THE ICT

The Institute of Concrete Technology was formed in 1972 from the Association of Concrete Technologists. Full membership is open to all those who have obtained the Diploma in Advanced Concrete Technology. The Institute is internationally recognised and the Diploma has world-wide acceptance as the leading qualification in concrete technology. The Institute sets high educational standards and requires its members to abide by a Code of Professional Conduct, thus enhancing the profession of concrete technology. The Institute is a Professional Affiliate body of the UK Engineering Council.

AIMS

The Institute aims to promote concrete technology as a recognised engineering discipline and to consolidate the professional status of practising concrete technologists.

PROFESSIONAL ACTIVITIES

It is the Institute’s policy to stimulate research and encourage the publication of findings and to promote communication between academic and commercial organisations. The ICT Annual Convention includes a Technical Symposium on a subject of topical interest and these symposia are well attended both by members and non-members. Many other technical meetings are held. The Institute is represented on a number of committees formulating National and International Standards and dealing with policy matters at the highest level. The Institute is also actively involved in the education and training of personnel in the concrete industry and those entering the profession of concrete technologist.
# The INSTITUTE OF CONCRETE TECHNOLOGY

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**Yearbook: 2006-2007**
This yearbook comes during what could possibly be best described as a period of transition for the Institute of Concrete Technology. As I write, we are in mid-stride of a momentous step in the forward march of the Institute – the proposed merger with the Concrete Society. This move is strongly supported by our membership and should benefit the Institute at least through shared resources, a heightened profile and increased conspicuity. The Concrete Society will gain a “professional wing” to further its education and training objectives. But rest assured that the Institute will retain its individual identity within the combined organisation. Interesting times, indeed.

After a long tradition of residential Advanced Concrete Technology courses, we have just seen the successful completion of the first web-based course. Exam results are yet to be released but I understand that feedback from participants has been very positive. Although classroom-based courses may continue in some areas, this marks a major change for the former UK-based course. Now almost anyone, anywhere in the world with internet access, a good grasp of English and a bubbling enthusiasm for our grey stuff is a potential candidate. Many “graduates” of the residential course will no doubt bemoan the loss of the personal contact with the array of experts who were coaxed and cajoled (but seldom bribed) into lecturing for so many years. But look around, many of them have now moved on – and so must the ACT course.

As you will see from the collected papers inside this yearbook, the 2006 Annual Convention Technical Symposium took “Sustainability” as its theme. And, in my opinion, it is difficult to think of a subject more worthy of this the most prestigious of events in the ICT calendar. By some definitions concrete can never be a truly sustainable material because of the inevitable consumption of at least some non-renewable natural resources. Nevertheless, if we instead substitute the term “reduced environmental impact” then there is a lot we can do to help in all parts of the so-called ‘concrete industry’. For example:

Designers can utilise concrete’s high thermal mass to increase the thermal efficiency of buildings and consequently reduce reliance on artificial heating and, in particular, air-conditioning with its high environmental impact.

Specifiers can encourage the use of secondary and recycled materials or, at the very least, not unnecessarily exclude their use through outdated or ill-informed exclusion clauses in their specifications.

Product suppliers can seek to offer products with increased levels of secondary and recycled materials content, and to minimise waste by the incorporation of reject products and off-cuts within the raw materials for new products.

The cement industry can continue to seek improved energy efficiency and further develop the use of non-fossil fuels.

Aggregate suppliers and concrete suppliers, like school canteens, can help by making sure there are healthy options on the menu, so to speak.

Researchers can continue to explore the properties of alternative aggregates, cements and other cementitious materials, and seek to identify any possible pitfalls. After all, just because something is hard and granular it doesn’t necessarily make it suitable as aggregate in concrete.

Even code-writers have a crucial role to play by ensuring that codes and standards contain no unnecessary barriers but also that any essential safeguards are in place to ensure these materials and products can be specified and supplied with confidence.

Perhaps it’s become a bit of a cliché, and I’m sure you don’t really need me to point it out, but we only have the one planet – let us as responsible concrete technologists use it wisely. By the way, whatever happened to those experiments making cement from moon rock?
INTRODUCTION

The Institute of Concrete Technology was formed in 1972. Full membership is open to all those who have obtained the Diploma in Advanced Concrete Technology. The Institute is internationally recognised and the Diploma has world-wide acceptance as the leading qualification in concrete technology. The Institute sets high educational standards and requires its members to abide by a Code of Professional Conduct, thus enhancing the profession of concrete technology. The Institute is a Professional Affiliate body of the UK Engineering Council.

MEMBERSHIP STRUCTURE

A guide on ‘Routes to Membership’ has been published and contains full details on the qualifications required for entry to each grade of membership, which are summarised below:

A FELLOW shall have been a Corporate Member of the Institute for at least 10 years, have a minimum of 15 years appropriate experience, including CPD records from the date of introduction, and be at least 40 years old.

A MEMBER (Corporate) shall hold the Diploma in Advanced Concrete Technology and will have a minimum of 5 years appropriate experience (including CPD). This will have been demonstrated in a written ‘Technical and Managerial/Supervisory Experience Report’. An alternative route exists for those not holding the ACT Diploma but is deliberately more onerous. A Member shall be at least 25 years old.

AN ASSOCIATE shall hold the City and Guilds CGLI 6290 Certificate in Concrete Technology and Construction (General Principles and Practical Applications) and have a minimum of 3 years appropriate experience demonstrated in a written report. An appropriate university degree exempts a Graduate member from the requirement to hold CGLI 6290 qualifications. Those who have passed the written papers of the ACT course but have yet to complete their Diploma may also become Associate members. All candidates for Associate membership will be invited to nominate a corporate member to act as Superintending Technologist. There is no minimum age limit in this grade.

A TECHNICIAN holding the CGLI 5800 Certificate in Concrete Practice must also submit a written report demonstrating 12 months experience in a technician role in the concrete industry. An alternative route exists for those who can demonstrate a minimum of 3 years appropriate experience in a technician role. All candidates for Technician membership will be invited to nominate a corporate member to act as Superintending Technologist. There is no minimum age limit in this grade.

A GRADUATE shall hold a relevant university degree containing a significant concrete technology component. All candidates for Graduate membership will be invited to nominate a corporate member to act as Superintending Technologist. There is no minimum age limit in this grade.

The STUDENT grade is intended to suit two types of applicant. 

i) The school leaver working in the concrete industry working towards the Technician grade of membership.

ii) The undergraduate working towards an appropriate university degree containing a significant concrete technology component.

All candidates for Student membership will be invited to nominate a corporate member to act as Superintending Technologist. There is no minimum age limit in this grade. There is a limit of 4 years in this grade.

Candidates are not obliged to attend any course (including the ACT course) prior to sitting an examination at any level.

Academic qualifications and relevant experience can be gained in any order for any grade of membership.

Corporate members will need to be competent in the science of concrete technology and have such commercial, legal and financial awareness as is deemed necessary to discharge their duties in accordance with the Institute’s Code of Professional Conduct.

Continuing Professional Development (CPD) is common to most professions to keep their members up to date. All members except students, are obliged to spend a minimum of 25 hours per annum on CPD; approximately 75% on technical development and 25% on personal development. The Institute’s guide on ‘Continuing Professional Development’ includes a record sheet for use by members. This is included in the Membership Handbook. Annual random checks are conducted in addition to inspection at times of application for upgraded membership.

ACT DIPLOMA

The Institute is the examining body for the Diploma in Advanced Concrete Technology. A residential course is run in South Africa. The worldwide web-based course is run from the UK, starting in September of alternate years. Further details of this course can be found on the website: www.actcourse.com and the ICT office has details of the others.
# Council, Officers and Committees - Summer 2006

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- **J. Wilson**
In 1997 the ICT chose “Concrete for the Next Millennium” as the subject for its Annual Convention Symposium. Well, here we are with the 2006-7 edition of the Yearbook some ten years on and well into the first decade of the Millennium in question. Have the prognoses made in 1997 been fulfilled or even surpassed or was it just well intentioned, idealistic naivety? To find out, I have re-visited the eight papers given at the Convention and report now on the reality?

The then ICT President, Ray Ryle, opened the Symposium by looking at ready-mixed concrete, both as a material and as an activity. In 1991 output was some 22 million cubic metres per year from 1200 plants in the United Kingdom and the prediction was that this would climb steadily from 2000 onwards rising to 24.5 million cubic metres in 2005 before falling back to 24 million cubic metres per year by 2010.

Information to hand today shows that in 2004 output was 22.2 million cubic metres from 1086 plants. For whatever reasons, the prognoses made in 1997 will be difficult to achieve.

In addition, we have seen further consolidation within the industry, going from approximately 25 providers to 22 with the acquisition of RMC Ltd by Cemex (Mexican) and Redland by Lafarge (French) and Aggregate Industries by Holcim (Swiss). Is it global economics or global opportunism? After all, concrete is a global material and such changes are probably inevitable. Overall, the trend is neutral to negative and within that trend issues such as plant sophistication, adoption of European standards and design codes covering cement, concrete and aggregates have been and are being adopted, driven by environmental pressures that are being encouraged by a political agenda. The use of ggbs, pfa, limestone, silica fume, burnt shale and natural pozzolanas are being encouraged and recycling is increasingly becoming part of a sound commercial strategy. The commitment to quality assurance procedures and standardisation has certainly been realised.

Concrete itself is making a direct contribution to thermally efficient buildings. Concrete is here to stay but its composition, functional effectiveness and ready provision will be subject to further change. The vision of ultra-low permeability and ultra-high strength concretes can all be met using admixture technology, coupled with additions selection and appropriate mix design. It is accepted that modern concrete is a complex, multi-phased composite and not simply sand, aggregate, cement and water.

To utilise this potential, attitudes to concrete also have to change and that requires education, training and reward. The Concrete Centre, the Concrete Society and the Institute of Concrete Technology are all to be applauded for what they do in this respect.

Conclusion 1

The ready-mixed concrete industry will align with demands for provision both in scale, variety and quality. Such repositioning causes change and that in turn can cause discomfort. The UK still remains as a market with a very low per capita consumption of concrete which will need to be changed fundamentally if the levels of growth predicted in 1997 are to be realised.

The Symposium programme then moved on to precasting with George Somerville. His paper was concerned with concrete quality and in particular, but not exclusively, concrete for bridges with the precast prestressed, inverted T bridge beams that first appeared as a nationally available component in 1961. The story is one of gradual improvement covering durability, materials, tolerances, design and detailing. There is an inevitable move towards computer-integrated design and manufacturers taking regard of national and international codes. Versatility seemed to be the watchword, providing a range of solutions. The potential for precasting was recognised but has it been realised? It would seem so, judging from the level of business being enjoyed and benefits resulting from the gradual adoption of “carousel” based plants. The promotion of modern methods of construction and off-site construction and pre-
planning also augur well for the precasting industry.

**Conclusion 2**

Precasting may come into its own taking further a process engineering approach, coupled with precision automation. Quality, convenience, speed and versatility are key with cost savings a potential added benefit. Government sponsored initiatives to maximise ‘off-site’ construction also play to the strengths of precast concrete solutions.

Doctor R F Bakker of Cemij BV Netherlands dealt with the re-use of materials in cement and concrete. In 1997 the use of ggbs, fly ash and associated secondary materials was well-established but less so alternative fuels for clinker production. Also at that time re-used demolition waste in place of coarse aggregate only comprised less than 1% of aggregate used. Dr Bakker’s view was rather negative and recycling and re-use were not predicted to increase significantly due mainly to cost disadvantage and questionable ecological trade-off.

**Conclusion 3**

The realisation of this somewhat gloomy prognosis about recycling for the UK is to be doubted with sustainability having a high political profile. Economics may well drive the environmental agenda and increasingly, waste materials will become secondary materials and entrenched attitudes will change.

Notwithstanding concrete’s proven advantages, the last 30-40 years have seen growing concern about reinforced concrete’s durability and maintenance. Corrosion preceded by carbonation was the concern of Dr M G Richardson (University College, Dublin).

The simple chemical conversion that is carbonation has been known since 1880 and up to 1990 some five hundred plus papers on the subject had been published. You might reasonably conclude that we should know all there is to know about the cause, effect and remediation associated with carbonation. The controlling factor of permeability and its reliable measurement in the laboratory and on site was regarded as key to both controlling and assessing the effect of carbonation. Understanding the inter-connected porosity of the paste phase has dominated our thinking and resulted in making and designing more durable concrete as well as modelling more predictably the onset and progress of steel corrosion.

Low permeability concrete requires:

- Low w/c ratio
- Good compaction
- Proper curing.

Admixture technology can achieve the first and the others should already be regarded as standard practice.

So, based on knowledge at that time, are we making better, more durable concrete now and will we continue to do so? Have we adopted the durability design option (refer to CSTR109)* resulting in performance-based specifications?

**Conclusion 4**

We have the knowledge to make durable concrete, particularly in temperate regions. However, transferring this knowledge into site best practice has some way to go. This again raised issues of training and the skill status at site level and the adoption of measured performance factors at design and specification stage. Ten years on, we have made some progress but the indications are it is not enough.

Much concrete that is placed is not seen i.e. underground, behind facades and underwater. The latter was the, in part, concern of Ms U Kjaer of Ramboll Hannemann and Hollund.

Denmark, as a consequence of its geography, has of necessity built many bridges and tunnels, typified by the Öresund link between Denmark and Sweden. Such structures are ambitious and strategic and are built to last. A service life of one hundred years is demanded for permanent elements and fifty years for those that are readily replaceable.

Quality control/assurance (ISO 9001) and good workmanship were considered as essential, plus adoption of modern technologies such as cathodic protection, epoxy-coated reinforcement, silane impregnation, permeable formwork and integrated sensors for monitoring corrosion.

These structures and others globally are living testimony to what can/should be achievable in relation to durable concrete. The clock is ticking. These structures will presumably be closely scrutinised and progress corroborated or confounded.

Conclusion 5

At say, five or ten year intervals, the actual performance of the structures should be quantified, declared and compared to what was expected. Such prudent auditing will help to identify which measures actually contribute to extended service life and consolidate the practice of achieving durable concrete even under adverse conditions so engendering increased confidence in the long term performance of concrete structure.

We hear a great deal about concrete quality. No matter how well the process of making and placing concrete is specified and controlled, to achieve the expected quality the materials have to be up to the task. In this respect, the quality of cement is crucial and no more so than when using blended cements. The South African experience is relevant and was described in the paper by Dr G R H Grieve of the South African Cement and Concrete Institute - “Blended Cements: Control of Quality”.

Cement quality variation would seem to be a major problem in South Africa, notwithstanding the existence of standards and a history of use of cement additives. One of the drivers behind this trend is cost, resulting in sub-quality extenders sometimes being used. The situation was exacerbated by high proportions also sometimes being used. Taken together, this raises concern over the long-term durability of the resulting concretes.

These examples highlighted the need to have confidence in the underlying testing and conformity certification procedures. In some ways, protecting the users from themselves. This is difficult if compliance to a standard is not mandatory.

Conclusion 6

At the time of writing this article, it is not known if the proven implementation of SABS has occurred. What is clear, if the checking of conformance is not carried out, entrepreneurial opportunity can create a legacy of problems. Discipline and market sampling/auditing are essential.

In the 1990s and currently construction activity in South East Asia and the Far East has been substantial. C C Stanley of Test Consult CEBTP Ltd gave an overview. In some ways, this part of the world readily adopts innovation and beneficial technical opportunity unhindered by excessive regulation, high taxation and political interference (part quote!). The problems familiar to concrete that have arisen are the same as in other parts of the world and in this regard history is repeating itself. Interestingly, the situation has kindled a commitment to high-performance concretes having exceptional durability, albeit at a price.

Concretes having strengths in excess of 135 MPa and slumps of 100 mm are in regular use. Such concretes give design opportunities, for instance, the Tsing Ma bridge. Major constructions such as this using tertiary blends and w/c ratios of 0.39. The Chek Lap Kok Airport, Petronas Towers in Kuala Lumpur and the Central Plaza in Hong Kong are testimony to the confident, if not aggressive, use of high-performance concretes.

Stanley predicted the trend to continue and that major activity would occur in Indonesia and South Vietnam.

Conclusion 7

There is opportunity for the best in concrete to excel in this region of the world. However, coupled with the opportunity is a real need to transfer the newer technologies to such advanced construction. There is an opportunity for skill and educational services to be offered. Is that happening, ICT and Concrete Society? I have reason to believe it is.

We can make every effort to provide excellent design, good materials and disciplined site practices that result in iconic structures. Nature then destroys all this effort in a matter of minutes by way of earthquakes. The result is social and material havoc. The insatiable demand for land use increases the likelihood of being subject to such conditions in the future and they need to be addressed. That was the concern of J E Roberts of The Engineering Service Centre of the California Department of Transportation.

The North Ridge Earthquake in 1994 was a severe test case for damage remediation. The task was Herculean. It is difficult to envisage how such forces could ever be resisted. Main arterial road slabs tossed about like confetti, supporting columns compressed like sponges.

Reclamation was rapid – a matter of months! Co-operation between all involved was exceptional and very effective. The disaster was also an opportunity from a design point of view.
Points to note:

- Select the right contractors
- Indulge in information sharing
- Give incentives/disincentive bonuses and penalties
- Continuous working 24 hours a day, 7 days a week.

What was not clear in detail was whether the reinstatement was performed using the latest seismic design criteria and how the designs differed from the originals. Notwithstanding that, it is claimed that the replacement structures will be able to withstand very large earthquake motion (!), displacement and ground movements without serious damage. Only time will confirm.

**Conclusion 8**

*Given a will to get things done, there is to be no limit to what can be achieved with concrete. Acts of God will always surprise but in the case of infrastructure reinstatement, concrete is still the material of choice.*

**SUMMARY, COMMENT AND PROGNOSIS**

Concrete is a sophisticated composite and becoming more so. It should be seen as such. Although some of the predictions made in the 1997 ICT Annual Convention Symposium have not yet been fully realised, the materials options and resulting versatility provided by concrete are almost unlimited. Concrete will still be the construction material of choice for the foreseeable future.

Concrete is a material of opportunity, but bringing together the vast reserves of data about concrete and its constituents, with day-to-day practices of design and constitution, requires ongoing encouragement and support at all levels.

At one level we should recognise the skill of the concretor, as we do electrician and carpenter, and at the other, concrete should figure more prominently in the education of engineers and architects, so closing the loop between exciting prospects and their practical realisation. On balance, we have entered the new millennium in good fettle. Concrete is only limited by our imaginations and the ability to transfer what we know into what can be done.
Graham Taylor, Executive Officer, is the real “face” of the Institute, a name which is known to all members as the man who does the routine organisation and administration which is necessary for the running of such an organisation. He appears at most events of the Institute, indeed he helps organise most of them, and sits on many committees. Graham has been Executive Officer of the Institute for nine years and has an unparalleled knowledge of the activities of the Institute. Prior to working for the ICT he was with the Cement and Concrete Association at their Fulmer Grange Training Centre. Graham’s discussion with Editorial Committee member Peter Oldham was held at the ICT office at Blackwater.

Q: Graham, you know as much about the Institute and its members as anyone. Before we discuss your present role, tell us a little about yourself. You have experience as an engineer working on some major Civils projects at home and abroad?

A: I worked for contractors mostly, on heavy civil engineering – motorways, power stations, terminals, chemical plants, etc. but also spent some time with a firm of consulting engineers. Just before we got married I spent 7 months on site in Sierra Leone building a jetty and my three-year contract in Zambia on a new facility for a copper plant was a condition of marriage. When we left Zambia our two young girls were getting to the stage where they needed stability in their lives so there followed over 13 years at the C&CA’s Training Centre, Fulmer Grange I also spent some time working for myself, a couple of years manning the BCA Hotline and a short period as Executive Secretary of Britpave, the concrete roads organisation.

Q: So what took you into civil engineering?

A: When at school, I had an idea to become a meteorologist but was persuaded by my father and a colleague of his that civil engineering was the thing to do. Civil engineering has a lot of freedom in it, being out on site and making decisions. And meteorology comes into it too – most of construction work is weather-dependant. But it wasn’t all sunshine out on site, those cold winter days have taken their toll – I now have some arthritis. But it’s been an enjoyable career, moving about in the UK and abroad.

Q: At some stage you decided to concentrate on concrete as a material rather than an engineering element. You found this to be more interesting or more challenging?

A: Dick Watson interviewed me for the job at C&CA and it was only then that I realised that I was already a concrete man – virtually all my previous work had been in concrete. And I took the CGLI courses whilst working for John Laing Construction and came away with the silver medal, just about 40 years ago. Most of the concrete work on site was very straightforward and it was in the days before concrete technology really took off. The ACT course has, I feel, had a considerable influence on the development of concrete since its inception 30 years ago.

Q: I understand your father was a master baker. Do you see any similarity in mixing materials for a concrete element and mixing materials for a large wholemeal?

A: I worked in dad’s bakery during holidays, making cakes mainly, and driving one of the delivery vans when I was old enough. The two processes do have similarities; it’s much the same art – mix proportions, constituents, moisture content and ‘workability’ all come into cake making; the main difference, of course, is the application of heat. I squirm at the use of the word ‘cement’ for concrete – you wouldn’t invite someone round for tea and offer them a slice of ‘flour’, would you? The big difference is that you can’t eat concrete leftovers and I was frequently told off for eating things like the off-cuts from Swiss rolls!

Q: Tell us a little about your family. Have you advised your children to follow a similar professional path to yours?

A: My wife, Sandra, was a teacher and we have been married for over 40 years now. It’s amazing how many engineers marry either teachers or nurses – there must be an inadequacy there, or is it a desire to be ‘mothered’? Our two girls both have children of their own. The older one lives in France where she and her husband are renovating an old farm property, turning the barns into gîtes. It has amazed me how well the grandchildren have settled into a foreign country, speaking French almost like natives and not wanting to return to life in England. The younger
daughter and her husband and 4-year old
daughter live quite close to us. We have recently
bought a modest cottage in France to be able to
spend time with both families. Neither of the
girls was interested in engineering, although Kate
She trained in hotel management and the other
one advises NHS trusts on fuel procurement
issues.

Q: I have heard you have a good bass
voice. You have always enjoyed choral
singing?
A: Yes, I love singing but am quite happy
being buried amongst the second basses; I don’t
have a solo voice – although I did play the
Captain of Gilbert and Sullivan’s HMS Pinafore
at school. I think by now I’ve sung most of the
more popular – and some not so popular - major
choral works from Brahms, Beethoven, Elgar,
Mozart et al. Being under the baton of Sir David
Willcox singing The Messiah at the Albert Hall
last November was the icing on the cake. I now
sing with a small, friendly choir; nothing too
adventurous but we enjoy doing a couple of
concerts a year.

Q: You are generally the person who has
most communication and correspondence
with members of the Institute. Do you think
the Institute represents itself well to the
membership and to industry in general?
A: Some of the things I’ve tried to do since I
took over from Roy Jolly are: keep the
membership together; keep them informed;
provide them with a focal point and help them
when they need it. I hope that I’ve succeeded on
that front. But I’m worried that the construction
industry, and the concrete sector in particular,
does not recognise the Institute for what it is.
The push towards multi-tasking, probably seen as
financially rewarding, has had an adverse effect
on our membership figures. My feeling is that
this will come home to roost in the future.

Q: The retention of identity is obviously
crucial, and the promotion of the Institute is,
as you say, essential. Do you think this will
be made easier after the proposed merger, or
does this worry you?
A: The Concrete Society seem to want to
make us a training and certification organisation
and it is therefore in their best interests to make
sure that the ICT has a high profile. ICT members
can also make valuable technical contributions to
the Society’s technical committees if they don’t
already do so. However, there has always been a
social side to the Institute, almost unique in
organisations of this kind, and this is an essential
part of its existence. The ACT course promoted
interaction amongst previously arms-length
people and disciplines. In short, we cannot afford
to lose our identity, and being part of a larger
organisation can only help.

Q: As “our man in Blackwater”, with all
the other varied and diverse trade,
professional and lobbying organisations
emanating from the cement and concrete
industry, do you feel the ICT, bearing in mind
our size relative to some of the larger
concerns, can feel it has a loud enough voice
in commenting on events and developments
which affect the Institute and its members?
A: I have the feeling that, apart from the six
employees who are members, there are people in
Riverside House who don’t fully understand where
ICT fits in. But most of those in my immediate
vicinity are there to sell cement and concrete to
specifiers and architects and are not all concrete
people. I do get invited along to some meetings,
such as the one determining what publications
are needed by the industry and I have hopefully
persuaded them to include site personnel. Most
of the inter-organisational co-ordination is
between the three main chief executive officers,
with occasional reference to the other guest
organisations.

Q: You are quite involved in the potential
closening of ties with the Concrete Society.
Your role will then be more important than
ever, in order to maintain the separate
identity of the Institute from the Society. Will
this be easy?
A: It is important that the Institute does not
lose its identity and this seems to be the view of
both organisations, especially our members, so it
should be easy. To this end I feel it is essential that
we continue to have someone dedicated to the
membership and to promote the Institute. If
things go to plan, I intend making sure that the
merger happens smoothly and then I shall retire; I
will take the presentation of beautiful crystal
glasses at Convention 2006 as a hint that this
happens!

Graham, many thanks for this interesting
and thought-provoking conversation. On
behalf of the ICT Council and Members, I
would like to thank you for your time and
thoughts. I hope that you and Sandra enjoy
the fruits of your labours on retirement and
wish you well for your time in France.
The origins of the UK nuclear industry go back to the 1940s when the Windscale complex [now Sellafield] was established as a military facility to produce weapons grade plutonium, under the United Kingdom Atomic Energy Authority. When this was no longer required the operation of Windscale was diversified to include reprocessing facilities and it became a civil complex to meet the needs of the young and fast developing nuclear power industry; Calder Hall, the world's first commercial nuclear power station, built by Taylor Woodrow was opened in 1957. Other facilities associated with providing fuel manufacturing capabilities and reactor research programmes were also established at different locations, including those at Harwell, Winfrith, Chester, Preston and the Dounreay complex in Scotland. This period was therefore the subject of an extensive new-build programme where leading edge technology, both in the nuclear science and the construction industry saw a vast expansion at various locations around the UK.

The resulting civil nuclear programme in the UK had reached its zenith by the end of the 1980s when approx 25% of energy needs came from this source, which was largely based on ‘gas cooled’ reactor technology as exemplified by both the Magnox reactors and the later Advanced Gas Cooled Reactors (AGRs).

Due to the relatively poor heat transfer properties of the coolant gas used (high pressure CO2) compared with that of high pressure water as used in the US designed Pressurised Water Reactors (PWRs), the reactor cores were relatively large, low density, affairs, resulting in the later Magnox reactors being particularly large, with volumes of up to 8000 cubic metres, necessary to generate the 600 MW electrical output required. The coolant was typically at 600°C at a pressure of 50bar.

Up until the early 1960s the Magnox reactors had been contained in welded steel pressure vessels of up to 75mm thickness with a separate, mass concrete, biological shield necessary to provide attenuation of both gamma rays and fast and thermal neutrons.

As the drive for increased economic efficiency resulted in the need for power stations with higher electrical output so the reactor size increased to a point where the limits of welding technology were reached for the steel plate of up to 100mm thickness used for containment.

The innovative solution then adopted, was to employ a single prestressed concrete structure to act as both the primary containment vessel and the biological shield. Gas tightness was achieved by providing a preformed, 20mm thick, mild steel lining to form the internal surface of the containment. This liner also acted as a permanent internal formwork for the concrete and, via both internal insulation fixed to the inside face of the liner and a grid of cooling water pipes welded to the outside face, ensured that generally the temperature of the concrete did not exceed 80°C during reactor operation.

As a result of the rapid growth in this civil nuclear programme, there arose an important need, which still exists today, to establish safe and reliable means of both reprocessing and long term...
storage of the various levels of waste generated both during operation and subsequent decommissioning. To support this need, starting from the mid-late 1970s, a 20-year expansion programme commenced at Sellafield to cope with the demand for reprocessing, both within the UK and commercially from overseas. These included large storage ponds, new reprocessing facilities, notably THORP (Thermal Oxide Reprocessing Plant), and a number of waste treatment plants and associated product stores. During this period, Sellafield was probably one of the largest construction sites in the world, and in the order of 1.5 million cubic metres of concrete, mainly of high quality structural grades, were produced.

**The Challenge for PCPV construction**

The advent of the Prestressed Concrete Pressure Vessel (PCPVs as they became known) created a unique and unprecedented challenge for the designers, the concrete technologist and the constructors. It was likened to the space race in civil engineering.

The design life of these structures was 30 years - although at the time of writing the two PCPVs at Wylfa, the largest nuclear containments in the world, have been successfully operating now for approx 40 years - with the concrete being subject to sustained but variable complex stress states of up to 15 MPa and variable sustained temperatures which could locally rise to approx 100°C.

Such operating conditions for concrete, let alone in such a demanding environment, were totally unprecedented and required an understanding of both the short and long term behaviour of concrete that went way beyond the civil engineer’s normal characterisation of the material in terms of ‘slump’ as a measure of its properties in the fresh state and 28 day compressive strength, as measured on an artificially cured 150mm cube, as providing a measure of its properties in the hardened state.

Essentially a detailed understanding of the material was needed at a fundamental physical and chemical level such that its properties could be adequately described at all stages through both construction and over the full range of conditions throughout its operating design life.

**Concrete properties for design**

The unique nature of the PCPVs required that relative movements were minimised and predictable. For example, fuel rods were generally loaded through the top cap of the vessel, while the reactor sat on the bottom cap. Excessive relative movement between the two would, therefore, severely jeopardise the operation of the reactors.

Movements occur in concrete for a variety of reasons, but principally as a result of changes in temperature, moisture or loading. Drying shrinkage was not considered to be significant due to the massive section sizes. Thermal movements occurred at various stages in the life of the vessels, beginning with construction. Concreting involved massive sections and was, in many respects similar to dam construction. Commonly, 2 m thick sections were cast using what was, at the time, considered to be high strength concrete (6000 psi, about 40 MPa). Early thermal movements were thus significant. Longer term thermal movements also occurred as the vessels were commissioned and operated and the design had to accommodate local temperature excursions.

A principal concern of the designers, however, was its long term deformation under sustained load, or creep, which was known to be significantly affected by temperature and moisture movement, as this would have significant impact on the performance of PCPVs.

At ambient temperatures, for structures such as prestressed concrete bridges and offshore oil and gas rigs, the effects of this property in terms of long term deflections and prestress relaxation can generally be adequately accommodated by applying a factor to elastic deformations. However, the critical importance of creep in calculating long term movements of the structure with respect both to tolerances on penetrations and plant and to prestress relaxation, meant that this simple approach was totally inadequate to determine the measures needed to either accommodate or mitigate its effects. Furthermore, at the time, the effects of both age
at loading and elevated temperature on this property had not been fully investigated.

As a result a pioneering research programme was commenced in the early 1960s to measure the magnitude of creep deformation at maximum design levels of sustained uniaxial load. The programme was designed to obtain data that would reflect the in-situ performance of the concrete \[1,2,3,4\]. The following factors were therefore taken into account:

- The structure would be several years old when prestressed and commissioned and different parts of the structure would be different ages when loaded. The original programme included testing at ages up to 400 days but subsequently, later age tests were undertaken for validation of data extrapolation
- The PCPVs are thick wall structures and drying would be insignificant. Specimens were therefore stored in a sealed, moisture stable state
- Construction comprised large pours experiencing significant temperature rise at early age. Recognising that this would affect the properties of the concrete, specimens were subjected to an early heat cycle.

Specimens were tested at temperatures of 20°C, 40°C, 65°C and 95°C, at loading ages of 7, 14, 28, 60, 180, 400 days, 3 years, 10 years and in some limited cases as late as 24 years, as part of the development of the safety case for continued operation beyond the notional design life of 30 years, sustained load being maintained over such a period of time as to enable confident extrapolation of the data over 30 years.

In the event, over a period of approximately 25 years, six number concretes, the details of which are given in Table 1\[5\], were comprehensively tested in a moisture stable ‘mass concrete’ state with representative samples being maintained under sustained load and deformation measurements made over a period in excess of 20 years.

