Ultra Rapid & High Performance Concrete for Extreme Industrial Environments

The use of calcium aluminate cement as the binder in refractory systems is widely known and well documented. A lesser-known approach to high-performance concrete involves the use of synthetic calcium aluminate aggregates along with the calcium aluminate cement. The addition of this unique aggregate imparts enhanced properties to concretes, enabling them to endure the toughest of industrial environments. It is based on this mechanism that Kerneos has developed Fondag, a dry mix concrete with suitably proportioned calcium aluminate cement and calcium aluminate aggregate, or "pure calcium aluminate systems. It provides high-early strength (return to service in a few hours), high-ultimate strength, outstanding resistance to both low and high temperature (- 180°C to 1100°C) and thermal shock, very good abrasion resistance, and high electrical resistivity. In this concrete, the paste to aggregate bonding is both mechanical, as well as chemical, and this unique affinity between aggregate and cement provides many of the enhanced properties of the systems.

Typical slag pit application in the steel industry.

In the traditional high-temperature industry (iron, steel, and aluminum), Fondag has been used for rehabilitating and protecting coke wharves, slag pits, sulphur pits, drossing areas, and mill scale flumes. Each of these applications relies on the material's ability to gain strength quickly, resist heat and thermal shock, and withstand repeated mechanical abuse and abrasion. Most industrial applications of these materials have carried the additional constraint of requiring a return to service in 24 hours or less, and pure calcium aluminate systems are capable of delivering over 40 MPa within 24 hours.

Temperature related problems in the steel industry…

Another application for Fondag is in the lining of fire training structures. These cast-in-place or block constructed buildings are used by fire fighters for live fire training purposes. Typically, large amounts of combustible materials such as wooden pallets or bales of hay are stacked and soaked with fuel oil prior to ignition. Once ablaze, temperatures exceeding 1000oC are not uncommon. To further test the integrity of the structures, fire-fighting trainees then

A burn facility in the fire-training industry

Trainees in action

quickly douse the flames with high-pressure water streams, resulting in extreme thermal shock. Conventional concretes are unable to withstand this type of repeated thermal abuse. Fondag has proven to be a reliable means of protecting these structures and are commonly used.

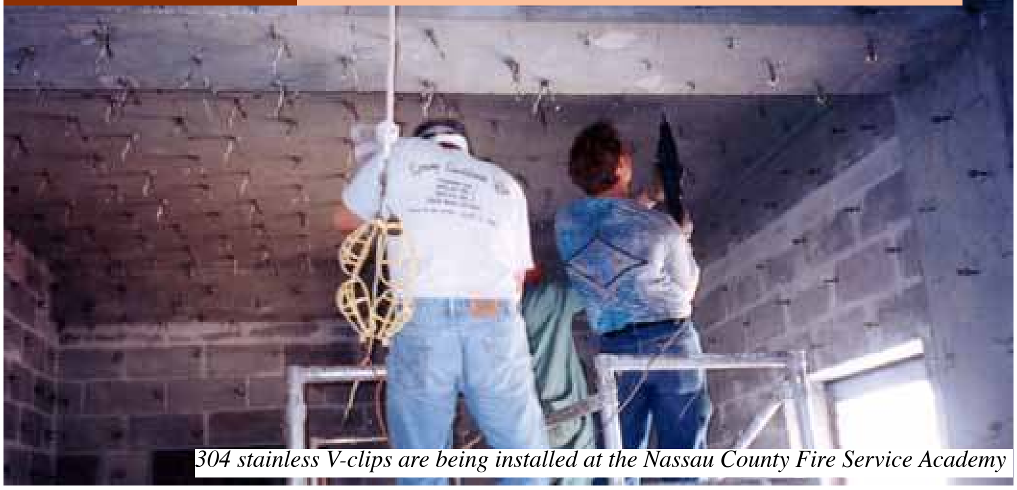
Beyond its applications as a refractory material for industry, Fondag has been used to rehabilitate dam structures such as spillways, sills, flushing gates, jetty heads, sluice beds, etc.

For most repair application schemes, preparation involves the removal of existing deteriorated material, a thorough cleaning of the affected areas to remove surface laitance, and the setting of an appropriate mechanical anchoring scheme, such as wire mesh or "V" clip type anchors. Anchoring can be critical in certain applications and in extremely high service temperature environments, a stainless steel anchoring system is recommended. Typical anchor types, spacing, and configurations are explained in detail in ACI 547R – Refractory Concrete. For any application involving thermal conditions, a minimum thickness of 100 mm of Fondag concrete is generally required. If extreme abrasion is present with high service temperatures, gunite materials can be manufactured to include the addition of 1.5 - 3.0% steel fibers. The service temperature will govern the choice of the anchor material. According to ACI 547R, "Carbon steel can be used for anchor temperatures up to 550°C. Type 304 stainless is suitable for anchor temperatures of up to 1000°C and Type 310 stainless is adequate up to 1100°C." A rebound rate of 15% on vertical surfaces is not uncommon. Overhead rebound rates can range between 20 - 30% depending on the substrate material, anchoring scheme, and gunning technique. The inclusion of stainless steel fibers may increase these percentages slightly. between 20 - 30% depending on the substrate material, anchoring scheme, and gunning technique. The inclusion of stainless steel fibers may increase these percentages slightly.

Once in place, and following the first evolution of heat at final set – normally within 2 hours – Fondag is protected from plastic shrinkage cracking through the use of a moist curing scheme such as misting, wet burlap, or a heavy application of a curing compound that conforms to ASTM C309. 24 hours after placement, the system can be considered ready for service One example of Fondag in use in the real world is at the Nassau County Fire Service Academy (NCFSA) in Bethpage, New York. This 14-acre facility is used to train firefighters from New York City and all of the surrounding areas. Beginning in 1991, the NCFSA began evaluating Fondag as a means to line its existing structures to protect them from the damage of daily training exercises. Conventional refractory shotcretes had proven to be a relatively short-term solution, and following 5 years of testing the NCFSA selected Fondag to line several thousand square feet of newly constructed building space constructed in 1998. The contractor that installed this material is Herman Sommer and Associates based in Newark, New Jersey.

Another example of high-temperature applications exists in the aerospace industry. Fondag is commonly used in areas of direct flame impingement in both private and governmental facilities. Areas where

Dam spillway application



304 stainless V-clips are being installed at the Nassau County Fire Service Academy

A refractory gunite installation at the Nassau County Fire Service Academy

The aerospace industry…

A petrochemical gunite installation…

this material is used include flame buckets, deflector pads, and exhaust tunnels. These areas experience both very high service temperatures as well as significant abrasion through airborne particulates. Typically, these installations will include stainless steel fibers, as mentioned above. These are areas where rockets and motors are developed and evaluated, or actually used in the case of Cape Canaveral. Atlantic Fire Brick and Supply Company, based in Jacksonville, Florida, installed Fondag in the flame bucket area of complex #37 at N.A.S.A.'s Cape Canaveral facility. Fondag was installed with traditional dry-gunite equipment in early 2000.

The petrochemical industry also has its share of severe refractory applications. Fondag is commonly used in sulfur pit applications in this industry. This is an area with moderately high operating temperatures and a severe chemical attack coming from direct molten sulfur contact. It is also commonly used in other high-temperature petrochemical applications such as boiler foundations. Fondag has been widely accepted in this industry by companies such as Exxon, Texaco, Mobile, and PeMex with a history in North America dating back to the early 1990's.

In summary, from the applications listed above, it can be seen that Fondag concrete based on pure calcium aluminate binder and aggregates is able to withstand many hostile environments that destroy normal concretes in a short period of time due to the combination of several aggressive attacks of different nature. For example, when considering an appropriate concrete material for high temperature applications, it is important to not only consider the temperatures involved, but the other aspects of the operating environment that could lead to premature failure. These would include thermal shock, abrasion, mechanical abuse, and chemical attack. Fondag designed around "pure" calcium aluminate systems will provide excellent long-term service in the aggressive environment of heavy industry. Furthermore, the ultra rapid hardening property of Fondag enables return to service within a few hours. This high installation efficiency and excellent long-term service allow owners to improve substantially the productivity. Successful application spans a wide range of industries, well beyond iron and steel, where their importance was first recognized. Future uses of these unique materials will be found by innovative contractors.
For more information and references on Fondag, please visit our website at www.kerneos.com or contact a Kerneos representative.

CORROSION PROTECTION OF REINFORCED CONCRETE STRUCTURES USING EMBEDDED GALVANIC ANODES

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Corrosion of reinforcing steel leading to structural deterioration and failure of reinforced concrete structures is a serious problem for port and highway agencies, and facility owners. Corrosion of reinforcing steel is recognized as the major cause of the deterioration of reinforced concrete structures. Exposure to seawater, chloride-containing set accelerators and de-icing salts, play a significant role in reinforcing steel corrosion. Long-term exposure to carbon dioxide is also cited as a contributor to the corrosion of steel in concrete as well.

Cathodic protection has been demonstrated to be an effective technique to control corrosion. It has been shown to be effective in mitigating corrosion damage and reducing the rate of the delamination per year to 0.04% from the average 1% per year for unprotected structures (1).

Embedded zinc sacrificial anodes have been included in patch repairs of steel reinforced concrete structural elements suffering from corrosion since the mid-nineties. The anodes installed in a UK bridge in 1999 have been monitored for 10-years and this monitoring data will be discussed. Galvanic anodes have been used widely in patch repair since then.

Recognizing the inadequate monitoring of impressed current cathodic protection that will make it in-effective, the Ministry of Transportation, Ontario, conducted a trial using distributed galvanic anodes in a bridge deck overlay to address the global corrosion issues in the structure. The trial had been monitored for a eight years and was considered a success. The newly developed distributed galvanic anode system has been used in various applications, including abutment overbuild, concrete deck overlays, concrete jackets for columns, piers and marine piles since its inception.

This paper introduces different levels of corrosion protection and the various galvanic anode systems used in concrete structures. Various applications of the galvanic systems are presented. Corrosion mitigation systems generally fall into three performance categories: corrosion prevention, corrosion control, and cathodic protection. In all categories, the anodes provide a level of protective current to the reinforcing steel to mitigate corrosion activity. However, they differ in terms of the intended application and the intensity of the protective current required for to achieve the mitigation objective.

Corrosion prevention is defined as preventing corrosion from initiating even though the concrete may be contaminated. Preventing corrosion from initiating is useful in the case of patch repair of chloride-contaminated concrete to mitigate the formation of secondary corrosion sites next to the previously completed repairs, and in likely corrosion areas in new construction such as tidal and splash zones. The objective of a corrosion prevention strategy is to provide sufficient current to the steel to prevent the initiation of the corrosion sites. Some research indicates that applied current densities as low as 0.5mA/m2 to 2mA/m2 of steel surface area have been shown to be effective to prevent corrosion from initiating for concrete with chloride concentrations up to 10 times the chloride threshold (3).

