# Concrete Beton

The Official Journal of The Concrete Society of Southern Africa

- **TECHNICAL PAPER:**
  The influence of aggregate stiffness on the creep of concrete

- **CONCRETE CHATTER**
  Report back on:
  - The Berg River Dam
  - National AGM
  - Inland Branch AGM

NUMBER 112
April 2006

CONCRETE SOCIETY
OF SOUTHERN AFRICA

# Contents



## Concrete Society of Southern Africa



ISSN No.: 1682-6116

OFFICIAL JOURNAL OF: The Concrete Society of Southern Africa

• PO Box 11529, Silver Lakes, 0054 • Tel: (012) 809 1824 • Fax: (012) 809 1823
• Physical Address: Silver Lakes Office Park, Silver Lakes, Pretoria
• E-mail: admin@concretesociety.co.za • Web site: www.concretesociety.co.za

President: D.C. Miles

CONCRETE SOCIETY OF SOUTHERN AFRICA

CONCRETE SOCIETY OF SOUTHERN AFRICA

## Vision

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

## Mission Statement

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

## President's Message

It is with great pride and honour that I accept this position of President of the Concrete Society of Southern Africa for the next two years. Many great people have led the Society in the past and I wish to live up to that standard and the wishes of Sandy Fulton.

There are a number of goals that I have for my term of office and I would like to take this opportunity to share them with you. Firstly, any organisation is only as strong or as good as its members. Although the Society has shown steady growth over the past few years, I am convinced that far more growth is possible. This will only be achieved by offering a superior service and value for money to all our members. We also need to promote the Society to prospective members and students. I would like to ask all our members to assist by helping to enrol new members who you feel will benefit from belonging to our Society.

The Society forms an integral part of the modern construction industry of Southern Africa. One of the biggest challenges that face our industry today is the shortage of skills. According to leading economists this situation will progressively deteriorate unless some major steps are implemented to address the situation. The Society has always and will always continue to promote education of our members, prospective members and students. This has been done through a number of ways, namely the technical seminars, the symposiums, site visits and the various pieces of literature that we distribute to our members. It is felt that this will to a certain degree help to educate our industry and increase the skills level. I can only urge you to make use of these services and to encourage your junior staff to attend these events and become members of the Society.

The Society has applied for registration with the Engineering Council of South Africa. This will enable the Society to issue CPD points for all our events. For our professional members this will no doubt be a valuable service.

Our Editorial Board has shown huge progress this past year in bringing you articles of value in our two publications, namely Concrete Beton and ConQuest. If you have any papers or articles that you would like to be published, please pass these on to them.

Branch Committees to a large degree are the unsung heroes of our Society. They offer their spare time to bring you these events. As the President of the Society, I will be assisting them, together with council's help, so that they can make your membership worthwhile. However we cannot rely on a few dedicated people to do all the work. If you would like to get involved with your local branch or have some advice or suggestions please contact your branch chairman.

Needless to say that I will not be able to achieve these goals by myself. I will always be grateful to the Branch Committees and council for their dedication and effort that they have given to my predecessors and look forward to that continued support during my term of office.

I would like to thank Lafarge South Africa who has allowed me to stand as President for the next two years. Without their support this would not have been possible. I also would like to thank Venance da Silva who has been President for the past two years for all his hard work and dedication to the Society. I look forward to working with him in the future. Lastly I would like to thank our administrator Irma Dyssel for all her work and dedication over the past few years.

If members would like to offer advice or suggestions they are more than welcome to contact me.

Yours truly,

Dave Miles
President 2006/2007

## Report back on Site Visit held on Saturday – 11 March 2006

*The Berg River Dam, Franschhoek*

### Background

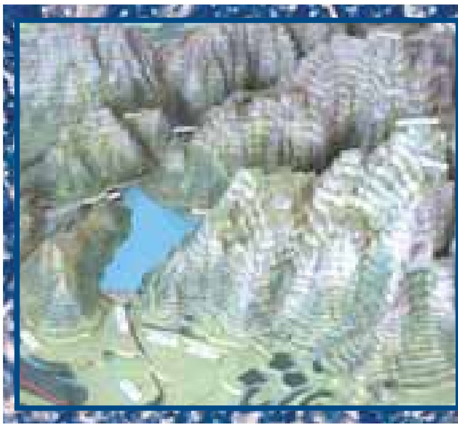
The Berg River Dam, situated in Franschhoek, forms part of the Berg River Water Project and is intended to alleviate Cape Town's water supply problems. It is a large civil engineering project and the completed dam will consist of: a 60m high dam wall with a gross storage capacity of 130.1 million cubic metres. Abstraction works and water transfer schemes are included in the project.

### Site Observations

The site visit was hosted by the Berg River Project Joint Venture and Mike Moody, Project Manager, presented a talk detailing the construction activities associated with the dam.

The dam wall is designed as a rockfill-type with a slip-formed, concrete upstream face. Overflows will take place through a lateral spillway and feeder tunnel system. Particular design attention was focused on a rotational joint at the base of the concrete face, which has a high movement range, to account for differential settlement of the underlying rockfill material. A high quality finish was achieved on the various concrete abstraction works, associated bridge and spillway structures.

The shear magnitude of the large scale civil engineering project, associated logistics, and quality of construction, were impressive.



*Scale model showing the Berg river dam, surrounding topography and portions of the water distribution network.*

*Some of the CSSA members listening attentively to the technical presentation.*

*The downstream face of the dam wall viewed from the information centre (note construction vehicles for scale reference).*

*The upstream face of the dam wall, showing earthworks in progress and preparations for the slide-formed concrete face.*

*Detail of the "blinding layer", nosing beam and large capacity rotational joint with starter bars for the slide-formed concrete face.*

*Future spillway under construction.*

## Report back on National Annual General Meeting held on Thursday – 23 March 2006

*The Kelvin Grove Club, Newlands*

The Annual General Meeting of the Concrete Society of Southern Africa was held on Thursday, 23 March 2006 at the Kelvin Grove Club, Newlands, Cape Town. The Western Cape Branch hosted the Concrete Society AGM as Dave Miles, a Western Cape CSSA member, was inaugurated as the President of CSSA for 2006/7.

