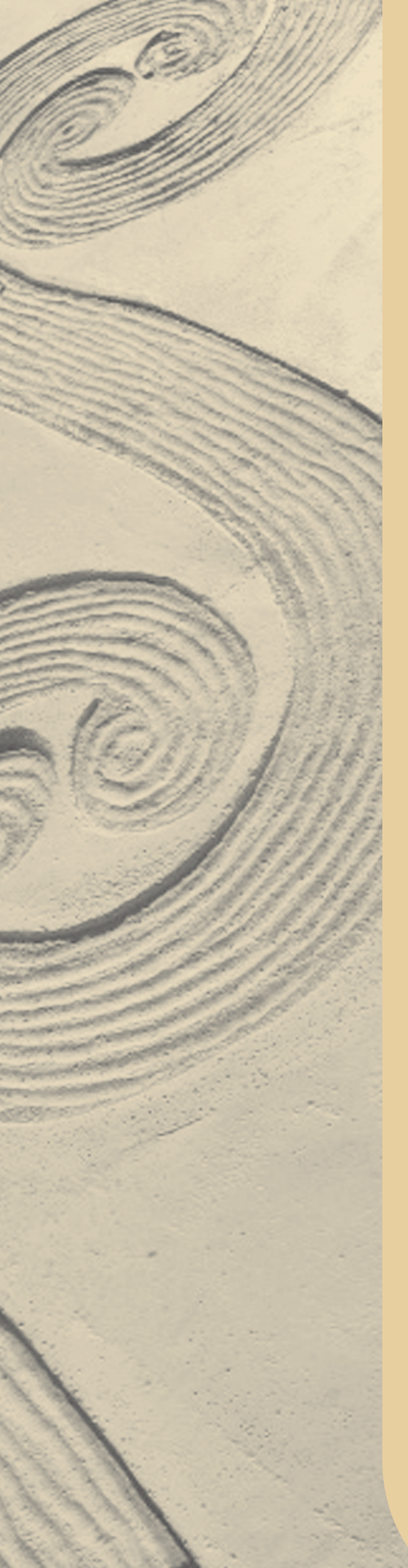
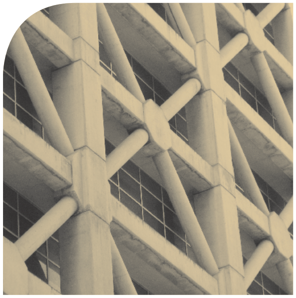
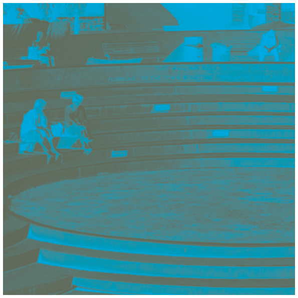
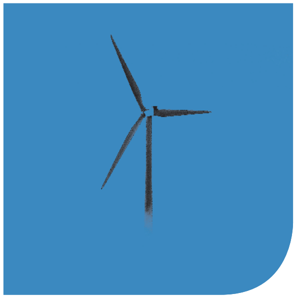








Concrete^3

Economic, Social, Environmental

Concrete in Sustainable Development

www.sustainableconcrete.org.nz

Contents

Sustainable development implies meeting the needs of the present without compromising the ability of future generations to meet their own needs.

1987 Brundtland report of the World Commission on Environment and Development

Introduction

Concrete is the most widely used construction material on earth. In many developed countries, concrete infrastructure comprises about 60% of the built environment.[1]

Concrete has shaped civilizations from as far back as Ancient Egypt and the Greek and Roman Empires. Today, it is indispensable in the development of infrastructure, industry and housing. Without concrete, the built environment would fail to accommodate our modern and demanding lifestyles. Given our reliance on concrete, it will inevitably play a major role in New Zealand's ability to pursue sustainable development.

The importance of sustainable development is currently dominating headlines, and as a concept is frequently defined as the practice of meeting present needs without compromising the ability of future generations to meet their own needs.

The quest for sustainability has been compared with New Zealand's nuclear free stance in the 1980s, and politicians have been enthusiastically pledging their support to make New Zealand the "first nation to be truly sustainable".[2] There is no question that sustainable development has been adopted as the philosophy to direct New Zealand's way forward, and as a means to find solutions that provide the best economic, social and environmental outcomes.

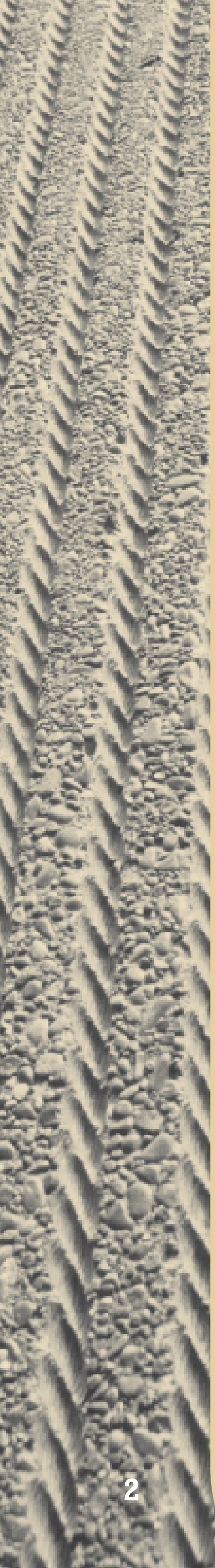
Produced from readily available raw materials, concrete's strength, durability and versatility ensure it provides solutions for the built environment that help achieve sustainable development.

At its most basic, concrete is a mixture of aggregates and paste. The aggregates are sand and gravel or crushed stone; the paste is water and Portland cement. Portland cement is the generic term for the type of cement used in virtually all concrete. Cement comprises from 10 to 15% of the concrete mix, by volume. Through a process called hydration, the cement and water harden and bind the aggregates into a rock-like mass. With appropriate mix design, concrete can be tailored for any construction requirement.

As outlined in the following sections, major efficiencies and innovations in the manufacture of cement and the production of concrete have been achieved over the past decades, while the CO_2 absorption capabilities of concrete are beginning to be fully understood. The reuse of concrete structural elements is becoming more commonplace, along with the recycling of concrete as aggregate. Furthermore, concrete's durability, thermal efficiency, acoustic performance, fire resistance and roading and stormwater management applications, will ensure that its contribution to a sustainable New Zealand construction industry continues to be significant.

This publication seeks to demonstrate how concrete contributes to both this and future generations' sustainable development, and will be of interest to architects, engineers, policy makers, contractors and clients, as well as others involved with the design, construction or operation of buildings and infrastructure.

Sustainable Development - Triple Bottom Line



Cementing Our Future

Over recent decades, there has been a significant drive towards sustainable practices in the cement sector. Production efficiencies have been introduced, along with the use of cement additives and alternative fuels. The development of new cements enabling depolluting and ultra-high strength concretes is ongoing, along with research into the CO_2 absorption properties of concrete.

Industrial Ecology

Considerable reductions in energy use (and therefore CO_2 emissions) in New Zealand have been realised by improving the efficiency of the cement kiln operation, a significant energy user.

Golden Bay Cement's Portland cement plant near Whangarei is operating at world's best practice for emissions management (Case Study 1). Further energy efficiencies and emissions control in cement manufacture are ongoing, as demonstrated by Holcim New Zealand's use of used oil as an alternative fuel in kiln operation (Case Study 2).

