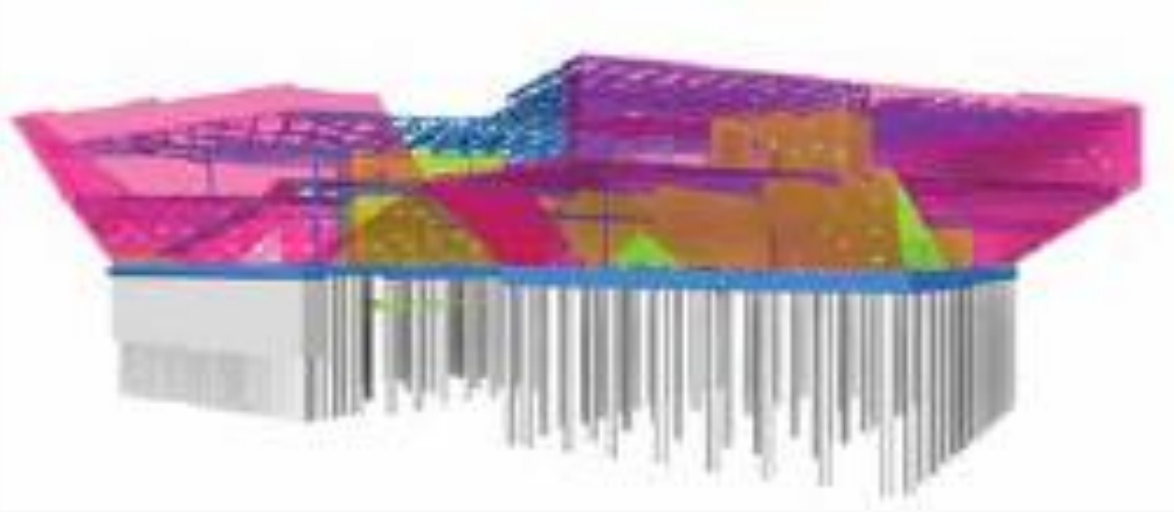
American Concrete Institute
Malaysia Chapter

MYCONCRETE

MARCH 2022 VOLUME 13, ISSUE 3

The Bulletin of the American Concrete Institute – Malaysia Chapter (e-Bulletin)



MyConcrete:
The Bulletin of the American Concrete Institute – Malaysia Chapter

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Published in Malaysia by
American Concrete Institute - Malaysia Chapter
70-1, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC),
46150 Petaling Jaya, Malaysia.

CONTENT

Contents of Bulletin	Page
President's Note	4
Introduction to ACI Malaysia Chapter	5
Past Presidents	6
Management for 2020-2022	7
Notice	8
Upcoming Events	10
Preceding Events	13
Article	14
Technical Report	18
Case Study	24
Membership	28
Premium Sponsors	31
Loyal Sponsors	32

Thank You Sponsors!

We take this opportunity to thank our sponsors for their contribution and support for this month's edition of the MyConcrete eBulletin.

Premium Sponsor	***ADEPT TECHNICAL SERVICES SDN BHD***
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PRESIDENT'S NOTE

Time has just flown by and a New Committee will be elected this coming 29 April 2022 at the 25th AGM. The current committee term was through the worst part of the Covid-19 Pandemic with all the "lockdowns".

It was a very challenging time for us but proudly the team managed to achieve the following:

- Monthly MyConcrete E-Bulletin
- Our 1st Technical Commentary No.1, "Water Intrusion Issue at Concrete Roofs"
- Monthly Online Talks
- The completion of the training manual, "The Concrete Field Technician"

We also have managed to plan two in-person events which will be carried out

- 25th Annual General Meeting and Dinner on 29 April 2022
- ACI-MBAM Joint Seminar on RC-Flat Roof – Criteria for Concrete Design, Waterproofing Skin and Maintenance of Water Seepage Related Issues Based on ACI-MY Technical Commentary No.1 on 20 May 2022

My thanks and appreciation to all committee members and secretariat who have worked hard to achieve all mentioned above.

With this, I end here and hope to see all of you at the 25th AGM on the 29 April 2022.

Thank you and Godspeed.

Martin DAVID
President
American Concrete Institute-Malaysia Chapter
Period 2020 - 2022

INTRODUCTION TO ACI MALAYSIA CHAPTER

American Concrete Institute - Malaysia Chapter (ACI-Malaysia) is a non-profit technical and educational society representing ACI Global in Malaysia, which is one of the world's leading authorities on concrete technology. Our members are not confined to just engineers; in fact, our invitation is extended to educators, architects, consultants, corporate, contractors, suppliers, and leading experts in concrete related field. The purpose of this Chapter is to further the chartered objectives for which the ACI was organized; to further education and technical practice, scientific investigation, and research by organizing the efforts of its members for a non-profit, public service in gathering, correlating, and disseminating information for the improvement of the design, construction, manufacture, use and maintenance of concrete products and structures. This Chapter is accordingly organized and shall be operated exclusively for educational and scientific purposes.

Objectives of ACI-Malaysia are:

- ACI is a non-profitable technical and educational society formed with the primary intention of providing more in-depth knowledge and information pertaining to the best possible usage of concrete.

- To be a leader and to be recognized as one of Malaysia's top societies specializing in the field of concrete technology by maintaining a high standard of professional and technical ability supported by committee members comprising of educators, professionals and experts.

- Willingness of each individual member/organization to continually share, train and impart his or her experience and knowledge acquired to the benefit of the public at large.

