres with higher strength were used in the C70 concrete because such fibres are recommended for high-strength concrete to obtain adequate toughening[15]. Note that direct comparisons cannot be made between the two concretes because the fibre densities are significantly different. The concretes are denoted hereafter by the base concrete denomination followed by the fibre dosage, as in Table 1.

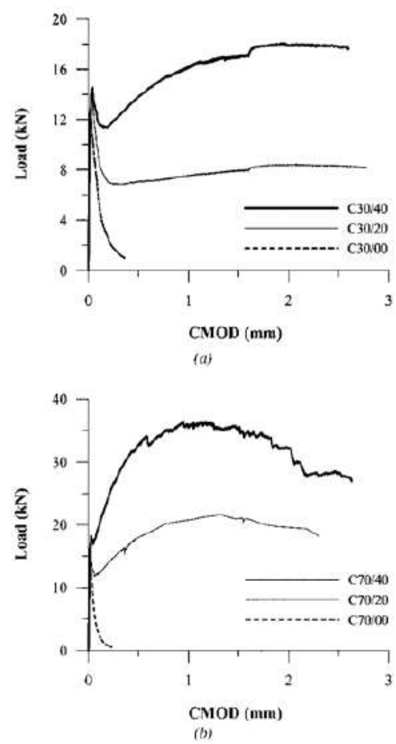

Fig. 4—Load crack mouth opening displacement curves in flexure for: (a) C30 concrete; and (b) C70 concrete.

Shear failure of steel fibre-reinforced concrete based on push off tests

All mixtures were prepared using a 0.25 m^3 vertical-axis forced-action mixer. The mixing procedure was as follows.

First, the gravel, sand, cement, and silica fume (in the case of high-strength concrete) were dry-mixed for 1 minute.
Second, water was added and the mixing continued for another minute, after which the high-range water-reducing admixture was incorporated. Lastly, in the case of plain concrete, the mixing was continued for another 3 minutes and then stopped. For the SFRCs, the mixing continued for 2 minutes and then the fibres were incorporated and the components were mixed for another 3 minutes. The mixtures were observed to be homogeneous with adequate workability.

Slump test results of the fresh concretes are presented in Table 3, along with other standard properties. A systematic reduction in the slump with an increase in fibre dosage is observed, as expected. The compressive strength *fc* and modulus of elasticity *E* were obtained through uniaxial compression tests of 150 x 300 mm cylinders at the age of 28 days. No significant influence of the fibres on *fc* and *E* could be identified, though the latter was seen to increase slightly with fibre dosage.

For each concrete, 150 x 150 x 600 mm beams were cast, all from the same batch, and compacted using a 50 Hz vibrating table. The filling of the moulds followed the recommendations of RILEM TC 162-TDF.[16] A preferential orientation of the fibres along horizontal planes can be expected in such specimens[17]. Therefore, it is important that the notch planes have the same orientation, with respect to the casting direction, in all the specimens. The top surfaces of the specimens were finished manually and covered with a plastic sheet. After 24 hours, the specimens were demoulded and placed in a fog room (at 20°C and 98% relative humidity [RH]) for 28 days, after which they were transferred to the laboratory for testing.

As mentioned previously, the beams were subjected to flexure prior to obtaining the prisms for the push-off tests. In the flexural tests, the specimen with a 25 mm-long notch at midspan (refer to Fig. 2) was tested under three-point bending. The typical load-crack opening (CMOD) curves are shown in Fig. 4. As it can be seen, toughness increases noticeably with fibre dosage and concrete strength, with a tendency toward hardening-type response in the high strength concrete (Fig. 4(b)).

Table 1—Mixture proportions of concrete

Components	C30			C70		
	C30/00	C30/20	C30/40	C70/00	C70/20	C70/40
Cement type CEM 1 52.5 R, kg/m³	349			480		
5 to 12 mm gravel, kg/m³	978			921		
0 to 5 mm sand, kg/m³	873			840		
Densified silica fume, kg/m³	–			48		
Water added, kg/m³	205			161		
w/c	0.57			0.35		
Naphthalene-based high-range water reducing admixture (solids % by weight of cement)	0.25			2		
RC-80/60 BN fibres, kg/m³	–	20	40	–	–	–
RC-80/30 BP fibres, kg/m³	–	–	–	–	20	40

Table 2—Characteristics of fibres used (as provided by supplier)

Properties	Fibre	
	RC-80/60 BN	RC-80/30 BP
Carbon content	Low	High
Length, mm	60	30
Diameter, mm	0.75	0.38
Minimum tensile strenght, Mpa	1100	2300
Modulus of elasticity, GPa	200	200

Table 3—Characteristics of concrete

Concrete	Slump, mm	f_c, MPa	E, GPa	π_c, MPa
30/00	150	40.2	30.0	4.1
30/20	140	38.9	31.8	6.2
30/40	110	38.3	31.8	5.9
70/00	200	77.7	36.6	5.5
70/20	130	76.5	37.2	8.2
70/40	50	77.8	38.9	10.0

Results of push-off tests

Failure modes

The typical mode of failure in unreinforced (plain) C30 and C70 concretes can be seen, respectively, in Fig. 5 and 6, where the two sides of the same specimen are shown. The first crack initiates on one of the notch faces, at approximately 20 mm from the notch-tip (marked as Point 1 in Fig. 5), and propagates towards the tip of the other notch (that is, Point 2). At about the same time, Crack 2-2 appears (refer to Fig. 5), which could be defined as a shear crack. Sometimes, only one crack of the 1-2 type appears, followed by almost instantaneous splitting failure. Because the cracking is dominated by tensile splitting, this type of test method has been criticized in the literature[18] as being inapplicable for obtaining the shear behaviour of plain concrete.

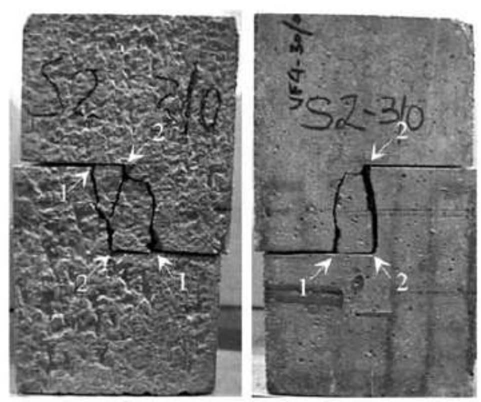

Fig. 5—Typical failure mode for plain C30/00 (both sides of same specimen).

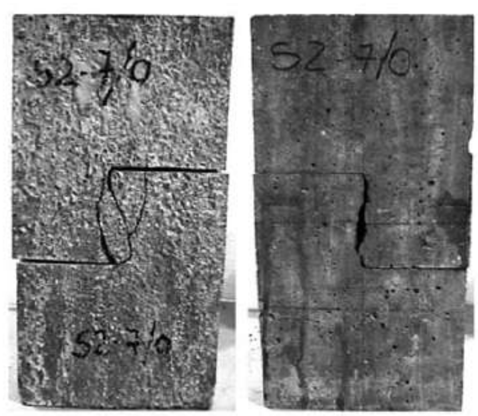

Fig. 6—Typical failure mode for plain C70/00 (both sides of same specimen).

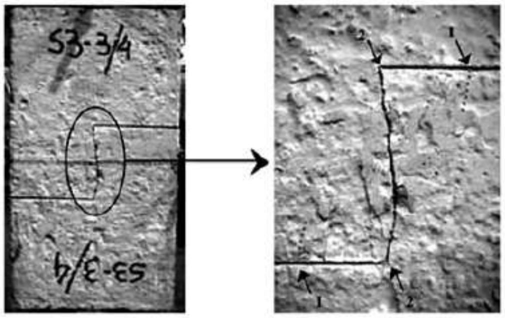

Fig. 7—Typical failure mode for C30/40 (same specimen, closer view on right).

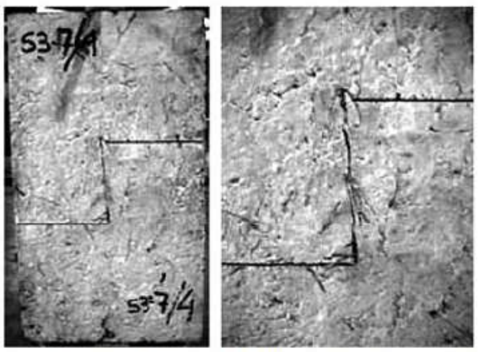

Fig. 8—Typical failure mode for C70/40 (same specimen, closer view on right).

The mode of failure in SFRC, however, is significantly different from that of plain concrete, as seen in the typical crack patterns of Fig. 7 and 8, for normal- and high-strength concretes, respectively.

Each of the figures shows one side of a tested specimen on the left and a closer view of the cracks on the right. Generally, failure occurs with the propagation of a vertical crack band that is approximately 10 mm wide. In some cases, there is secondary tensile cracking, that is, a crack starts at Point 1 (refer to Fig. 7) and develops to a length of approximately 10 to 15 mm (shown as dashed lines in Fig. 7).