In total approximately 400 samples were loaded together with a further 150 samples that were maintained under identical conditions as unloaded control samples.

Test samples took the form of 150mm diameter by 450mm long cylinders, which were sealed in butyl rubber jackets to simulate the mass concrete conditions (Figure 1). The 3:1 aspect ratio of the test cylinders was chosen to ensure that over the central 1/3rd height, where strain measurements were made, a uniaxial stress state existed, this being unaffected by the lateral restraint induced by the bearing plates of the loading frames.

<table>
<thead>
<tr>
<th>Station</th>
<th>Wylfa</th>
<th>Hartlepool</th>
<th>Heysham A</th>
<th>Heysham 2</th>
<th>Torness</th>
<th>Sizewell B</th>
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<tbody>
<tr>
<td>Source of materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cement</td>
<td>Padeswood</td>
<td>Weardale</td>
<td>Ribble</td>
<td>Ribble</td>
<td>Dunbar</td>
<td>Masons</td>
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<td></td>
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<tr>
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<td>Igneous</td>
<td>Glacial</td>
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<td>Sea dredged</td>
<td>Pit</td>
<td>Sea dredged</td>
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<td>40mm Dolerite</td>
<td>40mm Hornfels</td>
<td>40mm Dolerite</td>
<td>20mm Dolerite</td>
<td>20mm Sea dredged</td>
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<td>270</td>
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<td>-</td>
<td>-</td>
<td>-</td>
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<td>1090</td>
<td>1230</td>
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<tr>
<td>Density</td>
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<td>2435</td>
<td>2545</td>
<td>2440</td>
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<tr>
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<td>-</td>
<td>-</td>
<td>25</td>
<td>25</td>
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<tr>
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<td>55</td>
<td>52.5</td>
<td>60.5</td>
<td>61</td>
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</tbody>
</table>

\[1\] Secondary containment structure for Pressurized Water Reactor

Table 1: Concrete mix details \[5\]
Strain measurements were made internally using embedded vibrating wire gauges and externally at three locations set at 120° using a demountable Demec gauge.

With the exception of early work in the USA by the Bureau of Reclamation to support the design of dams in the '40s and '50s, where generally low strength concretes were employed, no such comprehensive programme of work has been undertaken anywhere else to date. An example of the results obtained for the Wylfa PCPV concrete is shown in Figure 2. The results were presented to the designers in the form of specific creep curves.

Combining the results from this work with theoretical studies by Counto in which multiphase models of varying degrees of sophistication were established using combinations of springs and dash pots in parallel and series, enabled constituent materials to be selected having properties that would minimise creep deformation. For example, whilst creep occurs largely in the cement paste phase, the stiffness of the aggregate, which accounts for

![Figure 1: The TEL (Taywood Engineering Ltd) creep test facility and research team (including Phil Bamforth, Roger Blundell and Roger Browne, circa 1971)](image1)

![Figure 2: Specific strain data for Wylfa at 20°C and 45°C](image2)
70% of the concrete by volume, is of overriding importance. It was established that if the aggregate had a modulus of greater than 11.0 million psi (76 GPa), creep would be acceptably low and similar from one concrete to another. The measurement of the E value of aggregate sources therefore became key to its selection. Hard, crushed limestone and dolerite were the favoured rock types.

Other key issues in mix design that were of importance in minimising creep included ensuring that the w/c ratio was generally less than 0.45 to ensure that on full hydration of the cement, a discontinuous capillary structure is achieved, thereby minimising movement of the absorbed water within the cement gel under the action of temperature or drying. Also paying particular attention to the packing of the total aggregate system (coarse and fine) was of importance to minimise the volume of cement paste whilst still achieving a workable mix.

Other critical properties

To support the calculation of temperature and temperature gradients in the concrete during both transient and steady state conditions, thermal conductivity and thermal diffusion coefficients of the concrete were measured. Elastic modulus under both initial and cyclic loading and long term shrinkage caused by the changing moisture state within the cement paste due to continued long term hydration of the ordinary Portland cement were measured on identical samples to those used for the creep tests.

The results from this programme were used to support the design of twelve PCPVs built at Wylfa, Hartlepool, Heysham (4No PVs), Hunterston and Torness nuclear power stations.

Concrete behaviour during construction

A particularly complex and vitally important region of the PCPV is the ‘standpipe (or SP) zone’ through which fuelling and reactor operational control are achieved via an array of up to 300 no. 300mm diameter tubes which run vertically through the 6metre thick pressure vessel top cap down to the top of the reactor core some 5 metres below the soffit of the top cap and upward to the fuelling floor which is itself some 4 metres above the top surface of the top cap. Due to prefabrication of the standpipe array, concreting of the top cap had to take place from fuelling floor level. Matters were made more complex by the thickness of the ligaments between standpipes being as little as 150mm.

For Wylfa, where the ligaments were 250 mm thick a mix, based on the main PV mix but with a reduced maximum aggregate size of 20 mm, was used to concrete the SP zone in twelve 0.5 metre thick pours. The low pour height ensured no heat of hydration problems.

For the PCPVs at both Hartlepool and Heysham where thinner ligaments existed, it was decided to cast the whole Standpipe Zone as a single 300 cubic metre pour via small diameter tremie pipes running from a temporary working platform set at fuelling floor level.

Two issues were of particular concern:
- Ensuring complete compaction of the concrete with the limited mechanical vibration that was possible.
- Eliminating distortion of the standpipes due to concrete movements caused by the heat of hydration cycle.

To achieve the above, a special high flow mix was developed using 20 mm aggregate, 2.5 times the normally recommended dose of a low sugar content calcium lignosulphonate workability aid and with 50% of the Portland cement being replaced by ground granulated blast furnace slag to reduce temperature rise during the heat of hydration cycle.

A number of samples were cast for creep testing and full scale mock-ups constructed on both sites to enable placing trials to take place using the actual labour to be employed at both locations.

Late life performance

During the 1990s many of the reactors in the UK had reached the end of their notional design life of 30 years but were still performing efficiently. To support their continued operation the Health & Safety Executive required that evidence be provided on the performance of all components of these highly complex structures, including the concrete. Fortunately, Taylor Woodrow had maintained a number of specimens under test, some for over two decades, and these formed the basis for a new research programme [7] with the following objectives:

1. To evaluate the long-term compressive strength development and the effect of the load and temperature history
2. To determine the effect of late-age thermal cycling on the compressive strength (to
determine the effects of a loss of coolant accident (LOCA) in which the temperature of the concrete may locally achieve a temperature of 150°C.

3. To measure the creep of concrete under late age loading.

In addition, a compendium of information on the concretes used in each of the PCPV’s was established, including (where available) the test results obtained during the design and construction phase of each Nuclear Power Station. From this data, models for predicting the late-life, properties of PCPV concrete were derived.

The late-life test programme demonstrated very clearly that the concrete was able to withstand sustained load and elevated temperature (up to 95°C) over a long period without detriment to its performance. Indeed, as shown in Figure 3, what were initially concretes with a 28-day characteristic cube strength in the

![Figure 3: Strength development of heat cycled PCPV concretes](image1)

![Figure 4: The relationship between elastic modulus and temperature for the Wyifla PVPC concrete](image2)
range of about 40-60 MPa (which at the time, before the advent of superplasticisers and silica fume, were considered to be ‘high strength’ concrete) had achieved values in the range of 60-75 MPa after 25 years.

A particularly interesting finding, only achievable by comparing the performance of the six PCPV concretes, was the effect of fly ash on the load-deformation behaviour. As shown in Figure 5, both the elastic modulus and the effective modulus after 100 days under load were significantly higher in the three concretes that contained fly ash (Heysham 2 and Torness (25% fly ash) and Sizewell (40% fly ash)). Further analysis indicated that the modulus was inversely related to the volume of cement paste, excluding the fly ash. This suggests that fly ash, while contributing to the strength of the cement paste, acts more like the stiffer aggregate in relation to the deformation behaviour. These findings are useful in two respects. Firstly, if the same relationship applies to all concretes, then the modulus (elastic and effective) of fly ash concrete may be estimated relatively easily from data on (Portland cement) concrete. Secondly, and perhaps more importantly, fly ash concrete can be seen to offer particular advantages for prestressed structures in terms of both reduced prestress loss and deformations.

The nuclear waste industry

The use of cement and concrete is not limited to the construction side of the nuclear industry. The UK nuclear industry evaluated a number of potential immobilisation matrices for a wide variety of active, classed as intermediate level, radioactive waste materials over 25 years ago and concluded that cement systems had many advantages over alternatives. These included:

- The ability to immobilise a wide range of generic waste types, both solids and liquids,
- Cementation science and technology are well known and understood
- Cement has a proven history for longevity going back to Roman times, and
- The alkaline environment provided by cement systems has certain advantages in minimising the solubility and migration of certain radionuclides.

Cements have therefore been subject to a detailed, on-going development programme initially by British Nuclear Fuels, now British Nuclear Group with support from relevant government departments, but also by other waste producers including United Kingdom Atomic Energy Authority. The overall objective was to develop through research and development, then scale up to operational levels a range of waste treatment processes, in parallel with the design and construction of a number of operational plants and surface interim storage facilities. These were to treat specific, large volume, waste streams and demonstrate to independent bodies the robustness of the overall process which in turn would underpin the physical, chemical and radiological stability of the immobilised waste products for an interim period of up to 200 years.

Figure 5: The relationship between modulus and paste volume (excluding fly ash)
prior to final disposal to an underground repository; full details of which have not been announced in the UK. The UK was the first country worldwide to successfully commission and operate large scale cementation plants for nuclear waste processing.

Grout systems are high quality cement-water grouts utilising significant proportions of pfa and ggbs blended with Portland cement. They are used either in an in-drum mixing process, where the mixing paddle is retained in the product container, to mix powders with liquid waste, or by manufacturing a cement grout in conventional high shear or other designed mixers, then adding this to solid waste in a suitable container. Either method is developed to produce an homogeneous, void free solid product. Powder properties are crucial to the grout performance and it is necessary to use more stringent specifications than those required in the BS and BSEN documents, in use within the general construction industry. It is noted that in most cases grouts are required to have low heat development, low water content, longer setting times yet be fully bleed free and to be extremely fluid. This may appear to be straightforward utilising today’s technology until it is realised that organic additives are presently not permitted in these grouts as they can have potential long term radiological implications. Compressive strength is not a principal factor though tends to be fairly high because of other designed properties; these can reach more than 70 MPa long term even when using high ggbs contents of up to 90%. Hardened grout properties are also important; one is low permeability. Values of liquid permeability can be 5-6 orders of magnitude lower than those for a high quality concrete, whilst equally important are physical properties such as dimensional stability and thermal characteristics.

The types of wastes create complex durability issues, more so when there is a requirement to demonstrate the long product life, noted above, to appropriate licensing and other independent authorities. In some ways a parallel can be drawn with conventional concrete aggregate, as both are ‘encapsulated’ by grout; however the wastes can have a much greater array of chemical and physical properties to evaluate and demonstrate stability for a longer period. They can include steel bar and sheet which are relatively inert but unusual in shape, various chemical sludges and flocs from reprocessing, many which are acidic, and reactive metals such as aluminium and magnesium alloys from which short and long term corrosion reactions can occur together with a range of laboratory and similar waste materials. Many of these properties can have a derogatory effect on the normal ‘rules’ of cement chemistry and hence require extensive evaluation to confidently understand and predict performance – a little more complex than sulphate, DEF or ASR though of course these also need to be considered. There is additionally research and development into non Portland cement systems to cope with the variety of smaller volume and more complex wastes.

Cement grouts are also employed extensively in the packaging of low level nuclear waste. Surface storage containers, or ISOfreights, are infilled with highly fluid Portland cement/pfa grout which acts principally as void filler though the material does have other advantages.

Containers for long term storage are primarily stainless steel drums though depending on waste type, can include a grout lining. One waste is placed in large precast concrete boxes manufactured from either standard density or high density mixes and production methods have included the use of self-compacting concrete to guarantee placing in narrow areas where complex steel reinforcement is located. Smaller concrete containers are used in France and incorporate high performance, corrosion resistant flexible metallic fibres as reinforcement.
As part of a programme of initial studies into the design of a long-life underground repository, funded by NIREX and undertaken in part by Taylor Woodrow, extensive development work was also undertaken to achieve a backfill between the waste containers and the rock strata. This material had somewhat unusual requirements in that it needed high flow for remote placing, low shrinkage and stiffness to achieve a crack free system, a sustained highly alkaline environment and a long term compressive not exceeding 10 MPa. To support this work a comprehensive study was undertaken of ancient construction materials of Graeco-Roman origin with the finally designed material containing a high proportion of hydrated lime.

Use of high density concrete and grout

The nuclear industry has traditionally been regarded as the originator of high density concrete where it is used for radiation shielding, though it should be noted that the majority of shielding concrete is standard density used in thick sections. Early work in USA in the 1950s initially resulted in the development of some of these materials, and further significant development was made during the 1980s, mainly at the Sellafield reprocessing site where a range of concrete relative densities between 3.4 and 8.75 together with a range of grouts between 2.8 and 6.6 were successfully designed and used in significant quantities. These can be used in structural locations apart from lead shot mixes which have a complex chemistry. In general the shielding effectiveness is proportional to the concrete density and is generally used where space is a premium; however, it can additionally be affected by the nature of the radiation though this is a very specialist topic beyond the realm of the concrete technologist.

Aggregate types can be naturally occurring or materials used in other industries for other purposes. The main ones include:

- Barytes [naturally occurring barium sulphate mineral ore]
- Magnetite and haematite [Iron ores]
- Iron and steel shot
- Various sizes and types of scrap iron and steel
- Ferroslag – an iron silicon slag
- Lead shot

The use of these high-density aggregate can also result in concrete with other usefully enhanced properties such as thermal conductivity and diffusivity. A particular example of these materials was developed at Taylor Woodrow in the developmental stages of the sodium cooled
fast reactor. Here, as part of a post-accident, heat removal system, concrete was required with a thermal conductivity in excess of 10 W/m°C, some four times that achieved with normal density concrete. Some results obtained are shown in Figure 7 achieved using a combination of graded iron/steel shot aggregate and ground haematite (iron ore) to partially replace the Portland cement[^10].

It is important to recognise that most of these materials have physical and chemical properties which can be challenging to traditional mix design methods and careful evaluation of these is always necessary both before and during use of these concretes and grouts. Designers and specifiers need to be aware that aggregate gradings, whilst being consistent, will frequently fail to comply with more traditional specifications though high quality concrete can still be produced using these materials. It is generally appropriate to start from basics to design these mixes and the characteristics of the mix in terms of aggregate/cement ratios and fines content will often appear to be extreme and unconventional. Water contents need to be minimised to prevent segregation and full use of superplasticisers is normally recommended to achieve workable mixes though magnetite has been used to produce self compacting concrete. One aspect of the shielding properties is to be able to estimate the long term water content likely to remain in the hardened concrete, small quantities of supplementary materials can also be added to accommodate these complex requirements. This factor together with detailed chemical analyses of mixes is a further requirement and an aid to assessing the radiological and shielding properties.

The properties of high density mixes depend on the aggregate to a greater extent compared to standard aggregates in conventional materials. Slump and flow characteristics of fresh mixes indicate a different behaviour compared with traditional standard-density mixes and experienced assessment is probably the best guide rather than to require compliance with standard specifications. Mixing, transportation and placing all require specific assessments and have differences from standard concrete. The hardened properties can be similar to standard concrete. Obviously the main property is the demonstrable attainment of a uniform density. High compressive strengths are possible but potential users are advised to consult specialist data or establish other more specific mechanical and thermal properties as necessary when considering their deployment in either structural or non-structural locations.

In summary high density concrete and grout can be successfully designed and produced with the help of competent concrete technologists. Quality management will be more stringent than for conventional density concrete and it should be appreciated this can often offset the higher unit costs of these materials.

### Future prospects for concrete in the nuclear industry

The recent indications by Government that nuclear power is to play a significant role in the future UK Energy policy is further confidence in the continued concrete utilisation within the nuclear industry. Future reactors are most likely to be of the Pressurized Water design (PWR) as currently being built at Olkiluoto plant in south-west Finland. This highly efficient design utilizes a comparatively small steel primary containment vessel but a large prestressed concrete thin shelled secondary containment which is designed to capture a high temperature (600 °C), high pressure steam release in the event of failure of the primary coolant system. The secondary containment also provides protection to the reactor system against extreme external events.

There will also be a substantial requirement for concrete and associated products in other related areas. The older power stations and the reprocessing facilities in various locations in the UK are now included in a large decommissioning programme, overseen by the Nuclear Decommissioning Agency (NDA) and this will continue for many years. There will be significant new-build within sections of this programme principally at the Sellafield complex and at UKAEA’s Dounreay complex in Scotland but additionally at the power stations themselves, to accommodate requirements for intermediate and low level waste treatment associated with both current and historical waste as well as decommissioning arisings. These in turn, will generate a requirement for additional surface storage facilities, themselves significant structures. A new positive environmental aspect of future build on existing nuclear licensed sites could be the use of recycled aggregates, won and reprocessed from demolition waste of existing buildings, these will of course be proven as ‘radiologically clean’. Finally, in the longer term, there are proposals for all the existing and future
surface-stored treated wastes to be transferred to a purpose built underground repository; this will also be a massive undertaking using large volumes of specialist grouts and concretes. Within this, the emplaced waste containers are likely to be encapsulated with a specially designed ‘back-fill’ cementitious grout which has been purpose-designed to maintain a long term alkaline environment appropriate to the local geology. It therefore suggested that the somewhat lean period of the past ten years or so for construction in the nuclear industry may relatively soon be replaced by a busy period in which there will be opportunity for the industry to capitalise on the use of new construction techniques and materials in a wide variety of projects.

ACKNOWLEDGEMENTS

The authors would particularly like to thank Dr Roger Browne (of Taylor Woodrow) whose foresight and intellectual courage led to the creation of the pioneering programme of concrete research undertaken at Taylor Woodrow, as well as the many civil engineers and concrete technologists that contributed to this remarkable team effort. The authors are also indebted to the Directors of Taylor Woodrow Construction and British Nuclear Fuels Limited and their clients for permission to use company information in preparing this paper.

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A major part of the ICT Annual Convention is the Technical Symposium, where guest speakers who are eminent in their field present papers on their specialist subjects. Each year papers are linked by a theme. The title of the 2006 Symposium was:

**CONCRETE FOR A SUSTAINABLE FUTURE**

Symposium Chairman: Stuart Bell, DipArch, RIBA, MIMMM, MICT.
Director, Marshalls.

Edited versions of the papers are given in the following pages. Some papers vary in written style notwithstanding limited editing.

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| **The Government’s View of Sustainable Construction**                | Andrew Frost  
| BSc(Hons), MEnvSc, MIEEM. The Concrete Centre                         |                                                                        |
| *One Coleman Street - A Case Study in the Use of Secondary Materials in Concrete* | Dr Bryan Marsh  
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| *Sustainable Concrete: How can additions contribute?*                | Dr Dennis Higgins  
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| MSc. Lafarge Cement UK                                                |                                                                        |
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| *Thermal Mass in Commercial Office Design*                            | Tom de Saulles  
| BEng, CEng, MCIBSE, MIMechE. British Cement Association               |                                                                        |
| *Sustainability and the Role of the Precast Industry*                | Martin Clarke  
| BSc(Econ), FRSS, FIQ. British Precast                                 |                                                                        |
| *Sustainable Drainage Systems for Our Modern Environment*            | Mark Watson  
| BEng(Hons). Marshalls Plc                                             |                                                                        |
George Martin is the Director of Rethinking at Willmott Dixon Construction. He was formerly the Director of Sustainability at BRE.

**ABSTRACT**

The issue of sustainability is discussed, identifying a circle of blame. Government initiatives and the means of minimizing operational impacts are examined. A case for recycling is given.

**KEYWORDS**

Sustainability, Government, Tools, Carbon, Emissions, Recycling

**INTRODUCTION**

The following is an outline of the presentation.

**WHAT IS SUSTAINABILITY?**

If the UK is serious about tackling climate change, we need fewer buildings which, whilst being aesthetically advanced, needs sophisticated but expensive heating and lighting, in order to deliver less carbon dioxide into the atmosphere.

Ironically, the ‘progress’ we have made to date includes:

- Increased UV exposure
- Famine in parts of the world
- Obesity in developed nations
- Deadly infections such as bird ‘flu
- War and Terrorism
- Poor air quality in urban areas.

**What is sustainable development?**

The Brudtland definition (1987) is: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.”
The reality is that the large companies take the money and subcontract practically everything; at this distance from the client, everything is cut to the bone.

There is also a vicious circle of blame (Figure 1):

There are many actors taking part:
- Constructors
- Manufacturers
- Institutions
- Trade Associations
- Unions
- Pressure Groups
- Users and the community
- Scottish Executive
- UK Government
- EU.

Figure 1: Vicious circle of blame:

Central Government construction projects

<table>
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<tr>
<th>Indicator</th>
<th>Baseline Performance 1999</th>
<th>Interim performance Dec 04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost predictability</td>
<td>25% of projects delivered within budget (with remaining 75% exceeding budget by up to 50%)</td>
<td>55% of projects delivered within budget</td>
</tr>
<tr>
<td>Time predictability</td>
<td>34% of projects delivered on time</td>
<td>63% of projects delivered on time</td>
</tr>
</tbody>
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Figure 2: Central Government construction projects
There are many government bodies involved:
- **DTI** Competitiveness and productivity
- **DEFRA** Environmental Management via the Environment Agency – Utilities
- **ODPM** Building Regulations, Housing, Planning, Urban Task Forces, Skills Overview
- **DH** Department of Health
- **Works and Pensions** – Health and Safety via the HSE
- **DIT** Transport
- **DIES** Education
- **Treasury and OGC**
- **Home Office** – Prison Service.

Construction is not a sector and the Government’s approach is fragmented.

The sustainability requirements and targets of the Government Construction Client’s Panel, to be delivered by March 2003, were:
- 100% of departments to use whole life costs
- 100% of new-build projects to achieve BREEAM or equivalent ‘excellent’ rating.

Of the 147 new-build construction projects undertaken only three have achieved an ‘excellent’ rating.

The EST and Energy Efficiency Partnership study was undertaken on 99 new dwellings in November, 2004 – 36 flats, 31 terraced houses, 21 semi-detached and 11 detached houses. They were all based on robust standard details of 2002 and construction had been signed off by Building Control as fully compliant with Part L. The results showed that 33% failed to achieve air permeabilities of 10 m³/h/m² at 50 MPa.

Some progress has been made and good examples of sustainability practice are The Great Western Hotel in Swindon, BedZED and Kingsmead School.

As far as central government construction projects are concerned the picture is shown in figure 2.

In March 2005, the Government published its sustainability development strategy under the title ‘Securing the future’. Its principles are:
- Sustainable consumption and production
- Climate change and energy
- Protection of natural resources and environmental enhancement
- Creating sustainable communities.

And the three key themes are:
- Involving people
- Government leading by example
- Getting serious about delivery.

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![Image: Initiative & Information Overload = Chronic confusion.](image)
Legislation and policy drivers are:

- Energy white paper – 60% CO2 reduction by 2050
- Better Building Summit – Code for Sustainable Building (CSB)
- Updates to Part L
- Planning – PPS 22 Renewable Energy – 10% requirement
- EU Energy Performance of Buildings Directive (EPBD)*
- Sustainable and Secure Building Act
- Waste Strategy – 10% recycled content in buildings
- Egan Review of Skills – Academy for Sustainable Communities
- Sustainable procurement task force.

*The EPBD requires member states to introduce, by the end of 2005, Minimum energy performance standards, energy performance certificates and regular inspection associated with boilers and air-conditioning systems.

There are many bodies set up to give help, as shown in Figure 3.

BREEAM suggests that all building types can be assessed, from Offices, through homes, schools, sports facilities down to garden sheds. It rates buildings using assessment credits and environmental weightings, to produce a single score.

**Materials carbon supply chain**

The carbon emissions from the production and transport of construction materials are a significant part of the construction industry. The carbon lifecycle of a typical building is:

- Materials production 30%
- Transport 14%
- Construction 29%
- Ongoing building operations 28%

Combined, materials production and transport make up 44% of all construction-related emissions. This can be reduced by improved extraction, manufacturing and sourcing processes, recycling and sourcing locally. Seventy-two percent of a building’s lifecycle carbon is embedded in the physical asset.

Designers can compare different designs and specifications directly by using the Green Guide to housing Specification (by Jane Anderson and Nigel Howard, first published in 2000, reprinted in 2005: BR390PP40), which gives simple ratings for building components.

The ODPM (formerly the DETR) has undertaken a project with 24 industry partners to get a consensus for methodology to apply LCA to all construction materials and a certification scheme.

There is a good economic case for increasing the recycled content at no extra project cost and indicative figures are shown in figure 5:
A statement made in April 2004 by Quentin Leiper, Carillion’s Director for Engineering and the Environment, states the business case: “Ignorance is bliss. If you do not work in a sustainable way, you are losing out! If you cannot see that it adds value, then you do not have a sustainable business. Being more sustainable is not just about the planet and feeling good; we in Carillion have learned that it is an essential part of improving the business.”
Andrew B Frost joined The Concrete Centre as Sustainability Manager in May 2005. Andrew is an environmental scientist and has been involved in a diverse range of projects ranging from environmental impact assessments, contaminated land reclamation and bioremediation, to the development of hydrological modelling techniques and investigations into pollutant flows in fractured aquifers using electrical resistivity tomography. In 2003 Andrew was awarded the John Connell Memorial Prize by the Institute of Environmental Sciences for his contribution to hydrological research.

Andrew describes his role as assisting specifiers to take a holistic view on sustainability, considering its intrinsically linked social, economic and environmental themes and to present a fair and balanced view of the outstanding sustainability credentials of concrete to people both inside and outside the concrete industry. He considers sustainability to be core to all business rather than a bolt-on and feels sustainability will come to the fore as people realise the global challenges our lifestyle has created in recent decades.

**ABSTRACT**

This paper discusses various aspects of sustainable development and puts this ethos into the context of the UK Government's view of sustainable development and construction, and its potential impacts and opportunities for the UK concrete industry. It concentrates on the way that the UK Government is driving their agenda but also considers the wider influence of Europe and global incentives. Possible future sustainable development implications for the UK concrete sector are also discussed.

**KEYWORDS**

Sustainable development, Concrete, Securing the future, Climate change, Kyoto, Energy, Emissions trading, Key performance indicators, Building Research Establishment, EcoHomes, BREEAM, Code for Sustainable Homes, Chain of custody, Climate change levy.
causing environmental pollution, degradation, and are leading to global climate change.

How this is best achieved is often a matter of opinion rather than fact, dependent upon different perspectives of the environment and views of nature. Recently, a concept has emerged that has attempted to bring together the best aspects of the differing viewpoints to try and harmonise the development of mankind with the protection of the environment. This is the concept of ‘Sustainable Development’.

The publication of Our Common Future in 1987, by the UN-sponsored World Commission on Environment and Development (WCED) led by Gro Harlem Brundtland, marked a watershed in our thinking on environment, development and governance. They issued a bold call to recalibrate institutional mechanisms at global, national and local levels to promote economic development that would guarantee “the security, wellbeing, and very survival of the planet”[5].

SUSTAINABLE DEVELOPMENT

Sustainable development involves maintaining our current rate of development whilst leaving suitable resources behind for later generations to continue to develop. Therefore environmental problems must be tackled by considering their relationship with the state of the economy and the wellbeing of society. We must take a holistic approach to each facet of sustainability, the environment, the economy and society as taken together; this triple bottom line includes everything that we need to consider for a healthy, prosperous and stable life. There are now over 260 definitions of sustainability but it is not a new philosophy, as shown in this Kashmiri proverb:

“We have not inherited the world from our forefathers -- we have borrowed it from our children.”

The call for sustainable development was a redirection of the enlightenment project, a pragmatic response to the problems of the times. While the broad goals were widely embraced, critics argued that steps toward their implementation would be thwarted; first, by fundamental contradictions between the renewed call for economic growth in developing countries and enhanced levels of ecological conservation; and, second, by the inattention to power relations among the local-to-global actors and institutions supporting unsustainable development. In retrospect, 19 years later, the critics appear to be more or less correct. While more attention is now being given to the environmental consequences of particular development projects, the primary drivers of environmental degradation (energy and material use) have burgeoned.

CONCRETE AND SUSTAINABILITY

Concrete has become by far the most popular and widely used construction material in the world [3]. Concrete is perceived to be and has been identified as the provider of a nation’s infrastructure, and indirectly as an indicator of its economic progress and stability, and indeed, of the quality of life [6].

The concrete sector is a vital component of the UK economy, directly employing over 40 000 people, supporting the construction industry that employs approximately 7% of the UK population [7] and accounts for approximately 10% of the UK’s Gross Domestic Product (GDP)[8].

Concrete is easily and readily prepared and fabricated in all sorts of conceivable shapes and structural systems in the realms of infrastructure, habitation, work and play. Its great simplicity lies in that its constituents are ubiquitous and are readily available almost anywhere in the world [6]. Concrete is at risk, however, of becoming a victim of its own success as:

• The production of one of concrete’s constituents, ordinary Portland cement (OPC), is a resource- and energy-intensive process consuming approximately 1.5 tonnes of raw materials [6] and producing approximately 1 tonne of carbon dioxide (CO2) for each tonne of OPC produced [2].

• In the UK the production of OPC accounts for approximately 2% of UK CO2 emissions [8]

• Globally the production of OPC accounts for approximately 7% of CO2 emissions [9].

To achieve sustainable development in the concrete industry we need to understand and appreciate what has happened in the world during our lifetime. During the last five decades there has been enormous social change, technological revolutions and unacceptable damage to our natural environment that has historically been treated as a free resource to plunder at will. To survive, the industry must embrace sustainability – it is not a fad, a passing phase, or a new bandwagon to jump on; it is intrinsic to our businesses and is with us to stay.
There are a number of global challenges which have put pressure on governments to address sustainable development. Unfortunately the world is not an equitable place, at present a quarter of the world’s people survive on less than $1US per day, raising moral questions about our own profligate consumerist lifestyles\[10\]. It is estimated that by 2050 there will be another three billion people on the planet, a 50% increase on current levels, and if they all aspire to the same way of life that we currently enjoy and lead in the West, there will simply not be enough resources to sustain that standard of living or the population\[10\]. Climate change is predicted to increase UK temperatures by up to 5 degrees by the end of the century and if left unchecked will lead to damaging consequences including serious loss of life \[11\].

At the Rio summit in 1992, governments from around the world, including the UK, committed to sustainable development. The UK Government was the first to produce its national strategy, in 1994, and in 1999 the UK Government outlined how it proposed to deliver sustainable development in ‘A Better Quality of Life’. This set out a vision of simultaneously delivering economic, social and environmental outcomes via four key aims which have formed the basis of subsequent Government policy:

- Social progress which recognises the needs of everyone
- Effective protection of the environment
- The prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment.

These key aims are measured by a series of headline indicators and since 1999 progress has been measured every year against these indicators \[9\].

Figure 1 shows the set of shared UK principles that the UK Government will use to achieve its sustainable development purpose. They bring together and build on the various previously existing UK principles to set out an overarching approach, which the four separate strategies can share \[10\].

The Government states that these principles will form the basis for policy in the UK and that for a policy to be sustainable, it must respect all five of these principles; their aim is to “achieve our goals of living within environmental limits and a just society, and we will do it by means of a sustainable economy, good governance, and sound science” \[10\].

**THE UK GOVERNMENT AND SUSTAINABLE CONSTRUCTION**

**Building Regulations**

The Building Regulations are the Government’s tool to ensure standards are met industry-wide. However, the planning system provides Local Authorities with the powers to include further specifications.
The update to Part L of the Building Regulations will come into force in April 2006. This will set standards aimed at achieving a 20-25% saving in CO₂ emissions compared to current regulations. Existing methods of demonstrating compliance will be replaced by a calculation of overall CO₂ emissions and comparison against a target value. This calculation will take into account any renewables used in the building [10].