PAST PRESIDENTS

1997 - 1998: Ir. Tee Ah Heng (Protem)

1998 - 2000: Ir. Dr. Kribanandan G. Naidu

2000 - 2002: The Late Ir. Dr. Norza

2002 - 2004: Ir. Soo Thong Phor

2004 - 2006: Mr. Seow Aik Guan

2006 - 2008: Ir. Boone Lim

2008 - 2010: Ir. Parnam Singh

2010 - 2012: Ir. Ng Kok Seng

2012 - 2014: Dr. Zack Lim

2014 - 2016: Dr. Zack Lim

2016 - 2018: Ms. Serina Ho

2018 - 2020: Dr. Sudharshan N. Raman

2020 - present: Mr. Martin David

MANAGEMENT FOR 2020-2022

BOARD OF DIRECTION (BOD) FOR 2020-2022

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NOTICE

Membership Subscription 2021

Gentle reminder that 2021 subscription is due.

Kindly note that payment can be made as follows:
Bank: Hong Leong Bank Berhad
Account Number: 291 0002 0936
Account Name: American Concrete Institute – Malaysia Chapter

Once payment has been made, it is important to send
Remittance Slip / Deposit Advice / Bank Transfer Receipt
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Digital Membership Certificate 2021

Members who have paid their subscription will receive their digital membership certificate.
See sample below.

Associate Organisation Student

INTERNSHIP PROGRAMME FOR ACI STUDENT MEMBERS

(SUBJECT TO TERMS & CONDITIONS APPLY BY COMPANIES)

Company Name	Company Address	Person To Contact	Business Involved
PLYTEC FORMWORK SYSTEM INDUSTRIES SDN BHD	No. 19, Jalan Meranti Permai 3, Meranti Permai Industrial Park, Batu 15, Jalan Puchong, 47100 Puchong, Selangor.	012 - 691 2883 (Mr.Louis Tay)	BIM Engineering Specialist, CME Project Delivery, IBS & Prefabrication Construction.
CRT SPECIALIST (M) SDN BHD	E5-5-25, IOI Boulevard, Jalan Kenari 5, Bandar Puchong Jaya, 47170 Puchong, Selangor.	012 - 313 5991 (Mr.James Lim)	Waterproofing Work, Concrete Repair & Strengthening, Injection & Grouting.
REAL POINT SDN BHD	No. 2, Jalan Intan, Phase NU3A1, Nilai Utama Enterprise Park, 71800 Nilai, Negeri Sembilan.	016 - 227 6226 (Mr.Chris Yong)	Concrete Admixture Production.
JKS REPAIRS SDN BHD	Star Avenue Commercial Center, B-18-02, Jalan Zuhal U5/178, Seksyen U5, 40150 Shah Alam.	017 - 234 7070 (Mr.Kathiravan)	Structural Repair Works, Structural Strengthening, Waterproofing System, Injection & Sealing, Concrete Demolition Works, Protective Coating For Concrete And Steel.
ZACKLIM FLAT FLOOR SPECIALIST SDN BHD	70, Jalan PJS 5/30, Petaling Jaya Commercial City (PJCC), 46150 Petaling Jaya, Selangor.	603 - 7782 2996 (Mr.Zack Lim)	Concrete Flatfloors.
UFT STRUCTURE RE-ENGINEERING SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repair, Construction Chemical, Carbon Fibre Strengthening, Protective Coating, Industrial Flooring, Soil Settlement Solution, Civil & Structure Consultancy Services, Civil Testing & Site Investigation.
SINCT-LAB SDN BHD	No 46, Jalan Impian Emas 7, Taman Impian Emas, 81300 Skudai Johor.	012 - 780 1500 (Mr.Lee)	Structural Repairing, CFRP Strengthening, Site Investigation, Civil Testing, Soil Settlement Solution, Civil And Structural Design And Submission.
STRUCTURAL REPAIRS (M) SDN BHD	No. 1&3, Jalan 3/118 C, Desa Tun Razak, 56000 Wilayah Persekutuan, Kuala Lumpur	012 - 383 6516 (Mr.Robert Yong)	Carbon Fiber Reinforced Polymer System, Sealing Cracks With Resin Injection, Re-Structure Repairs and Upgrade, Diamond Wire & Diamond Blade Sawing System, Diamond Core Drilling, Non-Explosive Demolition Agent.

Important Notes:

i) ACI Malaysia is only a platform for our members to advertise for interns.

ii) All application to be made direct to companies and would be subject to their terms and conditions.