This secondary crack is later arrested and the shear crack band develops along Plane 2-2. It appears that the fibres limit the opening of the tensile cracks, leading to a shear-dominated failure in the SFRC. This justifies the use of the present test methodology to study the shear failure response of fibre concrete, even though it is not entirely suitable for the analysis of such failure in plain concrete.

Load-displacement response

Figure 9 and 10 show the typical stress-versus-slip responses for the C30 and C70 concretes, respectively. Note that the nominal shear stress is obtained by dividing the applied load by the nominal shear-plane area of 93.8 cm^2.

For the plain concretes, a practically linear response can be observed up to brittle failure. The behaviour of the SFRC specimens is significantly different; the response is linear up to the first crack (indicated by a peak), followed by nonlinear behaviour. After the first peak, the load in the C30 fibre concretes tends to decrease gradually, indicating that the fibres do not affect the maximum load but cause a significant toughening effect. For higher fibre densities, as in the case of the C70 fibre concretes, there is an increase in the stress after the first peak (marked as "A" in Fig. 10), which is bigger for the higher fibre dosage, followed by a gradually decreasing post-peak response with significant residual strengths. The maximum shear stresses or strengths τu, are quantified in Table 3 for all the concretes; the values clearly reflect the significant increase in shear strength in the C70 concretes.

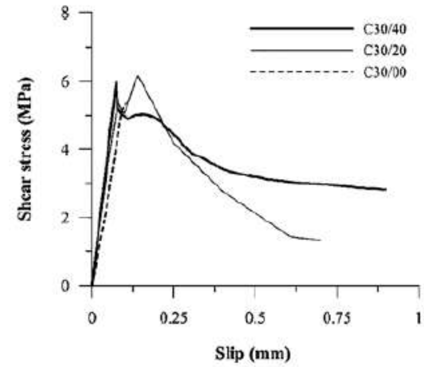

Fig. 9—Shear stress versus slip relationship for C30 concretes.

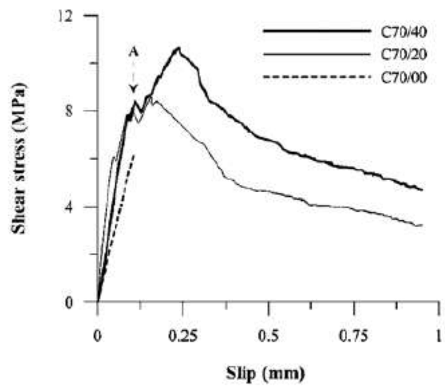

Fig. 10—Shear stress versus slip relationship for C70 concretes. (Note: "A" denotes first peak.)

It should be noted that the C70 concrete had shorter fibers with the same aspect ratio as the fibres in the C30 concrete, which results in a much higher density of fibres in the former case for the same dosage.[19] The toughening observed in the tests is a result of the pullout and dowel action of the fibers during the shear cracking. The pullout resistance tends to close the crack while the shear forces tend to open it due to the irregularity of the crack faces and aggregate interlock, as illustrated in Fig. 11. This produces a confining effect, which together with the dowel action of the fibers and friction between the crack faces, can lead to an increase in the shear strength and/or post-peak toughening, especially when the fibre density is high and there is better fibre-matrix bond. This is in accordance with the conclusions of the work of Walraven and Stroband,[20] where push-off specimens with traditional reinforcement or external restraint were studied.

The failure process can be further explained with the help of Fig. 12 (showing typical load versus slip and load versus crack width curves) and Fig. 13 (showing the corresponding curves of crack width versus slip). Until Point A (that is, the first crack), the matrix dominates the response, with negligible crack opening; beyond this point, the crack opens much further. Between first cracking and the maximum load (that is, Point B), the fibres are progressively activated and the matrix cracks completely. Thereafter, the shear fracture localizes in a dilating microcrack band, with the stresses being transferred through the fibres. There is a linear relation between the slip and crack width during this stage.

Toughness in shear failure

Traditionally, toughness of SFRC is defined in terms of the load-displacement response of a specimen under flexural load. There are

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several possible measures of toughness that can be defined in terms of this response, as discussed by Gopalaratnam and Gettu.21 Most of them are based on the shape or area under the load-displacement curve until a certain prescribed limit. Such approaches have been extended herein to permit the evaluation of shear toughness using the load-slip curve obtained in the push-off test.

Absolute toughness

First, the shear toughness is analyzed considering the absolute toughness $B^S_{s_{lim}}$, defined as the area under the stressslip curve until any prescribed slip limit s_{lim} where τ^s is the shear stress at the slip s.

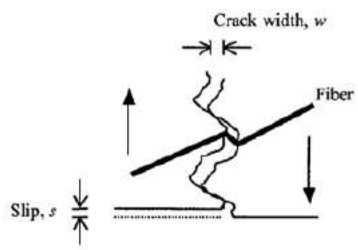

Fig. 11—Displacement along cracked shear plane.

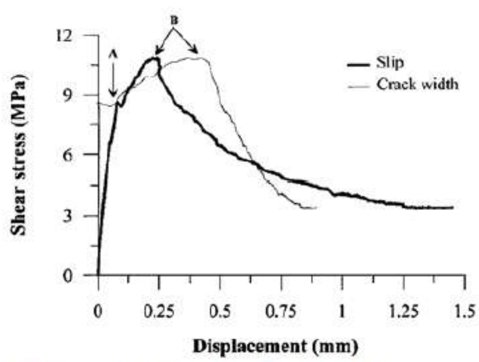

Fig. 12—Load versus slip and crack width relationships. (Note: "A" denotes first peak and "B" denotes maximum load.)

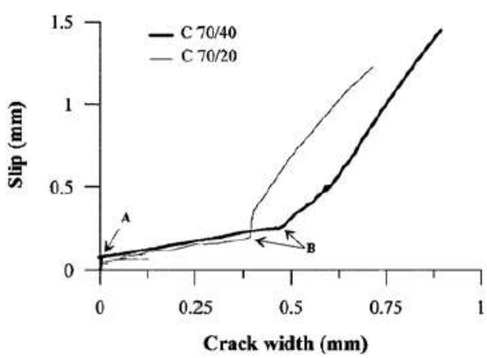

Fig. 13—Crack width versus slip relationship. (Note: "A" denotes first peak and "B" denotes maximum load.)

$$B^S_{s_{lim}} = \int_0^{s_{lim}} \tau^S(s)ds$$

Its evolution with an increase in slip limit can be seen in Fig. 14 and 15 for the C30 and C70 concretes, respectively. The choice of the slip limit has to be made considering the application, just as in the case of tensile toughening measures.[21]

For the C30/20 and C30/40 concretes, the absolute toughness does not exhibit a clear increase when 40 kg/m^3 of fibres are used instead of 20 kg/m^3, which is to be expected because the shapes of the stress-slip curves are similar. In the case of the C70 concretes, however, the trends clearly reflect the increase in toughness with an increase in fibre dosage, with larger differences at higher slip limits. For example, a 45% increase is achieved at a slip of 1 mm when the amount of fibres increases from 20 to 40 kg/m^3.

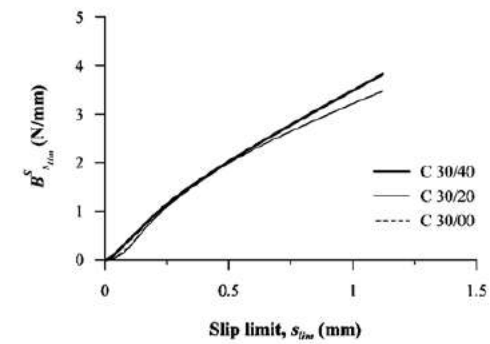

Fig. 14—Evolution of absolute toughness with slip limit (for C30 concretes).

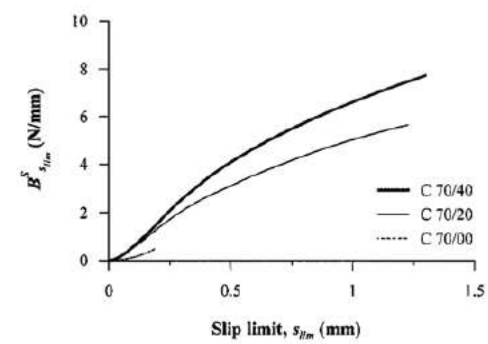

Fig. 15—Evolution of absolute toughness with slip limit (for C70 concretes).

Table 4—Eqivalent shear strength results

Concrete	Eqivalent shear strength results $f^s_{s_{lim}}$, MPa		
	$f^s_{0.25}$	$f^s_{0.50}$	$f^s_{1.00}$
30/20	4.7	4.1	3.7
30/40	4.5	3.9	3.8
70/20	6.4	5.9	4.6
70/40	7.3	7.1	6.6

Equivalent shear strength

As in the case of the equivalent flexural strength, which has already been introduced in design recommendations for SFRC,[22] the equivalent shear strength can be obtained as

$$f^S_{s_{lim}} = \frac{B^S_{s_{lim}}}{s_{lim}}$$

Average values of equivalent shear strength up to slip limits s_{lim} = 0.25, 0.5, and 1.0 mm are presented in Table 4, where the values are averages from three specimens. As in the absolute toughness, the incorporation of 40 kg/m^3 of fibres in the C70 concrete leads to a 45% increase of f^S 1.00 with respect to the concrete containing 20 kg/m^3 of fibres whereas the values are similar for the C30 concretes.