The Sustainable and Secure Buildings Act (passed in 2004) will allow building regulations to address the sustainability of new buildings as well as to address conservation of fuel and power, or prevention or reduction of greenhouse gas emissions in relation to existing buildings. It does this by amending the Building Act 1984 [10] by:

- Adding furthering protection and enhancement of the environment, facilitation of sustainable development, and furthering the prevention and detection of crime to the purposes for which Building Regulations may be made
- Adding demolition of buildings (to the existing design and construction matters) as a matter about which Building Regulations may be made
- Adding the re-use of building materials, recycling facilities, use and monitoring of fuel and power, and security (to structural stability, fire safety, etc) as matters for which the Building Regulations may make provision
- Allowing regulations to be made imposing sustainability requirements on existing buildings when they are altered, extended or there is a change of occupancy; for example, by requiring existing lofts and cavity walls to be insulated where it would be cost-effective
- Allowing regulations to be made imposing continuing requirements in relation to energy conservation and emissions – e.g. regular inspection and testing of boilers.

The Sustainable Development Commission is researching the techniques, costs, benefits and support mechanisms necessary to improve the resource efficiency of the existing building stock and work is now underway to see how existing Building Regulations can be updated to take into account this broader range of sustainable development issues.

THE PLANNING SYSTEM

The Government sees the UK planning system as key to achieving sustainable development. The Government’s new planning policy statement ‘Delivering Sustainable Development’ (PPS 1) sets out their vision for planning in England and the key policies which will underpin it. PPS 1 makes it clear that sustainable development is at the heart of the planning system. It sets the framework for reflecting the duty in the Planning and Compulsory Purchase Act 2004 for regional and local plans to be prepared with a view to contributing to sustainable development.

Other planning policies, set out in the Government’s Planning Policy Statements and Planning Policy Guidance notes, complement PPS1 in delivering sustainable development:

- Planning policies for housing (PPG 3) ensures that brownfield land is developed first for new housing, and that new housing is built at higher densities than previously, reducing the need for development on greenfield sites and that new developments are located in areas such as town centres which are accessible by means of walking, cycling and public transport thereby reducing reliance on the private car
- PPS 22 on renewable energy states that regional spatial strategies and local development documents should contain policies designed to promote and encourage, rather than restrict, the development of renewable energy resources
- PPG 25 encourages the use of sustainable urban drainage strategies as part of measures to reduce risk of flooding.

Sustainable development is built into every stage of the planning process. Regional plans, called Regional Spatial Strategies (RSS), are drawn up by Regional Assemblies (the regional planning body). The RSS, incorporating a Regional Transport Strategy (RTS), provides a spatial framework to inform the preparation of Local Development Documents (LDDs). These documents form the portfolio which collectively delivers the spatial planning strategy for a local planning authority’s area. The RSS also informs the preparation of Local Transport Plans (LTPs), and regional and sub-regional strategies and programmes that have a bearing on the use of land.

Many local authorities produce supplementary planning guidance (SPG) covering a range of sustainable design and construction issues and others are producing specific guidance on sustainable design and construction. For example,
Hull City Council has produced the following Supplementary Planning Guidance (SPG):

- SPG Note 2: Urban Green Space and Play Areas
- SPG Note 4: Housing
- SPG Note 23: Cycle Parking Facilities
- SPG Note 24: Nature Conservation and Development
- SPG Note 26: Designing for Energy Efficiency.

**BREEAM AND ECOHOMES**

Since its launch in 1999, the Building Research Establishment Environmental Assessment Methodology (BREEAM) schemes have been developed for industrial units, superstores, retail, health care, offices and housing. The housing scheme is known as EcoHomes. The scheme established best practice criteria against which buildings can be assessed, and depending on performance, schemes are awarded a rating of Pass, Good, Very Good or Excellent. The scheme is now used by clients to establish performance standards for new developments.

Initially BREEAM and EcoHomes were established as voluntary standards with the support of several private developers. For all public sector buildings (non-residential and residential) and private buildings on previously publicly owned land the schemes are now mandatory. All new Government buildings must achieve a rating of Excellent with refurbished buildings achieving a rating of Very Good.

The schemes unfortunately have three fundamental flaws:

- They focus solely on environmental impacts and fail to address sustainability in a holistic fashion
- The methodology is owned and developed by a commercial organisation
- Are biased with how they treat materials, only allowing credits for responsibly sourced timber.

The final point has hopefully been addressed by BRE and since the 1st March 2006 the timber credit in BREEAM has been replaced with a credit for ‘Responsibly Sourced Material’ used in structural and finishing elements, with credits available over four tiers:

- Tier 1 – 1 Credit ISO 14001 or EMAS or BS8555 at extraction & process stages
- Tier 3 – 2 Credits ISO 14001 or EMAS, or BS8555 equivalent requirements, Chain of Custody (CoC) & additional certification scheme requirements (stakeholder consultation)
- Tier 4 – 3 Credits ISO 14001 or EMAS, or BS8555 equivalent requirements, CoC & additional certification scheme requirements (take action on stakeholder consultation).

From the 6th April 2006 the new BREEAM credit for ‘Responsibly Sourced Material’ will become available in BREEAM EcoHomes, but with up to 6 credits available for structural elements and 3 credits available for finishing elements. This credit is currently in draft version only, but will be structured similarly to the BREEAM non-domestic tiers shown above.

**CODE FOR SUSTAINABLE BUILDINGS**

The Code was originally called for by the Sustainable Buildings Task Force report of 2004. The task force recommended that it be based on BRE’s EcoHomes system. The aim of the Code was to stretch voluntary standards for resource efficiency on key issues such as energy, water, waste and materials, which could collectively deliver significant carbon savings and to encourage builders to go beyond the letter of the regulations and minimise resource use from the start. The Code was to be developed to apply to all new buildings, with the focus initially on new housing stock and would in due course be applied to major refurbishments of the existing housing stock. The Government had initially been working closely with industry establishing a Senior Steering Group (SSG) to oversee the development of the Code. From the beginning, however, there were complications with the ODPM/BRE relationship which resulted in serious delays to the development of the Code. An initial outline of the Code was eventually produced at the end of 2005 and was a BRE/ODPM document with no direct involvement of any other stakeholders. The Code for Sustainable Buildings had become the Code for Sustainable Homes.

**CODE FOR SUSTAINABLE HOMES**

In the introduction to the consultation document for the Code for Sustainable Homes, the Government stated that it was introducing the Code to increase the sustainability of homes through non-regulatory means in response to a
perceived demand from homeowners and the development industry. All dwellings funded by or on land provided by Government or its agencies such as Housing Corporation and English Partnerships, would be required to meet the Code. In addition Government was encouraging local authorities to adopt the Code.

The Code would assess dwellings on a number of elements, giving credits to each element which are totalled, with a maximum of 100. These scores are then put into bands, ranging from level one (the basic) to level five (the best). There are six characteristics that all dwellings would have to be judged on and a further six voluntary ones. These are:

**Proposed mandatory elements**
- Energy efficiency
- Water efficiency
- Surface water management
- Site waste management
- Household waste
- Use of materials.

**Proposed optional elements**
- Lifetime homes
- Security
- Soundproofing
- Private external space
- Daylighting
- Home user guide.

There would therefore be tradability between elements to allow designers to choose how to reach levels two to five. Level one would require 30 marks out of 100, level two 45, level three 60, level four 70 and level five 80. In addition, level five homes would have to be ‘zero carbon’ which in practice will mean significant use of low and zero carbon technologies such as photo-voltaics, solar hot water and wind power.

A key difference from EcoHomes is the proposal that post-construction verification should be required under the Code. In EcoHomes it is an option.

Three days after the consultation period had ended the Government announced that it planned to strengthen the Code for Sustainable Homes alongside the introduction of new tougher building regulations on the 6th April 2006, in order to address climate change; stating that the new measures would raise the energy efficiency of new buildings by 40 per cent compared to 2002. They also plan to improve compliance by introducing air pressure testing for new buildings and state that the revised code will form the basis for the next wave of improvements to building regulations.

In addition the Government stated it would be doing further analysis of other issues raised in the consultation including proposals for further ways to increase the take-up of the Code, such as incentives in the planning system and for new developments, and the possibility of mandatory assessments against other Code requirements. These improvements will be developed over the coming months. As an interim measure all homes with English Partnerships or Housing Corporation funding will meet the new EcoHomes ‘very good’ Standard 2006 from 1st April 2006, which was published on the 9th March 2006. EcoHomes will be merged into the final Code later this year [12].

**THE FISCAL MEASURES**

**Aggregate Levy**
This was introduced in 2002 and is a UK tax on the commercial exploitation of rock, sand and gravel. There is one basic rate of £1.60 per tonne and includes primary land won- and marine won-aggregates [14]. The Aggregate Levy funds the Aggregate Levy Sustainability Fund, whose aim is to reduce the environmental impacts per tonne of aggregate extracted and help to stimulate the market for recycled and secondary materials [15].

**Landfill Tax**
The UK Government introduced the Landfill Tax in 1996 to provide a fiscal incentive to minimise waste as well as to identify opportunities for dealing with waste in a more productive way. When launched, for active waste the cost was set at £7 per tonne while inactive waste attracted a tax of £2 per tonne. In 2005 the rate for active waste was increased to £18 per tonne and through an annual escalator this higher rate will grow £3 per tonne in future years, on the way to a medium to long term rate of £35 per tonne [14].

**Climate Change Levy (CCL)**
The Climate Change Levy (CCL) was introduced in 2001 as a tax on the business use of energy providing an incentive to cut usage. Climate change agreements were introduced at the same time. Under the agreements, energy-intensive sectors covered by the levy – such as steel manufacturing – were given the opportunity to sign up to 10-year negotiated agreements covering energy use and/or emission reductions in
return for an 80 per cent discount on the climate change levy. There are currently 44 sectors with over 10,000 sites covered by the agreements. Significant carbon savings have already been made and some sectors have already achieved their 2010 targets. Following consultation with business, in the Budget 2004, the Government announced that the negotiated agreements would be extended to those sectors that pass an energy-intensity threshold, and can in some cases demonstrate the existence of international competition issues [10].

**UK Emissions Trading Scheme (UKETS)**

This is a voluntary scheme which aims to provide cost-effective emissions reductions and to give UK businesses a head start in emissions trading, before future international trading schemes begin to take force. At an auction in 2002, organisations bid emissions reductions over five years to 2006 in return for a share of incentive money. Participants have committed to reduce their baseline emissions by 11.88 million tonnes of carbon dioxide equivalent over the life of the scheme [10].

**EU Emissions Trading Scheme (EU ETS)**

This scheme was introduced in January 2005 and is a key component of the EU’s drive to reduce emissions of greenhouse gases. The UK Government’s approach to the EU ETS aims to balance the achievements of our environmental goals with the need for a stable supply of energy and the need to ensure the competitiveness of industry in the international market.

The UK is showing its commitment to the scheme by setting a cap on allowances in the first phase (2005-2007) that takes us beyond our Kyoto emissions target. A second phase of the EU ETS will commence in 2008 and run until 2012 to coincide with the Kyoto commitment period; all member States will be required to use the scheme to contribute to meeting their part of the EU’s shared Kyoto target [10].

**Tax breaks for developing brownfield sites**

In the 2001 budget the Government announced plans to abolish stamp duty on redevelopment in certain disadvantaged areas and a reduction of VAT to 5% on properties that have been empty for more than three years. The Finance Bill 2001 also offers an accelerated tax credit (up to 150%) to cover the costs of cleaning up contaminated land [10].

**Enhanced Capital Allowances**

These are available for a broad range of energy and water efficient technologies.

**Renewables grants**

The clear skies grant programme currently provides grants of 50% for solar water heating, wind, biomass and ground source heat pump. DTI grants are also available for photovoltaics through an EST administered scheme.

**THE FUTURE UK GOVERNMENT’S STRATEGY ON SUSTAINABLE CONSTRUCTION**

Increasingly UK legislation is having to follow EU legislation. The concrete industry needs to be mindful that the European Commission issued a Standardisation Mandate (M350) to the Committee for European Standardisation (CEN) on 29 March 2004. This mandate directs CEN to address the “Developing of Horizontal Standards for the Assessment of the Integrated Environmental Performance of Buildings” [12].

This mandate refers to the increasing risk of barriers to trade being created due to the further development of national standards for whole building works and environmental product declarations. It also refers to the increasing demands on industry for information, based on different methods required within EU Member States. The consequence of such demands is increasing costs on industry and the mutual non-acceptance of environmental product information; hence the mandate to CEN. CEN’s official response to mandate M350 sets out a proposed programme of work, in three sections [12].

- **Section 1** – dealing with the building level and the performance assessment
- **Section 2** – dealing with the construction products level and environmental products declarations
- **Section 3** – dealing with the building life cycle.

This proposed work programme will build on the International Standards Organisation (ISO) work on environmental management standards (ISO/TC207) and building standards (ISO/TC59) and seeks to establish European rules for:

- Harmonised Environmental Product Declarations (EPDs)
- Assessing health and comfort performance
- Environmental performance
- Life cycle cost performance.

CEN has created a dedicated CEN Technical Committee – CEN TC 350 Integrated
environmental performance of buildings – to develop the European standards on this work programme. ODPM will be monitoring these ongoing work streams and their likely outcomes[12].

The Government is also currently reviewing its Sustainable Construction Strategy and in January 2006 published their draft summary and report. This is attempting to take a holistic view of sustainability and is currently in the public domain for consultation, until 26th April 2006 [16].

CONCLUSION

Sustainability is not a new philosophy:

“Only when the last tree has died, the last river been poisoned, and the last fish be caught will we realise we cannot eat money.” – Cree Indian proverb.

Many people think that sustainability is a passing fad but it is not. It is an ethos that will last and become more important for one main reason; the decision makers of the world are breathing the same polluted air as all of us. This is why sustainable development will survive the departure of current prime ministers and presidents.

Currently there is very much a focus on the environmental aspects of sustainability and to a degree this is understandable; if we have too much of a detrimental impact on our environment, life as we know it will become unsustainable and man will become extinct. Therefore we can see that:

“In the long term, the economy and the environment are the same thing. If it is unenvironmental it is uneconomical. That is the rule of nature” ~ Mollie Beattie (first female Director of the US Fish and Wildlife Service).

The Government’s adoption of the EcoHomes methodology in the Code for Sustainable Homes and the drive to mandate this through planning legislation is a signal of their intent. Unfortunately the Code as it stands still primarily focuses on the environmental issues but social and economic are there, albeit as tradable options. In the future, policy must move towards a balance and hopefully the concrete sector will have a seat at the table.

Considering what has happened in the past it is highly likely that there will be a move from voluntary to mandatory for sustainable development regulation and legislation, and the following areas are likely to provide future challenges for the concrete sector of the UK:

• Sustainable procurement
• Harmonised Environmental Product Declarations
• Sustainability strategies for companies tied to European Key Performance Indicators
• Certification
• Transport and fuel economics
• Pensions
• Work-Time Directive
• Staff wellbeing, skills and retention of staff.

Change is a hard thing to manage and achieve, especially when there is uncertainty over the risks that we face. Many of the risks that the concrete industry faces today are surrounded by uncertainty and do not directly threaten economic progress at the moment but we need to be aware of what the future holds if sustainability is to be understood and embraced. It is no longer just a case of business as usual and if industry does not drive the change, governments will through mandatory legislation. Failure to take sustainability seriously may well lead to a reduced market share.

The concrete sector of the UK has challenges ahead but also has a great opportunity to show that from creation to the delivery of flexible, future-proof, sustainable construction solutions; concrete really is the sustainable material of choice.

REFERENCES


9. BCA, 2003, Sustainable development and the cement and concrete construction sector interim report


14. www.aggregain.org.uk/applications/agg


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**ABSTRACT**

The construction of a prime 18,000 m² office development at One Coleman Street in the heart of London is the first major use of secondary aggregates in concrete in London to reduce the environmental impact of the concrete materials. It is also the first major use of china clay stent coarse aggregate outside the locality of its production in the South-West of the UK. Environmental impact of the concrete was further reduced through the use of higher proportions of fly ash as a cementitious material than are currently typical for structural concrete.

**KEYWORDS**

Waste materials, Secondary aggregates, China clay stent, Fly ash, Structural concrete, Pile caps, Superstructure

**INTRODUCTION**

The structure

One Coleman Street is a nine storey (18,000 m²), composite steel and concrete-framed, prime office development in the City of London designed by Arup on behalf of developer Stanhope plc to replace the 50 year old Austral House. It has a complicated single layer basement which will provide access to the adjacent London Wall car park as well as future provision for pedestrian access to Crossrail. The structure is founded on piles and a watertight concrete ground slab. Construction of the pile caps commenced in December 2005.

**The use of secondary and recycled materials**

Sustainability has long been a key objective within Arup and the use of secondary and recycled materials is explored wherever possible and practical. Prior to the commencement of One Coleman Street the use of such materials within concrete had largely been restricted to the use of the secondary cementitious materials, fly ash (pfa) and blast furnace slag (ggbs). The potential for use of recycled concrete aggregate (RCA) had been explored previously but it was found to be unavailable from concrete suppliers in the London area mainly because, it was understood, of the high demand as fill. Moreover, the need for alkali testing with respect to alkali-silica reactivity and the exclusion of RCA concrete within BS 8500[1] from use in the predominantly DC-2 ground conditions on this site provided additional barriers. The practical potential for use of RCA and other secondary aggregates is discussed in a later section.

The possibility of using china clay stent coarse aggregate for the first time in a major London project was first suggested to the author by Jasen Gauld of RMC (Cemex). Enquiries within Arup revealed One Coleman Street as a potential project. Early discussions with the developer, Stanhope plc, produced an enthusiastic response and the concrete trade contractor, John Doyle, was soon brought on board. They chose to use London Concrete as the concrete supplier instead of RMC.

It was originally decided to use china clay stent coarse aggregate in approximately 6,000 m³ of concrete, comprising the pile caps, basement structure and superstructure elements including floor decks, and also to maximise the secondary cementitious materials content in these elements. Due to the innovative nature of the concrete it was decided not to extend these principles to the precast concrete façade. Conventional aggregates were used in the piles as this part of the project ran ahead of the main structure by some months and occurred prior to the decision to use stent aggregate. Moreover, it is understood from piling contractors that they
prefer rounded aggregates to crushed rock to achieve their desired handling properties. In the end, stent was not used in the core walls that used hybrid twin-wall panels. These were fabricated in Germany which was too remote from the aggregate source. Self-compacting concrete is used to infill the panels, so again, stent was not used.

### CHINA CLAY STENT

#### Origin

China clay is extracted using high pressure water jets to wash the kaolinised granite (china clay) from cliff faces formed by quarrying. The clay-laden water flows to the bottom of the quarry where it is pumped to treatment plants to settle out the china clay and dry it ready for export, mainly by sea from the port of Par close to the St Austell area in Cornwall where most of the UK china clay industry is based. The larger, unkaolinised granite rock fraction of the residual material is known by the term ‘stent’ and can range in size from less than 200 mm up to over 2 m in diameter.

Approximately 9 tonnes of waste are generated for each tonne of china clay produced. The composition of this waste varies from one location to another depending on the quality and age of the deposit. Typically it comprises 4.5 tonnes of stent, together with approximately 3.5 tonnes of sand and 1 tonne of micaceous waste.

According to the Cornwall County Council’s Local Minerals Plan[2] “over the years over 500 million tonnes of china clay waste has been tipped above ground within the [St Austell] area, occupying over 1700 hectares. Current waste production is approximately 22 million tonnes per annum, making this the most concentrated area of tipping in the UK having an overriding impact upon the landscape”. Traditionally this tipping, over the last 250 years, has been onto pyramid-shaped spoil heaps which has had a dramatic effect on the local landscape, known locally as the Cornish Alps (see Figure 1).

#### Concrete aggregate

China clay stent is classed as a natural secondary aggregate because it is a by-product of an industrial process not previously used in construction. As a secondary aggregate it is exempt from the UK government-imposed Aggregates Levy (currently set at £1.60/tonne); although it is understood that this has caused “a few murmurings of discontent elsewhere in the aggregates industry”. Stent appears to have

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Figure 1: Photograph showing production stockpiles of china clay waste (foreground and mid-ground left), uncrushed stent still on the quarry face (mid-distance right) and an old spoil heap (far distance)
previously been largely ignored by many studies of secondary materials for use in concrete or discounted because of a perception of it being a weathered, low quality material – which is characteristic only of the sources in the South Dartmoor area of Devonshire and not those in the St Austell area of Cornwall. For example, CIRIA Report C513 identifies china clay sand as a possible fine aggregate for use in concrete but not the stent fraction as a possible coarse aggregate. This is despite a long history of satisfactory use within ready-mixed concrete over much of Cornwall and parts of Devonshire. An advisory sheet issued by the Aggregates Advisory Service does, however, identify stent as an aggregate for concrete in accordance with the then current BS 882. It states that, “in particular the better quality stent has properties not dissimilar to crushed granite” and describes china clay by-products as “intrinsically suitable materials”.

**Source and supply**

Stent of a quality suitable for use as a concrete aggregate is available from at least two sources in the St Austell area. Atlantic Aggregates are able to supply material from the Gunheath Quarry by ship from the nearby port of Par. The material used in this project has been supplied by Bardon Aggregates from the Littlejohn Quarry by rail, direct to the rail head at their Bow plant in London where the concrete was produced in the adjacent London Concrete plant without the need for road transport of the aggregate prior to its inclusion in concrete.

Transportation by sea is limited by the relatively small size of ship that can use the harbour at Par with a current maximum cargo of 3400 tonnes on a spring tide. Transportation by rail also suffers limitation because of a maximum permitted payload of 900 tonnes on Brunel’s 1859 Royal Albert Bridge over the River Tamar at Saltash. This means that each train load of 1200 tonnes of aggregate has to be split into two to cross the bridge and then recombined before travelling on to London. Steep inclines between Exeter and Plymouth (the Devon Banks) impose further restrictions. At the time of writing this paper, three train loads had been moved from Cornwall to London, enough for over 3500 m³ of concrete. At least two more trainloads will be required to complete the in situ concrete. Continuity of supply of the aggregate was an essential requirement of the Arup specification to remove programme risk and make sure all quality issues were cleared before its use.

The current rate of production of china clay waste far exceeds the demand for the aggregate (and sand) so it has not been necessary to consider the use of any stock-piled material. Nevertheless, a study for the Office of the Deputy Prime Minister (ODPM) has estimated that possibly 45-100 million tonnes of the overall 600 million tonnes within stockpiles might be sufficiently accessible and of suitably high quality for future use. Perhaps surprisingly, much of the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test method</th>
<th>Value (class)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle density (oven dry / ssd / apparent)</td>
<td>BS EN 1097-6:2000</td>
<td>2.56 / 2.60 / 2.67</td>
</tr>
<tr>
<td>Water absorption</td>
<td>BS EN 1097-6:2000</td>
<td>1.7%</td>
</tr>
<tr>
<td>Micro-Deval coefficient</td>
<td>BS EN 1097-1:2000</td>
<td>21 (MDE25)</td>
</tr>
<tr>
<td>Los Angeles coefficient</td>
<td>BS EN 1097-2:2000</td>
<td>30 (LA30)</td>
</tr>
<tr>
<td>Polished stone value</td>
<td>BS EN 1091-8:2000</td>
<td>53 (PSV50)</td>
</tr>
<tr>
<td>Aggregate abrasion value</td>
<td>BS EN 1091-8:2000</td>
<td>4.1 (AAV10)</td>
</tr>
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<td>BS EN 1367-2: 1998</td>
<td>7 (MSV18)</td>
</tr>
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<td>Drying shrinkage</td>
<td>BS EN 1367-4: 1998</td>
<td>0.038%</td>
</tr>
<tr>
<td>Carbon dioxide content</td>
<td>BS EN 196-21</td>
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</tr>
<tr>
<td>Calcium carbonate equivalent</td>
<td>BRE SD1</td>
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<tr>
<td>Water soluble sulfate</td>
<td>TRL 447</td>
<td>0.01 g/l</td>
</tr>
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<td>TRL 447</td>
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</tr>
<tr>
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</tr>
<tr>
<td>Chloride content</td>
<td>BS EN 1744-1: 1998</td>
<td>0.01%</td>
</tr>
<tr>
<td>Water soluble sulfate content</td>
<td>BS EN 1744-1: 1998</td>
<td>0.01%</td>
</tr>
<tr>
<td>Total sulfur content</td>
<td>BS EN 1744-1: 1998</td>
<td>0.02%</td>
</tr>
<tr>
<td>Acid soluble sulfate content</td>
<td>BS EN 1744-1: 1998</td>
<td>0.01%</td>
</tr>
<tr>
<td>pH value</td>
<td></td>
<td>7.5</td>
</tr>
</tbody>
</table>

*Table 1: Physical properties of china clay stent aggregate from Littlejohn Quarry*
stockpiled area has become established habitat and is now protected; indeed one of the original pyramidal stockpiles (Alps) has even been listed to preserve a part of Cornwall’s industrial heritage.

**Properties**

The physical properties of the china clay stent coarse aggregate from the Littlejohn Quarry are given in Table 1. The particular results given here relate to a sample taken in late 2004 but are indicative of the general quality of the material. Properties of the aggregate available from the Gunheath Quarry are very similar.

China clay stent is an inherently variable material and is not all suitable for use as high quality concrete aggregate. Material from the Littlejohn and Gunheath Quarries is specially selected for purpose. It is fully in accordance with the requirements of BS EN 12620 and PD 6682-1 for concrete aggregate. Indeed, the delivered material stockpile at the aggregate plant was distinguishable from the stockpile of the normally used Croft granite, from Leicestershire, largely only by its different colour. The grading ranges and averages for the 10/20 mm and 4/10 mm fractions over a period of approximately two months are given in Table 2.

An advantage of secondary natural aggregate over many recycled aggregates is the ability to use it as 100% replacement of the normal coarse aggregate. And because it conforms to the requirements of BS EN 12620 and PD 6682-1, it can be used without restriction of strength class or exposure environment within concrete conforming to BS 8500 and BS EN 206-1.

Trial mixes using the Gunheath Quarry stent, although not performed as part of the development work for this project, showed the strength potential to be in excess of 70 MPa. A trial using 30% fly ash by mass of total cement content produced a four-day cube strength of 39.5 MPa.

**Petrographic analysis**

The essential findings of a petrographic analysis of a typical sample of china clay stent from the Littlejohn Quarry, performed in accordance with BS 812: Part 104: 1994 by STATS Ltd., are given in Table 3. It can be seen that the material is fairly typical of a crushed granite coarse aggregate. Although not quantified within this examination, petrographic analysis of the geologically similar Gunheath Quarry stent showed it to have a mica content of approximately 6%. The mica is, however, retained within the aggregate particles and imparts no significant adverse properties.

**Previous experience**

China clay stent has a long history of satisfactory use as a coarse aggregate within ready-mixed concrete in much of Cornwall and parts of Devonshire, driven not so much by sustainability considerations but because of its local availability and the lack of suitable alternatives. Indeed, china clay sand is also employed widely in ready-mixed concrete in these areas for the same reasons despite its unfavourable properties in terms of its high water demand and the consequent need for high cement contents.

<table>
<thead>
<tr>
<th>Sieve size (mm)</th>
<th>4/10 mm % passing</th>
<th>10/20 mm % passing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range Mean</td>
<td>Range Mean</td>
</tr>
<tr>
<td>31.5</td>
<td>--</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>100 100</td>
<td>93-100 97.3</td>
</tr>
<tr>
<td>16</td>
<td>100 100</td>
<td>64-81 73.4</td>
</tr>
<tr>
<td>14</td>
<td>100 100</td>
<td>40-64 54.6</td>
</tr>
<tr>
<td>10</td>
<td>84-95 90.5</td>
<td>5-19 14.6</td>
</tr>
<tr>
<td>8</td>
<td>33-58 44.2</td>
<td>2-10 6.4</td>
</tr>
<tr>
<td>6.3</td>
<td>8-19 11.8</td>
<td>1-8 4.4</td>
</tr>
<tr>
<td>5</td>
<td>3-10 5.8</td>
<td>-- --</td>
</tr>
<tr>
<td>4</td>
<td>2-7 4.8</td>
<td>1-6 3.4</td>
</tr>
<tr>
<td>2</td>
<td>2-5 3.7</td>
<td>1-6 3.0</td>
</tr>
<tr>
<td>1</td>
<td>1-5 3.2</td>
<td>1-5 2.8</td>
</tr>
<tr>
<td>63 μm</td>
<td>0-2 1.3</td>
<td>0-2 1.3</td>
</tr>
</tbody>
</table>

Table 2: Grading of stent coarse aggregate over a two month period
Future potential

According to the ODPM[7] “the main constraint on utilization up until now has been geography (cost of transport). With exemption from the aggregate levy and investment in the Port of Par, china clay waste is becoming an increasingly competitive source of sand and aggregate. The feasibility of moving substantial quantities of material by rail from Cornwall to a number of bulk fill projects in the South-East and South-West of England is also currently being investigated.” This project is believed to be the first such movement of a significant quantity for use as coarse concrete aggregate.

**FLY ASH**

Fly ash, or pulverised-fuel ash (pfa) has been in common use as a cementitious component in concrete in the UK for several decades. In this project we were keen on minimising the Portland cement content of the concrete to reduce CO2 emissions and associated environmental impacts, but not to impose unnecessary constraints on the concrete supplier. Ground granulated blastfurnace slag (ggbs) would have been equally acceptable. Nevertheless, the two concrete suppliers identified as being able to meet our specification requirement for china clay stent aggregate both use fly ash as their stock material.

In structural concrete, where fly ash is employed it is generally used at a proportion of 30% by mass of the total cement content (i.e. Portland cement + fly ash). Higher proportions are generally restricted to specialist applications such as heat minimisation in large pours, and to restrict early strength development in secant pile construction. We decided that, wherever possible, we would use 40% pfa by mass of cement in pile caps and 35% in superstructure elements. Two exceptions to this were the ‘watertight’ slab and a tower crane base, where specific design requirements applied:

- The fly ash content in the watertight slab was restricted to 30% because the mix composition was under external control due to the inclusion of Caltite integral water-resisting admixture. The manufacturers of Caltite have no experience of higher fly ash proportions and are not currently prepared to provide their normal guarantee at fly ash proportions greater than 30%
- The need for high early strength (30 MPa at 6 days) to enable the erection of the tower crane meant that a small section of one pile cap was constructed using a C40/50 CEM I concrete but still using stent aggregate. It was not practical to insist on the use of pfa in this concrete, particularly as it was placed in winter, but use of the CEM I concrete was restricted to the minimum area needed for the crane base with the rest of the slab cast with the 40% pfa concrete.

**STRUCTURAL CONCRETE**

**Specification**

The Arup specification was based, as usual, on the National Structural Concrete Specification[13] but the coarse aggregate was specified as being china clay stent. Arup concrete specifications usually only specify aggregate type where special properties are required, such as low or high density, or low coefficient of thermal expansion. The C32/40 compressive strength class pile caps
and the C32/40 watertight slab were specified as designed concretes but with specific cement combinations with 40% and 30% fly ash respectively. The C28/35 and C32/40 superstructure elements were specified as RC35 and RC40 designated concretes in accordance with BS 8500 but with the cement type required to be a 35% fly ash combination. Designed concrete was necessary for the pile caps because the ground conditions dictated a design chemical class of DC-2 and the corresponding designated concrete FND2 only guarantees a compressive strength class of C28/35 as opposed to the C32/40 required by the structural design.

It is unusual for Arup to influence the choice of concrete supplier or to liaise directly with them but it was obviously necessary in this case to ensure that our specification requirements could be met, and aspects of bringing a different product into the London market were fully coordinated for the client. Discussions commenced well in advance of construction to ensure sufficient time was available for identification of a suitable source of aggregate, obtaining test data, developing mix designs and performing trials, agreeing any costing issues and arranging delivery. In this first use we felt it necessary to require full test data for physical properties, petrographic characteristics and alkali-silica reactivity. This helped convince the client that risks were not being taken and the material could be delivered within the project procurement requirements. Our specification required that the aggregate was fully in accordance with BS EN 12620 and PD 6682-1, but this requirement was made in the knowledge that this was readily achievable.