**The elected office bearers of the CSSA Council for 2006 are:**

| | |
|---|---|
| • President | Dave Miles |
| • Vice-President | Francois Bain |
| • Immediate Past President | Venance da Silva |
| • Treasurer | Garth Gamble |

**The elected Council members for 2006 are:**

| | |
|---|---|
| • Peter Flower | |
| • Ken Newton | |
| • Nico Pienaar | |
| • Ken Brown | KwaZulu-Natal Branch Chair |
| • Philip Ronné | Western Cape Branch Chair |
| • Trevor Sawyer | Inland Branch Chair |
| • Malcolm Tinley | Eastern Cape Branch Chair |

*CSSA Councilors for 2006.*

*Inauguration of Dave Miles as President of CSSA.*

## Report back on Inland Branch AGM held on Thursday – 16th March 2006

*Bryanston Country Club, Bryanston*

The Inland Branch AGM was held at the Bryanston Country Club on 16th March 2006. It was preceded by a special presentation given by Mr Clive Sofianos (previously from Concor) of Concrete Proficiency. The presentation centred around the concrete design and production of special ‘dolosse’ that were supplied for the Coega Harbour project and was entitled “Meeting the dolos challenge, with regard to the client specification, available resources and contractor's programme”.

The speaker gave a very comprehensive summary of the many aspects of producing these unique precast concrete units, each of which weighed 30 tons. 26,000 units were produced which necessitated the production of almost 800,000 cu metres of concrete.

Aspects covered included, the concrete specification, aggregates, laboratory trials, site trials, final concrete mix, mixing and transporting, placing the concrete, stripping and lifting. Placing of the dolosse in their final positions was very critical and had to be done with the aid of GPS.

In thanking the speaker for his excellent and informative presentation Trevor Sawyer, Chairman of the Branch, confirmed that, in view of the challenge that had been met by Clive by achieving results that many had said were not possible, he was awarding him the 2005 Chairman’s Award, which gives recognition to an individual/team working at the coal-face of concrete design, production and placement.

*Clive Sofianos (left) receives the Chairman’s Award from Trevor Sawyer*

# The influence of aggregate stiffness on the creep of concrete

**G C Fanourakis* and Y Ballim****

* Associate Director, Department of Civil Engineering Technology, University of Johannesburg.

** He currently holds a Personal Professorship at WITS and he was the Head of the School of Civil & Environmental Engineering from 2001 to 2005. In 2006, he was appointed as the Deputy Vice Chancellor for academic affairs at Wits.

Dr G C Fanourakis

Prof Y Ballim

**Abstract:** *Creep is the time dependant increase in strain of a solid body under sustained stress. In concrete, the negative effects of creep are often responsible for excessive deflection at service loads which can result in cracking, creep buckling of long columns and loss of prestressing force.*

*While it is conceptually easy to appreciate that the stiffness of the aggregate in concrete will influence the magnitude of creep, the extent of this effect across the range of commonly used aggregates in South Africa has not been assessed. This paper discusses the results of an investigation that was aimed at quantifying the influence of aggregate stiffness on the measured creep behaviour of plain concrete.*

*The experimental programme included measurements of total creep on concrete specimens of two different strength grades for each of three different but commonly used South African aggregate types (quartzite, granite and andesite). In addition, elastic modulus tests were conducted on cores of the aggregate types assessed.*

*The test results revealed that no clear correlation exists between the creep of concrete and the stiffness of the included aggregate. These results appear to be attributable to the more dominant effect of other influencing factors such as the stress-strain behaviour of the aggregate/paste interfacial zone, particularly in the case of aggregates with elastic moduli in excess of 70 GPa.*

## Introduction

Creep is the time dependent increase in strain of a solid body under sustained stress. In concrete, the source of creep lies in the cement paste and the magnitude of creep is influenced by a wide range of variables. Some of these variables relate to the intrinsic properties of the concrete mixture while others are associated with extrinsic environmental factors. The intrinsic factors include aspects such as water : cement ratio, degree of hydration, age of the cement paste, cement type, moisture content, member geometry and size, aggregate content and aggregate properties. The extrinsic factors include applied stress, duration of load, age at first loading, load history, relative humidity, temperature and rate and time of drying.

## Technical Paper *(cont.)* - The influence of aggregate stiffness

In this context, the role of the aggregate is to reduce the extent of creep deformation in two fundamental ways: firstly by displacing some of the volume of the cement paste and secondly, by providing physical restraint against the deformation of the cement paste. This is true provided the aggregate is itself dimensionally stable. In its role as a physical restraint, it is conceptually easy to appreciate that the stiffness (or elastic modulus) of the aggregate would have a strong effect on the magnitude of concrete creep.

Separate research projects undertaken by Davis and Alexander (1992), The Concrete Society (1974), Soroka and Jaegermann (1972), Rusch et al., (1962) and Troxell et al., (1958) showed the aggregate type to have an influence on the creep of the concrete in which it is embedded. However, it is difficult to find definitive opinion in this work on the influence of the stiffness of the aggregate on the magnitude of creep deformation.

The work by Davis and Alexander (1992) considered eight of the most commonly used South African aggregate types, from 23 sources throughout the country. The results of this investigation led to the establishment of empirical "Relative Creep" values, ranging from approximately 0.7 to 1.5, for the different aggregate types. This important work showed that it was possible to cause a more than doubling of the creep deformation in concrete by simply changing the geological type of the aggregate. However, the work did not definitively separate the influence of the aggregate stiffness from other possible properties related to the aggregate type.