Residual shear strength

The residual strength can be considered to be a direct measure of the effective stress that can be transferred across an open crack. Table 5 shows the results of the residual strength at the same slip limits considered for the equivalent shear strength.

Table 5—Residual shear strength results

Concrete	Residual strength τ^{slim}_{res}, Mpa		
	$\tau^{0.25}_{res}$	$\tau^{0.50}_{res}$	$\tau^{1.00}_{res}$
30/20	4.7	2.7	2.7
30/40	4.1	3.1	3.2
70/20	6.9	4.2	2.6
70/40	8.7	5.8	4.3

The trends are the same as those observed earlier, though the residual strength for the C30 concrete seems to increase slightly with an increase in fibre dosage at larger slips. Nevertheless, the increases observed in the C70 concrete are much more significant.

CONCLUSIONS

Tests of notched specimens in the push-off configuration demonstrate the energy dissipation capacity of steel fibre-reinforced concrete in the post-cracking regime. The incorporation of fibres in concrete subjected to shear leads to a better mechanical integrity during failure. The pullout resistance and dowel action of the fibres can lead to considerable residual load-carrying capacity in shear dominated failure.

Significant improvements in the ductility of concrete during shear failure and some increase in the shear strength are achieved through the incorporation of steel fibres in both normal- and high-strength concretes.

The knowledge of the shear stress that can be transferred across an open crack is of great importance for fracture mechanics-based design approaches, where residual and/or equivalent shear strengths could be integrated along the sections of the structural element subjected to shear to calculate its shear load-carrying capacity. Studies on the enhancement of the shear cracking resistance of the web-flange interface in pre-stressed concrete I-beams have been carried out with promising results at the Universitat Politècnica de Catalunya, with promising results.[23] On the other hand, because the push-off test is simple, it can be used to assess the shear strength of SFRC for its incorporation in code-type structural design procedures. Nevertheless, because the fibres tend to have a preferential orientation,[17] due to the vibration during the compaction of the concrete or the placing procedure, the laboratory tests should be performed such that the failure plane represents the fibre distribution in the structural element.

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NOTATION

$B^S_{0.25}$ = absolute thoughness until slip limit of 0.25 mm
$B^S_{0.50}$ = absolute thoughness until slip limit of 0.50 mm
$B^S_{1.00}$ = absolute thoughness until slip limit of 1.00 mm
B^S_{slim} = absolute thoughness until slip limit of $^S lim$
E = modulus of elascity
f_c = mean value of comprehensive strength
$f^S_{0.25}$ = equivalent flexural strength up to slip limit of 0.25 mm
$f^S_{0.50}$ = equivalent flexural strength up to slip limit of 0.50 mm
$f^S_{1.00}$ = equivalent flexural strength up to slip limit of 01.00 mm
f^S_{slim} = equivalent flexural strength up to slip limit of $^S lim$
$\tau^{res}_{0.25}$ = residual strength at slip of 0.25 mm
$\tau^{res}_{0.50}$ = residual strength at slip of 0.50 mm
$\tau^{res}_{1.00}$ = residual strength at slip of 1.00 mm
τ^{res}_{slim} = residual strength at slip of $^S lim$

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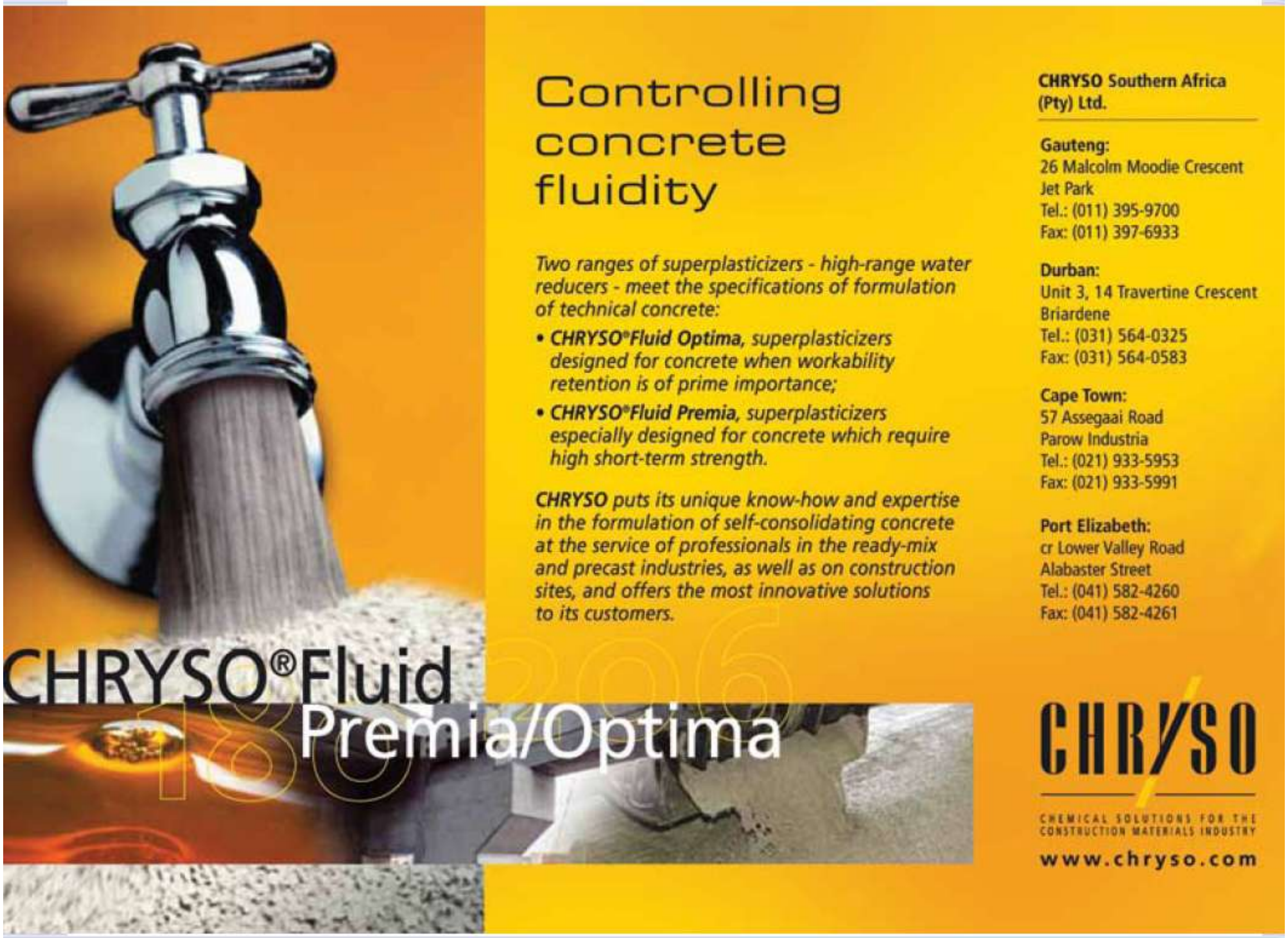

Constructing for durability

by George Evans: Grinaker-LTA Civil Engineering

1. Introduction:

The achievement of durability in concrete structures is reliant upon the satisfaction of many requirements throughout the construction process. The problem is that there is no single standard or code of practice on durability. The standards or codes of practice for the design of concrete structures or for concrete itself contain requirements or recommendations for the minimum quality of concrete, and when used correctly in project specifications, they provide a framework for the provision of durable structures.

Concrete is however a sensitive material, and its performance and durability can be significantly altered by minor constituents and poor workmanship. The fact that concrete is a complex porous chemical material, normally reinforced with steel and exposed to a wide range of environments, results in reinforced concrete being vulnerable to a large number of deterioration mechanisms than most other construction materials.

The challenge is to ensure that the rate of deterioration is not so rapid as to give problems within the required service life.

The introduction of durability index testing to evaluate the quality of the near-surface concrete enforces contractors to develop a better understanding of the concept "constructing for durability"; the art of producing durable concrete and maintaining those properties through all facets of handling to result in a hardened complex porous chemical material, capable of withstanding the service conditions over a period of time without significant deterioration.

2. Understanding of the concept: "Constructing for Durability"

Generally, durability is provided by the quality of the near-surface (covercrete) hardened concrete properties, which are influenced by its plastic state characteristics.

Homogeneity of the concrete through all facets of mixing, transporting, placing, compaction and protection will determine the variations in the potential durability. The homogeneity therefore depends on the workability required (based upon the selected transportation and placing methods) of the concrete that will influence:

- The ability to fill the formwork and surround the reinforcement with a limited energy supply,
- The ability to expel entrapped air and to achieve maximum density by optimum aggregate packing.
- The stability to avoid separation of water and large aggregates, (Segregation, which includes bleeding and plastic settlement)

Protection and curing procedures, will determine the extent the potential durability properties of the concrete are achieved.