The increasing use of supplementary cementitious materials (SCMs) to replace cement and therefore directly reduce embodied CO_2 makes sound ecological sense. SCMs are derived from lower embodied energy, industrial by-products or waste materials, and can result in environmental benefits, improved concrete performance, and long-term cost advantages.

As the global cement industry seeks to reduce CO_2 emissions per unit product produced, there has been a steady growth in the use of blended Portland cements containing SCMs. The most commonly used SCMs are amorphous silica, selected limestone, ground granulated blast furnace slag (waste from steel manufacture) and fly ash (waste from coal combustion).

Alternative Fuels

Cement manufacturers in New Zealand use alternative waste fuels for a substantial part of their operations, and are continually examining the practicalities of increased supplementation as part of their strategic operations.

The environmental benefits of using alternative fuels in cement production are numerous. The need to use non-renewable fossil fuels such as coal is reduced. Using alternative fuels also maximises the recovery of energy from waste, reduces methane emissions, and saves landfill space by using a product that would otherwise not have an outlet.

Golden Bay Cement uses wood waste along with standard coal to fuel its Portland kiln. Wood waste is a cleaner burning fuel than coal, and has the potential for greater production efficiencies while at the same time decreasing carbon emissions. This is also a much more environmentally friendly way to dispose of wood waste, which would otherwise be sent to landfills.

Golden Bay Cement has recently completed a partial re-design and technology upgrade to accommodate the change to mixed fuel use. Initially, wood waste fuel will account for some 10-20% of the company's production energy needs. With further work planned at the plant, it is likely there will be an even greater replacement of coal as the prime energy source.

Up to 20% of the total thermal energy requirement at Holcim New Zealand's Westport Works has been routinely replaced by used oil, making possible a very significant reduction in the consumption of non-renewable coal. During 2006, about 13,300 tonnes of used oil, provided through the government-approved Used Oil Recovery Programme, was consumed in the kilns.

Case Study 1

Golden Bay Cement Portland Plant Redevelopment

September 2006 saw the completion of a four-year project to improve Golden Bay Cement's Portland cement plant (near Whangarei). The redevelopment started in 2003, first by upgrading the kiln firing system, and then improving the clinker cooling and raw materials handling systems and installing closed circuit cement milling.

The major upgrade programme has resulted in an increased capacity to meet the current and future cement demand of the local market. Clinker making capacity has risen from 1750 tonnes per day to 2600 tonnes per day, with an overall production capacity close to one million tonnes. This increased capacity will also offer the ability to look at developing further export opportunities, while ensuring the quality and consistency of cement manufactured at the Portland plant.

The upgrade programme was also undertaken to improve health and safety at the plant through the introduction of new work practices using modern technology. As part of the improvement process, a team of occupational experts was commissioned to systematically document all the plant's standard operating procedures. A careful analysis of the collected data has greatly assisted in establishing best practice.

The plant is now performing to a more competitive level in terms of reliability and operational stability. The maintenance carried out will improve the collection of fugitive dust and reduce housekeeping requirements on site. The gas handling capacity of the kiln has been improved to reduce the visibility and volume of any adverse emissions affecting the environment, as well as improving the production process efficiency and minimising plant disruption.

Golden Bay Cement has reduced the cement plant's environmental impact, and is making a product with many sustainable advantages in its end use. The upgraded plant has fewer emissions and is more fuel-efficient: – a step in the right direction Towards Zero Harm.

World's Best Practice – Golden Bay Cement's Portland cement plant.

Depolluting (Photocatalytic) Concrete

Depollution means the removal of contaminants and impurities from the environment. The newest tool for achieving depollution is a photocatalyst.

Photocatalysts accelerate the chemical reaction whereby strong sunlight or ultraviolet light decomposes organic materials in a slow, natural process.[3]

When used on or in a concrete structure, photocatalysts decompose organic materials, biological organisms, and airborne pollutants. Dirt, soot, mould, bacteria and chemicals that cause odours are among the many substances that are decomposed by photocatalytic concrete. These compounds break down to have a minimal impact on the environment.

Titanium oxide (TiO_2), a white pigment, is the primary catalytic ingredient, and can be incorporated in the cement manufacturing process. When activated by the energy in light, the white pigment creates a charge that disperses on the surface of the photocatalyst, and reacts with external substances to decompose organic compounds.

Photocatalytic concrete has other environmental benefits, such as reflecting much of the sun's heat and reducing the heat gain associated with dark construction materials. This keeps cities cooler, reduces the need for air-conditioning and reduces smog. Designing projects with photocatalytic precast concrete also helps to promote aesthetic endurance, keeping the structure looking like new over time.

Ultra-high Strength Cementitious Materials

Recent developments in ultra-high strength cement materials have enabled the realisation of slender and more elegant forms, more visually appealing surface finishes, and lighter and more durable materials with longer service lives and lower maintenance costs.

Construction materials developed using ultra-high strength cement possess a unique combination of superior strength (compressive and flexural), ductility, aesthetic properties and durability. This enables the equivalent mechanical and load-bearing performance of conventionally built structures to be achieved, whilst requiring less raw material and primary energy, and generating fewer CO_2 emissions.[4]

CO_2 Absorption

Recent research confirms that the carbonation of concrete is a mechanism that counters much of the CO_2 emissions resulting from the original manufacture of cement.[5] Upon exposure to air, concrete and concrete masonry have the potential to absorb (sequester) atmospheric CO_2.

Concrete's absorption of CO_2 can occur either through the use of CO_2 curing technologies in the manufacture of pre-cast concrete products, or as a natural carbonation process that takes place over time. In both cases, the fundamental mechanism for CO_2 absorption is carbonation, which occurs during the service life of a structure and particularly after demolition. Even highly durable concrete with low permeability will sequester CO_2 rapidly when the structure is eventually demolished and recycled.

Traditionally, the carbonation of concrete has been associated with negative issues such as alkalinity loss and corrosion of reinforcement. However, these issues can be easily dealt with by appropriate design.

As carbonation has the potential to reduce the net CO_2 emissions of cement-based materials, it should be considered in life cycle analyses, and will also have a significant effect on the criteria for environmental labeling of cement-based materials.

Further international and New Zealand-based study is still required to accurately quantify the carbonation of concrete as a mechanism to mitigate CO_2 emissions. However, the concept that the world's concrete infrastructure could provide the single largest human-made carbon sink has genuine scientific merit.

Case Study 2

Holcim New Zealand Environmental Initiatives

Holcim New Zealand is firmly committed to the principles of sustainable development in its use of natural resources, and has made a significant effort towards achieving the highest possible level of environmental performance. The following initiatives demonstrate this commitment, and were integral in Holcim New Zealand recently being awarded ISO 14001 certification – an international standard specifying the requirements for an effective environmental management system.

Westport Works – CO_2 Reduction Using Alternative Fuels

Ten years of environmental monitoring data was recently reviewed by Holcim New Zealand. Emissions test data for the kilns operating with coal alone was compared with emissions data from the kiln where used oil is co-processed with coal.[6]

The results confirmed that co-processing of used oil has helped reduce the emissions of CO_2 at Westport Works when compared with using only coal for process heat. Furthermore, it had little other effect on kiln stack emissions, which were well within international limits.

Westport Quarry - Long-Term Rehabilitation

Holcim New Zealand's Westport quarry recently won the 2007 Aggregate and Quarry Association's Environmental Excellence Award for quarry rehabilitation.