A conformity age of 56 days was permitted for the 40% fly ash pile cap concrete because of the elements being buried in wet ground and because of their large size giving enhanced strength development due to the heat development during hydration.

Routine identity testing was specified due to the lack of previous production data for these unusual mixes and to provide a higher rate of confidence than would have been generated by the minimum rate of supplier testing required by BS EN 206-1 even at the enhanced test rates required for mixes with little or no previous production experience.

It was realised at the specification stage that the cost of stent aggregate concrete is currently greater than that of conventional concrete by approximately £4.5 per m². Care was needed to ensure that ‘value engineering’ exercises did not prevail as these often fail to see the value of reduced environmental impact as it is not expressed in pounds and pence.

**Mix designs**

The mix designs for the main elements employing stent aggregate and fly ash are given in Table 4. It is understood from the concrete supplier, London Concrete, that the mix designs are essentially the same as would have been used had their normal stock Croft crushed granite aggregate been employed. Special mix designs had to be developed for the 35% fly ash.

<table>
<thead>
<tr>
<th></th>
<th>C32/40 @ 56 days</th>
<th>RC35 35% pfa</th>
<th>RC40 35% pfa</th>
<th>C32/40 Calitite 30% pfa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pile caps</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(kg/m³)</td>
<td>246</td>
<td>228</td>
<td>263</td>
<td>287</td>
</tr>
<tr>
<td>Fly ash (pfa) – West Burton</td>
<td>164</td>
<td>122</td>
<td>142</td>
<td>123</td>
</tr>
<tr>
<td>Total cementitious</td>
<td>420</td>
<td>350</td>
<td>405</td>
<td>410</td>
</tr>
<tr>
<td>Coarse aggregate (stent)</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Fine aggregate (natural sand)</td>
<td>754</td>
<td>838</td>
<td>775</td>
<td>803</td>
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<tr>
<td>Target water</td>
<td>167</td>
<td>163</td>
<td>167</td>
<td>157</td>
</tr>
<tr>
<td>Actual w/c ratio</td>
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<td>0.47</td>
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<td>2370</td>
</tr>
<tr>
<td>Consistence class</td>
<td>S3 (pump)</td>
<td>S3 (pump)</td>
<td>S3 (pump)</td>
<td>S3 (pump)</td>
</tr>
</tbody>
</table>

Mixes (except Calitite mix) include Pozzolith 300N plasticiser

**Table 4: Mix designs for concretes containing china clay stent aggregate and pfa**
concretes because of the lack of experience of using this proportion. The stent coarse aggregate content was constant for each concrete, at 1000 kg/m³.

All concretes employed S3 consistence and were designed to be suitable for placing by pump.

CONSIDERATION OF OTHER RECYCLED AND SECONDARY AGGREGATES

Other secondary and recycled aggregates have featured in the concrete industry press including, in particular, china clay sand, slate waste, waste glass, incinerator waste and recycled concrete. The suitability of such materials was reviewed for use on this project and is summarised briefly below. Many other granular materials have also been the subject of research but consideration of these is left to more esoteric/academic publications. Such materials include sewage sludge ash, shredded tyres, bottle cork waste and even periwinkle shells!

China clay sand

China clay sand is available in large quantities from the same source as the stent as well as other outlets in Cornwall and Devonshire[14]. As for stent, production far outweighs demand making it a waste product exempt from the aggregates levy. It is suitable for use as concreting sand and, indeed, is in common use in ready-mixed concrete near its sources. Nevertheless, it is far from an ideal fine aggregate due to its high water demand which necessitates high cement contents to achieve the required level of workability and strength.

The need for increased cement contents, the cost of transport to London, and the ready availability of better concreting sands made china clay sand an unrealistic proposition for this project.

Slate waste

Slate waste is present in large quantities in several areas of the UK but is not currently available to the ready-mixed concrete industry on a sufficient commercial scale. Moreover we believed that the required level of technical experience of use in structural concrete for use on a current large project does not yet exist.

According to a study for the Welsh National Assembly[19], there remain three essential measures to implement before slate waste can realistically be considered a source of secondary aggregates for major UK markets. These are:

- Capital funding of rail line improvements
- Financial aid for the construction of rail freight terminal(s) and to reduce rail freight operating charges
- The implementation of the aggregates levy at its current level or higher.

Waste glass

The use of waste glass as a fine aggregate (RGA) in concrete has been shown to have some potential for future use[16]. Nevertheless, it is not currently available on a sufficient commercial scale, or with the required level of technical experience needed for a large project. The perceived risk of alkali-silica reaction is likely to remain a considerable barrier to its use until recognised standards or specifications are available covering its use.

Incinerator waste

Incinerator bottom ash aggregate (IBAA) shows some potential for future use in concrete[17] but reduced strength and modulus coupled with increased absorption and drying shrinkage suggest that considerable effort needs to be expended in the development of suitable mix designs. These materials are not currently available on a sufficient commercial scale or with the required level of technical confidence for use in structural concrete on a large project.

Recycled concrete (RCA)

Demonstration projects such as BRE Building 16 and the Wessex Water HQ, along with many research projects, have demonstrated the technical feasibility of producing good quality concrete incorporating recycled aggregates. BS 8500 allows coarse RCA to be used up to a mass fraction of 20% of coarse aggregate in designated concretes RC25 to RC50 and this effectively forms a ‘safe limit’ for designed and prescribed concretes. Nevertheless, none of the major ready-mixed concrete suppliers in the London area were able to supply concrete containing recycled concrete aggregate. The main reasons given by them were:

- Lack of availability – the demand for crushed demolition materials for fill and roadbase applications in the London area currently exceeds supply
- Lack of consistency – if available, supplies of RCA are likely to come from many different
sources and this would dictate the need for high rates of testing

- Higher risk for the producer, other than for low grade applications – this would probably result in an increase in cement content to (indirectly) provide a greater strength margin
- High fines content from crushing – it is understood from a leading UK aggregates specialist that the fines content from crushing can be as high as 50% by mass
- Disposal of fines – there is currently no use for the fines resulting from crushing (although use in foamed concrete shows some promise[18]). The fines would thus need to go to landfill with the resultant costs and which would go against the underlying principles of the use of secondary and recycled materials on this project
- Storage problems – batching plants would require an extra silo or stockpile as the recycled aggregate is only suitable when used to replace around 20-40% by mass of the normal stock coarse aggregate.

### SUSTAINABILITY BENEFITS

The effect of the use of stent aggregate and higher than normal fly ash content on the total recycled and secondary materials content within typical structural elements at One Coleman Street is shown in Tables 5 and 6. Table 5 contains a comparison, on a mass basis for the concrete alone, with the concrete that would typically otherwise have been used in the structure (conventional concrete). It can be seen that the secondary material content of conventional 30% pfa-cement structural concrete is typically in the range 4.5 to 6.0%. This is increased to between 47.5 and 50.0% (54% if free water is excluded from the calculation) by the use of the stent coarse aggregate and the higher fly ash proportions. No account has been taken here of the reinforcement.

### Table 5: Recycled and secondary material content, by mass, of stent aggregate concrete compared to equivalent conventional concrete

<table>
<thead>
<tr>
<th>Element</th>
<th>Pile caps</th>
<th>Basement slab</th>
<th>Superstructure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Coleman Street</td>
<td>Conventional</td>
</tr>
<tr>
<td>Concrete type</td>
<td>C32/40</td>
<td>C32/40 (Calite)</td>
<td>RC35</td>
</tr>
<tr>
<td>Fly ash level (% mass cement)</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Recycled/secondary content by mass of concrete (%)</td>
<td>5.5</td>
<td>6.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Fly ash level (% mass cement)</td>
<td>40</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Recycled/secondary content by mass of concrete (%)</td>
<td>50.0</td>
<td>47.5</td>
<td>47.5</td>
</tr>
</tbody>
</table>

### Table 6: Recycled and secondary content, by value, of stent aggregate concrete compared to equivalent conventional concretes

<table>
<thead>
<tr>
<th>Element</th>
<th>Pile caps</th>
<th>Basement slab</th>
<th>Suspended slabs &amp; internal walls</th>
<th>Transfer walls</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete type</td>
<td>C32/40</td>
<td>C32/40 (Calite)</td>
<td>RC40</td>
<td>RC40</td>
</tr>
<tr>
<td>Fly ash level (% mass cement)</td>
<td>Conventional</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Coleman Street</td>
<td>40</td>
<td>30</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Typical reinforcement content (kg/m³)</td>
<td>125</td>
<td>150</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Recycled/secondary content for typical conventional concrete (% value)</td>
<td>Concrete</td>
<td>16</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Concrete + reinforcement</td>
<td>56</td>
<td>60</td>
<td>51</td>
<td>66</td>
</tr>
<tr>
<td>Recycled/secondary content for stent concrete (% value)</td>
<td>Concrete</td>
<td>47</td>
<td>42</td>
<td>45</td>
</tr>
<tr>
<td>Concrete + reinforcement</td>
<td>72</td>
<td>72</td>
<td>67</td>
<td>77</td>
</tr>
<tr>
<td>Improvement in recycled/secondary content achieved (%)</td>
<td>Concrete</td>
<td>195</td>
<td>185</td>
<td>200</td>
</tr>
<tr>
<td>Concrete + reinforcement</td>
<td>29</td>
<td>20</td>
<td>31</td>
<td>17</td>
</tr>
</tbody>
</table>

1 the value of the Calite admixture has been ignored in calculation
2 all reinforcement assumed to be made entirely from recycled steel
Table 6 compares the recycled and secondary materials contents by value with those for conventional concrete. The comparison is made on the basis of assumed costs of individual materials and an overall concrete value taken as the approximate delivered cost of the concrete to the contractor. The high cost of the Calcrete admixture has been omitted from the calculation to avoid a consequent large distortion in the figures. Where reinforcement is included the value of the concrete has simply been adjusted to include the cost of the reinforcement but with no allowance for fabrication or fixing. The reinforcement contents used are typical for the particular type of element and all reinforcement has been assumed to have been produced entirely using recycled steel.

It can be seen that the conventional concrete has a secondary materials content of approximately 15-16% of total value due to the use of 30% fly ash by mass of the total cement. Incorporation of reinforcement into this calculation raises the secondary materials content for conventional concrete to approximately 51-66% depending on the type of element and the consequent reinforcement content.

Incorporation of stent coarse aggregate and increase in the proportion of fly ash resulted in a three-fold increase in value of the recycled and secondary materials content, excluding reinforcement, to 42-47% depending on the actual composition of the concrete. When reinforcement is included, the total recycled and secondary materials content rises to 67-77%; a proportional increase of 17-31% over the equivalent conventional concrete elements.

No attempt has been made at detailed quantification of the reduction in environmental impact of these concretes. Nevertheless, for every cubic metre of concrete placed in this structure, one less tonne of primary aggregate has been quarried and one less tonne of china clay waste has been tipped onto unsightly spoil heaps in Cornwall. The use of road transport of aggregate has been avoided but the 250 miles travelled by rail is approximately two-and-a-half times that for the primary aggregate that has been replaced. The energy used in processing the stent is similar to that of the primary aggregate except for the small saving of that involved in removal of overburden and blasting of the rock from the quarry cliff face; crushing and grading is similar for both materials.

Accurate embodied energy values would be needed to make precise calculations on the differences between various different sources if this were needed. Additionally, and unfortunately, the use of secondary aggregate did not provide any additional BREEAM (Building Research Establishment Environmental Assessment Methodology) points under the current material rating criteria. It is hoped that clearer designation of material properties will, in the future, be produced by the industry to make such comparisons and encourage future waste reductions.

THE PRACTICAL EXPERIENCE

Concrete supply

The supplier, London Concrete, reported that no problems were encountered in producing concrete in accordance with our specification and the contractor’s requirements for consistence. The stent aggregate was reported to behave similarly to their normal stock Croft granite coarse aggregate. A higher rate of visual inspection than normal was performed because this was a ‘new’ material to them. Nevertheless, the stent aggregate was found to be no more variable than their normal stock crushed granite.

Strength conformity has been demonstrated by the supplier’s routine production control and conformity control testing and through the results of identity testing. Conformity assessment at 56 days was permitted for the 40% fly ash concrete as is common practice for higher fly ash contents and was unrelated to the use of secondary aggregate.

Economics

The use of china clay stent coarse aggregate imported by rail in 1200-tonne loads from Cornwall has resulted in a marginal cost premium on the delivered cost of the concrete, despite the exemption of the stent from the Aggregates Levy. In this case, the developer believed the small extra cost was justified to achieve reduced environmental impact. The transport costs of the stent aggregate are believed to account for the greatest part of the cost premium, but increased testing rates have also contributed. It is difficult to see how the transport cost can be reduced for rail shipments, particularly with the constraints imposed by the load capacity of the Royal Albert Bridge, but there is scope for reduced testing. Movement of stent aggregate to London by sea
would allow greater quantities, but still relatively small in terms of sea transport, to be shipped in one consignment. We do not know whether this would reduce unit cost at the current high cost of shipping although plans to build a new freight terminal at Par, with rail links to the china clay pits, should reduce bulk transportation costs. It is also not known whether increased and steady demand could reduce the price of the aggregate at the quarry gate.

Placement

The main contractor, John Doyle, readily agreed to the use of stent aggregate concrete and to the use of higher than normal fly ash contents. They have reported no problems.

CONCLUSIONS

- The construction of One Coleman Street has demonstrated the feasibility of using 100% secondary coarse aggregates in a large scale project remote from the source of aggregate.
- This project has also demonstrated the feasibility of using higher than normal fly ash content cement combinations.
- The use of china clay stent secondary coarse aggregate has resulted in reduced depletion of natural resources and reduced dumping of waste, in accordance with current UK Government policy, but at an overall cost premium.
- The secondary materials content of the concrete, by mass, was increased from approximately 5% to approximately 50%, and, by value, from approximately 15% to approximately 45%.
- The china clay stent aggregate supplied was fully in accordance with current British and European Standards for aggregates, thus allowing the concrete to be specified and supplied fully in accordance with BS 8500.
- No practical difficulties were encountered at the concrete plant or on site due to the use of the china clay stent aggregate or the higher fly ash contents.
- The use of china clay sand and the use of recycled concrete aggregate were considered impractical on this project.

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ACKNOWLEDGEMENTS

Jasen Gauld of Cemex for the original suggestion of using china clay stent from Cornwall; Adrian Campbell of the Arup Building Sustainability London Group for adopting my suggestions; Stanhope plc Developers for putting reduced environmental impact above material cost; London Concrete, the concrete suppliers; Bardon Aggregates, the aggregate suppliers; John Doyle, the contractor.
Denis Higgins is Director General of the Cementitious Slag Makers Association. Previously he was Business Development Director of Civil & Marine Slag Cement Ltd and has considerable experience of concrete technology, including positions as senior materials advisor with the Cement and Concrete Association and head of concrete technology with Redland Research.

**ABSTRACT**

This paper reviews the additions available in the UK. It provides indicative data for the extent of their use and their environmental burdens relative to Portland cement. It concludes that additions are currently making a significant contribution towards reducing the environmental burdens of concrete, particularly in relation to greenhouse gas emissions.

**KEYWORDS**

Sustainability, Carbon dioxide, Environmental burdens, Portland cement, Ground granulated blastfurnace slag, Fly ash, Silica fume

**INTRODUCTION**

The European Standard for concrete BS EN 206-1[1] defines an addition as “a finely divided material used in concrete in order to improve certain properties or to achieve special properties.” and the Standard deals specifically with two types of inorganic additions:

- Nearly inert additions (type I)
- Pozzolanic or latent hydraulic additions (type II).

Type II additions are cementitious and actively contribute towards the strength development of concrete. As such they are permitted to count as part of the cement content and replace a proportion of the normal cement. Because Portland cement is the major contributor to many of the environmental burdens of concrete, there can be significant sustainability benefits in replacing it, as far as possible, with alternative materials. Additions will not necessarily replace Portland cement on a one-for-one basis and it is possible to include similar inorganic materials as part of the composition of factory-produced, blended cements to the European Cement standard BS EN 197-1[2].

Type II additions are generally by-products from high-temperature processes:

- Ground granulated blastfurnace slag from iron blastfurnaces
- Fly ash from coal power stations
- Silica fume from ferrosilicon arc-furnaces
- Natural pozzolanas from volcanic eruptions.

It is their high temperature history that makes them chemically reactive with water or alkali. Limestone fines can also be used as an addition in concrete. Limestone is, chemically, relatively inert but limestone fines, because of their fine particle size, can contribute towards strength by a physical, void-filling mechanism. Views differ on whether they should be considered as Type I or Type II additions.

Table 1 indicates the extent to which these additions are used in the UK (tonnes per annum).

<table>
<thead>
<tr>
<th>As an addition</th>
<th>As a component of blended cement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland cement</td>
<td>n/a</td>
</tr>
<tr>
<td>Ground granulated blastfurnace slag</td>
<td>2 000 000 tonnes</td>
</tr>
<tr>
<td>Fly ash</td>
<td>500 000 tonnes</td>
</tr>
<tr>
<td>Silica fume</td>
<td>3000 tonnes</td>
</tr>
<tr>
<td>Natural pozzolanas</td>
<td>minimal</td>
</tr>
<tr>
<td>Limestone fines</td>
<td>&lt; 10 000 tonnes?</td>
</tr>
</tbody>
</table>

**Table 1: Extent of use of additions in the UK**
**PRODUCTION AND PROPERTIES OF ADDITIONS**

**Ground granulated blastfurnace slag**

(GgbS) is a by-product from the blastfurnaces used to make iron. These operate at a temperature of about 1500˚C and are fed with a carefully controlled mixture of iron ore, coke and limestone. The iron ore is reduced to iron and the remaining materials form a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of ggbS it has to be rapidly quenched in large volumes of water. The quenching optimises the cementitious properties and produces granules similar to a coarse sand. This granulated slag is then dried and ground to a fine powder.

**Fly ash**

This is a general term for the fine ash carried over in the gases from a furnace and can refer to the ash from any furnace. However, the fly ash used as an addition in concrete is specifically pulverised fuel ash (pfa), which is produced when pulverised coal is burned in a coal-fired power station. The ash is carried out with the flue gases and these pass through electrostatic precipitators that remove the fine ash from the flue gases. In the UK this ash has historically been known as pfa, but the term fly ash is used in European Standards. Fly ash particles are very fine (typically <0.5 mm) and are normally used in concrete without any further processing. However if too coarse, they can be passed through an air-classifier to remove the coarser particles.

**Silica fume**

This is produced during the manufacture of silicon or ferrosilicon. This process involves the reduction of high purity quartz in electric arc furnaces at temperatures of over 2000˚C. SiO₂ gas, given off as the quartz reduces, mixes with oxygen in the upper parts of the furnace and oxidises to SiO₂, condensing into the pure spherical particles of micro-silica that form the major part of the smoke or fume from the furnace. The fume is collected in specially designed baghouse filters.

**Properties:**

Typically, the fineness of Portland cement is about 350 m²/kg, ggbS is about 450 m²/kg and fly ash and limestone fines are about 500 m²/kg. By contrast, silica fume is very much finer at around 18 000 m²/kg.

Table 2 shows typical ranges of chemical compositions for the major oxides present in UK cementitious materials.

The major factor that determines the cementitious activity of an addition is its chemical composition. A secondary factor is the fineness, with finer materials being more reactive. GgbS is closest to Portland cement in chemical composition and is actually a slow-setting cement in its own right. However, in practice, it needs to be blended with Portland cement to give an adequate rate of strength development. Fly ash and silica fume on their own do not have any cementitious properties but they do have pozzolanic properties, i.e. they react with the calcium hydroxide liberated when Portland cement hydrates, to form cementing compounds.

<table>
<thead>
<tr>
<th></th>
<th>Portland cement</th>
<th>GgbS</th>
<th>Fly ash</th>
<th>Silica fume</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaO</td>
<td>60 to 70%</td>
<td>35 to 45%</td>
<td>&lt; 10%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>SiO₂</td>
<td>20 to 22%</td>
<td>33 to 40%</td>
<td>35 to 50%</td>
<td>85 to 95%</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>4 to 7%</td>
<td>8 to 16%</td>
<td>20 to 40%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>MgO</td>
<td>1 to 3%</td>
<td>7 to 15%</td>
<td>&lt; 5%</td>
<td>&lt; 4%</td>
</tr>
</tbody>
</table>

**Table 2: Chemical composition**

<table>
<thead>
<tr>
<th></th>
<th>Permitted by BS 8500 [3] (BS EN 206-1 [1])</th>
<th>Typical proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td>GGBS</td>
<td>6 to 85% [3]</td>
<td>50%</td>
</tr>
<tr>
<td>Fly ash</td>
<td>6 to 55% [1]</td>
<td>30%</td>
</tr>
<tr>
<td>Silica fume</td>
<td>(up to 12.5%)</td>
<td>10%</td>
</tr>
<tr>
<td>Limestone fines</td>
<td>6 to 20%</td>
<td>15%</td>
</tr>
</tbody>
</table>

**Table 3: Replacement proportions for additions**
As mentioned previously, limestone fines make a physical rather than a chemical contribution.

The cementitious activity determines the extent to which it is possible to use an addition to replace Portland cement and indicative replacement proportions are shown in Table 3.

**ENVIRONMENTAL IMPACTS**

Measured by tonnage, Portland cement is easily the world’s major manufactured chemical. Unfortunately, its manufacture is highly energy-intensive and the energy used by the cement industry constitutes about 2% of global primary energy consumption. In addition, its primary raw material is limestone (calcium carbonate) and large quantities of carbon dioxide are released as this is decomposed in cement kilns. As a result of fuel burnt and the chemical decomposition of limestone, the cement industry is responsible for about 5% of total global carbon dioxide emissions. The major environmental burdens resulting from the production of a tonne of Portland cement are:

- Emission of one tonne of carbon dioxide
- Use of 1700 kWh of primary energy
- Extraction of 1.5 tonnes of minerals.

Carbon dioxide emission is the major sustainability issue associated with Portland cement. Historically, the manufacture of each tonne of Portland cement has resulted in the emission of well over 1 tonne of carbon dioxide. As a result of increased efficiency in operation, modern cement works emit somewhat less than this. Table 4 details the sources of carbon dioxide emissions associated with a cement works. It should be noted that some environmental accounting protocols do not include emissions associated with the production of electricity and/or allow emissions from the use of waste fuels to be ignored where the waste would otherwise have been burnt in municipal incinerators.

A major obstacle to reduction in carbon dioxide emission is the inherent emission of 0.5 tonne of carbon dioxide due to chemical breakdown of the limestone. Improvements in design and efficiency are unlikely to be able to reduce the total emissions much below 0.9 tonne of carbon dioxide and the only identifiable opportunity for further large-scale reduction is sequestration, i.e. to collect the carbon dioxide and prevent its emission into the atmosphere.

Additions are generally the by-products of other industries, which arise, irrespective of whether or not they are usefully used. As such, there are obvious environmental benefits in using them as replacements for Portland cement. If these by-products require further processing prior to use in concrete, there will be environmental burdens associated with the processing. Fly ash and silica fume are normally used without further processing and their environmental burdens are relatively small. The production of ggbs from blastfurnace slag involves processing (drying and grinding), which needs to be taken into account. Table 5 shows the environmental profile for the production of 1 tonne of ggbs, compared with typical values for Portland cement.

Limestone fines will also have some environmental burdens, arising from the quarrying, drying and grinding of limestone.

At first sight, it might appear that the best addition for increasing the sustainability of concrete would be the one with the lowest environmental burden. However there are several factors that need to be taken into account:

- The environmental impacts required to produce the addition
- The replacement level
- Any need for an increase in cementitious content to achieve specified 28-day strength
- Transport distances.

<table>
<thead>
<tr>
<th>Source</th>
<th>Indicative CO₂ emitted</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical decomposition (breakdown of limestone)</td>
<td>500 kg</td>
<td>The major source of CO₂ and intrinsically unavoidable</td>
</tr>
<tr>
<td>Fuel</td>
<td>350 kg</td>
<td>Use of waste as fuel can benefit sustainability</td>
</tr>
<tr>
<td>Electricity</td>
<td>80 kg</td>
<td>The CO₂ is normally emitted off-site, at a power station</td>
</tr>
<tr>
<td>TOTAL</td>
<td>930 kg</td>
<td></td>
</tr>
</tbody>
</table>

*Table 4: Indicative CO₂ emissions associated with the production of 1 tonne of Portland cement*
In practice, the replacement level and the need for extra cementitious content are the most important factors. Ggb is particularly effective because it is highly cementitious and can be used at high replacement levels (typically 50% or more) and can usually replace Portland cement on a 1:1 basis.

A UK Concrete Industry Alliance project studied the relative environmental benefits of using ggb and pfa in concrete. The calculated environmental impacts per tonne of concrete, relative to a reference Portland cement concrete, are shown in Table 6, for concretes of the same 28-day strength (C30).

From Table 6 it can be seen that replacing 50% of the Portland cement with ggb has resulted in a 40% reduction in the carbon dioxide emissions associated with the concrete. Use of fly ash has also resulted in a significant reduction. By contrast, replacing 50% of the Portland cement with ggb has only reduced mineral extraction by 8%. The environmental issue where additions have most to offer for concrete is carbon dioxide emission. By contrast, they have little effect on mineral extraction where the major burden for concrete comes from the aggregate.

Availability and transport are two further issues that are relevant to the use of additions. Ggb and fly ash are widely available, and transport distances from the point of production to the point of use are generally comparable to those for Portland cement. In practice, transport of cement and additions are relatively insignificant factors for the carbon dioxide burden of concrete because the carbon dioxide emission associated with moving a tonne of cement 100 miles by road is only about 10 kg, i.e. about 1% of the carbon dioxide associated with producing it.

**CONCLUSIONS**

Additions are currently making significant contributions to reducing the environmental burden of concrete, particularly in relation to carbon dioxide emission (greenhouse gas). In 2005, the use of ggb and fly ash saved the UK:

- 2.5 million tonnes of carbon dioxide emission
- 2 million megawatt hours of energy
- 4 million tonnes of mineral extraction
- Potentially, 2.5 million tonnes of material sent to landfill.

There still remains considerable potential for their increased use.
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THE ROLE OF THE ENGINEER IN ACHIEVING SUSTAINABLE DEVELOPMENT

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Career history includes ECD Energy Environment, Building Research Establishment and the development of the Sustainable Construction team at Scott Wilson.

Matt is an authority on assessing the sustainability of the built environment and is an experienced assessor in all forms of BREEAM as well as CEEQUAL.

ABSTRACT

This paper explores the role of the engineer in facilitating sustainable development. Reference is made to historical figures and extended to give a modern perspective.

KEYWORDS

Sustainable, Engineer, Development

INTRODUCTION

The UN Conference on the Human Environment in 1972 began to raise awareness of environmental issues on the international agenda for the first time. In 1983, the UN World Commission on Environment and Development, known as the Brundtland Commission, began studying the relationship between economic development and its impact on the environment.

The resulting report of the Brundtland Commission, Our Common Future, (1987), provided the original definition of the term ‘sustainable development’:

“Sustainable development is development which satisfies the current needs of society without compromising the needs of future generations.”

A more detailed quote from the same publication is more specific about the urgency of the situation due to scarcity of natural resources and ongoing changes to the planet:

“Over the course of the 20th century the relationship between the human world and the planet that sustains it has undergone a profound change ….. major, unintended changes are occurring in the atmosphere, in soils, in waters, among plants and animals, and in the relationships among all of these. The rate of change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise.”

Sustainable development is often described as the balance between social, economic and environmental pressure but another integral aspect is that the broad and global Brundtland definition must be interpreted in more detail at national, regional and local levels.

For example, the UK government breaks its sustainable development objectives down into four elements:

• Social progress which recognises the needs of everyone
• Effective protection of the environment
• Prudent use of natural resources
• Maintenance of high and stable levels of economic growth and employment.

BACKGROUND AND DEFINITION OF THE ENGINEER

History of engineering

The history of engineering can be roughly divided into four overlapping phases, as follows:

• Pre-scientific revolution: The prehistory of modern engineering features ancient master builders and Renaissance engineers such as Leonardo da Vinci
• Industrial revolution: From the eighteenth through to the early nineteenth century, civil and mechanical engineers changed from practical artists to scientific professionals
• **Second industrial revolution**: In the century before World War II, chemical, electrical and other science-based engineering branches developed electricity, telecommunications, cars, aeroplanes, and mass production

• **Information revolution**: As engineering science matured after the war, microelectronics, computers, and telecommunications jointly produced information technology.

The term ‘engineer’ is thought to have originated in the eleventh century from the Latin *ingeniarius*, meaning ‘the ingenious one’. The name, used for builders of ingenious fortifications or makers of ingenious devices, was closely related to the notion of ingenuity, which was captured in the old meaning of “engine" until the word was taken over by steam engines and their like. Leonardo da Vinci bore the official title of *IngeGrere Generale*.

**Modern definition of engineering**

The Engineering Council’s current official definition of engineering is given in their publication ‘Engineering 2000’:

> “Engineering is the practice of creating and sustaining services, systems, devices, machines, structures, processes and products to improve the quality of life; getting things done effectively and efficiently.”

**HOW HAS THE ENGINEER CONTRIBUTED TO SUSTAINABLE DEVELOPMENT?**

**Historical context**

The year 2006 is the 200th anniversary of the birth of Isambard Kingdom Brunel, one of the most famous and influential engineers in history, therefore it is apt to use one of his landmark designs, The Clifton Suspension Bridge, to demonstrate the link between engineering and sustainability.

In 1831, Brunel won a protracted competition to build a bridge to span across the Gorge between Clifton and Leigh Woods. He faced stiff rivalry from many eminent engineers of the day, as illustrated by the images in Figure 1.

The winning design by Brunel (shown in Figure 2) used the principles of advanced engineering to minimise the amount of materials and the cost of construction to produce a bridge that has far exceeded the original design requirements and is a lasting cultural icon. Brunel, in being a brilliant engineer, instinctively understood the concept of sustainable development long before the term was first used.

**Figure 1: Designs submitted for construction of the Clifton Bridge**
Modern perspective on the role of the engineer in sustainable development

Early in 2006, a search using the term ‘sustainability’ on the website of the Institution of Civil Engineers (www.ice.org.uk) gave 521 results, and the ICE itself has clearly stated the importance of the engineer in sustainable development as demonstrated by this quotation from the ICE Charter:

“The Institution of Civil Engineers believes that Sustainable Development is central to civil engineering and that ICE and the profession it serves must organise themselves accordingly.

In making this statement the Institution recognises the vital role played by its members in identifying the needs of society and devising and delivering solutions that are affordable and meet society’s aspirations. In fulfilling this role civil engineers contribute to economic growth, to environmental protection and to improved quality of life.”

The increasing integration of sustainability into the role of the engineer is further shown by studies such as the industry-supported ‘Engineer of the 21st Century Inquiry’, July 2000:

“Our vision is of an engineer who demonstrates through everyday practice:

• An understanding of what sustainability means
• The skills to work towards this aim
• Values that relate to their wider social, environmental and economic responsibilities and encourages and enables others to learn and participate.’

Sustainable development can be seen to be thought of as integral to the role of the modern engineer from the quotations provided above, however, with this comes increased responsibilities and pressures from a number of directions, including:

• Client expectations
• Planning requirements
• BREEAM and CEEQUAL ratings
• Revisions to Building Regulations
• Public image.

Engineering for sustainability

It can be clearly seen from the definitions given in this paper that high quality engineering is the key to delivering sustainability in that it is the role of the engineer to use his/her creativity to maintain the quality of life that Brundtland refers to whilst minimising resource use and depletion.

By addressing sustainability in terms of the four main components (as defined by the UK government ‘A Better Quality of Life’), the challenges and responsibility the engineer begin to take shape:
In summary, it is concluded that the concept of engineering preceded the concept of sustainable development but encompasses many of its key elements. The role of the engineer in delivering sustainable development is seen to be increasingly important. With this changing role, the pressures, demands and expectations placed on the modern engineer in terms of sustainability will no doubt expand.