UP COMING EVENTS

**** Please find attached RSVP form in the attachment. Refer Appendix 3.***

UP COMING EVENTS

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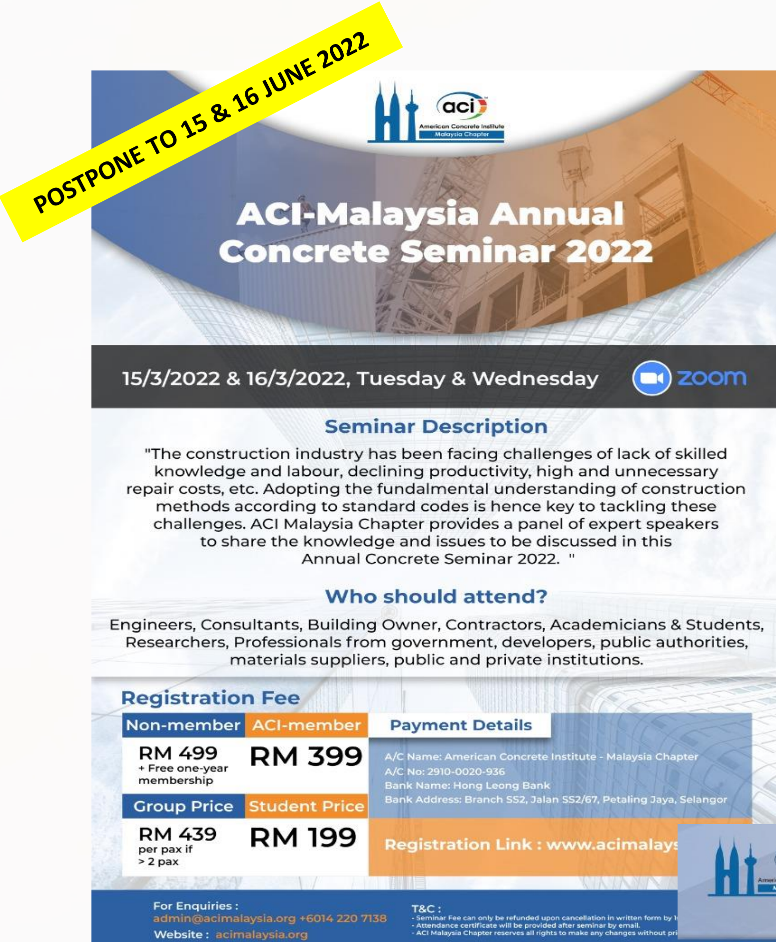

PRECEDING EVENTS

ARTICLES

Reprint from: CI Magazine
March 2021, Vol. 43, No 3,
Page 22-23

The Global Reach of ACI Certification: Growth in the Middle East

Construction has many benefits, including increased jobsite safety, reduced waste of materials and time, and early identification of design and construction challenges. Further, training and certification ensures that a region has a pool of qualified individuals well-suited for future projects.

Through its 30 certification programs, ACI is committed to ensuring a steady supply of individuals who can help ensure the quality and safety of concrete structures. For more than 35 years, ACI has been a trusted source of training and certification, with more than 100,000 ACI-certified individuals in almost 100 countries, including more than 1500 active certifications in the Middle East region alone. This worldwide scope is made possible through ACI's global network of sponsoring groups, delivering relevant certification programs to areas with specific needs.

Professors from the University of Technology–Baghdad prepare a concrete mixture as part of the ACI Train the Administrator program

Training the Administrators

As ACI has increased its focus on the construction markets in the Middle East and North Africa, it has become clear that more ACI certification programs are needed to support a rapidly growing demand. ACI's Train the Administrator initiative is a key part of the Institute's response to this need. The objective of this program is to assist ACI's international sponsoring groups in delivering industry-relevant certification programs to their communities. This dynamic program allows growth through the addition of new programs through new sponsoring groups, and it reflects ACI's strategic plan objective to establish and expand strong and productive relationships with external organizations and individuals.

Launching a Sponsoring Group

A few years ago, a group of professors from the Building and Construction Engineering Department at the University of Technology–Baghdad visited ACI World Headquarters with the hope of initiating a sponsoring group in Iraq. This group, comprising members of the ACI Iraq Chapter, spent several days learning and preparing for the Concrete Field Testing Technician – Grade I program, as well as the Concrete Construction Special Inspector program. Through the Train the Administrator program, the University of Technology–Baghdad is now able to administer ACI's programs to meet the unique needs of the area's specific concrete market.

Since its initial training, this sponsoring group has expanded to offer Aggregate Testing Technician – Level 1 and Concrete Strength Testing Technician certification in addition to the Concrete Field

Slump test being performed by University of Technology–Baghdad professors

Michael Morrison, ACI Manager of Certification Program Development (far left), reviewing testing procedures with the University of Technology–Baghdad professors

Testing Technician – Grade I and Concrete Construction Special Inspector programs.

The University of Technology–Baghdad is just one success story of sponsoring groups serving the Middle East and North Africa. The ACI Saudi Arabian Chapter–Eastern Province, Jordan Concrete Association, Advanced Construction Technology Services, and National Concrete Technology Center (Egypt) all provide ACI certification programs that lead to strong concrete construction communities, with more sponsoring groups under development to enhance ACI certification availability in the region.

Certification Is a Two-Way Street

Sponsoring groups select and conduct programs that meet local needs. Sometimes, a sponsoring group identifies a need that is not met by an existing program. The upcoming Concrete Construction Sustainability and Resilience Assessor (CCSRA) program, which will be going through a pilot program phase in the Middle East region in 2021, is one example of a local need that grew into a program that will be available globally. CCSRA has been developed to endorse the competence of individuals tasked to assess and oversee the sustainability and resiliency aspects of concrete construction. The need for CCSRA was identified by a sponsoring group during the early phases of a high-profile sustainable construction project in the United Arab Emirates. Identifying market needs and responding proactively ensures that the construction industry has the properly trained and certified individuals ready for the job.

More to Offer

The cited examples demonstrate that ACI's certification program is dynamic and capable of meeting local demands. To learn more about sponsoring groups in the Middle East, North Africa, and around the world, and the various programs they offer, contact Ahmad Mhanna, ACI Middle East Regional Director, at ahmad.mhanna@concrete.org, or visit www.concrete.org/certification.

