REPAIRING CRITICAL ASSETS USING HIGH PERFORMANCE CALCIUM ALUMINATE CEMENTS

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INTRODUCTION

There are a large number of important New Zealand infrastructure assets constructed of reinforced concrete. As with all reinforced concrete, maintenance and repair is an ongoing process and it is increasingly important to ensure that the asset is repaired to provide the maximum durability of repair, with the minimum time for the asset to remain out of commission.

Over the past few years proprietary calcium aluminate concrete products have been used in a variety of key New Zealand projects to successfully undertake remedial works that fulfil both of these objectives.

A BRIEF HISTORY OF CALCIUM ALUMINATE CEMENTS (CAC)

High alumina cement is not a recent development. It was discovered in France as long ago as 1865 that fused and crushed mixtures of alumina and lime have hydraulic cement properties. In 1888 a patent was issued in the United Kingdom for limestone bauxite cement.

It was not until the beginning of the twentieth century that high alumina cement could be manufactured in an industrial scale.

In 1908 Lafarge of France patented a cement product that became the worlds first commercially manufactured CAC in 1913, and has since been known as Ciment Fondue Lafarge.

Most calcium aluminate cements are still made using the Lafarge process where a mixture of limestone and bauxite is heated in an oven until it melts. The molten material is then tapped off and poured into steel moulds. The cooled blocks of clinker are broken down into coarse pieces and then ground into fine particles in a mill.

CALCIUM ALUMINATE CONCRETES

Calcium aluminate cements are broadly grouped into three kinds. The type, and ultimately the end use is determined by the percentage of alumina present in the composition.

For civil applications CAC with an alumina content of 40 - 50% are most widely used, with the higher 70 - 80% materials used primarily in specialist refractory applications.

Calcium aluminate concretes are a blend of both calcium aluminate cement (CAC) and very hard, dense and non-porous synthetic calcium aluminate aggregates produced in the same way as the CAC, but not ground down to the same particle size. These aggregates are therefore of exactly the same composition as the CAC. The resultant concrete has a range of unique properties that can be utilised in specialist concrete remedial works requiring one or more of the following characteristics.

1. Temperature Resistance

Calcium aluminate concrete is extremely stable at high temperatures, and in conditions of extreme thermal cycling from -184\textdegree C to 1093\textdegree C. In these same conditions Portland cement concrete becomes unstable and experiences mechanical and structural failure.

2. Cold Weather Applications

During hydration the binder generates heat through an exothermic reaction, which allows for placement in temperatures as low as -18\textdegree C.

3. Abrasion Resistance

The combination of the properties of the synthetic aggregates and the chemical bond formed between the CAC binder and the aggregate produces a concrete that has low porosity and high density. The relative abrasion resistance to other concretes can be seen in Figure 1.
4. Rapid Hardening

These concretes generate high strength at an early stage with 24-hour compressive strengths of 55 to 60MPa. These strengths are achieved without the use of set accelerators or other additives.

5. Corrosion Resistance

As opposed to traditional Portland cement concrete, calcium aluminate cement generates a negligible quantity of calcium hydroxide during the hydration process. This combined with its low degree of porosity and the composition of the aggregates enables the concrete to withstand weak acid attack (> pH 4.0). Figure 2 shows that even at pH 2 the loss of mass of calcium aluminate mortar is approximately 30% of that of a Portland cement mortar.

In addition to this improved resistance to mineral acids, it has been demonstrated [1] that calcium aluminate concretes can effectively inhibit the activity of the bacteria present in a microbiologically induced corrosion environment such as a wastewater sewer. By inhibiting the activity of these bacteria the calcium aluminate concrete can locally raise the pH level at the exposed concrete surface in the sewer. This in turn inhibits further bacterial activity, and the creation of the destructive sulphuric acid that the bacteria excrete.

The effect of the bacteria inhibiting phenomena of calcium aluminate concrete can be seen in Figure 3.

A number of studies over the last 10 years in chambers that simulate biogenic corrosion together with site evaluations have confirmed this phenomena in providing protection against the effects of corrosive sewer environments.