<table>
<thead>
<tr>
<th>Aspect of Sustainability</th>
<th>Role of the engineer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental protection and enhancement</td>
<td>• Ensure all relevant ecological legislation is followed</td>
</tr>
<tr>
<td></td>
<td>• Minimise pollution to air, land and water</td>
</tr>
<tr>
<td></td>
<td>• Evaluate options for environmental enhancement</td>
</tr>
<tr>
<td>Social integration and well being</td>
<td>• Consider impacts on communities</td>
</tr>
<tr>
<td></td>
<td>• Avoid possible health impacts</td>
</tr>
<tr>
<td></td>
<td>• Improve amenities and quality of life</td>
</tr>
<tr>
<td>Economic issues</td>
<td>• Evaluate whole life costs</td>
</tr>
<tr>
<td></td>
<td>• Minimise potential costs of environmental risks</td>
</tr>
<tr>
<td></td>
<td>• Encourage the use of local labour and resources to stimulate local economies</td>
</tr>
<tr>
<td>Resource use</td>
<td>• Ensure the most efficient use of materials, energy, water and other resources</td>
</tr>
<tr>
<td></td>
<td>• Avoid the use of materials known to be exceptionally scare or environmentally damaging</td>
</tr>
<tr>
<td></td>
<td>• Evaluate the use of the latest resource efficiency technologies</td>
</tr>
</tbody>
</table>
Danny Lawrence has worked in the cement industry for almost forty years, the last seven of which have been in the position of National Environment Manager for Lafarge Cement UK (formerly Blue Circle). Amongst his responsibilities is overseeing the development and use of a multi-site Environmental Management System (EMS) which is certified to both the ISO 14001 and EMAS standards. He holds a masters degree in Environmental Management.

**ABSTRACT**

This paper discusses the contribution the cement industry can make in developing a sustainable society and describes some of the work undertaken by the Sustainability Task Force at the British Cement Association (BCA) in conjunction with Forum for the Future. It also refers to some specific programmes undertaken by Lafarge Cement UK, one of the members of BCA.

**KEYWORDS**


**INTRODUCTION**

The Cement Industry is a long established industry providing an essential commodity which, in its manufacture, has environmental impacts which need to be managed. The traditional basic raw materials used are limestone and shale, or chalk and clay, which are natural materials extracted from the ground. Substantial amounts of energy are used to heat the materials in a kiln, creating emissions to air, including carbon dioxide, a greenhouse gas which contributes to global warming and climate change. The conventional fuels used are coal and petroleum coke, and the industry has increasingly sought to recover energy from various waste streams, such as scrap tyres.

Most cement works are located in rural areas, where the natural raw materials are found, and where they are often a major source of local employment and economic influence. The product though is used by a much wider society throughout the entire country, particularly in the towns and cities.

The industry has also invested heavily in new abatement equipment and the latest production techniques. In these overall circumstances whilst there is a significant environmental influence it can be seen that this is an industry that faces all three faces of sustainability - environmental, social and economic.

The cement industry has acted very responsibly to consider sustainability. Globally, the nineteen major cement manufacturers have committed to a “Cement Sustainability Initiative” which is overseen by the World Business Council for Sustainable Development. All four UK cement manufacturers have signed up to this initiative. In addition the BCA established a “Sustainability Task Force” which worked throughout 2005 in conjunction with Forum for the Future. The result of that work was presented in their report “Working towards Sustainability” which was launched in December, 2005 and which has now been embodied into their continuing programmes.

**WHAT IS SUSTAINABILITY?**

There are many definitions of sustainable development but most are similar to: “Sustainable development is development which meets the needs of today’s generation without compromising the ability of future generations to meet their needs.”

Often the debate centres on the environmental issues. For instance, we have all heard about climate change and global warming. For too long there have been differing opinions as to whether or not it is happening. I suggest we should all recognise that something has, and continues to happen, and that we should all act urgently to play our part in addressing the problem. The problem is global and all countries should recognise their responsibilities in order to reduce the impact. Also, the use of natural raw materials leads to questions on how long will it
last. Similarly, and particularly in the UK, there is a problem with waste. As a country we produce too much waste, consequently we are running out of landfill sites. The problem is compounded by our ‘throw away’ culture.

I believe it is right to identify, and manage, such issues, but Bruntland’s definition refers to something else - needs. The society we live in and are a part of, us discussing this paper, our employees, our neighbours, colleagues, all have needs. I would suggest that a large part of that need is for somewhere to live - houses, shops, towns, roads, sea defences, etc. It is one of the most basic needs we have as a society, and industries such as the cement industry, and the concrete/construction industry it feeds into, have a leading role to play in ensuring that they act responsibly in providing these products in a sustainable fashion.

If we can accept that cement and concrete have this part to play in developing a sustainable future, it is worth looking in more depth at the three areas of sustainability, and consider how the cement industry influences each. Also, as we consider these, I suggest it is also important to consider these in a life cycle approach. Whilst the major impacts may be in the production and use of cement and concrete, the benefits continue for a very long time. It is a concern that the life expectancy of buildings in many assessments is taken as 50 years, whereas we all know that cement/concrete buildings have a longer life span.

**THE ENVIRONMENT**

As mentioned previously, the cement industry is very tightly regulated, appropriately so. It is worth noting that the cement sector is one of the first three sectors, the others being chemical and nuclear, which have in conjunction with the Environment Agency developed a ‘Sector Plan’ [3]. This plan focuses on the key issues for the industry, although it is also perhaps of note that the Lafarge Cement UK annual environmental reports have included details of these issues for the past six years. The issues are:

**Releases to air**

The report lists oxides of nitrogen, sulphur dioxide, particulates and carbon dioxide. The report recognises that the industry has “a good record in reducing its environmental impacts”, and shows the following graphs.

Figure 1 shows that the industry’s emissions of oxides of nitrogen reduced by approximately 50% in the period 1994 to 2004, while sulphur dioxide emissions have dropped by approx. 30%.

![Figure 1: UK Cement sector Nitrogen Oxides and Sulphur Dioxide emissions 1994 to 2004](image)
Figure 2 shows how dust emissions have fallen and are now at a very low level. This graph shows total dust. Whilst this is the current measure for dust in cement permits it is noted that air quality standards are increasingly related to PM10 (particulate matter under 10 micron) and PM 2.5 and the industry has some data on these emissions which will receive more focus in the future. Similarly, whilst permits have historically included limits on major emission points such as cement kilns and cement mills, latest permits include reference to fugitive dust.

### Use Of Resources

The report identifies that the cement industry’s typical average consumption of raw materials in the EU is 1.54 tonnes for one tonne of cement. It also notes that due to the use of calcareous deposits (limestone and chalk) much of the material is lost as emissions of carbon dioxide to air, and further adds that the use of pulverised fuel ash and blastfurnace slag can reduce the use of natural raw materials.

This section also identifies the use of fossil fuels. Whilst it is not specifically mentioned in the report, it is worth mentioning the energy debate. I think we all recognise that we need to find alternatives: wind, wave, solar, nuclear. I believe they all will play a part to some extent, and we should never forget the contribution the cement industry can make with its potential to recover energy from waste.

### Generation Of waste

The report urges the cement industry to encourage its customers to use and dispose of products in an environmentally friendly way, and further states that the EA are developing a sustainable construction strategy in consultation with industry and other stakeholders. Whilst it is not specifically mentioned in the report, it should be noted that the industry has already reduced its own disposals to landfill particularly in disposal of cement kiln dust.

### Sector Plan Objectives

Whilst the industry has already achieved a lot there is clearly further to go. Each of the companies have their own improvement programmes, but for the industry the plan goes on to identify nine objectives which the industry/EA will work on. These are:

- To reduce the consumption of natural resources per tonne of cement manufactured
- To reduce the amount of cement process waste residues disposed of per tonne of cement manufactured
- To reduce pollution from cement manufacturing
- To reduce emissions of greenhouse gas emissions per tonne of cement manufactured
- To optimise the sustainable use of wastes from other industries or sources
To develop site restoration plans and biodiversity action plans
• To improve transparency, understanding and engagement between the Agency, industry and other stakeholders
• To work to risk-based regulatory and environmental management systems
• To promote product stewardship and wider supply chain benefits.

Against each objective performance measures and targets are set, using 1998 as the baseline, with targets for 2006 and 2010.

I would suggest that this demonstrates that the cement industry has already achieved a lot to improve its environmental performance, but further it has set challenging targets agreed with the regulator, and which are very much in the public domain. Further, I will show later in this paper how Lafarge Cement UK has performed over recent years on these environmental impacts, with figures taken from their annual EMAS statements. These have been verified by an independent, qualified third party.

**ECONOMIC ISSUES**

Perhaps the first economic link to sustainability is the obvious need that companies have to make profits from their operations. A company could invest millions into making environmental improvements, consulting with society etc, but if they fail to make profits because of it then they do not have a sustainable business. At the same time, responsible companies are aware that, increasingly, investors not only look at the financial performance of a company, but also at the ‘ethical’ side - do they respect the local community and the environment, are they honest, do they treat their staff well?

But if we move on from that very basic financial fact, there are wider economic issues to consider, and the work undertaken as part of the BCA Sustainability Task Force last year included some very interesting financial considerations relating to the sustainability of the industry.

One part of the project was the development of a business case for sustainability. This business case sought to allocate values to the costs and benefits of running a 12 million tonnes (approximate size of UK market) annual cement industry.

The costs side identified the negative impacts of the industry and were split into:

**Nuisance factors**

This put a cost to the nuisance a company has on the local community by the creation of dust, noise, pollution, etc from a cement works or quarry, nuisances which may affect the quality of life. The tonnage of raw material extracted was taken and multiplied by a range of market prices for this section were £1, £2 and £5 per tonne.

**Extraction**

As previously identified in the environment section, the industry extracts considerable amounts of raw material from the ground, notably limestone. Relating to sustainability, what would happen if the local natural resources were exhausted? The company would have to buy in the resource. Again the extracted tonnage multiplied by a range of market prices for

---

**Figure 3: Table of Sector Plan targets for the Cement Industry**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Measure</th>
<th>1998</th>
<th>2006</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Raw Materials</td>
<td>kg/ t</td>
<td>1468</td>
<td>1428</td>
<td>1413</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>kWh/t</td>
<td>1103</td>
<td>973</td>
<td>764</td>
</tr>
<tr>
<td>Disposal of Cement kiln dust</td>
<td>kg/t</td>
<td>22.9</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Disposal of other waste</td>
<td>kg/t</td>
<td>4.17</td>
<td>3.5</td>
<td>3</td>
</tr>
<tr>
<td>Dust emissions to air</td>
<td>kg/t</td>
<td>0.33</td>
<td>0.2</td>
<td>0.15</td>
</tr>
<tr>
<td>NOx emissions to air</td>
<td>kg/t</td>
<td>3.34</td>
<td>2.8</td>
<td>2.5</td>
</tr>
<tr>
<td>SO2 emissions to air</td>
<td>kg/t</td>
<td>2.56</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>CO2 emissions to air</td>
<td>kg/t</td>
<td>924</td>
<td>847</td>
<td>833</td>
</tr>
<tr>
<td>Recovered waste as raw materials</td>
<td>kg/t</td>
<td>25.7</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Recovered waste as fuel</td>
<td>kg/t</td>
<td>9.64</td>
<td>14</td>
<td>21</td>
</tr>
<tr>
<td>Sites with stakeholder communications</td>
<td>%</td>
<td>68</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

All the above measures are per tonne PCE (Portland Cement Equivalent)
limestone were used, at £4, £5.5 and £10 per tonne.

**Health and safety**

In this section the study considered the costs incurred by government, individuals and families, due to accidents, sickness and death resulting from incidents in the cement industry. I would very strongly point out that whilst actual frequencies were used, and proxies used for costs to health service, employees and families, the cement industry in the UK has a very good safety record and has indeed signed an agreement with the Health and Safety Executive.

**Energy use**

Relating back to the environment section, carbon dioxide, oxides of nitrogen and sulphur dioxide are emitted to the atmosphere, influencing air quality and climate change. In this section costs are allocated to each of these and equated to the actual tonnages emitted from the process in a year. Prices ranging from £5 to £25 per tonne for CO₂, £1050 to £3400 for NOₓ and £340 to £2400 for SO₂ were used.

**Waste disposal from the industry**

Whilst the industry has made huge efforts to reduce its own waste, there still remains some which must be disposed of. Again the actual tonnages were used and a Landfill Tax allocated to it. In addition, the study looked at the amounts of organic waste included here, and allocated costs from the potential release of methane from the landfill sites. Prices from £18 to £40 per tonne for landfill and £14 to £57 for methane were used.

The study did not only consider the negative sides of the equation. As stated, there were positive contributions from the industry. These were:

**Waste substitute for virgin raw materials**

Again tonnages of other ‘waste’ materials, such as PFA, blastfurnace slag and iron oxide, can be used by the industry, and actual tonnages were taken. To these the costs of landfill were considered, as well as the benefit of not having to use as much natural material.

**Waste substitute for fossil fuel**

Again if the waste recovered fuels had to be sent to landfill, there would be a higher cost to society. The actual recovered tonnages were again considered. To these were allocated values for reduced landfill use and also reduced CO₂ emissions. Interestingly, the lower value was based on no alternative fuels being treated as ‘carbon neutral’, the mid range as being only bio-mass fuels as carbon neutral (as per the EU Emissions Trading Scheme), whilst the high range was based on all alternative fuels being treated as carbon neutral, as is the case in the Climate Change and UK ETS.

**Employment and tax**

This considered the economic impact on the national economy, employees and the government through the payment of salaries and associated taxes. It includes payroll taxes, corporation tax, VAT, rates and environmental levies, but does not include specific local taxes.

<table>
<thead>
<tr>
<th>Category</th>
<th>Costs Mid</th>
<th>Costs Lower</th>
<th>Costs Higher</th>
<th>Benefits Mid</th>
<th>Benefits Lower</th>
<th>Benefits Higher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuisance factor</td>
<td>35</td>
<td>18</td>
<td>88</td>
<td>37</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>Extraction</td>
<td>97</td>
<td>71</td>
<td>176</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Health and safety</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy use</td>
<td>142</td>
<td>90</td>
<td>413</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste disposal from cement industry</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste substitute for virgin raw material</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>7</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>Waste substitute for fossil fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment and tax</td>
<td></td>
<td></td>
<td></td>
<td>216</td>
<td>216</td>
<td>216</td>
</tr>
<tr>
<td>Community programmes</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Built environment</td>
<td>478</td>
<td>318</td>
<td>637</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figures in £m

*Figure 4: The BCA business case for sustainability*
Community programmes

This covers monies paid by the companies to various local and national community schemes.

Built environment

As mentioned, one of society's needs is the provision of the built environment, schools, hospitals, roads, dams, flood defence, etc. A proxy was used for the value of the built environment for new buildings and infrastructure, construction additions and repairs and maintenance each year, based on the basis that the purchaser of an asset is prepared to pay no more than the value of the asset to them. Figures are available for the total built environment, and part of this shows the cement, lime and plaster industry share. This figure has been split as a proportion of the turnover of these three sectors.

The combined outcome of the exercise was to demonstrate that there is a business case for sustainability. More work has to be done, but it showed very clearly that there is a link between sustainability and economic issues which goes far beyond merely making a profit.

SOCIETY

I would like to consider this section in two parts (or three when considering the details I will give on Lafarge Cement later).

The Business case for sustainability

The preparation of the report detailed above was not the end of the sustainability programme for the BCA, indeed it still has a long way to go, with sustainability likened to running a marathon. However, the BCA did organise a stakeholder event to gather feedback from various groups during the project. There was a wide range of representation and the general feedback was very supportive. Some comments were made that it painted ‘too rosy’ a picture, but generally it was extremely supportive.

One of the most interesting feedbacks came on the figure for the Built Environment. As a member of the Task Force, and one directly involved in the preparation of the business case, I had been concerned that the figure might be viewed as being too high. With the three price ranges leading to figures from £318m to £637m, it was by far the highest. Yet the feedback was that it was felt to be too low, they believed our product should have an even higher value. Most re-assuring.

Communications with society

The cement industry is one which needs, more than most, to keep their neighbours informed of things that are happening. Perhaps the prime example comes with consultations when a works seeks to trial the use of an alternative fuel. The Substitute Fuels Protocol includes details of expectations on stakeholder consultation. I would suggest the industry was slow to recognise the impacts this can have.

We need to work with the local communities around our works and explain openly what effects issues such as recovering energy from scrap tyres will have on them. Until one understands the details, probably an initial reaction to the thought of tyre burning is the release of black smoke and sulphurous odours. This is not the case and unless we give them all of the facts and can convince them, why should they trust us? Of course, we only seek to do things which we are confident are safe for health and the environment, but we have to earn trust.

When we do not have that trust, it results in delays in permitting, which in turn creates subsequent delays in bringing about the environmental benefits that follow. It also has an adverse impact on our finances. To run a trial could typically cost about £1m, and delays in permitting make the certainty of investments and paybacks sometimes less favourable, or even doubtful.

Whilst I may feel that we were slow to recognise this, the industry now has a very proactive approach to communications. Again, this can be seen to be reflected in the Sector Plan mentioned earlier. The objective “To improve transparency, understanding and engagement between the Agency, industry and other stakeholders” includes the following performance indicators:

- Proportion (and number) of plants using community communication tools
- Proportion (and number) of substitute fuel proposals during the year that were proactively communicated by companies to local communities
- Proportion (and number) of local liaison meetings attended by Environment Agency officers
- Proportion (and number) of substitute fuel decisions during the year for which an Environment Agency Decision Document was issued.
So, it can be seen that the industry, and the Environment Agency that regulates it, are all very aware of the need for social involvement.

**LAFARGE CEMENT UK**

Whilst the whole of the UK cement industry takes a very responsible approach to sustainability, it would be remiss of me not to include some specific examples of us in Lafarge Cement UK.

**Environment**

Figure 5 shows the actual performance we have on the identified significant impact between 2000 and 2004. The figures reflect figures from our verified EMAS statements. We are currently in the process of having the 2005 figures audited by LRQA, the accredited auditors, and these will be available by mid year.

The work does not stop there.

**Our objectives for 2006 are:**

- Reduce energy consumption
- Work in partnership to increase our products sustainability
- Continue the development of plans to reduce fugitive emissions
- Maximise the use of waste in our processes as
  a) alternative fuels
  b) alternative raw materials
  c) xtenders for cement products
- Improve the efficiency of monitoring and reviews
- Continue the development of bio-diversity action plans.

**Social Issues**

Each works has a liaison body, with representatives from the company, local authorities, regulators and local community. We also issue newsletters, and hold Open Days when members of the public can come for a tour of the facilities. These are often arranged in conjunction with applications to trial new alternative fuels.

Figure 6 shows the extent of these activities in 2005.

**The Wider Lafarge UK**

The Lafarge group is the largest supplier of construction materials in the world. Apart from our cement operations, we also have aggregates, plaster and roofing divisions in the UK. We all realise that our individual products, whilst they all

<table>
<thead>
<tr>
<th>Fossil fuel - Gj/t</th>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.63</td>
<td></td>
<td>3.1</td>
</tr>
<tr>
<td>Particulates - kg/t</td>
<td>0.27</td>
<td>0.12</td>
</tr>
<tr>
<td>SO₂ - kg/t</td>
<td>2.06</td>
<td>2.01</td>
</tr>
<tr>
<td>NO₂ - kg/t</td>
<td>3.55</td>
<td>3.3</td>
</tr>
<tr>
<td>CO₂ - kg/t</td>
<td>850</td>
<td>800</td>
</tr>
<tr>
<td>CO - kg/t</td>
<td>2.02</td>
<td>2.33</td>
</tr>
<tr>
<td>Waste disposed</td>
<td>13.01</td>
<td>5.98</td>
</tr>
</tbody>
</table>

*Figure 5: LCUK performance 2000 to 2004*

<table>
<thead>
<tr>
<th>Newsletters</th>
<th>Open events</th>
<th>Exhibitions</th>
<th>Liaison meetings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>Circ.</td>
<td>Number</td>
<td>Visitors</td>
</tr>
<tr>
<td>Aberthaw</td>
<td>2</td>
<td>2200</td>
<td>1</td>
</tr>
<tr>
<td>Cauldon</td>
<td>1</td>
<td>2500</td>
<td>-</td>
</tr>
<tr>
<td>Cookstown</td>
<td>1</td>
<td>400</td>
<td>1</td>
</tr>
<tr>
<td>Dunbar</td>
<td>1</td>
<td>6000</td>
<td>-</td>
</tr>
<tr>
<td>Hope</td>
<td>1</td>
<td>4700</td>
<td>1</td>
</tr>
<tr>
<td>Northfleet</td>
<td>1</td>
<td>4000</td>
<td>-</td>
</tr>
<tr>
<td>Westbury</td>
<td>1</td>
<td>9400</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 6: Lafarge Cement UK stakeholder communications 2005*
have their own characteristics, are not final products. They go into making concrete, houses, roads and all the other infrastructure previously mentioned. We are seeking to find more on how we can contribute to the sustainable communities debate. We have a tremendous amount to offer, particularly in the use of wastes, and the benefits of increased thermal mass that comes with concrete buildings will bring to the thermal efficiency of buildings, especially when considering such items on a life cycle basis.

**SUMMARY**

So we believe the cement industry has a lot to contribute to sustainable construction.

On the environment side it is recognised that the industry has a good record of improvement, and there are challenging targets ahead as recognised in the Sector Plan.

On the economic front there is a business case for sustainability. We contribute a lot already, and even more work will be done over the coming years.

Finally, but not least, we recognise the importance of good relations with society, and believe in honest and open communications.

We believe that we have a very long term, sustainable future. As the debate moves forward we will strive to become recognised as leaders.

**REFERENCES**


Miles Watkins, has worked for Aggregate Industries for 10 years as the principal individual concerned with the company’s environmental and social responsibility. During this time, Aggregate Industries has certified all its sites to ISO14001, commenced an annual cycle of external sustainability reporting and has developed a sustainable product development programme.

**ABSTRACT**

This paper illustrates a view of sustainability from the perspective of a supplier of aggregates. It is explained how Aggregate Industries uses a stakeholder model to identify key issues and then applies the Business in the Community model of Community, Workplace, Marketplace and Environment to assist it in ensuring a holistic strategy is formed and implemented. The paper explains some of the initiatives that fall within the company’s strategy.

**KEYWORDS:** Aggregates, Quarrying, Sustainability, Community, Workplace, Marketplace, Responsibility, Social, Environment, Trust, Reporting, Disclosure, Performance, Knowledge.

**INTRODUCTION**

Sustainability is of growing concern to Aggregate Industries from operational, commercial and political perspectives. It is not something that can be ignored by organisations as the requirements placed upon them by their stakeholders ensures that this issue demands attention in one form or another. Failing to meet the needs of the stakeholders in an organisation could lead to considerable harm. Therefore, a programme of stakeholder engagement is essential.

**STAKEHOLDER ENGAGEMENT**

**Identifying Stakeholders**

The pressures of sustainability are manifested on businesses in a number of ways, through a variety of stakeholder groups. For Aggregate Industries, an indication of those pressures are listed in Table 1.

The difficulty for an organisation is to prioritise these pressures to ensure that activities are resourced appropriate to the risks and opportunities involved. At Aggregate Industries a stakeholder analysis tool is used to establish the relative importance of the pressures arising.

The basis for this tool is the theory that there is a distribution of stakeholders along an axis of essentiality to the organisation (Figure 1).

Clearly, such an academic model is of little use to a business so its contents have been translated into three easy questions:

- Is the stakeholder critical to the success of our business?
- Is the stakeholder negatively affected by our business?

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Stakeholder</th>
<th>How?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need to measure environmental performance</td>
<td>Environment Agency</td>
<td>Licences</td>
</tr>
<tr>
<td>Need to engage with the local community</td>
<td>Planning Officers and the Community</td>
<td>Direct action and the planning system</td>
</tr>
<tr>
<td>Need to report and disclose sustainability performance</td>
<td>Shareholders</td>
<td>Direct requirements</td>
</tr>
<tr>
<td>Need to develop sustainable products</td>
<td>Customers and Government</td>
<td>Shift in market patterns and policies</td>
</tr>
<tr>
<td>Need to manage carbon footprint</td>
<td>Energy Companies and Government</td>
<td>Cost of energy and political initiatives</td>
</tr>
</tbody>
</table>

Table 1: Examples of sustainability pressures from different stakeholder groups and how they are applied to the organisation
• Is the stakeholder of strategic importance to our business?

These questions represent a logical hierarchy as to how businesses can resource the proper fulfilment of relationships and thus manage the pressures that emerge from that engagement. Considering the practical implications in turn, the first question leads to those groups and individuals without whom the business would fail. Employees, customers and suppliers are common outputs from this question at the company level. The next question often highlights elements of the local community or special interest groups that for risk management reasons should be at least on the watch-list if not fully involved in an engagement process. The third question often finds trade associations and universities listed who provide useful services, either technical or intellectual, that can often lead to strategic advantages but not to essential business survival.

This is a convenient way of establishing priorities at different levels within the business as it can be used at the company, divisional or operational level. Indeed, it is recommended that this is the case and at Aggregate Industries it forms the basis of the Community Action Programme which is discussed later.

Again to simplify, Aggregate Industries has formed a stakeholder map to visualise the groups with whom it had determined a level of engagement is important for carrying out the aforementioned analysis (Figure 2).
Having identified the stakeholders that are deemed important to the organisation, a process of engagement is required to understand more about the pressures or issues that are of concern. The process of engagement is a very extensive subject indeed and therefore is beyond the scope of this paper. In short summary, engagement can take many forms from meetings, both formal and informal, to written communication to reporting. Generally, consideration needs to be given to what the most appropriate method is for each stakeholder group. In order to gain the maximum benefit from any engagement process, the aim should always be to develop trust.

**Developing Trust**

At Aggregate Industries, a very simple model is used to explain the development of trust (Figure 3).

The basic premise is that there needs to be a balance between performance and transparency to develop trust. Most seriously, if performance or commitments are exaggerated at any point, the belief that stakeholders hold in the organisation will be eroded, possibly to an unrecoverable extent in some cases. An illustration of this from outside the sector relates to Heathrow Terminal 5. All through the planning and public enquiry process of Terminal 5, it was stated that no further runways would be constructed at the airport. Post the granting of planning permission for the Terminal, the community now learns that a new runway is desirable. What faith can they have in the commitments of BAA in the future?

The opposite situation represented by this model is where the performance of the organisation is strong but the communication is weak. In this scenario, the organisation is not capitalising on its efforts and perhaps could be classified as an unknown quantity in the eyes of certain stakeholder groups. The realisation of this model is very simple.

1. Don’t lie
2. If you perform well, remember to tell.

Armed with an analysis of who the important stakeholders are, and having developed an appropriate engagement process that follows the principles of developing trust, the organisation should be in a position of knowledge regards the sustainability pressures on it. What is then needed is a systematic process to organise the activities that are created as a result of this engagement.

**THE BUSINESS IN THE COMMUNITY (BITC) MODEL**

Aggregate Industries has chosen to work to the BITC model for both organising and reporting its sustainability activities. A model that was itself developed through stakeholder engagement processes, the BITC approach helps an organisation look at the balance of its activities across the spectrum of sustainability. The model was developed as part of its Corporate Responsibility Index which is an annual benchmarking exercise including any organisation that wishes to participate (Figure 4). Aggregate Industries uses the BITC Corporate Responsibility Index as a health check on its sustainability strategy, taking that approach that a third set of eyes always provide a valuable perspective.

![Figure 3: The Trust Graph](image)

![Figure 4: The Business in the Community Corporate Responsibility Index Model](image)
It is important to have an overall framework to the tasks being undertaken to satisfy the needs of stakeholders from the simple perspective of being able to track progress. It is also possible that a consolidated approach consisting of a few quality programmes will satisfy the needs of a large number of stakeholder groups so a one-to-one relationship between activities and stakeholders need not be taken.

The remainder of this paper introduces the reader to some of the activities being carried out by Aggregate Industries to satisfy the needs of its stakeholders in its quest to tackle the sustainable development agenda. These activities will be presented under the order of the BITC model and be prefaced by the current performance level of the business as defined by the Corporate Responsibility Index (Figures 5, 9, 14 and 17).

**AGGREGATE INDUSTRIES’ SUSTAINABILITY ACTIVITIES**

**Community**

Relative to its immediate peer group, Aggregate Industries is performing well concerning community issues. For an organisation to manage its impact comprehensively, it is local community issues that are the most numerous and most diverse and they also occur at the lowest denominator of the company; i.e. the site level. The power of the neighbouring community to operations is increasing in its legal status through the planning system and under the stakeholder assessment criteria, these groups and individuals are migrating from being of strategic importance to being essential to the business. However, the company is not a charity and has a purpose of its own and tough decisions have to be made as to which activities of engagement are undertaken and which not.

To help guide the company’s choices in this area, a Community Policy (Figure 6) has been developed and rolled out through a specific training programme. This training helps the managers identify important stakeholders using the method previously described but also helps them decide whether a course of engagement is of mutual benefit. There are many acts that are basic philanthropy and as a result there are often better ways to invest into the community. The down-side of this however, is that these activities can be time consuming and it is often so much easier to write a cheque.

The manifestation of the Community Policy is termed the Community Action Plan. The current target is that all Aggregate Industries wholly owned sites are to have a Community Engagement Plan in place by end 2008. The process is based on a simplified version of ISO 14001 taking the principles of a plan-to-check-review approach and adapting it to the stakeholder model. First, managers define who their community is and then try to understand what it is they are likely to expect or demand from the organisation as both a company and member of that community. Secondly, managers decide which parts of the community are significant to them. This is achieved by using the three stage assessment as explained previously. Thirdly, engagement is planned based on locally agreed and implemented objectives. Finally, engagement is monitored and review progress periodically.

The engagement takes place in a number of ways, ranging from the use of public open days at quarries, specific events and schools visits, to donating time, money and skills to suit the needs of the communities. Even by simply responding to complaints from the community, engagement takes place, hopefully in a manner that satisfies the concerns of the complainant. The use of web-based communications at a local scale has been explored and local Liaison Group meetings take place regularly at many of the quarries and larger factory operations.

One of the more unusual ways in which Aggregate Industries is able to engage with local communities is through archaeology. Quarrying is a way to uncover the past. The discovery of archaeological finds at a site usually causes mixed feelings - excitement that it might be something
really interesting and nervousness as operations will need to be modified to cater for the presence of archaeologists.

Many sites contain artefacts of interest, but it is the sand and gravel sites which tend to contain significant finds from across the ages. Bestwall has been a working quarry and archaeological dig site in Dorset for more than 10 years. At Balblair, near Inverness, a dig has uncovered an ancient chambered cairn. The business is supporting this project in conjunction with the site owners.

Excavations during quarrying are often the only way to uncover past settlements and can realise important data. The recent discovery of fossilised human footprints in a quarry in central México has thrown new light on when humans first arrived in the Americas. While the archaeological sites associated with Aggregate Industries may not be quite so prominent, they do cast new light and understanding on the way human ancestors lived, worked and died and of course they are an important way of engaging with the local community.

Another unusual method of engagement for the quarrying sector is through land use and in particular restoration. Aggregate Industries at its Garside Sands operation in partnership with two other local quarrying companies recently teamed-up with the Sandpit Project and the local community to re-open a former footpath. With panoramic views of the Chiltern Hills, the restored footpath links Heath & Reach with other local villages and takes in a newly created nature reserve.

The opening ceremony was carried out by Councillor Rhys Goodwin and local resident Druuske Hawkridge, with an audience of key local figures, representatives from the Sandpit Project and the Countryside Agency, and the land and quarry owners. The footpath (Figure 7), which was closed due to previous quarrying operations in the area, was followed, with the walk finishing at the Sandstone Sundial - created using sandstone donated by Garside Sands and is believed to the one of the largest sundials in the country. It will stand as a memorial to a member of the local Preservation Society, Daphne Oram.
In pursuit of the balance of performance and transparency with the wider community, Aggregate Industries has established a website dedicated to the communication of sustainability issues (Figure 8). The web is a most convenient method through which to broadcast commentary and also to gain feedback.