Corrosion prevention strategy has been applied to concrete rehabilitation and structural extension projects since the 1990s. Embedded galvanic anodes are tied on the reinforcing steel at the interface between new and existing contaminated concrete. Once the new concrete is placed, the anodes begin to provide sacrificial corrosion protection to the steel in adjacent contaminated concrete. Anodes can also be used in hot-spot where corrosion is likely to occur such as tidal and splash zones of marine structure, to prevent corrosion from initiating.

Corrosion control is characterized by a significant reduction in the corrosion rate of actively corroding steel in concrete. Corrosion control may or may not completely stops on-going corrosion, but the reduction in corrosion activity will significantly extend the service life of existing corroding structures. In corrosion control applications the conditions for corrosion (such as chlorides) already exist and corrosion may have already initiated, but has not progressed to the point of concrete damage.

The applied current necessary to address corrosion activity (after corrosion initiation) is in the range of 1 to 7 mA/m^2 (0.1 to 0.7 mA/ft^2). Polarization of the reinforcing steel will typically occur at these current densities although the level of polarization may be less than the NACE 100mV depolarization criteria for cathodic protection.

Cathodic protection is intended to provide complete or virtually complete corrosion protection to the cathodically protected elements. The applied current is generally between 2 and 20 mA/m^2 (0.2 to 2.0 mA/ft^2). Current National Association of Corrosion Engineers (NACE) cathodic protection standards are based on a 100 mV depolarisation acceptance criteria. At these current densities and polarization levels, cathodic protection has demonstrated a very high level of corrosion protection as can be referenced in the literature.

Level of Protection

Table 1 Comparison of Corrosion Mitigation Strategies

	Corrosion Prevention	Corrosion Control	Cathodic Protection
Objective	Preventing corrosion from initiating in contaminated areas	Significantly reducing on-going corrosion activity	Stopping on-going corrosion activity
Current required per m^2 (ft^2) of Steel surface area	0.25 to 2 mA/m^2 (0.025 to 0.2 mA/ft^2)	1 to 7 mA/m^2 (0.1 to 0.7 mA/ft^2)	2 to 20 mA/m^2 (0.2 to 2 mA/ft^2)
Polarization	< 100 mV	< 100 mV	≥ 100 mV (2)

Figure 1 First Monitored Trial of embedded Galvanic Anodes in Patch Repair

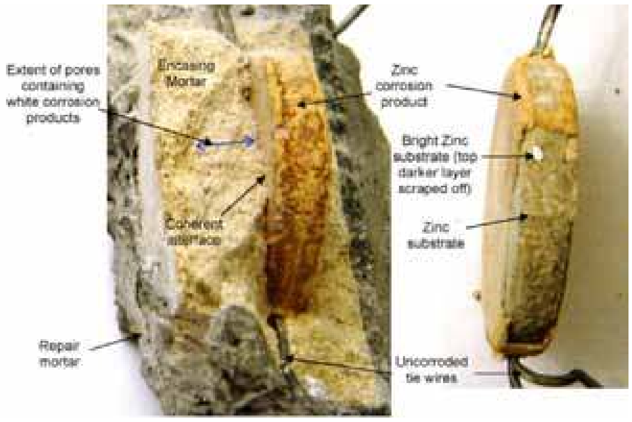

Figure 2 Removed 10 year old anode showing corrosion product around zinc and intact encasing mortar and Zinc core with part of the corrosion product broken off exposing the zinc substrate

Figure 3 Anodes installed at the edge of existing deck for the deck widening to prevent corrosion from initiating, Port Mann Bridge, Vancouver, British Columbia, Canada

Figure 4 Anodes installed around the perimeter of a bridge deck patch, shallowater, texas, usa

Embedded Galvanic Anodes for Corrosion Prevention

Patch accelerated corrosion has been well recognized in the concrete repair industry. Embedded galvanic anodes have been used patch repairs since the 1990s. The puck-like anode was produced from zinc metal encased in a specially formulated porous cementitious mortar saturated with lithium hydroxide (pH >14.5). Such an environment, with a reservoir of excess LiOH maintaining a constantly high pH, which is corrosive to the zinc and protective to the steel, was shown to sustain corrosion of the zinc while producing soluble zinc corrosion products that do not stifle the corrosion process of the metal.

The first monitored application of the embedded anodes was completed at the Leicester Bridge, UK, in 1999 (4). Estimation of the steel surface area within the repaired and affected adjacent area shows that the mean current density ranged between 0.6 mA/m2 and 3.0 mA/m2 with an overall mean of around 1.4 mA/m2 , generally within the suggested range for cathodic prevention. Using Faraday's law, and assuming an anode efficiency of 0.9 and utilization rate of 0.8 , a service life between 24 years and 37 years can be achieved for 60g zinc mass. Confirmation of the efficiency was provided by assessing removed anodes from an adjacent patch repair (Figure 1 & 2), which showed about 25-30% zinc mass loss over 10 years. Depolarization

Figure 5 Dilled anodes and line anodes installed at the side and bottom of the girder to control corrosion, Pointe Noire Wharf, Sept-Îles, Quebec, Canada (5)

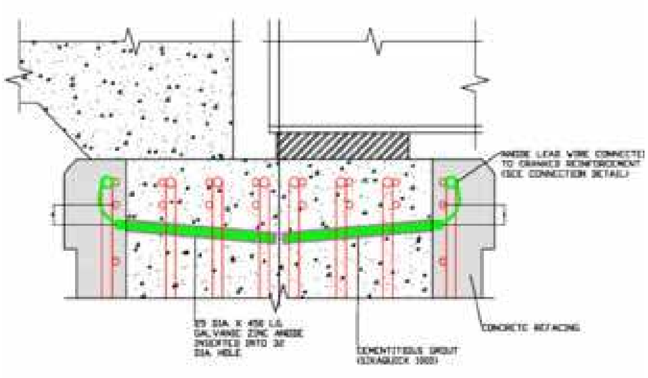

Figure 6 25mm diameter 450mm long Anodes installed in 500mm deep inclined drilled holes to control corrosion for the steels embedded deeply inside concrete arch way in Toronto Union Station of the steel reinforcement was rarely over 50mV initially but increased to 100mV after 9 years. Corrosion Prevention strategy can be used various applications including structural extension or widening, new construction and patch repairs.

Drilled-in Anodes for Corrosion Control

Corrosion control strategy with drilled-in anodes can be used in the sound concrete with high corrosion potentials and high chloride concentration, where delamination and spalling are expected as a result of corrosion (figure 5 & 6).

Distributed anode system (DAS) for corrosion control and cathodic protection

Since 1974, impressed current cathodic protection has been used in North America as part of the corrosion protection strategy to rehabilitate corrosion damaged bridges containing black steel (6). It has been well documented, that for cathodic protection to function properly and arrest corrosion the systems must be monitored on an ongoing basis, which is a major drawback because many transportation agencies, port authorities and facility owners may lack understanding of cathodic protection technology or ability to provide dedicated staff to conduct the required ongoing monitoring and maintenance.

What is needed is a sacrificial anode system that can supply sufficient current to provide effective cathodic protection, does not require specialized knowledge for installation and can significantly minimize the need for future monitoring and maintenance. With experience gained through the applications of pointed galvanic anodes in patch repairs for corrosion prevention and drilled-in anodes for corrosion control, the Ministry of Transportation, Ontario, Canada, and Vector Corrosion Technologies conducted a trial using distributed galvanic anodes in a bridge deck overlay to address the global corrosion issues in the structure in September 2003.

Except winter months when the bridge deck froze and current and corrosion potential readings were not reliable, more than sufficient current was being supplied by the anodes to meet the 100 mv criteria generally accepted as indicative of effective cathodic protection. The current density ranged from 2 to 6 mA/m^2.

After this successful trial of distributed anode system, this distributed galvanic anode system has been used in various applications, including abutment overbuilds, concrete deck overlays, concrete jackets for columns, piers and marine piles.

Figure 7 First Trial of DAS anodes in a Bridge Deck Overlay, Ontario, Canada, 2003

Summary

This paper introduces a range of corrosion protection systems of reinforced concrete structures by galvanic anodes. Each system can provide different levels of corrosion protection with different cost. An understanding of the capabilities of the available systems and various levels of protection allows engineers and owners to implement the best system for a given application.

Galvanic anodes provide protection using dissimilar metals and operate naturally without the need of external power. Galvanic systems do not require specialized knowledge for installation and can significantly minimize the need for future monitoring and maintenance, therefore more and more highway agencies, port authorities and other facility owners adopt them as their preferred corrosion mitigation solutions. Galvanic systems can be used to provide global corrosion protection including abutment overbuilds, deck overlays, jackets for columns, piers and marine piles. Galvanic system can also be used for targeted corrosion protection, such as concrete repairs, expansion joint repair and bridge widening.

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Figure 8 In 2006 Distributed anodes installed at the bottom of the girder to control corrosion, Pointe Noire Wharf, Sept-Îles, Quebec, Canada. Currents from the anodes ranged from 10-20mA/m2 depending on the seasons, and the polarization was well above 100mV

Figure 9 In 2006 DAS anodes installed in concrete jackets for 764 reinforced concrete piers supporting Robert Moses Causes, Long Island, New York, USA. Polarization is well above 100mV and the projected service life is more than the design service life of 35 years

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Prediction of Time of Initiation & Propagation for Corrosion of Steel in Reinforced Concrete

A condition assessment and structural capacity check for the beams at a production facility of a pharmaceutical plant were carried out. The assessment comprised of a visual inspection to ascertain the general condition followed by detailed testing involving ultrasonic thickness gauging. The occurrence of all observed defects with their extent and severity was recorded. A structural check was carried out to evaluate the structural adequacy and integrity against the existing and anticipated increased loading conditions that the structure would take in the future.

Core samples were taken from the reinforced concrete to predict the time taken for initiation of corrosion to take place in the beams. Using this data, a life-cycle-cost for repairs was developed over a 25 year period.

An engineering report documenting the findings of the condition assessment and capacity check was prepared. Ascent was retained to carry out detailed inspection of critical areas and propose remedial recommendations in the form of method statements and technical specifications for rectification of the observed defects.

Condition Assessment of Reinforced Concrete Barge Pier Structure

Introduction

A structural survey was carried out on a concrete barge pier built in the 1970s. Signs of widespread cracking and spalling of concrete was observed. Investigation was carried out to determine the extent of damage and life cycle costing was carried out to assist decision making on the type of repairs. Plans are underway to rehabilitate the structure using Cathodic Protection.

Work Executed

The extent of chloride penetration was determined in addition to other durability parameters. Calculations were also carried out to ensure that the structural integrity of the barge pier was not affected. Different repair methodologies (patch repairs vs. cathodic protection) was evaluated using life cycle costing (LCC) computer software models. Hence a decision was made to cathodically protect the barge pier structure based on lower life cycle cost over a 25 year period. Detailed technical specifications were prepared for the repairs for specialist repair contractors to tender for the project. The project of structural rehabilitation is expected to commence soon.