The purpose of the investigation reported here was to determine the influence of aggregate type and stiffness on the creep behaviour of plain concrete for up to six months under load. The specific objectives of this research were to:

- Determine the correlation between total creep of concrete and the elastic modulus of the aggregate used in the concrete;

- Assess the differences in the specific total creep behaviour of concretes of two different w/c ratios each containing one of three different commonly used South African aggregate types. The aggregate types considered were quartzite from the Ferro Quarry in Pretoria, Granite from the Jukskei Quarry in Midrand and Andesite from the Eikenhof Quarry in Johannesburg, South Africa;

- Compare the findings to those of Davis and Alexander (1992) who conducted research on the total creep of concretes containing quartzite or granite or andesite from the same sources as those used in this research.

### Experimental Details
### Materials

A single batch of CEM I 42,5 cement from the Dudfield factory of Alpha Cement was used for all the tests carried out in this investigation. Quartzite (Q) from the Ferro quarry in Pretoria, granite (G) from the Jukskei quarry in Midrand and andesite (A) from the Eikenhof quarry in Johannesburg were used as both the stone and sand aggregates for the concrete. The stone was 19mm nominal size and the fine aggregate was crusher sand.

Two rock boulders were collected from each of the quartzite (Ferro) and andesite (Eikenhof) quarries for the determination of the elastic modulus of the rock. Since the rocks observed in the Granite (Jukskei) quarry appeared quite variable, two boulders with visually different characteristics were collected from this quarry. All these boulders were obtained from the same areas in the respective quarries where rock material was obtained to produce the aggregates used to make the concrete samples for this investigation.

### Laboratory Procedures
#### Determination of elastic moduli of the aggregates

Measurements of aggregate elastic modulus or stiffness were carried out on samples obtained from the representative boulders collected as described above. The stiffness of each rock type as determined on the boulder samples was taken to be representative of the stiffness of the corresponding aggregates used in the concrete specimens.

Three cores measuring 42mm in diameter and 82mm long were cut from each set of two boulders and these were tested according to the procedure described in BS 1881 (1983) to determine the elastic modulus of the aggregates used in this investigation. Two LVDT displacement gauges were attached diametrically opposite each other on each core and strain measurements were taken over a length of 50mm.

The cores were tested in the Amsler type 103 compression testing machine which has a capacity of 2000 kN. The load and axial deformations of the specimens were autographically recorded by a Graphtech Data Recorder on an XY plotter over one cycle of loading and unloading. The cores were loaded to a maximum stress equal to approximately 25 per cent of the average unconfined compression strength values respectively determined by Davis and Alexander (1992) as 250 MPa, 190 MPa and 527 MPa for the quartzite, granite and andesite from the same sources.

## Technical Paper *(cont.)* - The influence of aggregate stiffness

### Concrete Mixture proportions

A total of six mixtures were prepared, using water/cement (w/c) ratios of 0.56 and 0.4, for each of the three aggregate types included in the investigation. For each mix, a constant water content of 195 l/m³ was used. The w/c ratios of 0.56 and 0.4 were chosen to respectively represent typical medium and high strength concretes used in practice. This approach ensured that, for the different aggregate types used, concretes with the same w/c ratio had the same volume of cement paste. Table 1 shows the mix proportions of the six concretes as well as the slump values obtained for the concretes.

**Table 1:** *Mix Proportions and slump test results of the concrete used in this investigation*

| Aggregate Type | Quartzite | | Granite | | Andesite | |
|---|---|---|---|---|---|---|
| Mix Number | Q1 | Q2 | G1 | G2 | A1 | A2 |
| Water (l/m³) | 195 | 195 | 195 | 195 | 195 | 195 |
| Cement (kg/m³) | 348 | 488 | 348 | 488 | 348 | 488 |
| 19mm Stone (kg/m³) | 1015 | 1015 | 965 | 965 | 1135 | 1135 |
| Crusher Sand (kg/m³) | 810 | 695 | 880 | 765 | 860 | 732 |
| w/c Ratio | 0.56 | 0.4 | 0.56 | 0.4 | 0.56 | 0.4 |
| a/c Ratio | 5.24 | 3.50 | 5.30 | 3.55 | 5.73 | 3.83 |
| Slump (mm) | 90 | 50 | 115 | 70 | 95 | 55 |
| Compressive Strength (MPa) | 37 | 65 | 38 | 65 | 48 | 74 |

### Preparation of concrete specimens

Six 100mm cubes were cast for each of the six mixes. In the case of each mix, three cubes were tested at seven days and three at 28 days after casting. The 28 day strength of each concrete, which is shown in Table 1, was taken as the average of the three compressive strength tests at that age. For each concrete type, six prisms, measuring 101.6 x 101.6 x 200mm, were prepared for the creep and shrinkage testing. All the concrete samples were cured in a water bath, at a temperature maintained at 22 ± 1˚C.

At approximately 21 days after casting, the prisms were removed from the curing bath and Demec targets were glued onto two opposite, formed sides of each prism, on a vertical axis symmetrically about the middle of the specimen, to accommodate a 100mm Demec strain gauge. A quick-setting glue (Schnellklebstoff X 60 Epoxy Glue) which adheres to wet concrete was used for this purpose. After the glue had set (approximately 15 minutes after application) the prisms were returned to the curing bath where they remained for a total of 28 days after casting.

### Creep and associated shrinkage tests

The prisms were removed from the curing bath at age of 28 days after casting and, for each mix, three prisms were used for determining the total deformation under load. The other three prisms were used for monitoring the drying shrinkage strains in the same environment as the creep samples but in an unloaded condition. Initial elastic strains were determined by obtaining strain measurements on each of the loaded samples within 10 minutes of the application of the full load on the samples.

