MYCONCRETE

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

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This Month's Highlight:

- Get to Know ACI-MY Technical Committee 2022-2024
- ACI-Malaysia Annual Concrete Webinar 2022
- Going Digital Award in Infrastructure
- Development of a Crack- Resistant Rubber-Modified Cementitious Repair Material

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

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Contents of Bulletin

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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. Tae Ah Heng (Protem)

1998 - 2000
Ir. Dr. Kribanan G. Naidu

2000 - 2002
The Late Ir. Dr. Norzan

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
Prof. Dr. Sudharshan N. Raman

2020 - Present
Mr. Martin David

Management for 2022 – 2024

Board of Directions (BOD) 2022-2024

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Mr. Chris Yong Hoe Chern

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Biodata of Technical Committee

Mr. Alex Yap Wei Keat, Head of Technical Committee

Mr. Alex Yap graduated with degree in Bachelor (Hons) Civil Engineering and started off his career as a project engineer in the Heavy industries. He is now specialized in concrete admixture and also the lead for MBSM Precast and Underground segment with experience of various mega project from high rise building, Infrastructure to Hydropower project in Malaysia as well as concrete related research projects. Currently, Mr. Alex is the executive committee member of ACI Malaysia and associate's member of MBAM.

Ir. Walter Yap, Secretary 1

Ir. Walter Yap obtained B.Sc in Civil & Structural Engineering from University College of Cardiff, Wales, UK in 1982. Obtained M.I.E.M and P. Eng in 1987. He worked in Drainage and Irrigation Department from1982 to 1988 involved in Tertiary Irrigation System at MUDA II project. After that he moved to work in construction company dealing with projects in North-South Highway, KLCC and KLIA.

From 2001 till to-date, most of the projects undertake were under the scope of Project Management Consultancy and C & S Consultancy services.

Ms. Loh Poh Yee, Secretary 2

Ms. Poh Yee completed her Bachelor in Engineering (Honours) Electronics from Multimedia University (MMU), and ventured into building associated career since 2017. From work experience in property management of stratified high-rise building, she learnt that water leakage is one of the major problems faced by parcel owners and the common area, which then help her to expand into building inspection and repair related to water leakage and façade defects for high-rise building.

Membership Subscription 2022

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
*to our **Administrative Office** for confirmation, via these channels:*
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Digital Membership Certificate 2022

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

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.

Upcoming Events

CONCRETE ON SITE TESTING OPERATOR CERTIFICATION (level 1)

4 AUGUST 2022

8:00 AM - 5:00 PM

UiTM SHAH ALAM

RM ~~1200~~ RM 900

The progression of concrete technology has been challenging to the construction industry yet, the fundamental of concrete testing know-how has been lacking especially to those on-site testing operators.

We are aware of the common problems faced during on site testing hence this practical course is specially developed based on international standards that enable you to understand the various forms of site testing that are required for better quality control.

Contents includes:-
Sampling, Slump test, Flow table test, Cube test, Specimen and moulds requirements, etc.

International Standards reference :-

MS 26-1-1
MS 26-1-2
MS 26-1-5
MS EN 12390-1
MS EN 12390-3

visit us at **https://www.aoct.com.my** for more info

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Preceding Events

ARTICLE

Reprint from CI Magazine, Volume 44, No 2, Page 28-35

Going Digital Awards in Infrastructure

Bentley Systems' 2021 *Year in Infrastructure* Conference

During the 2021 *Year in Infrastructure* and Going Digital Awards virtual event, Bentley Systems showcased its Going Digital Awards in Infrastructure winners on December 2, 2021. Katriona (Kat) Lord-Levins, Chief Success Officer at Bentley, announced the winners, which recognize the extraordinary work of Bentley software users advancing infrastructure design, construction, and operations throughout the world. Sixteen independent jury panels selected the 57 finalists from nearly 300 nominations submitted by more than 230 organizations from 45 countries encompassing 19 categories.

In addition, the recently launched Bentley Education program helps students develop the digital skills that are critical for building a qualified talent pipeline for infrastructure. As part of this initiative, Bentley Education established the Future Infrastructure Star Challenge, which encouraged students to develop a concept or idea for how they can change the world with infrastructure. Lord-Levins announced the winners of the Judge's Choice and the People's Choice from 144 submissions.

The Judge's Choice winner, which included a $5000 prize, went to Elif Gungormus Deliismail from the Izmir Institute of Technology in Turkey. On her project, "Mini-Modular Plant for Digitized Sustainable Campus," Deliismail used Context Capture and drone technology to create a three-dimensional (3-D) model of a rural academic campus to illustrate how a mini-modular plant coupled with smart centralized energy management and low-carbon fuel sources can transform energy performance.

"It makes me so proud that my project was recognized by such a leading company," Deliismail said. "Self-sustaining buildings are next-generation, environmentally friendly architecture, which will hopefully be a significant issue for infrastructure development for [future] generations."

The People's Choice winner, which included a $2000 prize, went to Rodman Raul Cordova Rodriguez from the Pontifical Catholic University of Rio de Janeiro, Brazil, for his "Innovative Dam and Hydroelectric Project." He examined how to improve water supply capabilities and hydroelectric operations through the lifespan of a multipurpose dam.

"I was concerned about the alarming facts about energy crisis and water supply worldwide," he said. "So, I took the opportunity to join the challenge and develop a creative, innovative, and sustainable idea in order to help solve the world's real problems with the use of technology and recyclable materials."

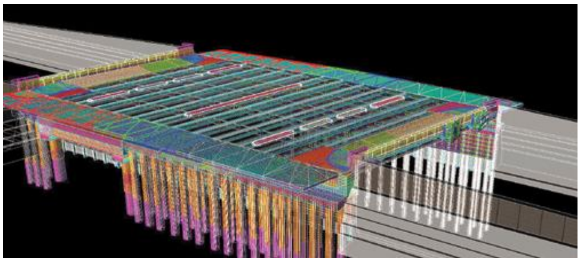
The winners of the 2021 Going Digital Awards in Infrastructure are:

Bridges

East 138th Street over the Major Deegan Expressway, New York City, NY, USA, by

New York State Department of Transportation (NYSDOT)

Originally built in 1938, the existing East 138th Street Bridge is being replaced to eliminate vertical clearance issues and optimize vehicle and pedestrian traffic demands. NYSDOT wanted to use a digital twin as the primary



East 138th Street Bridge *(image courtesy of NYSDOT)*

construction document. With the project located in a heavily congested area, the team needed to create the construction sequencing plan and accommodate existing utilities. They needed a hybrid modelling approach to generate a digital twin of the complex superstructure and pedestrian components.

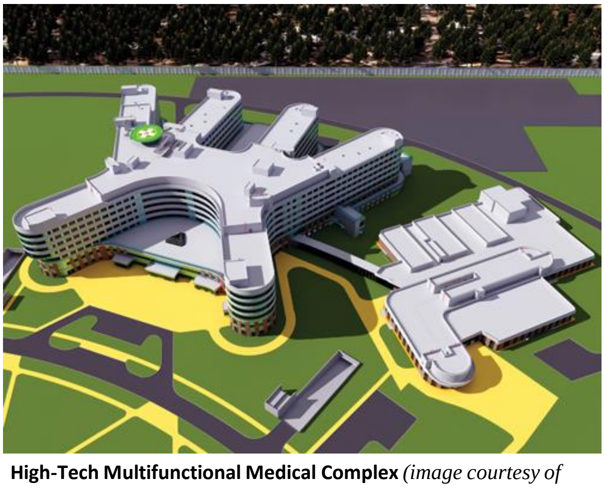
Already familiar with Bentley applications, they used OpenBridge Modeler, OpenRoads Designer, and ProSteel to generate an accurate 3-D model. iTwin Design Review provided a central platform for over 180 reviewers. Bentley's integrated technology helped identify and resolve costly issues prior to construction. SYNCHRO 4D facilitated visual, dynamic construction sequencing and traffic control planning for better project coordination. The digital twin is a tool for asset management and bridge inspection.

Buildings and Campuses

High-Tech Multifunctional Medical Complex, Yukki, St. Petersburg, Russia, by Volgogradnefteproekt, LLC

A high-tech multifunctional medical complex is being developed to improve the quality, diversity, and accessibility of medical care to residents throughout Russia. The largescale project presented technical and coordination challenges, compounded by a short 3-year timeline. Volgogradnefteproekt wanted to streamline workflows and collaboration among the contractor, designer, and client. The team needed interoperable digital technology to integrate scheduling, facility design, and construction management.