The equivalent age or degree of binder hydration is governed by the concrete materials composition and the effectiveness of the curing procedures to "densify" the concrete with time.

3. Transferring concrete technology into concrete structures:

Significant time and effort is afforded to structural design and the science of concrete technology, which focuses the selection and specification of concrete constituents, proportioning and plastic and hardened property performance to ensure optimum strength, resistance to deterioration and protection to reinforcement. This is a science supported by codes of practice, standards and laboratory test data.

The art of construction is to produce a structure, as designed, using construction materials selected for that purpose. During construction, lack of attention to proper quality control can produce concrete that may be inferior in both durability and strength to that assumed by the designer. Particular factors in this respect are: reproducing concrete with the selected constituents, transportation, discharge, placement, consolidation, protection and curing.

Durability refers to the materials: How long will it last? (Design)

Quality refers to the construction: How well was it built? (Construction)

If the same attention to design is afforded to the quality of construction and execution of work as was done with the introduction of self-compacting concrete in Japan during the early 1990's, a dramatic improvement in durability could be realised. This does not imply that SCC be used to address the quality of the placed concrete, but rather the principle.

4. Why transfer the science of concrete technology into concrete structures?

Concrete is a sensitive material, and minor constituents and poor workmanship can alter its performance and durability. The effects of the handling processes and environmental conditions may contribute towards more rapid deterioration if not controlled.

Concrete is a complex porous chemical material, normally reinforced with steel and exposed to a wide range of environments. It is not necessarily the concrete that deteriorates, but rather the corrosion of the reinforcing steel that makes it more vulnerable than most other construction materials.

5. How do we transfer the science of concrete technology into concrete structures?

5.1 Concrete Production:

Concrete can be consistently reproduced with the selected constituents through a controlled batching facility in which the materials, moisture contents, power consumption (indication of workability and consistency) and the concrete's plastic properties can be measured.

It is important that batch plant operators and supervisors should at all times be vigilant for any changes in slump or workability. Of all the components, the water is the simplest to introduce, has the greatest influence on the plastic and hardened properties, and is also a useful tool; it immediately indicates scale or batching errors or changes in the material properties. This is possible if the water batching system is accurate and if the batch plant operators are properly trained and supervised.

5.2 Transportation:

Consider the requirements that the mixed concrete shall be discharged from the mixer and transported as rapidly as practicable to its final position by means that will prevent segregation, adulteration, loss of ingredients and ingress of foreign matter or water and that will maintain the required workability at the point of placing.

5.3 Placing:

There are numerous factors that should be considered to ensure that concrete is placed into the formwork in a satisfactory state. The

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placing teams do not always understand the effect of the following on the variation in the potential durability of the concrete:

- The concrete should be deposited vertically into, or as close as possible to its final position to avoid segregation and displacement of reinforcement and other items that are to be embedded.
- Deposited concrete should not be so worked to cause it to flow laterally in such a way that segregation occurs.
- The concrete should not be heaped, but placed in uniform horizontal layers.
- Concrete should not fall freely through a height of more than 3 m, unless otherwise approved.
- When closed circuits are being concreted, placing should commence at one or more points in the circuit and proceed in opposite directions at the same time so that on completion of the circuit the junction or junctions are formed with freshly placed concrete.
- The rate of placing should be such that cold joints and planes of weakness in the hardened concrete are avoided.
- Trained supervisors should closely observe the placing procedures and operators.

5.4 Compaction:

There are several basic rules that should be followed to ensure that the concrete is properly compacted into a uniform, void free mass:

- The concrete should be fully compacted against the formwork and around reinforcement and other embedded items without displacing them during and immediately after placing.
- The concrete shall be free from honeycombing and planes of weakness.
- Adequate compaction should be achieved by mechanical vibration or other approved methods.
- Vibration should be continuously during the placing of each batch of concrete until the expulsion of air has virtually ceased.
- Immersion (poker) vibrators should be inserted vertically into the concrete to be compacted, at regular spacings not exceeding 0,6 m or 10 times the diameter of the vibrator, whichever is less.
- As soon as a water sheen is visible on the surface, the vibrator shall be slowly withdrawn from the concrete, care being taken to avoid the formation of voids.
- The rate of concrete placing should not exceed the capacity of available compaction equipment operators.
- Only skilled operators should be permitted to undertake compaction by vibration.

Note:

It is virtually impossible to over-vibrate a properly designed and proportioned concrete mix. The dangers and problems arising from under compaction are far greater than any arising from over-vibration. BUT, excessive mechanical vibration can cause the stone in the mix to settle and the mortar to be brought to the top. The wetter the mix, the more prone it will be to this type of segregation.

5.5 Delayed compaction, re-vibration:

Concrete may be re-vibrated 1 to 2 hours after placing, provided it is still workable, i.e. provided the vibrator will penetrate the concrete under its own weight, and on removal will close up the hole. Re-vibration may improve the surface finish of the concrete by reducing blowholes and eliminate plastic settlement and plastic shrinkage cracks, especially at the tops of doorways, arches, box outs columns and walls. It also ensures a good bond between concrete and rebar, and results in an increase of the compressive strength. Do not re-vibrate after the initial set has taken place.

5.6 Protection and curing:

Curing is the name given to procedures used to promote cement hydration, by the control of temperature and humidity conditions of the concrete, with respect to time after placement.

Concrete should be protected against moisture loss immediately after placement, compaction and levelling. Concrete is most vulnerable to the effects of early moisture loss at this stage and the protection is necessary to limit early evaporation and to avoid plastic settlement and plastic shrinkage, resulting in near surface (covercrete) stress. The curing efficiency will ultimately determine the magnitude to which the stresses will be compounded.

In general, the longer the period of curing, the better will be the quality of the concrete. This applies not only to its compressive strength, but also to its durability, impermeability, its resistance to wear, weathering and chemical attack, and to its freedom from crazing and shrinkage cracking.

Protection and curing are important to:

- Control early-age heat evolution and temperature distribution in the concrete structure to minimise the risk of thermal cracks,
- Controlling the humidity and temperature in the covercrete zone to enable effective hydration of the cementitious binder.
- Minimise excessively high or low temperatures.
- Prevent erosion by rain and flowing water.
- Control thermal gradients by limiting the rate of heat dissipation.
- Prevention of contamination, damage by frost or mechanical means.
- Limiting the effects of vibration and impact that could disrupt the concrete and interfere with its bond to the reinforcement.

5.7 Other considerations:

5.7.1 Cover/spacer blocks:

A lack of attention to the quality, size and location of spacer blocks could result the rapid deterioration of the reinforcement, which it is designed to support. Concrete spacer blocks made on the construction site must be made under strictly controlled conditions, to ensure that the following minimum requirements are achieved:

- Spacer blocks made from cement and sand should be made of the cement and sand used for the surrounding concrete.
- Proportions should be 1 volume of cement (loose), 1 volume of sand (dry and loose) and only sufficient water to produce a mix that can be thoroughly compacted.
- The annealed wire ties should not be inserted to more that 50% of the nominal depth of the spacer block.
- Spacer blocks should be cured in water for at least 14 d and should in any case be stored in water until used.

5.7.2 Use of "slush" or "priming":

It is common practice to prime pump line with a slush/mortar consisting of various proportions of cements and (not always) sand. This mixture is normally left to the pump operator to mix without control of the materials, proportioning and quantity. Whilst this is necessary for the pumping operation, the quantity and quality of the "slush" must be controlled; it is normally deposited into the forms resulting in grout loss, excessive bleed runs, sand streaking, discolouration, crazing etc.

Another application of "slush" or "priming is its placement into a column or wall shutter prior to concrete placement. This application is intended to compensate the potential concrete segregation caused by the placement method, reinforcement or height of free-fall and should ensure an improved bond to the substrate. Again, due to the lack of control of the materials, proportioning and quantity, the "slush" often results in grout loss grout loss, excessive bleed runs, sand streaking, discolouration, crazing, poor surface strength etc.

5.8 Cover to reinforcement:

Failure to achieve the specified concrete cover to steel reinforcement is probably the greatest single factor influencing the premature deterioration of reinforced concrete. The very large sums of money spent on repair and replacement of concrete structures worldwide could be dramatically reduced if the provision of adequate covercrete of appropriate quality, properly compacted and cured is assured.

Studies have shown that about half of the defects are attributable to site operations. Many of the problems leading to insufficient cover are related to defects in design, detailing or supply of materials (e.g. steel bending) These types of problems are unrelated to the required level of cover and thus cannot be solved by specifying increased cover. For example, if the deficiency in cover were the result of poor detailing leading to two bars needing to occupy the same space, or through omission or collapse of chairs supporting soffit reinforcement, then specifying greater cover would have no influence.

