THE ROLE OF CONCRETE IN SUSTAINABLE DEVELOPMENT

Rob Gaimster[1] and Chris Munn[2]

ABSTRACT

There has been a recent shift in emphasis towards the principles of sustainable development in New Zealand's built environment. Yet, there is a lack of credible information on the contribution that concrete products make to the sustainability of the built environment, particularly from a New Zealand perspective. This paper serves to outline the current position with regard to concrete's contribution to sustainable development in themes such as durability, fire performance, thermal mass, acoustic performance, recycling, storm-water management, roading, demolition and deconstruction et al.

By outlining concrete's sustainability credentials, gaps in the collective knowledge will also be identified. One such knowledge gap surrounds the promising potential of recarbonation. CO_2 sequestration is an important and significant property, which needs urgent research. Furthermore, to support the principle of recarbonation it will be necessary for the current embryonic aggregate recycling industry in New Zealand to develop significantly.

In conclusion, this paper will seek to challenge the industry to overcome complacency and strive for excellence in the sustainability paradigm.

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INTRODUCTION

Concrete is consumed in huge quantities throughout the world to shape the built environment. Only water is consumed more. Concrete has shaped everything from housing, schools, industry and water supplies, to roads and bridges. Civilisation is built on a concrete foundation.

The Government's commitment to sustainable development is stronger than ever, with the Prime Minister's recent opening address to Parliament firmly positioning it at the heart of the Government's policy platform. Comparing the quest for sustainability with New Zealand's nuclear free stance, the Prime Minister outlined a range of Government priorities designed to make New Zealand the "first nation to be truly sustainable". While critical of the Government's sustainable development policy, opposition leader John Key has also embraced it as a strategic issue by emphasising the importance of balancing sustainable resource management with economic development.

The United Nations defines sustainable development as *'development which meets the needs of the present without compromising the ability of future generations to meet their own needs'* (Brundtland Report, 2007). Sustainable development's uptake as a means to direct New Zealand's way forward, to find solutions that provide the best economic, environmental and social outcomes, is testament to its legitimacy (Figure 1).

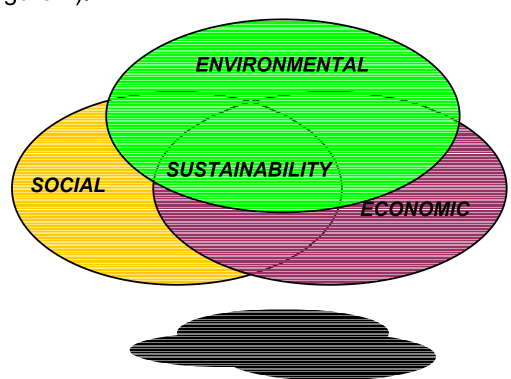

Figure 1: The Triple Bottom Line of Sustainability (Concrete Centre, 2006)

This paper outlines the contribution of concrete to the sustainability of this and future generations, as well as identifying areas for further investigation.

[1] Project Manager, Cement & Concrete Association of New Zealand

[2] South Island Plant Engineer, Allied Concrete Limited

CEMENTING THE FUTURE

Cement is the key ingredient in concrete manufacture. Significant quantities of CO_2 are emitted as part of cement production, due to the energy intensive nature of the industry, and the chemical process of calcining limestone into lime.

Cement producers have developed strategies to minimise their CO_2 emissions, which include the use of supplementary cementitious materials (SCMS) to reduce the energy required to produce clinker, the utilisation of waste fuels and improvements in the energy efficiency associated with cement manufacture.

Supplementary Cementitious Material (SCMs)

SCMs can substitute a proportion of the cementitious component of concrete. They are used for enhancing concrete performance in both its fresh and hardened states, promoting consistence, durability and strength. SCMs are industrial bi-product materials that would otherwise be landfilled as waste. In addition, they reduce the consumption of clinker component per unit volume of concrete.