They selected Open Buildings and Pro-Structures to generate a 3-D model and construction documentation for the entire facility, using ProjectWise to manage the design and approval processes. The solution improved and accelerated decision making



High-Tech Multifunctional Medical Complex *(image courtesy of Volgogradnefteproekt, LLC)*

Decision making and issue resolution by 20%, allowing the team to overcome a 2.5-month delay in the delivery schedule. By avoiding delay costs, they saved an estimated 30 million USD.

Using ContextCapture and four-dimensional (4-D) modelling enhanced efficiencies managing construction by 30%. The digital twin helped with asset management during operations.

Digital Cities

Ezhou Huahu Airport Project, Ezhou, Hubei, China, by Hubei International Logistics Airport Co., Ltd.; Shenzhen S.F. Taisen Holdings (Group) Co., Ltd.; and Airport Construction Engineering Co., Ltd.

Situated in the eastern part of Ezhou, Ezhou Huahu Airport is a new international airport and aviation logistics port, as well as Asia's first professional cargo airport. Covering 11.89 km2 (4.59 square miles), the project required integration of many process systems, presented complex geological challenges, and had an extremely tight schedule. With no existing civil aviation building information modelling (BIM) standards and 25 million model components, the design team needed a digital platform capable of supporting large volumes of multi-sourced data and intelligent life-cycle operations.

They selected Bentley's BIM applications to develop a 3-D airport model, shortening model delivery by 90 days. Using the Bentley iTwin platform, the team resolved 6000 issues to reduce costs by CNY 200 million. Bentley's solution reduced the construction period and promoted smart construction in China's civil aviation industry.

Ezhou Huahu Airport Project *(image courtesy of Hubei International Logistics Airport Co., Ltd.; Shenzhen S.F. Taisen Holdings (Group) Co., Ltd.; and Airport Construction Engineering Co., Ltd.)*

the 69-year-old Seattle airport. The project included constructing a three-story building, an elevated sterile corridor, and the world's longest pedestrian walkway over an active airport taxi lane. Clark Construction was responsible for the design and construction. Challenges included remotely assembling a 3 million lb (1.3 million kg) pedestrian bridge with a 320 ft (97.5 m) center span and then transporting it to the project location.

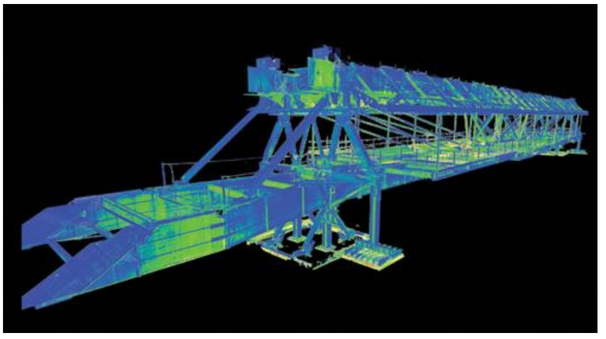
By leveraging BIM and reality modeling technology with Bentley's SYNCHRO 4D, Clark Construction developed a digital twin that was used to fully visualize the construction sequencing. They used the application to enable precise planning and execution to safely install and fit the iconic walkway within 3/8 in. (9.5 mm) without causing airport disruptions. The digital twin will be used by the Port of Seattle for facilities management purposes.

Geotechnical Engineering

Geological Survey of Water Conservancy and Hydropower Engineering, Tibet, China, by China Water Resources Beifang Investigation, Design and Research Co. Ltd.

Located in the high-altitude alpine region of Tibet, this hydro-complex for a water conservancy initiative is focused on irrigation, power generation, and improving the regional water supply. Knowing the importance of subsurface findings, the survey and design team faced challenging terrain and extreme environmental conditions that traditional survey methods could not accommodate. They explored digital data acquisition and 3-D modelling of geological data but found that many software products lacked integration and the ability to maximize data potential.

They selected Bentley's open, vendor-neutral ecosystem to produce solutions that would digitalize the production process. Using Context Capture to process data for geological



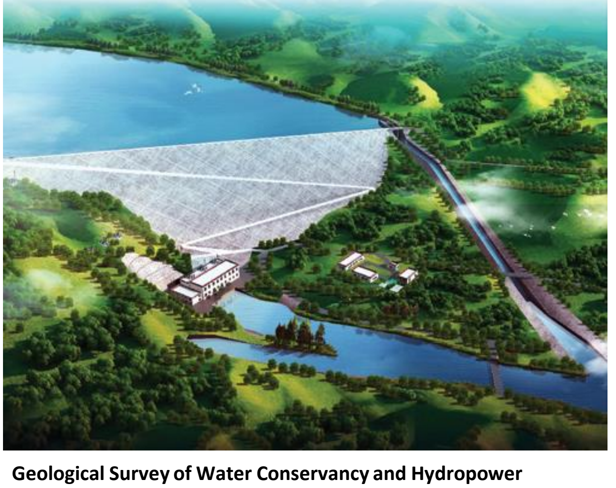
SeaTac Airport International Arrivals Facility *(image courtesy of Clark Construction Group, LLC)*

visibility and ProjectWise for multidisciplinary collaboration, new reusability of data for smart engineering evolved. The solution saved CNY 400,000 in survey costs and over 50% in survey time, improving data accuracy by over 10% and work efficiency by over 15%. Establishing a digital twin enhanced project management by 10%.

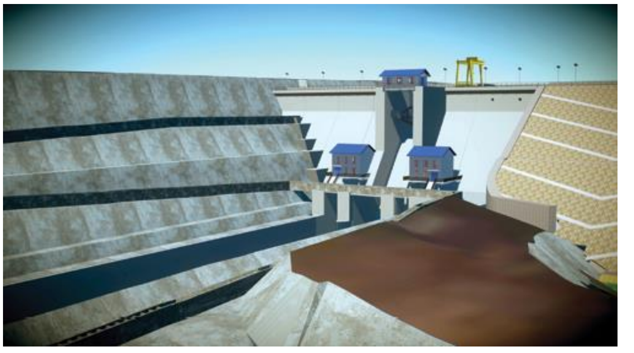
Land and Site Development

Dongtaizi Reservoir Project, Chifeng, Inner Mongolia, China, by Liaoning Water Conservancy and Hydropower Survey and Design Research Institute Co., Ltd.

The Dongtaizi Reservoir Project is a large-scale water conservancy initiative scheduled as part of China's 13th 5-year Plan period. The project's engineering, survey, and



Geological Survey of Water Conservancy and Hydropower Engineering *(image courtesy of China Water Resources Beifang Investigation, Design and Research Co. Ltd.)*



Dongtaizi Reservoir Project *(image courtesy of Liaoning Water Conservancy and Hydropower Survey and Design Research Institute Co., Ltd.)*

design unit Liaoning Water Conservancy and Hydropower Survey and Design Research Institute faced technical, geological, and coordination challenges. They realized that traditional design methods were insufficient and that they needed an integrated 3-D BIM approach to accommodate the geology, excavation, and dam design.

The team used ProjectWise as the collaborative design management platform, providing a connected data environment for the multiple disciplines. Open Buildings and Open Roads facilitated 3-D modeling and visualization that helped resolve difficulties designing the ecological fishway and complex concrete dam structure. Using Bentley's integrated applications, they completed the engineering design 2 weeks earlier than expected and reduced design errors by an estimated 90%. The digital models were handed over for construction monitoring, operations, and maintenance to achieve a full life-cycle BIM application.

Manufacturing

Converter-Based Continuous Casting Project of Jinnan Steel Phase II Quwo Base Capacity Reduction and Replacement Project, Quwo, Shanxi, China, by WISDRI Engineering & Research Incorporation Limited

Jinnan Steel Group invested in the Quwo Group (a merger of two steel production plants) to optimize the plant's industrial layout and achieve higher production quality, efficiency, and sustainability. As the general contractor, WISDRI faced technical and coordination challenges, compounded by limited space and a tight schedule amid COVID-19. They sought to streamline workflows and identify risks in advance through collaborative design and construction simulation technology.

They selected ProjectWise and Bentley's open modelling applications to digitally unify design among 16 different disciplines, reducing ambiguity and improving design quality. By performing collision detection, they eliminated 66 clashes, saving approximately CNY 1.7 million and reducing rework. Through construction simulation in SYNCHRO 4D, they cut construction by over 30 days and saved an additional CNY 3 million. The integrated digital approach minimized the impact of the pandemic and facilitated the development of a modern steel plant.