The website is designed around the concepts outlined in this paper using both the stakeholder approach and ordering around the BITC framework. There are a collection of Key Performance Indicators and associated interpretation, position statements on various topics and case studies to illustrate performance and commitment in different areas of sustainability, many of which have been drawn upon in the writing of the present paper.

In order to meet the specific needs of different stakeholder group, one can register and then log-on to the site which enables a custom report to be downloaded, containing only the elements that are desired by the reader. This is the main drawback with the printed sustainability report; there is often too much information contained within it.

Aggregate Industries has a mature approach to environmental management and this is reflected in the BITC score as illustrated by Figure 9. It can be seen that the business is ahead of both the peer group and wider industry in the index.

The ISO 14001 certification of the company environmental management system (EMS) continues to be the backbone of the environmental activity at Aggregate Industries. The programme of external checks of management competence demonstrates the commitment to the environment to its stakeholders. Also, the assessment programme ensures that the environment remains high on the internal agenda where it has to be balanced with other pressing issues for management attention. The EMS provides Aggregate Industries with a framework with which it can improve its performance. The specific management programmes, for example on carbon management and biodiversity, are all built into our overall systematic approach. The logical steps laid down in ISO14001 enable effective training to be provided.
An unusual feature of the Aggregate Industries EMS is that it is electronic, using an intranet based approach (Figure 10). This system has been in place since 1999 and allows easy integration with other areas of management such as health and safety or quality. Indeed it is with the latter subject that combined certification has been achieved for the majority of the business during 2005 (Figure 11).

Corresponding from pressure on the business from energy prices at a practical level and from climate change instruments at a political level, Aggregate Industries has embarked on a comprehensive Carbon Management programme with the Carbon Trust.

As more data are gathered on the carbon dioxide emissions from the business, assessment of the trends over time can be viewed (Figure 12).
Based on the current data, the UK business tends to show a higher per tonne figure than the US because there is more value-added activity, in particular in precast concrete building materials and asphalt. This indicates that more elements in the downstream process are combined.

A CO₂ objective has been set for the UK business of a 12.5% reduction relative to tonnes of production by 2010.

Biodiversity has been on the international agenda since 1992 when the Rio Earth Summit expressed concern about the decline in habitats and species in many parts of the globe. But biodiversity remains poorly understood and recognised. In 2005, Aggregate Industries UK published a Biodiversity Policy (Figure 13), to sit alongside the Group Environmental Policy and so focus attention on this key sustainability issue.

As a major landowner Aggregate Industries can have significant impacts on biodiversity and as a result it has been a long-standing, major element within the environmental programme. The company was the first in its sector to publish a Biodiversity Action Plan (BAP), in 2002. In 2005, the process of reviewing progress and making plans for the future was commenced. The BAP is due for reissue in 2007 and over the next two years what progress has been made will be established and what challenges remain identified.

At the same time as the review of the BAP, a new objective has been introduced: to maintain and enhance the biodiversity of the managed areas of UK BAP sites so that more than 80% are achieving favourable condition as defined by English Nature. This target is aligned with the Public Service Agreement target that English Nature has itself committed to achieving.

Aggregate Industries’ performance in the Marketplace element of the BITC index is arguably the area that needs the most development but it is the area that has received...
the most attention of late. As can be seen from the graphic in Figure 14, the construction sector lags behind overall industry performance.

In 2004, Aggregate Industries reported that Masterblock had achieved certification of its Envirobloc range (Figure 15) through the Building Research Establishment (BRE) scheme of environmental profiling. The process by which the products achieved certification is a relatively complex one, but can be described simply. Environmental profiling takes information about the product, its raw materials, the transportation of the materials to the factory, the energy used, manufacturing process inputs and outputs, and converts them into a single figure which describes the performance of the product during a standard 60-year life-time.

In this way products used for similar purposes can be compared by the person designing a building to ensure that the building creates the minimum or optimum environmental performance throughout the construction phase.

Environmental profiling will not tell you if something is environmentally friendly, simply that one product, both as a stand-alone product and when used in the construction of a building, has a lower impact when compared to others.

During 2006, Envirobloc will be joined by Enviromasonry which represents a range of masonry blocks of a high grade finish also certified by the BRE for their environmental profile. Both Envirobloc and Enviromasonry achieve ‘A’ Ratings using the BRE system for certain applications.

At the 2004 Civic Trust Awards, Bill Dunster Architects received the Sustainability Award, sponsored by Aggregate Industries, for the stunning and innovative development in Surrey known as BedZed, built by the Peabody Trust. Bill’s projects show the highest quality and highest standards of sustainable construction.

As a follow-on project he worked with Charcon to design and build a project called RuralZed (Figure 16). Located in Cornwall this project sought to develop his application of dense concrete structures in houses. At the centre of his design principle is the concept of thermal mass, which is provided by dense concrete structures in the floors and walls. The scale of RuralZed is much smaller than at BedZed and aims to develop techniques using thermal mass into projects for more affordable homes.

Using precast concrete structures of dense concrete from Charcon, RuralZed was completed in 6 weeks. Further similar properties are planned for demonstration purposes at the Eden Project in Cornwall.

Charcon supplied high quality, white concrete beams which were used as internal walls. Charcon’s Eco-mix (designed for Eco-flag and Eco-kerb products) was used, ensuring the highest environmental performance in terms of raw materials. Eco-mix comprises secondary aggregates instead of virgin materials. The internal walls are white to maximise reflection of natural daylight and so minimise the use of artificial lighting.

Thermal mass is a technique used by traditional and ancient builders to provide a structure which helps to regulate the internal temperature, through diurnal and seasonal fluctuations, by providing temporary heat storage and dissipation. Utilising the sun’s energy during the day to gradually heat the structure in winter, but in the summer the same materials provide a means of preventing over-heating. When the

![Figure 15: Masterblock’s Envirobloc range](image)

![Figure 16: An illustration of the RuraliZed development](image)
structure combines the benefits of thermal mass with natural ventilation systems, the need for air conditioning is removed. Bill’s projects use little energy compared to other buildings of similar size which adopt a lightweight approach.

The simplest way to describe the effect of thermal mass is to consider an old cottage with thick external stone-walls, flag-stone flooring and solid internal walls. In the summer, the interior is cool and in the winter, with a single fire in a fireplace, warm and cosy. The building’s dense materials provide a simple means of reducing highs and lows of temperature inside the structure.

With predictions of significant increases in maximum summer temperatures in the south-east of England as a result of Climate Change over the coming decades, comes concern that lightweight methods of construction will result in overheating and the need to install air-conditioning. With air-conditioning comes increased power requirements and more electricity to keep homes cool in hot summers.

Workplace

Only marginally above the peer group in the BITC assessment (Figure 17), Aggregate Industries is continuously innovating in the workplace to ensure that it is an attractive and secure environment in which to work.

One of the most significant difficulties of a growing organisation is that of knowledge management. It is extremely challenging to ensure that everyone has access to the information that they need and that the organisation learns from its mistakes and successes. An intranet system, Brains (Figure 18), is currently used to great effect and allows the transmission of both the serious and the light-hearted issues that characterise an organisation.

The company has also used the potential purchasing power of its 5000 UK-based employees to secure discounts at many stores supplying a full range of goods from cars to computers. The competition between businesses to attract the right kind of employees is getting ever more intense and a comprehensive system of benefits is generally seen as attractive to newcomers and time-served employees alike.

The construction industry is more dangerous than many and the safety and well-being of Aggregate Industries employees is foremost among company priorities. On both sides of the Atlantic additional time and resource has been devoted to identifying and managing risk and training employees on effective safety management and accident prevention. Where accidents have happened, immediate medical care has been arranged and everything possible done to enable injured employees to make a full recovery and a speedy return to work.

2004 marked another year of significant progress in health and safety performance. In the UK the HSE reportable frequency and incident rates fell, by 11% and 12% respectively, and the severity rate fell by 29%. By the end of the year the Aggregate Industries’ five-year frequency and severity rate reduction targets had been achieved ahead of schedule and the company was well on the way to achieving the incident rate targets.

In the US the number of lost time injuries fell from 67 in 2003 to 55 in 2004. Twenty-two of these were in the new south-west region meaning that the remaining five regions saw a reduction from 67 to 33, a major achievement. The number of days lost increased marginally from 2374 to 2404 but again the new region accounted for a major portion of the total in 2004 - 1044.

There were no fatal accidents involving employees in 2004 either in the UK or the US, but in December an independent haulier making a delivery to a construction site we were working on in Nevada was fatally crushed whilst trying to free his vehicle which had become stuck.

Figure 17: Aggregate Industries’ current Business in the Community Corporate Responsibility Index Workplace Score
CONCLUDING REMARKS

This paper gives an insight into how a quarrying company, Aggregate Industries, views sustainability. Sustainability is about meeting the needs of the stakeholders in an organisation. These stakeholders have many needs and these needs require prioritisation as to receive the appropriate resources commensurate with potential risks and opportunities. The aim at all times is to develop trust between the organisation and its stakeholders.

The engagement activities that are developed from understanding stakeholders’ needs should be organised in a way which is consistent to provide an overall framework to an organisation’s commitments. This will allow easier management of the issues and clearer communication of the results.
THE CONTRIBUTION OF ADMIXTURES IN SUSTAINABLE CONCRETE CONSTRUCTION

Philippe Ortega, BSc(Chem Eng.)

Chryso SAS

Philippe Ortega is a graduate in Chemistry from Lille University (France). He joined CHRYSO in 1998 in order to start a concrete admixture business in Germany, participating with Lafarge Cement to different concrete projects, specially the first developments of self-compacting concretes in the German precast and ready-mix industries. From 2002 up to now, he works in the CHRYSO Concrete Admixture Department, in charge of the Technical Development and Support for several areas (UK, Northern and Central Europe & USA), where he has been given the opportunity to participate to the achievement of big job sites such as Millennium Bridge in Poland and Nancy Creek Tunnel in Atlanta, USA

ABSTRACT

This paper discusses the growing role of admixtures in sustainability of concrete construction. Focusing on the most relevant types of cement and concrete admixtures, it shows how such products have a direct/indirect impact on the main sustainability criteria, first in their manufacture (use of biodegradable raw materials, conception of environmentally-friendly admixtures), then in their use (improvement of health & safety, environmental and durability aspects). Recent attempts to design and compute the global contribution of admixtures in concrete sustainability are finally described.

KEYWORDS


INTRODUCTION

Concrete is one of the most durable and cost-effective construction materials in use. Due to the development of town planning – there should be at least 20 megacities of more than 10 millions habitants in the year 2025 - larger and larger amounts of concrete will be required in the future. Thus, a concrete sustainable development is of major importance for the 21st century. So, how will it be possible to “meet the needs of the present without sacrificing the ability of future generations to meet theirs”, according to the definition of the United Nations?

Today, quality concrete is made in most cases with one or more admixtures, some of them already present in the cement, that are known as cement additives. Admixtures are designed substances with the aim of improving the fresh and hardened properties by their physical or chemical action. For example, in the fresh state, workability, homogeneity and setting behaviour can be controlled; but also the hardened concrete properties such as compressive and flexural strengths, shrinkage or porosity can be positively influenced by the use of an admixture.

The aim of this paper is to show how these various admixtures can give an answer to the question raised above. In that regard, two main aspects have to be considered in terms of concrete technology and sustainable development. First, it is important to look at the short-term impact of the production of Portland cement on the environment. According to some studies, manufacturing one tonne of cement releases around one tonne of CO2. Any means that would reduce the use of cement while keeping the overall concrete performance could certainly be considered as positive. The long-term behaviour of concrete or durability is the second main aspect that is important to evaluate, since it is nonsense to reduce the short-term impact on the environment if we exert a detrimental long-term influence on the same environment. We will see how admixtures contribute positively to both aspects, and moreover, how they improve some secondary sustainable properties, like aesthetic and protection criteria (lower costs for repair and
maintenance), social criteria (better and healthier working conditions).

We will first look at the cement additives, then the products for concrete and finally the concrete admixtures, examining also their own sustainability character. We will finally describe an attempt to quantify the contribution of superplasticizers – one of the most important types of concrete admixtures – to the sustainable development of concrete.

**CONTRIBUTION OF CEMENT ADDITIVES**

Ninety percent of the embodied energy of concrete is attributable to the Portland cement, since it has been estimated that the production of one tonne of Portland cement is associated to the release in the environment of an equivalent amount of CO₂. Cement admixtures (defined as products put into the clinker during the manufacturing process of the cement) can directly decrease that high energy consumption unfavourable with the environment, thanks to grinding aids – by making the grinding process more efficient, and, thanks to so-called activators, by accelerating the strength development of the clinker and the additions (mainly fly ash and blastfurnace slag).

Sustainability does not only consider the environment, but also the user. Health and safety are more and more taken into account in Europe regarding the Chromium VI in cement, a compound classified as extremely toxic because of its high oxidation potential and its ability to penetrate into human tissue. Due to its high solubility in water, it can easily come into contact with the skin during manual handling of wet mortar and concrete, and potentially cause allergic eczema. Admixture manufacturers have now found efficient ways to lower the Chromium VI content below 2 ppm, in accordance with the new European Directive. These products are called Chromium reducers, since they work as reducing agents.

**Grinding aids**

The grinding plant at a cement factory is used to reduce the particle size distribution of various materials. In a sense, a grinding plant uses energy through milling – to create fineness and it is the production personnel’s aim to optimise the fineness with the production rate whilst consuming as little energy as possible in the process. From a sustainability point of view, the grinding process is extremely inefficient, since only 5% of the total energy spent is transformed into additional surface area whilst the remaining 95% is lost through heat during the process. The main cause of this low efficiency in ball-mills is...
the apparition of surface charges developed during milling resulting in a re-agglomeration of fine particles.

The elimination, or at least a decrease of the agglomeration phenomenon, can be provided by cement grinding aids (mainly based on alcohol, polyol, polyamin, organic acid, acetate), that enable the partial neutralisation of the surface charges.

Grinding aids are definitely advantageous from a sustainability point of view because they bring a significant reduction of the energy used during grinding, a gain in productivity cement/raw materials, a maximisation in the operating of mills, a reduction in wear and tear of the grinding media and an improvement of the cement strengths at 1, 2 and 28 days, allowing further cement content optimisations.

Figure 3 gives a good idea of the possible energy savings thanks to grinding aids:

<table>
<thead>
<tr>
<th>Dosage grinding aid</th>
<th>Control</th>
<th>Chryso®Cem ADM 72</th>
<th>Gain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production t/h</td>
<td>0</td>
<td>300 ppm</td>
<td>-</td>
</tr>
<tr>
<td>kWh/t</td>
<td>100</td>
<td>115</td>
<td>15 %</td>
</tr>
<tr>
<td>MW/year</td>
<td>28,080</td>
<td>24,414</td>
<td>3,666</td>
</tr>
<tr>
<td>Energy saving (€)</td>
<td>1 kWh= 0.06 EUR</td>
<td>219 960 €</td>
<td></td>
</tr>
</tbody>
</table>

**Activators**

In order to lower the embodied energy of the concrete, more and more supplementary cementitious materials are used in Europe, which can replace Portland cement and reduce the required cement content. Slag and fly ash are the best examples. Moreover, since they are by-products of other manufacturing processes, they are taken to have minimal embodied energy.

The only disadvantage is a significant retardation of the setting times and the early strengths, when a high proportion of these mineral additions are added to the cement. That is why admixture manufacturers have developed special cement additives, so-called activators, which have an activation function which compensates for the strength loss up to a certain point. They can be classified in the following types: first the chloride and non-chloride based like nitrates, thiocyanates: they actually react with the clinker part of the cement and basically accelerate the kinetic of hydration. Then the alkali components, like NaOH, Na₂SO₄, Na₂CO₃, K₂CO₃, KOH, K₂SO₄: they react only indirectly with the mineral addition, as they bring the necessary amount of alkalinity to initiate the pozzolanic or hydraulic latent reactions (e.g. siliceous fly ash or calcareous fly ash and blast furnace slag).

Today, it is still a challenge for admixture manufacturers to find real efficient molecules susceptible to activate specifically those additions, especially slag, which remains the most complicated material to accelerate.

**Chromium reducers**

The European Directive 2003/53/CE, which prohibits the sale of cement containing more than 2 ppm of hexavalent Chromium after hydration, has been officially in place since 17th January 2005. For cement manufacturers, this is an additional constraint in their day-to-day life and they are looking for efficient, economical and flexible solutions to enable them to comply with the regulations.

Ferrous sulphate remains the most commonly used technology, because of its ready availability and relatively low cost. However, it has some real disadvantages: dehydration during cement grinding can reduce its solubility and, together with oxidation, reduces its effectiveness. At high dosage, there can be concerns of increased water demand, extended setting time and possible brown discoloration.

Today, several admixture manufacturers have developed easy-to-dose solutions in liquid form, based on tin chemistry. They can be directly dosed into the mill, in a mode of application similar to that of a conventional grinding aid. Compared to ferrous sulphate, they have better storage stability and are significantly more efficient at low dosage, with no risk of staining or retardation.
CONTRIBUTION OF PRODUCTS FOR CONCRETE

Big efforts from admixture companies have been made in recent years, in order to offer products for concrete that would be more sustainable for health and the environment. Typical products for concrete are, for example, release agents, whose mineral part has been more and more partially or totally replaced by vegetable-based raw materials. A similar trend goes for typical solvent-based products, like curing compounds or positive surface retarders, which are more and more water-based.

Vegetable-based products

Standard release agents are mostly based on mineral oils. Mineral oils are not ready biodegradable in the environment. They may contain toxic components as aromatic hydrocarbons and organic solvents which are hazardous for health and environment. Lung damage and skin irritation are possible risks. According to the European Directive 1999/45/EC, such products have to be labelled (often as harmful or flammable). In this procedure, the classification of the product depends on the environmental properties of the individual ingredient in combination with its concentration in the product.

In the last few years, many admixture suppliers have developed new types of release agents, based on renewable raw material – vegetable oil - either pure vegetable or vegetable-based. Such sustainability issues around releasing agents have become so important in France (the general trend on the European market of release agents is a consumption increase of vegetable-based products), that SYNAD (French Syndicate for Concrete and Mortar Admixtures), through a voluntary and autonomous action, has published in 2004 a classification of the release agents present on the market, according to their composition and their impact on environment, health and fire safety.

An interesting example of this classification is shown below: the product, called CHRYSO® Dem LVA, (CHRYSO) has been one of the first immediate release agents launched on the market, classified as pure vegetable-based.

Water-based products

Standard products for concrete like curing compounds or positive surface retarders are generally formulated with solvents, known as VOCs (volatile organic compounds). Certain VOC’s can react with air pollutants (typically from cars) to form hazardous materials such as ozone. Concerns are sometimes expressed about the effects of using VOCs indoors.

That is why many admixture suppliers have tried to make these products more sustainable,

CLASSIFICATION SYNAD

<table>
<thead>
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<th>Pure vegetable</th>
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<tr>
<td>Vegetable based</td>
</tr>
<tr>
<td>Vegetable emulsion</td>
</tr>
<tr>
<td>Pure synthesis</td>
</tr>
<tr>
<td>Synthesis</td>
</tr>
<tr>
<td>Synthesis oil emulsion</td>
</tr>
<tr>
<td>New mineral</td>
</tr>
<tr>
<td>Recycled</td>
</tr>
</tbody>
</table>

CHRYSO Dem LVA

**Synad Classification for Mould Release Agents**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Health</th>
<th>Fire safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very good</td>
<td>Good</td>
<td>Very bad</td>
</tr>
</tbody>
</table>

Figure 4: Synad Classification for Mould Release Agents
making the concrete itself more sustainable. Today, it is possible to find pure water-based curing compounds and positive surface retarders that show the same efficiency at least as the solvent-based ones.

**CONTRIBUTION OF CONCRETE ADMIXTURES**

Concrete admixtures can play a significant role in the sustainability of the concrete if they are cleverly used. Already the biggest part of consumed concrete admixtures, which are plasticizers (normal plasticizers make up about 40% of all admixtures sold in Europe) show a sustainable character, as they are biodegradable by-products of other industries. Moreover, admixture amounts in the concrete are so small (a few %) that they do not significantly increase the global embodied energy of the concrete.

Superplasticizers are the second major part of consumed admixtures: they currently make up about 38% of all admixtures sold in Europe. Since their introduction in the early 60s, they have become an essential component of concrete. In particular, the relatively new next generation superplasticizers, based on polycarboxylates, have allowed some of the greatest concrete innovations, in terms of cement content optimisation, use of supplementary cementitious materials and exceptional durability, all of these improvements being essential for increasing the sustainability of the concrete.

Also other types of admixtures, like air-entrainers, stabilisers, accelerators and water-repelling admixtures present some functions that can be very advantageous regarding sustainability, as we will see.

**Normal plasticizing admixtures**

Plasticizers are admixtures which, without modifying the workability, allow a reduction of the water content of a given concrete (min 5%), or which, without modifying the water content, increases the slump/flow or produce both effects at the same time. From a concrete sustainability point of view, they offer the following advantages:

- They are sustainable products on their own, as they are produced from pure biodegradable raw materials: typical bases are lignosulfonate (from the extraction of cellulose for paper pulping), gluconate (from corn, wheat or potato starch), as well as glucose syrup (from starch), molasses (from beet).

- They enable a reduction of the cement content in concrete up to about 5%, decreasing significantly the whole embodied energy. This is shown in the table below, which takes into account different sustainability parameters (durability, energy and cost effectiveness).

**Superplasticizing admixtures**

Superplasticizers are admixtures which, without modifying the workability, give a high water reduction (min 12%) or without modifying the water content, increase significantly the slump/flow, or which produce both effects at the same time.

Typical bases are sulfonated naphthalene formaldehyde condensates and sulfonated

<table>
<thead>
<tr>
<th>Aggregates</th>
<th>Water</th>
<th>Cement</th>
<th>Fluidity</th>
<th>Strengths &amp; durability</th>
<th>Cost</th>
<th>Sustainability</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizing admixture</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizing admixture + water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizing admixture - cement - water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure 5: Effects of plasticizing admixture on concrete sustainable properties*
melamine formaldehyde. In the last five years, a new generation of superplasticizers came onto the market: vinyl copolymers and polycarboxylic ethers (PCE), which appear to be much more powerful in terms of water reduction. Although such molecules are poorly biodegradable, studies supported by the European Federation of Concrete Admixture Associations (EFCA) have shown that the dissolved organic carbon (DOC) in the leachable fraction from concrete could almost completely be degraded within 28 days, indicating that these compounds are readily biodegradable.\[1\]

From a concrete sustainability point of view, superplasticizers offer the following advantages:

By reducing substantially the water content in concrete, they allow much higher potential cement savings (especially the new generation of PCE: up to about 15%), compared to standard plasticizers. Significant amounts of supplementary cementitious materials can be used, like fly ash, blast furnace slag or silica fumes (current replacement levels up to resp. 25%, 60%, 70%), which result in important energy savings and a significant reduction of global CO\(_2\) emissions. Moreover, higher strengths are often obtained long term, using such materials combined with superplasticizers. For example, a study made by Mukherjee reports that a significant increase in compressive strength was observed with superplasticized concrete containing 37% fly ash when compared with a control concrete, a result mostly due to a 20% reduction in water content that was brought about by decreasing the water/(cement + fly ash) ratio from a value of 0.35 to 0.28.\[2\] [3] .

---

**Figure 6:** Results of the biodegradation tests with the PCE products and the leachable fractions from concrete. Reference compounds (controls) were diethylene glycol in the OECD 302 B Test and sodium benzoate, respectively, in the OECD 301 A Test.

**Figure 7:** Compressive strength of superplasticized concretes containing fly ash.
An important consequence of the high water reduction allowed by superplasticizers is the improvement of the concrete durability, which is a relevant aspect of sustainability, as it helps to reduce maintenance and the need for reconstruction. Lowering the porosity and the permeability of concrete is the only way to reduce the intensity of an aggressive attack on a concrete structure. By doing so, the penetration of aggressive agents is slowed down and the lifespan of the structure is increased. As indicated in the table below, a lower water/cement ratio decreases the permeability of the concrete but it does so at the expense of the workability. Thanks to the addition of a superplasticizer, the rheological properties will be restored to a satisfactory level, and, if desired, it will even allow a lower water/cement ratio giving lower permeability, leading to concrete types such as high performance concretes, whose durability properties are fully recognized. Moreover, as most supplementary cementitious materials have good durability enhancement properties (slag cements are known for example for their good resistance against chemical aggressions), the fact that they can be used in larger amounts by adding superplasticizers is very beneficial in that regard.

Another aspect of the improved durability is the strength enhancement, that can reduce the amount of concrete required, minimizing the use of the raw materials that are basically natural resources. One good example is ultra-high performance concrete that offers flexural resistance exceeding 40 MPa with ductility and compression strength beyond 200 MPa. As structures can be designed without any secondary passive reinforcement and no shear reinforcement, it is possible to use much thinner sections compared to an ordinary concrete.

Last, but not least, some new generation PCE superplasticizers have contributed to better concrete durability - and consequently to improved sustainability - thanks to a significant improvement of the workability retention. Unlike the classical polynaphthalene- or polymelamine-based superplasticizers that just allow around 20 minutes open time, PCE superplasticizers can now be so designed to give several hours of slump retention. In the ready-mixed concrete business especially, this property minimizes the addition of extra water on site, avoiding a drop of the mechanical strengths and consequently assuring better durability.

Besides cement embodied energy optimisation and durability improvement, recycling and adaptive reuse is another significant sustainability factor. In Europe, the average quantity of construction and demolition waste is around 500 kg/head/year, and in the world, over one billion tonnes. More and more effort is being put into recycling this waste. Thus, crushed concrete is now used as aggregates in new concrete. One problem however is their particularly high water absorption, which would require an additional water amount, to the detriment of strength. By reducing the water demand, superplasticizers offer the possibility of compensating this extra need of water, in order to use these recycled aggregates much more efficiently.

We will not finish with superplasticizers without saying a word about self-compacting concrete, that couldn’t have emerged without the new generation of PCE products. self-compacting concrete combines in fact a lot of significant sustainable properties – first, the general use of supplementary cementitious materials in SCC mix designs, that keep the Portland cement content at a reasonable level, then an improved durability, as well as other sustainable properties: improvement of surface finish, which decreases concrete repair, no need for vibration to put the concrete in place, which decrease energy costs, and improvement of working conditions by avoiding noise.

### Other concrete admixtures

Besides water reducers, there are other common concrete admixtures that can play a significant role in the improvement of concrete sustainability:

- **Air entraining agents** work as durability enhancers, increasing the freeze/thaw resistance.
of concrete. This is an important property that has to be met satisfactorily when concrete is used for outdoor construction, in particular in northern countries. A closely spaced and uniformly distributed network of air bubbles through the use of such an admixture will provide the necessary protection against damage from freezing and thawing of ordinary concrete.

Viscosity-enhancing admixtures work as stabilisers in the concrete, improving its cohesive properties. Often put in fluid or self-compacting concretes, they contribute to concrete sustainability in the following ways: they enable a reduction in the global amount of fines, while still keeping the appropriate homogeneity in the fresh state. Thus, an optimisation of the Portland cement content is possible. They also assure a better control of the regularity of the concrete quality, as they avoid bleeding and segregation – all aesthetic and durability improvements that limit further repair costs or demolition, in the worst case scenario.

Accelerators work as strength enhancers. Currently used in cold weather, they can be a good alternative to steam curing. This is particularly advantageous in the precast industry, where concrete producers look for high early strengths (typically prestressed concrete). From a sustainability point of view, it is as much as saved energy. Let us note that some new generation PCE superplasticizers are also designed to increase significantly early strengths, and play, in that case, a similar role to accelerators.

**COMPUTATION ATTEMPTS: AN EXAMPLE**

It is a fact that in Europe, the concrete industry is more and more concerned about sustainability issues. We have just shown conclusively that admixtures play a positive role in the sustainability of concrete. The next step is to quantify this influence, in order to control it more objectively, with an aim of a continual improvement. Some work has been already done by the European Federation of Concrete Admixture Associations (EFCA), who published the Environmental Declaration for plasticizing and superplasticizing admixtures (for all main groups of superplasticizers used in concrete, namely sulfonated naphthalene formaldehyde, sulphonated melamine formaldehyde, vinyl copolymers and polycarboxylic ethers) in June 2002. These declarations are based on the figures from eight of Europe's largest admixture products. All relevant environmental parameters have been classified in six groups: raw material – input, emissions to air, and emissions to water, solid waste and total energy.

All these inputs and outputs build a so-called Eco-profile, with characteristics as shown below.

**Figure 9: Eco-profile for 1 kg superplasticizer 30-45 % active content**

<table>
<thead>
<tr>
<th>Raw materials-input</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal</td>
<td>g</td>
<td>62</td>
</tr>
<tr>
<td>crude oil (feedstock)</td>
<td>g</td>
<td>91</td>
</tr>
<tr>
<td>crude oil (fuel)</td>
<td>g</td>
<td>74</td>
</tr>
<tr>
<td>natural gas (feedstock)</td>
<td>dm³</td>
<td>0.13</td>
</tr>
<tr>
<td>natural gas (fuel)</td>
<td>m³</td>
<td>0.21</td>
</tr>
<tr>
<td>water</td>
<td>kg</td>
<td>7.4</td>
</tr>
</tbody>
</table>

**Emissions to air**:
- CO₂ kg 0.62
- CO g 2.1
- CH₄ (VOC) g 2.2
- methane g 1.2
- methanol g 1.1
- NOₓ g 3.5
- SO₂ g 5.6
- benzene mg 2.6
- heavy metals ug 0.26
- nickel (Ni) mg 0.29
- mercury (Hg) ug 10
- cadmium (Cd) ug 9.1
- Halon-1301 ug 8.0

**Emissions to water**:
- barium (Ba) mg 8.5
- copper (Cu) mg 0.28
- formaldehyde mg 9.0
- nickel (Ni) mg 0.25
- PAHs ug 23

**Solid waste**:
- Non-hazardous waste g 28
- Hazardous waste mg 1.8

**Total energy**:
- Total energy MJ 18

**Figure 10: Eco-profile for 1 kg plasticizer 30-45 % active content**

<table>
<thead>
<tr>
<th>Raw materials-input</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>coal</td>
<td>g</td>
<td>29</td>
</tr>
<tr>
<td>crude oil (feedstock)</td>
<td>g</td>
<td>0.42</td>
</tr>
<tr>
<td>crude oil (fuel)</td>
<td>g</td>
<td>77</td>
</tr>
<tr>
<td>natural gas (feedstock)</td>
<td>dm³</td>
<td>0.46</td>
</tr>
<tr>
<td>natural gas (fuel)</td>
<td>m³</td>
<td>11</td>
</tr>
<tr>
<td>water</td>
<td>kg</td>
<td>0.51</td>
</tr>
</tbody>
</table>

**Emissions to air**:
- CO₂ kg 0.38
- CO g 0.54
- CH₄ (VOC) g 1.1
- methane g 0.49
- NOₓ g 2.7
- SO₂ g 7.5
- benzene mg 1.9
- heavy metals ug 2.8
- nickel (Ni) mg 1.4
- mercury (Hg) ug 2.7
- cadmium (Cd) ug 3
- Halon-1301 kg 18.0

**Emissions to water**:
- Chemical Oxygen demand g 58
- barium (Ba) mg 1.5
- copper (Cu) mg 0.20
- formaldehyde mg 0.53
- nickel (Ni) mg 0.20
- PAHs ug 48

**Solid waste**:
- Non-hazardous waste g 26
- Hazardous waste mg 9.2

**Total energy**:
- Total energy MJ 6.4
In order to evaluate the environmental impact, the Eco-profile is translated in a so-called Life Cycle Analysis (LCA), which is a method now recommended by the European commissions. The dotted line on the chart below shows how the Eco-profile processes of admixtures fits in the whole life cycle of concrete.