Superplasticizers: past, present and future

From an accidental discovery a revolution in building technology and new solutions for environmental protection

Text by Giorgio Ferrari* and Francesco Surico* - Translation by Vincenzo Russo*


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Superplasticizers: the Past

It was the 1930s, and in the United States Ford and General Motors were committed to manufacturing faster and more powerful cars. Roads were widened and outside of urban areas three-lane highways were built: the central lane was devoted to overtaking for cars coming from both directions.

The danger created by such a road design became more evident every day, to the point that, due to the high occurrence of head-on collisions, the central lane would soon be better known as the "suicide lane." In trying to minimize the risk of fatal car wrecks, the Federal Highway Administration (FHWA) thought about changing the passing lane by modifying the color of the concrete pavement through the use of charcoal (carbon black). The first attempts were unsuccessful because the charcoal did not mix well with cement and the resulting color was not uniformly distributed on the surface, but instead formed isolated spots. Moreover, the exceedingly high quantity of charcoal used in the slurry caused a worsening in the development of the mechanical properties of the concrete. Trying to solve these problems, George Tucker, a researcher at the chemical manufacturing company Dewey & Almy, proposed the use of a dispersant based on naphthalenesulfonate condensed with formaldehyde, which turned out to be successful. In fact, thanks to the action of these molecules, the charcoal was able to perfectly distribute itself in the cement mix, providing the pavement with a well-defined and homogeneous color, even at low concentrations of dye. The biggest surprise, though, came when the tester at FHWA discovered that the central lanes made with charcoal and the new additive were characterized by mechanical strengths higher than those of the side lanes that did not contain any additives.

It was not hard to understand that the new additive, which meanwhile had reached commercial development under the name of TDA (Tucker Dispersing Agent), was not only effective as a dispersant for charcoal but also acted on the cement.

In fact, checks on construction sites pointed out that castings for the central lanes required much less water in the mix than those for the side lanes [1].

Thanks to the addition of TDA it was possible to create a fluid concrete with little mixing water that was easy to cast and had excellent mechanical properties in the hardened state: the first superplasticizer had just been born!

Tucker's invention was patented [2] and this gave rise to a number of studies of the effect of TDA on cement mixes.

The American Society for Testing Materials (ASTM), which had been hesitant to allow the use of any additive in cement, on the basis of a series of in-depth studies by the National Bureau of Standard (known today as NIST, National Institute of Standard and Technology), declared the use of TDA in cementitious systems safe [3]. During the 1960s and the 1970s researchers in the main companies in the field developed the so-called second-generation superplasticizers: Kenichi Hattori, at Kao Soap in Japan modified the synthesis of the naphthalenesulfonate (BNS) discovered by Tucker, significantly improving its dispersant and air entrainment properties [4], while Alois Aignesberger, at SKW, Germany, synthesized an accelerating superplasticizer based on melamine (MS), which was particularly effective in cold climates [5].

In 1975, professor Mario Collepardi, at that time teaching at the University of Ancona (Italy), developed "rheoplastic concrete," characterized by high fluidity (class S5, slump ≥ 22 cm) and not subject to segregation [6]. Thanks to the high dosage of naphthalenesulfonate-based superplasticizers and to the accurate study of mix-design, this concrete could be pumped for long distances without segregating and allowed the realization of complex cast structures, minimizing the need for concrete vibration.

In the 1980s superplasticizers became essential components of fluid and superfluid concrete and the benefits of their use were scien-

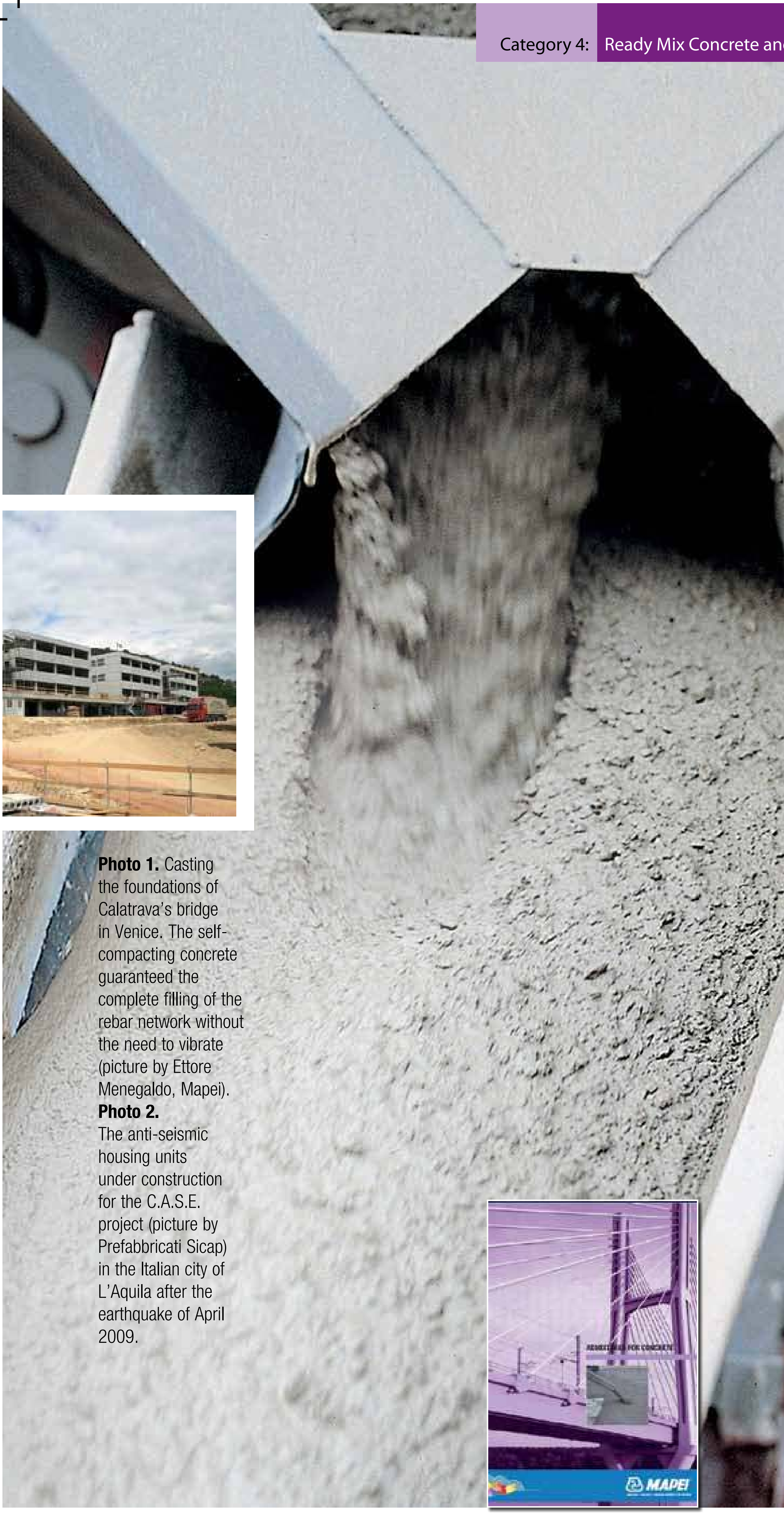

Photo 1. Casting the foundations of Calatrava's bridge in Venice. The self-compacting concrete guaranteed the complete filling of the rebar network without the need to vibrate (picture by Ettore Menegaldo, Mapei).
Photo 2. The anti-seismic housing units under construction for the C.A.S.E. project (picture by Prefabbricati Sicap) in the Italian city of L'Aquila after the earthquake of April 2009.

tifically proven with respect to the improvement of mechanical properties and durability of concrete. The study of the mechanisms of acting of superplasticizers led to the development of new molecules, with better concrete-dispersing properties. Nonetheless, the new products that were proposed, in addition to being costly, caused an excessive inclusion of air bubbles in the concrete which resulted in poor mechanical strengths and a detrimental effect on the surface of cast structures. For these reasons, the new superplasticizers were not accepted by the market, which continued to prefer the naphthalenesulfonate-based ones.

The New Chemistry of Superplasticizers

In 1992, in the Mapei laboratories, a new monomer was developed that utilized polyglycol ethers, raw materials up to then exclusively utilized in niche sectors, such as detergents and cosmetics.
This monomer, which was a polyglycol ether methacrylate, became the fundamental ingredient of a new low-air-entrainment superplasticizer that finally allowed the manufacture of concrete with an excellent conservation of workability without delaying the development of mechanical strength.
Up to then, in fact, maintaining the workability necessary to allow transport of concrete over long distances and in hot climates had been possible only through the addition of substances that hindered cement hydration (lignosulfonates, gluconates), slowing down concrete hardening, and delaying the demoulding process. The new additive, thanks to the entirely new molecular structure and mechanism of action, was able to effectively disperse the cement grains without retarding hydration. Moreover, the new molecule was much more effective than naphthalenesulfonate and could be used in significantly lower doses, rendering it notably more convenient in terms of costs. Last but not least, the new additive did not contain formaldehyde, a carcinogenic substance that was present in both

naphthalenesulfonate and melamine sulfonate [7].
An international patent was issued for the new product which was launched in 1993 under the name of MAPEFLUID X404 [8], becoming the first polyether carboxylate produced and distributed on the European market and the progenitor of the third-generation superplasticizers, based on an entirely new chemistry. The intense research work carried out in the Mapei laboratories led to a better understanding of the fundamental mechanisms that govern the interaction between additives and cement and to the perfect control of the synthesis and structure of the polymers that are the basic constituents of the DYNAMON superplasticizer family. The DYNAMON line provides a complete range of superplasticizers that cover all the needs of the concrete market.
Photo 1 shows the realization of the foundations of the Ponte della Costituzione (Constitution Bridge), the fourth bridge over the Grand Canal in Venice, better known as Calatrava's Bridge. The casting was completed using a self-compacting concrete (Rck > 65 MPa, w/c = 0.45, DYNAMON SP1 superplasticizer and VISCOFLUID SCC/10 viscosity modifying agent, both in 5.5 kg/m³ dosage).
The superplasticizers of the DYNAMON line were utilized for the C.A.S.E. (Complessi Antisismici Sostenibili Ecocompatibili Sustainable Eco-compatible Anti-seismic Complexes) project planned by the Italian Government for the reconstruction of the city of L'Aquila, destroyed by an earthquake on the 6th of April 2009 (photo 2). In less than 120 days, 187 new buildings were constructed at 19 locations around the city, making use of cutting-edge anti-seismic construction technologies.
The new apartment homes were built on concrete slabs which were held by columns equipped with shock absorbers capable of freeing the slabs from oscillations generated by telluric movements. Overall, more than 215,000 m³ of concrete with an average Rck of 40 MPa were cast, 115,000 m³ of which were self-compacting concrete, manufactured by different pre-casting companies under the direction of a single project head. Mapei contributed to the realization of the C.A.S.E. project with the following additives: DYNAMON SR 912, DYNAMON SR3, MAPECURE SRA 25, VISCOFLUID SCC/10 and VISCOSTAR 3K.


