Technical Seminar by David Ball
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Sustainable Concrete

The designers' new imperative

DavidBall Specialist Sands

DavidBall InstaRange

PUDLO

David Ball Group plc

Contents

Introduction
Worldwide co-operation over the issue of global warming comes down, in the end to "How does this involve me? Or, "what part can I play in the process of a sustainable future?" As a designer of buildings and structures for the future, this responsibility is paramount.

First, we must be review the problem and then we need to focus on the design issues, and ways we could respond to the need to conserve precious resources and make them last longer.

The paper recognises the key issues and suggests that less steel and less cement could be considered without compromising high durability.

What a designer hopes to achieve
"Places where people want to live and work, now and in the future. They meet the diverse needs of existing and future residents, are sensitive to their environment, and contribute to a high quality of life. They are safe and inclusive, well planned, built and run, and offer equality of opportunity and good service for all. They will require minimum possible energy use and low maintenance to be sustainable construction."
Securing the Future, Defining UK SDS, HM Government, 2005

Key findings of Climate Change Panel
Leading scientists from a wide range of countries submitted considerable evidence to the Inter-governmental Panel on Climate Change (IPCC).

To summarise the report's main findings:

Water An extensive increase in the frequency and severity of floods and droughts. This is already happening in many countries and is not a future problem. It is now.

Food Crop yield will increase in temperate regions for a global temperature rise of up to 3˚C, but above this point would decline. In tropical areas, yields will decrease.

Ecosystems Mass extinction, of 20-30% of species, is likely if global temperature rise exceeds 1.5 - 2.5˚C. After 2050 terrestrial ecosystems will become a net source of carbon for the first time.

Coastal areas and low-lying areas Millions will be vulnerable to flooding. Most corals will die with global temperature increases over 2˚C. Major cities, of high population have millions of residents living at or near current sea levels. They will be affected the soonest.

Health Millions worldwide will be susceptible to disease previously not experienced by them. Most vulnerable are the poor, the very young, the elderly and infirm. The construction industry, particularly at the design stage, has a major responsibility in this area.

Industry, settlement and society The poorer, often rapidly expanding communities near rivers and coasts are most vulnerable. The cost of extreme weather will increase.

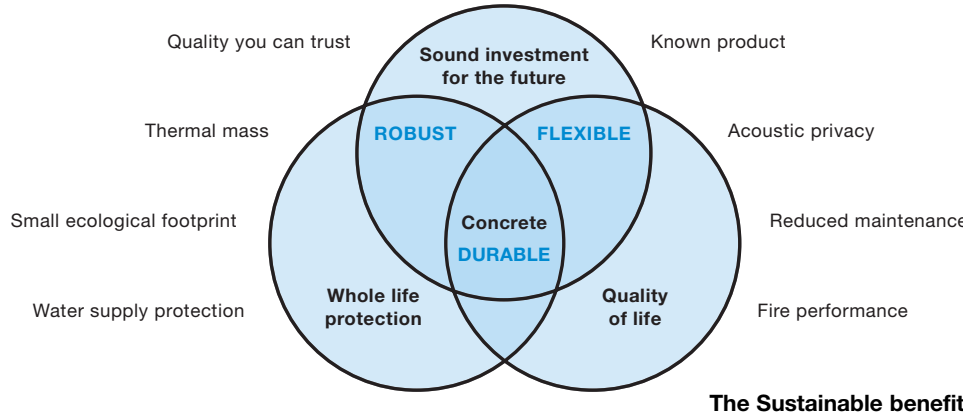
This supports the Stern Report's findings that the cost of mitigating climate change now, is significantly less than the future costs of dealing with its' impacts.

The Government's Climate Change Bill makes the UK the first country to legislate for reducing carbon emissions. It contains a pledge to reduce carbon dioxide emissions by 60% by 2050 and "to make real progress by 2020, defined as a 26-32% reduction against a 1990 baseline".