Some current contracts require the contractor to provide evidence that the cover achieved is as specified. This requirement is normally addressed by determining the depth of reinforcement by covermeter survey. It seems to be assumed that by imposing such a requirement will ensure that the specified cover is achieved! The covermeter survey is performed too late in the construction process to have any influence on the achievement of the specified cover. It is obviously practical and preferable to eliminate potential defects prior to concrete placement.

This requirement does however emphasise the importance of cover achievement and could be an effective means to enforce stringent checks of the cover prior to and during concrete placement. Tolerances for reinforcement location prior to concrete placement may need to be different from those after the concrete has been placed, to allow for the effects of settlement and formwork displacement.

6. Experiences and questions regarding Durability index testing:

6.1. The Oxygen Permeability index measures to a greater extent, the macro defects in hardened concrete. This index is therefore largely influenced by the material type and grading, bleeding, voids, degree of compaction, cracking etc. The nature of concrete handling in-situ is not precise, and is analogous with an art to accommodate variable site conditions. This will result in some results outside of the parameter of acceptance, not only due to the single point nature of the samples, but also because the specimen size is only 68-70mm in diameter.

6.1.1. Can a single specimen be accepted as a representative sample of some 100 – 150 m^2 of placed con crete?

6.1.2. What is the frequency of testing based upon?

6.2. Part 3 of the Durability Index Procedural Manual, May 2005 states for the water sorptivity test: "Four test specimens are required per test." This means that 4 cores have to be extracted.

6.2.1. How far apart must these cores be?

6.2.2. What research has been done to evaluate the effects of different mould release agents or their application rates?

6.2.3. Has any research been done on the effectiveness of different curing compounds and what application rates should be used?

6.3 On a recent project, a contractor was restricted to the cement type, proportion of extender, c/w ratio, aggregate type, slump, bleed rate, type of curing compound and nature of application. The preliminary laboratory and site laboratory cured specimens provided the expected "excellent" OPI and water sorptivity results. The contractor had the confidence that the results could be achieved as sufficient research with this combination of materials has been done, mainly under laboratory conditions. If the water sorptivity result relates to the degree of curing, the results obtained from field samples raises a significant question;

6.3.1. Why have unformed horizontal and sloped surfaces produced significantly superior water sorptivity results than those achieved from formed structures and "fully cured" laboratory specimens? The curing compound is only applied to the unformed surfaces once the floating operation is completed. These unformed surfaces are therefore exposed to much worse curing conditions compared to that of formed vertical surfaces, yet the water sorptivity indicates a superior degree of curing for unformed structures. The use of a "water-based" curing compound was specified;

6.3.2. Why must the contractor be penalised on the water sorptivity result when they have no control over the type of curing compound?

6.3.3. What effect does the delayed compaction effort of power trowelling have on the water sorptivity? It should not improve the water sorptivity but should influence the OPI. In this case there was no influence on the OPI, only an improvement of the WS.

6.4. By understanding the dominant mode of deterioration, exposure conditions etc. the Engineer reduced the rate of structural deterioration on a project by incorporating Fly Ash extended Portland cement composite, Dolomitic aggregates and adequate cover to reinforcement. The excellent control and enforcement of a stringent prescriptive specification resulted in the creation of a very durable structure, capable of withstanding the most severe exposure conditions.

6.4.1. What is the significance of the OPI and water sorptivity results in terms of overall durability or service life of the structure?

6.4.2. Have the OPI and water sorptivity results ever been calibrated against existing structures?

6.4.3. Can these DI values be used as a means of predicting the performance of structures?

6.5. The ambiguous adjudication of the concrete quality represented by the some field results must be clarified: If "full acceptance" is indicated by the OPI result, but the water sorptivity result indicates "conditional acceptance", "remedial acceptance" or even "rejection", is there confidence to issue an instruction to demolish the structure?

6.5.1. If remedial works to concrete surfaces are proposed to rectify either OPI or water sorptivity values, how do we validate the improvement without significant amendment to the test procedure?

6.5.2. What proposals have been considered or even proven to improve an OPI result from "remedial acceptance" to "conditional or full acceptance"?

6.5.3. The water sorptivity may be improved by a number of surface treatments, but this still has to be evaluated by research and modification to the test procedure.

6.5.4. Does this mean "reduced payment for the contractor" without an option to rectify the condition that is represented by a sensitive, small, isolated test?

6.6.Another project showed that the OPI values determined on the same cube specimens differed by up to 9%. Without mix modifica-

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fication, but with additional care in protection, stripping, handling and transportation of the specimens, the difference was reduced and the overall values improved. The DI results could be influenced by factors other than those detailed in current literature.

6.7. The initial inclusion and subsequent removal of the chloride conductivity test in specifications for a structure where there is no possibility of chloride-induced corrosion indicates a lack of understanding and interpretation of the DI values and what they represent.

6.8. Based upon the above experiences, it would be acceptable if the DI results were used to identify the most suited available materials and optimum proportioning to achieve the most durable concrete (material indexing). For the contractor, this of course can only be done after contract award, unless sufficient time is allowed at tender stage. Once the optimum DI values have been established, the contractor is already 40-50 days into the contract. If the DI values are used as a measure of acceptance, the contractor may have to re-design and re-test.

7. Extraction and submission of core specimens.

The following important guidelines are given in the Concrete Durability Index Testing Part 1: Standard procedure for preparation of test specimens from site elements:

7.1. Coring must take place between 28 and 35 days after casting, unless otherwise required by project specifications.

7.2. Core to a depth of 60-80 mm. The sides of the core must be parallel and within 5° of perpendicular to the face.

7.3. Break off the core from the concrete face with a hammer and chisel, ensuring the surface 35 mm is undamaged.

7.4. Mark each core and remove to the laboratory in sealed plastic bags.

7.5. Mark the test specimens with the correct reference number on the originally interior face.

7.6. Cut the first 5 mm from the exposed face of the core and discard. Cut the required thickness (25 ±2 mm) of the test specimen from the core. Note: The outer 5 mm can be removed by grinding with a facing machine as an alternative to cutting.

7.7. Where a specimen is damaged during this process, e.g. where aggregate spalls from the surfaces to be tested, such a specimen shall not be used for testing.

7.8. Between coring and cutting, the specimens shall be kept at ambient conditions in the laboratory for a maximum of 3 days.

7.9. The durability index test procedure shall be started immediately after cutting.

8. Conclusion:

In order that a concrete structure is durable, it is essential that each of its components be of adequate quality. The inseparable influences of design, materials and execution (construction) must be considered when constructing for durability.

A relationship between the owner, engineer and constructor should be established to determine practical and realistic Durability Index values that could be used to evaluate if additional protection to a structure is required and to monitor the quality of concrete.

The specification of durability indexes must be used with caution: the test equipment and methods are not yet approved national standards, and the number of laboratories capable of performing such tests during this infancy stage is limited.

A close look at Gautrain segmental viaduct elements construction

All photographs courtesy of Gautrain

When complete, the 80 km Gautrain rapid-rail route will include an approximate total 10,5 km of viaducts having being built, 15 km of tunnelling between Park and Marlboro Stations and 55 overpass and underpass bridge structures being constructed.

Three methods of viaduct construction will be used to build these structures; namely: short span, segmental or span-by-span and the balance cantilever method.

Smaller short-span viaducts such as those being constructed on the Gautrain alignment at Nelson Mandela Drive and at Viaduct 2 over the Jukskei River will be constructed, while two of the larger balanced cantilever viaducts will be built at Jean Avenue and John Vortser Drive and a total of 8,5 km of segmental viaducts along the alignment will be built.

To learn more about the technology used for the erection of the segmental viaducts Concrete Beton spoke to Bombela Civils Joint Venture (CJV) segmental viaduct erection team leader, Colin Calder.

He explains that in the Gautrain project, constructing of the viaducts will be done using two launching girders (with an individual weight of 400 t). These girders were designed in Singapore and fabricated in China.

"The larger of the two is 118 m long, and is able to construct a 50 m span between piers. The second one is 105 m long, and can build a maximum span of 44 m," says Calder.

In explaining the actual method of construction Calder points out that initially the launching girder rests horizontally on the piers while a crane lifts a precast viaduct segment, onto the girder and then onto a segment trolley. The trolley will transfer the segment to its intended position; offload it, and the return to be loaded with another segment.

Using this cycle the length of the girder between the piers will be filled with precast segments.

Taking this into consideration, it is easy to see why segmental construction through the use of launching girders causes less disruption to traffic flow than any other bridge building methods.

The crane used to lift the segments can usually be stationed on the side of the road and load the length of the girder across the stretch of road.

"The weight of a segment varies between 35 t and 60 t and it is 10,1 m wide. This is wide enough for two trains travelling in opposite directions. A 50 m span requires 20 of these segments and can weigh 1 100 t," explains Calder.

When all the segments have been placed, the segments are aligned and glued with epoxy.

A clear view of the launching girder.

Then high-tensile steel strands are run through the segments from one end of the pier to the other – each 50 m span has 16 tendons holding 19 0,6 inch steel strands (roughly 21 t of steel per 50 m span).

"A stressing platform is then placed at one end of the pier. The steel tendons are then stressed and this holds all the individual segments together," continues Calder.