Mining and Offshore Engineering

Construction of the Blagodatnoye Mill-5, Krasnoyarsk, Krasnoyarsk Krai, Russia, by Polyus

To increase gold production at the Blagodatnoye deposit, Polyus decided to build an additional service complex and Mill-5, a new gold processing plant. The project included the design, construction planning, and field supervision of two buildings and related infrastructure. Facing a complex design and construction modeling works among a team of over 100 employees, Polyus needed an integrated digital technology solution to implement data-driven, collaborative design and construction workflows.

They selected Bentley applications to establish seamless workflows, using 3-D models to link the construction schedule and generate reports to the field. Using ContextCapture reduced engineering design time by 22%. Working in a connected data environment with ProjectWise improved design communication by 12%. Performing construction simulation and developing cloud-based workflows optimized construction and installation works, reducing the time to facility commission by 42 days.

Power Generation

The World's First 60 MW Subcritical Blast Furnace Gas Power Generation Project, Changshu, Jiangsu, China, by Capital Engineering and Research Incorporation Ltd.

The Jiangsu Longteng special steel 60 MW project is the world's first ultra-high-pressure, subcritical gas generator set with the smallest installed capacity. Capital Engineering and Research Incorporation Ltd. undertook design and construction and faced technical and coordination challenges compounded by a short timeline and limited space. To prevent clashes and simultaneously construct the physical factory and its digital twin, they needed to use open modeling applications in a connected data environment.

They used Bentley applications to establish a collaborative design platform and perform construction simulation. With Bentley's openness, they built a digital model of the entire factory with an engineering data center to achieve digital delivery based on full life-cycle information, establishing the foundation for intelligent plant operations.

Project Delivery Information Management

HS2 Phase 1 Main Civil Construction Works, London, UK, by Mott MacDonald /SYSTRA JV with Balfour Beatty Vinci

Mott MacDonald/SYSTRA JV was awarded the design build contract for Phase 1 northern sector civil works of the High Speed 2 railway network (HS2). They had to manage over 1000 people working from 30 locations across more than 18 disciplines. The project required standardized processes and new technology for effective data management, change control, and transparent communication.

Already using ProjectWise, they integrated the Bentley iTwin platform, accelerating model access by 95% to save an expected GBP 200,000 annually, as well as reducing data extraction time from 2 weeks to only hours. They streamlined new deliverable creation with automatic metadata retrieval, reducing manual entry by 75%. Integrating advanced work packaging drastically reduced reporting times and streamlined information sharing, accelerating the project schedule.

Rail and Transit

Transpennine Route Upgrade, Manchester/ Leeds/ York, UK, by Network Rail + Jacobs

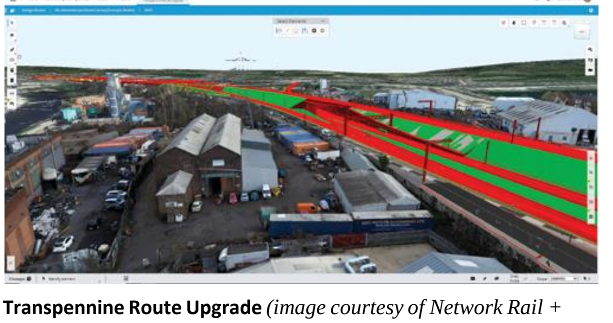
The Transpennine Route Upgrade is a GBP multibillion railway enhancement program to double capacity, reduce carbon emissions, and cut journey times on commuter routes between Manchester, Leeds, and York. When completed, the 100 km (62 mile) route upgrade will improve connectivity and provide economic benefits to the North of England. To bring together the large volume of data and disciplines involved, Network Rail tasked Jacobs with implementing a route-wide digital twin.

Realizing paper-based processes and Excel spreadsheets introduced unnecessary risk and inefficiency across the team, Jacobs used the Bentley iTwin platform with ProjectWise, ContextCapture, and other integrated applications. Using the digital twin allowed over 1300 staff to track, contribute, and analyze design data and asset information in real time. Improved access saved the team 20,000 hours in the first 6 months, worth an estimated GBP 1 million. Overall, the digital twin will save approximately GBP 15 million.

Reality Modeling

Diablo Dam Digital Twin Modeling, Whatcom County, WA, USA, by HDR

After the overtopping of the dam in Oroville, CA, USA, Seattle City Light initiated major safety reviews of its six dams, including Diablo Dam on the Skagit River. To improve survey safety and efficiency, as well as minimize risks associated with inspecting the 160 ft (49 m) high dam amid a global



Transpennine Route Upgrade *(image courtesy of Network Rail + Jacobs)*

pandemic, HDR's team was asked to provide aerial drone services to supplement physical inspections. A key goal was to use the captured data to create a digital twin model of the structure.

They selected ContextCapture and the Bentley iTwin platform to create a digital twin, accurate within 20 mm (0.8 in.), from over 82 million survey points. The team could merge architecture, engineering, and construction data with artificial intelligence across the life cycle of the structure, identifying current and future maintenance and repair needs to ensure safety. The digital twin provides a single reference point for the owner to understand the structure and reduces project costs, while increasing surveyor safety and facilitating decision-making.

Diablo Dam Digital Twin Modeling *(image courtesy of HDR)*

Road and Rail Asset Performance

Stone Arch Bridge Rehabilitation, Minneapolis, MN, USA, by Collins Engineers, Inc.

Collins Engineers was tasked with inspecting and designing the rehabilitation of the iconic Stone Arch Bridge in Minneapolis, ensuring that it remains a valuable asset. With its age and size, they faced challenges when developing repair plans that traditional data collection could not accommodate. When they had used reality modeling, it lacked the quality required for inspecting and modeling complex structures. To collect sufficient data and accurately model the bridge, they needed an integrated survey, modeling, and inspection solution.

Collins Engineers selected ContextCapture to generate a high-fidelity 3-D model from over 13,000 images, improving the quantity and quality of data. Using iTwin applications facilitated real-time model access, saving 20% of field time. The solution is expected to save 10 to 15% in construction costs due to improved project and bid data. They will use digital twins throughout the bridge's life cycle for future planning and maintenance decisions.

Roads and Highways

Trans Sumatera Toll Road Project Section Serbelawan-Pematangsiantar, Pematangsiantar, Sumatera Utara, Indonesia, by PT Hutama Karya (Persero)

PT Hutama Karya is responsible for constructing the Trans Sumatera toll road, spanning 2800 km (1740 miles) across Sumatra Island in Indonesia. The Serbelawan to Pematangsiantar section is a 28 km (17 miles) expressway projected to shorten travel time by 50%. Located in a remote and dense forest, the project presented data acquisition challenges while working with numerous disciplines and software platforms. Having experience using various BIM platforms, they sought interoperable digital modelling technology to accommodate large files and improve project collaboration.

They selected ContextCapture to deliver an accurate reality mesh of the remote project area in 28 days, compared to the 120 days it would have taken using conventional survey methods. Using OpenRoads and OpenBridge streamlined data and workflows, shortening coordination and approval time by up to 34 days, while PLAXIS helped avoid potential critical failure due to soft soil conditions. Bentley's integrated digital solution resolved compatibility issues and clashes, provided data continuity, and optimized collaboration to save 2.18 million USD.

Structural Engineering

The Pavilion at Penn Medicine, Philadelphia, PA, USA, by HDR and the PennFIRST Team

The Pavilion at Penn Medicine is a 16-story, state-of-the art hospital with a subterranean parking garage and a 1.25 million ft2 (116,000 m2) high-rise building with four pedestrian sky bridges. HDR provided structural design services and faced engineering and coordination challenges when ensuring the

Trans Sumatera Toll Road Project Section Serbelawan-Pematangsiantar *(image courtesy of PT Hutama Karya [Persero])*

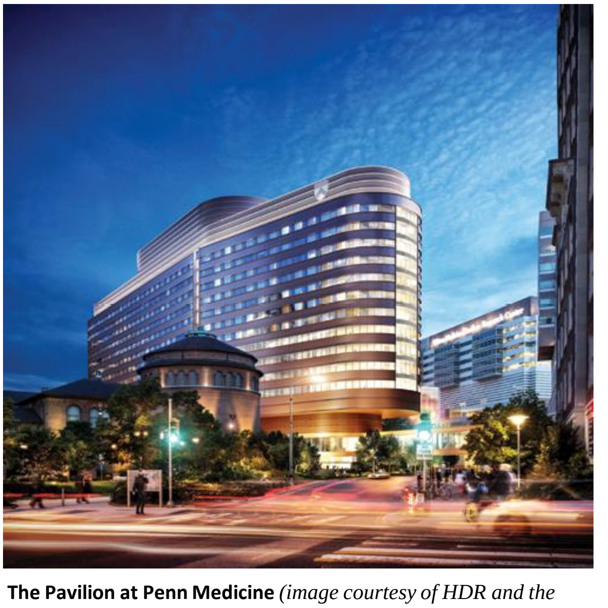
structural integrity of the irregularly shaped building on a narrow, urban site. To design and analyze the complex steel and concrete connections and supports on a short timeline while accommodating a large project team, they needed integrated structural modeling software.

