Highly Sustainable Concrete

By David Ball FCMI MCS FRSA

www.pudlo.com

INTRODUCTION

The new, independent branch of the Concrete Society in Abu Dhabi for the Middle East region will provide a holistic approach in terms of technical guidance, training and education to professionals and students and common standards and codes of practice, specification, and to the production of concrete and concrete structures.

The demand for better standards, more autonomy, greater co-operation and sharing of best practice is driven by the heavy demand for ultra durable, high-quality, high strength, high performance concrete to achieve the fast track, headline-grabbing construction in the Middle East. It will be the first overseas office for the Concrete Society since its inception over 40 years ago.

Thanks to advanced formulations and high performing admixtures, concrete readily provides corrosion, water-resistance and therefore increased durability to protect even the most vulnerable structures from the Gulf's corrosive cocktail of searing heat and saline ground waters. This region is acknowledged as the most aggressive environment on the globe, much worse than the Northern Hemisphere.

This paper explains how by reducing water permeability the construction industry can significantly increase the durability of concrete and reduce its environmental impact over the lifetime of a structure.

SUSTAINABILITY

What is Sustainability?

Sustainability means delivering not just economic profitability, but environmental performance and social well-being. Only when all three elements are balanced together is an industry truly sustainable.

By thinking about sustainability when we design, choose and use technology, our industry can play an important part in building a better world for the future.

The industry as a whole is working hard to reduce energy costs in cement production, which then feeds into reduced, embedded CO_2 costs in concrete. Energy use in the cement industry has already reduced by nearly 30% since 1990 with a corresponding 29% reduction in carbon dioxide emissions by UK cement manufacturers alone. The CO_2 savings over the same period amounted to over 3.9m tonnes, representing a rigorous and dynamic response to the threat of global warming.

In addition to the production of energy savings, cements blended with ground granulated blast furnace slag or pulverised fuel ash can further lower overall cement contents, and coupled with specialist high performing admixtures, this process can be taken even further.
In an extract from a 2007 independent evaluation of one such admixture, Mott MacDonald reported:

"The potential for reducing the quantity of reinforcement required to limit early thermal cracking in a section is likely to be in the order of 25% if all of the potential benefits of the admixture can be taken into consideration at design stage"

Individually the previous measures do not fulfill our definition of "Sustainable" however, if applied collectively they represent a credible and meaningful contribution to building a better world for the future

One further point when considering concrete and its sustainable credentials should also be considered.
When taking account of the environmental sustainability of a construction material it is disingenuous to consider only its embodied carbon dioxide. Embodied CO_2 is only part of the story, and when considering the sustainability of a construction material you need to look beyond the materials embodied CO_2 . Only then can this facet of its true environmental (sustainability) impact can be measured.
Over the life of a structure the operational CO_2 emissions have far more environmental impact that the embodied CO_2 materials used to build it.

A BCA (British Cement Association) study reveals that the split between embodied and operational CO_2 costs is 90% operational and 10% embodied. '*90% of the environmental impact of CO_2 associated with buildings arises during their operation lifetime from cooling, lighting and heating.'* Thermal mass slows down the temperature changes so that the fluctuations that occur outside a building are delayed and reduced within it. This process is known as Fabric Energy Storage. For FES to become effective the interior surfaces of the concrete must be left exposed. In buildings such as schools, hospitals and offices FES is more efficient, due to the amount of concrete exposed within the interior of the building.

A recent investigation of the CO_2 emissions from concrete and timber frame buildings both embodied and operational, over the lifetime of a building, was commissioned from Arup Research & Development. The study shows that a heavyweight, concrete building is more environmentally friendly in the long-term. This point, from the same R&D is used by the British Cement Association to argue the importance of operational CO_2 emissions as opposed to embodied. The CO_2 pay-back, in the instance of a low rise concrete structure, is 11 years according to Arup's Research & Development, but according to the BCO (British Council for Offices Guide), pay-back time for an office building can be as little as 6 years.