ARTICLES

Reprint from: The Star
Metro News, 28 January 2022

ACI-MY IN THE NEWS

THE American Concrete Institute-Malaysia Chapter (ACI-MY) has also shared its findings on leakage issue at PPR Sri Aman in Jinjang Utara based on visual observations during a recent site visit. Its observation was limited to level 16 of Block C and levels 3, 11, 16, and 17 of Block D as well as the the multi-storey carpark concrete roof slab.

ACI-MY is an independent select committee under the purview of the National House Buyers Association (HBA). Based on its visit to the people's housing project, it concluded that the water leaks or intrusion indicates that the structures are in distress. The report stated that there is a need to find out what is contributing to this distress and also the level so that corrective actions can then be taken after factors leading to the water intrusion are identified. Among its observations were the concrete ceiling at the corridor of level 17 is having water intrusion at the joint area of the slab and wall. It added the joint at the slab and wall could have opened up or cracks in the concrete slab section could have occurred. The possible causes could be due to, but are not limited to thermal movement, drying shrinkage, restraints and insufficient curing or a combination of factors. As for the possible water sources, it could be coming from the domestic water supply pipes from level 17 and going into the level 16 ceiling via the joints or through cracks. Additional indicators of water supply pipes leaking were that cement-sand screed topping at level 17 floor slab appeared to be fully saturated with water and the wall at level 17 also was found to have rising moisture symptoms. It was also observed that the crack at the ceiling had continuous water intrusion.

There were also possible sources of water intrusion at residential units as living rooms, the external beams and ceiling slab joints above windows have visible water marks. Leaks were also found at bathroom ceilings, as moisture could be seen originating from bathrooms directly above, which could be due to damage to the waterproofing membrane.

The joint at the connection between structural elements could have opened up or a crack of the concrete slab section could have occurred. The possible causes could be due to, but are not limited to, thermal movement, drying shrinkage, restraints and insufficient curing or a combination of factors.

As for the wall dividing the living room and bathroom, water intrusion could be coming from the box-up section of the domestic wastewater pipe and spreading inside the ceiling of the bathroom as well as into the living room ceiling. This can only be confirmed by hacking the box-up section for a visual inspection.

Over at the concrete flat roof at the multi-storey carpark, ACI-MY said there were localized cracks with water marks and stalactite formations which are indications of water intrusion. There was fungus growth on the slabs indicating water intrusion, the report noted.

In conclusion, the report suggested that corrective measures, treatment and repair works be carried out. It also recommended that domestic water supply pipes be checked for leaks by a plumber registered with a local water authority and have the leaks rectified. Among its recommendations are that sanitary pipes at the box-up section be checked to rule out any wastewater pipe leaks. The existing waterproofing system, it added, needs to be checked by waterproofing specialists, certified engineers and architects. The institute suggested that it would be good to involve the previous consultant and construction team as they would know the building best.

Reference:
https://www.thestar.com.my/metro/metro-news/2022/01/28/institute-identify-underlying-causes-so-corrective-measures-can-be-taken

TECHNICAL REPORT

Reprint from: CI Magazine
May 2021, Vol. 43, No 5, Page 28-32

Microbially Induced Corrosion of Concrete

Members of ACI Committee 201 Task Group 5 explain the science of biogenic acidification in sewer system structures

by Samuel J. Lines, David A. Rothstein, Brent Rollins, and Charles (Chuck) Alt

Despite being one of the most durable construction materials, concrete can exhibit deterioration resulting from contact with chemicals, minerals, or environmental conditions. Common mechanisms of deterioration include damage from freezing and thawing, salt attack, and carbonation. A lesser-known cause of deterioration is microbially induced corrosion of concrete (MICC).

The root cause of MICC has been well documented; after World War II, C.D. Parker discovered that a sulfur-oxidizing bacterium, Acidithiobacillus thiooxidans, was involved in converting hydrogen sulfide (H2S) gas into sulfuric acid (H2SO4).1 Parker originally called these bacteria Thiobacillus concretivorus because they eat concrete. The acid attacks the concrete, causing the surface to erode or "corrode," as it is termed in the sewer infrastructure literature (not to be confused with reinforcing steel corrosion). Since the initial identification of Acidithiobacillus thiooxidans, others have confirmed that it is the primary bacteria that causes MICC of concrete pipes in sewer systems.2 These bacteria live at a very low pH, perhaps 2 to 4, whereas concrete has a pH of about 13 after manufacture. The high initial pH of new concrete provides a period of immunity to most bacterial growth. As the surface pH of the concrete is lowered by carbonation and sewer gases, however, it becomes more hospitable to hosting bacterial colonies.

Based on work by Islander et al.3 and confirmed by House,4 the corrosion process has three distinct phases (Fig. 1). Phase one is carbonation of the concrete. Over time, the natural process of carbonation will gradually lower the pH of the concrete to below 9. Phase two is the biological attachment phase, when neutrophilic sulfur-oxidizing bacteria (NSOB) such as Thiomonas intermedia, Halothiobacillus neapolitanus, and Thiobacillus thioparus will begin to colonize. Sand and Bock,5 as well as Cho and Mori,6 state that these species are required for Acidithiobacillus thiooxidans to colonize. Acids react with the calcium hydroxide (Ca(OH)2) and calcium silicate hydrate (CSH) constituents of concrete that provide this high alkalinity.