HDR selected RAM Structural System and RAM Elements to create an integrated project model to analyze and ensure load and geometry accuracy. This single-model approach optimized coordination, reduced errors, and minimized risks when designing a high-quality, economical structure, while also saving time and money. Using Bentley's applications, they completed the foundation and superstructure design in less than a year. The design is environmentally conscious and includes construction and operational plans that support the client's commitment to sustainability.

Utilities and Communications

Suixian and Guangshui 80 MW Ground-based Photovoltaic Power Project of Hubei Energy Group, Guangshui, Hubei, China, by PowerChina Hubei Electric Engineering Co., Ltd.

When PowerChina Hubei Electric Engineering was hired as the engineering, procurement, and construction contractor to deliver an 80-MW, ground-based photovoltaic power station, they faced several challenges, including a short 10-month schedule with a requirement to realize a life-cycle digital twin application.



The Pavilion at Penn Medicine *(image courtesy of HDR and the PennFIRST Team)*

PowerChina Hubei selected OpenBuildings Designer and OpenRoads for 3-D modeling, as well as ProjectWise for collaborative design management. With Bentley, they developed photovoltaic design software for mountainous photovoltaic power projects. The solution optimized the design scheme, reducing land occupation and avoiding 40 potential rework scenarios to save more than CNY 800,000. Integrating SYNCHRO 4D accelerated construction by approximately 30 days. They used the Bentley iTwin platform to automatically generate digital twin models, avoiding approximately CNY 1 million in costs had the digital twins been developed during the operation stage.

Utilities and Industrial Asset Performance

Asset Data Lifecycle Program, Fort McMurray, AB, Canada, by Suncor

Canadian energy company Suncor saw an opportunity to improve asset information management at its largest and most complex facility. To improve data reliability and integrity, they sought to shift from a document-centric approach to an asset-centric program, requiring a cloud-based technology solution to achieve their goal.

They selected AssetWise ALIM as the basis for their Asset Data Lifecycle Program, streamlining asset information management capabilities and providing data that is simpler, more reliable, and more accessible. Working in a cloud-based environment, they are decommissioning their on-site IT infrastructure, reducing related support costs. The technology solution has the potential to save approximately CAD 12.4 million over a 5-year period, and the enhanced data will help improve asset performance.

Water and Wastewater Treatment Plants

Khatan Group of Villages Water Supply Scheme (Surface Water Treatment), Khatan, Uttar Pradesh, India, by Larsen & Toubro (L&T) Construction

The government of Uttar Pradesh initiated a water supply project to provide safe drinking water to a rural population of over 14 million people across 388 villages. L&T Construction was retained to design and construct the 160 million L (42 million gal.) per day water treatment plant, facing challenges designing and analyzing 200 different structures and over 3500 km (2175 miles) of piping amid a strict 6-month timeline. They realized that traditional applications were time-consuming and error-prone, requiring an integrated digital modeling and analysis solution.

They selected Bentley applications for hydraulic modelling and structural analysis, automating design works for the pipeline network and retaining wall. Engineering of the entire project took 6 months, compared to 8 months using manual methods. They reduced resource hours for network analysis by 50% and the structural design of 121 overhead tanks by 45%. Working in a connected data environment streamlined and automated workflow processes to achieve a sustainable supply of high-quality water.

Water, Wastewater, and Stormwater Networks

Contingency Plan to Ensure Supply in the Event of Drought, Joinville, Santa Catarina, Brazil, by Companhia Águas de Joinville (CAJ)

The city of Joinville experienced its worst water crisis in 30 years. Responsible for supplying water and sanitation services to approximately 600,000 residents in the municipality, CAJ Water Company initiated a project to develop a contingency plan to maintain water supply during worsening drought conditions. They evaluated three alternatives in the preliminary study. However, their initial solution yielded insufficient flow transfer, water shortages at the weakest points in the supply system, and a reduction in water transport efficiency. As a result, they needed to implement a more comprehensive study of the municipality's entire network.

CAJ Water Company used OpenFlows WaterGEMS to create a digital twin of the distribution system, modelling 285 km (177 miles) of network. Using the hydraulic model to simulate a new contingency plan, they determined an optimal solution that guaranteed supply in the event of a severe drought, while saving approximately BRL 4.5 million compared to their original proposal.

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TECHNICAL REPORT

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Development of a Crack-Resistant Rubber-Modified Cementitious Repair Material

From compatibility concepts to the field

by Alexander M. Vaysburd, Benoit Bissonnette, and Christopher D. Brown

Rehabilitating concrete infrastructure is one of the most significant challenges in civil engineering today, as more than 50% of the repairs performed on concrete structures have been found to show signs of premature failure within 5 years after completion.1 Concrete repair is not just a simple bandage for a structure experiencing damage; rather, it is a complex engineering task that presents unique challenges that differ from those associated with new concrete construction.

For a repair project to be successful, it must adequately integrate new materials with old concrete, forming a composite system capable of enduring exposure to service loads, ambient and enclosed environments, and the passage of time.

The premature deterioration and failure of concrete repairs in service is a result of a variety of physicochemical and electrochemical processes. Among the most serious causes is cracking in the repair material. Cracking may result in a reduction in the effective cross-sectional area of the repaired structure and always substantially increases permeability, which leads to premature corrosion and deterioration.

Cracks generally interconnect flow paths and thus increase effective permeability of the repair material. The resulting chain reaction of cracking → more permeable repair → corrosion of reinforcement → more cracking may eventually result in irreversible deterioration and failure of the repair.

Some 50 years ago, Valenta2 observed that "continuous cracks linking into wider cracks originating from the concrete surface play the biggest role in increasing permeability." Figure 1 schematizes a model of repair failure caused by cracking. Problems associated with premature failure of repairs have to a certain extent worsened in recent years, notably due to the increasing use of high-strength (or "high-performance") repair materials. These materials can be prone to early age cracking sensitivity, especially in the restrained movement conditions typical of repairs. It is beyond the scope of this article to provide a critical review of the theoretical and mechanistic considerations of cracking in brittle composites such as cement-based materials. In what follows, only specific aspects of cracking in concrete repairs comprising hydraulic cements will be emphasized.

Concrete Repair Failure

The composite repair system results from the setting and hardening of a semiliquid substance—the freshly mixed repair material—placed against a rigid concrete substrate. A bond
starts to develop in the contact area with the substrate as soon as the chemical reaction initiates in the repair material cement paste. As hydration proceeds, the repair material matures, and, after a limited period of moist curing, the repair material is exposed to the ambient air. Through these processes, the new material is subject to thermal deformations, autogenous shrinkage, and drying shrinkage. Because of the bond, free movement of the repair layer is restrained by the rigid substrate, leading to the development of significant stresses that may at some point overcome the material's tensile strength and cause cracking and/or debonding of the repair (Fig. 2).

Shrinkage-induced stresses are often considered to be the main cause of premature failure of a repair. The issue is not easily addressed, as the consequences of differential shrinkage depend on factors that include the age and quality of the concrete substrate, temperature and moisture gradients, boundary conditions (restraints), magnitude of induced stresses, and strain capacity of the repair material; and many of these are time-variant parameters. The primary significance of deformations caused by moisture content changes in cementitious materials is whether their occurrence would lead to cracking.