The loading frames were developed by Ballim (1983) and are based on the ASTM C512-76 (1976) creep frame, except the load is applied by a hydraulic flat jack instead of a compressed spring. The loaded prisms in the creep frames are shown in Figure 1 and the companion drying shrinkage samples in Figure 2.

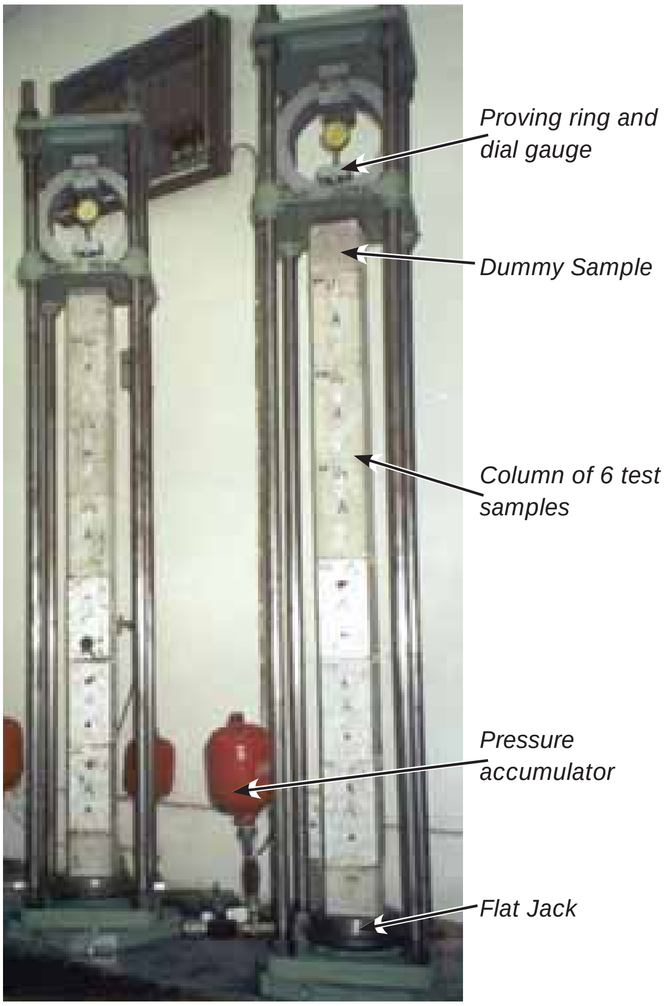



*Figure 1: Loaded prisms in creep frames*

*Figure 2: Companion drying shrinkage samples*

By means of an air conditioner and humidifier, the temperature and relative humidity in the room in which the frames were housed was kept between 23 ± 3˚C and 65 ± 5˚C, respectively. The prisms in each of the six creep frames were subjected to a constant stress equal to 25 per cent of the 28 day compressive strength of the relevant mix. The stresses were maintained to an accuracy of ± 0,5 MPa for a period of six months.

In both the creep and shrinkage tests, strains were measured using a 100mm Demec gauge across steel targets which had been glued onto opposite faces of the test prism. The Demec gauge is accurate to approximately 17 microstrain. Total strains were determined daily for one week, weekly until the end of one month, and approximately monthly thereafter for a total period of six months.

At each measuring period, the strain of each prism was taken as the average of the strains measured on the two opposite faces of the prism. The strain of each group of three prisms was taken as the average of the strains of the prisms in that group.

## Results and Discussion

### Determination of Creep Strain

The creep strain at any time was determined as:

$$\varepsilon_c\,(t) = \varepsilon\,(t) - \varepsilon_e - \varepsilon_{sh}\,(t) \qquad (1)$$

where,

| | | |
|---|---|---|
| $\varepsilon_c$ (t) | = | creep strain at any time t |
| $\varepsilon$ (t) | = | measured strain on the loaded samples at any time t |
| $\varepsilon_e$ | = | average instantaneous elastic strain recorded immediately after loading |
| $\varepsilon_{sh}$ (t) | = | drying shrinkage strain at any time t (from companion samples) |

In order to provide a basis for comparing the creep strains of concretes with different strengths and different applied loads, the results are presented in the form of specific creep (Cc), which is defined as:

$$C_c = \varepsilon_c\,(t)/\sigma \qquad (2)$$

$C_c$ therefore represents the creep strain per unit of applied stress. Details of the magnitudes of the elastic strains at loading and creep and shrinkage strains with time are given in the work of Fanourakis (1998).

### Drying shrinkage strains

As the shrinkage strains were used in the analysis of the creep strains, it is appropriate to comment on the measured shrinkage of the companion samples. The average cumulative drying shrinkage strain with time measured on the companion specimens of mixes with a w/c ratio of 0.56 (Q1, G1, A1) and those measured on the specimens with a w/c ratio of 0.4 (Q2, G2, A2) are shown in Figures 3 and 4, which are plotted to the same scale.

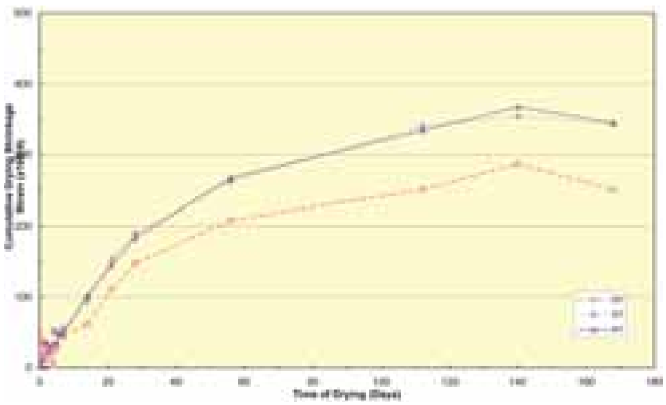


*Figure 3: Cumulative drying shrinkage strain versus time of drying for shrinkage specimens with a w/c ratio of 0.56*