Responsibilities of the construction industry
In the UK five million people live in flood-risk areas. It is estimated that one person in 10 worldwide, including one in eight city-dwellers, live less than 10 metres above sea-level and near the coast, which is an "at-risk zone" for flooding and stronger storms exacerbated by climate change .

The challenge is in two parts. Firstly designers must ensure that structures being built are capable of withstanding conditions of prolonged wet and high salinity, and secondly, that the industry itself reduces its environmental impact by minimising the amount of cement and steel it uses.

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



The Sustainable benefits of concrete

Design Issues

Adoption of Eurocodes

The Eurocodes are an assembly of 58 consistent norms, completed with national addenda. More and more countries outside Europe have shown major interest in the Eurocodes, and have even already accepted them in cases such as Vietnam,Singapore, Africa, China and India. Eurocodes offer a major advantage compared to current codes in the USA, where a multitude of norms of different institutes co-exist (e.g. AISC, AISI, ACI, UBC, IRC, ASTM, AWS, WFCM, NDS), in most cases not available in S.I. units.

Many engineers are unaware of the implications of these codes.

Across 26 countries, over 60% of European engineers believe that national building codes will remain in place after 2010. Nearly one in ten engineers believe that Eurocodes may only be used in the EU Member States. And only one out of seven engineers believes the Eurocodes will be introduced after 2010, which is actually the ultimate date of withdrawal of the national conflicting codes! Almost 60% don't believe the Eurocodes will be accepted on a worldwide basis in the coming five years.

Durability tests for concrete

It is important to consider the "key" issues when considering what the specification should be for high-durability concrete structures. Water transport mechanisms are the most critical but are not the only design criteria to be addressed. High on the list is water penetration but figures very significantly less than the DIN 1048 requirements are not justified. However, a considerable reduction in Water Permeability over normal, plain concrete of the same strength class can be achieved at relatively low cost.

The difference between plain and "treated" concrete is in the order of 5 fold; this is, a factor of 5 reduction in the key water transport mechanism of permeability when compared with an un-treated, plain concrete.

BS 1881 Part 122 Water Absorption

This is a true absorption test in that transport results from capillary action. However, of specified durability tests, the absorption test is the most reliable.

BS 1881 Part 208 Initial Surface Absorption Test (ISAT)

Whilst this is an absorption test in that transport results from capillary action, the test actually produces values of rate of absorption at a series of time intervals. Integrating these rate values, with respect to time, gives the total absorption through the exterior concrete surface over the test period.

This is more relevant to durability than absorption through a combination of exterior surfaces and interior cut surfaces, as in the previous test.

The ISAT test has similar reliability to the water absorption test, and generates low incidence of "extreme outlier" results. Samples should be tested in the same moisture condition, and not when saturated, which is probably easier to achieve in the Middle East than in more temperate conditions of the Northern Hemisphere. The only "variable" is the possibility of inconsistent or insufficient compaction of the test specimens.

Rapid Chloride Penetration Test

There is considerable concern over the increasing reliance on RCP test figures particularly in the Middle East where the most aggressive conditions for concrete structures known to man exist.

For example, in comparative 28-day to 56-day tests recently commissioned on a high-durability mix, typically giving 1000-1500 Coulombs at 28-days, the Rapid Chloride Penetration (RCP) values decreased by 30-40% between these ages.

The RCP test also gives some anomalously high results related to test equipment conditions and method. The standard is currently being revised and it is understood that this will include major changes to procedure. The test is therefore not recommended for production quality control purposes. However, if this is to be done, then at least three specimens must be cast from each concrete sample, and tested at the same age.

ASTM C1202

The results have little to do with moisture-driven, transport of chloride ions in concrete.