SCM's include pozzolans, such as fly-ash, which by themselves do not have any cementitious properties, but when used with Portland cement react to form cementitious compounds. Other materials, such as ground granulated blastfurnace slag, do exhibit cementitious properties.

There is a steady international growth in the use of blended Portland cements containing cementitious or pozzolanic by-products internationally (Glavind et al, 2005).

SCMs in New Zealand

General-purpose cement (type GP) is the most common cement type in New Zealand. In type GP cement, blending of up to 5% mineral fillers and up to 1% processing additives is allowed. This has the benefit of reducing the embodied energy of finished cement.

SCMs are not widely available in New Zealand. However, fly ash is available, but is of different chemical composition to that of ash from Australia, complying with the provisions of Type C according to the classification method contained in ASTM C 618-03. It has found general use at reasonable replacement levels in New Zealand.

Use of Alternative Fuels

The use of replacement conventional fuels by the cement industry makes both economic and environmental sense. Environmental benefits include:

- Reducing the reliance on non-renewable fossil fuels.
- Lowering emissions of greenhouse gases.
- Employing a waste material, which otherwise would be landfilled.
- Safely valorising waste with the organic constituents being completely destroyed.
- The containment of metals within clinker.

Golden Bay Cement (GBC), for example, has been using regionally sourced wood waste fuels for over a decade, and Holcim New Zealand Limited has been using waste oil since 1996.

GBC's wood waste is sourced regionally. The energy contributions of wood waste used by GBC equates to approximately 0.2 M GJ annually.

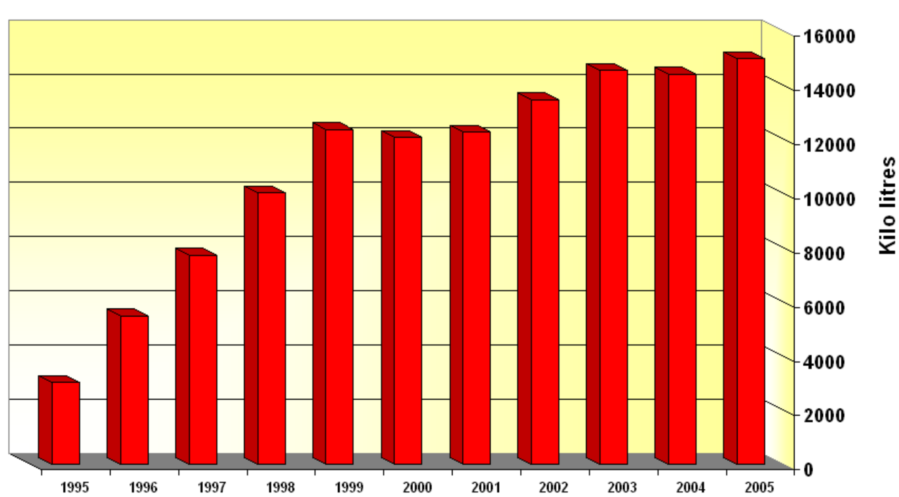

Figure 2: Used oil delivered and co-processed at Westport

The historical use of waste oils by Holcim is significant and is shown below (Figure 2). In 2005, a total of 15 million litres or approximately 0.5 M GJ of energy was produced by burning this fuel.

Holcim's use of waste oil aligns positively with the Government's waste strategy goals (www.mfe.govt.nz).

Energy Efficiency

Cement companies have reduced CO_2 emissions by improving the energy efficiency of the cement kiln operation. Significant reductions in energy use have been realised in recent decades and are occurring continuously. Utilising lower CO_2 fuels such as natural gas and near-carbon-neutral bio-matter has also assisted to reduce emissions.

In the period 1990-2000, the New Zealand cement industry reduced CO_2 emissions from thermal energy by some 18% (source: CIEMA Annual Report 2001). Reductions are continuing.