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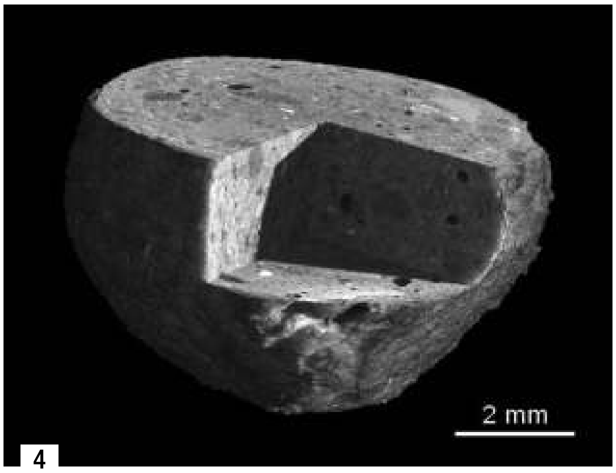

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Photo 3. The head of the tunnel boring machine utilized for the construction of Line C of Rome's subway system (picture by Alessandro Boscaro, Mapei-UTT Group).

Picture 4. Microtomography image of an HPSS aggregate. The virtual section of the granule shows an extremely compact low-porosity structure, made possible only through superplasticizers (picture by Matteo Parisatto, Geoscience Department, University of Padua, Italy).

The Future of Superplasticizers

The search for new superplasticizers and the development of new building technologies are closely interdependent activities. In fact, the research of new polymers has to respond to the construction industry's need for ever more reliable, quick and economical technologies and this can, at the same time, pave the way to the solution of not yet solved problems or to new applications. The use of additives of the DYNAMON line, as well as VISCOFLUID SCC/10 and VISCOSTAR 3K, for the production of self-compacting concretes has allowed the development of a revolutionary technology in the foundation poles sector that is faster and more environmentally friendly. When using this technology, concrete no longer fills up the rebar cages. Instead, the cages are lowered into holes already filled with concrete. In this way, thanks to the rheological properties and the high viscosity that characterize concrete, it is possible to eliminate the use of bentonite, which poses an environmental problem, and lowering the tied rebar beam cage becomes noticeably easier [9]. The tunnel boring machine (TBM) system represents the state of the art of the tunnel boring technology (Photo 3). This technology allows a complete mechanization of the boring phase and the simultaneous realization of the final lining with precast self-supporting segments produced on site. The most advanced machines are able to move forward at a rate of over 10 m per day. The production of the segments can become the limiting step in the process, and a high productive capacity is therefore necessary to support the digging activity. The new additives of the DYNAMON NRG series have been studied to develop high mechanical strengths at low curing times. This property, which derives from the utilization of special monomers that promote the cement hydration process without decreasing the workability of the mix, allows a considerable reduction in the time necessary to take off the formworks with an increased production capacity. The use of these superplasticizers allows the production of precast segments with mechanical strengths over 23 N/mm² after only 4 hours of steam curing at 60 °C, a performance that is impossible with the traditional superplasticizers.
The use of concrete in hot climates requires particular devices to prevent high temperatures from reducing the workability of the fresh mix below the allowed levels. In extreme cases, typical of the climatic conditions of Middle Eastern countries, the tempera-

ture of fresh concrete can get over 30 °C, even though ice chips are used to replace mixing water and, sometimes, liquid nitrogen is injected to cool down the mix. In these conditions, normal retardant additives are not suitable, since they have to be used at a dosage that severely damages mechanical strengths at low curing times. To solve this problem, the Mapei laboratories developed a new line of products, the CHRONOS (Chemically Reactive Nanostructural Superplasticizers) superplasticizers, that modify their chemical structure over time and activate in a progressive fashion, making up for the natural reduction of consistency of fresh cement. With CHRONOS VF 202, at 1.2% dosage, it was possible to manufacture concrete in critical conditions (27–29°C) maintaining a slump of 230 mm for 3 hours, without any delay in the development of mechanical strengths after 24 hours. The CHRONOS products are the first example of "smart superplasticizers," a new generation of "sensitive" polymers that, once added to concrete, modify their chemical structure over time depending on the environmental conditions and the task they are required to accomplish.

The future of superplasticizers is also represented by the development of new applications in non-conventional sectors.

One of the non-traditional fields of cement use is waste treatment, which Portland Cement Association (PCA) lists as one of the 16 main reasons of cement consumption in North America [10]. In the process of solidification/stabilization (S/S), cement is mixed with waste of various nature, to provide the waste with a better dimensional stability, "trap" the contaminants, minimize the leaching of toxic substances and finally improve the environmental compatibility of the waste.

To enhance the solidification/stabilization treatment, the Mapei laboratories developed the HPSS (High Performance Solidification Stabilization) system, an innovative process that makes use of the water-reducing power of superplasticizers to achieve environmental protection. With this process, contaminated land and sediments in the areas that undergo soil remediation are mixed with cement and tailor-made third-generation superplasticizers to afford granular cementitious conglomerates using the least amount of mixing water [11, 12]. The artificial aggregates so produced are characterized by low capillary porosity and low contaminant leaching levels. Moreover, thanks to the low water/cement ratio, these inert materials are able to satisfy the standards for their reuse in construction and civil engineering. With the HPSS process, the benefit of recycling contaminated sediments and lands, without sending them to landfills, is associated with the advantage of producing artificial aggregates, reducing the use of gravel pits and preserving the landscape. The density and compactness of an HPSS aggregate are shown in picture 4, obtained through computerized axial microtomography by the research group of professor Gilberto Artioli, at the Geoscience Department of the University of Padua (Italy), who received a grant from Mapei for the long-term project of developing knowledge concerning cement chemistry.

Mapei found in the application of the HPSS system to soil remediation a new possibility of developing a market for the superplasticizers. It is sufficient to think that, according to ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale - Superior Institute for Environmental Protection and Research), in Italy there are more than 13,000 potentially contaminated sites, 4,400 of which have already been declared to be contaminated.

To these figures one should add the number of abandoned mining sites, which is estimated to be over 1,500, and the areas included in the 54 Italian national interest sites, that account for more than 3% of the entire surface of the Italian country; furthermore, over 170,000 hectares of Italian marine port areas have been found to be contaminated [13].

Mapei's HPSS system has already been applied successfully by Mapintec, a joint-venture between Mapei and Intec for the commercialization of this technique, to three soil remediation sites and it has already been approved for future amelioration projects, including the Moranzani Project, which involves the treatment of over 100,000 m^3 of sediments in the Venice lagoon to produce HPSS aggregates. Based on this data, it is possible to predict a future growth of the application of superplasticizers in the framework of environmental protection which will account for a significant portion of the market of these products.

The history of superplasticizers proves that these polymers have been one of the key factors for the development of new building technologies and represent the key to the development of environmental technologies that allow a safe reuse of contaminated lands and sediments.

The synthesis of new reactive polymers, the "smart superplasticizers," that are able to modify their chemical structure based on the concrete environment and develop new functionalities over time, represents the current efforts of Mapei's research in this field, with the goal of constant improvement of the technology and properties of concrete. For Mapei the future of superplasticizers has already begun!

*Mapei Research & Development Laboratories

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Reducing Autogenous and Drying Shrinkage of Concrete by a Shrinkage-Reducing Admixture

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INTRODUCTION

A major drawback associated with concrete is its volume instability over time. Concrete shrinks when it is subjected to a drying environment. The extent of the shrinkage depends on many factors, including the properties of the material, mixture proportion, temperature, relative humidity of the environment, the age when concrete is exposed to the drying environment and the size of the element. If the shrinkage is restrained, cracks may occur. Avoiding shrinkage cracks, particularly at early ages, is critical to meet the intended design purpose throughout the facilities service life.

The use of water reducing admixtures generally has a tendency to reduce drying shrinkage. However, autogenous shrinkage may become more significant with the decrease in the water/cement ratio (w/c). ACI 116R defines autogenous volume change as a change in volume produced by the continued hydration of cement, exclusive of the effects of applied load and change in either thermal condition or moisture content.

The objectives of this study were to investigate the effect of SRA on the autogenous and drying shrinkage of concrete and also on properties of concrete cured at 30°C which is typical in a tropical environment. Control concrete and concrete incorporating SRA (1.5% by mass of cement) were cast at three different w/c of 0.60, 0.45 and 0.30. The effect of the admixture on slump, air content, initial setting time, and compressive strength at 3, 7, and 28 days were determined and discussed. Autogenous shrinkage of sealed specimens and total shrinkage of specimens exposed to a dry environment with a relative humidity of 65% were determined for up to six months.

EXPERIMENTAL

Materials

Normal Portland cement was used for all the concrete. The cement has a Blaine fineness of 337 m²/kg and Bogue composition of 67% C_3S, 9.1% C_2S, 7.5% C_3A and 8.5% C_4AF. Natural sand with a fineness modulus of 2.7 and crushed granite with maximum nominal size of 20mm were used. A naphthalene-based superplasticizer was added to obtain a target slump of 75 to 100mm for concrete with w/c of 0.30. The shrinkage-reducing admixture (SRA) was in liquid form and was used in a dosage of 1.5% by mass of cement.

Concrete mixture proportions

Six concrete mixtures were cast at three different w/c of 0.60, 0.45, and 0.30. At each w/c, one control mixture without the SRA and the other with the SRA were cast. The same amount of water as the SRA was deducted from the concrete with the SRA. The mixture proportions of the concrete are given in Table 1.

Concrete mixing and specimen preparations

After the materials for concrete were batched, they were mixed in a pan mixer. For each concrete mixture, six prisms of 100 x 100 x 500mm and nine cubes of 100 x 100 x 100mm were cast. Two prism specimens were sealed immediately after casting for autogenous shrinkage measurement. The four unsealed prisms were used for monitoring the total shrinkage; two of them were moist cured for 7 days, whereas the remaining two were exposed to dry environment after demolding at 24 hours. The nine cubes were used to determine the compressive strength and were cured in a moist room at 30 ± 2°C until the time of test. One cube of 150x150x150 mm was cast from mortar sieved from each concrete mixture for determining the initial setting time of the concrete.

Test methods

The slump, density, air content and initial setting time of fresh concrete were determined in accordance with relevant ASTM methods.

The first 24 hours autogenous shrinkage of the specimen starting from the initial setting time was obtained using a pair of laser sensors. Due to the limitation of the equipment, only one of the two specimens was used for this measurement. After 24 hours, the specimens were demolded and 5 pins were glued onto the two side-casting surfaces of each specimen along the centerline. On one of the surfaces, two pins were located 150 mm from each end and 200 mm apart, whereas on the other surface, two pins were located 50 mm from each end with one pin in the middle. The specimens were then resealed with aluminum tape and left in a room with controlled temperature of 30°C. The autogenous shrinkage was measured using a mechanical gauge at various ages up to 6 months.

The four prisms for total shrinkage were demolded also after 24 hours, and pins were glued onto each specimen as described above. Two of them were placed in the humidity controlled room at temperature of 30°C and relative humidity of 65%, whereas the other two were cured in a fog room at the same temperature for another 6 days before being exposed to the room with the relative humidity of 65%. The total shrinkage of the specimens was also measured with a mechanical gauge at various ages up to 6 months.