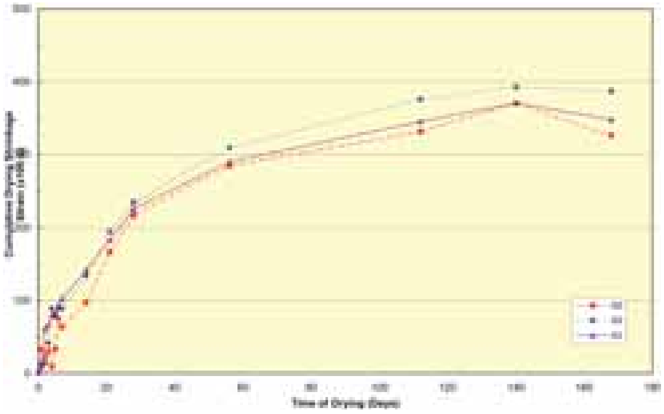


*Figure 4: Cumulative drying shrinkage strain versus time of drying for shrinkage specimens with a w/c ratio of 0.4*

With reference to Figures 3 and 4, it is evident that, for each aggregate type, the specimens with the higher w/c ratio (0.56) exhibited less drying shrinkage than those with the lower w/c ratio (0.4). In addition, it was noted that the difference between the shrinkage of the two strength grades of each aggregate type appears to reduce with time and the rate of shrinkage of all the mixes decreases with time. These trends are in agreement with the findings of Alexander (1993b).

The decrease in cumulative shrinkage at an age of 168 days (after loading), which is most pronounced for the quartzite concretes, is probably attributable to the increase in both relative humidity and temperature which resulted from a temporary breakdown of the air conditioner during the week in which those shrinkage strains were recorded.

Furthermore, the concretes containing quartzite aggregate displayed less shrinkage than both the granite and andesite concretes, for both w/c ratios. The specimens containing granite generally exhibited less shrinkage than those containing andesite in the case of the high w/c ratio, but more shrinkage than the andesite in the comparison of specimens with the lower w/c ratio.

Extensive shrinkage tests carried out by Davis and Alexander (1992) on concretes with aggregates from the same sources as those used in this project showed the relative shrinkage of the concrete containing granite to be higher than that of concrete containing quartzite but lower than andesite concrete.

This order of relative shrinkage with the use of different aggregates is generally but not precisely reflected in Figures 3 and 4. Nevertheless, according to Davis and Alexander (1992), the relative shrinkage values are intended for general guidance as the shrinkage of concretes containing aggregates from a particular source can vary significantly.

### Correlation of total creep with E of aggregate

The measured elastic moduli, ranges and averages for each of the three aggregate types (determined in this research) are shown in Table 2. The results for the granite represent the range and the average for the six cores tested, as the visually different boulders did not show different results. This table also includes the range and average values determined by Davis and Alexander (1992) for the same aggregates from the same sources.

For the purposes of comparing the influence of aggregate alone on specific total creep, the specific total creep values at 168 days (six months) after loading were modified to account for the different w/c ratios. This modification, which is similar to one carried out by Davis and Alexander (1992), entails adjusting the specific total creep values by the ratio of their compressive strengths at the age of loading, to the mean of the compressive strengths of all six mixes (54.5 MPa). The average of the two adjusted specific creep values for each aggregate type was then expressed as a ratio of the mean of the six adjusted values (61.549 x 10-6/MPa), to obtain a relative creep value for each aggregate type. The adjustment factors, adjusted specific total creep values and relative creep factors are given in Table 3 which includes the relative creep values determined by Davis and Alexander (1992) for the same aggregates.

**Table 2:** *Results of elastic moduli tests on cores*

| | Elastic Moduli of Rock Cores | | | |
|---|---|---|---|---|
| | Measured | | Davis and Alexander | |
| Aggregate Type | Range (GPa) | Mean (GPa) | Range (GPa) | Mean (GPa) |
| Quartzite (Ferro) | 59 - 88 | 73 | 42 - 98 | 70 |
| Granite (Jukskei) | 66 - 80 | 70 | 27 - 93 | 60 |
| Andesite (Eikenhof) | 82 - 94 | 89 | 80 - 110 | 95 |

**Table 3:** *Adjusted specific creep values, elastic moduli and relative creep coefficients*

| Measured | | | | | | | Davis and Alexander | |
|---|---|---|---|---|---|---|---|---|
| | | Specific Total Creep at 168 days | | | | | | |
| Mix | Adjustment Factor | Actual ($x10^{-6}$/MPa) | Adjusted ($x10^{-6}$/MPa) | Mean for Aggregate ($x10^{-6}$/MPa) | E (GPa) | Relative Creep | E (GPa) | Relative Creep |
| Q1 | 0.679 | 86.359 | 58.638 | | | | | |
| Q2 | 1.193 | 45.733 | 54.559 | 56.599 | 73 | 0.92 | 70 | 0.96 |
| G1 | 0.697 | 80.653 | 56.215 | | | | | |
| G2 | 1.193 | 51.902 | 61.919 | 59.067 | 70 | 0.96 | 60 | 0.74 |
| A1 | 0.880 | 76.997 | 67.757 | | | | | |
| A2 | 1.358 | 51.699 | 70.207 | 68.982 | 89 | 1.12 | 95 | 1.19 |

Figure 5 shows a correlation of the relative creep with average elastic modulus of the aggregate using the specific total creep results from this investigation and from the work by Davis and Alexander (1992). The letters Q,G and A denote quartzite, granite and andesite concretes, respectively. The results in Figure 5 indicate significant variations in the stiffness of aggregates from a particular source. Furthermore, the results show that, counter-intuitively, the higher the average elastic modulus of an aggregate, the higher is the relative creep of the concrete. The regression equations and correlation coefficients applicable to the results from this investigation and from Davis and Alexander's (1992) work, when considered separately and together, are given in Table 4.