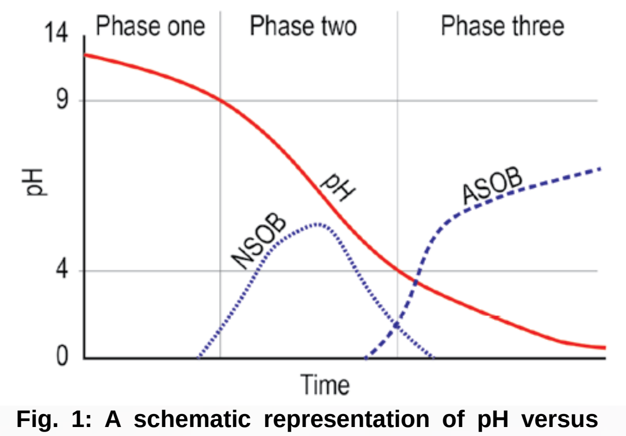

Fig. 1: A schematic representation of pH versus time for the three stage process of MICC

Phase three is the acid corrosion phase. *Acidithiobacillus thiooxidans*, an acidophilic sulfur-oxidizing bacteria (ASOB), produces a strong H_2SO_4, rapidly deteriorating the concrete.
Under extreme conditions, with high H_2S gas concentrations above the sewer liquid level, the erosion rate can reach up to 1/2 in./year (12 mm/year). Depending on concrete quality and sewer conditions, it can take anywhere from 2 to 15 years for the final phase to cause significant damage.

Sewer System Issues

From the 1940s through the 1970s, the United States experienced rapid development of suburbs, resulting in the creation of massive networks of underground infrastructure to handle sewer waste. Many of these networks consisted of combined sewer systems, designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe. In the late 1970s, Pomeroy and Parkhurst created a formula for forecasting the sulfide buildup in sewers.[7] This model allowed sewer engineers to design structures with additional concrete as a sacrificial layer. In 1985, the United States Environmental Protection Agency (US EPA) published the "Design Manual for Odor and Corrosion Control in Sanitary Sewerage Systems and Treatment Plants."[8] This became a model for engineers to use for designing better infrastructure.

It has been suggested that the Clean Water Act of 1977[9] and the Water Quality Act of 1987[10] affected the severity of degradation in sewers by reducing the flow of the sewage.[11] The new regulations led to the diversion of stormwater from sewer systems, which greatly reduced both the volume of liquid and the metals that are toxic to microbes in the sanitary sewers. The reductions in flow and toxic metals thus created an environment prone to increased amounts of H_2S gas.

Unfortunately, the existing predictive models did not adequately consider these changes. The formation of H_2S begins once the sewage water is deprived of dissolved oxygen, which takes some time after entering the sewage network. Sanitary sewage is partially decomposed by numerous strains of bacteria in the water and other naturally occurring processes. This bacterial activity consumes the dissolved oxygen in the water and, at some point in time, sewage reaches anaerobic conditions. Even before the water becomes anaerobic, the sediments and the scum deposits in the bottom of the sewer may be deprived of oxygen.

Some bacteria are adapted to anaerobic conditions and do not need oxygen to survive. One of these species is *Desulfovibrio sp.*, a sulfate-reducing bacteria (SRB) that converts the sulfate in the wastewater to H_2S. The H_2S has a low solubility in water, so it will tend to escape. When there is turbulence, the H_2S sulfide gas is released into the atmosphere above the waterline. As H_2S is heavier than air, it tends to stay in the underground sewage system. As the bacteria need some time to consume the dissolved oxygen in water, the formation of H_2S increases with the transit time in the sewage system. The longer the time the sewage water needs to travel from the household to the treatment plant, the more H_2S issues will occur.

Carbon dioxide (CO_2), thiosulfuric acid, and other mild acids abiotically reduce the pH of the concrete to around 9. This process can take months or even years, depending on the concrete quality. Once the concrete pH is below 9, colonization by alkaliphile microorganisms begins. Among them, a strain of *Thiobacillus* begins to colonize that is aerobic (requires oxygen). These bacteria convert H_2S into H_2SO_4. The weak H_2SO_4 produced by this strain lowers the pH of the concrete until it dies off and another strain colonizes. Each strain of aerobic *Thiobacillus* produces a stronger H_2SO_4 than the previous one.

While all concrete can be susceptible to this degradation, not all installations have the same environmental conditions that trigger the chain reaction. There is uncertainty about exactly what conditions must be present for the reactions to occur. Some theories suggest a high amount of sulfur in the water supply, a high iron content in the water, very hard water, and chemicals introduced into the waste stream, just to name a few. Sites with high relative humidity are reported as having more severity as well.[11] More research is needed to correlate lab testing and field conditions.

Fig. 2: Calcium sulfate (gypsum) forms a whitish foamy mass on concrete

Cement Hydration and MICC

During the hydration of cement, CSH is formed and provides the desirable properties of hardened concrete. Typical hydrated cement forms about 50% CSH. Another compound, $Ca(OH)_2$, is also formed and composes 15 to 25% of the cement paste by mass.[12] By days 3 to 7 of the hydration process, the mass of the concrete is primarily composed of three compounds: CSH, $Ca(OH)_2$, and calcium aluminoferrite hydrates.