In 1999 an evaluation [2] of a number of Portland cement based mortars, coal tar epoxy coatings, polymeric linings and a calcium aluminate concrete was carried out in an aggressive sewer drop structure in Melbourne. The structure has an average gaseous H₂S content of 65ppm in summer and average of 25ppm in winter.

The products to undergo the evaluation were applied to test blocks constructed of Portland cement concrete. After a suitable curing time the blocks were lowered in to the drop structure for evaluation over a 3-year period.

After 3 years in the structure the uncoated Portland cement control block (Figure 4) had deteriorated up to 25mm. After the same duration the surface of the block coated with SewperCoat (Figure 5) could only be removed up to 2mm by scratching, beyond this the surface was hard and sound. The proprietary Portland cement mortar had deteriorated to the
same degree as the untreated Portland cement control block.

Figure 4. Portland cement concrete test block after 3 years in Melbourne sewer drop structure.

Figure 5. Calcium aluminate concrete (SewperCoat) test block after 3 years in Melbourne sewer drop structure.

INTERNATIONAL EXPERIENCE

Calcium aluminate concretes have been used internationally on many hundreds of new construction, and remedial projects to provide solutions to a wide range of special applications.

Abrasion Resistance

A number of large important hydraulic structures have used the high abrasion resistance of calcium aluminate concrete to overcome erosion of concrete in the high wear zones of these structures.

CAC concrete was selected for the flushing gates of the Gebidem arch dam (Figure 6) in Switzerland constructed in 1996. The unusual aspect of this dam is the requirement for it to be flushed every year to remove a build up of silica moraine deposit. During this flushing operation the flow is between 12 and 50 m³ per second, water velocity is between 7 and 20 metres per second and some 300,000 – 400,000 m³ of fine and coarse aggregate material are flushed out with the 5 – 6 million m³ of water. The resultant rate of abrasion is considered to be equivalent to between 15 and 20 years in a normal river flow. After flushing once a year for three years the wear rate of calcium aluminate concrete has been found to be less than predicted, and an improvement on the traditional materials that have been used in similar applications. [3]

Figure 6. The Flushing Gates of the Gebidem Dam.

The abrasion resistance of these concretes is also used in the mining industry to effectively line ore-passes in underground mines. In this application a shaft constructed though relatively soft materials in a mine is lined with a CAC concrete. This allows the passage of the harder ores that are extracted from the mine to move through the ore-pass without it becoming worn and unstable.

High Temperature tolerance

Calcium aluminate concrete has been used in a variety of high temperature applications. These have included many hundreds of furnace floors, slag pits, and storage areas in the steel and aluminium production industries. Other applications include widespread use in fire training facilities and jet engine test bays, including installations at NASA facilities. The petrochemical industry also has a use for the product in high temperature areas such as boiler foundations and sulphur pits.

Biogenic Corrosion Resistance

It has been recognised for some time that calcium aluminate cements used in concrete mixes had improved resistance to the corrosive environment of sewer systems with humid conditions and long retention times in the pipe resulting in high levels of H₂S evolution.
Pipes using calcium aluminate cement where used in Singapore and Malaysia as long ago as 1933 and large quantities of calcium aluminate cement have been used in South Africa to manufacture sewer pipes since 1954. An inspection of these pipes in 1985 found them still to be in good serviceable condition.

In the United States calcium aluminate concretes have been used to rebuild many thousands of manholes, and a number of large remedial projects in man entry trunk sewers, including those requiring structural strengthening.

NEW ZEALAND EXPERIENCE

Lake Hawea Control Structure – Contact Energy

Lake Hawea is a natural lake that prior to 1955 had a lake area of 115.1 km² and had an average level of 327.7 m (MSL Dunedin). Lake levels were raised when the outlet was dammed in 1958.

The Hawea Control Structure was originally constructed in 1958 to raise the lake level by 20 metres providing storage in spring and summer that could be released into the Clutha River during periods of peak power demand.