MANUFACTURING ASPECTS OF CONCRETE

Concrete plants use water both as a concrete constituent and for washing down the plant and equipment at the end of each working day. Between 1200-2000 litres of wash-down water is used per truck, plus 120-140 litres per cubic metre of added water (extra to the moisture in the aggregate) for batching in the concrete (Dallas, 2006). This water can be highly alkaline and, can lead to environmental problems due to its extremely high pH value, if not properly managed (Sandrolini, 2000).

An efficient approach of recycling waste concrete is through the deployment of commercial reclaiming systems. These reclaimers separate out the aggregate and coarse sand portions from waste concrete, with the remaining liquid and fines going into the wash water recovery system and ending up in the slurry water component.

Use of Chemical Admixtures

Chemical admixtures are materials which when added to concrete at some stage during the production process impart beneficial properties in the plastic and/or hardened condition. Admixtures can promote durability and strength.

A further benefit of water reducing admixtures is that they can be employed to effect cement content reductions without any detrimental affect on workability or compressive strength. Cement content reductions of 10% are not unusual thereby reducing CO_2 emissions from cement production.

Admixtures have, in part, contributed to an important innovation in concrete technology, Self-Compacting Concrete (SCC).

ROLE OF SELF-COMPACTING CONCRETE IN SUSTAINABLE DEVELOPMENT

Global uptake of SCC is significant. SCC is able to flow and consolidate under its own weight, and completely fill formwork, even in the presence of dense reinforcement, while maintaining homogeneity and without the need for any additional compaction. SCC offers a number of advantages in comparison with conventional concrete.

The noise associated with the compaction of conventional concrete can be significant, at the building site or precast factory. SCC affords quiet casting therefore reducing the environmental loadings (noise) both for those involved at site level and 'neighbours' inadvertently in the vicinity. Furthermore, the vibration of concrete can lead to blood circulatory problems and 'vibration white finger'. SCC eliminates this issue.

Where strength is not the overarching factor, high replacement levels of waste products such as fly ash can be accommodated in SCC, and indeed enhance the rheology of the plastic concrete.

SAVING WATER AND PREVENTING FLOODS

Ever-increasing urbanisation and climate change impacts can result in flash-flooding. Storm-water therefore has to be carefully managed as it contains sediment, pollutants and reduces groundwater recharge, in turn diminishing aquifer supplies (EBN, 1994).

Concrete plays an important role in the management of storm-water. Concrete urban drainage systems are a benign, low impact design that protects and incorporates natural site features into erosion and sediment control, and storm-water management plans. These systems mimic natural drainage regimes, but do require regular maintenance to ensure optimum performance.

Permeable concrete pavers are one such example, and can play an important supporting role via their ability to allow rainwater drainage through the paved surface into the ground, before being released into sewers or watercourses. They can be used for drives, paths, general landscaping and other hard surface requirements

ROADING

In New Zealand, Transit NZ spends approximately 40% of its total budget on maintenance and operation of the state highway network each year. In some regions where fewer capital works are required, the maintenance spend exceeds the capital spend. In 2005/6, Transit planned to spend $355 million on the maintenance and operation of the state highway network (source: www.transit.govt.nz).

Local research has shown that the combination of rigidity and the smooth surface of concrete paving reduces vehicle fuel consumption for heavy vehicles. Opus International Consultants and the Department of Mechanical Engineering at Canterbury University have established that the coarser the roading surface, the more fuel is used by cars (New Zealand Concrete, 2001).

Concrete roads offer many advantages over flexible pavements, including:

- Lower maintenance costs.
- Fewer delays.
- Lower fuel consumption.
- Lower CO_2 emissions.
- Improved visibility - concrete pavement reflects a larger percentage of light after dark.
- Economic, when looked at from a life-cycle cost (CCANZ, 2004b).