$Ca(OH)_2$ is hydrated lime and does not contribute to the strength or other desirable properties of the concrete, except perhaps to maintain the protective high pH environment around the reinforcing steel. $Ca(OH)_2$ will easily react with acids and other compounds. The reaction with CO_2 forms calcium carbonate, resulting in what is referred to as concrete carbonation. When H_2SO_4 reacts with $Ca(OH)_2$, the result is a hydrated calcium sulfate mineral known as gypsum ($CaSO_4 \cdot H_2O$). As such, gypsum is a primary indicator of MICC and often appears as a whitish foamy mass on the concrete (Fig. 2).

In the next step of this process, the concrete disintegrates even more. After H_2SO_4 consumes $Ca(OH)_2$, it reacts chemically with the aluminates present in the cement paste. This reaction forms ettringite, an expansive sulfoaluminate compound. As the ettringite forms, it causes internal expansion, which in turn causes cracking and spalling to occur. This chain of events allows more penetration, access to $Ca(OH)_2$, and a snowball of chemical reactions and damage to concrete (Fig. 3).

Concrete Mixtures and MICC

In a harsh environment exposed to sulfates, chlorides, or acids, it is very important to use a high-quality concrete mixture with a low water-cement ratio (w/c). According to the book Design and Control of Concrete Mixtures,[12] "Decreased permeability improves concrete's resistance to freezing and thawing, re-saturation, sulfate, and chloride-ion penetration, and other chemical attack." It is very important to reduce the permeability to increase durability. A w/c of 0.45 is good for most concrete products that are not exposed to harsh conditions. If there is a potential that the concrete will be exposed to these harsh conditions, the w/c should not exceed 0.40.

In addition to a low w/c, the use of pozzolanic and secondary cementitious materials can increase the density and lower concrete permeability. Fly ash, slag cement, and silica fume are just a few of the options. Using one or more of these mineral admixtures in the concrete mixture design will increase the strength and density while lowering the porosity and improving chemical resistance. Promising work with nanomaterials like colloidal silica also indicates significant reductions in permeability.[14]

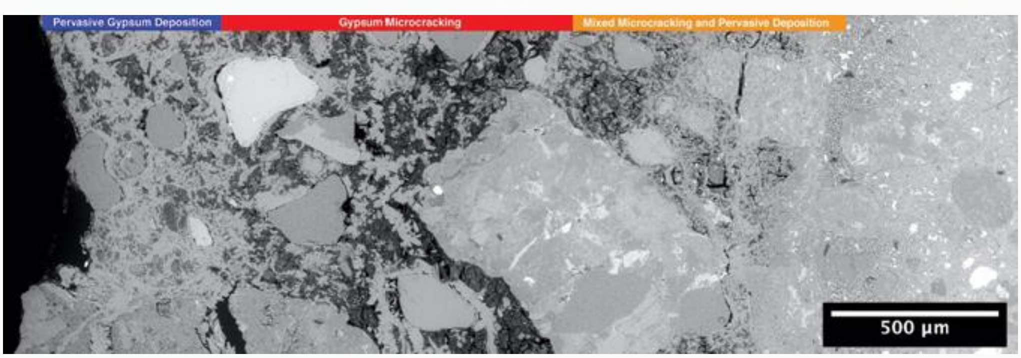

Fig. 3: A backscatter electron micrograph of alteration zones in a corroded concrete specimen (after Reference 13)

Protecting Concrete from MICC

While concrete densification is important to increasing the life of the concrete structure, it will not stop the biological process that causes the *Thiobacillus* bacteria to secrete H2SO4. However, concrete admixtures and surface-applied antimicrobial sealers are effective at reducing the effects of MICC.15 The effectiveness of these products can be evaluated using ASTM C1904.16

When a sewage structure is expected to be exposed to very high concentrations of H2S gas, the designer may choose to protect the concrete with a resin-based coating like epoxy or polyurea. These materials show good resistance to acid. However, most of them are of a hydrophobic nature—the concrete and the surrounding air must be dry enough to achieve a good bonding and polymerization. Resin-based liners do not impede the bacterial growth, so their surfaces will become very acidic with time. As long as there is no flaw, pinhole, or puncture, H2SO4 will not reach the concrete beneath.

Another approach to protect sewage concrete infrastructures from H2S corrosion is to apply a mortar made of calcium aluminate cement (CAC) and calcium aluminate aggregate. CAC is a specialty cement with a different chemistry than portland cement. CAC inhibits bacterial activity when the surface pH approaches around 4 under the activity of bacteria. CAC does not have a biocide effect (the bacteria are not killed),17 but bacteria go into stasis and stop transforming the H2S into H2SO4. As no new acid is formed, the corrosion process is drastically slowed.18-20 Thus, it is possible to protect ordinary concrete with a mineral barrier made of CAC rather than a polymer barrier. Antimicrobial additives have also been incorporated into these barriers.

Physical barriers such as liners and coatings are another option for controlling MICC. Membrane-forming liners have the ability to bridge cracks and other imperfections such as honeycombing that may be points of accelerated ingress. However, liners and coatings require periodic inspection and repair or replacement to ensure continued satisfactory operation. Liners and coatings can be tested using ASTM C189821 to validate performance in stage three of corrosion.

Summary

According to a 2002 study by the Federal Highway Administration (FHWA),17 corrosion of metals is estimated to annually result in about $36 billion in damage to the water and sewer system in the United States. MICC is probably a lesser-known and less-documented deterioration mechanism than steel corrosion or joint leakages that owners must deal with. A better understanding of MICC and the complex ecosystem of bacteria that drive it should permit engineers to improve design practices for new systems and rehabilitate existing structures. ACI Committee 201, Durability of Concrete, is working to improve the knowledge of this worldwide issue.