The project reflects Holcim New Zealand's long-term commitment to environmental performance, and was initially designed in the 1980s to mitigate the visual impact of quarry operations. However, its objectives quickly grew to incorporate biodiversity aspects of the quarry and its surroundings – these include indigenous forest, a lake within the area of the quarry workings and adjacent wetlands.

The overall goal of the rehabilitation is to restore a mosaic of indigenous forest and wetlands, with 60ha of the total 100ha area so far converted into regenerating and rehabilitated growth.

Environmental Monitoring at Holcim (New Zealand) Ltd Westport Works.

The rehabilitation concept is based on four key sustainable principles:

1) Rehabilitation should mimic natural forest regeneration;
2) Direct human contact is to be minimised;
3) Rehabilitation will be concurrent with quarrying operations; and
4) Cost must be well managed.

The land being restored has been divided into zones based on their specific ecological make-up. The most ecologically sensitive of these is the coastal restoration zone adjacent to the endangered New Zealand fur seal and little blue penguin colonies.

The project has had scientific input from its earliest stages through the School of Forestry at Canterbury University. The university supervised projects assessing the re-establishment of native species in the quarry environs and has presented reports on the success of the quarry so far. This work will form the basis for ongoing monitoring work to provide a long-term understanding of the results of the programme and hopefully establish the site as an important example of rehabilitation.

The additional resources provided and commitment of Holcim employees over the past 20 years has been an example of dedication and continuing effort.

A Sustainable Life Cycle

As with other construction materials, concrete has a life cycle that begins with its creation. However, as a result of its durability, the service life of a concrete structure is prolonged, and once the structure is no longer needed, it can be recycled as aggregate or its structural elements reused.

Recycling

The ready mixed concrete industry is reducing its environmental loading through a series of initiatives and process efficiencies. Many ready mixed concrete producers use recycled water, extracted from their production operations. Additionally, the extensive use of water-reducing admixtures typically enables water reductions of around 10% and a corresponding reduction in the use of cementitious material.

With enhanced understanding of the impact of water and waste disposal, there has been considerable progress in reducing wastewater discharge across the industry's production facilities. It is now common practice to use chemical wash waste systems and aggregate reclaimers to minimise wash waste and water from the cleaning of truck-mixer bowls and plant.

In some New Zealand urban markets, most notably Auckland, the supply of virgin aggregate is becoming limited.[7] As a result it is now viable to establish recycled concrete aggregate facilities in these regions. These plants are able to accept, process and on-sell recycled concrete aggregate. Recycled concrete aggregate is separated from its recyclable reinforcing steel, and can be processed into specific aggregate sizes.

The New Zealand Green Building Council has recently launched Green Star NZ, an environmental rating system for buildings. Green Star NZ awards points within its environmental impact categories for the incorporation of recycled materials in construction projects. As such, when a concrete structure is eventually demolished (most probably as it has no further use rather than failure due to age), the demand for recycled concrete as an aggregate source for structural concrete will increase from those seeking maximum Green Star NZ certification.

Reuse and Deconstruction

Potentially, the greatest recovery of the energy and material resources embedded in a building can be derived from the reuse of the complete structure.[8] Adaptive reuse means that the building is fit for a new use after it is no longer needed for its original use. Concrete buildings, especially those that employ frame structural systems, are well suited to this type of conversion. In most cases, the concrete structure will not require secondary fireproofing or acoustic treatment.

If a concrete building cannot be used in its complete form at the end of its life, then it can be deconstructed. Deconstruction is the partial or complete disassembly of an existing building and elements within it, to be reused in another building. It differs from demolition in that the building components are still in their original component parts.

Self-compacting Concrete (SCC)

SCC is defined as "a concrete that is able to flow under its own weight and completely fill the formwork, while maintaining homogeneity even in the presence of congested reinforcement, and then consolidate without the need for vibrating compaction".[9]

The noise associated with the compaction of conventional concrete can be significant. SCC affords quiet casting and the environmental loadings from noise are therefore reduced. It also eliminates the issue of blood circulatory problems caused by the vibration of concrete. SCC affords the designer greater flexibility in designing complex shapes. It is independent of the quality of mechanical vibration and therefore provides homogeneity leading to improved durability and potential for reuse.

Case Study 3

Golf Links Road, Christchurch New Zealand's First Recycled Road

Internationally, recycled roading materials are widely used. Previously regarded as waste products, the new trend has demonstrated that certain recycled materials, particularly crushed concrete basecourse, are cost-effective and can outperform natural materials.

In late 2003, Fulton Hogan sought the support of Christchurch City Council to help showcase the attributes of recycled materials in New Zealand. The objective was to minimise environmental impacts and encourage sustainable outcomes in the roading industry. A 300m-long stretch on Golf Links Road in Christchurch was chosen as the site for New Zealand's first "green" road, using 100% recycled materials.

Golf Links Road is a busy section of road behind a shopping mall, with high numbers of heavy service vehicles. Using recycled materials on this road has provided a true test of their constructability and durability.

After extensive research, crushed concrete and recycled asphalt were chosen as the most appropriate materials to use in construction of the road – both readily available and commonly used in other parts of the world. The road was completed in June 2005 and is made up of $3000m^3$ of concrete, including a sub-base of AP65 crushed concrete, and a base of AP40 crushed concrete. The top layer was made of recycled asphalt, using material from the millings of other job sites that was reheated and constituted into 15mm-thick asphalt.

One of the major challenges the Fulton Hogan team faced was ensuring that the concrete was substantially free from contamination by other building products, such as plastic, brick and timber.

The Golf Links Road project offered significant environmental and economic benefits. It proved recycling can deliver a huge reduction in the dumping of used concrete and asphalt, as the materials can be used repeatedly as roads are replaced. Significant cost savings can also be achieved. In addition, the use of recycled materials saves on non-renewable natural resources, such as quarry aggregate and petroleum-based bitumen.

Golf Links Road, New Zealand's first recycled road in development.

Recycled materials also offer performance benefits, as the residual cement content of the crushed concrete means it may have higher strength and can perform better than natural aggregate. In addition, the extra water required for compacting crushed concrete means it is well suited to winter construction, when the weather is not suitable for other materials.

When comparing the cost of materials used in isolation using recycled materials for the project had a small additional cost compared with the cost of using conventional materials. However, this does not take into account a whole of life consideration for the disposal of the materials involved, which would significantly increase the overall cost of using conventional materials.

The Golf Links Road project shows that the use of recycled crushed concrete and reclaimed asphalt product offer a high-strength solution, together with the additional benefits of cost reduction, higher performance, and suitability for winter construction.

A Sustainable Life Cycle

Cement Stabilisation

Stabilisation is the improvement of a soil or pavement material usually through the addition of a binder or additive. The use of stabilisation means that a wider range of soils can be improved for bulk fill applications and for construction purposes. The most common method of stabilisation involves the incorporation of small quantities of binders, such as cement, to the aggregate.

Stabilisation is used widely in both the construction of new roads and the rehabilitation or recycling of existing roads worldwide. It is used partly as a response to increasing traffic volumes and axle loadings that contribute to premature pavement failures, and partly where other roading materials are unavailable or the cost of material cartage is prohibitive.