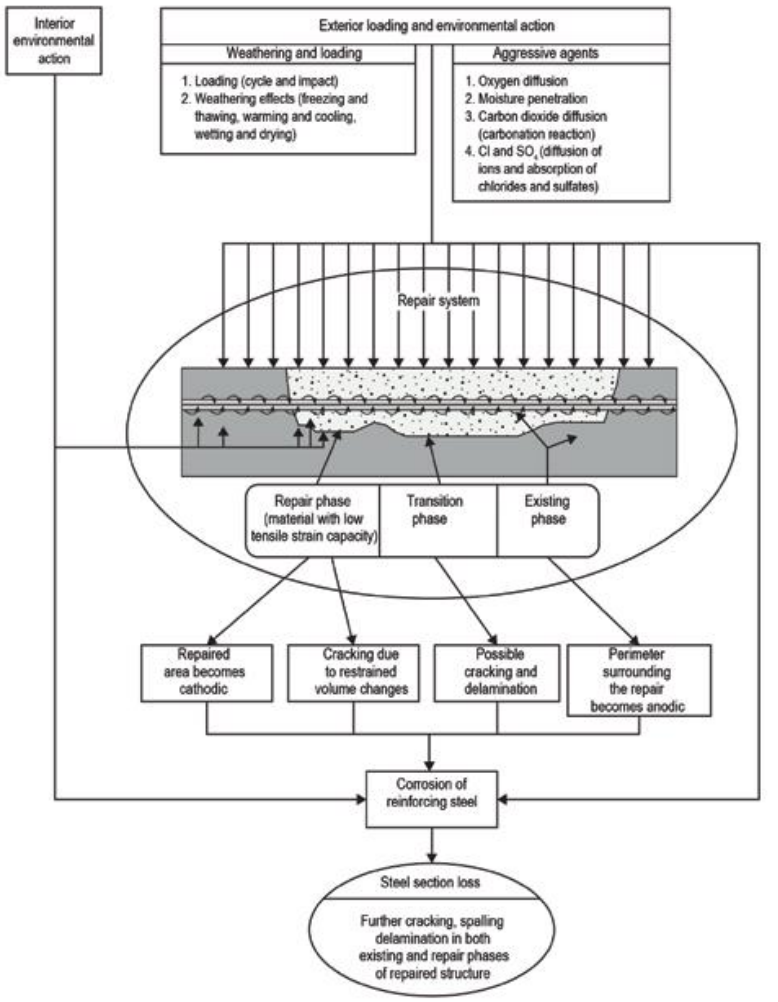

Fig. 1: Model of repair failure caused by cracking[3]

Here, the magnitude of the restrained shrinkage strain is the most dominant one, but it is not the only one governing the sensitivity to cracking. The other relevant material properties are:

- Tensile strength—the risk of cracking decreases as this parameter increases;
- Modulus of elasticity (MOE)—the elastic tensile stress induced by a given shrinkage strain decreases as this parameter decreases; and
- Creep—stress relaxation increases and the shrinkage-induced tensile stress decreases as this parameter increases.

the repair material to have greater tensile strength is a straightforward solution to cracking, cement-based materials are inherently brittle and exhibit sudden failure characteristics when the ultimate stress is reached.

The MOE significantly influences the tolerance of a material to restrained shrinkage without cracking. The factors affecting the MOE of a cement-based material are related to compressive strength and density. Thus, factors that affect strength, such as water cementitious materials ratio (*w/cm*); aggregate type, size, and grading; curing conditions; and age often similarly influence the MOE. An overview of the various parameters that influence the MOE of cement-based materials is presented in Fig. 3. Reducing the MOE of a repair material can lead to a lower stress build up due to restrained drying shrinkage and/or thermal strains at the interface between the repair material and the existing concrete substrate provided that the overall volume changes are not amplified as much.

Creep reduces tensile stresses from restrained drying shrinkage and thus reduces cracking in the repair material. Therefore, material with high creep, particularly during the early age, is desirable. Material with early high creep will typically have relatively lower compressive strength and slower strength development. Conversely, materials with high or very high early strength development will exhibit low creep behavior and thus have a greater risk of cracking. The biggest complexity in practical design of mixtures with increased creep can be attributed to the significant correlation between creep and drying shrinkage. The same factors that assist in achieving higher creep also lead in a number of cases to higher drying shrinkage. Unfortunately, the higher stress induced by drying shrinkage may in some cases more than offset the advantages of stress relaxation achieved by increased creep.

Durability of Repair Material

Over the last three decades, substantial progress has been achieved in improving the quality and versatility of concrete repair materials. Durability has been enhanced through the use of plasticizing admixtures, supplementary cementitious materials, air-entraining agents, and corrosion inhibitors. It is often perceived that a densified microstructure is one of the most effective means for enhancing

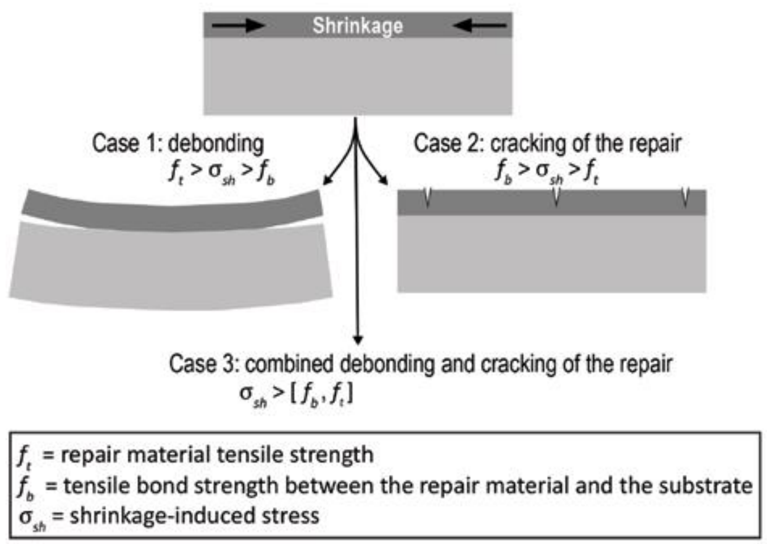

Fig. 2: Damage mechanisms in concrete repair systems (adapted from Luković et al.[4])

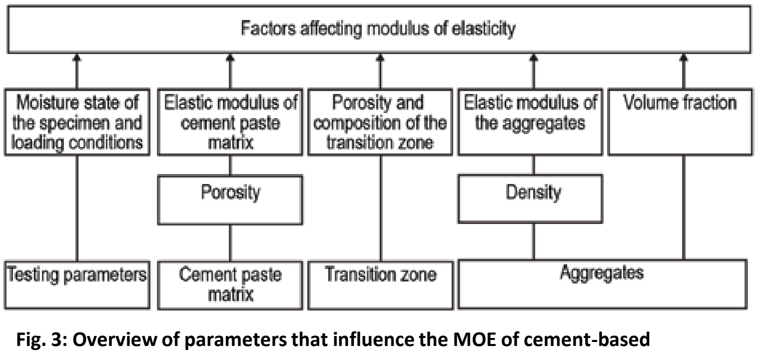

Fig. 3: Overview of parameters that influence the MOE of cement-based materials[5]

durability, as a dense microstructure generally leads to increased mechanical strength and lowered permeability, and reduced diffusivity of the material. This perception has led to the development of a handful of sophisticated and expensive high-strength repair materials with low bulk permeability.

However, many of these materials are prone to early age cracking, due to significant volume changes, high elastic modulus, low creep deformation, and overall more brittle behavior.6 Very few solutions have been targeted at the brittle nature of cement-based materials, which make them inherently sensitive to restrained volume changes.

The main objective of the project described in this article was to develop a cement-based repair material with reduced brittleness and improved resistance to cracking. A complementary goal was to make this material more environmentally friendly.

Recycled Waste Rubber

Over the last 30 years, several research projects have been focused on the properties and performance of rubber concrete and other rubberized cement matrix composites. Rubber obtained from waste tires and other waste rubber sources attracted interest for its natural ductility, energy absorption capacity, and low density. Recycled waste rubber is generally divided into two particle size categories: chipped rubber (3/4 to 1-1/4 in. [20 to 30 mm] particles) and crumb rubber (1/8 to 3/8 in. [3 to 10 mm] particles). Chipped rubber can be used to replace part of the coarse aggregate, whereas rubber crumbs can be used as fine aggregate.