Acknowledgments

We thank the members of ACI 201-TG5, Microbially Induced Corrosion of Concrete, for their input. We also thank Patrick McGrath and Jean Herisson for contributing to this article.

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CASE STUDY

Reprint from: CI Magazine
Jan 2021, Vol. 43, No 1,
Page 22-26

Cliffs of Concrete

The V&A Dundee, Scotland's first design museum, features a dramatic inverted pyramid design

by Deborah R. Huso

A concrete fortress balanced over the edge of the River Tay, the V&A Dundee, Dundee, Scotland, is the country's first design museum (Fig. 1). Featuring dramatic horizontal ledges of precast concrete, the three-story building's shape is that of two inverted pyramids (Fig. 2). Up close, the striated façade invokes images of the cliffs of the Scottish coastline (Fig. 3). From a distance, the building's form evokes a sturdy ship—a nod to the city's shipbuilding history (Fig. 4).

Designed by Tokyo-based Kengo Kuma & Associates, the complex structure of the £93 million ($121 million USD) museum supports exterior walls that twist both horizontally and vertically. The building also features a cantilevered "prow" that extends nearly 20 m (65 ft) beyond the building's footprint. Throughout the design phases, the architect and engineering firm Arup, based in London, the United Kingdom, used three-dimensional (3-D) modeling to plan the building.

Structural Gymnastics

The building design was prompted by an international design competition sponsored by the city of Dundee in 2010. Maurizio Mucciola—formerly of Kengo Kuma & Associates but now directing his own design firm, PiM Studio in London—served as project architect through the duration of the building's design and construction. "Kuma and I visited the site, which is quite special, being on a one-km-wide [0.6 mile] estuary of the river," he says. "It's an impressive setting, and the city of Dundee wanted us to reconnect the city with the river."

Fig. 1: The V&A Dundee, Dundee, Scotland, looks like a concrete fortress balancing over the edge of the River Tay *(photo courtesy of HUFTON + CROW)*

Fig. 2: The building has the form of two inverted pyramids *(photo courtesy of HUFTON + CROW)*

Fig. 3: The striated building façade invokes images of the Scottish coastline cliffs *(photo courtesy of HUFTON + CROW)*

Kuma's striking solution was to create a building that literally reaches out over the water. But there was more to this imposing museum's appearance than the water itself. Kuma also understood the museum's national importance, and so he wanted its exterior to reflect the Scottish landscape, using the country's northeast coast as inspiration for the striated cladding on the building.

The design phases took 2 years. Construction began in March 2015 and was completed in 2018.

The building's geometrical complexity necessitated the design teams use 3-D design tools (Fig. 5). "There are no straight lines," says John Tavendale, project manager with London-based Turner & Townsend, which managed the project's design and construction phases on behalf of the owner. "It required 3-D software from the start," he explains. "Looking at a traditional two-dimensional plan wouldn't have worked. If you look at the walls, they're curving in every direction. There's nothing that's the same shape."

Originally, the design team had planned to use precast concrete units for the structure of the building, according to Tavendale, but they determined that precast would not be practical for the building's dramatic cantilever. The designers and engineers then considered a hybrid structure of steel and concrete, but Kuma didn't like the way it would have divided the museum's interior. "[Cast-in-place] concrete allowed for [the desired] shapes and forms," Tavendale says, "while also keeping the weight minimal and allowing for the maximum occupiable space inside."

Fig. 4: From a distance, the building looks like a sturdy ship *(photo courtesy of HUFTON + CROW)*

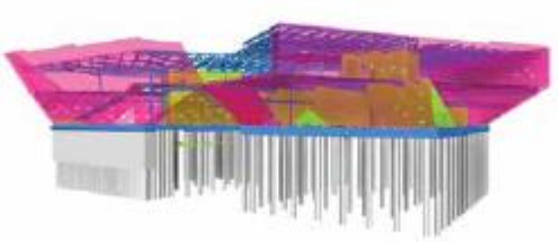

Fig. 5: Structural 3-D model of the museum *(image courtesy of Arup)*

Fig. 6: Two inverted pyramids are separate up to the second floor, at which point they are joined

"While the structure of the building is quite complex in terms of geometry," Mucciola says, "the principle is simple: the exterior of the building is a continuous shell wall." Floor slabs and the roof deck are supported by structural steel members tied to external walls, all of which are inclined outward.

A Hybrid of Concrete and Steel

Construction began, with the installation of a massive cofferdam filled with 12,500 tonnes (13,780 tons) of stone to hold back the River Tay while the museum's vast over-water prow was built. Work on the structure itself started 2 months later and involved erection of 21 separate wall sections, with no two alike (and none of them straight).

The two inverted pyramids that make up the building are separate up to the second level, where they are joined (Fig. 6). "There are no expansion joints," Tavendale explains. "[The museum] is an elastic shell designed to flex and move."

"The building is a hybrid structure of concrete and steelwork," explains Malcolm Boyd, Construction Manager for the Netherlands-based general contractor BAM. He continues, "The external walls, internal shear walls, and main cores are constructed using reinforced concrete, while the first floor, second floor, and roof are constructed using structural steelwork" (Fig. 7). Vertical loads are carried down the cores and façade walls to the foundation level. The foundation consists of a grillage of reinforced concrete ground beams spanning between individual pile caps that carry the building's load down to bedrock.