The advantages of using in situ stabilisation techniques to upgrade or recycle existing materials in deteriorated pavements include cost savings of between 30 and 50%, faster rehabilitation, maximisation of materials, and reduced noise and dust pollution.[10]

Compared to other rehabilitation alternatives, in situ stabilisation also saves on landfill space as excavated materials do not need to be disposed of, and minimises the quarrying of replacement materials, which are finite resources.

The other benefits of using cement stabilised roading include reduced rutting, the ability to produce smoother and longer lasting riding surfaces which result in lower fuel usage for transportation, a reduction in the layer thickness and lower maintenance. Recent applications of cement stabilisation in New Zealand have taken place on SH16 in Rodney, and between Hicks and Poverty Bays on SH35.

By allowing premium aggregate to be preserved, and by using marginal aggregate, cement stabilisation's ability to prolong the service life of New Zealand's roading network is completely in tune with the principles of sustainable development.

Reinforcing Steel

Pacific Steel, New Zealand's only reinforcing steel manufacturer, is the primary user of recycled scrap metal in New Zealand, converting more than 280,000 tonnes every year into reinforcing elements for the construction industry. This equates to approximately 265,000m^3 of saved landfill space. Every year some 90,000 car bodies that would otherwise have been left to rust away, polluting the environment, are recycled.

The carbon in end-of-life tyres is also utilised by Pacific Steel. Carbon is an important ingredient in steel making, and the opportunity exists to substitute carbon from pulverised coal with tyre-derived carbon. Historically, end-of-life tyres end up in landfills or littering the landscape. Therefore, by using the carbon in about 3000 tonnes of tyres annually, Pacific Steel's steel-making process is helping to eliminate a problematic source of waste.

Water, air, energy and storm-water controls are also in place at Pacific Steel. It is interesting to note that the Stubbles Report, an independent body of work commissioned jointly by Fletcher Building and the New Zealand Climate Change Office, recognises that Pacific Steel's operation converts scrap metal to reinforcing products as efficiently as any similar international mill.

These recycling initiatives and environmental controls not only reduce waste, but the local production also eradicates the CO_2 emissions that would arise from importing reinforcing steel into New Zealand. Pacific Steel's operation is an example of the potential synergies between manufacturing industries and the sustainable use of natural and physical resources.

Case Study 4

Precast Concrete Car Park Building Designed for Deconstruction and Reuse

Worldwide Parking Group Ltd has developed an innovative precast concrete system for car parking buildings around New Zealand that offers a range of benefits, from design versatility and speed of assembly through to the potential for reuse on other sites.

The precast concrete system's most striking feature is the patented demountable connections, which mean that at any given point in time, the structure's standard components can be dismantled and removed from the site for storage or re-erection on another site.

The technology refines established multi-storey, precast concrete technology by incorporating patented seismic connections and foundation systems, and new concrete mix designs, reinforcement and casting techniques. Rationalising component sizes has also led to efficiencies in cost and planning.

The system uses standardised precast concrete structural components that are assembled without the need for poured or welded connections, utilising patented reinforcement and connections. Innovation in the design of services, structural framework, fixtures, fittings and equipment, also make it possible to achieve rapid and orderly construction.

The precast concrete system was used in the construction of the Nuffield Street car parking building in Newmarket, Auckland. The building has four levels, with provision to add more car parks through the addition of another floor.

The car parking building has about 320 components, manufactured offsite by Stahlton Prestressed Concretes, Wilco Precast Ltd and Stresscrete. The components include columns, spandrels (which support the floors and act as handrails), and 18-tonne double-T floor pieces, measuring 2.5m wide and 16.7m long. The simple design involves placing the spandrels in rebates on the columns, with the double-T beams sitting over, and being bolted to the spandrels.

Assembly of the car parking building at Auckland Airport.

The Nuffield Street car parking building is the third Worldwide Parking Group system project completed in New Zealand, following the construction of two domestic terminal car parking structures at Auckland International Airport. The airport was seen as an ideal location to showcase the system's advantages as the buildings can be dismantled and re-erected as the airport's plans require.

The first domestic terminal car parking building was completed in April 2004 after a three-month construction period and is a single storey structure for 300 car parking spaces. The first building has performed well and has led to significant developments in the precast concrete system, which have been adopted in the construction of the second domestic terminal car parking building.

These innovative structures will become a more familiar sight as specifiers become aware of precast concrete's lifecycle cost advantages. Pre-engineered standardised concrete components ensure a low cost outlay, fast assembly, early occupation, minimal maintenance and potential reuse – all benefits which are attractive in a construction environment concerned with sustainability.

Concrete and the NZ Economy

The cement and concrete industry plays a substantial role within the New Zealand construction sector, which itself is crucial to the country's overall economic wellbeing. During 2005 and 2006 the economy, as measured by GDP, grew by an average of 2.05%. The value of all New Zealand building consents issued in 2006 was $11.18 billion, an increase of 2.2% over the previous year.

As the New Zealand economy grows, so too does the construction industry, and in turn the demand for concrete. Concrete's whole-of-life cost advantages, based on its inherent properties, also contribute considerably to New Zealand's sustainable economic development.

Local Reources

The cement and concrete industry has impressive credentials in terms of its use of materials that are extracted and manufactured within New Zealand. This is in line with the increased demand for building materials (and products) that are sourced and processed locally, thereby creating jobs and reducing the environmental impacts resulting from transportation.

New Zealand is virtually self-sufficient in concrete, and the associated materials required for its production. Along with the fact that ready mixed concrete is generally produced within close proximity to where it is cast, this means that concrete more than meets the sustainable development principle of products being consumed near to the place of their production.

Household Economy

The thermal capacity of concrete and concrete masonry, often referred to as its thermal mass, enables it to absorb, store and later radiate heat. Exposed concrete can absorb heat during the daytime, reducing temperatures by 3° to 4°C, and delaying peaks in temperature by up to six hours.[11] During the night, natural 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 can reduce or even eradicate energy-intensive air-conditioning, while maintaining a comfortable temperature for occupants. To optimise concrete's thermal mass, it must be used in conjunction with higher thermal insulation, window placement for good solar gains and natural ventilation as part of an integrated and sustainable passive design.

There has been extensive research modelling the performance of thermal mass in residential housing under New Zealand environmental conditions.[12] Thermal mass can also be effectively used in the commercial sector, with the Maths and Computer Science Building at Canterbury University an excellent example.

The use of concrete and concrete masonry in homes enables reduced energy consumption for heating through improved air-tightness. Further financial savings can be achieved as a result of concrete's ability to reflect natural light and therefore reduce the need for artificial lighting.

Building Rating Systems

The New Zealand Green Building Council's Green Star NZ rating system is used to assess the environmental impact of offices against eight environmental impact categories, plus innovation. Within each category, points are awarded for initiatives that demonstrate a project has met sustainable development objectives during the different phases of a building's development (design, fit-out and operation). Points are then weighted and an overall score is calculated, determining the project's Green Star NZ rating – 4 Star = Best Practice, 5 Star = New Zealand Excellence, and 6 Star = World Leadership.

Although a relatively new initiative, Green Star NZ is being widely recognised and accepted by the construction industry. Owners, operators, and their clients and tenants are being driven by the desire for "green certification" of a building, which will provide opportunities for the sustainable attributes of cement and concrete to be recognised.

Case Study 5

Meridian Energy Building – Wellington Waterfront Concrete Core to Sustainable Building Design

In December 2004, Meridian Energy identified the need for larger premises, and initiated a project to develop office accommodation that met its immediate and long-term operational needs, and reflected its commitment to renewable energy and sustainability.