Different software tools have been developed recently in order to make a quantitative assessment of all the inputs and outputs that characterise the concrete life cycle, including in particular the admixtures. Although they work with simplified environmental indicators using equivalency factors, they allow reasonable simulations.

One of these software tools, called EcoConcrete, developed with the assistance of a Dutch environmental consultant, INTRON B.V., is particularly interesting, since it was conceived in 2004 under commission of the European concrete industry in a joint project group including the BIBM (International Bureau for Precast Concrete), CEMBUREAU (European Cement Association), EFCA (European Federation of Concrete Admixtures Associations), ERMCO (European Ready Mixed Concrete Organization) and EUROFER (European Confederation of Iron and Steel Industries) [6].

**Example of use**

In order to estimate how big the influence of admixture can be on concrete sustainability, two reinforced slab mix designs are examined. The first mix without superplasticizing admixture and the second one with admixture, that allows a 20 kg/m³ reduction in cement, while keeping the same level of strength by water reduction and workability by plasticizing effect.

The mix designs are given in Figure 12.

<table>
<thead>
<tr>
<th>Without admixture</th>
<th>With admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>780</td>
</tr>
<tr>
<td>Gravel</td>
<td>980</td>
</tr>
<tr>
<td>Cement CEM 1 52.5</td>
<td>350</td>
</tr>
<tr>
<td>Effective water content</td>
<td>210</td>
</tr>
<tr>
<td>Superplasticizer</td>
<td>0</td>
</tr>
</tbody>
</table>

**Figure 11: Concrete life cycle, according to the EFCA Environmental Declaration**

**Figure 12: Concrete mix designs with and without superplasticizer**
Following assumptions, easy to parameterize, are listed below:

- **Functional unit**: 1 m² reinforced slab 20 cm thickness
- **Lifetime**: 50 years
- **Cement delivered by 28 t truck – distance 100 km**
- **Sand and gravel delivered by 28 t truck – distance 20 km**
- **Admixture delivered by 16 t truck – distance 150 km**
- **Reinforcement**: 45 kg/m³ delivered by 28 t truck
- **Concrete delivered by concrete truck – distance 30 km**
- **Placement of the concrete**: 25 t crane
- **Steel formwork delivered by 40 t truck – distance 100 km**
- **No repair nor maintenance**
- **Ball demolition**: 80% to rubbish tip and 20% recycled – transportation by 28 t truck, 25 km.

Figure 13 shows the calculated differences between the mix with admixture and the mix without admixture for every environmental indicator.

In our example, it is shown that a 20 kg/m³ cement replacement by 0.4% of superplasticizer enables a decrease in all the environmental impacts, except the chemical and non-chemical waste that increases slightly. The most relevant improvements are a decrease of 3.57 kg of CO₂ emission into the atmosphere (4.4%) and a decrease of 20.56 MJ of energy (2.8%).

**CONCLUSIONS**

Admixtures do not only contribute to a better concrete sustainability, they are essential to its development, mainly because they work directly on the two main issues that are:

- the decrease of the embodied energy and the reduction of CO₂ emissions, through the optimisation of the Portland cement content and the easier use of supplementary cementitious materials
- The durability, through a concomitant increase in compressive strength and reduction of porosity.

Concrete admixture producers have well understood the new potential of their products and are actively looking to make them more and more environmental friendly. In the same way, European commissions and associations are elaborating the new means to evaluate precisely the impact of admixtures on concrete sustainability, such as Eco-profiles and software tools that are able to show how admixtures fit into the whole life concrete cycle.

**ACKNOWLEDGEMENTS**

The author would like to express his appreciation to members of the SYNAD environmental commission in particular Gildas Le Guillerme for his helpful and thoughtful assistance.

![Figure 13: Impact assessment of the environmental parameters (CML indicators)](image)
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5 EFCA Environmental Declaration Normal Superplasticizing Admixtures – June 2002

6 Schwartzentruber A. EcoConcrete – A Tool to promote Life Cycle thinking for Concrete Applications, ORGAGEC Symposium, October 2005, pp 2-10.
ABSTRACT

This paper examines the impact of the ready-mixed concrete industry on sustainable development. It considers production aspects, the properties of concrete and innovation in terms of sustainability.

The paper concludes that while the industry should not be complacent, it does contribute significantly to sustainable development but is perhaps not a strong marketer in publicising its achievements.

The views expressed in this paper are those of the author and do not necessarily reflect the view of CEMEX UK Materials Ltd.

KEYWORDS


INTRODUCTION

Concrete is consumed in vast quantities throughout the world to shape the built environment. Only water is consumed more. Concrete has shaped housing, schools, industry, water supplies, roads and bridges.

Ready-mixed concrete is produced under factory controlled conditions and third party quality accreditation in over 1100 local plants across the UK. Today’s ready-mixed concrete is a modern construction material offering factory quality assurance, exact quantities, minimal waste and tremendous flexibility in construction.

The concrete industry, however, operates in a tremendously dynamic environment. A simple Porter’s Five Forces exercise, would demonstrate that in the UK there has been significant industry consolidation. The regulatory burden is ever-increasing through safety, health and environmental requirements. Substitute product industries such as steel and timber are investing significant sums in marketing campaigns. Furthermore, Government is advocating Modern Methods of Construction (MMCs) and off-site manufacture.

This paper seeks to examine the health of the concrete industry and in particular evaluates the association between concrete and sustainable development. In doing so it will be explored from a ready-mixed concrete perspective and because of the number of issues involved a ‘helicopter’ perspective will be taken.

SUSTAINABILITY DEVELOPMENT AND THE ROLE OF CONCRETE

Sustainable development involves meeting present needs without compromising the ability of future generations to meet their needs or leave lasting problems. At face value therefore, it might be difficult to see concrete’s role in sustainable development. The concrete industry utilises cement in large quantities, a significant contributor of carbon dioxide emissions. Furthermore, the industry harvests large quantities of virgin aggregates.

The industry has, however, made tremendous inroads in contributing towards sustainable development and the presentation of this paper will follow the simplistic model illustrated in Figure 1.

THE PROPERTIES OF CONCRETE AND SUSTAINABILITY

The thermal capacity of concrete (sometimes called thermal mass or fabric energy storage), enabling it to absorb, store and later radiate heat, is well documented. In all buildings, heat is generated by people, computers, equipment, lighting and solar gain. Buildings therefore have a tendency to overheat during the warmer months of the year. Exposed concrete can absorb this heat, and daytime temperatures can be reduced by 3° to 4° C, while peaks in temperature can be delayed by up to six hours. At night ventilation is used to cool the concrete, priming it for the next day.
Some 90% of the total energy used in buildings is for heating, cooling and lighting. Employing the thermal mass of concrete gives the opportunity to reduce or even eradicate energy-intensive air conditioned, while maintaining a comfortable temperature for occupants.

The durability of concrete allows for whole buildings to be refurbished and reused. A concrete frame structure can be stripped back to its frame for redesign and refurbishment. Concrete elements from one building can also be reused for another application in a new building. For example, concrete piles and foundations have been reused within new build design, avoiding landfill and transportation costs, whilst cutting the time and cost of project delivery[2].

Furthermore, concrete from site demolition can be reprocessed for recycling and reused as aggregate in a new development.

The United Kingdom Government has developed a strategy for sustainable development and has committed to reduce greenhouse gas emissions by 12.5% by 2012 under the Kyoto Protocol. Furthermore, it has set its own target of a 60% reduction for the period 1990 to 2050.

Figure 2 illustrates that the environment impacts embodies in the manufacture of cement and concrete are approximately % of UK totals. It can be seen however that the operation and use of buildings tends to have a significantly greater impact on the UK’s environmental performance.

**IS THE PRODUCTION OF READYMIX SUSTAINABLE?**

The ready-mixed concrete industry has made a significant contribution towards sustainability although it is probably under-publicised its environmental credentials. Materials and production aspects will be discussed in the following sections.

**Cements and cement additions**

The ready-mixed concrete industry in the UK typically utilises two cement additions, pulverised fuel ash (pfa) and ground granulated blastfurnace slag (ggbs). Fly-ash is a pozzolanic by-product of the burning of pulverised coal in thermal power plants. Ggbs is a by-product of iron manufacture.

The industry produces some 24 million cubic
metres per annum consuming 6000 kt of CEM I to EN 197[3], 1800 kt of ggbs and 400 kt of pfa.

The industry differs somewhat from the practice in other European countries because it is commonplace for both ggbs and pfa to be combined at the ready-mixed concrete producer’s plant. Factory blended cements are however becoming more widely used. Figure 3 illustrates the wide-scale use of cement additions in the UK.

The average ratio of tonnes of carbon dioxide produced per tonne of cement clinker is significant. Approximately one tonne of CO₂ is released in the production of a tonne of Portland cement. The average clinker content of CEM I cement is considerably higher than a factory blended CEM IIB-V for example. In simple terms therefore, conversion from CEM I to CEM IIB-V could save some 0.2 t CO₂ per tonne cement

The incentive for converting from CEM I to factory blended production is therefore an important step in the drive to:

- Reduce CO₂ emission per unit product produced
- Maintain the drive toward sustainability in the cement sector through minimising emissions of CO₂ and its contribution to climate change.

Concretes made with fly-ash and ggbs in conjunction with hydraulic cement have improved hardened concrete properties through hydraulic or pozzolanic activity[4]. The benefits, particularly in terms of their influences on durability are well recognised. Concretes manufactured with both pfa and ggbs will, in comparison with an equivalent or even higher concrete grade made with CEM I, exhibit a reduction in the permeability to liquids and gases, a greater resistance to penetration by ions such as sulfates and chlorides and an improvement in the phase composition of hydration products, providing they are effectively cured[5].

Furthermore, the rate of heat evolution associated with blended cements is reduced as the blend level is increased. In mass pours, this permits greater heat dissipation, reducing thermal gradients, thermal strains and the risk therefore of early thermal cracking[6].

Figure 3: Consumption of cement additions in UK

1 Under the European Union Emissions Trading Scheme (EU ETS), each installation is given a free allocation of CO₂ that is based on historic emissions minus adjustments to accord with the cement sector’s share of the UK National Allocation Plan (NAP).

The UK National Allocation Plan was determined by Government and states the total CO₂ emission for the UK for installations that hold Greenhouse Gas Emission Permits. The National Allocation is therefore a cap on emissions.

Conversely an installation that emits less than its allocation can make the CO₂ available for others who has exceeded their allocation to buy.

This is the core principle of emissions trading. It is basically a ‘polluter pays’ principle. Those that are inefficient are likely to have to purchase CO₂ from those that are more efficient. Any surplus could be traded on the EU ETS market.
Recycled and Secondary Aggregates

The United Kingdom uses approximately 270 million tonnes of aggregate in construction every year. About a quarter of this aggregate is produced from recycled and secondary sources. The use of recycled and secondary aggregates has doubled since 1989 and these sources are expected to increase still further in importance to meet future aggregate demand.

The growth in recycled and secondary aggregate use has been driven by a number of factors. These include:

- Political encouragement (Department of the Environment, 1995)
- Landfill tax and a levy on natural aggregates
- The adoption of sustainability objections by materials companies
- More enlightened specifications for aggregates, asphalt, concrete and unbound mixtures.

Indeed, Lay[7] posits that aggregate extraction probably fits the criteria for sustainable development, although there is no room for complacency. Lay also warns however that The Waste Framework Directive[8] can add a burden of regulation and cost to recycled aggregate manufacture and use.

From a ready-mixed concrete perspective Standards have anticipated demand for recycled aggregates (RA) and have opened the door with respect to their use. For sound technical reasons however there are limitations placed on RA. The reuse of these materials on, or near, the site where they were generated will bring environmental benefits. Where they have to be transported a significant distance, however, they may not be the most environmentally or economically sensible solution as shown in Figure 2, although their use will minimise waste and reduce use of natural resources. This also illustrates some of the complexity associated with the concept of sustainability, in that benefits in one factor or area can be detrimental in another.

Concrete specifications

Both BS EN 206-1[9] and BS 8500[10] recognise and encourage the use of ‘recovered’ and ‘recycled’ aggregates in concrete. Recovered aggregates are defined as aggregates recovered from wash water or fresh concrete. Recycled aggregates (RA to BS 8500-1, 3.1.10) result from the reprocessing of inorganic material previously used in construction. Recycled concrete aggregate (RCA to BS8500-1, 3.1.II) comprises primarily crushed concrete.

While some requirements for coarse RA are specified (RA 8500-2, Table 2) they are insufficient to form an adequate specification. As the potential composition of RA is highly variable and so the additional specification requirements should be assessed on a case-by-case basis taking into account the specific composition of the RA in question.

The approach to recycled aggregates adopted in BS 8500-2 allows all potentially available materials to be reused. In other words this British Standard ensures that there are no technical barriers to the full use of recycled aggregates. However, care must be taken to use recycled aggregates from a source suitable for the new development in question.

The role of the minimum cement content criterion in the specification of concrete has served the industry well. Recent research[11] suggests however that the important parameter in achieving durable concrete is water/cement ratio (w/c) and not minimum cement content. Indeed Dhir et al[11] observe that specifying a maximum w/c ratio, will, when linked to the water demand, lead to a de facto minimum cement content.

It is appropriate at this time therefore, to review the role of minimum cement content because prescriptive, onerous minimum cement content criteria will disadvantage the concrete industry, in terms of cost and environmental issues.

In the long term the fib Model Code for Service Life Design[12] may well negate the need to specify by minimum cement content. It will be a more environmentally sound way of specifying because materials will be judged on performance in specific exposure conditions.

Ready-Mixed Concrete Production-Towards Zero Waste

The rising costs of water and waste disposal costs has led to progress in reducing waste water discharge across the ready-mixed concrete industry’s production facilities. A number of systems are therefore employed. In the UK for example, CEMEX primarily uses automated batching systems to batch efficiently and secondary utilises stone washing systems, chemical wash waste systems and aggregate reclaim systems to minimise wash waste.
**Water**

Many ready-mixed concrete producers utilise recycled water, extracted from their production operations. Furthermore the extensive use of water-reducing admixtures typically facilitates water reduction of around 10%.

**RCA – An example**

CEMEX has, for example, been recycling waste concrete at its East Manchester operation for a number of years. CEMEX’s plant in Greater Manchester feeds the East Manchester plant with returned concrete. CEMEX is aware of the provenance of this material in terms of its original constituents. Mobile crushing plant is employed to reprocess the returned hardened concrete. The reprocessed material is highlighted in Figure 4.

The reprocessed material is currently being used in ‘green’ collect concrete and lower grade strength concretes.

**Social Engineering**

The cement, concrete and concrete aggregate industries directly employ approximately 40,000 people and form part of the construction industry, which employs 7% of the UK workforce. The industries take their stakeholder relationship very seriously and endeavour to be good neighbours in their interactions with local communities.

**INNOVATION**

There are many ways in which the concrete industry has embraced innovation and advocated modern methods of construction.

In terms of innovation, this paper considers three areas, innovation in logistics, innovation in concrete technology and innovation in concrete systems.

**Innovation in logistics and ideas from yesteryear**

Ready-mixed concrete producers seek to optimise their logistical operations by seeking innovative solutions to minimise the environmental impact of transport movements.

For example, the first major freight to travel through Gloucester’s Historic Docks in over 30 years by barge occurred recently and was facilitated by British Waterways. CEMEX who operate this service has recently commenced deliveries of gravel by barge through Gloucester Docks on its journey from CEMEX’s processing plant at Ryall, in Worcestershire, to its concrete plant south of Gloucester.

The journey symbolises the return of major barge freight activity to the heart of Gloucester and brings significant benefits to the area, including: reduction in road traffic; less fuel consumption; lower carbon dioxide emissions; visually unobtrusive and a quiet means of transport.

A 380-tonne barge travels twice a week covering a distance of 14 miles. Each barge journey by water will take 20 lorry loads off the roads of Gloucestershire and Worcestershire.

Furthermore, commercial barges are now a
familiar sight on the River Severn in Worcestershire transporting aggregates between Ripple quarry and the handling facility at Ryall.

Since February, two 200-tonne capacity boats have been making seven trips a day on the two-mile run (Figure 5). It is the first major freight traffic to flow on the waterway for many years.

The switch to canal transport follows a £1 million freight facilities grant from the Department for Transport. New wharves have been built at both sites to handle the freight traffic, which is expected to cut 340 000 lorry journeys over the next decade.

In addition, cement has been delivered by river to a number of CEMEX Readymix plants for several years.

Furthermore, ready-mixed concrete producers are seeking where possible to take deliveries of aggregate and cement at night, again to minimise environmental loadings. In 2005, the ready-mixed concrete industry took delivery of several hundred thousand tonnes of cement and cement additions between the hours of 6pm and 5.59am. Finally a number of CEMEX’s plants have been fitted with ‘smart-silo’ technology to ensure flexibility in cement deliveries.

**Innovation in Concrete Technology**

There has been significant innovation in concrete technology in recent years. Advances have, however, tended to be admixture centric. Innovation in superplasticiser technology for example has led to the development of polycarboxylic ethers, which promote hydration whilst providing a neutral set. Self-compacting concretes (SCCs) in particular have benefited.

Furthermore, in terms of innovation more concrete technologists are making more use of rheological techniques in determining the performance of new concretes.

**Rheological developments – SCC’s and Slipforming**

The rheological requirements of self-compacting concretes are well documented[13]. The two main requirements are for a highly fluid material which has significant resistance to segregation.

To achieve a highly mobile concrete, a low yield stress is required and for a high resistance to segregation, tightly controlled viscosity and cohesion. If a material requires an external stress to be applied to cause the structure to yield and consequently flow, this stress is known as the yield stress.

Water can be added to decrease the yield stress, but unfortunately this addition also lowers the viscosity, whereas the addition of a superplasticiser will also lower the yield stress and will only lower the viscosity slightly. The viscosity of a mix can be increased by changes in mix constituents or the addition of a viscosity modifier, but this will increase the yield stress of the paste. Thus, it is desirable to find a happy medium between the two parameters. Figure 6 describes the relationship between shear rate and shear stress for a range of concretes.
Similarly, CEMEX has established four key rheological criteria for slipforming concretes, i.e., plastic viscosity (and viscosity profile), yield stress, cohesion and plastic limit. The qualitative stress against shear rate relationship for three different concretes is shown in Figure 7.

Successful slipform concrete enables a finish profiled concrete to be produced in a single process. This again places specific rheological demands on the concrete.

Fowler[13] posits that the plastic viscosity of structured materials is not constant and that viscosity varies with shear rate. For slipform operations, the plastic viscosity must remain stable across the vibration frequency range as well as delivering a polished smooth finish out of the mould.

Slipform concrete requires a tightly controlled high yield stress as flow and compaction are required at 40 000 Hz equivalent vibration but needs to be rigid under its own mass whilst subject to gravity.

Cohesion and plastic limit is also important to stability and finishability. Cohesion levels must be high to enable the paved profile to be retained and the surface to remain smooth upon polishing. It must not sag or collapse which occurs when the cohesion limit has been exceeded.

Consequently, in order to meet these exacting requirements the cement type and content, sand, aggregate shape and grading and admixture type and dose are all critical.
Innovative Systems

In terms of innovative concrete systems, it is acknowledged that a whole myriad of are worthy of mention, e.g., tilt-up construction, concrete basements, pervious concrete, insulated concrete formwork, slipforming et al. For brevity a limited number have been chose for discussion.

Insulated Concrete Formwork

Insulating Concrete Formwork (ICF) systems use forms made of rigid construction or combinations of insulation and concrete that remain in place after the concrete hardens to form part of the finished wall. See Figure 8. Whilst they have primarily been used for residential construction their use in other commercial applications is becoming more widespread because their cost is comparable with other construction systems.

Furthermore, they are now recognised as a modern method of construction and can deliver eco-excellence in terms of residential construction.

Slipforming Concrete Barrier

Owing to the number of fatalities caused by crossover accidents on the motorway network, the Highways Agency has acted.

The Highways Agency will shortly be publishing TD 19/06. All Motorways with traffic densities of 25 000 vehicles/day will have central reserve of rigid concrete safety barrier to a minimum of H2 containment (13 000 kg). See Figure 9. This is a major increase from the current N2 containment (1500 kg).

Basements

Land availability in the UK is in decline while its cost has been steadily rising in the UK. The introduction of a modern concrete basement offers improved land utilisation, no overall change in the height of the building and potential energy savings of 10%, whilst providing a flexible living space. The benefits of modern concrete basements are shown in Table 1.

The Concrete Centre and the Basement Information Centre supported by the BRE and ODPM intend to introduce an approved basement contractors list with quality assurance and insurance backing in 2006. It is anticipated that this will assist in the take-up of concrete basements by the house-building fraternity.

Pervious concrete

In the USA, concrete in the guise of pervious concrete is a feature of storm water management systems limiting the disruption of natural water flows by eliminating storm water run-off, increasing on-site infiltration and eliminating

Figure 8: Pouring ICF
contaminants. Pervious paving can be used either to recharge ground water or to store storm water allowing water to percolate through, filter contaminants and recharge the water system.

Pervious concrete is an example of incremental innovation and is ostensibly a development of no-fines concrete. A no-fines pavement is placed over a highly permeable layer of open-graded gravel and crushed stone.

**CONCLUSIONS**

In conclusion, the ready-mixed concrete industry has and is continuing to contribute towards sustainable development and this paper has examined some of the initiatives from storm water management, use of local and regional materials, recycling initiative, minimising energy use, thermal properties and eco-excellence, and use of cement additions. Perhaps the industry is guilty of under-playing its role in contributing towards a more sustainable environment for us all.

Furthermore, perhaps the wrong question was explored in this paper. How sustainable is concrete? Well how sustainable is a world without it?

<table>
<thead>
<tr>
<th>Homeowners gain:</th>
<th>Developers gain:</th>
<th>The environment gains:</th>
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<tr>
<td>More living space</td>
<td>Better utilisation of building land</td>
<td>Reduced energy demand</td>
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<tr>
<td>Enhanced property values</td>
<td>Improved use of sites with difficult ground</td>
<td>Decreased use of insulation materials</td>
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**Table 1: The benefits of basement construction**

![Figure 9: Extruded concrete safety barrier](image)

![Figure 10: An example of pervious concrete](image)
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Tom De Saulles is the Building Sustainability Manager at the British Cement Association, specialising in energy use in buildings, particularly the application of passive heating and cooling techniques. Tom previously spent ten years working for the Building Services Research and Information Association (BSRIA), where he researched and compiled a number of publications for the construction industry including illustrated guides on building services systems and design guidance on free cooling. He is a chartered building services and mechanical engineer, and is currently compiling a thermal mass design guide.

**ABSTRACT**

This paper discusses the various issues and techniques that relate to the application of high thermal mass exposed concrete floor slabs in commercial office design. It also considers the relative difference between the embodied CO₂ of concrete and the in-use savings in CO₂ which it can provide through operational energy savings.

**KEYWORDS:**

Thermal mass, Mixed-mode, Thermal linking, Coffered slab, Embodied CO₂, Overheating, Night cooling, Diurnal temperature, Floor plenum, Free cooling, Ground water.

**INTRODUCTION**

The case for using thermal mass in office design is now stronger than ever, and is supported by a wide range of techniques that exploit the excellent thermal properties of concrete floor slabs. These range from the simple combination of an exposed slab and night ventilation, to the relatively new approach of using water to regulate slab temperature. The increasing use of thermal mass for passive cooling is largely being driven by a combination of rising energy prices and the need to build more sustainability to help mitigate the rapid onset of climate change, whilst also adapting to the impact of rising temperatures. Despite the benefits that concrete has to offer in terms of thermal mass, there is often a reluctance to specify concrete due to a perception that its embodied impacts are more significant than its energy saving potential. However, new research commissioned by The Concrete Centre/BCA and undertaken by Arup has shown that the opposite can be true providing the thermal mass is effectively utilised.

**THE ARCHETYPAL OWNER-OCCUPIED HIGH THERMAL MASS OFFICE**

Over the last two decades the UK has experienced significant growth in the demand for air-conditioned offices, typified by the ubiquitous speculative development, incorporating variable air volume (VAV) or fan coil systems. However, the 1990s also saw some of the larger owner/occupier construction clients opting for a night-cooled, high-mass solution when procuring a new headquarters or other high profile building. These low energy concrete frame buildings share many similar features, suggesting that they have, to a large extent, achieved an optimal design solution. This type of development has proved to be very successful and continues to be built today; however, the design techniques they employ have largely failed to transfer into the more mainstream speculative office market. To some extent, this is starting to change as tenants consider more carefully the running costs of highly serviced buildings and their desirability if it becomes necessary to sublet the property. The challenge for developers and designers is to apply the lessons learned from existing prestigious owner-occupied high thermal mass buildings into the commercial market, whilst maintaining the essential building requirements that tenants expect.

The owner-occupied offices mentioned above use a combination of thermal mass and night cooling as an alternative to mechanical air-conditioning. In addition to providing reduced operating costs and a good working environment, the typical client brief also required demonstrable evidence of their organisation’s ‘green’ credentials. In meeting these needs, a popular solution was, and continues to be, a concrete-frame building with exposed soffits.
capable of providing a high level of thermal mass. Night cooling is used to purge heat built up in the slab during the day, ensuring a relatively stable internal temperature during hot weather; a technique that is well suited to the relatively high diurnal temperature swing experienced in the UK.

Typically, the form of these buildings is characterised by long narrow floor plates, usually with a central atrium to allow a high rate of natural ventilation and good daylight penetration. This configuration has proved very successful and has become a standard approach for this type of building. The floor slabs, which may be either cast in situ or precast are typically coffered, and are a key component in the design, since they help fulfil the functional, structural, aesthetic and acoustic requirements of the brief in a single element. In comparison to a flat slab, the formation of coffers or other profiled finish can approximately double the surface area and enhance overall heat transfer by up to 25%. The shape of the coffer is also designed to improve the acoustic performance of the office by focussing noise onto acoustically absorbent wings that form part of the suspended light fittings located below each coffer. Typical, a peak temperature reduction of around 3ºC can be achieved over a 24-hour cycle[1]. Slab thickness is usually between 200 and 300 mm, which provides sufficient heat capacity to help prevent overheating during extended periods of hot weather. The combination of exposed concrete soffits with a natural ventilation night cooling strategy can offset heat gains of approximately 20 W/m² providing the diurnal temperature swing is at least 5ºC [2]. The increased surface area provided by forming coffers or troughs can increase this to 25 W/m².

To date, these high thermal mass offices have largely been the preserve of the owner/occupier construction client, whose design brief reflects their intention to operate the building over a relatively long period, thus making steps to reduce operating and business costs a worthwhile investment. At the other end of the market, property developers and investors such as the large insurance providers, generally opt for safe, low risk designs which can be easily let and provide a short payback. A belief that sustainable construction is prohibitively expensive has generally acted as a barrier to its uptake. However there is evidence of a change in this sector which includes projects such as the National Trust HQ in Swindon, Plantation Place in London and Belvedere Court in London[3]. Other examples of concrete frame, high-mass speculative office developments include Number One, Leeds City Office Park and the Addison Wesley Longoman office in Harlow[4].

**BRINGING THERMAL MASS INTO MAINSTREAM OFFICE DESIGN**

Monitored data and occupant feedback from several owner/occupier high mass offices provides good evidence of their relatively low energy consumption and comfortable internal environment[5,6,7,8]. The general success of these buildings in meeting their brief is not in question and they will no doubt continue to be built throughout the UK. However, the challenge remains one of transferring and adapting the technology into a speculative office context, and finding practical design solutions that meet the operational and financial demands of this market. In addition to the technical challenges, there is also the issue of occupant control, which is a major factor in the success of high thermal mass buildings, especially those that use natural ventilation. For individuals used to playing no part in the control of their environment, it is vital that they understand the design intent of their office and the impact that their actions can have on comfort and energy use. This requires more than a 10-minute briefing, and is an important part of the handover process. In many ways this is harder for the tenant of a speculative office who, unlike owner/occupier organisations, is unlikely to have had any involvement in the design process and may have a lower threshold of commitment in helping ensure the building functions as intended. For this and other practical reasons, it may well be that the design is less reliant on natural ventilation which typically requires a high degree of occupant control, and favours instead mechanical ventilation or water cooling of the floor slabs. This and other technical design issues are examined in the remainder of this paper.

**Ceiling voids**

A major barrier to the uptake of thermal mass is the use of suspended ceilings to conceal services and located luminaries, etc. Whilst this is a convenient solution for the speculative office market, which requires flexibility and convenience, it is largely incompatible with passive design. Permeable ceilings provide a compromise solution by allowing a degree of thermal linking between the room air and slab. An open area of 20% is about the maximum that can be used if the slab is to remain hidden[9].
Thermal performance of permeable ceilings varies with the type of slab, ceiling tile and percentage of open area. Research undertaken by Oxford Brooks University suggests that an open area of 20% will allow about 40% of the convective heat transfer that would occur with a fully exposed slab\[9\]. However, the use of perforated metal tiles with the acoustic backing removed, does allow some heat to be absorbed and re-radiated, thus increasing the radiative heat transfer. Permeable ceilings therefore offer a compromise where the services cannot be moved and/or profiled metal decking needs to remain hidden from view.

Multi-service chilled beams offer another means of exposing the slab, by offering a convenient and neat solution for locating ceiling services and providing the additional cooling capacity sometimes required in more challenging environments. The beams are directly suspended from the underside of the slab, and can also be designed to incorporate sound-absorbing panels to deal with sound transmission problems that can occur.

**Mixed-mode ventilation and air conditioning**

The use of a mixed-mode (natural and mechanical) ventilation solution has proved to be a popular option in the owner/occupier high thermal mass office, as it provides greater overall control of ventilation and internal temperature. The need for a mixed-mode solution is likely to be even stronger for the speculative office market, which does not generally have the benefit of green field sites and atrium-enhanced natural ventilation. Additionally, the noise and security issues that can result from openable windows may preclude the use of natural ventilation alone, especially in urban environments. It is also likely that any passive cooling strategy used in a commercial office will be supplemented by mechanical air conditioning to ensure overheating is avoided during very hot weather. This approach has been used at a number of owner occupied buildings including the RSPCA headquarters in West Sussex.

**Floor voids**

Whilst ceiling voids present a challenge in high thermal mass office design, floor voids are generally beneficial, which is fortunate since exposing the slab will require an alternative location for routing the displaced services. For buildings with mechanical ventilation, the floor void also provides a convenient means of introducing air into the office space via floor-mounted outlets. The void acts as a plenum to distribute the air, allowing some heat transfer between the air and the top of the slab, with the added benefit that less ductwork is required. Where heat transfer is optimised by creating turbulence in the void, it is possible to increase the convective heat transfer, to around 10-20 W/m²K\[10\]. The actual rate of heat transfer depends upon achieving a balance between the mean speed of motion of the air and the time it spends in the floor void without incurring excessive fan gains. This requires the floor diffusers to be adequately balanced. One way of achieving this is to divide the floor void into approximately square compartments, each containing several diffusers, and supplying each compartment via a damper linked to a central plenum duct running across the floor\[10\].

The use of floor voids for fresh air distribution and supply is an established technique and is not a barrier for the use of thermal mass in commercial office design. It does, in fact, offer a number of advantages over ceiling based systems including\[11\]:

- A reduction in the resources required to construct the building
- The ability to provide a high proportion of fresh air to the occupants
- Lower maintenance and churn costs
- Lower energy consumption.

**Cooling loads**

A naturally ventilated high thermal mass office will provide comfortable conditions for environments with a modest cooling load and good solar control. More demanding applications may require the increased performance provided by mechanical ventilation. This can increase the cooling capacity from 25 to 35 W/m²\[12\], due to the improved convective heat transfer, typically achieved by the use of the floor void as an air supply plenum. A higher performance of 40 W/m² is possible using hollow core slabs with forced ventilation, otherwise referred to under its trade name of ‘Termodeck’. This has proved to be a popular system in the UK, with around 50 installations to date. Typical applications include university and school buildings, to which it is ideally suited, and has resulted in the exceptionally low energy Elizabeth Fry Building at the University of East Anglia. This 4-storey building has a gross floor area of 3250 m², and a total energy consumption of approximately 60
112 kWh/m²/y \[13\]. So far, Termodeck has not proved popular for commercial offices, which is largely due to perceived flexibility issues.