The walls rise an impressive 19.75 m (65 ft). "The external façade wall is inclined away from the building and relies on the roof and floor-level primary beams and trusses to tie it back to the building and provide stability from overturning forces and wind," Boyd adds.

Fig. 7: The building is a hybrid structure with external walls, internal shear walls, and main cores constructed using reinforced concrete, and the first floor, second floor, and roof constructed using structural steelwork

Fig. 8: Façade walls remained propped until the internal floor plates, beams, and slabs were fully tied into the structure and the concrete had reached design strength

Because the façade wall supports the floor and roof steelwork but also relies on these elements for stability, the walls had to remain propped until the internal floor plates, beams, and slabs were fully tied into the structure and the concrete had reached design strength (Fig. 8). "The roof consists of a structural metal deck which acts as a diaphragm between the steel roof beams and transfer trusses, which in turn span between the internal concrete cores and external façade wall," Boyd explains. "Lateral stability is provided through the diaphragm action."

The walls were constructed using formwork, with each wall divided into uniquely shaped 2 x 2 m (6.6 x 6.6 ft) blocks. Because of the complex geometry, each piece of formwork was bespoke, according to Boyd.

"It was like an enormous three-dimensional jigsaw," Tavendale says. Each piece of formwork had a global positioning system (GPS) identifier to ensure it was correctly positioned within tolerance.

Fig. 9: Façade walls made of dark and smooth concrete

All formwork and shoring had to stay in place until the roof was in place.

Formwork was positioned on-site by a crew of 30 joiners. Construction conditions were often challenging. "We were hanging things off of cranes in wind, rain, and snow," Tavendale remarks. Yet despite the building's complex design and the often trying construction conditions, the team maintained the requisite (and astounding) 2 to 3 mm (0.08 to 0.12 in.) of tolerance for each piece's placement. Some of the concrete walls were up to 25 m (82 ft) high, and some were cantilevered. Yet even with such height, the walls were only 300 mm (12 in.) thick. Tavendale describes the building's construction as "structural gymnastics." The building is "overhanging and leaning out and leaning in," he adds.

While the thin walls kept costs and weight down, they also created a host of other challenges. "They can create torsion," Tavendale explains, "but we could not have cracking in these walls."
"The concrete is a design feature in itself," says Mucciola. Careys Civil Engineering tested many mixtures to accommodate Kuma's desire for a very dark and smooth concrete for the walls (Fig. 9). The final mixture included fly ash and silica fume.

To ensure a high-quality finish, formwork supplier PERI, based in Weissenhorn, Germany, applied Zemdrain to the wall formwork. Zemdrain is a controlled permeability formwork liner that drains water from the surface of fresh concrete. This reduces the probability of microcracking and bugholes, and it renders the concrete denser and less permeable. The liner thus improves the appearance of concrete as it increases its resistance to environmental effects (in this case, the brackish water of the nearby estuary).

Fig. 10: The cliff face appearance of the building's exterior was executed with 2429 precast concrete panels

"Every square meter of that façade is a different curvature," Tavendale says. Each of the 2 x 2 m blocks of formwork exhibited different curvatures. It was an incredible challenge to make sure the concrete was compacted without any airspace or holes in the heavily reinforced walls.

Meanwhile, the beams spanning the floors and roof had to be tied into the walls via a concrete ring beam. Tavendale says there were 440 individually designed connections between the building's structural steel and the concrete walls. Each piece of steelwork was bolted to anchors in the concrete at a unique angle. Once the formwork was removed, the deformation of the structure essentially welded the steelwork and bolts together.

"It was a very slow build," Tavendale remarks. "But all those structural gymnastics were on the ground floor. Once you get to the second floor, everything straightens up."

The Crowning Touch

The application of 2429 precast concrete panels—manufactured by Techcrete based in Dublin, Ireland—established the appearance of a cliff face on the building's exterior (Fig. 10). Techcrete applied a retarding agent onto the formwork to allow for the removal of a superficial layer of concrete, exposing some of the large aggregate and enhancing the rough surface of the panels.

Each precast panel was attached to the structure with brackets. Additionally, a 300 mm gap between adjacent planks was designed to create the "stacked" appearance of the walls.

The precast panels weighed up to 2000 kg (4410 lb) with spans of up to 4 m (13 ft). The high loads and complex geometry complicated the design of the connections to the thin and heavily reinforced walls. Drilling into the cast-in-place walls would risk weakening the structure, so the team cast channel anchors into the walls, using a total station to make sure every bracket was in the right place. Despite a tiny tolerance, only three of approximately 5000 preplaced anchors needed to be moved, according to Mucciola.

Boyd says installing the precast planks was a challenge due to the building's outward inclining walls. First-level panels were installed using a lift truck. Second- and third-level panels were installed using mobile cranes. To prevent the crane ropes from snagging on the building above, the team designed a bespoke, counterbalanced rig they could alter for different sections and angles of the walls.

The museum was opened in September 2018. "I learned that nothing is impossible if you get the right team with the right solutions," Mucciola says of the project. "We didn't accept bad compromises; we kept working till we solved the problem."

Success ensued.

Project Credits

Owner: Dundee City CouncilDesign Architect: Kengo Kuma & Associates Structural Engineer: ArupProject Manager: Turner & Townsend Contractor: BAM Construct UK Subcontractor: Careys Civil Engineering Precast Concrete Producer: Techcrete
Selected for reader interest by the editors.

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