If there is any more evidence required to establish the inadequacy of this testing method for the purpose of determining the actual chloride ion permeability of concrete, then ASTM C1202 provides that in abundance. The test precision statement, under Clause 13, allows for a variance of 42% between the results of two tests on concrete from the same batch, conducted by the same operator; and increasing this allowance to a variance of 51% if the tests are carried out by two different laboratories. Irrespective of any other consideration, such a poor level of accuracy alone is sufficient, to effectively disqualify any testing method as a quality control instrument.*

The confusing aspect that the charge passed would indicate a substantial transport of chloride ions when in fact the source of chlorides was removed proves unequivocally that the results of Rapid Chloride Permeability Testing bear absolutely no relation to chloride ion migration or permeability. They are merely reflecting the electrical conductivity of the concrete specimen.

Recommendations

1. Recent work done by David Pocock, of Halcrow and Jerry Corrans of Al Naboodah, Laing O'Rourke J/V Ltd, has highlighted difficulties in specifying and interpreting durability tests for concrete quality control. Unlike compressive strength, which is a definitive property, durability is not easily measurable. This is further complicated by the inherent unreliability of some of the test methods. Unfortunately, at present there are no "perfect" durability test methods. Therefore, it is essential to consider the issues presented when assessing durability results, and not to view results in isolation, but rather to assess results from the various tests collectively.
2. The ISAT test has the advantage of being suitable for in-situ testing and hence could be used to examine variations in site curing. Compliance with trial mix values will provide additional assurance of production and curing controls.
3. It is not clear how the results of the electrically-accelerated ASTM and AASHTO tests relate to water transport mechanisms responsible for chloride ingress into concrete, in particular diffusion, other than inactivity.
4. Sufficient evidence has been presented that results obtained from Rapid Chloride Permeability tests are not at all related to chloride ion migration, or the resistance against it. This has effectively invalidated Rapid Chloride Permeability testing as a suitable quality control instrument.

Typical specification for Durability parameters

Test method	Maximum limits at 28 days
Water absorption – BS 1881 Part 122	<2%
Water permeability – DIN 1048	<10mm
Rapid chloride permeability (RCP) – ASTM C1202	<2000 coulombs

Use of Steel

About half of all concrete produced in Britain is reinforced. Unlike structural steel the reinforcing steel made in the UK is made entirely from recycled steel which itself can be recovered for reuse at the end of the building or structure's life. Although steel manufacture is an extremely energy-intensive business, the energy needed to produce one tonne of reinforcing steel is as low as half of that needed to make one tonne of structural steel from iron ore.

There has been a 45% decrease in the production of primary aggregates between 1989 and 2001 and a 94% increase in the use of recycled and secondary aggregates. This shift towards recycled or alternative aggregates in place of freshly quarried material is forecast to continue. By 2011, 30% of all aggregates are expected to come from a non-primary source, equivalent to 70 million tonnes.

Supply of Primary v. Secondary and recycled aggregates (Tonnes MN.), 1989 - 2011

	1989	2001	Forecast 2011	% Change 1989 - 2001	Forecast % Change 1989 - 2011
Primary	300	164	164	-45	-45
Recycled & Secondary	32	50	70	+94	+119
Total	**332**	**214**	**234**	**-35**	**-29**

Whole-life costing techniques for design evaluation
For some time, it has been acknowledged that the use of an initial cost basis, *ie* the lowest possible tender, for selecting a design and construction process is not the most cost effective in the longer term. The use of whole life or life cycle costing to evaluate the relationship between initial and in-service costs, and hence to determine the most cost beneficial scheme, has underlined the need to select materials and systems that will enhance durability and avoid costly maintenance and repair operations.

For best results, whole life costing requires the reliable prediction of deterioration rates and should include disruption costs to take account of any maintenance and repair work that requires the closure of the structure. To enable the selection of the most cost effective design solution, a whole life costing exercise should consider initial costs together with the service life costs discounted back to a value that would apply at the time of construction. Taken together these costs can then be used as a means of comparing the true cost of providing and maintaining a structure for a given service life.