Concrete Road Barriers

A whole-of-life cost analysis carried out by the UK Highways Agency, which has recently specified the Concrete Step Barrier (CSB), concluded that the CSB offered substantial benefits in terms of safety and cost. The safety benefits associated with the CSB are better vehicle containment, reduced impact severity and a secure working environment for road maintenance and traffic management teams.

The CSB is designed to achieve an essentially maintenance free serviceable life of not less than 50 years. The *cost* benefits associated with CSB are:

- Competitive installation cost.
- Negligible replacement or repair costs.
- Reduced traffic congestion.
- Reduced whole life costs (Britpave, 2006).
- Less working width in the central reserve than other barrier systems.

Cement Stabilisation of Sub-bases and Substrates

Stabilisation is the improvement of a soil or pavement material usually, but not always, through the addition of cement. The most common method of stabilisation involves the incorporation of small quantities of binders to the aggregate. These binders include: cements (Portland, blended cements and cementitious blends); lime; bitumen and miscellaneous chemicals. Cement is the most commonly used binder.

The benefits of cement stabilising road pavement layers are manifold:

- Reduced risk of early failure/rutting.
- Reduced cost due to use of in-situ recycled and/or locally available materials.
- Environmental benefits from pavement recycling through less use and transport of quarried aggregates.
- Providing a means by which in-situ pavement materials can be recycled, improved and reconstituted back into the pavement structure.
- Provide trafficable sub-grades as a construction expedient.

Furthermore, cement stabilised roading provide further advantages in reduced rutting, the ability to produce smoother and longer lasting riding surfaces resulting in lower fuel usage for transportation, and a reduction in the layer thickness and lower maintenance (Kirby, 2006a)

THERMAL ASPECTS (INCLUDING PASSIVE SOLAR DESIGN)

Concrete has an essential role to play in passive solar design, mainly through its ability to absorb and later release large amounts of heat and therefore minimise temperature fluctuations. This results in a building that is more comfortable and healthier to live in, during both winter and summer (EECA, 1994).

This ability to function as a structural element while providing thermal mass makes concrete an extremely important construction material (Donn and Thomas, 2001). It is recognised that for cool and temperate climate zones (such as those experienced in New Zealand) well designed high mass construction with a high level of insulation, provides the foundation of sound passive solar design (Reardon, 2001).

The benefits of good solar design can be best shown by the following temperature charts which examine the indoor/outdoor temperature fluctuations of two houses, over wintertime and summertime (see Figure 3).

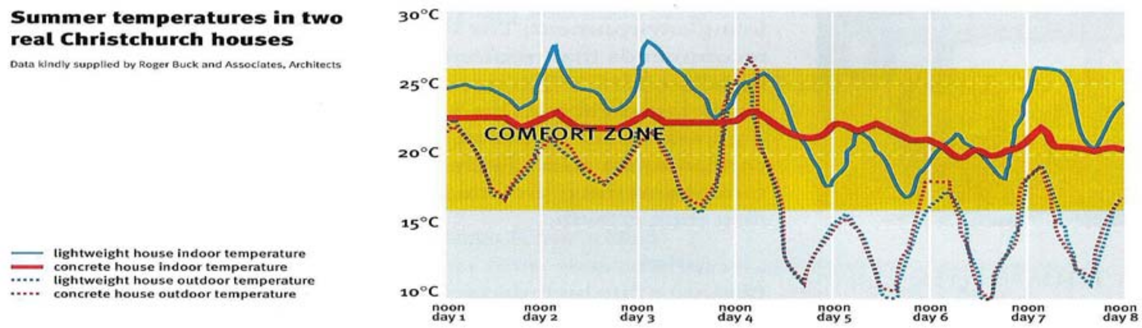

Figure 3: Summertime temperatures of two real houses

The lightweight house, shown as a blue line, has a poor thermal design with a high temperature variation (of approximately $\pm$ 6^{o}C around average). The heavyweight house, shown as a thick red line, has a good thermal design, illustrated by the minimal temperature variation (of approximately $\pm$ 2^{o}C of average) within the yellow comfort zone.