Table 1- Proportions of the concrete mixtures

w/c	Cement	Water	Fine agg	Coarse agg	SRA	Superplasticizer
	kg / m³ of concrete					
0.60	342	196	688	1059	0	0
0.60	342	191	688	1059	5.13	0
0.45	456	201	588	1060	0	0
0.45	456	194	589	1060	6.84	0
0.30	480	133	734	1061	0	5.45
0.30	480	129	733	1060	7.2	5.45

Table 2 - Effect of the SRA on the properties of concrete

Concrete Mixtures w/c	Concrete Mixtures % SRA	Slump (mm)	Air Content (%)	Fresh concrete density (kg/m^3)	Initial Setting Time (mins)	28-day Compressive Strength (MPa)
0.60	0	90	1.3	2350	236	42.6
	1.5	110	1.3	2350	264	38.2
0.45	0	95	1.2	2375	213	52.6
	1.5	105	1.8	2365	240	51.3
0.30	0	105	1.8	2460	217	77.6
	1.5	120	1.6	2450	277	72.6

RESULTS AND DISCUSSION

Slump and air content of fresh concrete

Slump - The slump values are shown in Table 2, and the incorporation of SRA increased the slump slightly. The results are consistent with those by Schemmel et al. [1] and Nmai et al. [2].

Air content - From Table 2, it appears that the SRA did not have significant effect on the air content of the fresh concrete and this is similar to the results reported by Folliard and Berke [3] and Nmai et al. [2]. In the research by Schemmel et al. [1], it was reported that SRA mixtures tend to have lower air contents than those without the admixture.

Initial setting time

From the results presented in Table 2, the SRA seems to have slight retarding effect on the initial setting times of the concrete. For the concrete with w/c of 0.60 and 0.45, the initial setting time was delayed for approximately 30 minutes. However, for the concrete with w/c of 0.30, the initial setting time was delayed for 60 minutes. Folliard and Berke [3] reported retardation of the initial setting time by about two hours. However, Nmai et al [2] mentioned that the SRA might retard the initial setting time by less than an hour.

Although the incorporation of the superplasticizer did not seem to affect the initial setting time of the control concrete, the combined addition of the superplasticizer and the SRA appear to delay the initial setting time of concrete more than that in which no superplasticizer was used (Table 2). This might be attributed partly to the higher dosage of the SRA in concrete with w/c of 0.30 and partly to the combined effect of the two admixtures used. Brooks et al. [4] found out that SRA has negligible effect on the setting times of normal strength concrete, but has significant retarding effect when used in combination with superplasticizer in high-strength concrete. It was mentioned in reference [5] that the use of SRA with other admixtures might exhibit retarding properties with the net retardation more than the simple additive effect of the two admixtures used separately.

Compressive strength

The compressive strength of the concrete at 28 days is also given in Table 2. It can be seen that the 28 days compressive strength for the mixtures with 1.5% SRA shows a reduction of about 3 to 10 %. Reduction of the compressive strength of concrete with SRA was also observed by other researchers [3, 6, 7]. Weiss, et al. [8] found that the percentage reduction in compressive strength is greater for the mixtures with lower w/c ratios. This was not observed in this study.

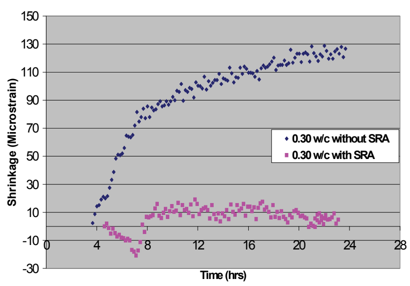

Fig 1 -- First 24 hours Autogenous Shrinkage for concrete with w/c 0.30

Autogenous shrinkage

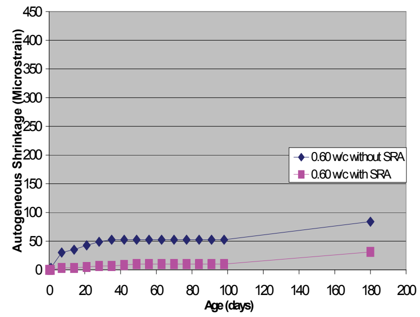

Fig 2 -- Autogenous Shrinkage for concrete with w/c 0.60

Autogenous shrinkage was measured from the initial setting time and the results are presented in Figs. 1 to 4. Autogenous shrinkage within the first 24 hours was significant only for the concrete with low w/c of 0.30 and was negligible for those with higher w/c of 0.45 and 0.60. For the concrete with w/c of 0.30, the incorporation of SRA almost eliminated the autogenous shrinkage within the first 24 hours as shown in Fig. 1. This indicates that the incorporation of the SRA helps in preventing early age cracking.

The autogenous shrinkage after 24 hours was measured by the mechanical gauge and the first 24 hours autogenous shrinkage was added to obtain the total autogenous shrinkage from the initial setting time up to 180 days. The autogenous shrinkage was higher and hence more pronounced at the lower w/c, and developed more rapidly in the first three to four weeks compared with later age. The results shown in Figs. 2 to 4 indicated that the incorporation of the SRA reduced the autogenous shrinkage, and the reduction was most significant for the concrete with w/c of 0.30. The reduction in the autogenous shrinkage by the SRA ranged from 39 to 81 % at the end of 91 days and 24 to 63 % at the end of 180 days (Table 3). The reduction of the autogenous shrinkage by the use of the SRA has been believed due to the reduction in the

Table 3 - Autogenous shrinkage of concrete

Concrete mixtures w/c	% SRA	Autogenous Shrinkage (Microstrain) (From the initial setting time onwards till the age specified) 28-d	91-d	180-d
0.60	0	49	53	84
	1.5	7	10	31
% reduction		**86**	**81**	**63**
0.45	0	78	117	172
	1.5	41	71	131
% reduction		**47**	**39**	**24**
0.30	0	232	279	323
	1.5	88	119	148
% reduction		**62**	**57**	**54**

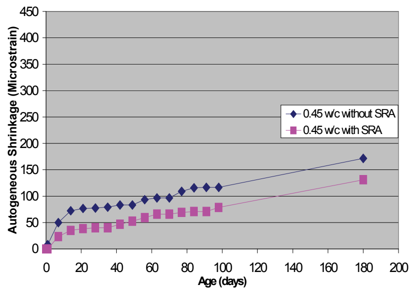

Fig 3 -- Autogenous Shrinkage for concrete with w/c 0.45

surface tension of the pore solution, thus self desiccation of the concrete [9].

Total shrinkage

Total shrinkage is the shrinkage of concrete exposed to dry environment which includes both the autogenous and drying shrinkage. The total shrinkage of concrete with different w/c and with initial moist curing of 1 and 7 days are presented in

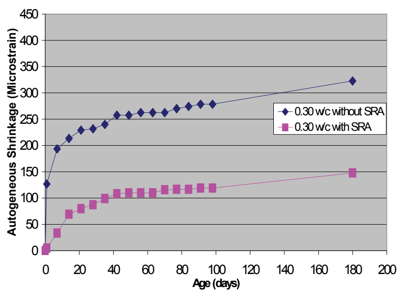

Fig 4 -- Autogenous Shrinkage for concrete with w/c 0.30

Figs. 5 to 10. The percentage reduction in the total shrinkage of concrete by the use of the SRA at 28, 91, and 180 days is summarized in Table 4. The reference point for the total shrinkage also started from the initial setting time.

The results indicated that the total shrinkage is reduced generally with the reduction in w/c and with the use of the SRA. The use of the SRA appears to reduce the total shrinkage more than that by the reduction in w/c. The results in Figs. 5 to 10 show that the SRA reduced shrinkage at early age when concrete is most vulnerable to cracking.

Comparing the shrinkage of concrete with

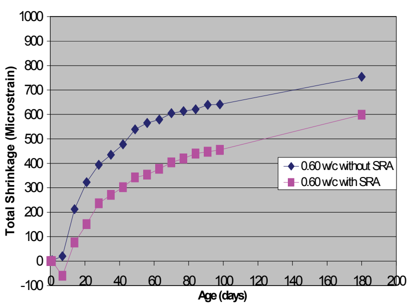

Fig 5 -- Total Shrinkage for concrete with w/c 0.60 (7-Days Moist Curing)

Table 4 -- Total shrinkage of concrete

Concrete mixtures		Total Shrinkage (Microstrain) * (1-Day Moist Curing)			Total Shrinkage (Microstrain) * (7-Days Moist Curing)		
w/c	%	28-d	91-d	180-d	28-d	91-d	180-d
0.60	0	500	671	795	394	639	754
	1.5	353	536	653	236	447	599
% reduction		**29**	**20**	**18**	**40**	**30**	**21**
0.45	0	485	660	812	387	589	728
	1.5	299	476	620	208	410	553
% reduction		**38**	**28**	**24**	**46**	**30**	**24**
0.30	0	530	630	725	455	566	670
	1.5	270	391	479	176	298	405
% reduction		**49**	**38**	**34**	**61**	**47**	**40**

** 1st 24 hrs autogenous shrinkage + total shrinkage after 24 hrs*

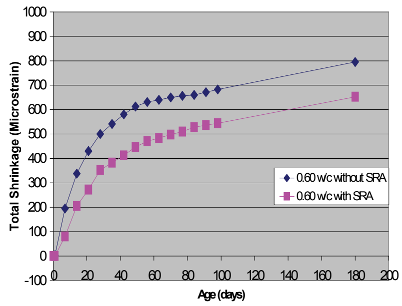

Fig 6 -- Total Shrinkage for concrete with w/c 0.60 (1-Day Moist Curing)

1- and 7-day initial moist curing, the longer moist curing reduced the shrinkage as expected. Since at job sites it is often specified that concrete should be cured in moist condition for 7 days, the shrinkage of concrete with initial moist curing of 7

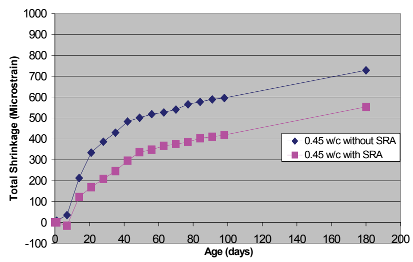

Fig 7 -- Total Shrinkage for concrete with w/c 0.45 (7-Days Moist Curing)

days are used for comparison and discussion. The shrinkage of concrete with 1 day moist curing will be used to separate the drying shrinkage from the total shrinkage and this will be discussed in the following section.

From Table 4, the reduction in the total shrinkage for the specimens with 7 days initial moist curing range from 40 to 61% at 28 days, 30 to 47% at 91 days and 21 to 40 % at 180 days due to the use of the SRA. It appears that the lower the w/c of concrete, the greater the reduction in the total shrinkage when the SRA was used. The observed trend is consistent with that reported by Folliard and Berke [3].