With regard to early-age thermal crack control, it is important to recognise the form of restraint as this may have a significant effect on crack widths. Under conditions of uniform EDGE restraint, the crack width is limited in part by the restraint as it determines the magnitude of restrained strain that can occur. Under conditions of END restraint, the crack width is determined by the tensile strength of the concrete and the stress that is transferred to the steel when a crack occurs. In this case, for the same magnitude of contraction, the crack widths may be more than double those occurring under edge restraint conditions and different expressions apply in the calculation of crack width. These conditions are defined in EN1992-3.

Note All underground concrete must be tanked with a robust membrane OR be provided with some other means of preventing movement of moisture from the ground through the foundations to the superstructure.

The 'other means' refers to integral waterproofing of the sub-structure concrete to control, in particular, capillary moisture rise and hydrostatic pressures. Providers of integral waterproofing admixtures for concrete must have a continuous track record of 50 years before being considered for use in the region.

CASE STUDY

Durability issues in the Arabian Peninsula
The CIRIA/Concrete Society Guide to the construction of reinforced concrete structures in the Arabian Peninsula, is widely accepted in the Region. The companion document; The Concrete Society Guide to the maintenance and repair of reinforced concrete structures in the Arabian Peninsula, which was prepared in association with the Bahrain Society of Engineers, has similarly been well received.

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.

Marine exposure is extremely aggressive. This is brought about by the high salinity of the local sea water and the high temperatures leading to rapid evaporation and quick build up of salt concentrations in the surface concrete. Concrete subject to cycles of wetting and drying are particularly vulnerable because of the ready availability of both oxygen and moisture.

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.

Any construction joint or movement joint, in an exposed part of a structure should be seen as a potential long-term durability problem. Thus the aim of the design and the construction sequence should be to eliminate joints as far as possible in the following:

- Basements
- Tunnels
- Marine structures
- Water-retaining structures
- Desalination plants and power stations.

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. That moisture state is a function of relative humidity, hydrostatic water pressure, water absorption, water vapour permeability and capillary absorption. All moisture transport mechanisms must be determined and controlled in order to provide long-term durability and meet the sustainability criteria.

The Arabian Peninsula, of which the UAE is only a part, is an environment recognised as among the most difficult in the world. This does not mean that complex forms justified by analytical processes should not be adopted, but in general they demand a higher standard of materials and workmanship than can be expected without additional cost, and increase the risk that the structure will fail to perform satisfactorily.

Burj Al Arab Hotel, Jumeriah, Dubai
The world's tallest hotel stands on an artificial island.

Durability benefits of water resisting concrete
Mott MacDonald was recently engaged by David Ball Group PLC, to evaluate the potential benefits of using an PUDLO, integral water-resisting concrete admixture, for structural concrete.

The main conclusions were as follows:-

Shrinkage
Testing carried out by RMC (test method not reported) indicated a value of 0.028% and tests carried out by Al-Futtaim Bodycote (test method not specified) in Dubai reported a value of 0.023% at 28 days. This is some 34% below UK control mixes and clearly demonstrates the capability of producing low shrinkage concrete mixes that include PUDLO CWP, provided there is careful selection of the other mix constituents. The reduction is partly due to reduced water demand in the plastic state and better particle packing achieved in PUDLO-modified concrete.

Water Transportation Mechanisms
The test data shows that water absorption (sorptivity), initial surface absorption, permeability penetration, water vapour permeability are significantly less than a control, Portland cement concrete.

Testing, relative to the control mix, at constant workability carried out at Imperial College indicated that in the PUDLO CWP modified mix sorptivity was 33% of the control value and water permeability was 13% of the control value. At constant w/c ratio of 0.45, these became 59% and 72%; whilst at a w/c of 0.38 they became 47% and 89% respectively. This indicates that PUDLO CWP provides and improvement in performance over and above that of just reducing the w/c ratio of the mix.