"Until this point the weight of the span has been carried by the launching girder. It is now transferred to the piers and the launching girder is moved forward using a chain pulling unit to the next pier where the process begins again."

On average it takes approximately four days to complete one span.

The first viaduct span has been completed at viaduct three of the Gautrain project, which will cross Allandale road, in Midrand. The second girder has started building the first span at viaduct 13, which will cross Centenary Way, in Modderfontein.

According to published Gautrain information the second method of construction, the balanced cantilever construction method, is known for successfully building bridges in difficult geographical areas such as busy highways, deep valleys or wide rivers.

Cantilever bridges involve in situ, cast-in-place construction. This method does not rely on the use of scaffolding placed on the ground to support the structure while being built.

Cantilevering is therefore ideal for the two viaducts that need to be built over the busy interchanges of the N14/Jean Avenue and N1/John Vorster Drive in Centurion. Surface space for construction is extremely limited at these intersections. A specific challenge is the small median of the N1 freeway where one of several piers is required to support the viaduct.

The cantilever bridge was a major breakthrough in the history of engineering and has been successfully used for bridges around the globe. An example is the Stolmasundet Bridge in Norway with the longest span in the world for a pre-stressed concrete girder bridge. The main span at Stolmasundet Bridge is 301 m.

Construction starts by first inserting reinforced concrete shafts or piles into the ground. These will be sunk into the ground until they reach the dolomite bedrock. A concrete shaft can reach a depth of between

The two launching girders being used in the segmental construction method were designed in Singapore and fabricated in China for the Gautrain project.

The two viaducts on the Gautrain rapid rail link project being built using the 'balanced cantilever' construction method are situated at Jean Avenue and John Vorster Avenue in Tshwane.

Viaduct over Jean Avenue:

• Length:	571,5 m
• Number of spans:	6
• Longest span:	121 m
• Mid-spans:	3,5 m deep
• Spans on top of the piers:	7,5 m deep

Viaduct over John Vorster Drive:

• Length:	502,75 m
• Number of spans:	6
• Longest span:	109,8 m
• Mid-spans:	3,5 m deep
• Spans on top of the piers:	6,2 m deep

20 m and 30 m deep. This will ensure a solid foundation for the viaduct, especially given the fact that dolomite formations contain cavities. Extensive geological investigations precede the sinking of the shafts which measure 7 m in diameter.

Once a pier is securely in place, construction of the viaduct segments can start. The first cast-in-place section will be constructed on top of the pier (segment on pier). From here concrete sections are completed one-by-one, moving along in both directions simultaneously until they meet in the centre of a span.

Supporting each segment as it is being assembled, is a mobile formwork traveller which will be attached to the viaduct. The mobile formwork will therefore be supported by each segment previously completed.

This process continues symmetrically in segments until the centre of the span is reached. Segments are continuously in balance and a closing segment will be cast when the centre of a span is reached. When all the sections are constructed, the shape of the viaduct is completed.

The viaducts will be constructed at an acute angle where the rail alignment runs diagonally over the interchanges. This requires a unique engineering solution. The piers are shaped elliptically so that they are sufficiently slender to fit into confined areas between carriageways and ramps in the interchanges, but strong enough to support the viaduct superstructure. The pier heads, which are also shaped elliptically, are rotated relative to the piers itself where required so that the bridge bearings can be positioned at right angles to the viaduct alignment.

To ensure a ready supply of high strength concrete, a batching plant will be erected at each construction site. The sections of the viaduct spans will be pre-stressed. During pre-stressing, steel cables, running through the concrete sections, are put under tension and anchored at the ends. This method of reinforcement is ideal for the needs of a rapid rail link where viaducts need to accommodate two rail lines for trains travelling in both directions at a maximum speed of 180 km per hour.

Safety nets are securely fitted around the formwork traveller. Safety barriers will be placed on the ground, especially around the construction of the piers.

Minor traffic diversions can be expected and sufficient information will be provided closer to the time. However, traffic will not come to a complete standstill for the duration of the viaduct construction. Cantilevering involves construction above the top of the piers while the traffic flow continues on the roads below.

The third method, short span or M beam is generally used for smaller bridge types.

Viaduct 13 has a span of 105 m (44 m clear span) and is currently being built over Centenary Way in Modderfontein.

Gautrain rapid-rail link project viaduct construction at glance:

- 10,5 kms of viaducts will be constructed on the 80 km route of Gautrain.
- 55 overpass or underpass bridge structures will be built.
- 112 000 m^2 of bridges and viaduct structures will be built.
- 300 000 tonnes of cement will be used.
- 750 000 m^3 of stones and soil will be mixed into the concrete.
- 50 000 tonnes of reinforcing steel will be used.
- Completion of the Centurion viaducts is expected by the end of 2009.

Cement Specifications – SANS 50197-1 Common cements

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

South Africa adopted two new cement specifications in 1996, one of them being SABS ENV 197-1 "Common cements". This standard specification covered a wide range of portland cement based binders. The other standard was SABS ENV 413-1 "Masonry cement".

ENV 197-1 was revised and adopted as SABS EN 197-1 and has now been redesignated as SANS 50197-1 "Composition, specifications and conformity criteria for common cements".

This TIP covers cements to SANS 50197-1 only.

Cement types:

The standard covers five broad types of cement in terms of cement composition:

CEM I Portland cements
CEM II Portland composite cements
CEM III Blastfurnace cements
CEM IV Pozzolanic cements
CEM V Composite cement

Type I cements are equivalent, in terms of composition, to the old Ordinary and Rapid Hardening Portland cements and may contain up to 5% of minor additional constituents.

Type II/A cements may contain between 5 and 20% extender, except when the extender is silica fume where the upper limit is restricted to 10%. Permissible extenders are limestone (code "L" or "LL" depending on the total organic carbon content of the limestone), slag ("S"), siliceous fly ash ("V"), calcareous fly ash ("W"), silica fume ("D"), natural pozzolan ("P"), artificial pozzolan ("Q"), burnt shale ("T"), and blends of any two or more of the above ("M").

Type II/B cements may contain between 20 and 35% extender, the extender coding being the same, except there is no provision for a CEM II/B-D.

Type III/A cements may contain between 35 and 65% ground granulated slag, but normally contain around 50% slag.

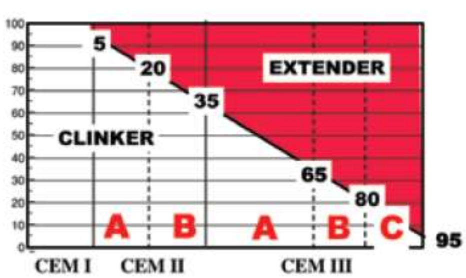
Currently, common cements made by the major producers include CEM I, CEM II/AL, CEM II/B-S, CEM II/A-V (or W), CEM II/B-V (or W), CEM III/A, CEM II/A-M and CEM II/B-M. CEM IV and CEM V cements are available in inland regions of South Africa.

Some producers do not use the "/" and the notation then reads CEM II A, CEM II B, etc.

Composition ranges for types I, II and III are shown graphically below:

SANS 50197-1: CEMENT TYPES COMPOSITION

TYPES I, II AND III



Strength classes:

Apart from composition, the standard covers three strength classes, each class having a separate requirement for high early strength products. These strength classes are:

32,5 N and 32,5 R
42,5 N and 42,5 R
52,5 N and 52,5 R

Where the numerals indicate the lowest strength, in MPa, which the cement must reach when tested in accordance with test method EN 196. The suffix "N" denotes normal early strength and the suffix "R" denotes high early strength.

In essence each class of cement must pass over a strength hurdle at either 7 or 2 days and through a strength window at 28 days. For example, in the case of a 42,5N class product the early age minimum strength (or hurdle) is 10 MPa at 2 days and the 28-day window is between 42,5 and 62,5 MPa.

In practice producers aim more or less at the middle of the 28 day window which means that the average strength of a 42,5 N class cement, when tested to EN 196, is of the order of 50 MPa.

The strength class of the cement does not imply that one cannot make, for example, 50 MPa concrete from a 32,5 N cement. It simply means that more cement is required per cubic metre of concrete than if a class 42,5 N cement were used. In other words different classes of cement have different strength versus water/cement ratio relationships.

Graphically the strength requirements can be shown as follows:

Combined composition and strength notation:

It follows that cements are now described as follows, for example:

Type I cements CEM I 42,5 N, CEM I 42,5R
Type II cements CEM II/A-L 32,5 N, CEM II/B-M (L-S)32,5 N
Type III cements CEM III/A-S 32,5 N

The cement type and strength class are, to a point, independent of each other. It is quite possible to make a CEM II/A, CEM II/B or CEM III/A as a 32,5 or a 42,5 MPa product.