Drying shrinkage

Miyazawa and Tazawa [10] suggested that the drying shrinkage occurred in concrete exposed to dry environment can be determined by subtracting the autogenous shrinkage strain of corresponding sealed

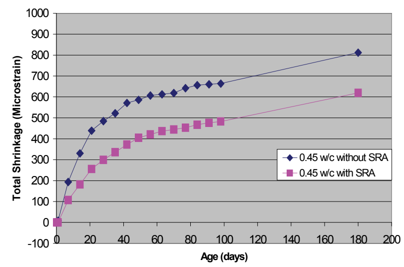

Fig 8 -- Total Shrinkage for concrete with w/c 0.45 (1-Day Moist Curing)

concrete specimen from the total shrinkage strain of the exposed specimen. However, the autogenous shrinkage determined from the sealed specimen does not reflect the exact autogenous shrinkage of the exposed specimen. The autogenous shrinkage under drying condition is probably lower compared to the autogenous shrinkage in the sealed condition due to the lower degree of cement hydration in the former. The difficulty of separating autogenous shrinkage and drying shrinkage from the total shrinkage was also brought up by Yang and Sato

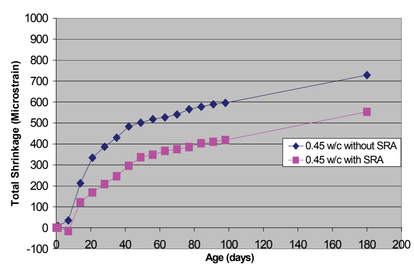

Fig 9 -- Total Shrinkage for concrete with w/c 0.30 (7-Days Moist Curing)

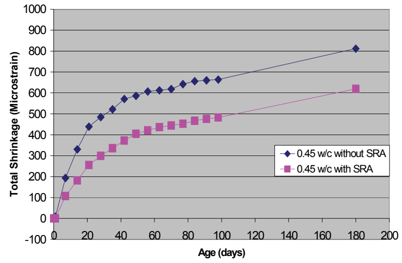

Fig 8 -- Total Shrinkage for concrete with w/c 0.45 (1-Day Moist Curing)

[11] stating that the autogenous shrinkage under drying condition was overestimated when the value from the sealed specimen was used. The principle of superposition assumes that this overestimation of the autogenous shrinkage is negligible, at least for concrete with low w/c.

Based on the principle of superposition, the drying shrinkage was obtained by subtracting the autogenous shrinkage from the total shrinkage of concrete with 1 day moist curing, and the results are given in Table 5. The drying shrinkage was reduced by 15 to 26% at 91 days and 13 to 24% at 180 days for concrete with the SRA.

It is clear that the concrete with higher w/c experiences more drying shrinkage, whereas the concrete with lower w/c experiences more autogenous shrinkage. From practical stand point, it is the early age autogenous shrinkage and the total shrinkage of concrete exposed to dry environment after initial moist curing that are most important when potential shrinkage cracking is concerned. The use of the SRA in concrete reduced both autogenous and drying shrinkage, thus the total shrinkage of concrete.

CONCLUSIONS

Based on this study, the following conclusions may be drawn for concrete with w/c from 0.30 to 0.60 with 1.5 % shrinkage reducing admixture (by mass of cement) cured at 30±2°C.

1. The use of the SRA resulted in slight increase in the slump value of the concrete. However, the SRA did not affect the air content of the fresh concrete.

2. The SRA seems to have retarding effect on the initial setting time of concrete.

3. With the dosage of 1.5% SRA, the 28 days compressive strength of concrete was reduced slightly by 3 to 10%.

4. The SRA is effective in reducing the autogenous shrinkage and the shrinkage of concrete exposed to dry environment. The use of the SRA almost eliminated the autogenous shrinkage of the concrete with w/c of 0.30 within the first 24 hours. For the concrete with 7 day initial moist curing, the use of the SRA reduced the total shrinkage by 40-61% at 28 days and by 30-47% by 91 days.

Table 5 -- Separation of drying shrinkage (DS) from total shrinkage (TS)

Concrete		Shrinkage at 91 days				Shrinkage at 180 days			
w/c	% SRA	TS	AS	DS	AS/TS, %	TS	AS	DS	AS/TS, %
0.60	0	671	53	618	8	795	84	711	11
	1.5	536	10	526	2	653	31	621	5
% reduction		**20**	**81**	**15**		**18**	**63**	**13**	
0.45	0	660	117	543	18	812	172	640	21
	1.5	476	71	405	15	620	131	488	21
% reduction		**28**	**39**	**26**		**24**	**24**	**24**	
0.30	0	630	279	351	44	725	323	403	45
	1.5	391	119	272	30	479	148	331	31
% reduction		**38**	**57**	**23**		**34**	**54**	**18**	

AS – autogenous shrinkage

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High Early Strength MIGHTY Concrete Admixtures based on Napthalene Sulfonate

Mr Yusuke Yoshinami, Global R&D, KAO Corporation

Recently, environmental issues are of utmost importance and we, at KAO Corporation, have to take into consideration this concern during the production of our admixtures. This is definitely applicable for concrete manufactures as their main raw material, cement, is one of the biggest industry which discharges carbon dioxide emissions into the environment. Cement clinker production contributes about 5% of global total CO2 emissions from fuel use and industrial activities. This results in CO2 emissions for concrete reaching more than 130kg/ton. In order to reduce CO2 emissions, alternative materials useful for concrete manufacturing have to be considered. Examples of which include fly ash, slag, etc.

In the case of using these materials, one main problem encountered by concrete producers is the reduction in strength and especially so for early strength. If 25% fly ash is used to replace ordinary cement, the 1 day strength could be reduced by as much as 30%. This is a serious problem especially in the pre-cast concrete industry. Also, steam curing is quite often used in the pre-cast concrete industry. This method incurs very high fuel costs and subsequently very high CO2 emissions as well. If either the curing time or the curing temperature can be reduced, or if curing can be totally eliminated, it will be commercially economical for the concrete manufacturers as well as beneficial to the environment.

In consideration of the above issues, it will be excellent if concrete admixtures are able to counter the reduction in strength when such alternative materials are used. Therefore in KAO, we have headed towards this direction and developed a new early strength type concrete admixture based on naphthalene sulfonate which we would like to introduce for use in eco-friendly concrete.

KAO is the inventor of Sodium Naphthalene Sulfonate Formaldehyde Condensate type superplacticizer for concrete. This superplasticizer was invented in 1962 by Dr. Hattori who was a KAO Corporation researcher. And ever since, KAO has been the market leader in Japan, China and ASEAN countries for nearly 50 years. In a continued bid to improve concrete technology and especially in high strength concrete, KAO has developed a new early strength type superplasticizer based on naphthalene sulfonate. We focus this development by paying special attention to the hydration reaction for C3S and C3A. During the hydration process, the volume of voids in the cement will affect the compressive strength. Our new developed chemical can create a lot of minute crystalline cores and these minute crystalline cores can diminish voids in the cement thereby resulting in high early strength for concrete. Of course, PC type admixtures can also counter the effects of lower early strength but PC type admixtures are very sensitive towards other constituent materials in concrete and not as robust as Napthalene type admixtures.

By using this new technology and by replacing 25% of cement using fly ash, tests have shown that the 1 day strength is the same as using 100% cement. We can show an example in Table 1 below.

Table 1

No	W/P (%)	W/C (%)	S/a (%)	Slump (cm)	Unit content (kg/m3)						Strength (MPa)
					Water	Cement	Fly Ash	Sand	Gravel	Admixture	1day
1	41.4%	41.4%	42.0%	5.0	145	350	0	780	1120	2.80	28.1
2	41.4%	55.8%				260	90	780	1120		19.3
3	41.4%	55.8%						780	1120		29.2

Admixture
1, 2 ; Sodium Naphthalene Sulfonate Formaldehyde Condensate type (MIGHTY 150)
3 ; New product

As for the effects of steam curing, as shown in Table 2 below, you can get the same result comparing a concrete undergoing steam curing against the new chemical without steam curing!

Table 2

No	W/C (%)	S/a (%)	Slump (cm)	Unit content (kg/m3)					Strength (MPa)	
				Water	Cement	Sand	Gravel	Admixture	1day	28days
1	27.6%	38.0%	5.0	135	490	680	1130	5.39	45.3	84.9
2								8.33	65.2	85.1

Admixture
1 ; Sodium Naphthalene Sulfonate Formaldehyde Condensate type (MIGHTY 150)
2 ; New product

This new product is based on Sodium Naphthalene Sulfonate Formaldehyde Condensate but has been modified by KAO's high technology for concrete admixture in accordance to our new company policy "Eco Together". That means we strive to develop new products together with customers based on eco-friendly concepts. KAO will always develop new chemicals for customers benefit.

Eastern Pretech GROUP

Eastern Pretech Group (EP Group) is one of the region's largest industry players in precast concrete and dry-mix plaster & mortar products.

As a key business unit and wholly-owned subsidiary of SGX-listed industrial conglomerate NATSTEEL LTD (NSL), EP's core competence is in:

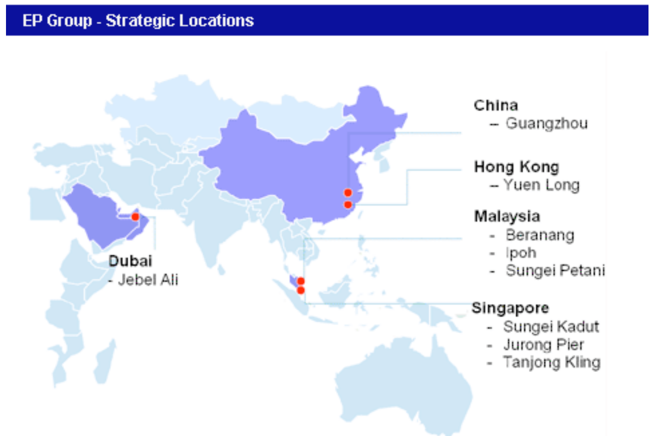
- Engineering Design and Manufacturing of **Precast Concrete components**; and
- Formulation and Manufacturing of **Drymix Plaster and Mortar products**

Asia and Middle East Market presence

With operations spanning Asia and Middle East, EP Group has strategic manufacturing facilities in Singapore, Malaysia, Hong Kong, China, UAE and Europe.

In Asia and Middle East, EP group's market leadership positions has enabled the group to be a leading value-added provider of integrated construction product solution in the building, industrial and infrastructural sectors.

In Europe, the group's marine and land-based prefabricated bathroom and marine fire door business has strong niche presence in Finland, Norway and Russia.