When used to replace aggregates in cement-based materials, rubber particles induce significant variations in material properties. Numerous studies demonstrate that the partial replacement of aggregates with rubber negatively affects the strength properties of cement-based composites proportionally to the replacement rate.7 Partial replacement of aggregates also lowers the MOE (Fig. 4). Using an instrumented steel ring to conduct restrained shrinkage tests, Kiang and Jiang8 found that the addition of rubber particles leads to reductions in both

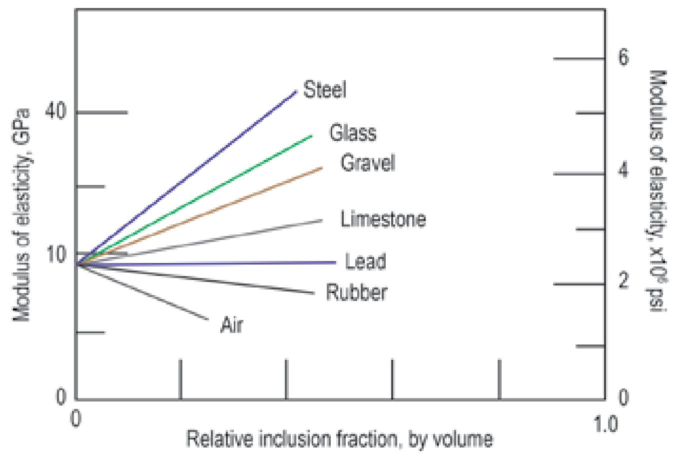

Fig. 4: Effect of various materials on MOE of concrete5

tensile strength and shrinkage stress of paste and mortar specimens. They observed that when the rubber fraction is less than 20% by volume of mortar, the reduction of shrinkage stress is more than that of tensile strength, so cracking time is retarded.

Although much research has been conducted thus far on the use of recycled rubber in cementitious composites, no study has been reported yet on such materials specifically intended for concrete repairs. Due to the ability of the rubber to withstand large tensile deformations, the particles act in cement-based systems as miniature springs distributed throughout the material's matrix, halting very effectively the development of microcracking. At the macroscale, this results in enhanced ductility and significantly reduced sensitivity to restrained-shrinkage cracking.

One major drawback of rubberized cement-based composites is reduced compressive strength. There are many reasons for the lower strength of these materials:

- Low stiffness of rubber particles. Under a given strain, the particles draw very low stresses, and the other components in the matrix must carry most of the load—an effect that has been termed "reduction of the effective surface of concrete" by Eldin and Senouci[9];

- Weak adhesion of rubber particles and cement paste. The hydrophobic character of rubber results in the formation of a weak paste-rubber aggregate interfacial transition zone (ITZ)[10];
- Entrapment of air. The hydrophobic character of the rubber particles causes air entrapment during mixing, which is known to affect directly the compressive strength[11];
- Reduced sand content in the matrix. Fine aggregates play an important role in the material's strength,[12] and the replacement of a fraction of the sand with crumb rubber results in a weakened matrix; and
- Excessive amounts of rubber particles. A high concentration of rubber in the mixture leads to increasing rubber-to-rubber contacts within the matrix. These can carry very little stress, aggravating further the "reduction of the effective surface of concrete."

MOE

MOE is a key property of cementitious repair materials because it impacts the ability to resist both restrained shrinkage-induced cracking and debonding from the substrate. The MOE is closely related to the stiffness of the aggregate makeup of the mixture. The elastic modulus of mineral aggregates used in concrete is typically of the order of 7.25×10^6 psi (50 GPa), while that of rubber is less than 1450 psi (0.01 GPa), so the MOE of rubberized cement-based materials is inevitably lower than that of ordinary cementitious materials.

From the viewpoint of developing crack-resistant mixtures, favorable modifications with regard to the MOE offer quite a complex task. On the one hand, using low-modulus aggregates, increasing the paste content, and using lower strength lower strength material reduce the MOE, and as such reduce restrained shrinkage stresses. On the other hand, these same factors generally increase shrinkage.

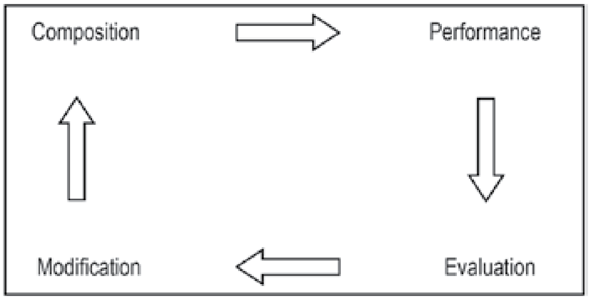

Fig. 5: A material development approach[5]

Crack-Resistant Repair Material

Research and development efforts reported herein were aimed at developing a crack-resistant cement-based material for structural and protective repairs. The goals were to meet the performance requirements of ACI 546.3R-14[13] and to satisfy environmental and economic requirements. The repair material was developed using the general approach shown in Fig. 5. Guiding parameters in the design process included:

- Mechanical characteristics for crack resistance:
  - Moderate 28-day compressive strength of 4000 psi (27.6 MPa),
  - Moderate to low early strength, ◦ Low early MOE; and
- Composition for environmental friendliness:
  - Type II cement,
  - Pozzolan (fly ash),
  - Low amount of silica fume, and
  - Low-modulus recycled rubber aggregate.

Developing a repair material in accordance with these parameters was intended to balance repair performance needs and environmental considerations. The first category of requirements relates to the repair material's engineering properties. These mainly concern the final, hardened state characteristics, such as strength, permeability, and the properties governing the sensitivity to cracking—drying shrinkage, tensile strength, and MOE. In addition, fresh state properties such as workability, pot life, rheology, and the ability to "wet" the substrate are primary considerations in the formulation of repair materials. Also, it is important to evaluate how the material properties are affected by variations in ambient temperature and humidity during placement, curing, and service.

Laboratory experiments

Previous research has shown that it is challenging to produce a homogeneous mixture with an even distribution of rubber. Previous work has also shown that a potentially significant reduction in strength limits the rubber content achievable in practice. Hence, screening tests were conducted to estimate the maximum rubber content practically achievable.

The basic requirements set out at the beginning of the design process were a *w/cm* value of 0.40 and a 28-day compressive strength of 4000 psi. Mixtures developed for the screening tests were prepared with ASTM Type I/II cement, Class C fly ash, silica fume, fine and coarse mineral aggregates, fine rubber crumb aggregates, a high-range water-reducing admixture (ASTM C494/C494M Type F), a defoaming agent, and water. The mineral aggregates met the requirements of ASTM C33/C33M, "Standard Specification for Concrete Aggregates." The coarse aggregate was a 3/8 in. granite pea gravel, with specific gravity of 2.48 and absorption of 1.93%. The coarse aggregates used in the tests were dry. The specific gravity of fine aggregate was 2.65 and absorption was 1.01%. Crumb rubber was used as a fine aggregate replacement, with the amount varying from 0 to 30% by volume of sand. The crumb rubber was clean, without cord (steel belting). It had a specific gravity of 1.2 and adsorption was insignificantly low. The particle size ranged from 1/32 to 1/8 in. (0.75 to 3.5 mm).

Mixture proportioning was performed in accordance with the absolute volume method per ACI 546.3R-14. A series of preliminary "trial-and-error" tests were conducted. Batches were produced with various proportions of constituents, all with *w/cm* = 0.40. The mixtures were optimized to satisfy the guiding parameters discussed earlier and to exhibit adequate workability, minimum bleeding, and the absence of rubber segregation. Screening test results revealed that to meet ordinary strength requirements, rubber replacement rates could hardly exceed 20%. From the extensibility and crack resistance point of view, a higher fraction of rubber crumb substitution might have been desirable, but the amount of rubber was limited by practical strength requirements and other compatibility requirements.

Five candidate mixtures were then designed for sensitivity to cracking and chloride permeability. Based on the preliminary test results and considering the information from previous investigations, a nominal rubber substitution rate of 20% by volume of the sand was selected for further optimization and fine-tuning to meet the objectives of the project. To compensate for compressive strength reduction resulting from the presence of rubber particles and at the same time to provide improvements in the material microstructure, silica fume was added to the candidate mixtures. The silica fume was also used to provide a relatively cohesive paste, with the additional benefits of:

- Improving the bond between rubber aggregate and cementitious matrix. It is known that the bond between cement paste and aggregate particles increases with the consistency of the paste; and
- Preventing segregation. The low specific gravity of the rubber particles relative to the replaced sand (1.2 versus 2.48) makes rubber aggregates highly sensitive to gravitational segregation.