The construction project adopted Ecologically Sustainable Design (ESD) objectives to ensure the Meridian building would respond to and utilise external environmental conditions. To help achieve the ESD objectives, designers referred to the Australian Green Star office building rating tool.

The designers' efforts to optimise energy use and year-round comfort included extensive use of natural light and ventilation, as well as insulation. In the building, solar gains are controlled by active shading systems, while the natural air supply is sourced entirely from the outdoors. These innovative features have been integrated into an overall passive design through the thermal mass properties of the building's concrete shear wall core and other exposed concrete surfaces.

The designers of the Meridian building were aware that concrete walls, columns and floors have the capacity to store and release heat. This function has the effect of regulating the internal environment by reducing and delaying the onset of peak temperatures, to create healthy working environments for the occupants and reduce energy consumption costs for building tenants and owners. This can also be cost-effective if the concrete utilised is already part of the building's structural components.

The use of exposed concrete as part of an integrated passive design to achieve low energy thermal comfort has been widely used in commercial offices throughout the UK and Europe. The Meridian building's focus on ESD, and its profile at the forefront of sustainable building design, should increase the understanding and appreciation of concrete's thermal mass properties within New Zealand.

Meridian Energy building on the Wellington waterfront.

The Meridian building's ESD credentials have also been increased by the use of Holcim New Zealand's Duracem. Duracem is blended cement with an iron blastfurnace slag content of around 65%. The decision to utilise concrete containing a supplementary cementious material enabled a reduction in the Portland cement content and therefore an increase in the building's "green" rating.

Used in the Meridian building's jump-formed concrete shear core and the external precast elements, Duracem's unique blend reduced the permeability of the concrete, inhibiting chloride ions from reaching and corroding the reinforcing steel, and therefore preventing any resulting expansion, cracking and spalling of the concrete. Duracem cement was also used in the Meridian building's concrete piles, which are submerged to a depth of around 18m.

The Meridian building has created a new environmental performance benchmark for New Zealand's commercial buildings. To help realise the objectives of their sustainable design philosophy, the building's planners have looked towards concrete's thermal mass properties and the benefits of concrete incorporating an SCM, such as blastfurnace slag.

Concrete and the NZ Economy

Concrete Roads

Roads play a very important part in any nation's infrastructure. Their construction and maintenance, and the vehicles that travel over them, consume large amounts of energy. This energy use results in atmospheric emissions, the reduction of a non-renewable resource, and other environmental impacts. Any reduction of the lifetime energy use associated with roading, even if only by a small percentage, will have significantly positive implications for sustainable development.

Concrete roads are durable and safe. They are considerably less prone to wear and tear defects like rutting, cracking, stripping, loss of texture, and potholes that can occur with flexible pavement surfaces. This low maintenance requirement is one of the principal advantages of concrete pavements. There are well-designed concrete pavements that have required little or no maintenance well beyond their 40-year design lives. Less maintenance also means fewer traffic delays, a huge advantage on some of our already congested highways.

Fuel consumption is a major factor in the economics of roading, with the rolling resistance of the pavement being an important contributor to the fuel consumption and the corresponding CO_2 production. Rolling resistance can be attributed in part to a lack of pavement rigidity. In the case of a heavily loaded truck, energy is consumed in deflecting a non-rigid pavement and sub-grade. Using rigid concrete pavement will result in less fuel consumption, and a decrease in associated emissions.[13]

In New Zealand, concrete pavement, such as the Peanut Roundabout near the Port of Napier (Case Study 6), is currently restricted to areas requiring high-strength roading components. This is mainly as a result of first-cost rather than a whole-of-life cost approach. The lifetime costs of concrete roads are, however, lower than asphalt.

Another benefit of using concrete as opposed to alternative flexible pavements is a reduced need for street lighting, due to higher surface reflectivity after dark. Better light reflection on the brighter surface could potentially result in electricity savings of about 30% for lamps, lampposts and signs.[14] However, the largest savings from higher surface reflectivity are to be gained from a reduction in accidents, and the associated loss of life and serious injury.

Concrete Road Barriers

The benefits of concrete road barriers make them a suitable and affordable alternative to wire median barriers. Concrete road barriers can easily meet the performance criteria required for New Zealand's roading infrastructure, as evidenced by recent developments from overseas.

Developed in the Netherlands, the Concrete Step Barrier (CSB) has proven successful in preventing dangerous motorway accidents where the central barriers have failed to restrain a crashing vehicle from crossing over into the face of oncoming traffic.[15] Their profile design minimises injury by redirecting the vehicle along the direction of the flow of traffic.

Concrete barriers also require less working width in the central reserve than other barrier systems, allowing motorway lanes to be increased in number without major planning and traffic disruption.

A whole-of-life cost analysis carried out by the UK Highways Agency, which has recently specified CSB, concluded that the it offered substantial benefits in terms of safety and cost. CSB is designed to achieve an essentially maintenance free serviceable life of not less than 50 years.

Case Study 6

Peanut Roundabout – Port of Napier
Concrete Roads for Low Speed, High Stress Applications[16]

Concrete is often used on industrial pavement sites within New Zealand that have high volumes of heavy traffic. However, the initial cost to the public roading network of using concrete has meant that bitumen-bound materials have been preferred.

Even so, short sections of concrete pavements in high-stress areas can provide a long-term solution with minimal maintenance. Therefore, Transit New Zealand is now trialling short concrete road sections to take advantage of the superior strength and robustness of concrete.

The Peanut Roundabout in Napier is an example of a trial site that is part of Transit New Zealand's programme. This section of SH50 carries most of the fully laden trucks bound for the Port of Napier and has a history of surfacing distress due to the tight curvature and high volumes of heavy vehicle traffic.

The brief for the project was to design and construct a sound and rigid concrete pavement that provided adequate skid resistance for the traffic environment. In addition, construction of the road had to be finished with minimal delays to the travelling public.

Construction of the roundabout was completed in just five days. On the first day, the existing pavement was removed and stockpiled, the subgrade prepared and the proof rolled. On day two, the stockpiled pavement was stabilised and the surface prepared for concrete.

On day three, the road was concreted and cured. Concrete with a compressive strength of 30MPa was used along with mixed grades of sealing chip and crushed aggregates. Polypropylene and structural synthetic fibres were used to reduce plastic shrinkage and increase flexural strength. The concrete was screeded by hand, delivered at 60mm to 80mm slump, and superplasticised to around 110mm in order to achieve the desired workability.

Poorly designed and constructed joints can lead to differential settlement. To overcome this, dowelled joints at 200mm centres were employed at regular 5m intervals transversely along the road to suit the road geometry. The concrete was poured directly up to the cut edges, with no local thickenings or slab anchors used.

Peanut Roundabout – Port of Napier.

On day four the joints were saw-cut, and on day five the line marking was completed, and the road opened once adequate concrete strength was confirmed.

Since the roundabout was completed, the pavement has performed well – no cracking is visible and no differential settlement is evident. Expected wearing of the surface has occurred in the running path, while in the low-speed environment skid resistance is not compromised.

The use of concrete in road pavements is a practical way of providing a long-term durable solution for highly stressed local sections of roads. As demonstrated by this trial site, a sound pavement structure, adequate surface texture, and constructability during a short time period can all be achieved with the use of concrete.