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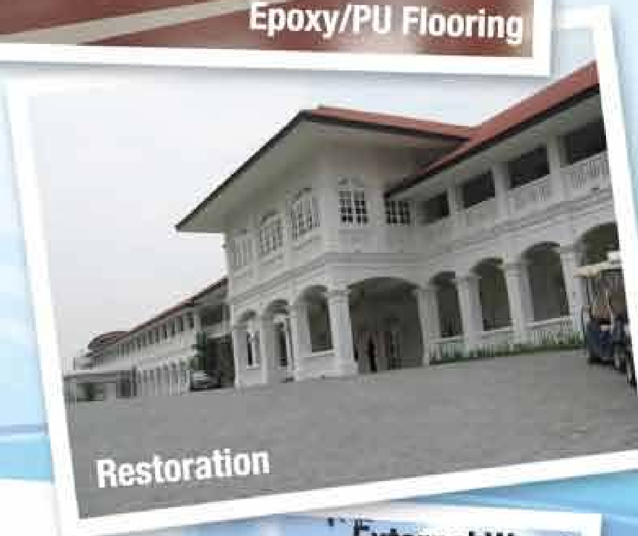

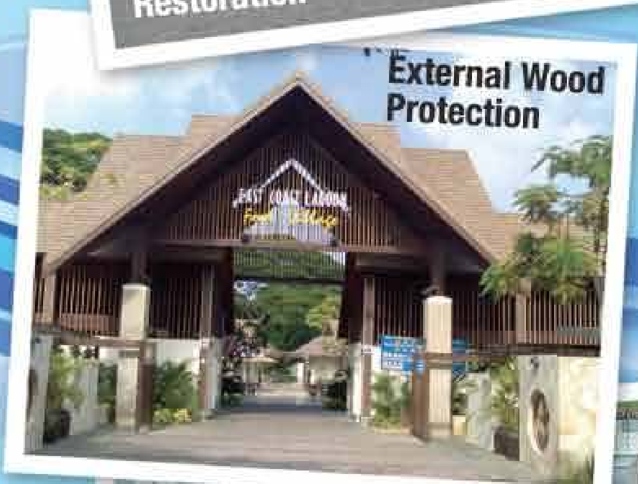

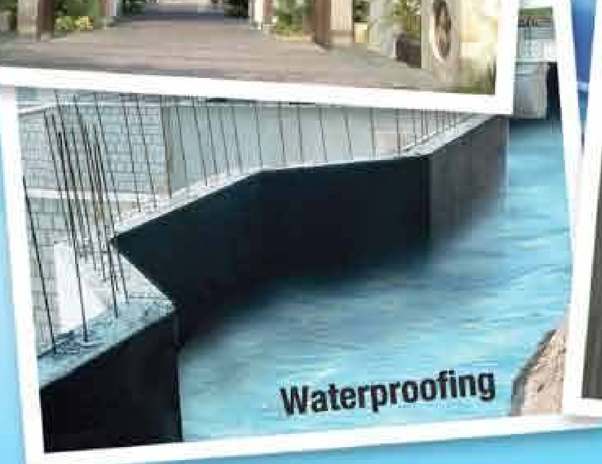

New State-of-the-art Multi Utilities Complex

A new state-of-the-art multi utilities complex comprising a co-generation plant, a desalination plant, and a waste water treatment facility will commence operations to convert coal to clean energy. HSL Constructor Pte Ltd is the approved Engineering, Procurement and Construction (EPC) contractor for the proposed biomass/coal jetty situated at Tembusu Crescent, Jurong Island.

Under this project, HSL undertake the design of the jetty, submission of approved drawings to relevant authorities, procure the necessary materials and construct the entire jetty. The proposed jetty shall be designed for safe berthing of vessels & barges with minimum capacity of 5000 DWT and maximum capacity of 15000 Dead Weight Tonnage (DWT). Upon completion, this jetty will facilitate the loading and unloading of biomass and coal sourced locally and from neighboring countries.

During tendering stage, we realized that the Reinforced Concrete (RC) jetty deck cannot be constructed in-situ, on top of the pile cap. It would be extremely difficult to fabricate and cast the concrete without a proper platform while at the same time, maintaining the quality of the product and preventing concrete spillage. The option of precasting the concrete deck not only eliminate these problems, but it also speed up the construction process since it can be done concurrently with other works.

Once the project was awarded, the jetty deck was designed as a precast structure which is then made into a monolithic structure upon topping it up with concrete in-situ. The Jetty Deck or berthing platform will be of a thick reinforced concrete slab spanning 160 meters across (consist of 72 precast concrete slabs weighing 16-22 tonnes each) at every 10m to 15m construction joint with a width of 22 meters. The deck surface will be of power float finish with a concrete hardener. Throughout the entire construction phase, this method ensured that the schedule was running smoothly as there was minimal interface and concrete curing. By adopting this methodology of precast and cast in- situ topping, the time spent on formwork, rebar installation and in-situ concrete casting is greatly reduced and quality of the jetty deck is greatly enhanced. This increased in Productivity has lead to early completion of the whole jetty deck by almost two months.

With rising fuel prices and an increasing demand for energy becoming a global concern, HSL is proud to contribute our construction excellence towards this co-generation plant, which will provide an economically and environmentally sustainable alternative for utility supplies.

Marine Civil Engineering

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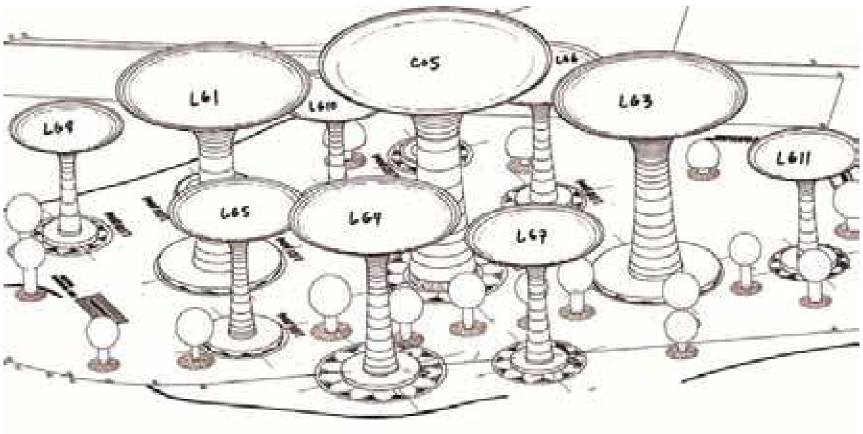
Erection of Lion Grove Supertrees At Gardens By The Bay (Marina South)

By Edwin Soh, Von Lee, Expand Construction Pte Ltd

INTRODUCTION

The Supertrees are structures that have the conceptual look of natural trees, but built in larger size proportions. There are 12 numbers of Supertrees (ST) in the Lion Grove area with varying heights; 5 ST (LG2, 8 to 11) are 25m high, 3 ST(LG4,5,7) are 30m high, 1 ST(LG4) is 37m high, 2 ST (LG1,3) are 42m high and 1 (C05) is 50m high.



Each Supertree has a circular main core in reinforced concrete structure. The shortest Supertree of 25m in height has an overallcore diameter of 2.07m while that of the 42m Supertree has a core diameter of 3.8m. C05 has a 4m outer diameter main core with another outer layer of circular wall measuring 7.3m in overall diameter.

Nine Supertrees which are 25m to 37m high have only the main concrete cores and are non-habitable. The other Supertrees namely 42m high LG1, LG 3 and 50m high C05 are habitable with lifts within the main cores and access staircases. Top portion of C05 is enlarged to cater for commercial space with a roof terrace viewing gallery, making it distinctly different from the other 11 Supertrees.

Each of the Supertrees is cladded with stainless steel trunk skin from its base level up to throat level (approx. two third of height of the main structure). Above the trunk skin are the carbon steel core head-ribs and canopy elements which are supported on the upper level of concrete core. The canopy overall diameter is at the same magnitude to the height dimension of the corresponding Supertree.

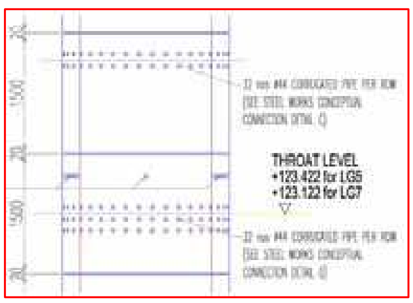
THE CHALLENGES

The concrete core structure construction requires accurate interface with steel works trunk skin and canopy elements. As the steel elements are fixed to one another in close tolerance bolting connection, the connection positions in concrete core have to be done accurately, especially at the throat level.

The entire steel canopy is pre-assembled at ground level, and thereafter jacked up to final position at the top of core. Project specifications require fair face concrete structure construction. Changing radii of spiral staircases of 42m LG1 & 3 demands high quality control of dimensional tolerances in the context of fair face construction compliance.

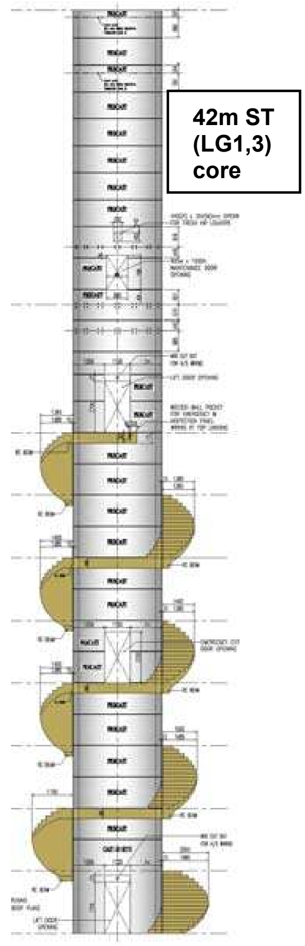
As for 50m C05 structure, other than the spiral staircases, there are also the spandrel walls spiraling round the main core wall and supported on four columns. The main core wall also serves as M&E compartments, meaning the main core is also profiled with carved out recesses in it. At the upper level of C05 where the spandrel walls terminate, 16 numbers of relatively thin radial fins project outward to form increasing floor plate size and inclined radial wall with restaurant (bar) level having overall floor diameter more than twice the diameter of spandrel wall core or more than four times the main core diameter. Constructing top mushrooming structure also in fair face concrete finish poses a challenge in normal cast in situ method of construction.

Steelworks connection sleeves to core

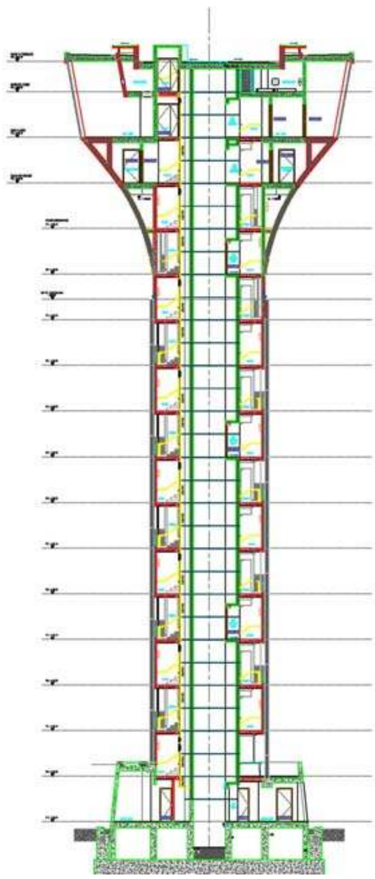


SOLUTIONS

Given the quality demand of the fair face concrete finishing and close tolerance of steel works bolting, the appropriate solution to be adopted requires consistent workmanship. Precast solution was chosen



50m C05 structure sectional view



to make this possible. Conversion of cast in situ structure to precast solution was made for super-structural portion of main core above its entrance door. Panel sizes were modularized based on 1.5m high wherever possible. Structural connection between each precast core component is achieved through the use of rebar couplers in through grouted sleeves. For 42m ST, panel height was 1.325m being governed by staircase landing levels. Its main cores are first constructed. The next stage of work is the erection of steelworks canopy, followed by spiral staircase using precast flights and jointed to the cast in situ floor landing. Weight of panels ranges from 4.5t up to 9t. Since the core can be constructed independently of surrounding landscaping works, installation of panels can be done using mobile cranes at near distance. Mobile climbing working platform was adopted as the means of access which involves only up and down the main core.