Four radial gates control flows through concrete sluices passing beneath the earthen dam. Each sluice is approximately 3.3m high, 3.25m wide x 80m in length down stream from the radial gates.

The sluice invert is overlaid with a granolithic concrete topping 50mm thick that had delaminated in areas and scoured through into the base concrete exposing reinforcing steel.

Repairs to damaged and eroded concrete and exposed reinforcing steel were required in each sluice in turn with the main objective to ensure the structural integrity of the structure was maintained. Upstream and downstream bulkheads isolated each sluice with temporary dewatering systems to allow repairs to be carried out on walls and invert. A 900mm shaft at the downstream end provided access for materials, with personnel access via the upstream gate structure at the dam crest.

The original tender called for a 15.5 week contract period from 2 September - 20 December 2002. The original specification required the mass concrete repairs to be carried out using Portland cement concrete containing silica fume admixture, with a minimum compressive strength of 50MPa at 28 days. Other irregular defects and cavities were to be repaired using a proprietary repair mortar. All concrete was to be continuously cured for 28 days before returning the sluice back to service.

In addition to its conforming bid, Contech offered an alternative using FONDAG, a Lafarge Aluminates calcium aluminate concrete. This product allowed for an earlier return to service, as an alternative to the specified products that required a 28 day curing period.

The application methodology called for a minimum depth of 50mm at any point within the repair area. After saw cutting the perimeter of each repair area, breaking out and water blasting a bond coat of epoxy tie coat, or a slurry coat mix was applied to the substrate prior to application of the FONDAG concrete.

Figure 7. FONDAG concrete placing in floor of a sluice at the Hawea Control Structure.

The FONDAG was placed (Figure 7) using the same techniques as in regular concrete. The rate of hydration after initial set for FONDAG concrete is very fast and care was taken to ensure that the specified finish for the surface was achieved before this occurred.

As soon as the specified finish had been achieved a coat of a wax-based curing agent was applied to the surface. Approximately 4 hours after placement the repaired area was covered with wet burlap and a layer of plastic on top.

While the FONDAG data sheet states that the product reaches 24-hour compressive strengths of 55 – 60MPa, test cylinders were taken and tested off-site at 7 days with results ranging from 64 to 77.5MPa.
As noted above the original contract period using specified products ran for 15.5 weeks to 20 December 2002. An alternative programme using FONDAG allowed a return to service almost eight weeks earlier. This earlier return-to-service became important to Contact Energy with outages scheduled for other generation structures in November.

This time saving is an example of how the unique properties of calcium aluminates concretes can not only satisfy the technical requirements of a remedial project, but also offer other tangible benefits.

A twelve-month Defects Liability period is still in operation, and a physical inspection of the repairs in each sluice in April 2003, after six months service, revealed no deterioration in the repaired areas.

**Western Interceptor**

Watercare Services is the bulk supplier of water and wastewater services to the greater Auckland area. A CCTV inspection verified signs of advanced hydrogen sulphide induced corrosion in a section of the Western Interceptor, a main feeder pipeline to the Mangere Wastewater Treatment Plant.

Tenders were called for the design and build of an effective lining system to return the affected pipe to original condition and to provide a minimum 50-year design life.

The affected section comprised a 65m length of 1.5m diameter reinforced concrete pipeline that had been in place for some 40 years. Contech, in association with civil contractor, Tunnel and Civil Ltd, were contracted to repair the damaged section in June – August 2002. Stage one was the installation of a steel bypass line to carry the flow (up to 1100 ltr/sec) the interceptor was conveying and allow access into the damaged section.

Stage two involved the cleaning and relining of the pipe, in a very restricted time frame to minimise the time the section of pipe was out of commission. To reline the Western Interceptor, Contech used Lafarge Aluminates’ SewperCoat. The product was applied using dry-spray gunite techniques, which are particularly suited to the difficult access and the distance the material had to be conveyed (Figure 8). Prior to application the pipeline surface was prepared by very high pressure water jetting and new steel reinforcement installed.

The SewperCoat was applied at an average 35mm thickness over the original pipe and average thickness of 75mm where new steel was installed. The thicknesses provided were to satisfy the client’s requirement that the life of this section of the pipe be extended by a minimum of 50 years.