Concrete and You

As daily life becomes more hectic with increasing demands placed on our time, we all crave a peaceful home environment as respite from the outside world. Concrete's inherent properties of durability, strength, thermal mass, fire and acoustic performance, along with its suitability for storm-water management applications, make it an ideal construction material to keep our families safe, secure, warm and dry.

Durability and Longevity

Concrete and concrete masonry endures. As a highly durable construction material with low maintenance requirements, well-designed concrete structures can be expected to exceed their minimum service life as specified in the New Zealand Building Code, and in some cases last for centuries (Case Study 7). Over recent decades, technological advances have led to high performance concrete that can be engineered to suit the most demanding specifications.

Concrete's long life means it is more likely that a concrete building will come to the end of its life because no further use can be found for it (social or economic obsolescence), rather than the concrete having failed due to age. As such, concrete's durability allows for the chance to repeatedly strip the building back to its structural framework for redesign and refurbishment, after the initial use of the space has passed. Concrete foundation elements from one building can also be reused for another application in a new building.

Concrete also has the ability to resist extreme weather events such as flooding, which is predicted to become a more common occurrence in New Zealand as a result of climate change. Concrete's water resistance makes quick re-occupancy possible as cleaning, drying and repair are minimised. This has economic as well as social and environmental benefits.

Comfort

The World Health Organisation recommends a minimum indoor temperature of 16ºC to reduce the risk of respiratory infections.[17] Concrete's thermal mass helps maintain temperatures above this level. In a concrete structure, temperatures are less likely to drop below 9ºC, a level where there is an increased risk of dust mites and allergens. Concrete walls also tend to remain at a more stable temperature, reducing condensation and thereby minimising mould and fungi growth.

Fire Performance

Concrete structural elements are known to have good inherent fire performance. Concrete is non-flammable, non-combustible, and more robust in fire than other structural systems as it can absorb a greater amount of heat before reaching critical overload.

Concrete simply cannot be set on fire. As it does not burn, concrete does not emit any environmentally hazardous smoke, gases or toxic fumes. In addition, unlike some plastics and metals, concrete will not drip dangerous molten particles. Concrete also acts as an effective fire shield as its mass confers a high heat storage capacity while its porous structure provides a low rate of temperature rise.

The majority of concrete structures are not destroyed in a fire, and can therefore be repaired easily, minimising inconvenience and cost. Everyone from private owners and insurance companies, to local and national authorities, share the economic benefits of fire safety, and its contribution to the sustainable upkeep of critical infrastructure.

Concrete's superior fire performance also ensures that buildings remain stable during fire. This enables occupants to survive and escape, while also allowing emergency services to work safely.

Case Study 7

The Pantheon – Rome
Built to Last Millennia

Almost 2000 years old and virtually intact, the Pantheon in Rome stands as testament not only to the engineering skill of an Empire that accelerated the development and application of concrete, but also to the durability of concrete as a sustainable construction material.

The Pantheon ("Temple of all the Gods") was originally built as a temple to the seven deities of the seven planets in the state religion of Ancient Rome. Built of concrete, it has been in continuous use throughout its history, and is the best preserved of all Roman buildings.

The Pantheon's massive portico, consisting of three rows of eight columns, leads to the rotunda, upon which rests the building's most distinctive feature – its 43.2m-domed concrete roof.

In order to support the dome, eight-barrel vaults in the massively thick 6.4m rotunda wall carry its downward thrust. In the absence of steel reinforcing, the dome's weight was minimised through several design features. The dome is configured as five rows of 28 square coffers that diminish in size as they approach the central 8.7m diameter opening (oculus) at the top of the dome. The coffers not only enhance the aesthetic of the building, but more importantly they reduce the thickness and therefore the weight of the concrete dome. At its base the concrete dome is more than 6m thick, but diminishes to about 1.2m at the edge of the oculus.

Also crucial to the dome's reduced weight are the variances in the type of concrete. Towards the oculus, unglazed to further reduce the dome's weight, a much less dense concrete mix was used containing a relatively light pumice aggregate.

While the Romans cannot be credited with the invention of concrete, an honour belonging to the Egyptians, they were certainly instrumental in its large-scale uptake. This adoption is based upon the use of volcanic ash from near Pozzuoli, which when combined with lime resulted in a concrete far stronger than anything previously produced.

Pantheon - Rome.

Pozzolanic cement, as the material became known, quickly established itself as a core construction material in all large-scale Roman construction projects. The theatre at Pompeii, built in 75 BC relied heavily on concrete, as did the Colosseum, built around AD 82. As the largest and most iconic of Roman amphitheatres, the Colosseum made use of dense concrete in its foundations, as well as lightweight concrete in its numerous arches and vaults.

Hundreds of examples of Roman structures made using concrete still stand today, ranging from magnificent temples and sporting arenas, to functional bridges, aqueducts, reservoirs and sewers. There are even instances of the underwater use of concrete in Roman breakwaters. Their continued existence today embodies not only the enterprise and innovation of their creators, but also the long-term durability of concrete.

Concrete technology has undoubtedly developed over the centuries, but it is not a coincidence that the designers of Te Papa, New Zealand's national museum, chose concrete as its structural material to achieve a 350-year expected life without significant maintenance.

Concrete and You

Robust and Secure

Concrete will not rot, rust or corrode. In fact, concrete actually gets stronger throughout its life. Reinforced concrete, with its capacity to accommodate alternative load paths, is ideally suited to New Zealand's seismic conditions.

Concrete's high resistance to wear means less maintenance, which is particularly important as the consequences of global warming have led to more extreme weather patterns. In certain regions of the world, concrete's ability to withstand increasingly severe storm events has led to a surge in concrete construction.

In the path of unpredictable and violent climatic conditions, concrete buildings offer their inhabitants added security from debris. Concrete's virtual impenetrability also contributes to community and personal safety, as it can withstand willful damage and resist arson.

Acoustic Performance

The sound insulation and acoustic performance of buildings has grown in importance over the past decades due to the trend for inner-city apartment living and multi-unit housing complexes. The proliferation of high-powered entertainment systems has also placed unprecedented demands on housing in terms of its acoustic performance.

Due to its high-density, concrete has advantages over lightweight construction materials in various aspects of acoustic performance, specifically reducing airborne noise transmission, reducing noise from exterior sources and providing sound separation between adjoining rooms.

While exposed concrete may heighten impact sound, various integrated design solutions have been developed to address the problem of incorporating an adequate degree of acoustic absorbency without reducing the thermal functionality of an exposed concrete surface.

The overall sustainability implications of concrete's acoustic absorption properties lie in the potential to enhance building occupants' productivity, health and wellbeing.

Storm-water Management

There are many opportunities where concrete products can be used to improve storm-water control. The amount of impermeable land is increasing, and as it grows so too does the amount of storm-water that flows along its surface as run-off.

How storm-water is managed has a tremendous effect on pollution levels in streams, rivers and lakes as it contains sediment that strips nutrients from the land, and pollutants such as pesticides from agricultural land, bacteria from livestock wastes, and fuels and oils from vehicles. Excessive storm-water also reduces groundwater recharge and therefore diminishes aquifer supplies.[18]

The use of pervious (also referred to as permeable) concrete and pervious concrete pavers can play an important role in an overarching management strategy to mitigate the environmental impacts of storm-water. This role is based on their ability to allow rainwater to drain through the paved surface in a controlled way into the ground before being released into sewers or waterways. Their applications can be as diverse as drives, paths, general landscaping or other hard surface requirements.