Cements available from PPC Cement in the Coastal region:

The following cements are available from PPC Cement in the coastal region from Alexander Bay to the Border region:

- CEM I 42,5N OPC from Riebeeck and Port Elizabeth works
- CEM I 42,5R RAPO from De Hoek and Riebeeck works (as far east as Plettenberg Bay)
- CEM II/B-M (L-S) 32,5R SureBuild from De Hoek works (contains Corex slag and limestone extender)
- CEM II/A-L 32,5R SureBuild from Port Elizabeth

Ground Granulated Corex Slag (GGCS) is also available in bulk by road from PPC Saldanha. The slag is the subject of PPC TIPS 3, 4 and 5, and University of Cape Town Research Monograph No 6, available from the Department of Civil Engineering.

Quality Assurance in Cement Manufacture

By Steve Crosswell Pr Eng MICT (PPC Technical Support Manager)
Photographs: Richard Jansen van Vuuren

Part 1 – Quarry to Kiln

Scope:

The scope of this TIP is to serve as an introduction to Quality Assurance practice at a typical PPC cement plant. It is not intended to cover quality policy, procedures or practice at any particular plant in any detail.

Introduction:

All Portland cements and cement blends sold in South Africa must comply with SANS 50197-1: Cement - Part 1: Composition, specifications and conformity criteria for common cements.

This standard prescribes composition requirements in terms of clinker content, main constituent and minor constituent contents. It also sets limits on compressive strength, initial setting time, expansion, sulphates (as SO3), chlorides, loss on ignition and insoluble residue content. The standard does not cover cement fineness or alkali contents.

As far as the consumer is concerned, the main concerns are usually consistent strengths and setting times. Obviously it is in the producer's interest to produce as consistent a product as possible as well, and this is achieved through the quality assurance procedures applied at the cement plants.

The user should so ensure the supplier plant holds the SANS 9001 and 14001 marks as well as permit the appropriate products in terms of SANS 50197-1.

The quality system employed by the plant should cover raw materials, process materials (coal, refractories, grinding media, grinding aids, gypsum, slag etc), and process control.

Laboratory facilities:

A production facility should incorporate a fully equipped laboratory. Such laboratories contain sophisticated analytical equipment capable of analysing all raw and process materials as well as clinker and finished cement. There are also physical testing facilities for testing physical properties of cement such as fineness, setting time and compressive strength (which is tested on mortar samples in accordance with SANS 50196-1).

Furthermore back-up laboratory providing assistance with process optimisation and control is also advisable.

The quarry at PPC's Dwaalboom facility in the Northern Province.

Raw materials:

The main raw materials used in cement manufacture are limestone and shale. Limestone supplies the calcium oxide and shale the silica and alumina required for portland cement manufacture. Supplementary sources of silica, e.g. siliceous sand, and iron, e.g. laterite, may also used in order to achieve the correct chemical composition for particular cement.

It follows that these materials need to be analysed in order to design the most suitable mix for the kiln feed.

Unsuitable material, for example limestone containing excessive alkalis or organic carbon or magnesia, is screened off prior to storage and put aside for subsequent use, possibly as aggregate or for mine rehabilitation.

Stacking and reclaiming facilities at PPC's Dwaalboom facility in the Northern Province.

Storage and Pre-Blending of Materials:

Pre-blending is an essential step in ensuring uniform kiln feed in terms of composition. In essence the raw materials are stacked in a specific way, for example in long stockpiles, and reclaimed in another, for example transversely across the stockpile. There are various methods of stacking and reclaiming, but in each case the aim is to blend each raw material to be as uniform (chemically) as practically possible.

Tipper trucks empty raw material into crushers which is then processed for stockpiling.

Raw Milling and Homogenisation:

The raw materials are accurately weighed as they are fed to the raw mills. The feed rates are continuously adjusted based on the results of x-ray analysis of the raw meal, the composition of which is closely controlled to achieve a specific clinker composition. At this stage account must also be taken of the coal composition as the ash content of the coal will also contribute to the clinker composition.

Raw meal fineness is closely controlled as it affects the rates of reaction of the material in the kiln (most of the clinker forming reactions in the kiln are solid solution reactions). This in turn affects retention time in the kiln and hence kiln output.

From the mill the raw meal is transported to the raw meal silo which is designed as a blending silo. As the raw meal enters and flows down the silo it is thoroughly mixed to ensure uniform kiln feed.

Other quality measures:

At this stage in the cement manufacturing process various other controls have also been applied. These include air quality at the quarry, crushers, screens and mills; ground water quality at the quarry and noise abatement measures at the mills.

On the process side, all equipment is remotely monitored and checked on a continuous basis. Typical checks include plant speed, oil pressures, temperatures, gas analysis, flow rates, masses and so forth.

Part 2 – Kiln to Customer

Scope:

This TIP follows on from TIP 16 and covers Quality Assurance practice, in general terms, between clinker manufacture and delivery of the finished cement to the customer. It does not cover quality policy, procedures or practice at any particular plant in any detail.

The older of the cement mills in operation at PPC's Dwaalboom facility in the Northern Province.

Clinker manufacture:

The raw meal is fed from the raw meal silo to the rotary kiln. Depending on the plant the raw meal is preheated in multi-stage preheaters by the exhaust gas from the kiln (most, but not all, kilns have preheaters). Typical kiln entry temperature for a four-stage pre-heater would be of the order of 800°C. After heating the raw meal, the exhaust gases are cleaned in electrostatic precipitators or bag filters and the clean gas is released to the atmosphere. Gas composition and dust contents are monitored. The dust that is collected in the filters is called cement kiln dust, which is collected and fed back into the kiln as part of the kiln feed material. Coal quality is checked regularly as mentioned in TIP 16.

As the kiln feed travels down the kiln, carbon dioxide is driven off (a process called calcining) and the clinker forming reactions begin. As mentioned in TIP 16 only about 20% of the material actually melts and most clinker reactions occur as solid solution reactions. The clinker reaches a maximum temperature of around 1450°C in the burning zone before falling into the coolers where it is cooled by the secondary air that is sucked in through the coolers. (Primary air for the burning process is supplied with the pulverised coal fuel).

Samples of clinker from the coolers are taken for testing and analysis. Operating conditions in the kiln are continuously monitored and controlled by a sophisticated kiln process control system.

Clinker is then transported from the cooler outlet to the clinker storage silo(s).

Milling and blending:

The next stage in cement manufacture, for CEM I cements, is milling the clinker, together with a small amount of gypsum (which controls setting time), and the permitted amount of minor additional constituent, to the required fineness.

In the case of Portland limestone cements, and some Portland fly ash cements, the limestone or fly ash constituents are interground with the clinker and the gypsum to produce the finished cement.

In the case of some other Portland fly ash cements, Portland slag cements, Portland composite cements, and blastfurnace cements, the clinker is interground with the gypsum and any minor additional material which may be used in that particular cement. At this stage it is called unblended cement (UBC). The UBC is stored in a silo until blended with the required amount of fly ash or ground granulated slag at a blending plant, whereupon it becomes the finished cement.

In many plants processing aids are used in cement milling. These materials, commonly called grinding aids, are added to the mill feed in very small amounts. Their function is to reduce the energy required for milling, and/or to increase mill output. Materials are also available which enhance strengths at either early or later ages, depending on requirements.

In any event cement samples are taken at the mills and tested for chemical composition, compressive strength, setting time and fineness.

It is appropriate here to discuss cement fineness briefly:

- Fineness is not a specified requirement for cement in terms of SANS 50197-1. It is a final control method used to control compressive strength within specified limits. The target fineness of any particular cement is a function of the reactivity of the cement clinker (and other constituents) and the target strengths. The reactivity of the clinker, in turn, depends on the chemical composition and the mineralogy and crystal structure of the clinker. This is why cements from different factories are ground to different finenesses despite being in the same strength class.
- Generally speaking, a finer ground cement from a particular source will have a higher early strength than a more coarsely ground cement from the same source. The 28 day strength is also likely to be higher.

- Fineness is routinely measured in two ways, either using an air permeability method, such as the Blaine method, or by measuring the residue retained on a fine sieve, typically 45 micron. In the first case it is expressed as surface area in units of m^2/kg or cm^2/g and in the second as a percentage by mass.
- Neither method gives any information regarding cement particle size distribution. (This is analogous to testing of fine aggregate where the fineness modulus does not describe the grading of the sand, only an indication of the average particle size).

The packaging station at PPC Dwaalboom.

Packing, loading and dispatch:

Cement is dispatched either in 50 kg bags or in bulk tankers, both by road and rail. Bagged cement is available in loose bags, unitised in 40 bag units, unitised and palletised, and unitised palletised and shrink-wrapped.