Comparable testing of mixes at constant workability, carried out by Taywood Engineering, RMC and the BBA confirmed similar results.

Initial surface absorption tests (ISAT) carried out in accordance with BS 1881: Part 208, in the UK by both Taywood Engineering, and RMC and in the Middle East by Al-Futtaim Bodycote and Fugro Middle East, all returned values for PUDLO CWP modified mixes which were below the lower limit of sensitivity for the test i.e. too low to measure. These results are unique and contribute to greatly enhanced durability.

Durability Characteristics
Oxygen diffusion testing carried out by RMC, on mixes of constant workability, confirmed that PUDLO CWP modified concrete resulted in being 61% of that of the control concrete.The chloride ion diffusion coefficient measured by RMC limited showed the value for the PUDLO CWP modified concrete to be 31% of that of the control. These results, taken together with strength and moisture transport figures, indicate significant durability enhancement when using the integral admixture.

In addition, the indirect, Rapid Chloride Permeability test in accordance with AASHTO T 277 method which measured electrical charge passed and relates this to chloride ion penetrability tests has been carried out on a number of PUDLO CWP modified concrete mixes. In all cases the results gave either a low or very low designation.

Comparison with Other Products
PUDLO CWP admixture also compared favourably with improved or significantly improved performance characteristics over other integral water-resisting concrete systems currently available. In particular, it is considered that the combined admixture system adopted by PUDLO CWP would be more effective where there is a continuous water head or high water pressures compared with systems that that do not control the shrinkage behaviour of the concrete.

Material Properties
PUDLO CWP admixture enables the production of an integral, water-resisting concrete for membrane-free basement or below ground construction. It comprises a multi-blend, fine powder which contains other components such as hydrophobic and pore blocking elements and an efficient water reducer. It appears to convert, during hydration, the free lime in O P Cement to the more stable and harder Calcium Silicate Hydrate. This would account for the consistent, high strength compressive figures for PUDLO modified concretes over the same plain mixes of the same class but without PUDLO.

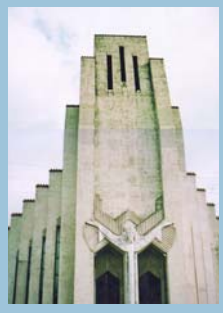
Concrete produced using PUDLO CWP admixture is more effective under conditions of a continuous head of water or higher water pressures than water-resisting concretes that rely entirely on hydrophobic or pore blocking admixtures alone.

Protection against water ingress will rely on design and construction of a high quality concrete, with cracking controlled to prevent the penetration of moisture to an acceptable degree.

There appears to be potential for reducing the quantity of reinforcement required to limit early thermal cracking in a section, provided all the potential benefits of PUDLO CWP admixture in concrete can be quantified and taken fully into consideration.

BS 8110 states that "…design, including design for durability, construction and use in service should be considered as a whole…Calculations alone do not produce safe, serviceable and durable structures. Suitable materials, quality control and good supervision are equally important…".
With typical values of wall reinforcement falling






Below from left to right
The AIG Building, membrane free construction with PUDLO.
AIG underground Membrane free construction with PUDLO.
Cork Church, PUDLO documentation found in original paperwork.
Service tunnels under Addenbrooke's Hospital Cambridge.

between 0.5% and 1.5%, it may be concluded that there is likely to be an increase in capacity to be gained from the increase in strength arising from the reduction in w/c in concrete containing the PUDLO CWP admixture (28 day compressive strengths of 60 MPa to 80MPa have been reported for site produced concrete) instead of Grade 35 concrete typically used in calculations to BS 8007.

Taking into account the reduced drying shrinkage to between 13% and 25% decrease in the quantity of reinforcement required to control thermal and shrinkage movements would be possible. Going back to first principles, the derivation of the steel area can potentially take advantage of the reduction in drying shrinkage.