Low impact design is an approach for site development that protects and incorporates natural site features into erosion and sediment control and storm-water management plans. This new approach contrasts with the conventional approach of discharging storm-water directly to large scale piped systems. These systems mimic natural drainage regimes and improve visual and amenity forms.

Whether of the conventional type or the turf block type, pervious concrete is a simple and effective means of reducing the amount of storm-water. Its use may reduce the necessity for other more expensive storm-water reduction measures, thus contributing towards sustainability, both environmentally and economically.

Case Study 8

Kaikoura's Lyell Creek - Flood Protection System Functional and Aesthetic

Designed to protect Kaikoura from flooding, the Lyell Creek floodwall utilises the durability and versatility of concrete to create a piece of town infrastructure that is both effective and aesthetically pleasing.

Kaikoura has been flooded 16 times since 1923, including the devastating Christmas Eve flood of 1993 that caused $12 million in damage and prompted a review of the town's flood protection. After careful assessment of available reinstatement options, it was decided to provide a channel with the capacity to convey all the floodwater that could flow under the SH1 bridge to the sea.

The challenge was to provide a flood channel through the backyards of shops and the most frequently used tourist area in the township. Given the very limited space available, and the requirement for increased flood capacity, a new continuous protective concrete wall was selected as the only practical solution to address flooding issues. Construction began in 2004 and was completed two years later. The project is the culmination of 10 years' work by Environment Canterbury to provide better flood protection further upstream.

The 400m-long wall has been designed to keep floodwaters out of the town. While the floodwall can contain a 160m^3 per second flood, the foundations were designed to allow the height of the floodwall to be increased to match any future growth in flood capacity that could result if the state highway bridge was raised.

The floodwall has numerous innovative features, such as a section with an adjustable weir installed, which will allow fine-tuning during floods to maximize flood capacity. Removable stop logs have also been incorporated to allow town floodwater back into Lyell Creek in the event that water gets into the town upstream at the state highway bridge.

Where possible, the position of the wall has been adjusted to improve car parking and access to buildings. A wavy wall top was incorporated into the precast concrete panels, which along with an exposed concrete aggregate surface decoration enhances the visual appeal and evokes the nearby seascape.

Kaikoura's Lyell Creek - Flood Protection System.

With co-operation from Kaikoura District Council, the finished work also incorporates a concrete amphitheatre and a new concrete footbridge to the beachfront, which are well used by locals and tourists alike. Inviting the locals to choose the wording that would be cast into the concrete contributed to community ownership of the project. After consideration, the local runanga suggestion was adopted: "KI UTA KI TAI - The Conservation and Protection of the Mountains to the Sea".

Extensive consultation during the project revealed opportunities for associated community enhancements. The result is an innovative, flexible, cost-effective and aesthetically acceptable piece of infrastructure that relies heavily upon concrete to not only mitigate flooding, but also to foster civic beautification and social inclusion.

Supporting Renewable Energy

Supporting Renewable Energy

As New Zealand's population and economy grows, so too does its demand for electricity. With diminishing fossil fuels and an increased awareness of their environmental impact, the spotlight has fallen on renewable energy sources. Wind power is increasingly looked to as the renewable energy source of the future. The inherent properties of concrete can maximise production capacity through innovative and robust foundation design, as well as facilitating the construction of taller and stronger wind towers.[19]

Wind Farm – Concrete Foundations

Concrete is well suited for use in a range of foundation types for both onshore and offshore wind towers. As turbines become larger, foundation costs become a significant proportion of the total cost of wind farm development and influence the overall cost of energy. Foundation design and selection of materials is therefore critical.

Concrete foundations can be designed in a range of sizes, shapes and densities to optimise tower stiffness, foundation pressures, and reinforcement and formwork requirements. They can be designed as ground bearing or as a pile cap and can incorporate excavated material from site to maximise foundation stability and eliminate site waste.

Concrete Wind Towers

With the anticipated growth in wind farms throughout New Zealand, increased emphasis will be placed on higher power outputs. To meet this demand, wind towers will have to become taller and stronger in order to gain access to more powerful wind currents and accommodate larger turbines and rotor spans. These requirements mean that concrete is the ideal construction material.

Depending on site conditions and accessibility, both in situ and precast methods of construction are suitable for concrete wind towers. In situ construction can assist to overcome a problematic site, while also requiring minimal form and space. Precast techniques enable high quality sections to be produced efficiently under controlled conditions.

Flexibility of construction methods means concrete is suitable for demanding offshore installations. Gravity foundations can be constructed onshore and delivered for assembly using existing flat top barges. A similar procedure can be followed for the delivery of individual precast concrete sections of the pylon.

Concrete's high dampening properties can help reduce noise emissions and structural fatigue in wind towers. The use of concrete in gravity foundations also improves dynamic response, while the wind towers in-service performance can be optimised further through pre-stressing.

Concrete wind towers may incur a greater initial investment than using alternative materials, but could prove extremely economical over their prolonged life due to durability and higher power generation potential. Pre-stressed concrete wind towers can also accommodate multiple future-generation turbine retrofits, thereby increasing service life.

When constructing concrete wind towers, the levels of embodied energy and CO_2 are significantly reduced in comparison with other materials, as is the period of operational time required to offset the energy consumed during their construction.

As a durable and versatile construction material, concrete can facilitate taller and stronger wind towers which can help New Zealand meet its current renewable energy supply targets and in so doing contribute to sustainable development.

Case Study 9

Te Apiti Wind Farm
Turbine Foundations - Design and Construction[20]

Te Apiti was Meridian Energy's first New Zealand wind farm and is the largest in the Southern Hemisphere. The wind farm's total installed capacity of 90MW generates enough clean, sustainable electricity to meet the electricity needs of approximately 45,000 homes. These large structures are now a striking feature on the local landscape. What is not so obvious is the concrete foundation that supports each structure.

Prior to the construction of the wind farm, a comprehensive geotechnical investigation was undertaken by Opus International Consultants Ltd to determine the ultimate foundation bearing capacity and soil shear modulus.

Foundations for wind turbines are low-frequency machine loaded structures subjected to coupled horizontal-rocking vibrations. Therefore, extreme loads, production loads and fatigue loads were all analysed during the design phase. To optimise the diameter and thickness of the pad, preliminary design studies were also undertaken with a simple rigid disk model.

Forces on the foundation pad were analysed using a model that indicated large variations in both bending moment and shear force across the width of the pad and these were averaged for design. Grade 500E reinforcement was used to provide the necessary flexural strength and to maximise fatigue resistance. The transfer of vertical forces from the tower steel shell into the concrete foundation via embedment of the cylinder was also resolved.

Following the exhaustive design process, engineers selected a shallow gravity pad foundation as the most appropriate design for each of the 55 turbine structures at Te Apiti to rest upon. These concrete pad foundations are suitable for most ground conditions. The pads are a 16m wide octagonal shape with depths varying from 2.55m at the centre to 1.5m at the edges. Each pad contains 375m^3 of 30MPa concrete and 28 tonnes of reinforcing steel. This is a total of 22,000m^3 of concrete for the wind farm.

Te Apiti Wind Farm.