Using water to cool the slab provides the highest cooling capacity. This technique uses polybutylene pipes embedded in the slab, through which water is circulated at 14°C - 20°C during the summer, providing a maximum cooling capacity of approximately 65 W/m². During the winter, a flow temperature of 25°C - 40°C can be used to provide heating. In bespoke systems the pipe work is positioned as required and attached to the reinforcing, which keeps it in place when the concrete is poured. Alternatively, water-cooled slabs can be supplied as precast units known in the UK under the trade name of ‘Thermocast’. This option has the advantage of enabling pipe work to be tested under factory conditions before dispatch. The coffered slabs can be made in spans up to 13 m in length, and can be used in steel frame or in situ structures. A conventional chiller can be used to supply water during the summer which, due to the high flow temperature, can be configured to make good use of free cooling\[14\]. Alternatively ground or lake water can be used, although care needs to be taken with the latter option, which can prove to be too warm during the summer for effective cooling\[15\]. The use of ground water is an increasingly popular option in London for all types of office, including a recent speculative development\[3\]. The reasons for this include the space saved by avoiding the need for heat rejection plant, and the relative ease in obtaining an extraction licence, helped by a rising water table.

**Operational and embodied CO₂ in high thermal mass concrete buildings**

Despite the benefits that concrete has to offer in terms of thermal mass, there is often a reluctance to specify it due to a perception that its embodied impacts are more significant than its energy saving potential. Whilst the embodied CO₂ of concrete can be higher than that associated with alternative materials, in many cases the difference is relatively small, and becomes largely insignificant when compared to the savings in operational CO₂ emissions that thermal mass can provide during the life of a building. Designers often fail to recognise this point, tending instead to focus purely on the embodied impacts of construction materials.

In reality, the slightly higher embodied impacts of concrete and masonry products can be offset in relatively few years of operation providing effective use is made of the thermal mass to minimise the energy used for cooling (and in some cases heating as well).

To fully validate this argument the concrete sector commissioned Arup to compare the embodied and operational CO₂ emissions of a simple semi-detached house built using a lightweight frame and also in a traditional masonry format with concrete walls and floors, providing varying levels of thermal mass. The result showed that there is a slightly higher embodied impact in the masonry construction, but that this can be offset in approximately 11 to 25 years (depending on the level of thermal mass) if the thermal mass is used to optimise energy use in summer and winter\[16\]. The thermal modelling undertaken used real weather data, modified to take account of the UKCIP02 climate change scenario, which reflects the most likely changes to UK weather over the 21st century.

Beyond the point at which the additional CO₂ burden in masonry construction is offset, the total CO₂ emission (embodied and operational) becomes less than that of the equivalent low thermal mass version of the dwelling. In other words the whole life CO₂ impact of a masonry house can be lower than an equivalent low thermal mass house if the benefits of thermal mass are exploited.

Whilst the research focused on dwellings, it seems likely that a favourable result may also be achieved with other types of building especially offices, which are likely to experience greater benefits in the summer, and less benefit in the winter since passive solar design is not as relevant.

**CONCLUSIONS**

The combination of high thermal mass and night cooling is a key technique in the field of sustainable building design, and is set to play an important part in helping commercial office design adapt to the effects of climate change, rising energy prices and more demanding building regulations. It can also contribute to the long-term value and usability of these buildings, ensuring a good return on investment in a commercially driven market.

For many office developments, it looks likely that thermal mass will be combined with mixed mode ventilation, and may possibly be
supplemented by air conditioning. There are a number of reasons for this including the need for enhanced cooling performance in more demanding office environments, and the need to overcome issues relating to security, noise and the general letability of buildings. The trend towards the use of urban and brownfield sites may also exacerbate noise and security issues.

Whilst the current focus in sustainable construction is largely centred on the embodied impacts of construction materials, it can be shown that the in-use benefits of thermal mass can offset the higher embodied CO₂ associated with concrete in a relatively few years. This highlights the need to take a more holistic approach to building design, which considers both embodied and in-use impacts during the life of a building.

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Martin Clarke is the Chief Executive Officer of British Precast and was formerly the Director of Marketing for the British Cement Association.

**ABSTRACT**

This paper looks at the external pressures on the precast sector to become more sustainable in all respects. It reviews the response of the sector to date through British Precast and its product groups, using precast flooring as a case study. The paper includes a review of the Be Aware project launched in 2006 to minimise waste in factories and on site.

**KEYWORDS**

Precast, Sustainability, Sector strategy.

**INTRODUCTION**

I am pleased to present this report from British Precast on the precast sector’s progress on sustainability – highlighting our ‘More from Less’ programme. In this and future reports we will set out the sustainability issues for our industry, our commitments to tackling those issues, and chronicle our progress. We are doing this because the choices on sustainability are simple: be proactive and reap the benefits, or ignore it and suffer the consequences.

I believe that a more sustainable approach is the key to the future of the precast industry; an industry that produces more outputs from fewer inputs, has more profitable operations at less cost, is more efficient with less waste, and has more trained staff with fewer accidents.

**WHY SUSTAINABILITY MATTERS**

Sustainability is about ensuring that development meets the needs of the present without compromising the ability of future generations to meet their own needs. It covers a wide range of issues, including:

- Social progress that recognises the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment

Many governments, international bodies and multi-national corporations have realised that it is no longer simply desirable to address these issues, but it is now essential, in order to ensure future growth. Business analysts are reporting that those industries and companies that are really improving their performance on sustainability issues are reaping the benefits of growth and investor confidence, whilst those that are not are being left behind.

There is another compelling reason to address sustainability. The Government published its strategy for sustainable development in 1999, setting out ten guiding principles to its policies that would encourage a more sustainable approach to all aspects of life. In the 2005 revision of this strategy, it is clear that where measures to enable and encourage changes in behaviour are not sufficient to change entrenched habits, ways to catalyse change will be introduced. Industry can therefore be assured that it needs to take sustainability seriously, or it will face an increasing amount of social and environmental legislation in the future.

**THE PRECAST CONCRETE INDUSTRY**

The precast concrete industry is an important national industry producing over 35 million tonnes of products annually for the construction sector, worth in excess of £2 billion. There are around 800 precast factories located across the UK, which provide direct employment for 22 000 people and many more in upstream and downstream sectors.

Precast concrete products make a significant contribution to the built environment; they are widely used in public and private sector projects of many sizes, from housing and landscaping, through commercial buildings to highways and infrastructure.

Precast products are made to consistent high quality standards using a combination of skilled labour and automated processes. Mass produced
products range from small hydraulically pressed items such as concrete bricks, paving and roof tiles, to larger extruded or wet-cast items such as pipes, piles and floor beams. Bespoke items include large wet-cast products such as cladding panels and structural units designed and manufactured to specific architectural and engineering requirements.

**BRITISH PRECAST**

British Precast is the trade federation for precast concrete manufacturers in the UK. Founded in 1964, its federated structure acknowledges that the precast sector is, in fact, a matrix of industries, each with its own characteristic markets and supply chains, technologies, standards and lobbying issues. British Precast exists to manage this matrix through a number of product groups and associations, each with its own agenda and devolved budget. Spanning all product areas are a number of overarching issues common to all members. The management of these issues – research, building regulations, design codes, health and safety, training, government relations and sustainability – is the other role of British Precast and is growing in its importance. Increasingly sustainability is becoming the supreme consideration.

**OUR PROGRESS ON SUSTAINABILITY**

Making progress on sustainability is about continuously improving economic, social and environmental performance, regardless of whether the subject is a country, industry, company or factory. British Precast is actively encouraging better performance in the precast industry, ensuring that our members continue to prosper, but at the same time protecting the industry’s workforce, reducing its reliance on non-renewable resources and ensuring that its products are the best performing when developing sustainable communities.

Our progress to date includes:

- 1999: Environment and Health & Safety committees formed to provide a pan-sector approach to these important issues
- 2001: Concrete Targets Award scheme announced to improve health and safety across the industry
- 2002: Best Practice Awards started in order to recognise and promote excellence amongst the membership in the areas of innovation, health and safety, and environment (now sustainability)
- 2002: British Precast joins the DEFRA and DTI Pioneers Group to signal its willingness to develop a sector sustainability strategy applicable to the precast industry
- 2003: British Precast’s governing council agree to support a research project with Loughborough University to develop a sector sustainability strategy
- 2004: Environment Committee becomes the Sustainability Committee, with issues such as corporate social responsibility and community relations now included in its remit
- 2004: Sector Sustainability Strategy Project started (see later for details)
- 2005: Concrete Sector Sustainability Working Group set up to facilitate a joined up approach to sustainability from the cement and concrete industry
- 2005: Launch of Concrete Targets 2010 safety scheme. As a sector our aspiration is a zero accident, zero lost-time industry. Having achieved a 45% reduction in four years, this new phase calls for a further 50% reduction in the next five years.

Work also goes on behind the scenes with British Precast staff and representatives contributing to initiatives such as the Code for Sustainable Homes and the review of the Government’s strategy for sustainable construction, which will affect the whole construction industry.

**OUR COMMITMENT TO SUSTAINABILITY**

British Precast is committed to the development of a more sustainable precast industry and is working to deliver on that commitment through its committees, Best Practice Awards and the Sustainability Strategy Project. But we cannot achieve it without the commitment and participation of our members, for which I thank them. I would also encourage all non-members to join British Precast, to commit their support and make sustainability their number one business issue.
TOP 10 BUSINESS ISSUES IN THE PRECAST INDUSTRY

An industry survey in August 2005 identified profitability and competitiveness to be the top business issue for the precast industry. A workshop held at Loughborough University in September then identified ten further issues that contributed to this; these are briefly explained below.

Profitability & Competitiveness
- Health & Safety – The costs associated with legal compliance and lost time are increasing
- Employment – The recruitment and retention of skilled staff is becoming a problem in some areas
- Supply Chain – We are being affected by poor payment practices and increasing transport costs
- Social/Community – Our manufacturing sites and processes can affect local communities and environments
- Resources – We need to reduce our water consumption and use primary materials
- Market Image – Precast concrete is not yet seen as ‘green’ despite its good whole life performance
- Legislation – An increasing amount of complex and constantly changing legislation is affecting every part of our business
- External Threats – We are facing unequal comparisons and taxes with respect to other materials and imports
- Waste – The rising costs and restrictions on waste disposal are increasing the pressure to recycle and reuse
- Energy – The need for more efficiency is increasing as energy costs rise.

SUSTAINABLE SOLUTIONS

The precast industry, through British Precast and the efforts of individual companies, is already implementing solutions to improve its sustainability. The profitability and competitiveness of the industry is intrinsically linked to its sustainability. However, we are more advanced on some issues and in certain parts of the industry than in others, and still have many challenges ahead.

Sustainability
- Health & Safety – A reduction of 45% in accidents has been recorded over the last 4 years. New sector safety award scheme Concrete Targets 2010 launched in December 2005
- Employment – Proskills licensed as the Sector Skills Council for the precast manufacturing sector. British Precast announces formation of a sector Training Committee
- Supply Chain – Companies are rationalizing their logistics networks. Fuel efficient driver training underway. Load stability research programme with HSE
- Social/Community – Companies are initiating local community relations projects. Biodiversity schemes underway where feasible
- Resources – Investment in water recycling and treatment plants. Introduction of robotics to increase productivity, improve occupational health and quality
- Market Image – Introduction of British Precast Best Practice awards for safety, innovation and sustainability. Promoting success stories and best practice through product group channels
- Legislation – British Precast works continually through the CPA. Major effort to improve standards, codes and building regulations
- External Threats – Partners in Carbon Trust funded project to ensure fairness in LCA comparisons. Regular exchanges on competing materials claims and actions internationally
- Waste – Companies are cutting waste to landfill by recycling and reusing materials. Participating in a DTI funded project to design out construction waste
- Energy – Companies are implementing energy efficiency schemes and investing in more efficient plant. Carbon Trust project applications under development.

SECTOR SUSTAINABILITY STRATEGY PROJECT

A sector-wide approach to sustainability is of increasing importance to the efficient, effective and responsible operation of business. In fact the Government has encouraged trade associations and sector representative bodies to develop sector sustainability strategies, because these
provide a focused way of addressing sector-specific economic, social and environmental issues. British Precast's governing council made a commitment in 2003 to develop a sector sustainability strategy applicable to the precast industry, and in 2004 a research programme was started with Loughborough University to facilitate development and implementation of this strategy.

Working with the Department of Civil and Building Engineering at Loughborough University will allow the project team access to specialist knowledge on sustainability and strategic management in the construction industry.

In order to produce a strategy document, the research programme will:

- Identify the economic, social and environmental impacts, both good and bad, of the sector
- Establish the precast industry's awareness and understanding of the opportunities and threats related to sustainable development
- Establish objectives, targets and indicators for future improvement.

Successful implementation of the strategy will require:

- Identification of actions to achieve those targets and objectives
- Accounting for the industry's actions by reporting progress
- Developing consensus amongst industry stakeholders.

British Precast members will be encouraged to commit to the strategy and the initiatives it produces, provide data to monitor progress and reap the benefits that a more sustainable precast industry brings.

The project is currently investigating the industry's sustainability priorities, the actions it needs to take and those it is already taking.

**THE IMPORTANCE OF ENERGY**

Dominant in our ‘More from Less’ programme is the drive to improve the carbon footprint of precast products and to meet the challenge of rapidly escalating energy costs. An example of one company's approach to energy saving.

Tarmac Concrete Products recognised the need for saving energy and how a company wide effort was required in order to achieve maximum benefits. A target of reducing specific energy consumption (i.e. energy used per unit production) by 15% between 2004 and 2014 was set, and the Save (Save Energy) campaign launched in order to achieve this.

A company steering group was formed that developed and implemented a strategy that involved all levels of employees and provided a sound framework for monitoring and reviewing progress, and achieving the targets set. The campaign included an employee save booklet, site surveys, training of all managers, advice and assistance from the Carbon Trust, site survey guides and employee toolbox talks.

The campaign has been very successful in a very short period from launch. Energy awareness has increased significantly across the business and early indications are that the reduction targets will be met and probably surpassed.

In addition to reductions in specific energy consumption, reductions in CO₂ emissions from efficient use of energy and alternative fuels have been achieved, together with increases in plant availability as maintenance improves and reductions in solid waste as manufacturing techniques improve.

**2005 SUSTAINABILITY AWARD WINNERS**

The aim of the Sustainability Awards, sponsored in 2005 by The Concrete Centre, is to reward excellence within the British Precast membership and to publicise the industry's progress towards sustainability. Entries were invited on either a single-site or company-wide basis, and judged against their sustainability benefits, innovatory approach, wider applicability and employee participation.

The winning entries in the single-site category demonstrated the positive link between profitability and a rigorous approach to waste minimisation. Many of the entries were relatively simple and cost-effective solutions to common problems that everyone in the industry could learn and benefit from. Marshalls' Eaglescliffe Works won the category with their work to reduce water consumption, running costs and their overall environmental impact. Significant results were produced through the combined efforts of everyone that works at the site, together with the effective implementation and combination of their Quality, Health and Safety, and Environmental Management systems into an integrated management system. Recycling of previous waste streams, including used pallets, steel waste and reject concrete is now fully implemented.
The winning entries in the corporate category showcased the efforts of the larger member companies who, with their specialist teams, are working to establish more sustainable production and operational platforms. Marley Eternit won the category for their development of a company-wide life-cycle assessment (LCA) program. As a result of this, Marley Eternit is leading the way by having LCA data for all of its products, is reducing the environmental impact of its products, and is influencing the supply chain by running CPD seminars on sustainable pitched roofing.

**KEEP IN TOUCH**

This paper only gives a superficial view of our activity in sustainability. We have a proactive Sustainability Committee open to all members and also organize six-monthly conferences ‘Sustainability for the Concrete Producer’ jointly with BRMCA. The next two are June 8th and November 30th 2006 both at Loughborough University – details from www.britishprecast.org . We also attend the regular concrete sector sustainability working group meetings.  
Our specialist website is  
www.sustainableprecast.com  
Our safety website is at  
www.concretetargets2010.org  
We have also joined the 2006 DTI funded Be Aware project aimed at reducing construction waste. Further details from the author.
Mark Watson is currently employed within the Technical Department of Marshalls plc. Marshalls are the largest provider of modular precast concrete paving products in the UK for both the domestic and commercial markets. He mainly advises specifiers on the successful application of Marshalls products, carries out a number of CPD seminars and is involved in trouble shooting of any concerns regarding the successful use of Marshalls’ products.

**ABSTRACT**

This paper discusses the issue of sustainable drainage systems (SuDS). Initially the paper discusses traditional drainage methods, then the need for SuDS and the benefits of the economic, social and environmental aspects. The main different methods currently available to achieve SuDS are then discussed with further considerations for the designs of projects.

**KEYWORDS**


**INTRODUCTION**

Nature uses magnificent methods of regulating itself, ensuring different aspects of the environment work together and complement each other’s activities. This ensures the performance of landscapes which have been unaffected by human activity. There is often very little, if any flooding. However, when the land does begin to be used for activities supporting society, whether these are activities such as construction developments, agriculture, etc, which are all necessary for our modern way of life, by altering the characteristics of the land we are also disrupting the regulating methods offered by nature. This can result in localised and regional flooding as a result of our own actions. Therefore, there is a real need for drainage systems which allow our development and growth as a society whilst also working sympathetically with nature.

The following descriptions highlight the potential impact of urbanisation on natural drainage.[2]

Within the natural environment, where the land has not been used by man, of all precipitation, approximately 95% will infiltrate into the ground, and either be absorbed by the vegetation and top soil or recharge the ground water. Of the remaining 5%, a small proportion will become evapotranspiration (water evaporation from land) and the remaining amount will be surface water discharging into water courses.

When the land becomes used for agriculture, although the surface remains soft, due to the removal of topsoil and vegetation, the proportion of water infiltrating the ground is now reduced to 70%, with the majority of the remaining 30% entering water courses.

If this is taken a stage further and the land is developed on, creating hard features such as roadways and buildings, in a typical suburban environment, using traditional drainage methods, it would be realistic to expect just 30% of all the rainfall to enter the ground whilst a much increased amount of 70% will be discharged into water courses.

For a typical inner city environment, the amount of water entering the ground is just 5% of all the rainfall, whilst 95% of the rainfall is being discharged through traditional drainage systems into water courses. This is the complete opposite of the unaffected natural site discussed above.

**TRADITIONAL SURFACE WATER DRAINAGE SYSTEMS**

Traditionally, rainfall landing on hard landscaping features (e.g. carriageways, car parks, etc.) and buildings has been channelled away through a series of pipes into the surface water drainage system. This surface water would then be either discharged into a water course if suitably clean or fed into a combined surface...
water and foul sewer drain, which would then take the water to be cleaned with the raw sewerage. Depending on the type of water entering the system, the surface water may have required treatment through an interceptor to remove any potential pollutants.

Whilst this type of system has proven to be relatively effective in the past, there are limitations to this approach towards addressing surface water. By continually discharging surface water into the water courses, this is starving the ground water levels whilst also placing a vast additional burden on existing water courses.

Currently, a high proportion of the surface water drains are either operating near or at their full capacity. This dictates that during heavy rainfalls, the peak surface water runoff can easily exceed the capacity of the surface water drainage system, leading to flooding, whether on a local or regional basis.

There is also a change in our precipitation characteristics, in particularly rainfall. Since 1961, there has been a 50% rise in the number of three consecutive days of rainfall events. This means currently the surface water drains are working near capacity in an environment that is tending towards higher peak flows. This can all lead to poor water quality, flooding and erosion.

In Figure 1, this shows a simple rainfall event offering a peak surface water runoff of 20 l/sec. If the surface water drainage system has a maximum capacity of 40 l/sec, there is plenty of excess capacity available.
However, if we now reconsider the Figure 1 scenario, but with two additional rainfall events, as shown in Figure 2, reflecting the change in precipitation characteristics, although each individual storm does not exceed the maximum capacity of the drainage system, the overall surface water runoff far exceeds the maximum drainage capacity. This is where the potential for localised and regional flooding originates.

**THE NEED FOR SuDS**

The role of sustainable drainage systems (SuDS) is to mimic natural drainage methods. This entails promoting the use of drainage methods and techniques that will recharge the ground water, as close to the source of the rainfall as possible, and reducing the volume of surface water being discharged from a development. Techniques that allow the infiltration of surface water into the ground are ideally suited to meeting the needs and requirements of SuDS.

In areas of unsuitable ground conditions for infiltration, such as clay soils, bedrock, etc, different techniques can be used to attenuate the surface water. Once attenuated, the water can be gradually discharged in such a manner that there is no sufficient additional burden added to the existing surface water drainage system.

The use of these techniques allows a number of final outcomes, from total elimination of surface water discharge from a development, through a reduced amount volume and finally to total surface water discharge, but in a slow controlled manner which is acceptable for existing drainage systems. The consideration to the use of different methods depends on the desired outcome. Aspects to consider when looking at the different methods available include the ground conditions, availability of land, the volume of water to be addressed, the potential to increase the amenity value and the local biodiversity of the site.

In Figure 3, the graph shows the effects that a development has on a natural catchment. It can be seen from the graph, there is a gradual increase and then decrease in the runoff from the catchment area. The curve is relatively flat, reflecting the gradual changes in flow rate and offers a low peak flow for surface water runoff. After the development of the site, by altering the characteristics of the site, the peak flow rate is much greater, occurring much sooner after the rainfall. This shows the more aggressive effect of the developed site runoff, with a greater volume, occurring much faster. As there are no features to control or restrict the speed of the surface water, the following base-flow is reduced as the surge of water has passed. The use of SuDS is intended to mimic the original natural surface water runoff flows, reducing the volume being discharged and slowing the rate of flow. Both scenarios are reducing or eliminating the peak offered by the traditionally developed site.[2]

The use of SuDS is being driven by Planning Policy Guidance Note 25 (PPG25), Development and Flood Risk and is required to comply with the Building Regulations: Part H.
DIFFERENT TECHNIQUES FOR ACHIEVING THE REQUIREMENTS FOR SuDS

There are a variety of different methods currently available to achieve our needs and requirements for SuDS. The following methods are the most commonly used but do not form an exhaustive list. For different developments offering different challenges, innovative methods are being explored and used, creating new methods as the concept of SuDS develops and matures.

SuDS can be any method or technique that contributes towards a more sustainable development by:

- Managing the environmental impact at source, rather than downstream
- Eliminating or managing the surface water runoff volumes, reducing the impact of urbanisation
- Protecting or enhancing the surface water quality
- Being sympathetic to setting and needs of the local community
- Providing or enhancing wildlife habitats
- Providing or enhancing amenity value
- Encouraging groundwater recharge (in suitable ground conditions).

With a number of the different systems discussed, the main features are the infiltration of water into the ground, with any solids or pollutants being addressed by biological activity within the soil. In addition, a number of the systems also rely on the adsorption (attaching or binding to surfaces within the drainage feature, e.g. vegetation, aggregates, etc.) of solids or pollutants, before being exposed to the biodegradation of the particles.

Preventative Measures

These are measures which can be employed to prevent the need to discharge off site any of the rainfall landing on it. Rainwater harvesting would be an excellent example of this technique.

Rainwater harvesting is a method of collecting the rain which fall onto roofs, and then storing this water in a tank until required for use. When required, the water is then pumped to the point of use. This would be for ‘grey water’ applications, such as flushing toilets. This type of application displaces what would otherwise be a demand for mains-water. In the process, the volume of water collected is not being discharged as surface water into any type of drainage system, whether traditional or SuDS. Therefore, the possible need for discharging any water from the site is prevented.

Filter Strips and Swales

Filter strips and swales are vegetated surface features which allow the surface water to run through the strip (Figure 4). This reduces the speed of the surface water runoff, allowing sedimentation to occur and preventing potential localised erosion further downstream. The vegetation removes and retains any organic and mineral particles, which are then absorbed by the ground.

Swales can be further used for combining the conveyance (using a gentle gradient) and infiltration of surface water runoff through a site, depending on the ground conditions. The conveyance route chosen can be such to mimic natural drainage patterns.

Infiltration Devices

Infiltration devices are systems which can be either surface features or below ground, and are engineered to boost the storage capacity of the existing ground for the runoff entering them. A surface system would be an infiltration trench or infiltration swales coupled with infiltration basins.
A soakaway is an example of a below-ground system (Figure 5). The runoff water can either be treated as close to the source as possible or it may be conveyed to the infiltration device either by a swale or pipe, depending on the use and extent of the site.

In certain instances, where surface infiltration devices have been employed, these can generally appear dry except for periods of heavy rainfall.

**Basins and Ponds**

Basins and ponds are structures that are designed to hold water when it rains. The difference between the two structures is a basin is usually dry and are usually flood plains and detention basins. This allows basins to be used for recreational purposes during dry times.

Ponds always contain water, with the volume varying with the amount of rainfall received and/or the application of the pond. Typical ponds would be used as balancing or attenuation ponds, retention ponds or wetlands. This provides excellent opportunities for biodiversity. Due to the flow characteristics and the provision of vegetation of a pond, sedimentation can occur.

Both basins and ponds are designed to control peak flows of water and to then gradually discharge them once the potential for flooding has passed. With both methods, the adsorption of any solids to vegetation or the soil is also promoted, further cleansing the water before discharge.

**Permeable Pavements and Porous Surfaces**

A porous surface is a surfacing material which is a combination of hard and soft landscaping. These types of products combine the structural requirements of a load-bearing surfacing product for trafficking whilst offering grass growth through the product’s voidage, to create a ‘grassed’ paved area. A porous surface allows rainfall to enter the voids but these systems can be prone to ponding during heavy or prolonged rainfall as a porous surface does not offer any water storage features or capacity.

A permeable pavement is one which allows the surface water to enter it and has a designed storage capacity beneath for the surface water (Figure 6). The surface water can then either be allowed to infiltrate directly into the ground or be attenuated before being discharged from the pavement to a suitable outlet. This is very much dependent on the ground conditions.

The use of modular paving offers an ideal solution for permeable pavements, using open graded aggregates to form the bedding course (typically a 2/6 mm aggregate) and sub-base.
(typically a 4/20 mm aggregate) to ensure structural stability whilst providing hydraulic performance. The use of open-graded aggregates allows:

- The structural pavement performance - ensuring the pavement's design is reflective and effective in relation to the application.
- The necessary hydraulic performance - to store the water in the voidage offered by the aggregate (typically 32% voidage)
- The filtrating of the water trapping sediment and pollutants – pollutants and heavy metals are adsorbed by the aggregate. Research shows oil bio-degradation in permeable pavements by microbial communities.[5]

A permeable pavement can be used for a variety of applications, successfully being exposed to trafficking and loadings for which it is designed. Therefore, a dual purpose is achieved of a system which offers a carriageway in a development whilst also allowing developers a means of meeting their SuDS requirements and maximising the use of the land for a new development.

The applications and use of permeable pavements is growing as confidence in the system is gained within the construction industry. The pavements can be designed for applications from a basic car park, to areas exposed to trafficking by heavy goods vehicles. Their application in container storage areas has also been successfully undertaken.[6]

FURTHER ASPECTS FOR CONSIDERATION

The use of SuDS techniques therefore aims to balance the issues of social, economic and environmental aspects and these must be considered in new development designs.

Social Aspects of SuDS

From some different technique used, particularly wetlands and ponds, the use of picnic tables and creating footpaths through the different areas has been noted as people, particularly local residents, start to use these features as amenities. This has been seen initially with the development of ad-hoc paths indicating a regular usage. Features such as basins can be used for recreational purposes can encourage more social interaction within a society.[7]

The use of SuDS, by allowing new developments, does not prevent the development of new housing estates or business parks. This allows a community to develop in a responsible and sustainable manner.

The emotional effect and impact plus the severe inconvenience that flooding has on people's lives must also be considered and how the use of these systems can significantly reduce, if not eliminate, these concerns.

Economic Aspects of SuDS

The use of SuDS is allowing new areas to be developed which previously would not have been possible due to surface drainage concerns. This is allowing the creation and expansion of existing businesses, through the initial construction phase and then the use of the new development. The business, by operating in the community, is generating money for the local and wider economies.

The use of some techniques removes the need for traditional drainage methods. This can offer cheaper construction costs and long-term whole life costs. This is achieved when a direct comparison is made between traditional methods using gullies, piped systems, etc, and the use of, say, a permeable pavement. In example projects that have been executed for motorway service areas, it is claimed that savings in the region of 20 to 40% can be achieved when SuDS is used compared to traditional drainage methods.[8]

Eliminating, or at least dramatically reducing, the potential for flooding, can prevent heavy financial costs associated with the disruption and cleaning of flood water and the mess left behind, thereby preventing the costs incurred in the flooding initially and allowing a business, for example, to continue trading.

In addition, with the different methods being used, new opportunities are created for companies to develop products and services to satisfy the demands of the industry and clients. As with so many aspects of industry, innovation and product developments are always being undertaken to further the developments of existing markets and removing the barriers to usage in other aspects of the market.

Environmental Aspects of SuDS

SuDS allow the volume of water, its potential for erosion, the content of solids and pollutants to be readily addressed and achieve cleaner water. SuDS promotes the use of grey water to reduce our reliance on drinking quality mains water for applications that do not require high standard of cleanliness.
We are reducing or eliminating the potential for flooding and the associated implications by mimicking nature’s approach. The systems discussed promote the removal of pollutants and allow biological activity to break them down further without the need for aggressive additives.

In the event of a spillage, with traditional drainage methods, the spill has the ability to cover a very large area very quickly. With a SuDS approach, a spillage can be contained in a small area, reducing the risk of widespread pollution. Depending on the nature of the spill, the appropriate action can then be taken.

New and enhanced wildlife habitats can be created whilst providing elements of softer landscaping for developments.

**Project Designs**

When designing projects, the use of the different SuDS discussed previously need to be considered to achieve the desired effect for the development. The use of the different SuDS need to be assessed for their suitability. Examples of design considerations are:

- The availability of land for using certain methods may be a limiting factor. Certain methods use a greater land area for a sole purpose
- The use of ponds can be coupled with water features, which add amenity value to a site whilst aerating the water. This can be used to produce a water feature outside a development for example
- The suitability of the ground conditions for infiltration. If the ground conditions are unsuitable, the surface water may not filter away sufficiently quickly and/or cause long term instability of the soil; the height of the water table requires consideration.
- The use of a permeable pavement for the dual purposes of meeting SuDS requirements whilst also providing a structural pavement. This allows a more efficient use of the land available
- The discharge of roof water (e.g. discharge into an infiltration device, or a permeable pavement sub-base, etc)
- The volume of water to be accommodated (e.g. location, storm-return period, etc.)
- Maintenance of the system

There are an increasing number of projects which use either one or more of the systems to achieve their SuDS requirements. The use of individual methods in isolation can be an option for certain developments whilst the use of a combination of methods can provide a more desirable result.

For example, the use of a permeable pavement for a park-and-ride scheme can increase the number of parking spaces available by having the pavement behave as the sole feature. Whereas, for a prestigious office development, the use of surrounding wetlands and ponds can add to amenity value and desirability of the development.

In the future, we may see a greater use of green roofs, allowing water to be addressed before it is discharged, or the attenuation of water in gutters or roof spaces. These methods would allow more water to be addressed without solely relying on ground techniques to address the issues. Financial incentives such as grants and tax benefits could be offered for the use of sustainable systems, whether newly or retrospectively fitted to encourage and promote a more widespread use of SuDS.

**CONCLUSION**

There is no doubt that SuDS currently provide benefits for our communities and will provide the sustainable development of our future society. There are a number of techniques available to allow the successful use of SuDS in all applications, whether a green or brown field site, in an urban location or a rural area, for any type of development, whilst balancing the needs and requirements of social, economic and environmental pressures.

The systems offer cleaner water, reduced surface water discharged and manages the potential for flooding at source, rather than creating features to prevent flooding in urban areas.

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