The wintertime benefits of thermal mass were also cited in the study (Arup, 2004).

ACOUSTICS

Concrete is inherently superior compared to lightweight construction in reducing airborne noise transmission, reducing noise from the external environment and in providing sound separation between adjacent rooms.

Concrete offers a good barrier to airborne sounds, while impact sounds can be mitigated using suitable floor and ceiling finishes. One issue in well performing passive buildings is that they do not generate enough background reverberation and unwanted speech maybe heard, particularly in open-plan offices. This can also be designed out using electronic sound conditioning.

FIRE PERFORMANCE

Concrete does not burn or melt. It will also not produce smoke, emit toxic fumes or drip molten material (Concrete Centre, 2004). Concrete structural elements are known to have superior inherent fire performance as not only are they non-combustible, but an endothermic reaction occurs within the cement paste during a severe fire.

This is important from a sustainability context because it reinforces each facet of the triple bottom line model. Good fire resistance properties also have another benefit in that the building reinstatement cost after a fire is often less that that required for other common structural materials. Furthermore, good fire performance results in improved protection when other disasters strike, such as post earthquakes and hurricanes.

DURABILITY AND LONGEVITY

Concrete is robust which affords the opportunity to strip back a building many times to its structural framework, for redesign and refurbishment. Concrete foundation elements from one building can also be reused for another application in a new building.

Since concrete buildings are likely to be demolished due to planning changes and usage changes rather than physical (i.e. durability) condition, engineering for deconstruction and reuse is therefore important. A key to more sustainable concrete structures is maximising the potential to which they can be stripped back to their concrete core, then rebuilt. Providing specifications which support this, through the use of such initiatives as open building systems, access to wall and roof elements and modular design, will assist this process.

Part of a building's longevity is the ability of its component elements to resist extreme weather events, such as flooding. As a consequence of climate change, flooding is predicted to become more frequent in New Zealand (Camilleri, 2000). Concrete's water resistance as a building material means that the re-occupancy of a building can occur quickly, as cleaning, drying and repair is minimised. At most, concrete would only require low cost cosmetic repair.

RECYCLING OPTIONS

In some urban sectors in New Zealand (most notably Auckland), the supply of virgin aggregate used for concrete is becoming a diminishing resource (Park, 1999). As a result, it has become viable to set up concrete crushing operations in these regions. These crushing plants are able to accept, process and on-sell demolition concrete and rubble.

There will undoubtedly be a market 'pull' for recycled aggregates from, for example, the New Zealand Green Building Council Green Star Office

Design rating tool, which encourages the recycling of waste or demolition concrete by awarding points as follows:

- One point if 10% of all aggregate used is recycled aggregate.
- Two points if 20% of all aggregate used is recycled aggregate.

There are many benefits of using recycled aggregate in New Zealand. The potential to increase the usability of cleanfills alone is considerable. It is estimated that concrete accounts for some 26% (by weight) of the waste stream in the Auckland Region, (Patterson, 1997). In addition, there are the benefits of replacing a diminishing resource and reduced tipping fees for contractors. At present, only non-premium roading products and base courses are being made from the demolition aggregate.

There have been several attempts to address this situation in New Zealand (Park, 2001). Preliminary investigations by BRANZ found that using recycled demolition rubble as coarse aggregate is a viable proposition.

Demolition and Deconstruction

Potentially, the greatest recovery of the energy and material resources embedded in a building can derive from the reuse of the complete structure (Gjerde, 2003). Concrete buildings, which employ frame structural systems are well suited to this type of conversion. Benefits include its clear spanning capability together with its structural durability. In most cases the concrete structure will not require secondary fireproofing or acoustic treatment (Gjerde, 2003). At the moment, there is limited research, development and initiatives which pertain just to the reuse of whole buildings or building elements/components.