As with all calcium aluminate concretes the rapid strength development of the SewperCoat permitted flow back through the interceptor within a few days of the final SewperCoat application.

**Rotorua WWTP overflow – Rotorua District Council**

The overflow pipe at the Rotorua Wastewater Treatment Plant was showing signs of severe deterioration due to attack of the concrete pipes and manholes from hydrogen sulphide. The 650mm diameter pipe is 160 metres long and includes four manhole risers.

The contract called for rehabilitation of the pipeline invert and the manholes with a calcium aluminate based mortar. The mortar was applied by hand to the pipe invert at an average thickness of 30mm.

Rotorua City Council specified a calcium aluminate product as it has found that this product has been effective in past projects where H₂S has affected Portland cement concrete structures.

![Figure 8. Application of Calcium Aluminate Concrete (SewperCoat) to the Western Interceptor.](image-url)
Earth Filter Number 3 – Mangere WWTP

Watercare treats and disposes of approximately 304,000m$^3$ of Auckland’s wastewater each day at its Mangere Wastewater Treatment Plant. Foul air drawn from the sewage treatment process is treated through odour control earth filters.

Constructed in 1995, earth filter No. 3 has a perimeter concrete block wall with a surface area of 590m$^2$ and a central air plenum with a surface area of 585m$^2$. Watercare scheduled a refurbishment contract in February – March 2002 when it became apparent that there was deterioration in the performance of the bio-filters.

The specified repairs to the walls called for a proprietary epoxy repair mortar with an epoxy paint to the entire concrete block wall. A calcium aluminate mortar (SewperCoat) was approved for use in-lieu of the epoxy mortar.

The repairs involved the application of approximately 4000 litres of SewperCoat to the perimeter wall and the central plenum. Repair areas were marked up and the concrete block surface prepared using ultra high volume low-pressure water blasting. An average thickness of 30mm SewperCoat was applied using pneumatically placed dry spray techniques (gunite).

As the SewperCoat could be applied to a damp substrate and is able to be over-coated in 24 hours, this proved to be advantageous in this difficult wastewater environment.

Preheater Tower – Golden Bay Cement

In 2001 a condition assessment of the GBC Preheater Tower basement revealed deterioration in the form of cracking, spalling and corroding steel reinforcement to a section of the first floor level concrete slab. Extreme heat due to spillage from the kiln above was identified as the cause of the deterioration in this area with material exceeding 1000°C occasionally being deposited on the concrete surface below. Approximately 15m$^2$ of slab, 300mm thick, was identified as requiring repair.

The proposal to repair this section of slab using a calcium aluminate aggregate mixed with calcium aluminate cement was attractive to Golden Bay Cement given the advantages of this material over ordinary Portland cement concrete. It produces superior mechanical performance of high temperature and thermal shock resistance. The rapid strength development (compressive strength 50MPa in 24 hours) enabled a program to be developed which allowed the client to quickly return the tower and kiln to service.

Work was undertaken during the GBC February 2002 plant shutdown. A temporary propping system to support the Preheater Tower was installed prior to the removal of the deteriorated concrete using conventional breakout. The exposed reinforcing steel was cleaned and/or replaced as necessary and the broken out section of slab reinstated. The high early strength property of the CAC concrete allowed the early removal of the temporary propping system which enabled slab and surrounding plant to be re-commissioned on time.

CONCLUSION

This paper has outlined the characteristics of the calcium aluminate concretes and demonstrated how calcium aluminate concretes have been successfully utilised in various applications that require its special properties to overcome a specific problem. The introduction and growing use of these materials has resulted from asset owners demanding solutions, which will see their structures repaired for the medium-long term and restored to service at the earliest time. This early return to service is more often than not a critical consideration for a structure where the costs and disruption of it remaining out of service can have a significant impact on the operation.

Given the age and deterioration of many of New Zealand’s critical concrete structures, the innovative use of these materials provides effective new options for this aging infrastructure.

REFERENCES