A defoaming agent was added to minimize the amount of entrapped air caused by the addition of rubber aggregate to the mixture. For each mixture, several adjustments were made by varying the dosage in fly ash, silica fume, water-reducing admixture, and ultimately rubber to meet the requirements for compressive strength while achieving the desired workability (6 in. [150 mm] slump), preventing rubber segregation and excessive bleeding, and minimizing the entrapped air content. The optimized mixtures ended up with 17% in rubber substitution for sand by volume. They all had a satisfactory rubber particle distribution.

Testing

Specimens were tested in compression in accordance with ASTM C39/C39M, "Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens," at 28 days of age.

Resistance to cracking was tested in accordance with ASTM C1581/C1581M, "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage," with ring specimens being monitored daily for evidence of cracking. The test results are summarized in Table 1.

Based upon these results, two mixtures, C5-5 and C5-7, were selected for a more comprehensive characterization. Several standard test methods and one nonstandard test method were used. In addition to the two tests performed in the previous round of tests, the selected mixtures were tested for splitting tensile strength (ASTM C496/C496M, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens"), MOE (ASTM C469/C469M, "Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression"), length change or free shrinkage (modified ASTM C157/C157M, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete"), and chloride permeability (ASTM C1202, "Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration"). The "Baenziger Block" test, a nonstandard procedure, was also conducted to evaluate the performance of the two materials with respect to shrinkage-induced cracking in a representative repair layout situation.

Table 1:

Compressive strength and cracking resistance test results

Mixture identification	Compressive strength per ASTM C39/C39M, psi (MPa)		Resistance to cracking per ASTM C1581/C1581M
	7 days	28 days	
C5-1	3660 (25)	4540 (31)	Crack at 21 days
C5-3	2540 (18)	3740 (26)	Crack at 32 days
C5-4	2680 (18)	3880 (27)	> 90 days
C5-5	3580 (25)	4680 (32)	> 104 days
C5-7	4010 (28)	4760 (33)	> 55 days

Table 2:

Additional characterization of mixtures C5-5 and C5-7

Property/Test	Age, days	C5-5	C5-7
Splitting tensile strength, psi (MPa)	7	447 (3.1)	397 (2.7)
	28	399 (2.8)	365 (2.5)
MOE, psi (GPa)	7	2.63×10^6 (18.1)	2.46×10^6 (17.0)
	28	3.03×10^6 (20.9)	3.05×10^6 (21.0)
Length change, $\times 10^{-6}$	7	40	40
	28	410	370
Rapid chloride permeability, coulomb	28	1976 (low permeability)	1583 (low permeability)
Baenziger Block	90	No crack	No crack

The results of the second series of tests are summarized in Table 2.

The results of tests performed on mixtures C5-5 and C5-7 demonstrated that both mixtures satisfied the established criteria. However, based on the results of the ring test (ASTM C1581/C1581M) and slightly "friendlier" constructability properties, mixture C5-5 was selected as a prototype mixture for further experimental repair application under controlled field conditions.

Field experiments

Experimental field repairs were carried out on U.S. Navy concrete structures selected by officials with the Naval Facilities Engineering Systems Command, Port Hueneme, CA, USA. The experiments consisted of a formed vertical repair and a trowel-applied horizontal repair. The field-testing program included mixing, placing, curing, and monitoring of the repair. In addition, tensile bond strength tests were carried out on-site and petrographic examinations were performed on core specimens extracted from the aged repairs. The repair material was manufactured and packaged in accordance with ASTM C387/C387M, "Standard Specification for Packaged, Dry, Combined Materials for Concrete and High Strength Mortar," by a manufacturer of conventional repair products.

The horizontal repair was located on a pier deck slab (Fig. 6(a)), and the vertical repair was located on a slab that was rotated to the vertical (Fig. 6(b)). The repair dimensions were chosen to proportions and the surface-area-to volume ratio of typical surface repairs made on Naval facilities. Formwork for the vertical repair was constructed using plywood in accordance with the applicable provisions of ACI 347R-14,14 and it included two chutes ("bird mouths") on the top for concrete placement.

The prepared concrete surfaces of the cavities were water saturated for 16 hours prior to repair applications to produce saturated surface dry (SSD) conditions at the time of repair material placement. After mixing, the repair material was placed in horizontal repairs using a shovel and in vertical repairs directly from buckets. For both repair types, the repair material was consolidated using an internal vibrator. The formwork for the vertical repair was also vibrated using an external vibrator. Weather conditions at the time of placement were favorable to plastic shrinkage with full sun, wind gusts up to 21 mph (35 km/h), and a relative humidity in the low 50%. Immediately after finishing, the horizontal repairs were covered with wet burlap and plastic sheet, and they were moist cured for 72 hours. For the vertical repairs, curing was performed in the formwork for one week, with water sprinkled from the top twice during the first 48 hours. Repairs were monitored for cracking for

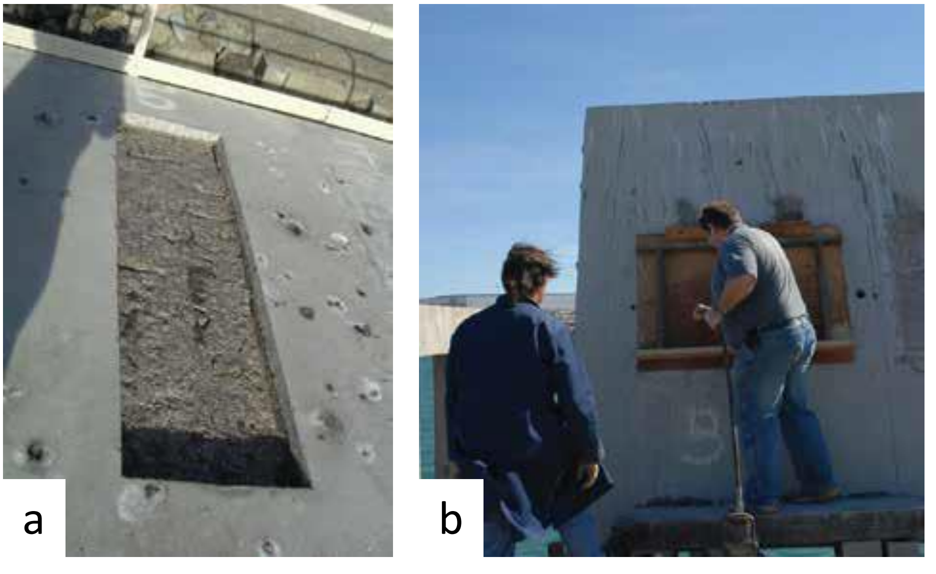

Fig. 6: Repair areas selected for field experiments at the U.S. Navy facility in Port Hueneme, CA, USA: (a) horizontal, on the pier, 73.5 x 19.5 in. (1840 x 490 mm) and 3 in. (75 mm) deep; and (b) vertical, on an existing slab installed upright next to the selected pier, 48 x 36 in. (1200 x 900 mm) and 3.5 in. (88 mm) deep5

10 months and sounded with a hammer for voids and delaminations. Over the monitoring period, no cracking was observed on any of the repairs, and the sounding did not reveal any voids, no delamination.

Using the results from the testing program, a comprehensive material data sheet was developed based on the protocol set out in ACI 364.3R-0915 (shown in Table 3).

Field Applications

The performance of the repair material is being evaluated in several concrete rehabilitation projects. Two of these projects are described herein to provide examples of typical applications where the characteristics of the repair material can be advantageously exploited. One project is the repair of a deteriorated parking garage deck in Utica, NY, USA, completed in 2016. The rubber-based repair material was selected for its lower shrinkage-cracking sensitivity. The job involved patch repairs and then resealing of the exposed areas. As shown in Fig. 7, the patches had somewhat unusual geometries. The repairs were also shallow in some areas, and the exposed reinforcement was generally not undercut. Even so, no debonding, cracking, or bond line shrinkage have been observed after 4 years in service.