The European practice of constructing precast concrete buildings that can be dismantled has been available and popular in the market for a number of years. The need for earthquake resistant connections had made this practice difficult and expensive in New Zealand, until new design methods became available in 2004. Auckland International Airport Ltd has already built some of these structures aimed at allowing maximum planning flexibility. The two new parking buildings situated at the Domestic Terminal are designed to be relocated as the airport's needs change.[3]

[3] Stringleman, Hugh (14 May 2004). The carpark that moves as needed. *The National Business Review*. 54-01.

New Zealand's Reinforcing Steel

New Zealand's reinforcing steel is made from 100% recycled, locally sourced scrap. The New Zealand steel reinforcement industry recycles some half a million tonnes of scrap steel per annum which is then used in reinforced concrete, further underlining the sustainability credentials of reinforced concrete.

RE-ABSORPTION OF CO_2

'Carbonation' is the term given to the reaction which takes place between atmospheric carbon dioxide [CO_2] and the hydration products of a hardened Portland cement matrix, which forms the binder of concrete. The main reaction involves the dissolution of Portlandite [$Ca(OH)_2$], which is re-precipitated as calcium carbonate. This is summarised in Equation 1, although the actual reaction mechanism and the ions involved may be much more complex (RILEM, 1976):

$$Ca(OH)_2 + CO_2 + H_2O \rightarrow CaCO_3 + 2H_2O \qquad \text{(Eq.1)}$$

A Danish study reports that approximately 50% of the volume of concrete used for blocks in Denmark will be carbonated in the service life period of 70 years (Kjellsen et al, 2005).

The applicability of results to New Zealand requires careful examination (Lee, 2007). Issues that need to be considered are:

- The energy (and therefore resulting CO_2 emissions) required to reprocess demolition concrete.
- The availability of reasonable quantities of suitably crushed and stored concrete.
- The quality and size of the reprocessed concrete aggregate (since finer fractions have greater surface area and more potential therefore for carbonation).
- The durability implications for reinforced concrete.

Given the uncertainties for the New Zealand context, it is not possible at this stage to quantify a precise figure. However, research demonstrates that it is significant enough not to be neglected in a calculation of the net emissions in the concrete industry.

SOCIAL ISSUES

There is a perception amongst the general public that concrete precludes greenery.

Yet there are many social benefits that can be attributed to cement and concrete products, such as:

- Versatility: concrete is a key building ingredient in housing, schools, hospitals, roads and many more civil engineered structures that make up the built environment within which our society and economy functions.

- Low maintenance: ease of care (of particular importance to the elderly, sick or disabled) and imperviousness to vandalism.

- Better indoor air quality: concrete produces no VOC emissions, is more resistant to mould and allows bare floors, which minimises dust mites (and additionally provides thermal mass) (Nielsen and Glavind, 2006).

- Safety: concrete is fire, wind, vibration, sound transmission and seismically resistant. Sound transmission resistance is becoming more important as housing densities increase, people work more from home, live longer and expect a greater range of use from their houses.

CONCLUSION

In conclusion, the concrete industry has and is continuing to make an invaluable contribution towards sustainable development and this paper has examined a range of initiatives and applications that demonstrate this fact. Areas requiring further investigation, such as CO_2 sequestration through recarbonation, have also been identified.

New Zealand's self-sufficiency in concrete and the materials needed for its manufacture make it the construction material of choice from an economic, environmental and social perspective.

While awareness and appreciation of concrete's contribution to New Zealand's sustainable development is growing within the industry, we must not become complacent. In fact, up to this point in time the New Zealand concrete industry could be accused of under-playing its role.

Having gathered the available information, identified gaps within the collective knowledge, and in doing so answered the question – how sustainable is concrete in New Zealand?- it is now time to lobby influencers, specifiers and consumers with the question - how sustainable is a world without concrete?

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