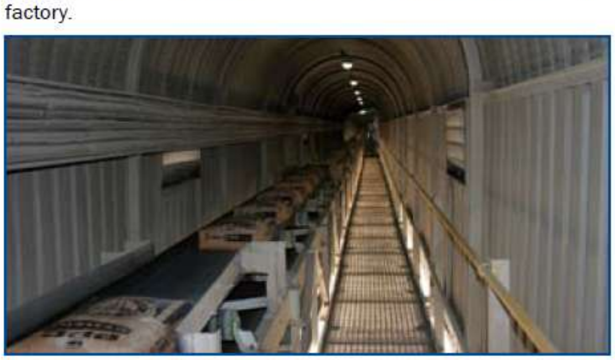
Cement for export is also available in 'big bags'. These bags have a capacity up to two tons. A number of quality issues arise here:

- Dust control at the packers and bulk loading spouts.
- Spot samples of cement are taken for testing and analysis. These samples are used to assess compliance with SANS 50197-1.
- Accurate weighing of the cement and vehicles in terms of the Trade Metrology Act and in terms of the Road Traffic Ordinance.
- Correct description of the product on the bags and delivery notes.
- Sealing of bulk tankers with the correct seals. All access points to the tankers are sealed with numbered, colour-coded seals. Seal numbers are shown on the delivery note for checking by the customer on arrival.

Seal colour codes typically for PPC cements products are as follows:

SureBuild 32,5N and 42,5N (Orange), OPC 42,5 N (Black), RAPO 42,5R and 52,5N (Red) and Ground Granulated Corex Slag (Purple).

Customers must not accept deliveries from tankers with broken or missing seals. Such tankers must be sent straight back to the factory.



Final product ready for distribution.

CI releases 530-08 for masonry structures

530-08: Building Code Requirements and Specification for Masonry Structures and Related Commentaries

The American Concrete Institute has announced the release of one of its best-selling publications, 530-08: Building Code Requirements and Specification for Masonry Structures and Related Commentaries.

This publication is published by the Masonry Standards Joint Committee (MSJC), consisting of The Masonry Society (TMS), American Concrete Institute (ACI), and the Structural Engineering Institute (SEI) of the American Society of Civil Engineers (ASCE).

This publication is a must-have for masonry professionals, as it covers the design and construction of masonry structures, and is written in a format that may be adopted by reference in a legally-adopted building code.

Highlights and updates to the 2008 edition include: quality, inspection, testing, and placement of materials; the placing, bonding, and anchoring of masonry; and the placement of grout and reinforcement. This specification is intended to be referenced in the project specifications. Individual project requirements may supplement the provisions of this specification.

As always, members of ACI receive a discount on all ACI publications.

This document can be ordered online at www.concrete.org

- Publishing date: February 2008
- ISBN: 1-929081-29-4
- Number of pages: 236
- Price: $100.00 (ACI members $75.00)

ACI releases 2008 Edition of Manual of Concrete Practice

Best-selling publication available in hard copy, CD-ROM, or online version

The American Concrete Institute (ACI) is pleased to announce the release of the 2008 edition of one of its best-selling publications, the Manual of Concrete Practice (MCP).

Containing more than 190 documents, the MCP is the most comprehensive and largest single source of concrete practice information available in one set of books. The MCP is a must-have for concrete professionals in any facet of the industry and contains all of the ACI documents needed to answer any questions about code requirements, specifications, tolerances, concrete proportions, construction methods, evaluation of test results, and many more topics. The MCP also includes the 2008 version of ACI "318-08, Building Code Requirements for Structural Concrete and Commentary (ACI 318-08)."

The MCP is available in a traditional hard copy version, which contains a set of six books and a separate index, an easy-to-use CD-ROM version, or an online version.

To order visit www.concrete.org

- Publisher: American Concrete Institute
- Publishing date: March 2008
- ISSN: 0065-7875
- Hard copy price: $768.50 (ACI members $497.00)
- CD-ROM price: $654.50 (ACI members $407.00)
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ACI announces new publications

Tenth Edition of ACI Manual of Concrete Inspection Released

The American Concrete Institute announces the availability of four new publications to educate and inform industry professionals on the newest concrete-related information and technology. As always, ACI members receive a special discount (up to 40%) on all publications. Publications can be ordered by visiting www.concrete.org

Manual of Concrete Inspection

This manual is intended to guide, assist, and instruct concrete inspectors and others engaged in concrete construction and testing, including field engineers, construction superintendents, supervisors, laboratory and field technicians, and workers. Designers may also find the manual to be a valuable reference by using the information to better adapt their designs to the realities of field construction. Because of the diverse possible uses of the manual and the varied backgrounds of its readers, it includes the reasoning behind the technical instructions.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- Number of pages: 200
- Price: $127.50 (ACI members $77.00)

522.1-08: Specification for Pervious Concrete

This specification covers materials, preparation, forming, placing, finishing, jointing, curing, and quality control of pervious concrete pavement. Provisions governing testing, evaluation, and acceptance of pervious concrete pavement are included. Also available in PDF form.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- ISBN: 978-0-87031-271-7
- Number of pages: 7
- Price: $32.50 (ACI members $20.00)

ITG-5.1-07: Acceptance Criteria for Special Un-bonded Post-Tensioned Pre-cast Structural Walls Based on Validation Testing

This document applies to structures in regions of high seismic risk or to structures assigned to high seismic performance or design categories. It defines the minimum experimental evidence that can be deemed to satisfy the use of un-bonded post-tensioned pre-cast structural walls (shear walls) for bearing wall and building frame special reinforced concrete shear wall systems, as defined in ASCE/SEI 7-05, when those walls do not fully satisfy the intent of the prescriptive requirements of Chapter 21 of ACI 318-05. This document includes mandatory Acceptance Criteria and non-mandatory Commentary, and is written so its requirements can be coordinated directly with the requirements for special pre-cast structural walls in Section 21.8 of ACI 318-05. Also available in PDF form.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- ISBN: 978-0-87031-270-0
- Number of pages: 19
- Price: $48.50 (ACI members $30.00)

SP-249: Selected Landmark Paper Collection on Concrete Materials Research

This publication highlights 13 papers that have significantly influenced the field of concrete and cement-based materials over the years. The original objective of this effort was to increase awareness of the significance of concrete materials research as a whole and therefore raise the profile of the field. But what has also resulted is the creation of a collection of seminal papers, many of which continue to stand the test of time as vital and valid studies. This volume should take its place on the bookshelves of anyone interested in concrete materials research, and will serve as outstanding teaching material and inspiration for students in the field.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- Number of pages: 700
- Price: $108.50 (ACI members $66.00)

SP-250CD: Textile Reinforced Concrete

This CD-ROM contains papers originally presented in a symposium on textile-reinforced concrete (TRC) sponsored by ACI Committee 549 during the ACI Fall 2005 Convention in Kansas City, Mo. The symposium explored the current state of the art and recent advances in material science, mechanical behaviour, production methods, and practical applications of TRC. Important topics covered include material science and technology of textile reinforcement and cementitious matrix used in TRC, design methods for TRC, structural behaviour of TRC, applications of TRC, production methods of TRC, and numerical modelling of TRC composites. The papers presented in this publication have been peer reviewed by experts in the field according to the guidelines established by ACI.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- Price: $63.50 (ACI members $39.00)

SP-251CD: Design and Applications of Textile Reinforced Concrete

This CD-ROM contains seven papers that provide insight into the state-of-the-art design and application of textile-reinforced concrete (TRC). The topics cover the following: materials aspects related to serviceability; strength and damage accumulation; TRC for flexural strengthening of reinforced concrete structures - structural behaviour, design model, and application for a concrete shell; use of TRC as a subsequently applied waterproof structure; application of TRC for lightweight structures; and sandwich panels with thin-walled TRC facings for structural exterior walls and non-structural façades.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- Price: $58.50 (ACI members $35.00)

SP-252CD: Health Monitoring Systems and Sensors for Assessing Concrete

The objective of this CD-ROM is to increase awareness of leading research that applies this technology to concrete structures, and to promote interest in the field. The subject matter of the selected papers represents a broad range of topics, from the development of specific types of embedded sensors for concrete to the implementation of wireless sensor networks to managing infrastructure systems. This volume will be of interest to engineers, researchers, and students who wish to learn more about this important, dynamic, and developing topic.

- Publisher: American Concrete Institute
- Publishing date: March 2008
- Price: $62.50 (ACI members $37.00)

Nominations called for:

FULTON AWARDS 2009

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 in concrete construction.

Awards will be made in the following categories:

- Civil Engineering Project;
- Building Project;
- Unique Design Aspects;
- Concrete in Architecture; and
- Construction Techniques.

Any project completed during 2007 or partially completed during 2008 is eligible for entry, and projects may be entered in more than one category. The Cement and Concrete Institute is the anchor sponsor for the Fulton Awards.

The closing date for nominations is 30 November 2008.

Francois Bain, president of the CSSA says the next awards will again be made over the weekend of 19 to 21 June 2009 at the Champagne Sports Resort in the Drakensberg.

"By presenting the awards over a weekend in the country, the CSSA aims to give far greater exposure to all entrants and the projects than in previous years which tended to focus more on winning and commended entries. There will be more emphasis placed on all the entries for the Fulton Awards 2009 with a special exhibition created for the nominated projects," explains Bain.

The weekend in the Drakensberg would also enable the construction industry to network at a work-related function.

"The main awards evening – a black tie gala occasion – will take place on Saturday, 20 June 2009," adds Bain.

For nomination forms and entry packs, contact the administrator of the CSSA on Tel: 011 326 2485 or email: admin@concretesociety.co.za