Sustainable Benefits of Concrete

Reduce energy for cement production.

Reduce the overall cement contents while maintaining or improving the required performance characteristics.

DURABILITY

"*The durability of concrete is principally related to the ability of water (with or without aggressive ions), oxygen and carbon dioxide to penetrate concrete pore structure"*
(Neville 1995).

The durability of concrete is more commonly defined as the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties.

Ultimately, durability in this region is defined by the moisture state of concrete. By controlling all known moisture transport mechanisms and inhibiting oxygen permeability, durability can be determined.
The durability of concrete is a function of concrete's performance against relative humidity, hydrostatic water pressure, water absorption, water vapour permeability and capillary absorption. These are distinct, separate and well characterised moisture transport mechanisms. Dedicated and well used tests have been developed to measure and control their behaviour in concrete.

This highlights the correlation between durability and sustainability, and will show that as little as 1% increase in the density of concrete, through reducing the voids and porosity, not only gives a considerable improvement in its strength, but a significant (by a factor of 5) reduction in water permeability. The accompanying slides will show improvements of the microstructure of the cement paste particularly at the aggregate/cement interface which leads to high durability, low maintenance and long-life expectancy structures, even in severe exposure class situations. Such improvements in microporosity provides resistance to sulphate and chloride ion transport within the concrete matrix

MAXIMISING SITE FOOTPRINT

One of the principal concerns of designers for the region is durability, and durability should be a clearly identified issue in the design process. The owner's required service life should be clearly established and, along with this, a clear idea of the condition or conditions which constitute the end of service life. The return on capital investment in the region is relatively rapid and owners may only require a life of 20 years to recoup their investment. At the other end of the scale, landmark projects, mosques, museums, monuments and elements of infrastructure such as tunnels and bridges may be required to function for 100 years or more.

Moisture from the ground can also find its way via the foundations to members above ground. If the moisture contains salts, these can become concentrated by evaporation from surfaces and corrosion of reinforcement is the result. It is necessary for the moisture to be intercepted at source by robust tanking of foundations or other appropriate means.
Tunnels and basements in the coastal region can suffer in a similar way if saline groundwater penetrates and evaporates at the inside or outer faces

Coupled with high salinity, in high-solar radiation conditions, ultra-low permeable concrete is vital to achieve if the structures are to be considered 'sustainable' or durable.
Without waterproofed concrete in the sub-structures in this region, there will be considerable maintenance and repair costs required within 5 -10 years from the time of construction.
The key influencing factor is the presence or absence of moisture. This is not only because corrosion requires the presence of moisture but also because the transport processes associated with carbonation and chloride ingress are entirely dependent on the moisture state of the cover concrete.

Everywhere you look in the region, deep holes are being excavated to build substructures for what will eventually be the superstructures of the future. Many of these excavations are the beginning of landmark, iconic buildings. By utilising this below-ground space for a variety of uses, often in combination, the use of the ultimate building is much more efficient both in terms of productivity and operational energy costs. Large shopping malls for example, require secure retail storage facilities as well as attractive, well lit parking spaces as close to the final retail area as possible.

Other substructures of the superstructures begin many metres below ground level often incorporating deep and relatively thick concrete piles, in addition to secant or contiguous piling around the perimeter. Due to the very high water table levels, which is brackish, the structures act like a sponge. Moisture, particularly driven or accelerated by high solar radiation above ground, draws moisture in a steady flow out of the ground to evaporate off just above ground level. This is known as capillary rise which is faster in the Arabian Peninsula than anywhere else known on Earth. Until recently, the common way of dealing with this situation in the region was to install relatively complex tanking systems in order to reduce the rate of capillarity and of course, the consequent corrosive mechanisms to the embedded reinforcement steel.

Fortunately, the publication the recent 'Guide to the Design of Concrete Structures in the Arabian Peninsula' includes a section on ways of protecting the substructures of superstructures. A practice, widely used over the last 10 years, has been the waterproofing of concrete as an alternative to the rather time-consuming and expensive methods of tanking, to say nothing of the difficulty of carrying out this work under site conditions.