Due to the thickness of the foundations (2.55m maximum), they contain a huge volume of concrete. As such, there was a risk that large temperature rises associated with heat-of-hydration effects could result in thermal gradients across the depth of the pad sufficient to cause thermal cracking. The concrete supplier, Higgins Concrete Ltd, therefore designed a concrete mix to control temperature rises. This was achieved primarily by the partial substitution of the highly reactive Type GP cement with fly ash. The use of a larger 30mm aggregate also enhanced the strength properties of the concrete, and minimised thermal gradients.

Te Apiti wind farm embodies a sustainable approach to the construction of infrastructure on many levels. It generates renewable electricity without producing greenhouse gases and therefore protects the environment. Concrete foundations guarantee long-term durability within a demanding environment, while the use of a supplementary cementitious material has reduced the Portland cement content of the concrete and further enhanced the project's contribution to sustainable development.

Summary

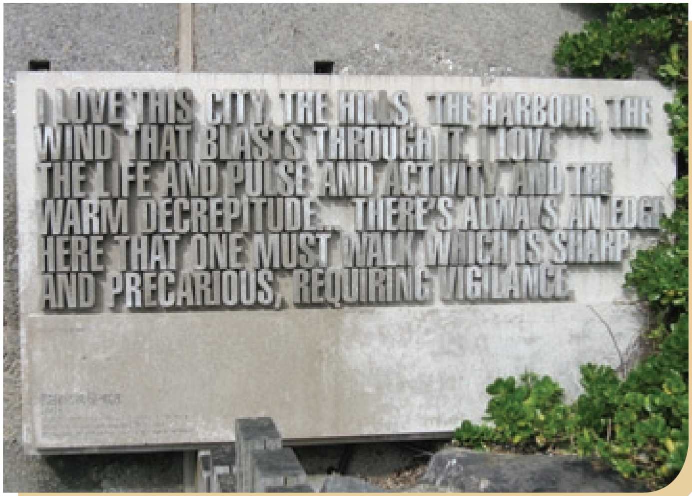
The need to strive for sustainable development is now recognised as a global imperative.

Strategies that encompass economic, social and environmental solutions within an overarching holistic approach are required to ensure that future generations are not disadvantaged by current consumption patterns.

Recognising the importance of immediate action, the cement and concrete industry of New Zealand has fully committed to the quest for sustainable development.

Efficiencies and innovations during concrete's manufacture, along with its inherent properties in a range of applications, ensure that concrete provides solutions to the built environment that help New Zealand achieve sustainable development.

The question should not be, how sustainable is concrete? But rather, how sustainable is a world without concrete?



Wellington Writers Walkway.

References

[1] Mak, S.L. (1999). Sustainable use of concrete through carbon abatement and sequestration. Proceedings of the Int. Power & Energy Conf., Churchill, Victoria, Australia, 1999.

[2] Rt. Hon Helen Clark. *Speech notes for address to Buddle Findlay Sustainability Seminar.* Wellington. (8/05/2007). Retrieved August 2007 from www.beehive.govt.nziPrint/PrintDocument.asDx?DocumentID=29235

[3] Chusid. Michael. (2006) *Words you should know: depollution, photocatalysis - photocatalysts keep concrete clean and depollute the air we breathe,* Precast Solutions, Fall 2006.

[4] Lukasik, J.Damtoft, J. S., Herfort, D., Sorrentino, D. & Gartner, E.M. (2007). Sustainable development and climate change initiatives, *Proceedings of the 12th International Congress on the Chemistry of Cement (ICCC)*. Montreal, Canada. 2007.

[5] Danish Technological Institute. *CO_2 uptake during the concrete life cycle.* (2006). Retrieved August 2007 from http://www.danishtechnology.dk/building/14460

[6] Halliday, L. Slaughter, G. Rynne, M & Bluett, J. (2007). Ten years of the New Zealand used oil recovery programme, *Proceedings of the 14th World Clean Air and Environmental Protection Congress (IUAPPA).* Brisbane, Australia. 2007.

[7] Park, Stuart. (1999). *Recycled concrete construction rubble as aggregate for new concrete.* BRANZ SR 86. Porirua.

[8] Gjerde, Morten. (2003). Deconstruction: helping to foster a sustainable concrete industry. *Proceedings of the New Zealand Concrete Industry Conference.* Taupo, New Zealand.

[9] *Self compacting concrete: a review.* (Technical Report 62). (2005). Surrey, England: Concrete Society.

[10] Wilmont, T. D. (1991). The recycling opportunities in the effective management of road pavements. *Proceedings of the Local Government Engineering Conference,* Hobart, Australia.

[11] *Designing comfortable homes: guidelines on the use of glass, mass and insulation for energy efficiency.* (2001). Wellington, New Zealand. Cement and Concrete Association of New Zealand.

[12] Gjerde, M. & Munn, C. (2003). A comparison of cost and thermal performance of concrete and lightweight housing systems In New Zealand, *Proceedings of the 21st Biennial Conference of the Concrete Institute of Australia.* Brisbane, Australia. 2003.

[13] Jamieson, N.J. & Cenek, P.D. (1999). *Effects of pavement construction on the fuel consumption of trucks. Options for a post millennium pavements symposium.* New Plymouth. New Zealand Institute of Highway Technology. 1999.

[14] Young, S. Turnbull, S. & Russell, A. (2002). *What LCA can tell us about the cement industry?* An independent study commissioned by the WBCSD.

[15] Munn, C. (2006). Concrete road barriers key to safety on roads. *Concrete,* 50(1), 4.

[16] Hart, Gordon & Johnson, Richard. (2006) Concrete roads for high stress applications. *Proceedings of the Transportation and the Pursuit of Excellence, NZIHT & Transit NZ 8th Annual Conference.* Auckland, New Zealand.

[17] *Designing comfortable homes: guidelines on the use of glass, mass and insulation for energy efficiency.* (2001). Wellington, New Zealand. Cement and Concrete Association of New Zealand.

[18] Environmental Building News. (1994). *Stormwater management – environmentally sound approaches.* 3(5). 1-18.

[19] *Concrete wind towers.* (2005). Surrey, England: Concrete Centre.

[20] Davey, R. & Green, R. (2006). Te Apiti wind farm turbine foundations: design and construction. *Proceedings of The New Zealand Concrete Industry Conference.* Christchurch, New Zealand.

Further Reading

Concrete Thinker (www.concretethinker.com)

Sustainable Concrete (www.sustainableconcrete.org.uk)

Concrete through the ages: from 7000 BC to AD 2000. (1999). Berkshire, England: British Cement Association.

Acknowledgements

Golden Bay Cement (www.goldenbay.co.nz)
Holcim (New Zealand) Ltd (www.holcim.com/nz)
Pacific Steel (www.pacificsteel.co.nz)
British In-situ Concrete Paving Association - Britpave (www.britpave.org.uk)
Environment Canterbury (www.ecan.govt.nz)
Fulton Hogan (www.fh.co.nz)
Higgins Concrete Ltd (www.higgins.co.nz)
Hiway Stabilizers (www.hiwaystab.co.nz)
Meridian Energy (www.meridianenergy.co.nz)
New Zealand Green Building Council (www.nzgbc.org.nz)
Opus International Consultants (www.opus.co.nz)
Worldwide Parking Group (www.worldwideparkinggroup.com)

"We have not inherited the world from our forefathers - we have borrowed it from our children." **Kashmiri proverb**

Cement & Concrete Association of New Zealand
Level 6, 142 Featherston Street, Wellington, New Zealand

ISBN: 978-0-908956-19-7 (paperback)

First published 2007

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www.sustainableconcrete.org.nz