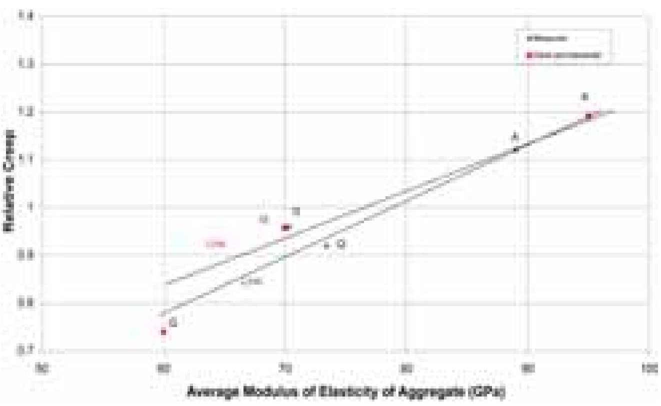



*Figure 5: Relationship between relative creep and elastic modulus of aggregates*

**Table 4:** *Correlation of relative creep to average modulus of elasticity of aggregates for the data shown in Figure 5*

| Line | Data Source | Regression Equation | Correlation Coefficient (r) |
|---|---|---|---|
| A | Measured | y = 0.010x + 0.229 | 0.941 |
| B | Davis and Alexander | y = 0.012x + 0.052 | 0.973 |
| | Combined | y = 0.012x + 0.092 | 0.965 |

The correlations in Figure 5 show an opposite trend to those established by Rusch et al., (1962) and The Concrete Society (1974) which indicate that the higher the elastic modulus of the aggregate, the greater the restraint offered by the aggregate to the creep of the paste. However, their work included a wide spectrum of materials as aggregates, ranging from lightweight materials to normal density rock aggregates. An analysis of their results shows that creep of concrete becomes relatively insensitive to aggregate stiffness in the case of aggregates with a modulus of elasticity in excess of approximately 70 GPa. Hence, the correlations shown in Figure 5 are not necessarily in conflict with the trends established by other researchers for the fairly narrow spectrum of normal density concrete aggregates assessed in this investigation. In a separate analysis, Alexander (1993a) also found no correlation between the magnitude of the creep of concrete and the elastic modulus of the aggregate used in the concrete.

## Technical Paper *(cont.)* - The influence of aggregate stiffness

From the above, it is clear that, for the range of aggregates assessed, the effect of variations in the elastic modulus of the aggregate on creep deformation is overshadowed by other factors which appear to be related to the geological origin of the aggregate but remain un-quantified at this stage.

### Time dependent creep strain

The specific total creep (basic and drying creep) values measured on the prisms of each of the six mixes since the time of first loading are shown in Figure 6.

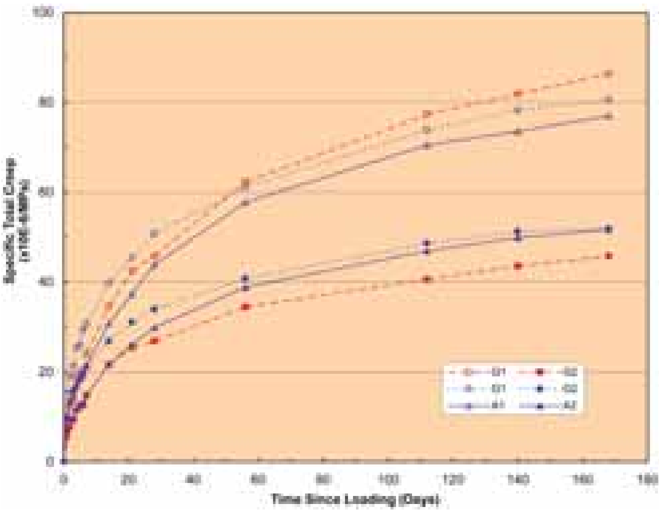



*Figure 6: Specific total creep versus time since loading*

It is evident from Figure 6 that, for each of the aggregate types, the mix with the lower w/c ratio (stiffer mix) yielded a lower specific total creep value. This is in accordance with the findings of Reutz (1965), Ballim (1983), Smadi et al., (1987), Addis (1992) and Fiorato (1995).

The reason for the abovementioned trend is that the concrete with the higher strength and stiffness has a relatively lower porosity of the hardened cement paste matrix in comparison with the lower strength concrete (Muller and Kuttner, 1996). Furthermore, the curves of the higher w/c ratio (0.56) mixes indicate that the order of increasing specific total creep of concrete, for most of the test period, with the use of the different aggregates, to be andesite, granite and quartzite. By relative comparison, the positions of the specific total creep curves of the lower w/c ratio (0.4) mixes differ in that the quartzite concretes yielded the lowest specific total creep values. Hence, when considering the average elastic modulus values of the three aggregate types, which are given in Table 3, it is evident that no correlation exists between the specific total creep of the concrete and the stiffness of the aggregate included in the concrete.

The investigation conducted by Davis and Alexander (1992) on creep of concretes with various aggregates, including those used in this research, showed concrete creep with the use of these aggregates to increase in the order granite, quartzite and andesite. Referring to Figure 6, it is evident that the positions of the specific total creep curve of the andesite concretes (in the case of the higher w/c ratio) and the granite concretes (in the lower w/c ratio) are in disagreement with the results of Davis and Alexander (1992). This further reinforces the point that, in this narrow range of aggregate elastic moduli, variations in concrete creep deformation characteristics cannot be explained by variations in the elastic modulus. The reasons for these variations need to be sought in other parameters related to the geological origin of the aggregate and its interaction with the cement paste.