25m Supertree core wall panel installed into position

Modularization of C05 main core was based on two pieces of 1.5m precast panels and stitched cast together using metal jump form. The entire main core was erected in first stage of construction process, following which the outer enclosure walls together with the spiral staircases and supporting perimeter columns were constructed. Upper levels radially projecting structural frames was discretized into precast elements such as radial fins, segmented walls at Back of House, Bar Level, Service Zone and Roof Terrace levels. Unlike 42m ST spiral staircase which was cast as a full panel, solution for C05 spiral staircase construction was revolutionary. As the flight reinforcement spans widthwise, fully cast panel poses connection challenges. Precast permanent soffit formwork was adopted for the flight and landing. To achieve fair face finish on the top surface of flight, moulded risers and threads metal formwork system was adopted.

The solutions to meet the requisite work schedule and contractual specifications were implemented as set out from the commencement of project. Simplification of work process concept via factory production, structural design value engineering, finished goods prefabrication methodology leading to cleaner site work environment have contributed positively to site productivity. A study of productivity for precasting of C05 upper levels precast components yielded 50% productivity improvement over conventional cast in situ construction (information extracted from compilation of labour productivity data under BCA Mechanization Credit scheme submittal).

Precasting Back of house inclined wall

C05 Precast spiral flight permanent formwork panel

ADVANTAGES OF PROPOSED SOLUTIONS

The advantages of proposed solutions are as follows:

a. Modularization directly improves productivity

By precasting the main cores in modular segments and stacking one panel on top of another with continuity reinforcement, it was possible to control the workmanship right at the production floor. This method of segmenting the main cores into suitable height modules discretize the work process on the ground level and improve productivity of work.

b. Pre-fixed work platform instill safety culture and reduce downtime

Every alternate stack of precast panels (except C05 panels) is pre-installed with internal working platform to enable the workmen gain immediate access to the inner area right at the point of installation. Thus, downtime of workers can be reduced or even avoided.

Core wall internal access platform pre-fixed to alternate level of panel before installation enhances work safety

Typical 25m Supertree

c. Neat joints enhance esthetics and reduce defects

The continuity reinforcement was spliced using coupler bars and the installed panel was grouted from the top of panel. In this way, the connection work was done within the segment's horizontal joint without requiring sealing up of connection grouting points.

d. **Use of templates in precasting improve accuracy and reduce abortive work**

Pre-determined position of steel works bolting connections points were set out relatively easier and more accurately using templates at the production floor Doing so allowed smoother site work flow in both concrete as well as steel works..

It does away with tedious drilling on reinforced concrete core wall, with risk of weakening the core with hundreds of through holes for one level of steel works connection. For LG1&3, template for cast in coupler bars in main core wall precast panel for spiral staircase reinforcement connection can be done in good accuracy with also lesser manpower at production floor.

e. Moulding for profiled elements favours precasting

For 50m C05, in view of the profiled main core wall, moulds can be assembled and checked at the production floor much more readily, even so with repeated casting of elements. It also ensured sharp concrete edges can be maintained during precast demoulding.

f. Mechanization using mast climbing working platform reduces worker fatigue in vertical movement with positive work improvement

The use of mass climbing working platform on site allows direct vertical transportation of workmen to any level of constructed core in a coordinated manner. The work processes are streamlined with ease of access along any length of the core, thus enhancing group work with positive contribution to improved productivity.

g. Precasting of C05 elements enables accurate construction to meet fair face finish requirement

Starting from main core to curve infill partition wall, spiral staircase flights, landings, spandrel wall, radial fins, inclined radial walls, roof wall and other elements, many of C05 structural and non structural elements were proposed to be in precast construction. Where in situ stitching joints

C05 in situ spiral flight thread & riser top cover mould eliminates resetting of riser & thread conventional formworks

were required, metal formwork was adopted to achieve matching quality of interface with precast elements.

h. Use of metal mould for C05 spiral staircase cast in situ risers and threads ensures dimensional consistency and reduce measurement for each flight

The method of constructing the spiral staircase with top capping mould to form cast in situ threads/risers has ensured the as cast surface of risers and threads are in fair face finish. The resulting surface needs no add-on finishing layer, and reduce defects and labour. Self compacting concrete was used to achieve the desired result.

The choice of construction methodology invariably influences the outcome of labour productivity on site. Making precasting as the construction method enables simplification of work at height to ground level work with ease in forming, reinforcing, casting, inspection and verification before placing unto final position on site. Hence, the advantages are clear as depicted above.

50m C05 installed precast main cores with services compartments

open spiral staircase soffit using precast formwork panel

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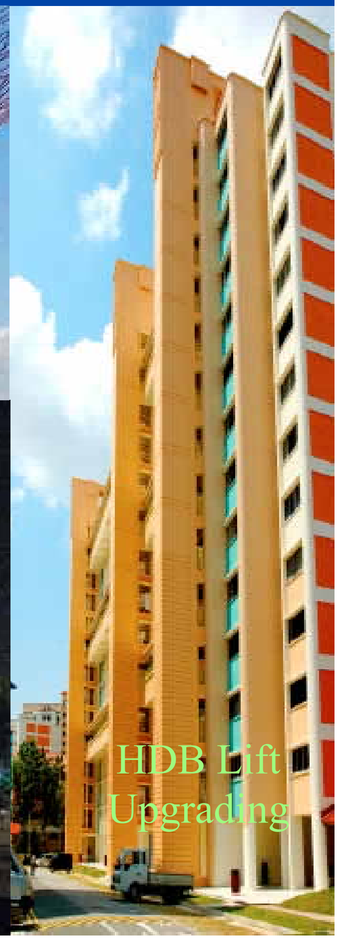
Supertrees @ Gardens By the Bay


HDB Lift Upgrading

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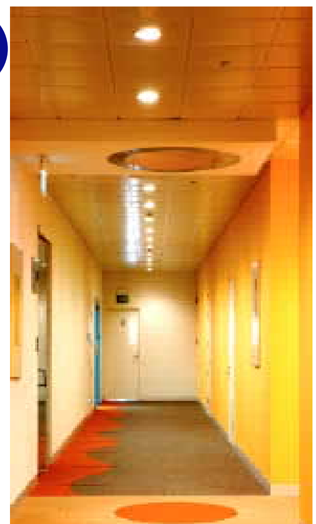
City Hall Barrier Free Accessibility Enhancements

Expand Construction Pte Ltd

Founded by Chairman, Mr Von Lee Yong Miang on 8 July 2000, Expand Construction Pte Ltd has grown from a two man outfit to an A1 construction company in Singapore in the short span of ten years.

The company has grown from strength to strength, year on year, and has been elevated from the lowest ranking C3 category of the Building Construction Authority Contractor Registry to the current A1 category, achieving promotion of 8 ranks in 10 years. Expand is currently registered with BCA CW01- A1 for building with unlimited tendering capacity and BCA CW02-A2 for civil engineering works up to $85million tender capacity per contract.


Upgrading works at The Alpha and The Gemini, Science Park II

For enquiries, email to expand@singnet.com.sg, Tel :62988066. Co Reg. No. 200005999D

T·Y·LIN INTERNATIONAL PTE. LTD.

TYLin International Pte Ltd, since its establishment in 1972, has provided consultancy services to more than 400 clients in the region and has handled over 600 projects. The firm has re-invented itself over recent years and taken on a project management role with proven capability to deliver an integrated package of services covering every aspect of the project, tackling complex projects requiring the co-ordination and management of many different experts and professional disciplines. The descriptions below highlight some of the challenges and innovative solutions to meet the complex requirement in many of the projects:

The Interlace

The residential development generally consists of 31 interconnected 6-story blocks or taller superblocks that are stacked together in a staggered arrangement based on a hexagonal grid. The challenge in the structural design is to present a structural system that will enhance flexibility in the architectural layout, while achieving a buildable design within the optimum time of construction for the project.

Reflections at Keppel Bay

Designed by one of the most ingenious and celebrated architects in the world, Daniel Libeskind, this residential development will showcase Singapore as the premier location for waterfront living. The towers are arranged in pairs of short and tall towers, each linked by three sky bridges. On top of each tower is a lush, landscaped garden terrace of suspended planters, supported on the tower by a crown of circular steel pipes.

The double curvature of the towers with tapering sides poses extreme challenges to the structure during the design and construction phases. Careful consideration and analysis must be carried out to determine the expected lateral deflections during construction. In order to bring the building back to the designed location, adjustments must be made progressively. Other considerations include, but are not limited to, wind loading and human comfort.

The Fullerton Hotel

Fullerton Hotel and One Fullerton - a 70-year old Conservation Building that has been restored and redeveloped into a high-class 394-room hotel. The complex redevelopment of the old structure required many unique and unconventional mechanical engineering design solutions in order to include artistic feature such as 2-story louvered glass windows and a large, 8-story skylight. Other features introduced include:

Elimination of environmental noise and vibration to the guestrooms through the skylight. Air conditioning without diffuser at Town Coffee House. Open-air air conditioning of the roof garden above the Straits Club. Atrium air conditioning and food odour containment in the kitchen facility of the Atrium Restaurant. Installation of window sprinklers to exceed fire department requirements for shared single-glass windows. Smoke Control System for the large basement and the 1,100 square meter atrium.

Kim Chuan Underground Depot

It is the first underground depot in the world with stabling capabilities for 70 trains to serve the Circle Line (CCL) and Downtown Line 3 (DTL3) that operate using an automated driverless train system. The Depot is over 1 kilometer long and approximately 150 meters wide at mid-point, and over 20 meters below ground at track level.

It houses train system operations and related maintenance, which includes all necessary cleaning, maintenance, overhaul facilities, operation control center, depot control center, training facilities and storage areas for the vehicle fleet and associated railway system. Value engineering was done on the base concept design, which resulted in a change from 2-level to single-level stabling, and involved re-layout of all workshops, rooms and facilities as well as re-alignment of all trackworks. The net savings include a major reduction in built-up areas, as well as a reduction in volume in terms of the construction and E&M running costs. Despite a total savings of close to $100 million, the envisioned capabilities of the Kim Chuan Underground Depot were not compromised.

The NUS Main Bridge

It links the existing Kent Ridge Campus to the new NUS University Town across the Ayer Rajah Expressway (AYE). The double curvature on plan makes the design of the precast segment bridge construction even more challenging.