The second case study is the restoration of a 500 ft (152 m) tall, 40-story office building in Philadelphia, PA, USA, in 2016. The building was erected in 1974, and it is the tallest reinforced concrete building in the city. The rubber-based material was chosen for horizontal application, including long form-and-place repairs at the parapets, as well as vertical application. In addition to low cracking sensitivity, the other main parameters influencing the material selection by the specifier were the compressive strength, which had to match that of the parent concrete, and the flexibility to use a single product in both manually applied, small patches (Fig. 8) and larger form-and-place applications. Once repairs were completed and cured, the structure was painted with an elastomeric coating. In both

Table 3:
Prototype material data sheet per ACI 364.3R-09[15]

Property	Standard	Data		
Physical characteristics:				
Bulk density (after immersion)	ASTM C642		2.25	
Absorption (after immersion), %	ASTM C642		7.2	
Voids (permeable pore space), %	ASTM C642		15.6	
Mechanical strength and behavior:		**1 day**	**7 days**	**28 days**
Compressive strength, psi (MPa)	ASTM C39/C39M	1525 (10.5)	3427 (23.6)	5574 (38.4)
Flexural strength, psi (MPa)	ASTM C78/C78M	382 (2.63)	516 (3.56)	662 (4.56)
Splitting tensile strength, psi (MPa)	ASTM C496/C496M	182 (1.25)	299 (2.06)	463 (3.19)
Direct tensile strength, psi (MPa)	CRD-C164	—	293 (2.02)	420 (2.90)
Short-term bond strength, psi (MPa)	ICRI No. 210.3 (formerly 03739)	110 (0.76)	232 (1.60)	399 (2.75)
Volume change properties and behavior:				
Modulus of elasticity, $\times 10^6$ psi (GPa)	ASTM C469/C469M	1.96 (13.5)	2.64 (18.2)	3.07 (21.2)
Compressive creep (28 days), $\times 10^{-6}$/psi (MPa)	ASTM C512/C512M		0.329 (47.7)	
Coefficient of thermal expansion, $\times 10^{-6}$/°F (°C)	CRD-C39		5.70 (10.3)	
Length change (28 days), $\times 10^{-6}$	ASTM C157/C157M		470	
Cracking resistance (time to cracking), days	ASTM C1581/C1581M		> 32	
Durability:				
Freezing-and-thawing resistance	ASTM C666/C666M,	**Cycles**	**DF, %**	**Exp., %**
	Procedure A	125	< 60	0.21
Scaling resistance, lb/ft^2 (kg/m^2)	ASTM C672/C672M		0.0091 (0.044), visual rating: 0 to 1	
Rapid chloride permeability, coulomb	ASTM C1202		1218	
Chloride ponding (3 months), % weight	ASTM C1543	**Depth, in. (mm)**	**Cl^-, %**	
		0.4 to 0.8 (10 to 20)	0.056	
		1.0 to 1.4 (25 to 35)	0.020	
		1.6 to 2.0 (40 to 50)	0.012	
		2.2 to 2.6 (55 to 65)	0.012	
Sulfate resistance (6-month expansion), %	ASTM C1012/C1012M		0.048	

the vertical patches and formed elements, the material was applied successfully and performed quite satisfactorily, without reported cracking to this day. Hence, the field performance of the material is quite promising, especially considering the severe exposure conditions experienced in both case studies. Many other projects are in the planning stage.

Fig. 7: A parking garage deck in Utica, NY, USA, repaired with the rubber-modified repair material, after 4 years in service

Summary

Failures observed on repaired concrete structures often correspond to either one of the following two modes: cracking in the repair material layer and/or delaminating at the interface due to stresses induced by differential shrinkage between repair and concrete substrate, followed in many instances by corrosion of reinforcing steel, more extensive cracking and delamination, and spalling.

Numerous measures have been taken over the years to improve durability and service life of concrete repairs, but very few have targeted one of the root causes of the problem—the inherent brittleness and low deformability of cementitious materials. The approach taken in the development and practical application of the repair material described in this article deviates from the current emphasis on high-strength, high-density, low-bulk permeability materials, being instead directed toward balancing strength, ductility, and compatibility with the existing concrete substrate. Such an approach is desirable in the development of cementitious materials for repair applications with minimum maintenance and extended serviceability between repair cycles.

Fig. 8: Restoration of a 40-story reinforced concrete building in Philadelphia, PA, USA, in 2016. Spalled areas were repaired with a rubber-modified repair material. Repairs were to be subsequently covered with a polymer coating

Acknowledgments

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References

1. Matthews, S.L., “CONREPNET: Performance-Based Approach to the Remediation of Reinforced Concrete Structures: Achieving Durable Repaired Concrete Structures,” *Journal of Building Appraisal*, V. 3, No. 1, May 2007, pp. 6-20.
2. Valenta, O., “Durability of Concrete,” *Proceedings of the Fifth International Symposium on the Chemistry of Cements*, V. 3, Tokyo, Japan, 1968, pp. 193-225.
3. Vaysburd, A.M., and Emmons, P.H., “Visible and Invisible Problems of Concrete Repair,” *Indian Concrete Journal*, V. 75, No. 1, Jan. 2001, pp. 13-24.
4. Luković, M.; Ye, G.; and van Breugel, K., “Reliable Concrete Repair: A Critical Review,” 14th International Conference: Structural Faults and Repair, Edinburgh, Scotland, UK, July 3-5, 2012, 12 pp.

5. Vaysburd, A.M.; Bissonnette, B.; and Brown, C.D., "Development of a Crack-Resistant Durable Concrete Repair Material for Navy Concrete Structures," SBIR No. N47408-03-P-6791, 2010, 235 pp.
6. Li, M., and Li, V.C., "Influence of Material Ductility on Performance of Concrete Repair," *ACI Materials Journal*, V. 106, No. 5, Sept.-Oct. 2009, pp. 419-428.
7. Tian, S.; Zhang, T.; and Li, Y., "Research on Modifier and Modified Process for Rubber-Particle Used in Rubberized Concrete
for Road," *Advanced Materials Research*, V. 243-249, May 2011,
pp. 4125-4130.
8. Kiang, J., and Jiang, Y., "Improvement of Cracking-Resistance and Flexural Behavior of Cement-Based Materials by Addition of Rubber Particles," *Journal of Wuhan University of Technology—Materials Science Edition*, V. 23, No. 4, Aug. 2008, pp. 579-583.
9. Eldin, N.N., and Senouci, A.B., "Rubber-Tire Particles as Concrete Aggregate," *Journal of Materials in Civil Engineering*, V. 5, No. 4, Nov. 1993, pp. 478-496.
10. Li, Y.R.; Zhu, H.; and Liu C.S., "Experimental and Economic Analysis of Airport Crumb Rubber Concrete (CRC) Pavement," *Advanced Material Research*, V. 250-253, May 2011, pp. 605-608.
11. Mehta, P.K., and Monteiro, P.J.M., *Concrete: Microstructure, Properties, and Materials*, third edition, McGraw-Hill Education, New York, NY, 2006, 659 pp.
12. Neville, A.M., and Brooks, J.J., *Concrete Technology*, second edition, Prentice Hall, London, UK, 2010, 442 pp.
13. ACI Committee 546, "Guide to Materials Selection for Concrete Repair (ACI 546.3R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 72 pp.
14. ACI Committee 347, "Guide to Formwork for Concrete (ACI 347R-14)," American Concrete Institute, Farmington Hills, MI, 2014, 36 pp.
15. ACI Committee 364, "Guide for Cementitious Repair Material Data Sheet (ACI 364.3R-09)," American Concrete Institute, Farmington Hills, MI, 2009, 12 pp.

Note: Additional information on the ASTM standards discussed in this article can be found at **www.astm.org**. CRD-C39, "Test Method for Coefficient of Linear Thermal Expansion of Concrete," and CRD-C164, "Standard Test Method for Direct Tensile Strength of Cylindrical Concrete of Mortar Specimens," are available at **www.wbdg.org/ffc/army-coe/standards**. ICRI Technical Guideline No. 210.3 (formerly 03739), "Guideline for Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials," is available at **www.icri.org**.

Selected for reader interest by the editors.

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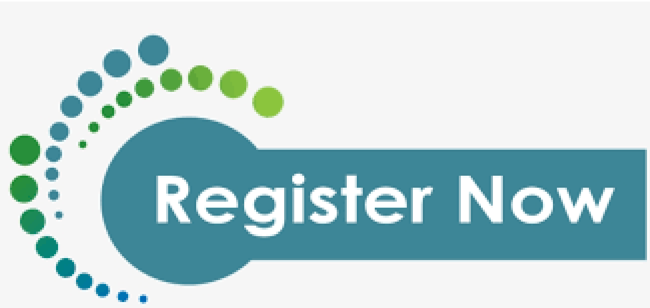

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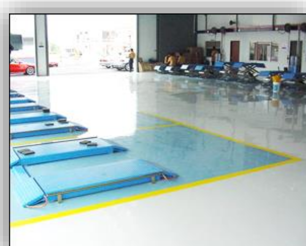


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