### Conclusions

The specific total creep values at six months after loading were modified to relative creep values to eliminate the expected influence of the different w/c ratios on the creep exhibited. These results indicated that a significant positive correlation exists between the relative creep of concrete and the elastic modulus of the included aggregate. For the concretes of each aggregate type, the higher the elastic modulus of the aggregate, the more the relative creep of the concrete. An identical trend was established using data from Davis and Alexander (1992) for the same aggregates as those considered in this investigation but pertaining to an age of five years after loading. These correlations show an opposite trend to those established by Rusch et al., (1962) and The Concrete Society (1974), which indicate that the higher the elastic modulus of the aggregate, the greater the restraint offered by the aggregate to the creep of the paste. However, an analysis of their results indicates creep of concrete to be relatively insensitive to aggregate stiffness in the case of aggregates with a modulus of elasticity in excess of approximately 70 GPa, which appears to be the case in this investigation.

For the concretes made with each of the aggregate types, at any age after loading, the mix with the lower w/c ratio (0.4) yielded a lower specific creep value.

At any age after loading, the specific total creep values for the lower w/c ratio mixes, with the use of the different aggregates included in this research, increase in the order quartzite, andesite and granite. In the case of the higher w/c ratio, the specific total creep values of the concretes made with different aggregates increase in the order andesite, granite and quartzite. These results confirm that, for the fairly narrow spectrum of normal density aggregates with relatively high elastic moduli that were included in this investigation, no correlation exists between the creep of concrete and the stiffness of the included aggregate.

The unexpected abovementioned results appear to be attributable to the stress strain behaviour of the aggregate/paste interfacial zone, which is in turn dependant on the density of the zone and the strength of the bond between the aggregate and the paste.

## Acknowledgements

The authors wish to thank the NRF, the Cement and Concrete Institute and Eskom for funding support of this project. Holcim (South Africa) are also particularly acknowledged for their generous contribution of the cement and aggregates used in the investigation.

## References

Addis, B.J. (1992) Properties of High-Strength Concrete made with South African Materials, PhD thesis, University of the Witwatersrand, Johannesburg.

Alexander, M.G. (1993a) Properties of Aggregates in Concrete, Report on Phase 2 testing of concretes made with aggregates from a further 10 different quarries, and associated design recommendations, Research Report, Department of Civil Engineering, University of Cape Town, Rondebosch, pp. 23, 32, 75, 76, 85.

Alexander, M.G. (1993b) Two experimental techniques for studying the effects of the interfacial zone between cement paste and rock, Cement and Concrete Research, Vol. 23, No. 3, May, pp. 567-576.

ASTM C512-76 (1976) Standard Method of Test for Creep of Concrete in Compression, ASTM Book of Standards, Part 14, Philadelphia: American Society for Testing and Materials.

Ballim, Y. (1983) The Concrete Making Properties of the Andesite Lavas from the Langeleven Formation of the Ventersdorp Supergroup, MSc thesis, University of the Witwatersrand, Johannesburg, pp. 22-31, 67, 71-73, 80.

BS 1881 (1983) Testing Concrete, Part 121: Method for Determination of Static Modulus of Elasticity in Compression, London: British Standards Institution.

Davis and Alexander (1992) Properties of Aggregates in Concrete (Part 2), Hippo Quarries Technical Publication, Sandton, South Africa, Mar., pp. 1-27, 42-43, 46-47.

Fanourakis, G.C. (1998) The Influence of Aggregate Stiffness on the Measured and Predicted Creep Behaviour of Concrete, MSc (Eng) dissertation, University of the Witwatersrand, Johannesburg.

Fiorato, A.E. (1995) Engineering properties of high-strength and conventional strength concretes, Proceedings of the Third National Concrete & Masonry Engineering Conference, San Francisco, California, June, pp. 13.

Muller, H.S. and Kuttner, C.H. (1996) Creep of high-performance concrete - characteristics and code-type prediction model, Proceedings of the Fourth International Symposium on Utilization of High-Strength/High-Performance Concrete, Paris, pp. 378, 379.

Reutz, W.A. (1965) A hypothesis for the creep of hardened cement paste and the influence of simultaneous shrinkage, The Structure of Concrete, proceedings of an international conference, London, Sept., pp. 319-344.

Rusch, H., Kordina, K. and Hilsdorf, H.K. (1962) Der einfluss des mineralogischen charakters der zuschlage auf das kriechen von beton, Deutscher Ausschuss fur Stahlbeton, Berlin, No. 146, pp. 19-133.

Smadi, M.M., Slate, F.O. and Nilson, A.H. (1987) Shrinkage and creep of high-, medium-, and low-strength concretes, including overloads, ACI Materials Journal, Mar./Apr., pp. 229.

Soroka, I. and Jaegermann, C.H. (1972) Properties and possible uses of concrete made with natural lightweight aggregate, Part 1, Report to the Ministry of Housing, Haifa Technion.

The Concrete Society (1974) The Creep of Structural Concrete, London: The Society, Technical Paper No. 101.

Troxell, G.E., Raphael, J.M. and Davis, R.E. (1958) Long-time creep and shrinkage tests of plain and reinforced concrete, Proceedings ASTM, Vol. 58, pp. 1101-1120.