PUDLO CWP admixture significantly improves 28-day cube strength results. Reduction in the w/c ratio, while maintaining concrete workability, is achieved with the plasticising component in the admixture this, together with the other components, enhances the strength.

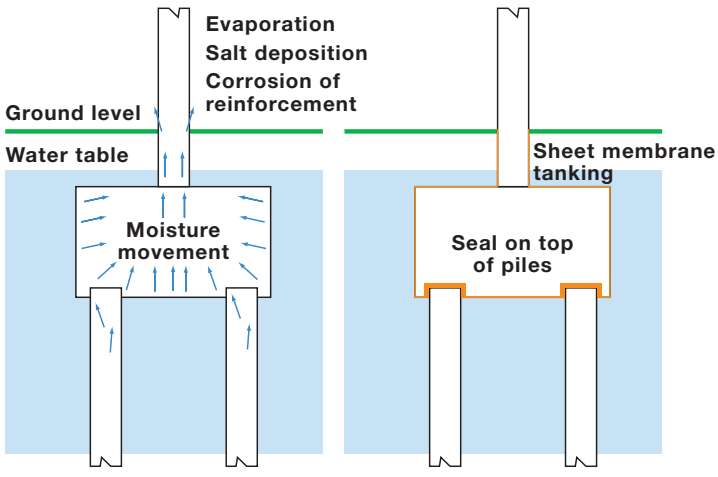
In more aggressive e.g. Middle East environments, the enhanced durability performance of PUDLO CWP modified concrete may be mobilised to achieve the desired design life of the structure without the need for excessively large increases in concrete cover or the introduction of additional forms of surface protection.

Concrete cover to BS8110 and BS8007
The main properties and benefits of using PUDLO CWP admixture to improve water-resistance of concrete can be summarised as follows:

- significantly reduced water permeability
- reduced water absorption
- improved compressive strength
- improved chloride ion penetration resistance
- reduced w/c content ratio
- improved oxygen diffusion resistance
- reduced drying shrinkage of up to 34% therefore, reduced quantity of cracking
- improved workability

By enhancing the water transport properties and cement paste microstructure, PUDLO CWP improved the durability characteristics of the concrete such that membrane-free construction can be undertaken.

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 the potential benefits of PUDLO CWP admixture can be taken into consideration.



Conclusions

If consistent, independent compressive strength tests show 20-30% increase in strength over control concretes, there must be a case to consider reducing cement content to target actual design strengths. Why produce concrete of 70-80 MPa strengths when the design calls for 40 MPa?

If there is no significant improvement in reducing potential crack widths from 0.3mm to 0.2mm, why specify reinforcement steel levels of at least 25% higher to achieve no real benefit?

Tanking systems are notoriously difficult to fix in-situ due to site conditions and once they fail, not only is the concrete vulnerable to aggressive ground and climate parameters, it is usually impossible to locate the exact area of membrane failure.

Designers should use products which reduce both initial and whole-life costs, save energy, save time and have technical and site support services are insurance-backed for a minimum of 20 years and have over 100 years, continuous track record.

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Sustainable Concrete

The designers' new imperative

The David Ball Group
David Ball Group is a world leading developer and manufacturer of specialist sand and cement products. This includes PUDLO CWP the first and technically most advanced concrete treatment for the production of watertight, corrosion-resistant concrete structures.

David Ball Group is also widely regarded as the market leader in the supply of Standard Reference Materials.

For more than 35 years David Ball Specialist Sands has been exporting its unique ultra-high-quality industrial sands around the world for cement testing, electric fuse filling, man made fibre production, water filtration, and all areas where consistency and quality of product are paramount.

PUDLO has a time-proven, unrivalled track record of successful use, spanning over 100 years all over the world. Manufactured exclusively under ISO 9001 accredited quality systems at our factories in Bar Hill near Cambridge, PUDLO eliminates the need for external membranes, thereby saving materials and construction program costs.

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