The Institution of Structural Engineers in its document published in 2004 'Design and Construction of Deep Basements, including cut-and-cover structures', points out that membranes (tanking) prevent autogenous healing of early age cracks and encourage greater drying shrinkage and goes on to say '***for these reasons it is generally better to avoid tanking'.*** The new design guide now recommends an alternative using a high-range, integral waterproofing admixture to provide an ultra-low permeability to concrete. One such material has now been used continuously in the region for the last 10 years, with great success.

INNOVATIVE DESIGN

The UAE has been startling the world by employing innovative design, creating iconic and landmark structures giving it worldwide recognition far beyond its geographical size. It is estimated that this will not only cause designers to follow the success and high standards created here, but draw visitors in increasing numbers to the region to admire and enjoy these new facilities. Once the global recession is over, the Arabian Peninsula will be one of the best tourist, cultural and conference destinations on earth.

LOW LIFE-TIME COSTS

Every asset owner wants to minimise disruption to the use of the facility built. Significant reductions in long-term maintenance and on-going costs can result by insisting on waterproofed concrete of ultra-low permeability from the beginning. The key to achieving high-durability and long-term sustainable concrete structures is to control the moisture state of the concrete. That involves significantly reducing water absorption, capillarity, water permeability and chloride ion migration. The secret lies in designing a concrete mix incorporating an admixture which will achieve these parameters. Careful attention is paid to the key components within the microstructure of the concrete which increases the density by 1%, but has the effect of increasing compressive strength by up to 30% while, at the same time, blocking the pores and coating cement grains with a hydrophobic film.

By specifying a concrete with low water/cement ratio (maximum 0.4) and using a waterproofing admixture which can produce ultra low permeable concrete, (ultra low rather than just reducing the permeability) the result is a more workable concrete in the plastic state with very significant improved durability characteristics once hardened. It will also provide the designer with a competitive advantage over other systems and materials such as tanking membranes and protection boards. This not only reduces embodied CO_2 demand significantly, but will help reduce operational CO_2 in the future by eliminating repetitive coatings or remedial works.

RESEARCH AND DEVELOPMENT FOR FUTURE MATERIALS

David Ball Group PLC at Cambridge is unique in the industry by funding high levels of research and development at academic institutions in order to achieve lowest possible material use while at the same time making such developed materials last significantly longer. At the time of writing DBG plc is funding three PhD students in the Engineering Department of Cambridge University looking at how concrete of the future will actually absorb carbon dioxide from the atmosphere with the aim of producing carbon neutral structural concrete in the near future. This is an exciting area of work not only because of its impact on operational CO_2, but the possibility of eliminating corrosion before it can develop.

The industry needs to join in and address the issues of over use of cement *and binder* contents in structural concrete. Lower cement contents, with low water/cement ratios, automatically reduces water requirements, improves dimensional stability, reduces permeability and has an immediate and positive impact on the sustainability of concrete.

Conclusion

A Sustainable Construction Strategy has been developed for concrete on behalf of the Concrete Industry Sustainable Construction Forum (CISCF) which is a representative body of the different industries and trade bodies.

The Strategy has been developed in association with Forum for the Future and will help deliver the targets set out in the joint Government/construction industry Sustainable Construction Strategy announced on June 2008. It is a commitment by the concrete industry to a common vision, strategic objectives, commitments and indicators which will benchmark industry performance and demonstrates continuous improvement for the future in delivering sustainable construction. The vision for the strategy is:-

“By 2012, the UK concrete industry will be recognised as the leader in sustainable construction, by taking a dynamic role in delivering a sustainable built environment in a manner that is profitable, socially responsible and functions within environmental limits.”

The Concrete Society supports the initiative from the Middle East to start a Concrete Institute here so that local training, sustainable and best practice programmes can be developed for the region.