# Branch Calendars for 2006

| Date | | Function | Venue/Co-ordinator |
|---|---|---|---|
| **Inland Branch** | | **Inland Branch Chairman Contact Trevor Sawyer Cell: 073 249 0242** | |
| 04 | May | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| 11 | May | Young Concrete Engineers' Conference | SAICE, Midrand |
| 01 | Jun | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| 06 | Jul | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| 17 | Jul | Technical Meeting - Concrete Dam Construction | To be advised |
| 03 | Aug | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| | Sep | Technical Meeting - Self compacting concrete | To be advised |
| 07 | Sep | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| 16 | Sep | Annual Concrete Boat Race Day | Germiston Lake Club |
| 05 | Oct | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| | Oct | Concrete Conference - jointly with C&CI | To be advised |
| 02 | Nov | Branch Committee meeting | C&CI, Waterfall Park, Midrand |
| 10 | Nov | Chairman's Banquet | To be advised |
| **KwaZulu-Natal** | | **Kwa-Zulu Natal Chairman Contact Ken Brown Tel: 031 205 2707 or Cell 082 554 5460** | |
| 16 | May | Technical Meeting - to be advised | Greg Parrott |
| | May | Concrete Canoe Race | Rolf Schutte |
| | June | Technical Meeting - to be advised | Barry |
| 18 | July | Technical Meeting - Ash Resources | Raj Naidoo |
| 28 | July | Golf Day - Bluff Golf Club | Garth Gamble/Wayne Smithers |
| 15 | August | Technical Meeting - to be advised | Dion Kuter |
| 19 | September | Technical Meeting - to be advised | Ken Brown |
| 17 | October | Egg Protection Device competition | Rolf Schutte |
| 21 | November | Technical Meeting - to be advised | Wayne Smithers |
| **Western Cape** | | **Western Cape Branch Contact Philip Ronné Tel: 021 950 7500 or Cell 083 775 3677** | |
| 02 | May | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 18 | May | Young Engineers Symposium presentation | LT2, Dept. of Civil Eng., UCT |
| 06 | Jun | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 22 | Jun | MTM - SARMA's role in the concrete industry | LT2, Dept. of Civil Eng., UCT |
| 04 | Jul | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 20 | Jul | MTM - Punching Shear - design aspects and repair | LT2, Dept. of Civil Eng., UCT |
| 01 | Aug | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 17 | Aug | Site visit - The Coliseum | To be advised |
| 31 | Aug | Concrete Cube Casting date | n.a. |
| 05 | Sep | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 21 | Sep | MTM - Student talks/Structural health monitoring | LT2, Dept. of Civil Eng., UCT |
| 28 | Sep | Concrete Cube Crush-In & Branch Social | To be advised |
| 03 | Oct | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 19 | Oct | Site visit - Hout bay Harbour | To be advised |
| 07 | Nov | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| 16 | Nov | Annual Cocktail party | To be advised |
| 05 | Dec | Branch Committee meeting | 3rd Floor, Ninham Shand Building |
| **Eastern Cape** | | **Eastern Cape Branch Contact Venance da Silva Tel: 041 505 8000 or Cell 082 777 0083** | |
| | May | Cement factory visit | PPC |
| | July | Seminar on new fibres | To be advised |
| | Jul/Aug | Precast flooring | To be advised |
| | October | Concrete Floors - Bryan Perrie/Chris Howes | To be advised |

# Diary of Forthcoming Events

## DIARY 2006

| | | |
|---|---|---|
| 11 May | Midrand, Johannesburg, SA | 3rd Young Concrete Engineers', Practitioners' & Technologists' Conference |
| 15-17 May | Kuala Lumpur, Malaysia | 8th International Conference on Steel Space & Composite Structures |
| 5-8 June | Naples, Italy | 2nd International fib Congress |
| 12-14 June | Espoo, Finland | European Symposium on Service Life and Serviceability of Concrete Structures |
| 13-15 June | Edinburgh, Scotland | International Conference and Exhibition: Structural Faults and Repair |
| 15-17 August | Singapore, Malaysia | 31st Conference on Our World In Concrete And Structures |
| 27-29 September | Padova, Italy | 3rd Int. Conference on Protection of Structures Against Hazards |
| 24-26 October | Hong Kong, China | 10th Int. Conf. on Inspection, Appraisal, Repairs and Maintenance of Structures |
| 29-31 October | Hong Kong, China | 3rd International Conference on Fibre Reinforced Materials |
| 26-29 November | Dubai, UAE | Joint Int. Conference on Construction Culture, Innovation and Management |
| 4-6 December | Kuala Lumpur, Malaysia | 2nd International Conference on Problematic Soils |

## DIARY 2007

| | | |
|---|---|---|
| Tbc | Kangwon, Korea | 12th International Conference on Polymers in Concrete (ICPIC'07) |
| 14-16 February | Cape Town, SA | International Concrete Conference and Exhibition |
| 23-25 May | Dubrovnik, Croatia | Concrete Structures including Development and Prosperity |
| 4-6 June | Tours, France | 5th International Conference on concrete under severe Conditions |
| September | Stuttgart, Germany | Connections between Steel and Concrete |
| 4-6 September | Dundee, Scotland | 7th International Congress on Concrete: Construction's Sustainable Option |
| December | Abu Dhabi, UAE | 8th IFHS Conference |

# Announcement

**The Department of Education has again granted its accreditation to the Concrete Society of Southern Africa's journal**


## Concrete/Beton

Concrete/Beton, accredited under the new rules, invites academics to submit technical papers on concrete research and practice. A panel of eminent professionals will review all technical papers and on approval, the paper will be submitted for publication.

This service is free of charge and affords significant benefits for authors and their institutes:

- **Financial rewards from the Department of Education**
- **Prestige gained by peer review and industry dissemination**
- **Automatic entry for the Richard Robinson prize for the best paper published each year.**

**You are invited to submit material for publishing**

Contact : The Concrete Society of Southern Africa
C/O Mrs Irma Dyssel
Phone: (012) 809 1824
PO Box 11529
Silver Lakes
0054
e-mail: admin@concretesociety.co.za

OFFICIAL JOURNAL OF: The Concrete Society of Southern Africa

• PO Box 11529, Silver Lakes, 0054 • Tel: (012) 809 1824 • Fax: (012) 809 1823
• E-mail: admin@concretesociety.co.za • Web site: www.concretesociety.co.za

President: D.C. Miles

CONCRETE SOCIETY OF SOUTHERN AFRICA

CONCRETE SOCIETY OF SOUTHERN AFRICA